

Air Force Institute of Technology

AFIT Scholar

Theses and Dissertations

Student Graduate Works

3-2022

Persistence and Mitigation of PFAS within Concrete Stormwater Drainage Infrastructure

Jason R. McDonald

Follow this and additional works at: <https://scholar.afit.edu/etd>



Part of the [Environmental Engineering Commons](#), and the [Environmental Indicators and Impact Assessment Commons](#)

Recommended Citation

McDonald, Jason R., "Persistence and Mitigation of PFAS within Concrete Stormwater Drainage Infrastructure" (2022). *Theses and Dissertations*. 5413.
<https://scholar.afit.edu/etd/5413>

This Thesis is brought to you for free and open access by the Student Graduate Works at AFIT Scholar. It has been accepted for inclusion in Theses and Dissertations by an authorized administrator of AFIT Scholar. For more information, please contact AFIT.ENWL.Repository@us.af.mil.



**PERSISTENCE AND MITIGATION OF PFAS WITHIN CONCRETE
STORMWATER DRAINAGE INFRASTRUCTURE**

THESIS

Jason R. McDonald, Captain, USMC

AFIT-ENV-MS-22-M-234

**DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY**

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

DISTRIBUTION STATEMENT A.
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

(IF your document is limited, place your Destruction Notice Here)

The views expressed in this report are those of the author and do not reflect the official policy or position of the United States Marine Corps, Department of Defense, or the United States Government. This material is declared a work of the U.S. Government and is not subject to copyright protection in the United States.

AFIT-ENV-MS-22-M-234

PERSISTENCE AND MITIGATION OF PFAS WITHIN CONCRETE
STORMWATER DRAINAGE INFRASTRUCTURE

THESIS

Presented to the Faculty

Department of Aeronautics and Astronautics

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the
Degree of Master of Science in Environmental Engineering and Science

Jason R. McDonald, BS

Captain, USMC

March 2021

DISTRIBUTION STATEMENT A.
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

PERSISTENCE AND MITIGATION OF PFAS WITHIN CONCRETE
STORMWATER DRAINAGE INFRASTRUCTURE

Jason R. McDonald, BS

Captain, USMC

Committee Membership:

Dr. Eric G. Mbonimpa, PhD
Chair

Maj Trevor W. Sleight, PhD
Member

Dr. Matthew L. Magnuson, PhD
Member

Abstract

The persistence, fate, and transport of per- and poly-fluoroalkyl substances, which have been shown to have adverse effects on human health, have been previously studied in environmental media such as soils and groundwater. This study investigates concrete, a medium that is rarely studied but frequently present in instances where PFAS originating from AFFF releases and spills have occurred. Used heavily throughout aviation firefighting, AFFF poses environmental hazards due to the length of PFAS degradation and toxicological implications, thus its classification as a forever chemical. From the very limited reports to date, studies have suggested very slow release from concrete, potentially serving as a long-term source, prolonging its environmental persistence. This work discusses the development of a fate and transport model that can be applied to PFAS contaminated concrete including stormwater channels that may drain from AFFF release points. This study consisted of three phases: (1) saturation and contamination, (2) desorption and flushing, and (3) sampling and analysis. The study used AFFF to investigate retention of PFAS by the concrete, as well as the ability of chemical dyes to trace the hydraulics of flowing water through small mock channels and its permeation in the concrete. A desorption model developed from this data incorporates properties of the concrete and simulated hydrological runoff, along with mechanistic terms for both diffusion and adsorption kinetics. This model can be used to estimate the length of time PFAS may remain above a given action level and provide a model that can be easily adapted to DoD and civilian installations to better manage and mitigate PFAS.

Acknowledgements

I am incredibly grateful and humble for the continued support and guidance that I have received from mentors, advisors, and most importantly, my wife and children during this thesis process. I would like to thank my thesis advisor Dr. Eric Mbonimpa and committee members Maj. Trevor Sleight and Dr. Matthew Magnuson for their consistent mentorship and direction during the development, experimentation, and writing portions of this process. Your commitment to the success of this study has been invaluable and was a much-needed respite when I was unsure of which direction to go. Additionally, I would like to thank Dr. Daniel Felker, Dr. Willie Harper, and Lt Col John Stubbs of the Air Force Institute of Technology for your continued assistance and leadership. I would also like to express my gratitude to Kevin Custer, Nick Nigro, and the other members of Pace Analytical Services that helped this process along and were always available to answer any questions that I may have had. Special thanks to the University of Dayton – Department of Civil and Environmental Engineering and Engineering Mechanics for your assistance and use of your facilities. Most importantly, thank you to my wife and children for everything you have done in support of me and my career. No amount words can describe the gratitude and value that I have for your patience, encouragement, and presence during this milestone. Nothing I do or any success I have comes without your support and sacrifice. I love you guys and thank you for everything that you have done.

Jason R. McDonald

Table of Contents

	Page
Abstract.....	5
Table of Contents	7
List of Figures.....	9
List of Tables	11
I. Introduction	13
General Issue	13
Problem Statement.....	15
Research Objectives	15
Research Focus	17
Methodology.....	17
Assumptions/Limitations.....	18
Implications	20
II. Literature Review	20
Chapter Overview.....	20
Stormwater Drainage Channels and Simulated Site Selection.....	21
Per- and Polyfluoroalkyl Substances.....	22
Aqueous Film Forming Foam	26
EPA Regulatory Limits and DoD Guidelines	29
Environmental and Health Issues	30
PFAS Desorption in Concrete Media	32
Relevant Research	33
Summary.....	36
III. Methodology.....	36
Chapter Overview.....	36
Materials and Equipment.....	37
Channel Design	39
Concrete Mix Design.....	42
Mock Channel Construction.....	45
Contamination and Reactor Setup	49

Sampling and Analysis	55
Simulated Location Site and Watershed Runoff	59
Kinetic Modeling.....	62
Summary.....	65
IV. Analysis and Results	65
Chapter Overview.....	65
Allura Red Dye Results	66
Brilliant Blue Dye Results.....	70
Methylene Blue Dye Results	75
3M Light Water™ – AFFF Results.....	79
Kinetic Modeling of PFAS Compounds	89
Option 1 – Arrhenius Constant Model	93
Option 2 – Desorption Constant Model.....	96
Summary.....	98
V. Conclusions and Recommendations	99
Chapter Overview.....	99
Conclusions of Research	99
Significance of Research	102
Recommendations for Action.....	104
Recommendations for Future Research.....	104
Summary.....	105
Appendix A	107
Appendix B.....	108
Appendix C.....	111
Appendix D	114
Appendix E	118
Appendix F	119
Bibliography	179

List of Figures

Figure 1 - Mock Channel Dimensions (A)	41
Figure 2 - Mock Channel Dimensions (B)	42
Figure 3 - Concrete Forms.....	45
Figure 4 - Concrete Mixing	47
Figure 5 - Finished Concrete Forms	47
Figure 6 - Compression Testing	48
Figure 7 - Reactor Setup.....	51
Figure 8 - MasterFlex L/S® Pump and Pump Head	52
Figure 9 - Concrete Powder Samples	57
Figure 10 - MCAS Futenma Arial Map (Google Maps, 2021)	60
Figure 11 - Allura Red AC Reactors	66
Figure 12 - Allura Red AC Concentrations	68
Figure 13 - Allura Red Concentration Data	69
Figure 14 - Brilliant Blue Reactor #2 Tubing	72
Figure 15 - Brilliant Blue FCF Concentrations	73
Figure 16 - Brilliant Blue Concentration Data	74
Figure 17 - Methylene Blue Reactors.....	75
Figure 18 - Methylene Blue Concentrations	77
Figure 19 - Methylene Blue Concentration Data	78
Figure 20 - Concrete Powder Collection	82
Figure 21 - Concrete Powder Concentration vs. Depth.....	84
Figure 22 - PFAS Reactor after 36 Hours	87

Figure 23 - PFAS Compound Desorption Curves	89
Figure 24 - Allura Red AC Calibration Curve	111
Figure 25 - Methylene Blue Calibration Curve	112
Figure 26 - Brilliant Blue FCF Calibration Curve.....	113
Figure 27 - PFAS Compound Decay Curves	118

List of Tables

Table 1 – AFFF 3M Light Water Properties	37
Table 2 - Surrogate Dye Properties	38
Table 3 - Channel Ratios	40
Table 4 - Mock Channel Design Parameters	41
Table 5 - Prescribed Mix Characteristics	43
Table 6 - Compression Testing.....	49
Table 7 - Reynolds Number Calculations	54
Table 8 - Surrogate Dye Time Intervals	56
Table 9 - Concrete Powder Physical Properties	57
Table 10 - Peak Runoff Summary	61
Table 11 - Allura Red AC Properties	67
Table 12 - Allura Red AC Summary	67
Table 13 - Brilliant Blue Summary	71
Table 14 - Brilliant Blue Properties.....	71
Table 15 - Methylene Blue Properties.....	76
Table 16 - Methylene Blue Summary	76
Table 17 - PFAS Stock Solution Concentrations	79
Table 18 - Control Reactor Samples Concentrations	80
Table 19 - Concrete Powder Contamination Summary.....	83
Table 20 - Concrete Powder Area Under Curve.....	85
Table 21 - PFAS Concentration Summary	86
Table 22 - PFAS Channel Physical Properties	86

Table 23 - Percent Desorption of PFAS in Concrete	88
Table 24 - Desorption Constants - Method 1	91
Table 25 - Desorption Constants - Method 2	92
Table 26 - Desorption Constants - Method 3	92
Table 27 – Option 1: Tau Variables (τ).....	94
Table 28 – Option 1: Values of τ	94
Table 29 – Option 1: Kinetic Modeling Variables	95
Table 30 - Option 2: Tau Variables (τ).....	96
Table 31 - Option 2: Values of τ	97
Table 32 - Option 2: Kinetic Model Variables	97
Table 33 - Concrete Mix Design	107
Table 34 - Allura Red AC Dye Desorption Data	108
Table 35 - Methylene Blue Desorption Data.....	109
Table 36 - Brilliant Blue FCF Desorption Data	110
Table 37 - Allura Red AC Calibration Curve Data	111
Table 38 - Methylene Blue Calibration Curve Data.....	112
Table 39 - Brilliant Blue FCF Calibration Curve Data	113

PERSISTENCE AND MITIGATION OF PFAS WITHIN CONCRETE STORMWATER DRAINAGE INFRASTRUCTURE

I. Introduction

General Issue

Since the industrial revolution, chemical pollution in the environment has been rising exponentially (Landrigan et al., 2020). Though pollution is an unavoidable consequence in industrial and economic growth, environmental responsibility charges us to limit the contamination of natural resources to the best degree possible. As we continue to research and engineer new technologies and scientific advances, we must study not only the primary causes and effects of these pollutants, but also the secondary and tertiary as well. Per- and polyfluoroalkyl substances (PFAS) are one such group of chemicals that has garnered scrutiny in public health and environmental studies due to negative health effects and persistence in the environment. Awareness and mitigation of PFAS continues to be a growing factor in decision making and future planning at both public and legislative levels. Understanding the common pathways and transport media for PFAS will help scientist and researchers better advise the public and governmental agencies on the health risks and contamination sources of these chemicals.

While several studies have been conducted on the fate and transport of PFAS through soils (Nanthi Bolan et al., 2021; Schaefer et al., 2021), chemical analysis on distribution in waterways and oceans (Kwok et al., 2015), and public health hazards that PFASs present (Domingo & Nadal, 2019), there has been very limited research into the fate and transport of PFAS within concrete structures. In fact, throughout the literature review, as described in later sections, only one source was found that was consistently

cited on PFAS desorption in concrete (Baduel et al., 2015). PFAS in concrete poses a challenging problem, especially the concrete around maintenance aprons, helicopter pads, runways and taxiways, and also within stormwater drainage infrastructure around Department of Defense (DoD) aviation installations. Because the desorption of chemical compounds, including PFAS, differs depending on the media type that the contaminant is in, concrete is a novel media type that should be further investigated and researched. Given that PFAS, specifically those found in legacy firefighting foams, were potentially used at some point during an installation's lifespan, desorption characteristics of PFAS in concrete is an important study in advancement of mitigating future releases of this forever chemical.

Long chain PFAS, commonly found in the form of perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA), are considered as such due to having a carbon chains longer than or equal to six (Kempisty et al., 2018). These types of PFAS have been traditionally used in legacy firefighting foams generally referred to as Aqueous Film Forming Foams (AFFF). Though its use and resourcefulness in firefighting operations has been extremely beneficial to the DoD and other civilian agencies, both AFFF and the PFAS compounds contained within have become a major concern for both public health and environmental impacts. Considering that all DoD aviation installations will have some form of concrete in their construction, the sorption and desorption of PFAS into these porous concrete structures is of paramount concern when decisive actions and mitigation plans are being considered.

Problem Statement

With the limited research in the desorption characteristics of PFAS in concrete, a useful and effective model for estimating persistency, defined as the amount of time that PFAS will remain above a given regulatory limit, must be established to better understand and mitigate PFAS releases into the environment.

Research Objectives

The overarching objective of this study was to test the sorption-desorption rates and fate and transport of PFAS within concrete. The semi-porous concrete found in stormwater drainage structures was selected as the model for this study, however, results are anticipated to be applicable to many forms of concrete. Various testing methods were utilized along with testing the same parameters on chemical dyes for potential use as PFAS surrogates in future studies.

Objective 1 – Study and analyze the desorption of PFAS (3% AFFF solution) from concrete in a simulated mock stormwater drainage channel.

Hypothesis: PFAS desorption trends can be determined by sampling water-runoff from a previously contaminated concrete channel at certain time intervals.

Subtask 1.1 – Estimate and apply an appropriate level of initial concentration to the concrete channels to yield realistic and measurable results over the course of the experiment.

Subtask 1.2 – Evaluate if the concentrations of detected PFAS increase over time as water is flowed over the channels.

Subtask 1.3 – Contrast the recorded concentrations of PFAS against the initial concentration applied to the block to determine the rate of change.

Objective 2 – Study and analyze the desorption of chemical dyes (Allura Red AC, Brilliant Blue FCF, and Methylene Blue) from concrete in simulated mock channels for future use as PFAS surrogates in similar studies.

Hypothesis: Since PFAS compounds in AFFF vary in ionic composition (Will J. Backe et al., 2013), the use of zwitterionic, cationic, and anionic dyes should show relevance to the desorption of individual PFAS compounds.

Subtask 2.1 – Estimate and apply appropriate initial concentrations (stock dye solutions) of the chemical dyes to the mock channels to yield measurable and relatable results for comparison to PFAS desorption data.

Subtask 2.2 – Develop calibration curves for each of the three surrogate dyes for comparison against recorded desorption values.

Subtask 2.3 – Evaluate if the concentrations of the surrogate dyes change over time due to channel flushing.

Subtask 2.4 – Compare recorded desorption results to calibration curve data to determine total desorption of surrogate dyes.

Subtask 2.5 – Contrast desorption data of surrogate dyes with the desorption data of the corresponding ionization of the PFAS compounds in AFFF.

Objective 3 – Build and establish the validity of a desorption model for PFAS from semi-porous concrete to determine the persistency of PFAS to remain above a given regulatory limit.

Hypothesis: The PFAS desorption model will be able to accurately determine the amount of time the contaminate will remain above regulatory limits.

Subtask 3.1 – Determine the thermodynamic and kinetic constants for the model from the recorded PFAS desorption data.

Subtask 3.2 – Given a predetermined location (MCAS Futenma), determine the annual hydrological runoff within a stormwater channel using open-sourced data.

Subtask 3.3 – Determine the physical properties of the designed concrete mock channels for use in the kinetic model equation.

Subtask 3.4 – Determine the kinetic desorption model equation using existing studies for DoD stormwater drainage systems.

Research Focus

The focus of this research is to determine a kinetic desorption model to determine the time that a given PFAS contaminant will remain above a regulatory limit by testing a 3% AFFF solution and the potential use of chemical dyes for surrogate use in comparison to PFAS contaminated concrete.

Methodology

Parameters to analyze desorption rates of both the PFAS solution and the surrogate chemical dyes began by constructing mock channels from a concrete mix design based on Department of Defense (DoD) engineering regulations and publications. The experiment was divided into two distinct groupings for testing and analysis: PFAS testing group, using a 3% solution of 3M Light Water™ and reverse osmosis (RO) water, and the chemical dye testing group, which included a 0.05 mM solution each of Allura

Red Dye AC (AR), Methylene Blue (MB), and Brilliant Blue FCF (BB). The primary methods of analysis were conducted using a Sciex 5500 Liquid Chromatography Tandem Mass Spectrometer (LC/MS/MS) with isotope dilution for the PFAS samples and by using an Agilent Technologies *Cary 60* Ultraviolet-Visible Spectrophotometer (UV-Vis) for the chemical dye samples. Mock concrete channels were placed into enclosed system reactors and were then flushed with recirculated RO water. Three samples at various times were collected from the single reactor in the PFAS group. The chemical dye group produced eighty-one samples for each of the three chemical dyes. Collected data was then used in correlation with peer-reviewed literature and kinetic modeling to produce an equation to predict persistency of PFAS in concrete stormwater structures.

Assumptions/Limitations

Several assumptions and limitations were presented in the construction of the concrete mock channels, most importantly the selection of mix design and max aggregate size (MSA). Given that there are several variables that will affect the overall structure of the concrete, liberties were taken with selection of the mix design parameters. Mix design will regulate the final compressive strength, water to cement ratio, and aggregate composition; porosity and permeability will determine the presence of open pores, particularly capillary pores that allow for the flow of liquids through the concrete; and density and viscosity of the PFAS and chemical dye solutions will also factor into the depth the solution could potentially reach within the concrete (Thompson, 2014). The most generalized MSA (3/8") and cement type (Portland Type II) were selected to give the closest comparison to DoD publications and what would typically be found in the

built environment. It should be noted that changing these two parameters would have the greatest effect on the porosity of the concrete and thus also the desorption of any of the tested compounds if tested using different mix designs.

Viscosity of the chemical dyes was also of concern in that if the ratio of dye to RO water was too high it could adversely affect the initial sorption of the dye into the mock channels. Literature supports that if the dye concentration was greater than 2% by volume the viscosity of the prepared solutions could be altered, specifically at low shear rates (Kim & Cho, 2003). The 0.05 mM solutions for the chemical dyes were selected based on the principle that the given ratios of the dye-water solutions would be well below this limit; 0.00248% (AR), 0.00396% (MB), and 0.0016% (BB).

Ultimately, the principal challenge in this experiment was found in establishing the end point for the PFAS desorption with the 3M Light Water™ AFFF solution in comparison to the chemical dyes. The greatest factors in using the chosen equation for the kinetic model was the concentration equilibrium (C_{eq}) versus the initial concentration (C_c) of the contaminant, as seen in Eq 8 later in this text. Finding the appropriate time intervals for sampling in the PFAS trial proved central to estimating the correct C_{eq} . Reviewing the supplemental materials by Baduel et al. (2015), estimates were made that the PFAS would reach equilibrium around the same time for the concrete channels tested in this experiment as was the concrete pad tested in Baduel et al. study. Their analysis found that the characteristic time to reach steady state was in the range of five to fifteen hours for PFOA and one to one and a half for PFOS (Baduel et al., 2015). While porosity and permeability vary from one concrete channel to another for the reasons stated above,

this seemed to be an appropriate assumption in limiting the number of samples and subsequently the overall cost of the experiment.

Implications

There are several significant benefits to having a working kinetic model for the desorption of PFAS in concrete drainage channels. Most notably, the application of the model to determining the persistency of PFAS compounds over time. This experiment will also provide supplementary research into a facet of PFAS/AFFF studies that is limited in published literature. It will assist in establishing a baseline for further research into PFAS desorption modeling in concrete and provide additional recommendations and best practices for such experiments. Finally, understanding the residency and persistence of AFFF in concrete will enable DoD installation engineers and commanders to develop better policies and mitigation measures prior to and after spills and releases.

II. Literature Review

Chapter Overview

The purpose of this chapter is to identify pertinent background information in relation to the structure and purpose of stormwater drainage channels, the hazards associated with PFAS contamination in AFFF releases, and summarize both DoD and the Environmental Protection Agency (EPA) regulatory limits and guidelines. This chapter will also establish the need for kinetic modeling of PFAS desorption rates in concrete drainage infrastructure to better understand its fate and transport in the built environment. Background information containing peer-reviewed research in PFAS desorption through

various media types is presented along with a similar research study on the desorption of PFAS found in an Australian firefighting training ground (FTG).

Stormwater Drainage Channels and Simulated Site Selection

One of the obstacles in construction of military air stations and air bases is the need for water drainage from operating surfaces. These surfaces include maintenance aprons, runways and taxiways, and any other roadways or paved surface that can accumulate standing water and impede normal operations. To control these waters and divert the flow of water into appropriate areas or off installation, flood control channels, to include stormwater drainage channels, are constructed. The purpose of these channels is to convey heavy storm water flows away from areas that could become inundated with standing water and result in stoppages of military operations or cause property damage or loss of life (USACE, 1995).

During the design phase of channel construction, the most critical parameter that must be established is the amount of water that the channel is expected to hold, or the peak runoff rate. The most common method for estimating peak runoff rates in urban catchment is the rational method, which has been used extensively since the nineteenth century (Chin, 2019). This method assumes that the runoff rate is a constant ratio to the rainfall rate for a given area. Though more complex methods of estimating runoff exist, to include the unit hydrograph model, the rational method still remains the standard method for civil engineers in managing systems that only require the peak flow for runoff estimation (Chin, 2019).

The peak runoff rate is a key component of the kinetic desorption model used for this experimental study in estimating persistency. While an estimated runoff rate using speculative parameters for a fictitious site would still fit within the purposed kinetic model, a more appropriate method would be to select a site for simulation and use empirical data for modeling. Thus, Marine Corps Air Station (MCAS) Futenma located in Okinawa, Japan was selected as the simulated site location for all future calculations in this study.

MCAS Futenma is of prominent concern for PFAS and AFFF due to multinational partnerships and Status of Forces Agreements (SOFA) between the U.S. and Japan, as well as the presence of numerous AFFF fire suppression systems and political sensitivities around historical inadvertent activations of these systems. The airfield boasts a C-5/C-17 capable, 9,000-foot runway that serves as a major supply and logistics hub for the U.S. Marine Corps (USMC) within the Pacific region (Eldridge, 2012). Use of MCAS Futenma as the simulation site for peak runoff rate, along with other hydrological data from the installation, will provide more understanding to the extent of the PFAS contamination issues surrounding the air station. This will also give the model more validity in its application to actual DoD installations more over a broader span and limit assumptions within the model itself. Calculation of the peak runoff rate for the selected simulation site is described in subsequent sections of this text.

Per- and Polyfluoroalkyl Substances

Persistence of PFAS is a growing concern for both environmental and public health reasons. PFAS has been found to be persistent in the natural environment and consists of more than 5,000 different chemical species (N Bolan et al., 2021; Sima &

Jaffe, 2021). Originally synthetically made in the 1930s, PFAS compounds have been commercially produced for a variety of industrial applications and products (Buck et al., 2011; Moody & Field, 2000). PFAS compounds have also had wide-spread use in consumer based products to include non-stick cookware, water-resistant garments, and food packaging (Ahrens, 2011; Ahrens & Bundschuh, 2014). These chemicals have also been found in agricultural lands stemming from biosolid soil amendments obtained from wastewater treatment plants (Sepulvado et al., 2011; Vo et al., 2020; Zareitalabad et al., 2013). The abundance of these chemicals throughout commercial and industrial use has led to multiple long-lasting concerns.

PFAS compounds are identified by the number of carbons present within the carbon-chain tail. Long-chain PFAS differ from the short-chain varieties based on this carbon number. Long-chain PFAS include all perfluoroalkane sulfonates (PFSA) compound species with a carbon-chain length greater than or equal to six, while within the perfluorocarboxylic acid (PFCA) varieties any species with a carbon-chain greater or equal to eight are classified as long-chain (Kempisty et al., 2018). Further explanation on chain classification involves a more broadened approach for PFAS compounds. Classification for all PFAS include long chains as greater than seven, short chains as falling between four to seven, and ultra-short chains as two to three carbon molecule chains (Ateia et al., 2019).

The PFAS molecule has a very specific chemical nature with two main components: one end being the functional group and the other as a carbon-chain tail. The functional group head can vary due to the type of PFAS compound; however, all functional group heads are water attracting and have hydrophilic characteristics. The

carbon-chain tail of the molecule varies in length and carbon structure depending on the compound, but retains hydrophobic, water-repelling qualities (Buck et al., 2011).

Because of this hydrophilic-hydrophobic structure of PFAS compounds, it is chemically well suited for its ability to extinguish Class-B hydrocarbon fires at the air-liquid interface (Interstate Technology Regulatory Council, 2017).

Another critical classification of PFAS compounds is the differentiation in the functional groups found in the hydrophilic head. These classifications include categorization as sulfonates, carboxylates, phosphonates, and alcohols (Buck et al., 2011). Major important groups are found in perfluoroalkyl acids (PFAA) which also include perfluoroalkyl carboxylic acids (PFCA), the aforementioned PFSA, and polyfluorinated compounds or fluorotelomers comprising fluorotelomer sulfonates (FTSA), fluorotelomer carboxylates (FTCA), and fluorotelomer alcohols (FTOH) (Buck et al., 2011). These polyfluorinated compounds (FTSA, FTCA, and FTOH) are a key environmental concern as they represent precursor compounds to the PFAA (Barzen-Hanson et al., 2017; Buck et al., 2011; Houtz et al., 2013). This separation in classification between polyfluorinated compounds and PFSA is important due to the characteristic long-term degradation of polyfluorinated compounds into PFAA even after initial PFAS contamination has been resolved.

PFAS species are aliphatic, organic compounds in which carbon atoms form open chains, as found in alkanes, and not in traditional aromatic rings. They are split into two main structural characteristics: partially fluorinated (polyfluorinated) and fully fluorinated (per-fluorinated) alkyl chains that are comprised of carbon (C) and fluorine (F) atoms (Buck et al., 2011). This structure of the carbon-fluorine bonding is both

exceptionally strong and makes the PFAS highly resistant to numerous different conditions in the natural environment. This resistance to biodegradation, along with other physicochemical properties to include high thermal stability, increase the resilience and persistence of PFAS making them a pronounced environmental concern and bioaccumulative (Omo-Okoro et al., 2020).

Fate and transport of PFAS compounds in the natural environment relies on several different factors surrounding the individual chemical and ionic properties of separate PFAS compounds and the type of media through which the compound is traveling. One of the largest distinctions is found in the increase in adsorptive properties of long chain compounds over the shorter chain varieties (Chen et al., 2013; F. Wang & Shih, 2011; Zhao et al., 2014). Furthermore, PFSA are also usually more adsorptive than PFCA of similar chain length (Higgins & Luthy, 2006). This can lead to an increase in the persistency of the PFSA compounds within porous media due to the ability of these longer chain PFAS molecules to have stronger bonds to the media they have been adsorbed into. For the purpose of this study, the persistency is directly correlated to the levels of mitigation and remediation that would be necessary for a known contaminated concrete surface.

Remediation of PFAS can pose numerous challenges when found in various media. For drinking water purposes, removal of PFAS is not completely effective using traditional decontamination methods (N Bolan et al., 2021; Gagliano et al., 2020; Simon et al., 2019; Vu & Wu, 2020). PFAS removal has also been studied in soil remediation methods as way to mitigate its fate and transport through groundwaters and into more mobile waterways (Chen et al., 2013; Glüge et al., 2020; Houtz et al., 2013). Further

remediation and mitigation efforts are needed to fully understand fate and transport of PFAS through both the natural and built environments. Increasing available studies on the relationships between PFAS desorption and concrete surfaces will help to improve mitigation techniques and procedures. This will also give a better understanding for the DoD on the amounts of PFAS that are leaving installations through stormwater drainage channels and the amount of time those contaminants will be of significant impact to environmental and health concerns following AFFF releases.

Aqueous Film Forming Foam

AFFF, an important firefighting agent for both military and civilian use, is recognized as a major contributor to the current concentrations of PFAS in the environment (by David Kempisty & Racz, 2021). DoD introduction to PFAS use began in the 1960s in large part due to the introduction of firefighting foams, specifically AFFF. In 1963, the United States Navy launched an initiative with 3M® to create better firefighting foams than the preceding protein-based foams (Hayes & Faber, 2019). Through development of improved techniques and procedures in firefighting operations, foams have developed to more effective and efficient methods. Most firefighting foams of today, including AFFF, have shifted from protein-based foams of yesteryear to the per-fluorinated or fluorine-free compounds that are predominately used today (Kempisty et al., 2018). Though its use and resourcefulness in firefighting operations has been extremely beneficial to the DoD and other civilian agencies, PFAS and AFFF are still a major concern for both public health and the environment.

Two primary production techniques are used in the production of PFAS containing AFFF: electrochemical fluorination (ECF) and telomerization (Barzen-Hanson et al., 2017; Buck et al., 2011). The ECF process produces the longer chain PFAS, predominantly found as PFSA, and the telomerization technique results in the production of polyfluorinated fluorotelomers (W J Backe et al., 2013; Buck et al., 2011). In conjunction with the strong carbon-fluorine chemical bonding, this makes AFFF, both long and short chain, ideal for firefighting operations and highly effective at extinguishing hydrocarbon and polar solvent fires (Interstate Technology Regulatory Council, 2017). While its use in firefighting is of great value to both the DoD and civilian entities, the strong carbon-fluorine bonding results in the negative environmental effect of longer half-lives and increased degradation properties (Y. Wang & Liu, 2020).

With increases in scrutiny and both environmental and health concerns surrounding the use of PFAS-based AFFF, phasing out began in the early 2000s in conjunction with the decision by 3M®, the primary producer, to reduce and discontinue production of long chain PFAS (3M, 2000). In late 2002, the EPA included close to 100 PFAS chemicals to the Significant New Use Rule (SNUR) requiring notification prior to the manufacture, production, or import of any of these compounds (U.S. Environmental Protection Agency, 2017). Continuance of this rule allowed for some minor use for technical aspects on the conditions that they were at minimal volume and significantly reduce exposure and release. This eventually led to the inclusion of both PFOS and long-chain PFOA and the ban in production of PFOS and PFOA compounds (Agency for Toxic Substances and Disease Registry, 2021; U.S. Environmental Protection Agency, 2017).

Transport of AFFF and the containing PFAS compounds within the natural environment is complex and difficult to fully comprehend for many reasons. Co-contamination, varying amounts of PFAS compounds and precursors present in the specific formulation, and porous media properties all have conflicting roles in the persistence and degradation of AFFF. Formulations from different manufactures have been found to have more than 50 unique PFAS compounds anywhere from two and up to 12 carbon-chains (Barzen-Hanson et al., 2017; Barzen-Hanson & Field, 2015; Place & Field, 2012). It should be noted that the variations in AFFF formulation plays an important role in the adsorption and desorption of PFAS compounds not just based on media types but also within media types as well. Furthermore, the specific and primary usage of AFFF as a fire suppressant will also have a high degree of hydrocarbon and non-aqueous phase liquids (NAPL) in water runoff from fuel sources in areas where firefighting operations have occurred (Brusseau et al., 2019; Guelfo & Higgins, 2013; Silva et al., 2019). While presence of these NAPL co-contaminants has not been widely examined, studies suggest that they will impact the overall fate and transport of AFFF (Brusseau, 2018; Silva et al., 2019).

Traditional use of AFFF for firefighting operations by the DoD and civilian agencies is primarily in the suppression of aviation fires. Examination of the surrounding groundwater and soils near military and civilian operating facilities has shown an increase of groundwater PFOS levels near 35 percent (Rice, 2019). Even though the use of legacy firefighting foams, to include AFFF containing PFOS and PFOA, have been outright banned or restricted, issues with newer AFFF variations are still present. In the early 2000's it was initially reported that the presence of PFOA was not likely from the

newer AFFF formulations, however analysis of C6-based foams since then has shown that roughly 20 percent of the PFAS present were precursors to PFOA and therefore had potential to form PFOA in the environment. Moreover, the remainder of the PFAS found in C6-based AFFF was found to have additional precursor qualities to the short-chained PFAA (by David Kempisty & Racz, 2021).

EPA Regulatory Limits and DoD Guidelines

Regulatory limits and guidelines surrounding the use of AFFF and other fluorinated foams has predominantly arisen within the past few decades. Most notably, of the regulations that have impacted the use AFFF the first was the introduction of the amendments to the Safe Water Drinking Act (SWDA) in 1996. The SWDA fundamentally changed the way that the EPA took on regulatory development processes. In 2009 the EPA released Provisional Health Advisories for both PFOA and PFOS to quantities of 400 ppt and 200 ppt, respectively (U.S. Environmental Protection Agency, 2009). Additionally, the EPA included PFOS and PFOA and the Third Contaminant Candidate List (CCL3) and pushed forward in 2012 in further developing national occurrence data by including six PFAS on the final Third Unregulated Contaminant Monitoring Rule (UCMR3). This list included PFOS, PFOA, PFNA, PFHxS, PFHpA, and PFBS (by David Kempisty & Racz, 2021). These limits were again revised in 2016 with the release of the EPA Lifetime Health Advisories for PFOS and PFOA to 70 ppt in drinking water, however there no current advisories for short-chain PFAS.

Although these CCLs established by the EPA, along with the UCMR3, create many restrictions on use and production, there are still issues with PFAS that need to be

addressed. Many of the chemical constituents of PFAS and the PFOS and PFOA precursors either were grandfathered in prior to the 1996 SWDA amendments or need additional information on the relevance to human health effects and environmental persistence (Sullivan, 2001). Even with these limitations, PFOS and PFOA remain emerging contaminants within the scope of the EPA regulatory reviews and are a major focus of literature (Simon et al., 2019).

DoD use of AFFF is largely governed by different federal statutes but must also meet the requirements set forth in Military Specification (MilSpec) MIL-F-24385F under the control of the Navy Sea Systems Command (NSSC). As such, the Naval Research Laboratory (NRL) is the DoD designated institution for certification of the DoD AFFF Qualifying Products List (Sheinson et al., 2002). Since the 2016 EPA LHA, the DoD has pushed further and adopted a limit of 800 ppb as its target MilSpec for both PFOS and PFOA (Naval Sea Systems Command, 2017). Continued use of AFFF is closely monitored with additional research and studies carried out by the NRL to reevaluate and update DoD guidelines and regulations as new data is discovered.

Environmental and Health Issues

Following production and manufacture, PFAS compounds have a wide variety of pathways into the environment and the human body. As such, products that are produced for commercial use, and those found in fluorinated foams, are more susceptible to transport and distribution throughout the environment than they are to degrade (by David Kempisty & Racz, 2021). The extent of this PFAS dissemination has been extensively studied with indications that all parts of the globe are contaminated to some degree even

including the north pole (Bossi et al., 2005). This is largely in part to the ability of PFAS compounds to migrate extremely well in both water and soil leading to contamination of food and drinking water supplies (by David Kempisty & Racz, 2021). This has led to numerous contaminated sites in the United States and world-wide.

Some drinking water sources near highly contaminated sites have over two orders of magnitude above the EPA health advisory limits and account for the majority of PFAS exposure within the local areas (by David Kempisty & Racz, 2021). Though exposure pathways can be presented through several different routes (inhalation of indoor air, outdoor air, and dust; and digestion of food), the primary exposure pathway is through ingestion of surface water through drinking water systems (Agency for Toxic Substances and Disease Registry, 2021; Kempisty et al., 2018). Based on the findings from the UCMR3, approximately 1.3% of 36,972 public water systems were shown to have PFOS and PFOA results above the health advisory limit (U.S. Environmental Protection Agency, 2015).

Bioaccumulation of PFAS in the human body is directly related to the extended degradation once inside the body. Half-lives for PFOA can range from two to ten years with half-life for PFOS increasing to as much as 27 years (Agency for Toxic Substances and Disease Registry, 2021; Kempisty et al., 2018). Studies have shown that PFAS compounds have been detected in nearly 98% of serum samples collected from a civilian U.S. population over the age of 12 to include additional examinations of AFFF related fluorochemicals in blood from several different countries (Calafat et al., 2007; Kwok et al., 2015; Olsen et al., 2017).

PFAS Desorption in Concrete Media

Desorption of contaminants is partially correlated to the adsorption mechanism used in the initial bonding of PFAS compounds to the media surface. Adsorption of PFAS onto the surface and through a porous media is associated to the mechanism of the chemical reaction. The primary sources of adsorption in peer-reviewed literature are electrostatic and hydrophobic interactions. Though ion exchange is directly related to electrostatic interactions, the cationic and anionic exchange properties are widely studied in PFAS laboratory experiments (Li et al., 2018). Hydrogen bonding is another form of the adsorption mechanism for PFAS that has been examined but was determined to be minor in traditional environmental conditions (Du et al., 2014; Zhang et al., 2019).

Ionization is also a relevant characteristic of the desorption mechanism from porous media surface as well. Some classes of zwitterionic, cationic, and anionic PFAS have been identified and associated with the specific formulations of AFFF used by the DoD (Will J. Backe et al., 2013). Anionic PFAS are the most widely studied in literature and have identified for desorption in contaminated soils (Nanthi Bolan et al., 2021; Sörengård et al., 2020). Though not as extensively studied, cationic and zwitterionic compounds have an increasing interest in both the adsorption and desorption mechanisms and properties (Barzen-Hanson et al., 2017; Xiao et al., 2019) showing potential for increased contamination, in the form of precursors compounds, than the degraded anionic PFOS and PFOA (Adamson et al., 2020; Nickerson et al., 2021).

For desorption and adsorption in porous concrete, limited studies have been completed on the removal of PFAS or the effects of AFFF through the media. Studies have shown the desorption properties and chemical diffusion into concrete (Thompson,

2014), though at the time of writing, few were specifically related to PFAS desorption (Badel et al., 2015). The subsequent section reviews the limited information regarding desorption of PFAS and AFFF in porous concrete.

Relevant Research

While several studies have been conducted on the fate and transport through soils, chemical analysis, and public health hazards that AFFFs present (Domingo and Nadal, 2019; Kwok, et al., 2015), there has been very limited research into the fate and transport of PFAS/AFFF within concrete structures. Published literature has well studied adsorptive behaviors in porous media that involve interactions with organic carbons, soil types including reactions with clays and silts, and the effects inorganic ions, pH, and saturation have on the desorption behaviors of PFAS (Barzen-Hanson et al., 2017; Söregård et al., 2020; Yi et al., 2018).

What has not been thoroughly studied, is the sorptive characteristics of PFAS in concrete. As of the writing of this study, only one such research initiative extensively sought to examine the desorption behavior of PFAS, more specifically AFFF in concrete. That study was conducted by Baduel et al. (2015) as part of a University of Brisbane research project on a FTG in Australia that had been in service since 1983 (Badel et al., 2015). The Baduel et al. study was purposed to examine the occurrence and fate of 15 different PFAS and one FTSA (6:2 FTS) at a FTG that had been contaminated by continuous use of AFFF.

For Baduel et al., the experiment was focused on the existing contamination of the FTG by first taking concrete samples from the site for analysis and then by constructing

and performing a desorption test to remove the PFAS. The contamination profile of the site was investigated by determining the surface and vertical mass loading of 15 PFAS to include 11 PFCA (C4-C14 PFCA), four PFSA (C4, C6, C8, C10 PFSA), and one FTSA (6:2 FTS) (Baduel et al., 2015). Desorption of the PFAS compounds from the concrete was achieved by building a 62 cm² plastic frame at 16 different locations on the FTG concrete pad. Frames were then filled with 100 mL of MilliQ water at a depth of 15 mm and corresponds to the expected water levels from a strong rain event or consecutive training exercises (Baduel et al., 2015). Samples were taken at various time intervals to show the desorption of PFAS from the concrete pad sites over the elapsed time. After samples were collected, they were analyzed via high-performance liquid chromatography (HPLC) and tandem mass spectrometer. Concrete powder samples were also collected from the FTG pad at 10 different locations with retrieval of 2-3 g of powder per sample. These samples were then extracted with 4 mL of methanol under sonification for 15 minutes (Baduel et al., 2015). The kinetic desorption experiment was repeated twice at 4°C and 24°C, representative of the upper and lower temperature ranges for the FTG site (Baduel et al., 2015).

One of the primary constraints of the Baduel et al. study is that the experiment was based on the desorption of PFAS from contaminated concrete using a stationary water source as the catalyst for concrete rehydration. The experiment described in this text sought to build upon this desorption principle with the change from a stationary water source a mobile rehydration source through continuous flowing water through a concrete channel. Both rely on the principle that as water is poured onto or across the surface, the concentration of PFAS in the water increases at an exponentially decreasing

rate eventually reaching steady state (Baduel et al., 2015). This follows the model approach of exponential decay increasing form (EDIF) as seen below:

$$y = C(1 - e^{-kt}) \quad (\text{Eq 1})$$

Key features of the EDIF are an asymptotic relationship to $y=C$ to the right, the function passes through the origin, and is bounded by C at the upper limit (Larson et al., 2010). This is the basis for kinetic modeling for both this experiment and the Baduel et al. study. However, where they analyzed the model at specific locations in the concrete pad at the FTG, this study seeks to apply the model more broadly through its application throughout the channel.

Baduel et al. (2015) was able to show a spatial distribution and vertical profile of the tested PFAS and FTSA. Total mass of the PFAS in the FTG pad was estimated to be 250 g at a depth of 0-0.5 cm for surface contamination and 1700 g for the whole pad at a depth of 0-12 cm deep (Baduel et al., 2015). PFAS concentrations varied within the pad from 10 to 200 $\mu\text{g/g}$ with PFOS as the dominant PFAS compound. Through the kinetic model presented, time to remove 50% of the existing concentrations for PFOS, PFOA, and 6:2 FTS were 25, 1, and 0.7 years, respectively. Additionally, removal of 90% of these compounds through rainwater and firefighting exercises was found to be 82, 4, and 2 years, respectively (Baduel et al., 2015). The most significant of these findings was the result in which the model showed that the estimated time for PFOS to come under the EPA regulatory guidance of 200 ppt (based on the 2009 EPA guidance) would not occur until 2230 (Baduel et al., 2015). This is perhaps the most definitive evidence that experiments on the desorption of PFAS in concrete structures should be further investigated and improved mitigation standards enacted.

Summary

This chapter summarizes the relevant background information on the structure and purpose of stormwater drainage channels and the selection of the simulated site for establishing other variables needed for kinetic model of PFAS desorption in porous concrete. It also explores the properties of both PFAS compounds and AFFF and their effects on the natural environment and human health. An in-depth review of the methods used for PFAS desorption in concrete was reviewed to establish the basis for kinetic modeling in this experiment. Issues surrounding the limited research on desorption from concrete was shown to validate the need for additional studies that specifically investigate PFAS contamination in stormwater drainage channels.

III. Methodology

Chapter Overview

The purpose of this chapter is to detail the methods and procedures that were used throughout the experiment and research process; the accompanying materials, equipment, and design parameters; and the theory and development of the kinetic desorption model. Three chemical dyes and one PFAS solution were tested in comparison with each other to show any relationship or correlation in desorption behaviors. Contaminants were tested in a closed system and samples were collected at various time intervals to show changes in desorption concentrations. Chemical dye samples were analyzed in the Air Force Institute of Technology (AFIT) Environmental Engineering laboratory, while the PFAS samples were sent off-site to a third party for analysis by Pace Analytical Services.

Results for the experiment were recorded for further analysis and assessment in later sections.

Materials and Equipment

Though the main premise of the experiment was to analyze the desorption of PFAS from concrete, three additional chemical dyes were also used to test for any relationship to PFAS in desorption performance. The PFAS contaminant was a 3% solution of FC-600F 3M Light Water AR-AFFF that was collected from a stock sample within the AFIT Environmental Laboratory (Table 1). Chemical dye surrogates were chosen based on previous research and ionic charge. Due to the caustic nature of poured concrete, and the ionic variations between different mix designs, selected dyes should show variations in different ionic characteristics within the concrete coupons.

Table 1 – AFFF 3M Light Water Properties

Property	Value	Units
Boiling Point	100	°C
Vapor Pressure (@20°C)	17.8	mmHg
Vapor Density (@20°C)	0.65	1 atm
Evaporation Rate	<1.0	1 BuOAc
Solubility in water	Complete	N/A
Specific Gravity	1.0	N/A
Percent Volatile	85%	N/A
pH	8.5	N/A
Viscosity	1950	cP
Appearance and Odor	Translucent, amber colored liquid	

Allura Red AC (AR) is a well-known anionic dye that has been studied in clay-adsorption models and shown to have low adsorption when competing with OH⁻ ions (Saavedra-Labastida et al., 2019). Methylene Blue (MB) on the other hand is an organic cation that desorbs well when used against inorganic sorbents (Söregård et al., 2020).

With the two ends of the ionic spectrum selected, a balanced approach was taken to select the third dye in the experiment. For this, Brilliant Blue FCF (BB) was selected based on its nature to contain both positively- and negatively-charged functional groups, or as a zwitterionic dye (Bikos & Mason, 2019).

Table 2 - Surrogate Dye Properties

Chemical Name	Chemical Formula	Molecular Weight	Molarity of Stock Solution	Concentration
Allura Red AC	$C_{18}H_{14}N_2Na_2O_8S_2$	496.42 g/mol	0.05 mM	24.8 mg/L
Methylene Blue	$C_{16}H_{18}ClN_3S$	319.85 g/mol	0.05 mM	16.0 mg/L
Brilliant Blue FCF	$C_{37}H_{36}N_2Na_2O_9S_3$	792.86 g/mol	0.05 mM	39.6 mg/L

Stock solutions of the surrogate dyes were created using concentrations required for each dye to represent a 0.05 mM solution. Powder dyes were weighed using plastic weighing trays to obtain precise weights as listed in Table 2. The powdered dyes were then added to 500 mL of RO water in 1.0 L volumetric flasks through analytical transfer. RO water was then added to the flasks to bring the total volume of the solution to 1000 mL. Magnetic stir bars were then added to the flasks and solutions were mixed using a Southwest Science magnetic stirrer for 24 hours. Solutions were refrigerated until used in the experiment.

Post-preparation of the solutions, six-point calibration curves were developed to test recovered samples against for concentration within the reactors. Standards were diluted to known values with UV-Vis absorbance measured at RO blanks, 100%, 50%, 10%, 1%, 0.5%, and 0.1% concentrations. Calibration standards were well mixed for 20 seconds each using a vortex mixer before calibration analysis using the *Cary 60* UV-Vis. Wavelengths were measured using the *Cary 60* Scan program and measured wavelengths

were found to be 504 nm, 664 nm, and 630 nm for AR, MB, and BB, respectively. The *Cary 60* Simple Reads program was used to analyze the calibration standards for building the calibration curve. Additional information on the surrogate dye calibration curves can be found in Appendix C.

The primary equipment used for analysis of the surrogate dye reactor samples was the *Cary 60* UV-Vis utilizing the *Cary 60* Simple Reads program. Three samples were collected from each reactor at the varied time intervals. Samples were drawn from the reactors using a 1,000 μ L pipette with plastic pipette tips. Collected samples were then placed in 1.0 cm plastic cuvettes at a volume of 2.0 mL for each sample. Reactor samples were then analyzed using the *Cary 60* UV-Vis and *Cary 60* Simple Reads program and data recorded for further analysis.

Samples from testing the 3M Light Water™ solution were split into two distinct categories for analysis: liquid samples and powder dry samples. For the liquid samples, three reactor samples (described below) were taken at 3 hrs (PR₁), 6 hrs (PR₂), and 36 hrs (PR₃) each with a total volume of 25 mL. An additional 50 mL PFAS stock solution was made to reflect the 3% AFFF solution prepared to the 3M® manufacture's specifications for fielded use by combining 1.5 mL of the stock solution to 48.5 mL of RO water.

Channel Design

The first step in designing the mock channels for testing was to select an appropriate channel structure similar to the infrastructure at MCAS Futenma. After inspecting aerial satellite imagery of the installation and taking approximated measurements of the existing channel, selection of a trapezoidal channel design was

determined to be the best fit. Approximations were made for the existing channel's top and bottom width by uploading satellite imagery into the QGIS™ software and using the measurements feature to record the data. The mock channel was then designed at a 1:60 scale based on the estimated measurements. Values for the top and bottom widths of the mock channels were adjusted slightly for ease of construction and to achieve more precision in the final concrete molds.

Table 3 - Channel Ratios

Measurement	Value	Units
Estimated Top Width (E_T)	16.75	ft
Estimated Bottom Width (E_B)	9.75	ft
Ratio (E_B / E_T)	0.582	
Mock Channel Top Width (M_T)	8.5	cm
Mock Channel Bottom Width (M_B)	5.0	cm
Ratio (M_B / M_T)	0.588	

Once the top and bottom widths were determined for the mock channel design, an equal side slope of 1.75 was applied to the channel to determine the remaining parameters for the channel design. The Manning roughness was selected at 0.013 as a median between finished and unfinished concrete due to the variability between the constructed channels (Young et al., 2011). The slope of the channel was established at 0.001 (m/m) to limit the turbulence of the influent flow through the channel. The remaining parameters are displayed below in Table 4 and Figures 1 and 2.

Table 4 - Mock Channel Design Parameters

Variable	cm	m	US Standard Unit
Side Slope on bank 1, z1	1.75		
Side Slope on bank 2, z2	1.75		
Discharge, Q (m ³ /s)	6.28E-05		2.22E-03 ft ³ /s
Velocity, V (m/s)	9.30E-02		3.05E-01 ft/s
Water Depth, y (m)	1.0	0.01	0.033 ft
Top Width, T (m)	0.085		0.279 ft
Bottom Width, b (m)	5.0	0.05	0.164 ft
Manning Roughness, n	0.013		
Channel Slope, S (m/m)	0.001		
Unit Conversion, k	1.0		
Channel Area, A (m ²)	6.75	0.001	0.007 ft ²
Channel Wetted Perimeter, P (m)	9.031	0.090	0.296 ft
Hydraulic Radius, R (m)	0.747	0.007	0.025 ft
Froude Number, F	15.322		
Hydraulic Mean Depth, h _m	0.008		

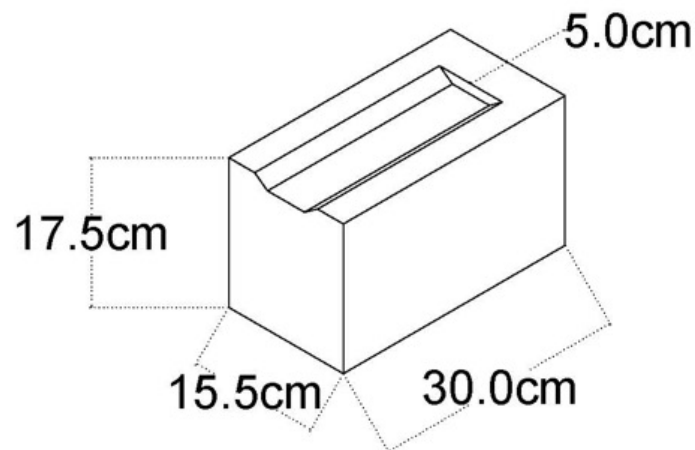


Figure 1 - Mock Channel Dimensions (A)

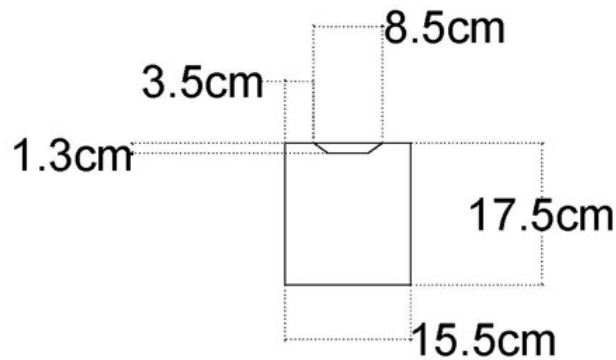


Figure 2 - Mock Channel Dimensions (B)

Concrete Mix Design

As a media type, concrete varies drastically between different mix designs and can even have fluctuating characteristics between samples of the same batch (Yang et al., 2011). Aspects that can alter the structural and chemical properties of concrete include water to cement ratio, selection and size of aggregate, type of cementitious material, and additives to the mix. Due to these factors and that the purpose of this research was to study the characteristics of PFAS within stormwater channels on DoD installations it was imperative to select the most analogous parameters that would be found in these environments.

Establishing the experimental design to predict the expected persistency of AFFF within the semi-porous concrete is based on several different variables that effect the overall structure of the concrete. Mix design will regulate the final compressive strength, water to cement ratio, and aggregate composition. Porosity and permeability will determine the presence of open pores, particularly capillary pores, that allow for the flow

of liquids through the concrete; and the density and viscosity of the PFAS/AFFF will also factor into the depth the chemical could potentially reach within the concrete (Thompson, 2014). This implies that the structural composition of the concrete holds a crucial role in the assessed outcome in terms of persistency. When combined with small variations in cement ratios and aggregates, structural composition can change the overall time of desorption, specifically due to the porosity of the concrete mix. It is therefore paramount that the tested concrete mix design match as closely as possible to the actual concrete that could be found within the stormwater infrastructures aboard DoD installations.

The process for selecting a concrete mix design began by reviewing appropriate literature and DoD publications and engineering manuals. The bulk of concrete mix design calculations followed the processes described in Marine Corps Reference Publication (MCRP) 3-40D.4, Concrete and Masonry. Additional information was provided from the United States Army Corps of Engineers (USACE) EM-1110-2-2007, Structural Design of Concrete Lined Flood Channels. After review, it is likely that the characteristics of the actual channel design at MCAS Futenma closely match those listed below in Table 5.

Table 5 - Prescribed Mix Characteristics

Property	Value
Compressive Strength	25 MPa (3000 psi)
Curing Time	28 days
Portland Cement	Type I/II
Slump	3 in.
Fine Aggregates	%Fines 4.0-6.0
	SG 2.65
Coarse Aggregates	MSA 0.375 in.
	SG 2.70
	%Fines <1.0

The first major factor in the concrete mix design was to select the appropriate MSA. The MSA is the largest coarse aggregate size to be used in order to prevent undesirable areas to include voids that can arise from the aggregate getting stuck between reinforcing bars, wires and concrete forms (USMC, 2012). Honeycombing, areas in which there is segregation of coarse aggregates or the tendency of aggregates to clump together and not be incased by the mortar, is another concern with the size of the aggregate (McCormac & Brown, 2014). Since this experiment was focused on the desorption of chemical contaminants from a small-scale model channel, and that the dimensions of the mock channel were smaller than those that would be found in the built environment, the MSA was selected at 3/8 in. to account for the reduced size of the channel and limit the adverse effects of selecting a larger sized aggregate.

The next factor in the concrete mix design was to select an appropriate cement additive. Since the simulated test site is one that is near the ocean and prone to high salinity, Portland Type I/II was selected to reduce the heat of hydration and provide some resistance to soils and waters with high sulfates (McCormac & Brown, 2014). Sakrete Portland Cement Type I/II was used for the mix design given the proximity of MCAS Futenma to ocean waters and the high levels of salinity found in natural rainwaters within the area. By using a Type I/II cement, the final mix design will have a more similar structural characteristic to the concrete found at MCAS Futenma.

Once these two guiding factors were established, the remaining procedure relied again on the direction as described in MCRP 3.40D.4. A mix table, shown in Appendix A, was created to track the data and calculations for the mix design. Calculated values

are shown for the mock channel proportions, test cylinders, total concrete used, and batch proportions.

Mock Channel Construction

Channel construction was completed using the selected concrete mix design in coordination with plywood forms. Typical concrete forming of larger structures would allow for floating, a process by which the aggregates are embedded just beneath the surface and small imperfections of high and low spots are removed (USMC, 2012). Since this method could not be used due to the size of the form, negative concrete forms were constructed so that the concrete mix could be poured into the mold with the channel face on the bottom of the mold (Figure 3). This resulted in the finished mock channel having a smoother, more finished surface than if the channel was cut into the channel after pouring.



Figure 3 - Concrete Forms

The concrete mix was then made according to the mix design in Appendix A using the Civil Engineering Laboratory at the University of Dayton. The mix was split into three batches to control volume output and transferred into the forms after each batch. Measurements for each batch was based on weight of the individual materials and aggregates to limit and reduce variation between batches. Portland cement was first added to the cement mixer followed by the sand and gravel and allowed to thoroughly mix before adding water in small amounts at a time. This ensured proper mixing of all materials. After mixing, the batch was then poured into the plywood forms and then tamped and leveled.

The concrete mock channels were then allowed to cure for 28 days in accordance with American Concrete Institute (ACI) standards following ACI 308-92, *Standard Practice for Curing Concrete*, and ACI 308.1-98, *Standard Specification for Curing Concrete*. While the mock channels were being cured, additional measures were taken to ensure that the mix design exceeded the standard strength of 25 MPa (3000 psi). A total of nine test cylinders, as designed in Appendix A, at 4 in. diameter and 8 in. height were constructed and compression testing completed as required by Sections 26.5.3.2 and 26.12.1.1 of ACI 318-19, ACI 301-20 *Specifications for Concrete Construction* and ACI 311.6-18 *Specification for Testing Ready Mixed Concrete*.



Figure 4 - Concrete Mixing



Figure 5 - Finished Concrete Forms

Three test cylinders were selected at seven, fourteen, and twenty-eight days and tested using a Forney 502 Series Block Tester Compression Machine (Model# F-502-F-TPILOT). Cylinders were loaded into the Forney tester with unbonded neoprene caps at both ends of the cylinder following American Society for Testing and Materials (ASTM) standard ASTM C1231. Once inserted into the Forney machine, full advance of the piston was introduced until approximately 10% of the max load was achieved. The

piston was then advanced at a metered rate of 500 lbs/sec until the max failure yield was reached.



Figure 6 - Compression Testing

The max failure yield was found for each test cylinder and then converted into compression strength using the following formulas:

$$Area_{cylinderface} = \pi r^2 \quad (Eq\ 2)$$

$$Compressive\ Strength = \frac{Max\ Failure\ Yield}{Area_{cylinderface}} \quad (Eq\ 3)$$

As final compressive strength was calculated, the data was then recorded below in Table 6. Test cylinders were then inspected for breakage patterns following ASTM C39, *Standard Test Methods for Compressive Strength of Cylindrical Concrete Specimens*, and the data recorded. Max compressive strength for all nine samples tested demonstrated that the mix design was above standards and the concrete design would meet the specifications detailed above.

Table 6 - Compression Testing

Curing Duration	Sample	Max Failure Yield (psi)	Compressive Strength (psi)	Breakage Type (ASTM C39)
7 day	1	53550	4261	Type 6
	2	58300	4640	Type 3
	3	63215	5031	Type 6
14 day	4	65730	5231	Type 3
	5	67820	5397	Type 2
	6	63665	5066	Type 2
28 day	7	73645	5861	Type 3
	8	76560	6093	Type 2
	9	72845	5768	Type 2

After the 28-day curing time had passed, the mock channels were then broken from the molds and washed using a pressure washer to remove any loose particles or debris from the plywood mold that may clog tubing or disrupt flow in the reactor setup.

Contamination and Reactor Setup

Once the mock channels were cured for 28 days, the channels were then capped at the open end with plexiglass and secured using GE All Purpose Silicone. The sealant for the plexiglass was set aside to cure for 24 hours prior to saturation. For the surrogate dyes, three concrete channels for each dye were saturated with 225 mL of the 0.05mM solutions. The channels were placed inside a temperature-controlled environment within the AFIT Environmental Engineering Laboratory and allowed to fully evaporate at 17.8°C (± 0.2 °C) and 81.0% ($\pm 0.3\%$) relative humidity. This follows an assumption that only the water will evaporate from the channels, thus allowing the absorbed dye to remain in a stationary phase until rehydrated through the flushing process.

In order for this assumption to be correct, all three surrogate dyes used in the experiment must either have low volatile properties or not be non-volatile in nature. This

is the case for both BB and AR as both exist completely in the particulate phase as a salt and are non-volatile (National Center for Biotechnology Information, 2004a, 2020).

Though MB is not expected to volatilize from moist soils or dry soil surfaces based on a vapor pressure of $7.0\text{E-}07$ mm Hg at $25\text{ }^{\circ}\text{C}$, it can exist in both the vapor and particulate phases in ambient atmosphere (National Center for Biotechnology Information, 2004b).

Though the assumption for limited volatility of the surrogate dyes from the concrete coupons during the saturation/evaporation stage of contamination is validated, there is additional evidence of some volatility of the MB dye by this experiment in a mobile phase after hydration and discussed in later sections of this report.

Saturation and contamination of the PFAS coupons was achieved by mixing 6.0 mL of the 3M Light Water™ solution with 194.0 mL RO water to create a 200.0 mL PFAS stock solution. The stock solution was then added to two concrete channels 25.0 mL at a time in two-hour intervals until full saturation was achieved. Once fully saturated, both PFAS channels were allowed to completely dry, evaporating the RO water from the stock solution and leaving behind the PFAS solution adsorbed into the concrete. This follows the same generalized assumption for volatility as the surrogate dyes. It is assumed that the PFAS within the stock solution will not evaporate with the RO water as drying occurs. This is based on the low vapor pressure of the 3M Light Water™ and standard boiling point as prepared in the 3% stock solution ($100\text{ }^{\circ}\text{C}$) (3M, 1999). This assumption follows previous research in PFAS as an evaporation retardant for other chemical compounds (Glüge et al., 2020) and additional studies that show that PFAS evaporation is limited in soils (Azzolini, 2014; Nanthi Bolan et al., 2021).

Once coupons were completely dried and the contamination solution was evaporated, construction of the reactors was the same for the nine surrogate dye channels and the one PFAS contaminated channel. The main component of the reactors was the enclosed container used to hold the concrete channels and the circulated RO water in the system. A 29-quart Hefty™ container made from PP#5, polypropylene, fitted with a closable lid was used for the main reactor. This material is consistent with sampling equipment guidelines from the USEPA for PFAS sampling from non-drinking water sources (U.S. Environmental Protection Agency, 2020).

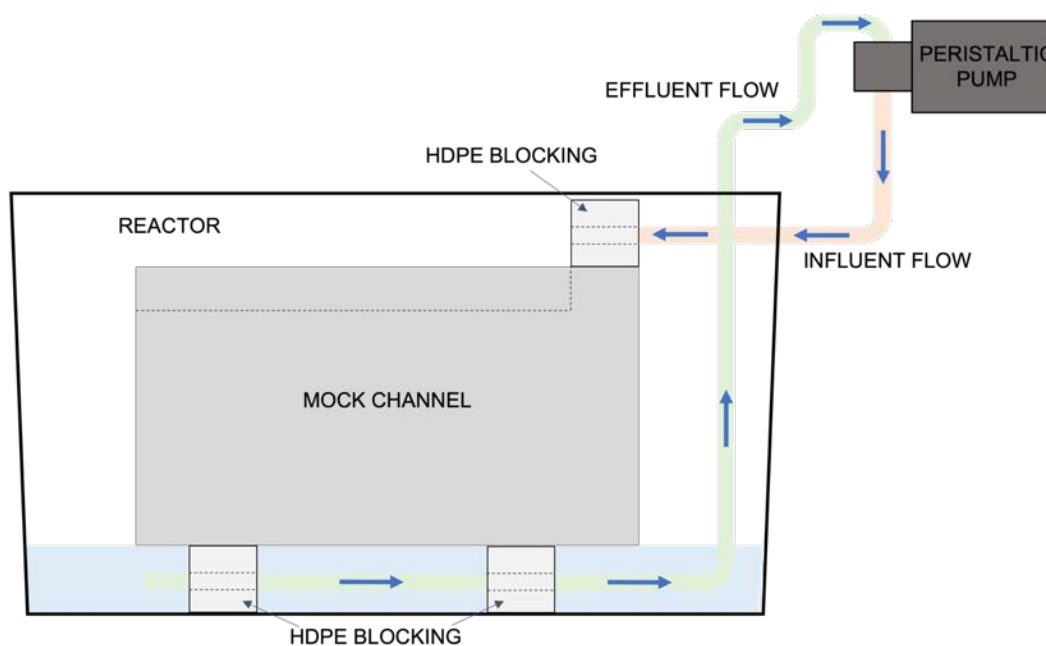


Figure 7 - Reactor Setup

The setup of the reactor was established to simulate open channel laminar flow across the contaminated surface. The channels were raised using HDPE blocking so that the RO water in the lower reservoir did not contact the mock channel and allow desorption from the lower surface. HDPE blocking was sourced McMaster-Carr meeting ASTM D4976 standards, *Standard Specification for Polyethylene Plastics Molding and*

Extrusion Materials, and acceptable as a PFAS sampling equipment material by the USEPA due to its limited ability to absorb PFAS compounds (Michigan Department of Environmental Quality, 2018; U.S. Environmental Protection Agency, 2020). Half-inch diameter holes were also drilled into the HDPE blocking using a stainless-steel drill bit to allow for insertion and proper holding of tubing for circulation of flow.



Figure 8 - MasterFlex L/S® Pump and Pump Head

HDPE tubing (3/8 in ID, 1/2 in OD) sourced through Cole-Palmer was then inserted through the HDPE blocking. Tubing was then heated using boiling RO water to bend the tubing to the appropriate shape. HDPE hose barb unions (3/8 in ID), also sourced from Cole-Palmer, were then used to connect the HDPE tubing to a more flexible tubing to run through the peristaltic pump. An eight-inch section of MasterFlex L/S® high-performance precision tubing (Versilon™ A-60-N, L/S 35) was used to run through

the peristaltic pump head. Versilon™ tubing has sustained good resistance to both acids and alkalis and operates well within nonaging and nonoxidizing properties (MasterFlex(TM), 2020). A MasterFlex L/S® standard digital drive with open-head sensor (Model# EW-07522-28) peristaltic pump was used in conjunction with a MasterFlex L/S® multi-channel pump head (High Performance, 4-Channel) (Model# EW-07536-04) for the driving mechanism of the reactors.

To ensure adequate time for desorption to occur within the channel, flow through the reactor systems needed to remain close to a laminar state. If the flow became turbulent, it would be too extreme for accurate desorption of the contaminants over the short 25.0 cm distance. This is a direct departure from typical open flow channels that involve water and have larger characteristic lengths as they generally have large Reynolds numbers (Young et al., 2011). Calculation of the Reynolds number for the designed mock channel was completed using the following equation:

$$Re = \frac{\rho V R_h}{\mu} \quad (\text{Eq 4})$$

Where ρ is the density of water, V is the average velocity flowing through the channel, R_h is the hydraulic radius, and μ is the dynamic viscosity of water (Young et al., 2011). In determination of the Reynolds number for open flow channels, less than 500-600 is considered to be laminar flow, between 500-600 and 2000 the flow is referred to as transitional flow, and anything above 2000 is considered to be turbulent flow (Lim, 2018).

Table 7 - Reynolds Number Calculations

Design Parameter	Property	Value	Units
Peristaltic Pump (as constructed)	Flow Rate (Q_p)	3.08E-05	m ³ /s
	Cross-sectional Area (A_t)	1.14E-03	m ²
	Average Velocity (V_p)	2.70E-02	m/s
	Hydraulic Radius (R_h)	9.53E-03	m
	Reynolds Number (Re)	243	unitless
Mock Channel (as designed)	Flow Rate (Q_C)	6.28E-05	m ³ /s
	Channel Area (A_C)	6.75E-04	m ²
	Average Velocity (V_C)	9.30E-02	m/s
	Hydraulic Radius (R_{hC})	7.47E-03	m
	Reynolds Number (Re)	655	unitless

Reynolds numbers were first calculated for the designed mock channel and then repeated with the flow rate through the peristaltic pump (Table 7). To relate the flow through the channel to the measured flow through the pump a relationship first had to be determined. Using the distinction that flow (m³/s) is directly proportional to the average velocity (m/s) and the cross-sectional area of the tubing, the following association was used:

$$Q_p = A_t V_p \quad (\text{Eq 5})$$

Where Q_p is the flow rate through the pump, A_t is the cross sectional area using the inside diameter of the tubing, and V_p is the average velocity through the pump. In comparison to the mock channel flow, the cross-sectional area is replaced by the channel area of the as designed.

Given that the recorded temperature of the laboratory was 17.8 °C, interpolation of known values for the density of water (ρ) and dynamic viscosity (μ) were found to be 998.635 kg/m³ and 1.059 mPa-s, respectively (Davis & Masten, 2014). These values were then used in the calculation of the Reynolds number for each parameter.

It was determined during pilot testing that using the designed flow rate (Q_p) at 37,68 mL/min would result in a transitional flow and cause unwanted splashing across the channel. The flow rate was therefore reduced to 1,850 mL/min ($3.08\text{E-}05\text{ m}^3/\text{s}$) to reduce splashing and give a lower flow rate for desorption. In both situations, flow through the channel is still in the general region for laminar flow and consistent for modeling on the reduced scale for the mock channel desorption experiment.

Sampling and Analysis

Reactors were started with 3,500 mL of RO water added to the lower reservoir of the system and ran continuously between 96-97 hours for the surrogate dyes and 36 hours for the PFAS testing reactor. Samples were taken using a 1,000 μL Thermo Scientific Finnpiquette F2 single-channel pipettor with a polypropylene Finntip (Item# UX-25001-71). Three plastic cuvettes were each filled with 2 mL from the reactor per time interval for all three surrogate dyes. Samples were then tested using an Agilent Technologies *Cary 60* UV-Vis and data recorded in the appropriate tables in Appendix B. Time intervals for the surrogate dye testing are displayed below in Table 8.

PFAS testing samples were taken at 3 hours, 6 hours, and 36 hours based on the data presented in the study conducted by Baduel et al. that showed that the time need to reach steady state was near the range of 5 to 15 hours for PFOA and only 1.0 to 1.5 hours for PFOS (Baduel et al., 2015). Choosing these time intervals for this experiment would ensure that the desorption of PFAS compounds was recorded before and after steady state was achieved. Samples (25.0 mL) were collected using the same pipette equipment as the surrogate dyes and transferred to 250 mL HDPE sample bottles provided by Pace

Analytical. PFAS samples were then stored in a cooler, on ice until shipped to the Pace laboratory in Minneapolis, Minnesota for analysis.

Table 8 - Surrogate Dye Time Intervals

Allura Red AC	Methylene Blue	Brilliant Blue FCF
30 min	30 min	30 min
1 hr	1 hr	1 hr
3 hrs	3 hrs	3 hrs
11.5 hrs	18 hrs	13 hrs
26 hrs	27.5 hrs	24 hrs
49 hrs	48 hrs	48 hrs
62 hrs	73 hrs	72 hrs
76 hrs	96 hrs	96 hrs
97 hrs		

Three dry powdered concrete samples were then collected from the second PFAS contaminated block. Two half-inch diameter holes were drilled into the channel surface of the concrete. RO water was used to aid in the drilling for the holes and to reduce the amount of particulate lost into the ambient air. Markings were placed on a carbide concrete masonry bit at 25 mm, 50 mm, and 75 mm depths as stopping points for drilling. Crushed powder was collected from both drilled cavities a minimum weight of 15.0 g per sample. Stainless steel lab scoops were used to collect the powder at each depth before placing into a plastic weighing tray (Figure 9). After the powder material was collected at depth and weighed, the sample was then transferred into 250 mL HDPE bottles and labeled for identification. Additional data on the concrete powdered samples is listed below in Table 9. All samples were allowed to fully dry prior to sealing in HDPE bottles for shipping.

Table 9 - Concrete Powder Physical Properties

Sample ID	Depth	Weight
CB ₁	0 – 25 mm	16.2 g
CB ₂	25 – 50 mm	15.3 g
CB ₃	50 – 75 mm	15.8 g

A total of eight PFAS samples were sent to be analyzed by Pace Analytical. In addition to the three 25 mL PFAS reactor samples and the three ~15 g concrete powder samples, two additional samples were analyzed. The first was a 50 mL sample prepared according to 3M® specifications for a 3% Light Water™ solution at a 3:97 ratio. The second was a 250 mL control reactor sample. This sample was pulled from a control reactor using the same setup as all other reactors, to include container, tubing, and pumps. Additionally, an uncontaminated concrete channel was placed into the reactor as well. The reactor was run for 24 hours prior to pulling the sample using similar equipment and methods used for the PFAS contaminated reactor. Use of the control reactor sample was essential to gathering a baseline for an existing PFAS contamination in the system prior to saturation.



*Discoloration of the pictured concrete powder samples is due to the RO water that was added to assist in drilling

Figure 9 - Concrete Powder Samples

Pace Analytical analyzed the samples for thirty-six different perfluorinated compounds using the DoD Quality Systems Manual (QSM) 5.3 for PFAS analysis. Though not technically a test method, the DoD QSM 5.3 and 5.4, published in September 2020 and late 2021 respectively, provides a baseline for laboratory quality control requirements related to DoD projects (Pace Analytical, 2022). Specifically in relation to the study presented here, Table B-15 of the publications refers to the requirements for PFAS testing in matrices other than drinking water (Pace Analytical, 2022). Laboratory blanks were prepared and analyzed with the samples for additional quality control measures. Blanks were found to be free of targeted perfluorinated compounds, indicating the sample procedures did not significantly contribute to the analyte concentrations of the samples.

Samples were processed by using the Pace Analytical PFAS by Isotope Dilution (537M) procedure following PACE SOP MIN4-0178. Concrete powder samples were processed by methanol extraction using 5.0 g of material with 9.0 mL aliquot of 0.2% ammonia/methanol fortified with a preestablished quantity of isotope dilution extracted internal standards (EIS). Extracts were then treated with 50 mg ENVI-Carb™ and then filtered prior to concentration using nitrogen (Pace Analytical, 2021). Liquid reactor samples were also fortified with a preestablished quantity of isotope dilution EIS prior to being passed through a solid phase extraction (SPE) cartridge (Strata™ PFAS, WAX/GCB sorbent, and weak anion exchange mixed mode) to extract the analytes and EIS. Analytes and EIS were then eluted from the cartridge using small amounts of ammonia/methanol solution for analysis (Pace Analytical, 2021). Samples were also processed in conjunction with laboratory spike samples. Recovery results of spike

samples were within method limits and indicated that that extraction was performed as expected. Four injection internal standards (13C4 PFOA, 13C4 PFOS, 13C2_PFDA, and 13C2_PFHxA) were used and passed for each analysis in the batch validating that the equipment was working as expected.

Simulated Location Site and Watershed Runoff

There are many different variables that must be included within desorption calculations and kinetic modeling. For this experiment, a location site had to be selected to simulate rainfall, stormwater runoff, and peak discharge that all factor into the governing kinetic model. MCAS Futenma was selected based on location and other prominent environmental issues stated in previous sections that relate directly to the purpose of this study. Key data from MCAS Futenma that was needed in the desorption model were the drainage area, land use data, annual rainfall, and other meteorological data for the selected watershed area.

The best approach for the given scenario was to use the rational method for estimating peak discharge through the selected stormwater drainage channel. This assumes an ideal case of constant rainfall over the impervious surface. The rational method equalizes the denominator to one and thus negates the need for additional calculations for the rate of change in the rainfall amounts (Chin, 2019). This assumption is validated for this experiment due to the requirement for peak discharge not needing to be exact and that the final kinetic model will not accurately reflect exact parameters found in a specific place. The base equation for the rational method (Eq 6) follows an

empirical relationship between the peak runoff rate, Q_p (ft³/sec) and the rainfall intensity, i (in/hr):

$$Q_p = CiA_w \quad (\text{Eq 6})$$

where C is the runoff coefficient (unitless) and A_w is equal to the total area of the water shed (acres) basin running to the stormwater drainage channel (Chin, 2019). Since there were two distinct areas for the water shed, paved surfaces and grassy areas, the equation was then modified to reflect the variations in runoff coefficients for these areas:

$$Q_p = \sum C_i i A_i \quad (\text{Eq 7})$$

where C_i and A_i are the runoff coefficients and land areas, respectively, for the given water shed. The rainfall intensity remains unchanged for the second equation. Unit conversion is not needed for acreage or intensity because an additional coefficient of 1.0083 can be assumed as just 1.00 for the purpose used in this experiment.

The total rainfall runoff from MCAS Futenma was to obtained satellite imagery of the installation (Figure 10). An arial map was downloaded from Google Maps (Google Maps, 2021) and then uploaded using the QGIS™ software for further analysis.



Figure 10 - MCAS Futenma Arial Map (Google Maps, 2021)

Using land use data obtained from the Japan Aerospace Exploration Agency (JAXA) in coordination with additional resources from the Environmental Affairs Branch of Marine Corps Bases Butler, a total water shed area of 272.63 acres was estimated for the stormwater channel at the southwestern corner of the base. JAXA data was again used to determine the total hard surface concrete areas, 128.73 acres, and the total natural grassy areas, 143.90 acres.

Runoff coefficients were then assessed for each land use area. Using known tables for these coefficients from published texts (Davis & Masten, 2014), the coefficients were determined to be 0.20 for natural grassy areas and 0.85 for paved surfaces. Additional meteorological data, to include average yearly rainfall (1,817 mm/yr, 8.17E-03 in/hr) was also collected for Ginowan, Okinawa and is provided with the summary of the data stated above (Climate-Data, 2021). Using the data provided below in Table 10, the peak runoff rate for MCAS Futenma was found to be 1.13 ft³/s. This calculation formed the basis of the flow rate for the mock channel design limits discussed in previous sections and for the calculation of persistence in the kinetic model.

Table 10 - Peak Runoff Summary

Variable	Value	Units
Average Annual Rainfall (i)	8.17E-03	in/hr
Total Water Shed Area (A_w)	272.63	acres
Total Hard Surface Area (A_p)	128.73	acres
Total Grassy/Natural Areas (A_G)	143.90	acres
Runoff Coefficient Paved (C_p)	0.85	unitless
Runoff Coefficient Grassy (C_G)	0.20	unitless
Peak Runoff Rate (Q)	1.13	ft ³ /s

Kinetic Modeling

Producing a model that is useful in determining the persistence of AFFF/PFAS in the concrete stormwater channels is based on the study by Baduel, et. al. Within the that study, kinetics of desorption were measured at surface levels for three compounds (PFOA, PFOS, and 6:2FTS) at two temperatures (4°C and 24°C) (Baduel et al., 2015). They found that when pure water is poured onto the contaminated concrete, the concentration of chemicals in water increases exponentially ($1 - e^{-kt}$) reaching steady state at a given interval (Baduel et al., 2015). They also found that the variation in PFOS concentrations ranged from 80 ng/g at the furthest corner of the pad to over 200,000 ng/g near the FTG drainage pipe. This establishes the complexity of measuring PFAS compounds across the entire surface and shows the variation in magnitude of two separate locations within the same pad (Baduel et al., 2015). Using this guideline, it was determined that showing the persistence of PFAS related to effluent flows in stormwater drainage channels to be both valuable and a more direct measure of the hazards that PFAS compounds may present over time.

Using modeling techniques proven by Baduel et al., this study attempts to develop a model that will show the estimated AFFF/PFAS desorption in water from the concrete stormwater system at MCAS Futenma in a simulated environment and determine a likely persistence time that contaminant will continue to be a health an environmental hazard to the air station and surrounding local community. For this study, the target concentration level relative to time will be set by existing EPA standards. In accordance with a 2016 EPA Lifetime Health Advisory (LHA), this contamination level will be 70 ppt to achieve the lowest risk of adverse health risks (U.S. Environmental Protection Agency, 2016).

One of the major departures of this experiment compared to the Baduel et al. study is that temperature differences could not be accounted for given the required timeline for the project detailed in this writing. As such, this study relies heavily on the work accomplished by Baduel et al. in determining the desorption constant using an Arrhenius equation for the dependence on temperature. Carried forward from Eq 1, the governing equation for the kinetic model then becomes:

$$C(t) = C_{eq}(1 - e^{-kt}) \quad \text{Eq 8}$$

Where $C(t)$ is the concentration of the effluent at time t , C_{eq} is the equilibrium or steady state concentration of the measured PFAS compound, and k is the mass transfer constant. Fitting the relationship of C_{eq} and its dependency on the desorption constant K_{des} , we arrive at:

$$C_{eq} = \frac{C_c}{K_{des}} \quad \text{Eq 9}$$

Where C_c is the measured concentration from the concrete powder samples in previous subsections. Since Baduel et al. was able to show that the desorption constant does indeed rely on temperature, the expression below in Eq 10 was assumed valid for this experiment as well, even though it is known that different concrete mix designs will result in different desorption rates of PFAS compounds. The variable T is the absolute temperature of the ambient air in the experiment, which was steady at 17.8°C within the laboratory.

$$K_{des}(T) = A * e^{B/T} \quad \text{Eq 10}$$

Using the exponential decay increasing form equation (Eq 8), a model was created in Python™ to determine the equilibrium concentration of each PFAS compound

and the surrogate dyes. The model in Python™ was built using the non-linear least squares method (NLLS) for the fitting algorithm due to the parameters in the functional part of the model. Using the NLLS method also fits with the two main parameters of the kinetic model in that the function is smooth with respect to the unknown variables and that criteria for the parameter estimates using the NLLS method has a unique solution (NIST/SEMATECH, 2012). Scripts and coding for the Python™ modeling are displayed in Appendix D.

Once the C_{eq} had been determined, K_{des} could then be found using Eq 9 and therefore converting the laboratory temperature to Kelvin (290.95K) would allow for finding the Arrhenius constants A and B from a linear fit of $\ln(K_{des})$ on $1/T$. Even though the results of the experiment presented in this were limited for PFOS and PFOA, the equilibrium concentration for these compounds, along with concrete powder concentrations near the surface will be used for the kinetic model. Other PFAS compounds could not be effectively modeled due to not having the additional thermodynamic Arrhenius constants as analysis was only conducted at one temperature.

The remaining inputs needed for the kinetic model depend on the rainfall amounts from the simulated site and concrete properties of the mix design. The persistency of PFAS to remain in the given concrete stormwater drainage channel effectively displays the desorption of the PFAS compounds as related to the first-order differential equation given in Eq 8. Using the remaining parts of the model that was created by Baduel et al., the resulting kinetic model for persistency is given as:

$$C_L(t) = C_{cD} * e^{-t/\tau} \quad \text{Eq 11}$$

Where C_L is the concentration at a given limit or advisory and τ is expressed by the following:

$$\tau = \frac{A * h * \rho * e^{B/T}}{R} \quad \text{Eq 12}$$

Where ρ and h are the concrete density and thickness, respectively; R is the total rainfall runoff through the channel in one year and A and B are the given Arrhenius constants from the Baduel et al. study for PFOS and PFOA.

Summary

This chapter summarizes the methods and approaches used to establish the experimental setup and testing parameters for determining the desorption characteristics of PFAS compounds and the chosen surrogate dyes. It also details the approaches used in determining the kinetic model variables to include rainfall runoff from MCAS Futenma and the building of the model itself. A summary of the channel design and construction guidelines and limitations are discussed along with all established testing guidelines to show that the concrete mix selected and built are within standards for DoD construction and tested within standards as established by the ASTM.

IV. Analysis and Results

Chapter Overview

The purpose of this chapter is to discuss the recorded results of the experiment and contrast any comparisons between the surrogate dyes and the individual PFAS compounds within the tested AFFF solution. The results of the PFOS data are then input

into the kinetic model described in the previous section to determine the persistence of the compound in the channel. Comparisons are made between the desorption characteristics of the surrogate dyes and different PFAS compounds based on ionic composition. Limitations and assumptions of the experiment are further discussed to give additional guidance for future studies related to desorption of PFAS compounds in stormwater drainage channels.

Allura Red Dye Results

Testing of the concrete channels to show the desorption of Allura Red AC followed the established methods in the previous section. A total of 225 mL of AR was used to saturate the concrete channels and full evaporation of the RO water in the saturation matrix was achieved within 72 hours of initial contamination. The initial saturation concentration was 24.8 mg/L and the mass of the dye in the contaminant was 5.58 mg. The desorption data from the experiment is displayed in Appendix B and summarized below in Table 11.



Figure 11 - Allura Red AC Reactors

Using the data, a graphical depiction of the concentration in the effluent vs. time was created to show the increased presence of AR as time progressed (Figure 12). Data shows this increase from 6.91% to 32.49% of the original saturation concentration at 0.5 and 97 hours, respectively. Additional information for the AR testing is also provided in Table 12 to show the physical properties of the channel pre- and post-testing.

Table 11 - Allura Red AC Properties

	Starting Volume (mL)	Ending Volume (mL)	Volume Delta (mL)	Initial Temperature (°C)	Final Temperature (°C)	Initial pH	Final pH
Block 1	3500	2987	513	10.2	12.8	5.12	8.62
Block 2	3500	2938	562	10.2	13.1	5.12	8.91
Block 3	3500	3038	462	10.2	12.9	5.12	9.13
Average	3500	2987.7	512.3	10.2	12.9	5.12	8.89

Table 12 - Allura Red AC Summary

Group ID		Time (hrs.)	Average Absorption (abs.)	Runoff Concentration (ppm)	Mass of Dye in Runoff (mg)	Average Mass of Dye in Runoff (mg)	Average Percent Contaminant Desorbed (%)	Standard Deviation of Mass in Runoff (σ)
AR ₁	Block 1	0.5	0.0646	0.1951	0.5828	0.3858	6.91	0.2531
	Block 2		0.0613	0.0341	0.1003			
	Block 3		0.0638	0.1561	0.4742			
AR ₂	Block 1	1	0.0678	0.3512	1.0491	0.6092	10.92	0.4230
	Block 2		0.0620	0.0699	0.2054			
	Block 3		0.0645	0.1886	0.5730			
AR ₃	Block 1	3	0.0676	0.3398	1.0151	0.8818	15.80	0.2637
	Block 2		0.0646	0.1967	0.5780			
	Block 3		0.0677	0.3463	1.0522			
AR ₄	Block 1	11.5	0.0753	0.7187	2.1468	1.6759	30.03	0.4269
	Block 2		0.0715	0.5333	1.5669			
	Block 3		0.0695	0.4325	1.3140			
AR ₅	Block 1	26	0.0711	0.5122	1.5299	1.2203	21.87	0.3656
	Block 2		0.0663	0.2780	0.8169			
	Block 3		0.0695	0.4325	1.3140			
AR ₆	Block 1	49	0.0778	0.8390	2.5062	1.5840	28.39	0.8007
	Block 2		0.0680	0.3626	1.0653			
	Block 3		0.0686	0.3886	1.1806			
AR ₇	Block 1	62	0.0777	0.8325	2.4867	1.6383	29.36	0.7461
	Block 2		0.0682	0.3691	1.0844			
	Block 3		0.0697	0.4423	1.3436			
AR ₈	Block 1	76	0.0777	0.8341	2.4916	1.7697	31.72	0.6446
	Block 2		0.0693	0.4260	1.2516			
	Block 3		0.0712	0.5154	1.5659			
AR ₉	Block 1	97	0.0768	0.7902	2.3605	1.8130	32.49	0.4892
	Block 2		0.0705	0.4829	1.4188			
	Block 3		0.0718	0.5463	1.6598			

It should be noted that there was an 8.16% decrease in the desorption of the saturation contaminant between the 11.5 hour and 26-hour samples. In reviewing study data from other surrogate dyes, this was consistent with the decreases shown in the pilot study using BB and in the MB trail. It is assumed that due to the increase in temperature from the friction of the peristaltic pump that of the reactor system reached near 100% humidity around this time interval. Excess moisture surrounding the block would then increase penetration of the dye into deeper layers within the concrete block via pores and cracks that would not otherwise be hydrated. The decrease in volume within the reactor systems averaged around 512.3 mL of RO that was absorbed into the channel. The penetration of RO through the top channel surface was anticipated for the study, however additional penetration through the sides and bottom of the channel was not and can only be assumed to have occurred from the increase in humidity within the reactor.

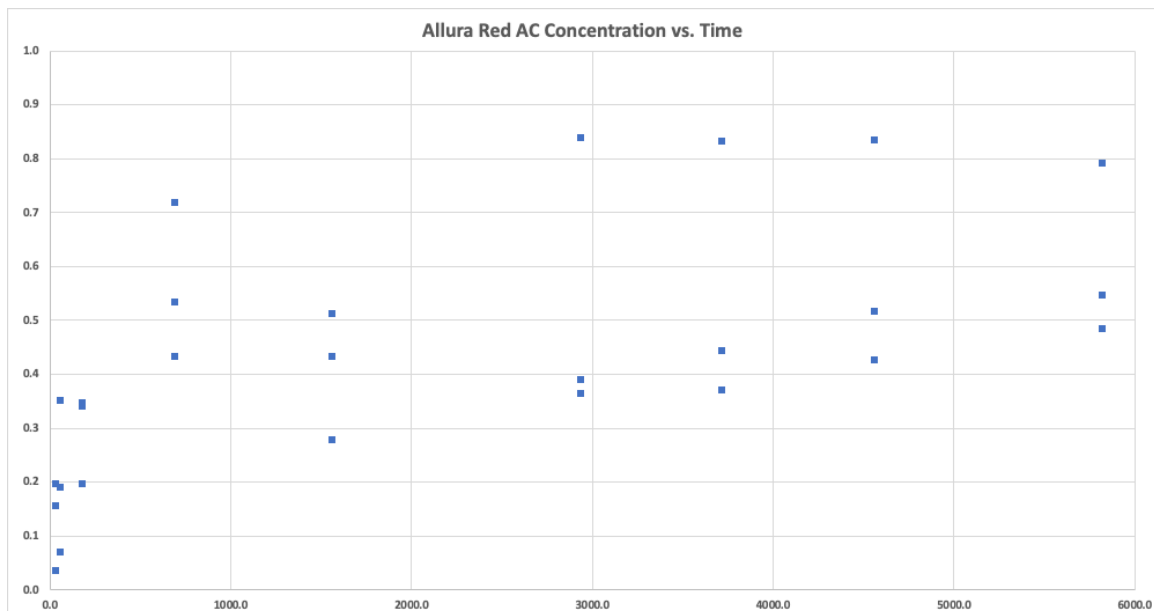
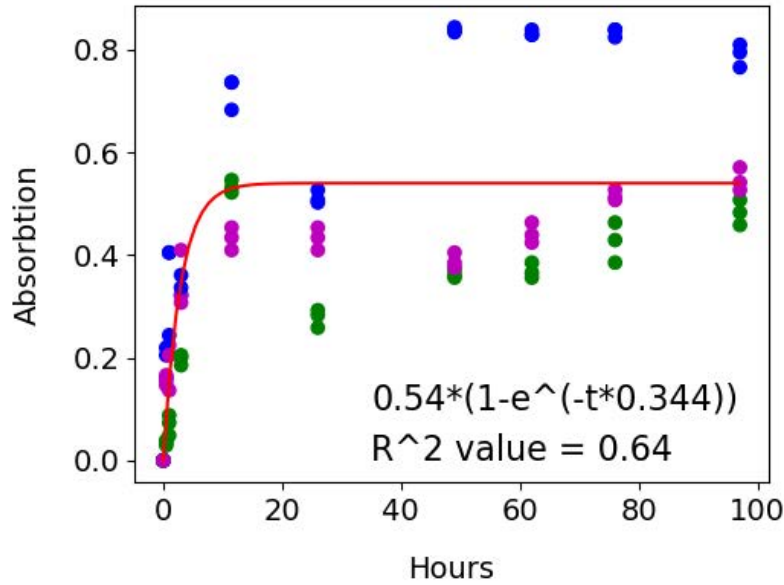


Figure 12 - Allura Red AC Concentrations

Data for AR testing trials was then averaged for the concentrations within each time interval and plotted against the time that the samples were collected. Using Python™ software, an equation of the line was fitted to the data to relate the concentration at time as given in Eq 8. This representation is shown in Figure 13:



Colors denote data from individual blocks, while the red line is from the averaged data across all three blocks.

Figure 13 - Allura Red Concentration Data

The equation given here can be rewritten to show a more direct translation of Eq 8 as given by:

$$C(t) = 0.54(1 - e^{-0.344t}) \quad \text{Eq 13}$$

Where the equilibrium concentration, C_{eq} , is equal to 0.54 mg/L and the mass transfer constant, k , is equal to -0.344. Since the r squared value in this case is relatively low, 0.64, trials would need to be repeated several times to limit the variation in concentration levels between the concrete channels. Additionally, statistical analysis of the data shows that the average standard deviation between the AR channels was around 0.4903 mg for

the calculated mass in the runoff effluent. Using these standard deviations, a 90% confidence interval (CI) was built for each time interval as well. This shows that the average CI for all AR channels was around ± 0.4657 mg for the mass of the dye in the effluent. This is a large percentage of the total mass desorbed throughout the experiment, 1.8130 mg, at 97 hours and would give additional reason to the fact that the R squared value was so low.

Brilliant Blue Dye Results

Testing for the Brilliant Blue followed in the same manner as the AR and the methods described in previous sections. Full evaporation of the saturation matrix used for the BB trials was achieved in 94 hours. Increase in the time for evaporation could have been due to different variables, the most likely being the structure of the concrete channels. It was noted that the surface within the channels for the BB trial channels was smoother than the other AR, MB, or PFAS channels. Less pitting and more cementitious material on the surface of the channel could have hindered absorption through the channel surface leading to greater evaporation times.

Desorption data for the BB trials is displayed in Appendix B and summarized below in Table 13. Graphical depiction of the concentration in the effluent vs. time show a steady and more uniform increase over time as compared to the AR trials (Figure 15). Percentage of the contaminant desorbed from the channels increased from 5.77% at 0.5 hours to a total of 21.04% at 96 hours. Initial saturation concentration of the saturation solution was 39.6 ppm with a mass of the dye in the solution at 8.92 mg. Information in

Table 14 shows the physical properties of the channel pre- and post-testing for the BB trials and shows a discrepancy in excess water loss for reactor #2 after 72 hours.

Table 13 - Brilliant Blue Summary

Group ID		Time (hrs.)	Average Absorption (abs.)	Runoff Concentration (ppm)	Mass of Dye in Runoff (mg)	Average Mass of Dye in Runoff (mg)	Average Percent Contaminant Desorbed (%)	Standard Deviation of Mass in Runoff (σ)
BB ₁	Block 1	0.5	0.0472	0.0080	0.0256	0.5144	5.77	0.7302
	Block 2		0.0530	0.1015	0.1639			
	Block 3		0.0737	0.4332	1.3538			
BB ₂	Block 1	1	0.0472	0.0075	0.0239	0.5577	6.25	0.7985
	Block 2		0.0534	0.1074	0.1734			
	Block 3		0.0762	0.4722	1.4757			
BB ₃	Block 1	3	0.0499	0.0507	0.1621	0.6778	7.60	0.8109
	Block 2		0.0567	0.1603	0.2588			
	Block 3		0.0789	0.5160	1.6126			
BB ₄	Block 1	13	0.0548	0.1303	0.4164	0.9297	10.42	0.8363
	Block 2		0.0652	0.2959	0.4779			
	Block 3		0.0845	0.6063	1.8947			
BB ₅	Block 1	24	0.0620	0.2452	0.7834	1.1069	12.41	0.6858
	Block 2		0.0715	0.3980	0.6427			
	Block 3		0.0845	0.6063	1.8947			
BB ₆	Block 1	48	0.0654	0.3002	0.9592	1.2432	13.94	0.7324
	Block 2		0.0736	0.4306	0.6953			
	Block 3		0.0881	0.6640	2.0750			
BB ₇	Block 1	72	0.0726	0.4156	1.3278	1.5280	17.13	0.7168
	Block 2		0.0827	0.5775	0.9326			
	Block 3		0.0931	0.7436	2.3237			
BB ₈	Block 1	96	0.0756	0.4637	1.4814	1.8767	21.04	0.5590
	Block 2		N/A	N/A	N/A			
	Block 3		0.0921	0.7270	2.2720			

Table 14 - Brilliant Blue Properties

	Starting Volume (mL)	Ending Volume (mL)	Volume Delta (mL)	Initial Temperature (°C)	Final Temperature (°C)	Initial pH	Final pH
Block 1	3500	3195	305	10.3	12.6	5.34	9.16
Block 2	3500	1615	1885	10.3	12.9	5.34	8.72
Block 3	3500	3125	375	10.3	12.7	5.34	8.96
Average	3500	2645.0	855.0	10.3	12.7	5.34	8.95

While performing the experiment for the BB trial, the Versilon™ tubing for reactor #2 shifted inside the multi-channel head of the peristaltic pump sometime between 72 and 96 hours after the trial began. The tubing became pinched between the side of the tubing channel and the clamping mechanism. This caused excessive wear on

the out wall of the tubing and eventually forming a split in the tubing itself. While the pump continued to run properly, the dye solution within the reactor began to leak from the tubing at the multi-channel head instead of recirculating through the system as expected. Based on the recovered volume of the solution from the other two reactors and the recovered solution from reactor #2, it is estimated that approximately 1545 mL of solution was lost through the split tubing. This is consistent with the pump flow rate at 1850 mL/min and the loss of suction after the tubing ruptured. Data for the BB trials in Appendix B does not show the results for block #2 due to this loss.



Figure 14 - Brilliant Blue Reactor #2 Tubing

Total absorption of water in the reactor systems for the BB trials was less than the that of the AR, MB, and PFAS reactors. The average water absorption of the concrete channels, excluding reactor #2 was measured at 340 mL. The BB trial reactors also did not show the characteristic drop in dye concentration around the 24-hour mark as was

seen in the MB and AR trials. It is possible that the smoother finish on the channels that lead to the increased time for evaporation of the saturation matrix also contributed to the decrease in absorption of solution through the sides and bottom of the BB channels from the increase in humidity. Temperature increases for the BB reactors was consistent with what was observed in the AR and MB reactors. Reactors for the surrogate dyes saw an average temperature increase ranging from 2.4 to 2.7°C and humidity within the reactors reached maximum between 23 to 28 hours. Since there were no other measurable differences between the reactors of the surrogate dyes, it is concluded that the outer structure of the smoother concrete channels selected for the BB trial contributed most to the decrease in absorption after reaching maximum humidity within the reactors.

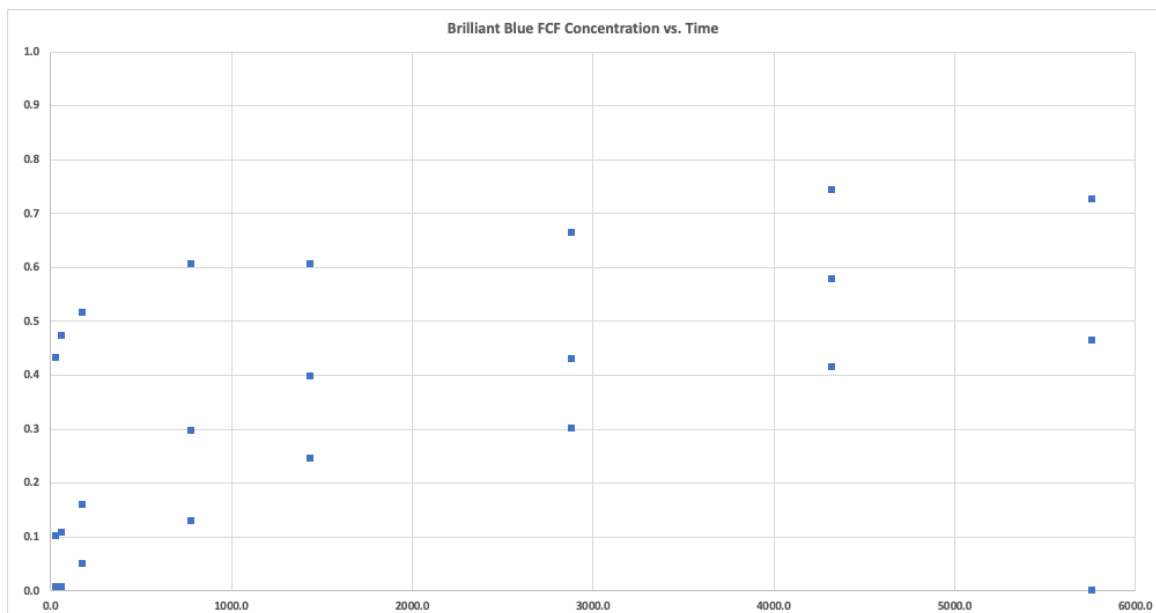
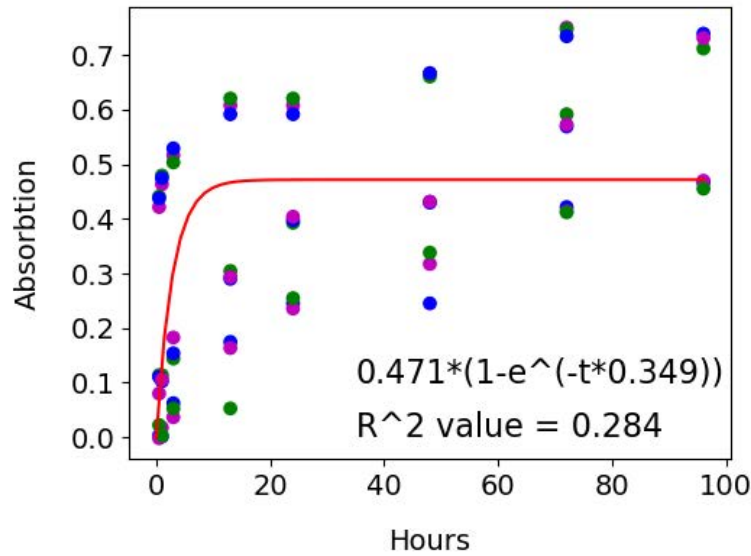


Figure 15 - Brilliant Blue FCF Concentrations

After recording all the data points for the BB trial, the data was then transposed into the Python™ software in the same manner as the AR data. Figure 16 shows the results of fitting Eq 8 to the data to obtain the trendline equation:



Colors denote data from individual blocks, while the red line is from the averaged data across all three blocks.

Figure 16 - Brilliant Blue Concentration Data

The equation of the trendline was then rewritten to show the direct translation of Eq 8:

$$C(t) = 0.471(1 - e^{-0.349t}) \quad \text{Eq 14}$$

Where $C(t)$ here is representative of the concentration at time t for BB, the equilibrium concentration of BB is 0.471 mg/L, and a mass transfer constant of -0.349. Plotting this data and finding the trendline for the BB trials shows an even lower R squared value (0.284) than the AR trial. This difference is expected given that the average standard deviation of the BB trial channels was also greater at 0.7338 mg indicating a larger spread in the concentration of the effluent. Block #3 for the BB trial began at a much higher concentration (1.3538 mg) than did block #1 (0.0256 mg). This variation in concentration continued throughout the experiment though the gap between the two gradually closed by the 96-hour mark. The difference at 0.5 hours was 1.33 mg/L and

closed to 0.79 mg/L by the end of the trial. This further shows the differences in desorption of concrete even when both channels come from the same mix design and use the same contaminant in the effluent solution.

Methylene Blue Dye Results

Again, the Methylene Blue trials were carried out in the same manner as the previous surrogate dyes. The saturation matrix for the MB trials followed a similar pattern of evaporation as the AR trials reaching complete dryness within 72 hours. The channel surface structure showed the same physical properties as the AR channels with less cementitious material near the surface and more pitting within the channel. Initial saturation concentration was measured at 16.0 mg/L with a mass of dye in the contaminant at 3.6 mg.

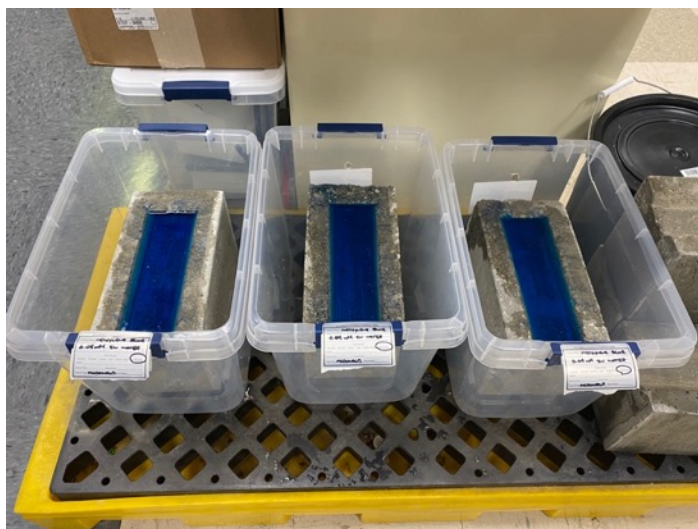


Figure 17 - Methylene Blue Reactors

Desorption data for the MB trials is shown in Appendix B and summarized below in Table 15. Graphical depiction of the concentration in the effluent vs. time (Figure 18) show a similar increase over time as the AR trials with a measurable drop in the obtained

concentration around the 24-hour mark. The increase in desorption percentage ranged from 10.83% at 0.5 hours to a maximum of 13.45% at 48 hours. Information in Table 16 shows the physical properties of the channel pre- and post-testing for the MB trials.

Table 15 - Methylene Blue Properties

	Starting Volume (mL)	Ending Volume (mL)	Volume Delta (mL)	Initial Temperature (°C)	Final Temperature (°C)	Initial pH	Final pH
Block 1	3500	3145	355	10.3	12.4	5.34	8.53
Block 2	3500	3130	370	10.3	13.2	5.34	8.94
Block 3	3500	3160	340	10.3	12.9	5.34	8.81
Average	3500	3145.0	355.0	10.3	12.8	5.34	8.76

Table 16 - Methylene Blue Summary

Group ID		Time (hrs.)	Average Absorption (abs.)	Runoff Concentration (ppm)	Mass of Dye in Runoff (mg)	Average Mass of Dye in Runoff (mg)	Average Percent Contaminant Desorbed (%)	Standard Deviation of Mass in Runoff (σ)
MB ₁	Block 1	0.5	0.0604	0.1016	0.3196	0.3898	10.83	0.0636
	Block 2		0.0629	0.1297	0.4060			
	Block 3		0.0639	0.1404	0.4438			
MB ₂	Block 1	1	0.0621	0.1205	0.3789	0.4289	11.91	0.0434
	Block 2		0.0642	0.1441	0.4511			
	Block 3		0.0642	0.1445	0.4566			
MB ₃	Block 1	3	0.0648	0.1508	0.4742	0.5833	16.20	0.1279
	Block 2		0.0671	0.1763	0.5517			
	Block 3		0.0719	0.2291	0.7240			
MB ₄	Block 1	18	0.0649	0.1519	0.4777	0.5628	15.63	0.1261
	Block 2		0.0657	0.1608	0.5032			
	Block 3		0.0714	0.2239	0.7077			
MB ₅	Block 1	27.5	0.0639	0.1408	0.4428	0.4736	13.16	0.0774
	Block 2		0.0632	0.1330	0.4164			
	Block 3		0.0672	0.1778	0.5617			
MB ₆	Block 1	48	0.0617	0.1160	0.3649	0.4841	13.45	0.1183
	Block 2		0.0685	0.1922	0.6015			
	Block 3		0.0651	0.1537	0.4858			
MB ₇	Block 1	73	0.0558	0.0506	0.1592	0.2255	6.26	0.0583
	Block 2		0.0584	0.0795	0.2487			
	Block 3		0.0589	0.0850	0.2686			
MB ₈	Block 1	96	0.0573	0.0676	0.2127	0.2535	7.04	0.0553
	Block 2		0.0579	0.0739	0.2313			
	Block 3		0.0602	0.1001	0.3165			

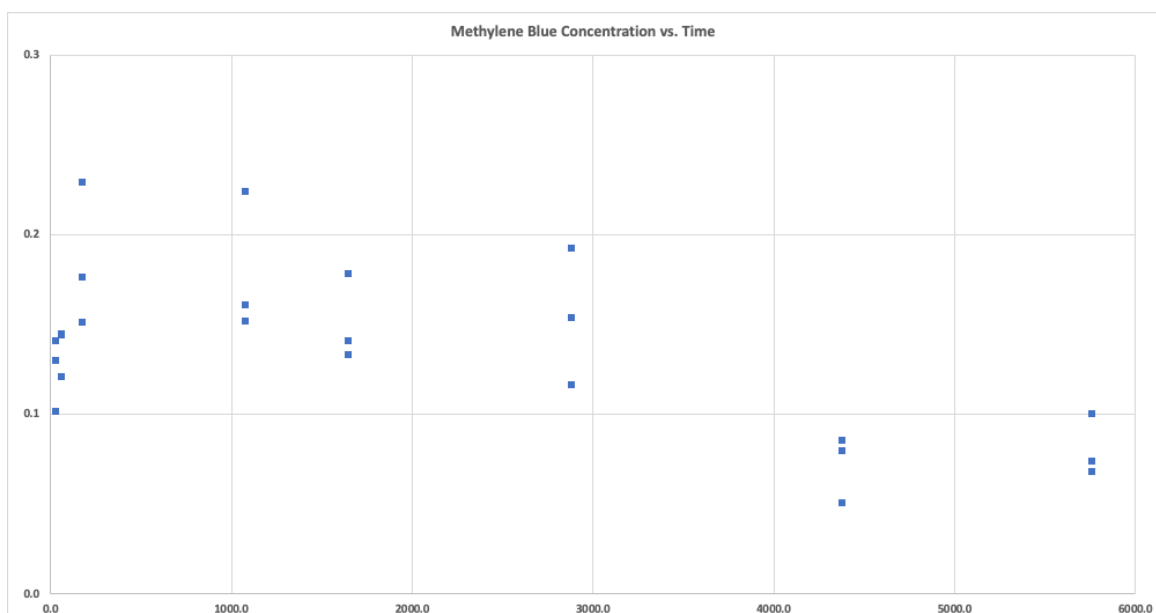
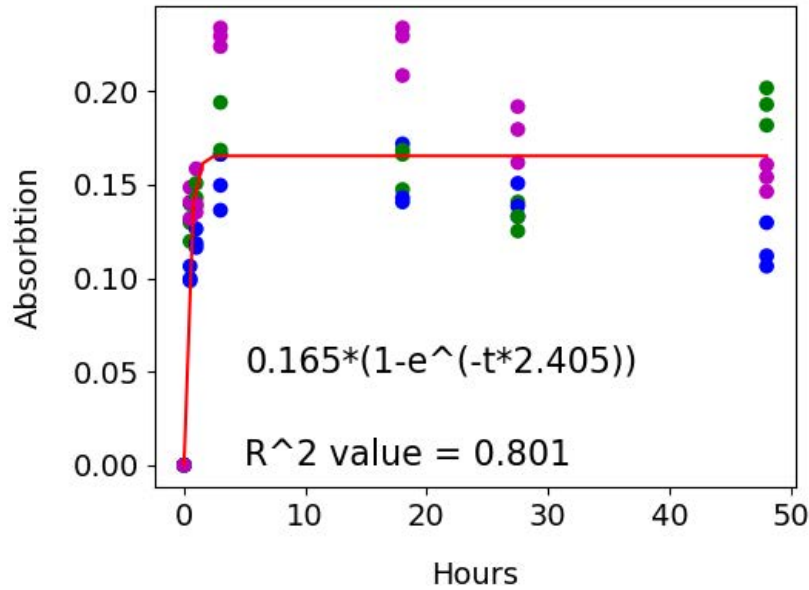


Figure 18 - Methylene Blue Concentrations

Full data of the trial in the appendix shows additional data collection point at 73 and 96 hours. While these points were collected in the same manner as other samples, a new lot of cuvettes was used before the 73-hour sample. Though comparison data between the cuvette lots was accounted for prior to collecting the 73- and 96-hour samples, the data still shows a significant decrease in the absorption concentrations after the cuvettes were changed. For this reason, the data for the desorption curves was only calculated using the first six sample sets. These sets were modeled in Python™ in the same manner as the AR and BB trials with the results display below in Figure 19.



Colors denote data from individual blocks, while the red line is from the averaged data across all three blocks.

Figure 19 - Methylene Blue Concentration Data

An equation for the trendline is shown in Figure 19 and was then transposed to fit the formatting of Eq 8:

$$C(t) = 0.165(1 - e^{-2.405t}) \quad \text{Eq 15}$$

Where $C(t)$ in this case is equal to the MB concentration at time t , 0.165 mg/L is the equilibrium concentration of the effluent runoff in the reactor, and -2.405 is equal to the mass transfer constant. The results for the MB trial showed the highest R squared value of the surrogate dye trials at 0.801. This correlates with the smallest standard deviation for the mass of the dye in the runoff as well at 0.082 mg with a 90% CI at an average of ± 0.0779 mg across the MB samples.

3M Light Water™ – AFFF Results

Testing and sampling of the PFAS reactors compared the 3% solution of 3M Light Water™ and RO water to the results from the blank control sample, the three reactor samples taken at 3-, 6-, and 36-hours, and the three concrete powder samples. Analysis of the samples was conducted by Pace Analytical Services, LLC by use of LC/MS/MS to determine the PFAS contamination of the sample matrices. Many of the samples tested were via analysis of diluted samples given the high concentrations of PFAS compounds in the original samples. These results were taken from the secondary dilutions to minimize matrix effects and ensure results were within the calibration range (Pace Analytical, 2021). Reporting limits for the samples were set to the method detection limits (MDL) and followed the DoD QSM 5.3 method for sampling.

Table 17 - PFAS Stock Solution Concentrations

Compound	Concentration (µg/L)	Dilution Factor	CAS No.
PFBA	840	1x	375-22-4
PFPeA	640	1x	2706-90-3
PFBS	1800	1x	375-73-5
PFHxA	2300	1x	307-24-4
PFPeS	1900	1x	2706-91-4
PFHpA	410	1x	375-85-9
PFHxS	25000	1x	355-46-4
PFOA	1300	1x	335-67-1
6:2 FTS	81	1x	27619-97-2
PFHpS	2500	1x	375-92-8
PFOSAm	160	1x	754-91-6
PFOS	130000	10x	1763-23-1
PFNS	140	1x	68259-12-1
PFDS	83	1x	335-77-3
PFDoS	40	1x	79780-39-5
PFHXDA	40	1x	67905-19-5

The prepared PFAS stock solution (3% 3M Light Water™ combined with 97% RO water) was the first sample to be analyzed to create a baseline for the known

concentration into the channels. A total of 16 PFAS compounds were found above detectable limits in the stock solution. This number is comparable to known PFAS compounds found in testing 3M Light Water™ from previous studies and other works (Nigro, N. and Custer, K., personal communication, January 12, 2022). Detected concentrations were recorded below in Table 18 for further comparison to other collected samples. A full list of the sample analysis report can be found Appendix F.

Concentrations listed in Table 18 are reported in micrograms per liter (µg/L) which is equivalent to parts per billion (ppb). Data for the PFAS stock solution shows significantly high concentrations of both PFOS (130,000 µg/L) and PFHxS (25,000 µg/L). Along with the data for PFOA (1,300 µg/L), PFBS (1,800 µg/L), and PFHxA (2,300 µg/L), PFOS and PFHxS data show reliable baselines for mass balance comparison in the desorption of PFAS in the effluent channel runoff.

Table 18 - Control Reactor Samples Concentrations

Compound	Concentration (ng/L)	Dilution Factor	CAS No.
PFBA	73	1x	375-22-4
PFPeA	56	1x	2706-90-3
PFBS	160	1x	375-73-5
PFHxA	210	1x	307-24-4
PFPeS	190	1x	2706-91-4
PFHpA	36	1x	375-85-9
PFHxS	1300	50X	355-46-4
PFOA	100	1x	335-67-1
6:2 FTS	1.6	1x	27619-97-2
PFHpS	210	1x	375-92-8
PFNA	2.7	1x	375-95-1
PFOSAm	3.8	1x	754-91-6
PFOS	6300	10x	1763-23-1
PFDA	1.4	1x	335-76-2
PFNS	5.9	1x	68259-12-1
PFDS	2.1	1x	335-77-3

The next sample that was needed for baseline comparison was the sample blank from the control reactor. As stated in previous sections, the blank sample was collected from a reactor that was constructed in similar fashion to the AR, MB, BB, and PFAS reactors with the only exception being that the concrete channel in the reactor was not contaminated by the PFAS stock solution nor the surrogate dyes. Data for the blank sample is shown in full in Appendix F and summarized below for found concentrations within the sample.

As seen in Table 18 for the control reactor sample concentrations, PFAS contamination compounds were found in the blank sample. The PFAS compounds found in the blank sample show similar patterns of contamination ratios to that of the 3M Light Water™ matrix. Noticeable departures from the 3M Light Water™ matrix are the inclusion of perfluorodecanesulfonic acid (PFDS) and perfluorononanoic acid (PFNA) and the omission of PFDoS and PFHXDA. This display of PFAS contamination could be due to a variety of errors in the collection and analysis process to include cross contamination from gloves, equipment used during collection and testing, and potentially from techniques used within either the laboratory where the sample was collected or where the sample was analyzed. After reviewing laboratory notes and discussion with technicians at Pace Analytical, the most probable cause of this cross contamination came from aspiration of the pipette used to collect the samples. Since the PFAS stock sample and blank sample were both collected using the same pipette, it is possible that a small droplet of the stock sample contaminated the internal components of the pipette. Because of this, cross contamination would have still been possible even though pipette tips and

gloves were changed between collecting the stock sample and the blank sample from the control reactor.

Even though there is evidence of cross contamination from the 3M Light Water™ sample to the blank sample, the data still shows very small quantities of the PFAS compounds found during analysis. This still enables the data to be usable for comparison to desorption characteristics because the found contaminants were in the ng/L (ppt) range and the remaining data from the PFAS reactor samples and concrete powder samples were both in the µg/L and µg/Kg, respectively, both in the parts per billion (ppb) range. This also further illustrates the need for both the PFAS stock sample and control reactor sample data in forming the baseline for the remain PFAS testing.



Figure 20 - Concrete Powder Collection

After baseline measurements were completed samples for the concrete powder were then analyzed using the methods discussed in previous sections. Full data for the powder samples is listed in Appendix F and summarized below by selecting samples that showed presence of PFAS contamination throughout all three sampled layers. The data

in Table 19 has been adjusted from the reported numbers in the appendix to align all values to scale without the dilution factors that were applied in the laboratory during analysis. Concrete powder samples show a consistent downward trend in contamination levels through the vertical profile. This is consistent with the Baduel et al. study that also showed a decrease in contamination as depth was increased. It is also similar to the data collected at site closest to the effluent pipe from the FTG in the Baduel et al. study. Site #14 showed concentrations for PFOS at 223,982 ng/g and 651 ng/g for PFOA which is closely matched to the data found in the concrete samples for this study at 480 µg/Kg for PFOA and 180,000 µg/Kg for PFOS.

Table 19 - Concrete Powder Contamination Summary

Compound	Concentration (µg/Kg)			CAS No.
	CB1 (0-25mm)	CB2 (25-50mm)	CB3 (50-75mm)	
PFBA	370	4.8	2.1	375-22-4
PFPeA	340	4	1.7	2706-90-3
PFBS	790	120	4	375-73-5
PFHxA	14000	240	8.9	307-24-4
PFPeS	9500	150	5.2	2706-91-4
PFHpA	170	3	1.2	375-85-9
PFHxS	240000	16000	3450	355-46-4
PFOA	480	9	4.5	335-67-1
PFHpS	570	9.2	5.4	375-92-8
PFNA	0.18	0.057	0.031	375-95-1
PFOSAm	220	8.4	3.3	754-91-6
PFOS	180000	56000	13000	1763-23-1
PFNS	1.8	0.76	0.4	68259-12-1
PFDS	0.84	0.34	0.2	335-77-3
PFDoS	0.6	0.29	0.14	79780-39-5

Four PFAS compounds found in the concrete powder samples were selected based on the reviewed literature as the most common and most hazardous to the environment and public health for further investigation (Askeland et al., 2020; Calafat et al., 2007; Söregård et al., 2020). The data for PFOS, PFOA, perfluorohexanoic acid

(PFHxA), and perfluorohexanesulfonic acid (PFHxS) were generated into graphical depictions and fitted with exponential trendlines to show the effect of depth on the adsorption levels of the compounds (Figure 21). After fitting the curves, the equation of the trendline was then used to determine an approximate percentage of contamination within the vertical profile by depth. This serves two primary purposes: (1) to show the change in absorption throughout the depth of the concrete channel, and (2) to show the effects of the downward vertical leaching behavior of both short-chained (PFHxS and PFHxA) and long-chained (PFOS and PFOA) PFAS compounds as described by the Baduel et al. study.

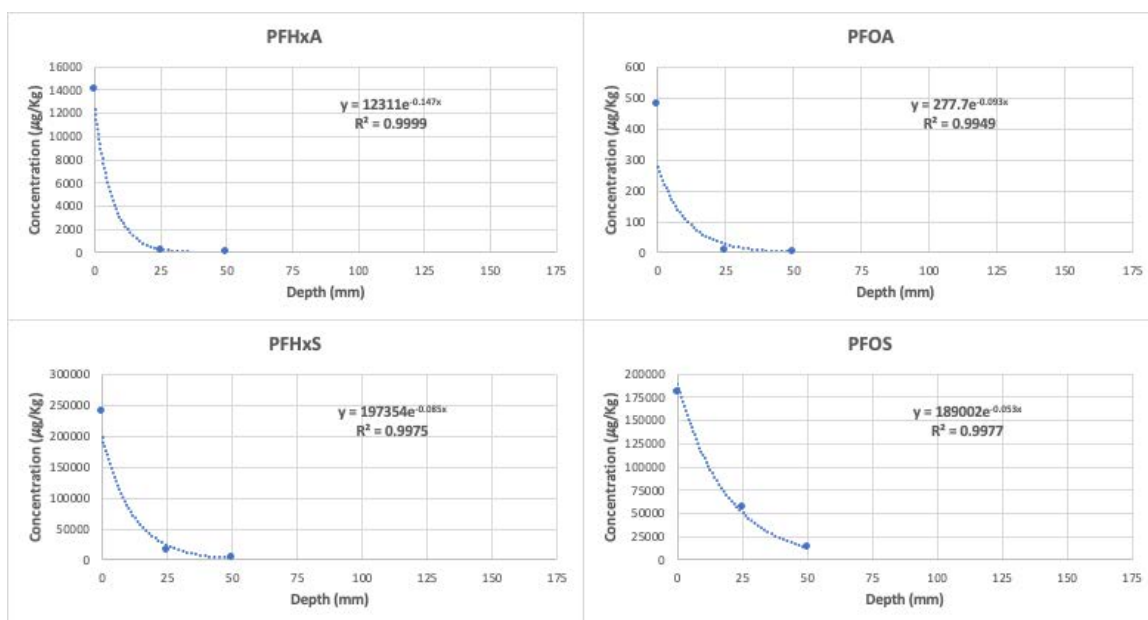


Figure 21 - Concrete Powder Concentration vs. Depth

The equation of the trendlines were then used to calculate the area under the curve to determine the percentage of contamination at each depth interval. These equations were also used to estimate the total concentrations at the bottom of the concrete channels using the maximum depth of the mock channels at 162.5 mm (Table 20). The

calculations suggest that while the majority of the PFAS contamination remains near the surface across all four compounds, only the PFOS was able to reach the bottom of the channel at a significant percentage (1.86%). This contrasts with the data found in the Baduel et al. study which showed that the shorter chain PFAS compounds (PFHxA and PFHxS, both C6) had a higher downward vertical leaching behavior than the longer-chained versions (PFOS and PFOA, both C8) (Baduel et al., 2015; Xu et al., 2020). This could also further suggest that downward vertical leaching behavior may also highly depend not just on the chain length of the PFAS compound but also the structural mix design of the concrete and pH of the concrete media.

Table 20 - Concrete Powder Area Under Curve

Compound	Percentage of Area Under Curve			
	0-25 mm	25-50 mm	50-75mm	75-162.5mm
PFHxA	97.47%	2.47%	0.06%	<0.01%
PFHxS	88.06%	10.52%	1.26%	0.17%
PFOA	90.22%	8.82%	0.86%	0.09%
PFOS	73.43%	19.52%	5.19%	1.86%

A total of 200 mL of the PFAS stock solution was added to the PFAS reactor concrete channel in the same manner as described in the methods section. After each application of 25 mL was added to the channel it was allowed to fully evaporate, approximately six hours, before applying the next application. Once the full 200 mL of the PFAS stock solution was added to the channel and the last application had fully evaporated, the channel was then placed into the reactor to begin the trial. Samples were collected at three, six, and thirty-six hours and bottled for further analysis at Pace Analytical. Full results for the PFAS trials are listed in the report in Appendix F and summarized below in Table 21. Additional information regarding cross-contamination of the blank sample is described in later sections.

Table 21 - PFAS Concentration Summary

Compound	Concentration ($\mu\text{g/L}$)			CAS No.
	PR1 (3 hr)	PR2 (6 hr)	PR3 (36 hr)	
PFBA	38	32	68	375-22-4
PFPeA	22	18	44	2706-90-3
PFBS	39	46	88	375-73-5
PFHxA	ND	ND	130	307-24-4
PFPeS	30	38	80	2706-91-4
PFHpA	12	20	46	375-85-9
PFHxS	420	440	1100	355-46-4
PFOA	ND	ND	61	335-67-1
6:2 FTS	110	110	75	27619-97-2
PFHpS	48	50	90	375-92-8
PFOSAm	38	38	24	754-91-6
PFOS	1900	1300	2200	1763-23-1
PFHXDA	40	49	50	67905-19-5

Additional physical properties were taken from the PFAS reactor channel and recorded for comparison to the surrogate dye channels (Table 22).

Table 22 - PFAS Channel Physical Properties

Property	Initial Value	Final Value
Volume of Effluent	3500 mL	3165 mL
Temperature of Effluent	10.8°C	13.6°C
Weight of Concrete Channel	17.91 Kg	18.26 Kg
pH of Effluent in Channel	5.34	7.26

By inspecting the volume of effluent after the trial was completed, the PFAS channel performed most similarly to the BB and MB trials for volume delta. The volume delta for the PFAS trial was at 335 mL which is approximate to the BB trial blocks #1 and #3 at 305 mL and 375 mL, respectively, and the average volume delta for the MB trial at 355 mL. These values are significantly lower than the AR trial that averaged at 512.3 mL yielding a much greater absorption of the effluent through the channel. The change in pH was another factor that was significantly different for the PFAS trial as compared to the surrogate dye trials. The pH for the surrogate dye trials ranged from 8.76 to 8.95 whereas the PFAS trial saw a lower pH at 7.26. These results show the

acidic nature of the 3M Light Water™ solution and were expected. This also relates the pH to other studies which found an increased tendency of both PFOS and PFOA to desorb from other materials at a lower pH (Azzolini, 2014; Omo-Okoro et al., 2020).

The most drastic departure from the surrogate dye trials was found in the temperature increase in the PFAS trial. Temperature of the effluent increased from 10.8°C to 13.6°C within the PFAS trial reactor which is almost a full degree Celsius higher than the surrogate dye trials. This increase in temperature also occurred even though the PFAS reactor was ended after 36 hours, several hours prior to the end of the surrogate dye trial reactors at 96 to 97 hours. This indicates that the rate of temperature increase for the PFAS reactor was higher than that of the surrogate dyes. Even though this rate was not measured consistently through any of the trials it does introduce another avenue to investigate the effects of temperature on PFAS desorption.

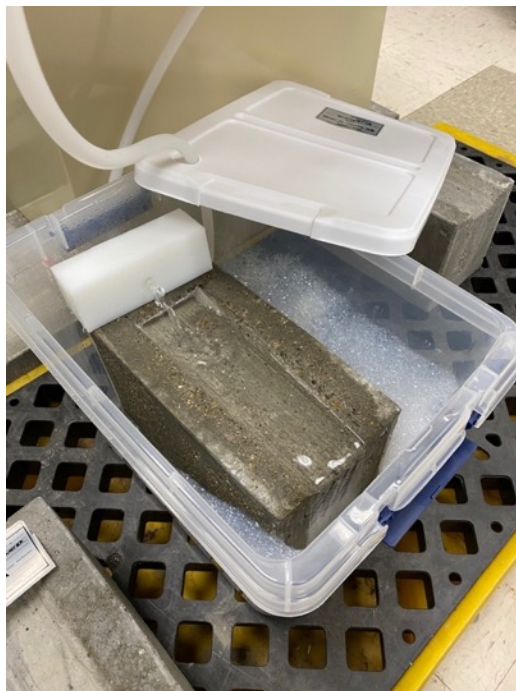


Figure 22 - PFAS Reactor after 36 Hours

Ionic composition of PFAS compounds is another aspect that has had limited research in the classification of the compounds into the categories of cation, anionic, and zwitterionic. Though there are known categories for some anionic compounds (PFOA, PFHxA, PFBA, and 6:2 FTS), there is very little data that is available for cationic and zwitterionic PFAS compounds (Kah et al., 2021). What is known from literature is that PFBS, PFPeS, and PFHxS can show cationic or zwitterionic properties based on the formulation of the compounds. For instance, the aAmA classification of these compounds denotes the zwitterionic -amide amino carboxylate form while the aAm classification identifies the cationic -amidoamine form of the compound (Will J. Backe et al., 2013). Additional research is still needed to show any relationship between the ionic composition of the surrogate dyes and PFAS compounds.

Table 23 - Percent Desorption of PFAS in Concrete

Compound	Initial Mass in Solution		Final Mass in Effluent		Percent Desorbed (%)	CAS No.
	Volume = 3500 mL		Volume = 3165 mL			
	Initial Concentration (μg/L)	Initial Mass (μg)	Maximum Concentration (μg/L)	Final Mass (μg)		
PFBA	840	2.94	68	0.21522	7.32	375-22-4
PFPeA	640	2.24	44	0.13926	6.22	2706-90-3
PFBS	1800	6.3	88	0.27852	4.42	375-73-5
PFHxA	2300	8.05	130	0.41145	5.11	307-24-4
PFPeS	1900	6.65	80	0.2532	3.81	2706-91-4
PFHpA	410	1.435	46	0.14559	10.15	375-85-9
PFHxS	25000	87.5	1100	3.4815	3.98	355-46-4
PFOA	1300	4.55	61	0.193065	4.24	335-67-1
6:2 FTS	81	0.2835	0.11	0.00034815	0.12	27619-97-2
PFHpS	2500	8.75	90	0.28485	3.26	375-92-8
PFOSAm	160	0.56	24	0.07596	13.56	754-91-6
PFOS	130000	455	2200	6.963	1.53	1763-23-1
PFNS	140	0.49	50	0.15825	32.30	68259-12-1

Data collected for the PFAS trials was transposed into Python™ to generate the same desorption curves using Eq 8 as those found for the surrogate dyes. This information is provided in Appendix E with selected PFAS compounds displayed below in Figure 23. Only those compounds that were found through all three iterations of

sampling were generated into desorption curves. Unfortunately, this study did not generate enough data points to conclusively denote usable curves for any of the compounds found during analysis. Therefore, direct correlation of ionic composition between the surrogate dyes and the 3M Light Water™ solution could not be determined.

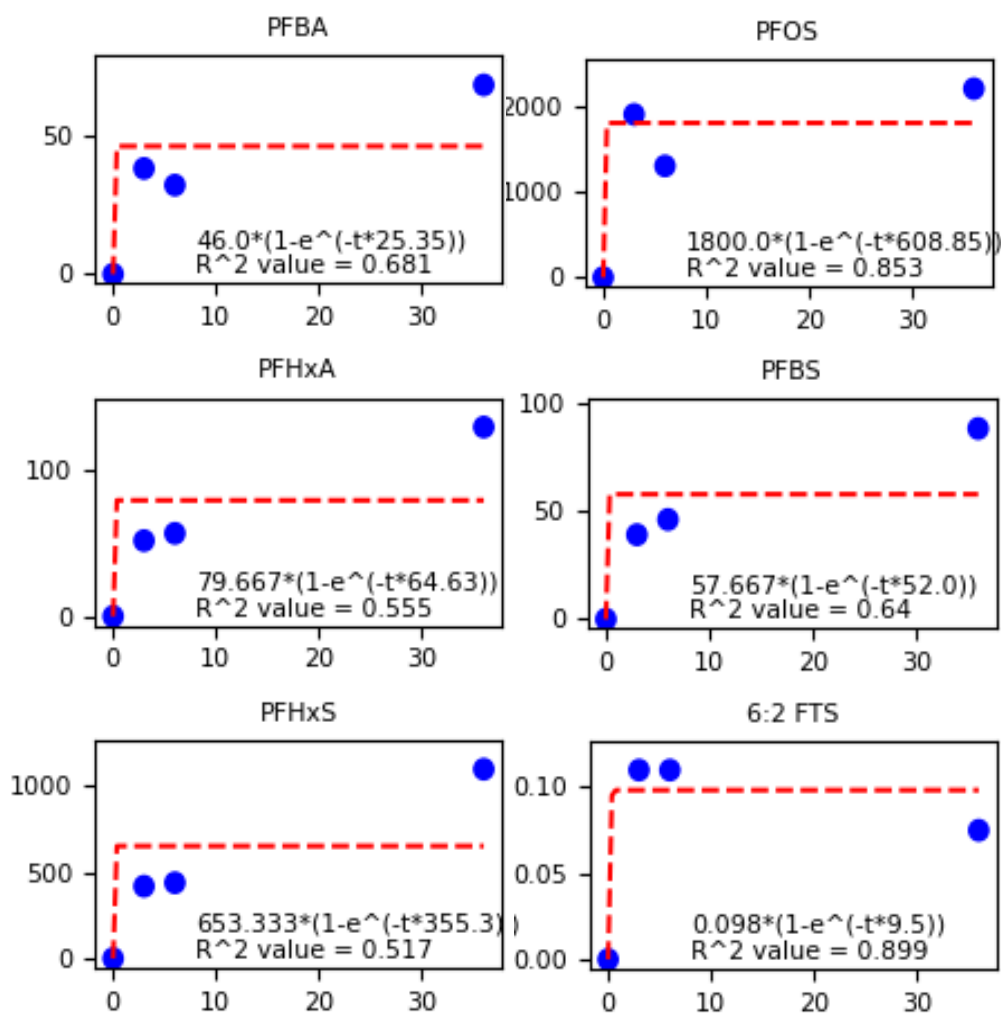


Figure 23 - PFAS Compound Desorption Curves

Kinetic Modeling of PFAS Compounds

As previously stated, since desorption of PFAS compounds and the related desorption constant, K_{des} , is dependent on temperature, the only data found in this study

that could be used for kinetic modeling was that of PFOS and PFOA using the Arrhenius constants from the Baduel et al. study. Since data was limited for 6:2 FTS during the concrete powder testing, assumptions were made to attempt adjustment of the model for thickness and the surface concentration for only one depth (50 mm). The dependency on temperature is based on using an assumed modification of the basic Arrhenius equation as shown in Eq 16:

$$K = Ae^{\frac{-E_a}{RT}} \quad \text{Eq 16}$$

By dissecting the basic Arrhenius equation in relation to activation energy, E_a , and the universal gas constant, R , it can then be determined that the thermodynamic constant B in Eq 10 is equivalent to the ratio of $-E_a/R$, thus having units of K^{-1} to offset the temperature units in Kelvin. Activation energy is directly related to the adsorbate/adsorbent relationship, in this case the concrete channel and the PFAS compound, which has also been found in other studies to be highly dependent on pH (Lee et al., 2012; Yin et al., 2016). Since the governing equation of the kinetic model follows first order kinetics and the corresponding desorption constant is also of the first order, s^{-1} would be the units for A , the pre-exponential factor. By using the Arrhenius thermodynamic constants from the Baduel et al. study, K_{des} was then found by linear interpolation for PFOS, PFOA, and 6:2 FTS at 22.9°C and recorded below in Table 24.

At this point it is important to note that the desorption constant can be found using three separate methods. The first, as shown in Table 24, can be interpolated from Eq 10 using the temperature in lab (17.8°C) and the Arrhenius constants from the Baduel et al. study denoted as K_{dB} . This method depends on the accepted parameter that the value of steady-state concentration is dependent on temperature and can increase two to threefold

between temperatures of 4°C and 23°C (Baduel et al., 2015). While this general constraint is shown to be true in various different media types (Attallah et al., 2016; Nanthi Bolan et al., 2021; Xie et al., 2018), to include concrete (Baduel et al., 2015), it would be assumed for this specific concrete mix and not entirely accurate in the representation of dependency of PFAS desorption on temperature.

Table 24 - Desorption Constants - Method 1

Compound	K_{dB} (mL/g)	A^*	B^*
PFOS	2193.44	0.2985	2635.5
PFOA	93.24	1.673E-04	3917
6:2 FTS	59.44	3.099E-05	4282.9

*Arrhenius constants interpolated at 22.9°C (296.05K)

The second method of deriving the desorption constant is established from Eq 9 using the found concentration at depth, h , for the concrete powder samples as C_c and the equilibrium concentrations, C_{eq} , from the desorption curves created from Python™ software. This desorption constant, denoted as K_{dc} , would be simple ratio of the found concentration to the assumed equilibrium concentrations as shown in Table 25. The maximum value of PFOA (61.0 µg/L) was used for the C_{eq} since only one value of PFOA was found during the PFAS trial analysis. It should also be noted that the C_c value for 6:2FTS was assessed at 0.24 ug/Kg as the only data point from concrete powder testing. This method is more representative than the previous in calculating the actual concentrations analyzed from the specific concrete mix design test here. However, there may be error given the limited number of samples collected from the PFAS reactor and the varying coefficients of determination as given from the R squared values.

Table 25 - Desorption Constants - Method 2

Compound	K_{dC} (mL/g)	C_c (ug/Kg)	C_{eq} (ug/L)	Depth, h (mm)
PFOS	105.55	190000	1800	25
PFOA	7.87	480	61	25
6:2 FTS	2.44	0.24	0.098	50

The third method involves using the highest recorded concentration found for the liquid samples as C_{max} against the measured concentrations found in the powder samples, C_{cD} , at a depth of 5.0 mm using the trendlines from Figure 21. The 50.0 mm depth was used for the 6:2FTS samples since only one concrete powder sample returned concentration data. Discrepancies in the 6:2FTS data show an increase in the concentration from the prepared 3M Light Water™ solution (PR0) at 81.0 ug/L to the first drawn liquid sample from the PFAS reactor (PR1) at 110.0 ug/L. This is assumed to be an error in the reported dilution concentration and was corrected three orders of magnitude to 0.11 ug/L to reflect the common ratio of PR0 and PR1 for the PFOS and PFOA samples at these points. This also aligns with the variation in the desorption constants found in the Baduel et al. study for these three PFAS compounds. The desorption constants using method three, denoted as K_{dM} , are perhaps the most accurate representation of these constants for the specific concrete mix design tested in this experiment.

Table 26 - Desorption Constants - Method 3

Compound	K_{dM} (mL/g)	C_{cD} (ug/Kg)	C_{max} (ug/L)	Depth, h (mm)
PFOS	656.82	1445003.46	2200	5
PFOA	2.85	174.43	61.0	5
6:2 FTS	2.18	0.24	0.11	50

The variations in the desorption constants (Tables 24-26) suggest that the desorption is highly dependent on the chemical properties within the mix design, as the Baduel et al. study used established concrete and this study used freshly cast concrete. Studying the differences in the pH of concrete and how these variables factor into determining the desorption constant may further explain this phenomenon. Concrete made with high-alkali cement, as found in Portland Type I/II, would generally have a pH value above 13 (Kakade, 2014). Through the process of carbonation in the concrete, the pH value would gradually reduce to around a pH of 9, however, this process is slow and would generally take one to two years of atmospheric exposure to effect the concrete carbonation process but only down to around 1 mm (Kakade, 2014). The concrete channels used throughout this experiment were freshly made and generally tested in the reactors within 2 to 3 months following construction. At this point there are two options for calculating the persistency of the PFAS compounds in the constructed concrete channels in this experiment; an Arrhenius constant option (Option 1) and another option in which the Arrhenius constants are replaced with the desorption constant, K_{dM} , using the relationship found in Eq 9 (Option 2).

Option 1 – Arrhenius Constant Model

The first option relies on the thermodynamic Arrhenius constants derived from data from the Baduel et al. study and the K_{dB} found above in Method #1. This option would be a straightforward operation for finding τ by using A and B in Eq 12, however would neglect the concentration data found during the liquid sample analysis of the PFAS reactor. The modeling process is continued by constructing a table for the values needed

in Eq 12 for τ as shown in Table 27. A second adjustment was made to align the simulation model with previous research. By taking the trendline equations from Figure 21 for PFOS and PFOA, the concentration could then be found near the surface of the channel at a depth of 5.0 mm. This could not be done for the 6:2 FTS sample because only one data point was provided during analysis, therefore the depth for the model for 6:2 FTS remained at where the data point was found. In conjunction with the thermodynamic constants A and B from Method #1, the following table was created.

Table 27 – Option 1: Tau Variables (τ)

Compound	A	B	Density, ρ (g/mL)	Depth, h (mm)	R (mm/yr)
PFOS	0.2985	2635.5	2.269	5.0	1818.0
PFOA	1.673E-04	3917		5.0	
6:2 FTS	3.099E-05	4282.9		50.0	

These values are then inputted into Eq 12 below to find the value of τ using a constant temperature equivalent to the average temperature of Ginowan, Okinawa at 22.9°C (296.05K) (Climate-Data, 2021):

$$\tau = \frac{A \cdot h \cdot \rho \cdot e^{-B/T}}{R} \quad \text{Eq 12}$$

Table 28 – Option 1: Values of τ

Compound	τ
PFOS	13.688
PFOA	0.582
6:2 FTS	3.709

These values were then added back into Eq 11 below and Table 29 was built to show the variables for the equation. The desired concentration level, C_L , was taken from the EPA LHA advisory for PFOA and PFOA of 70 ppt and converted to appropriate units

for inclusion in the kinetic model. Since there is no standard LHA guideline for 6:2 FTS provided by the EPA, the same 70 ppt was used for modeling purposes.

$$C_L(t) = C_{cD} * e^{-t/\tau} \quad \text{Eq 11}$$

Table 29 – Option 1: Kinetic Modeling Variables

Compound	C_L ($\mu\text{g/L}$) <i>ppb</i>	C_{cD} ($\mu\text{g/Kg}$) <i>ppb</i>	τ
PFOS	0.070	1445003.46	13.688
PFOA		174.43	0.582
6:2 FTS		0.24	3.709

By solving for t in Eq 11 we arrive at the following equation (Eq 18) to determine the persistency of PFOS, PFOA, and 6:2 FTS to reach 70 ppt within the effluent runoff given the properties of the concrete channel, the simulated site runoff for MCAS Futenma, and the thermodynamic constants derived from the Baduel et al. study.

$$t = -\tau * \ln\left(\frac{C_L}{C_{cD}}\right) \quad \text{Eq 18}$$

Estimations were made to show the desorption of PFOS, PFOA, and 6:2 FTS at 50% and 90% reduction within the concrete channels. As described in the Baduel et al. study, these times are equivalent to 0.69τ and 2.30τ , respectively (Baduel et al., 2015). Using these equivalencies, estimation of 50% removal of the simulated desorption would occur at 9.5, 0.4 and 2.6 years for PFOS, PFOA, and 6:2 FTS, respectively. Reduction to 90% of the initial contamination levels would be found at 31.5, 1.3, and 8.5 years for the same compounds, respectively. Final persistency of these three PFAS compounds to reach below the 70 ppt EPA limits for drinking water standards is estimated at approximately 200 years for PFOS at this concentration level, with PFOA and 6:2 FTS projected at 4.6 years each. These results agree with the results from the Baduel et al.

study that showed a timeline of approximately 215 years for their sampled concrete to reach the 2009 EPA LHA of 200 ppt. This also shows the high level of persistence for PFOS; however, the data suggests a faster desorption rate of PFOA and 6:2 FTS from the concrete channel.

Option 2 – Desorption Constant Model

The second option relies on the desorption constant found using the ratio of the maximum concentration found in the liquid samples against the concentration at depth for the concrete powder samples as described in Method #3 in previous sections. This is based on principles established in the Baduel et al. study for relationship between the desorption constants and the Arrhenius constants. By rearranging Eq 9 to solve for K_{dM} and then setting it equal to the same value found in Eq 10 we can conclude the following:

$$K_{dM} = \frac{C_c}{C_{max}} = A e^{-B/T} \quad \text{Eq 19}$$

Moving forward with the established value of τ in Eq 12, it can also be concluded that tau also exists as the following:

$$\tau = \frac{K_{dM} * h * \rho}{R} \quad \text{Eq 20}$$

Using the same values for depth (h), density (ρ), and average rainfall (R) as found in Table 26 for Option 1, the following table was created to show the tau variables for Option 2 in conjunction with the desorption constant, K_{dM} .

Table 30 - Option 2: Tau Variables (τ)

Compound	K_{dM} (mL/g)	Density, ρ (g/mL)	Depth, h (mm)	R (mm/yr)
PFOS	656.82	2.269	5.0	1818.0
PFOA	2.85		5.0	
6:2 FTS	2.18		50.0	

These values were then inputted into Eq 20 above to find the value of τ using the established constant temperature equivalent of 296.05K.

Table 31 - Option 2: Values of τ

Compound	τ
PFOS	4.099
PFOA	0.018
6:2 FTS	0.136

Using the same methodology for kinetic modeling as was used in Option 1 the values of tau were then combined with the desired concentration level, C_L , and the concentration at depth from the concrete powder samples, C_{cD} , to approximate the time to reach the EPA LHA limit of 70 ppt in the effluent runoff. The data for these calculations was recorded below in Table 32 before being inputted into Eq 18 in the previous section to find the PFAS persistency.

Table 32 - Option 2: Kinetic Model Variables

Compound	C_L ($\mu\text{g/L}$) <i>ppb</i>	C_{cD} ($\mu\text{g/Kg}$) <i>ppb</i>	τ
PFOS	0.070	1445003.46	4.099
PFOA		174.43	0.018
6:2 FTS		0.24	0.136

As was conducted for the previous option, calculations for the reduction to 50% and 90% of the initial concentrations was performed. The removal of 50% concentration was found to be 2.8 years for PFOS with reduction at less than one month for PFOA and 6:2 FTS. Reduction to 90% of the initial concentration for this option would show removal in 9.4 years for PFOS and less than 4 months' time for PFOA and 6:2 FTS. Final persistency to reach the desired level of 70 ppt would occur in 60 years for PFOS and less than two months for both PFOA and 6:2 FTS.

Using the desorption constant option for finding persistency at 70 ppt shows as much faster desorption timeline than what was projected using the Arrhenius constant option. This suggests that the differences in the concrete from this study and the study conducted at the Australian FTG are greater than originally hypothesized. Neither of these options for estimating persistency can be assumed to be exact. Option 1 using the Arrhenius constants relies heavily on the activation energy for the estimation of B which will differ depending on the chemical properties of the concrete tested. Option 2 would be more indicative of the chemical properties found in the concrete tested in this experiment, however, more samples would need to be collected to determine the true equilibrium concentration.

Summary

This chapter summarizes a desorption testing experiment for PFAS contamination in mock concrete channels. Although a limited number of data points were obtained and analyzed for desorption of PFAS compounds, kinetic modeling of the persistency of PFOS and PFOA were still able to reproduce similar results to previously established research. Desorption modeling using first order rate constants were able to show the potential for this method to expend exponential decay increasing form curves in describing persistency. Desorption experimentation was also completed using three chemical dyes to model their removal from the same concrete structural design. The data for these chemical dyes was also compared to PFAS desorption trials for potential use as surrogates based upon ionic composition. While direct correlation between the surrogate dyes an individual PFAS compounds could not be made given the limited data points for

the PFAS desorption trials, this experiment still shows one potential method for ionic comparison. Kinetic desorption testing of PFOS and PFOA were able to expound upon previous modeling techniques for application to stormwater runoff within concrete drainage infrastructure. Additionally, analysis of concrete powder samples was able to show methods for concentration estimation at various depths through exponential trendlines.

V. Conclusions and Recommendations

Chapter Overview

This chapter summarizes the results of experimentation along with the limitations and recommendations for future studies in the desorption of PFAS from concrete samples. The study was able to replicate similar results of kinetic modeling to that of previously accomplished research, however, additional data would need to be collected to refine the methods use here for DoD applications. Research should most definitely be continued in this specific area highlighting additional mitigation and remediation techniques and procedures.

Conclusions of Research

The overarching objective of this research study was to test the desorption of PFAS compounds from semi-porous concrete typically found in stormwater drainage systems to determine the persistency of PFAS chemicals to remain above a given limit or guideline. This experiment conducted desorption testing by saturating eleven separate mock concrete channels with a known concentration of a 3M Light Water™ solution and three chemical dyes. Samples were taken from the effluent water in the reactors and

analyzed using LC/MS/MS via isotope dilution for PFAS liquid samples and methanol extraction for concrete powder samples. Surrogate dye samples were analyzed using UV-Vis to obtain sample concentration based against previously established calibration curves. Analysis showed a general increase in sample concentrations as time progressed through the experiment, however, both PFAS and chemical dye samples had issues and experimental errors that hindered the consistency with the results. Further experiments of this type should aim to reduce these errors and refine the coefficient of determination, or R squared values, by adding additional data points and sampling time intervals. Even with the drawbacks from sampling and analysis errors, the objectives of the experiment were either met or partially achieved with recommendations for further research in this area.

The first objective was to study and analyze the desorption of a known PFAS matrix concentration from a simulated concrete drainage channel. Samples for this portion of the experiment were taken at 3-, 6-, and 36-hour time intervals. Intervals were selected based on previous research that showed the characteristic times to reach steady state for PFOS, PFOA, and 6:2 FTS with the objective to capture early upward trends for the desorption curves and one additional collection at an established time interval after concentration at equilibrium had been achieved (Badel et al., 2015). Though many of the PFAS compounds the 36-compound analysis provided by Pace Analytical fit to this time interval assumption, there were others that did not and therefore desorption curve could not be properly calibrated using the first order kinetic model as found in Eq 8 of this study. Further studies into the desorption of PFAS from concrete should aim to collect several samples at various time intervals in order to better fit sampling data to the

model presented here. What this study was able to show is that the kinetic desorption model is usable for general estimations of persistency of PFAS to remain in concrete. Additional studies would be needed to determine the effects of pH, temperature, and concrete physical properties (i.e., water to cement ratio, aggregate size, and air entrainment) to further refine the model to a broader range of concrete types and structural design.

The second objective of this study was to investigate and analyze the desorption of chemical dyes (AR, MB, and BB) from the same structural design for the concrete mock channels. This study aspired to show the potential use of these chemical dyes as surrogates for PFAS compounds based on the parameters of ionic composition. Limited data point with the PFAS trials inhibited the ability to accurately show this relationship based on ionic composition alone. This study was able to show consistency of data points between three different concrete channels for each dye. With all three dyes, the rise and fall of concentration levels followed regular patterns within the data sets for the dyes. Additionally, a slight decrease, or leveling of concentration levels was reliably seen in all dye reactors once humidity reach near 100% within the reactor system. This decrease in concentration is assumed to be related to the concrete absorbing additional water from the system through surfaces other than the top channel itself thus adsorbing dye from the effluent onto new uncontaminated concrete surfaces. Replication of this experiment would need to limit this absorption by reducing the humidity within the system and ensuring that the adsorption-desorption process could only occur within the top channel of the concrete block.

The last objective of this study was to establish the validity of a desorption model adapted from the Baduel et al. study that could be applied to DoD stormwater drainage channels in determining PFAS persistency. This study was able to prove the ability of the adapted model to generally estimate PFAS retention in concrete stormwater channels, however, further studies would need to replicate this experiment with different concrete structural designs at varying temperatures to better refine the model. The Baduel et al. study suggests that over longer periods the concentrations within the surface layers of the concrete evolve homogeneously and that there is active diffusion of PFAS compounds in that layer (Baduel et al., 2015). If this assumption is correct, then investigating different concrete structural designs for surface level desorption would return more precise concentration estimations. Through peer-reviewed runoff methods, climate data from MCAS Futenma was accurately applied to the model to produce estimations of PFAS contamination in a scaled model of the southern stormwater drainage channel using simulated concentration data. Further studies are needed to investigate the thermodynamic and kinetic constants used in the model for more accurate PFAS concentration estimations in DoD stormwater systems.

Significance of Research

PFAS is a known hazard to both the environment and to public health. Even though several categories of PFAS, to include PFOS and PFOA, have been restricted in their use at large, decades of use in DoD AFFF have left lasting impressions on both the natural and built environments. Legacy AFFF foams commonly relied on longer chain PFAS that have been shown to have increased adsorption properties in soils and other

media types (Brusseau et al., 2019; Chen et al., 2013). Though these foams have been phased out in favor of AFFF containing short chained PFAS varieties, the short chain PFAS have also been found to have increased fate and transport through the environment (Ateia et al., 2019).

While use of AFFF on DoD installations has definitive benefits in extinguishing aircraft fuel fires and saving lives in aviation operations, its use still has secondary and tertiary effects on both human health and the environment. Decades of AFFF use in both legacy and shorter chain forms embedded these toxic PFAS chemicals into the stormwater drainage channels surrounding DoD aviation installations. As the DoD continues to modify, upgrade, and decommission installations both stateside and throughout the world, increase knowledge of PFAS retention and desorption in various media types will only improve environmental stewardship. Continued research into desorption characteristics is needed to better understand the long-term effects of PFAS persistency in these concrete structures.

This study shows the significance of this type of model in a media that has rarely been studied in the academic and professional fields. By performing and analyzing desorption characteristics of PFAS compounds in concrete more effective mitigation and remediation techniques can be developed to limit the affects that these chemicals have on both humans and the environment. Many times, the exact structural mix design of existing concrete channels is not known and laboratory testing to determine both chemical and physical properties of the concrete are expensive and time consuming. Building upon the desorption testing of chemical dyes as PFAS surrogates will allow for

more wide-spread testing in both laboratory and field experiments to determine PFAS concentrations in concrete drainage structures.

Recommendations for Action

As shown by both this experiment and the Baduel et al. study, surface level concentrations are of greatest concern for stormwater runoff in concrete channels. Development of short-term mitigation techniques is needed to capture PFAS contamination from AFFF releases and mishaps. Potential exists for use of activated carbon in conjunction with slice gates at installation discharge locations to further reduce spillage of PFAS and AFFF surface foams from DoD installations. Experimentation in the use of concrete sealants could also show promising results in capturing existing concrete PFAS contamination in the stationary phase as it exists in dry conditions. This study theorizes that since the purpose of concrete sealants is to retard water and not allow its penetration into the concrete, then by proxy, along with other assumption presented in this experiment, adsorbed PFAS compounds within the concrete structure could not rehydrate and therefore not move into a mobile phase. This would hinder desorption of PFAS from the concrete and reduce additional contamination from leaving DoD installations through stormwater drainage channels.

Recommendations for Future Research

Future research into the desorption of PFAS from concrete stormwater channels should be continued with an emphasis on the additional parameters of temperature, pH, and structural mix design of the concrete. Replication of this study would need to increase data points and amount of time intervals tested for PFAS trials to better

understand the desorption characteristics and provide more data for kinetic modeling. Though this study focusses on desorption through continuous flow of water across a channel, additional studies could be conducted to show desorption from a completely submerged concrete specimen and potentially yield similar results. Further experimentation could also vary the size, shape, and density characteristics of the concrete specimen. Though this study was conducted to simply to further develop a previously established methodology and broaden its use specifically to DoD installations, further research of this type should focus mainly on replication and uniformity of the testing parameters. Perhaps the largest contribution to this study would be the supplementation of additional data points to refine the kinetic model and show direct correlation between the use of surrogate dyes and ionic composition of PFAS compounds.

Summary

This research is yet one more stone in path toward better understanding the relation between PFAS desorption and concrete as a porous media type. Use of legacy and short chained AFFF foams have no doubt contaminated the concrete stormwater drainage structures at every DoD aviation installation. Our job as stewards of the natural environment is to understand the ramifications of our operations and practices and minimize their impact. Knowing how long our current and past operational procedures could affect the natural environment is part of that responsibility. This experiment evaluated the desorption of PFAS compounds found in AFFF from concrete channels to garner more knowledge of that impact. While this study is not complete and still needs

additional information to refine the kinetic model, its significance in a field that is limited by other research initiatives is invaluable. Additional research in this field should definitely be pursued by other researchers and scientists.

Appendix A

Table 33 - Concrete Mix Design

Mixture ID: Medium Aggregate Mix Design (3/8 in. MSA)				Design Proportions (Non SSD)		Mock Channel Batch Proportions		Test Cylinder Batch Proportions		Total Concrete		Batch Proportions			
Y _D	Design Batch Size (ft ³)					27	0.0103 (yd ³)		0.0022 (yd ³)		0.2263 (yd ³)		0.1387 (yd ³)		
Cementitious Materials				SG	Amount (lb/yd ³)	Abs Volume (ft ³)	Amount (lb)	Volume (ft ³)	Amount (lb)	Volume (ft ³)	Amount (lb)	Volume (ft ³)	Amount (lb)	Volume (ft ³)	
CM1	Portland Type II Cement			3.15	677.78	3.448	7.01	0.036	1.460	0.007	153.406	0.780	94.000	0.48	
CM2															
CM3															
Total Cementitious Materials:					677.78	3.45	7.01	0.04	1.46	0.01	153.41	0.78	94.00	0.48	
Aggregates			FM	Absorption %	SG	Amount (lb/yd ³)	Volume (ft ³)	Amount (lb)	Volume (ft ³)	Amount (lb)	Volume (ft ³)	Amount (lb)	Volume (ft ³)	Amount (lb)	Volume (ft ³)
A1	3/8" Quikrete All Purpose Gravel (100 lbs/ft ³) @ 12.7 ft ³ /yd ³		2.7	1.70	2.70	1270.00	7.538	13.1409608	0.078	2.74	0.016	287.45	1.706	176.13	36.189
A2	Quikrete All Purpose Sand			1.70	2.65	1571.91	9.506	16.26	0.098	3.39	0.020	355.78	2.152	218.01	35.519
A3						2841.91	17.04	29.41	0.18	6.12	0.04	643.23	3.86	394.14	71.71
Water			Water (lb/yd ³) concrete		SG	Amount (lb/yd ³)	Volume (ft ³)	Amount (lb)	Volume (ft ³)	Amount (lb)	Volume (ft ³)	Amount (lb)	Volume (ft ³)	Amount (lb)	Volume (ft ³)
W1	Water for CM Hydration (W1a +W1b)		305		1.00	305	4.888	3.16	0.051	0.66	0.011	69.03	1.106	42.30	0.678
	W1a. Water from Addmixtures		0			0		0		0		0		0	
	W1b. Water Needed from Table 3-3		305			305		3.16		0.66		69.03		42.30	
W2	Water for Aggregates, SSD		46.3		1.00			0.48		0.10		0.00		6.42	
	Total Water (W1 + W2):		351			305.0	4.888	3.63	0.058	0.76	0.012	69.03	1.106	48.72	0.781
Cement-Cementitious Materials Ratio			0.45												
Water-Cementitious Materials Ratio			0.45												
Slump, Slump Flow (in.)			3.00												
M	Mass of Concrete		lbs.		3824.69		40.05		8.34		865.67		536.86		
V	Volume of Concrete		ft ³		25.380		0.270		0.056		5.744		72.968		
T	Theoretical Density (M/V)		lb/ft ³		150.697		148.189		148.189		150.697		7.358		
D	Design Density (M/27)		lb/ft ³		141.655										
A	Air Content ((T-D)/T x 100%)		%		6.0										
Y	Yield (M/D)		ft ³		27										

Appendix B

Table 34 - Allura Red AC Dye Desorption Data

AR Trial Results			Starting Volume (mL)	Ending Volume (mL)	Volume Delta (mL)	Final Temperature (°C)	Final pH	Saturation Volume (mL)	Saturation Concentration (ppm)	Saturation Concentration (mg/L)	Mass of Dye in Contaminant (mg)	29-Oct-21		
Allura Red AC Dye			Block 1	3500	2987	513	12.8	8.62	225	24.8	24.8	5.58		
			Block 2	3500	2938	562	13.1	8.91						
			Block 3	3500	3038	462	12.9	9.13						
			Average	3500	2987.7	512.3	12.9	8.89						
						Initial RO values	10.2	5.12						
Group ID		Time (hrs.)	Absorption 1 (abs.)	Absorption 2 (abs.)	Absorption 3 (abs.)	Average Absorption (abs.)	Runoff Concentration (ppm)	Runoff Concentration (mg/L)	Mass of Dye in Runoff (mg)	Average Mass of Dye in Runoff (mg)	Average Percent Contaminant Desorbed (%)	Time (min)	Standard Deviation of Mass in Runoff (σ)	90% Confidence Interval
AR ₁	Block 1	0.5	0.0639	0.0651	0.0648	0.0646	0.1951	0.1951	0.5828	0.3858	6.91	30.0	0.2531	0.2404
	Block 2		0.0612	0.0614	0.0613	0.0613	0.0341	0.0341	0.1003			30.0		
	Block 3		0.0640	0.0638	0.0636	0.0638	0.1561	0.1561	0.4742			30.0		
AR ₂	Block 1	1	0.0689	0.0689	0.0656	0.0678	0.3512	0.3512	1.0491	0.6092	10.92	60.0	0.4230	0.4017
	Block 2		0.0624	0.0621	0.0616	0.0620	0.0699	0.0699	0.2054			60.0		
	Block 3		0.0652	0.0634	0.0648	0.0645	0.1886	0.1886	0.5730			60.0		
AR ₃	Block 1	3	0.0672	0.0675	0.0680	0.0676	0.3398	0.3398	1.0151	0.8818	15.80	180.0	0.2637	0.2504
	Block 2		0.0647	0.0644	0.0648	0.0646	0.1967	0.1967	0.5780			180.0		
	Block 3		0.0672	0.0690	0.0669	0.0677	0.3463	0.3463	1.0522			180.0		
AR ₄	Block 1	11.5	0.0757	0.0746	0.0757	0.0753	0.7187	0.7187	2.1468	1.6759	30.03	690.0	0.4269	0.4055
	Block 2		0.0715	0.0718	0.0713	0.0715	0.5333	0.5333	1.5669			690.0		
	Block 3		0.0690	0.0699	0.0695	0.0695	0.4325	0.4325	1.3140			690.0		
AR ₅	Block 1	26	0.0714	0.0709	0.0710	0.0711	0.5122	0.5122	1.5299	1.2203	21.87	1560.0	0.3656	0.3473
	Block 2		0.0666	0.0659	0.0664	0.0663	0.2780	0.2780	0.8169			1560.0		
	Block 3		0.0690	0.0699	0.0695	0.0695	0.4325	0.4325	1.3140			1560.0		
AR ₆	Block 1	49	0.0777	0.0779	0.0778	0.0778	0.8390	0.8390	2.5062	1.5840	28.39	2940.0	0.8007	0.7604
	Block 2		0.0680	0.0682	0.0679	0.0680	0.3626	0.3626	1.0653			2940.0		
	Block 3		0.0689	0.0685	0.0683	0.0686	0.3886	0.3886	1.1806			2940.0		
AR ₇	Block 1	62	0.0776	0.0778	0.0776	0.0777	0.8325	0.8325	2.4867	1.6383	29.36	3720.0	0.7461	0.7086
	Block 2		0.0685	0.0681	0.0679	0.0682	0.3691	0.3691	1.0844			3720.0		
	Block 3		0.0693	0.0701	0.0696	0.0697	0.4423	0.4423	1.3436			3720.0		
AR ₈	Block 1	76	0.0775	0.0778	0.0778	0.0777	0.8341	0.8341	2.4916	1.7697	31.72	4560.0	0.6446	0.6122
	Block 2		0.0701	0.0685	0.0694	0.0693	0.4260	0.4260	1.2516			4560.0		
	Block 3		0.0710	0.0711	0.0714	0.0712	0.5154	0.5154	1.5659			4560.0		
AR ₉	Block 1	97	0.0772	0.0763	0.0769	0.0768	0.7902	0.7902	2.3605	1.8130	32.49	5820.0	0.4892	0.4646
	Block 2		0.0705	0.0710	0.0700	0.0705	0.4829	0.4829	1.4188			5820.0		
	Block 3		0.0717	0.0723	0.0714	0.0718	0.5463	0.5463	1.6598			5820.0		

Table 35 - Methylene Blue Desorption Data

MB Trial Results			Starting Volume (mL)	Ending Volume (mL)	Volume Delta (mL)	Final Temperature (°C)	Final pH	Saturation Volume (mL)	Saturation Concentration (ppm)	Saturation Concentration (mg/L)	Mass of Dye in Contaminant (mg)	5-Nov-21		
Methylene Blue Dye			Block 1	3500	3145	355	12.4	8.53	225	16.0	16.0	3.6		
			Block 2	3500	3130	370	13.2	8.94						
			Block 3	3500	3160	340	12.9	8.81						
			Average	3500	3145.0	355.0	12.8	8.76						
						Initial RO values	10.3	5.34						
Group ID		Time (hrs.)	Absorption 1 (abs.)	Absorption 2 (abs.)	Absorption 3 (abs.)	Average Absorption (abs.)	Runoff Concentration (ppm)	Runoff Concentration (mg/L)	Mass of Dye in Runoff (mg)	Average Mass of Dye in Runoff (mg)	Average Percent Contaminant Desorbed (%)	Time (min)	Standard Deviation of Mass in Runoff (σ)	90% Confidence Interval
MB ₁	Block 1	0.5	0.0601	0.0608	0.0602	0.0604	0.1016	0.1016	0.3196	0.3898	10.83	30.0	0.0636	0.0604
	Block 2		0.0629	0.0638	0.0620	0.0629	0.1297	0.1297	0.4060			30.0		
	Block 3		0.0646	0.0639	0.0631	0.0639	0.1404	0.1404	0.4438			30.0		
MB ₂	Block 1	1	0.0617	0.0626	0.0619	0.0621	0.1205	0.1205	0.3789	0.4289	11.91	60.0	0.0434	0.0412
	Block 2		0.0637	0.0641	0.0648	0.0642	0.1441	0.1441	0.4511			60.0		
	Block 3		0.0634	0.0638	0.0655	0.0642	0.1445	0.1445	0.4566			60.0		
MB ₃	Block 1	3	0.0647	0.0635	0.0662	0.0648	0.1508	0.1508	0.4742	0.5833	16.20	180.0	0.1279	0.1214
	Block 2		0.0662	0.0687	0.0664	0.0671	0.1763	0.1763	0.5517			180.0		
	Block 3		0.0714	0.0719	0.0723	0.0719	0.2291	0.2291	0.7240			180.0		
MB ₄	Block 1	18	0.0667	0.0641	0.0639	0.0649	0.1519	0.1519	0.4777	0.5628	15.63	1080.0	0.1261	0.1197
	Block 2		0.0645	0.0664	0.0662	0.0657	0.1608	0.1608	0.5032			1080.0		
	Block 3		0.0700	0.0719	0.0723	0.0714	0.2239	0.2239	0.7077			1080.0		
MB ₅	Block 1	27.5	0.0632	0.0648	0.0637	0.0639	0.1408	0.1408	0.4428	0.4736	13.16	1650.0	0.0774	0.0735
	Block 2		0.0625	0.0639	0.0632	0.0632	0.1330	0.1330	0.4164			1650.0		
	Block 3		0.0658	0.0674	0.0685	0.0672	0.1778	0.1778	0.5617			1650.0		
MB ₆	Block 1	48	0.0608	0.0613	0.0629	0.0617	0.1160	0.1160	0.3649	0.4841	13.45	2880.0	0.1183	0.1123
	Block 2		0.0686	0.0676	0.0694	0.0685	0.1922	0.1922	0.6015			2880.0		
	Block 3		0.0651	0.0657	0.0644	0.0651	0.1537	0.1537	0.4858			2880.0		
MB ₇	Block 1	73	0.0543	0.0566	0.0564	0.0558	0.0506	0.0506	0.1592	0.2255	6.26	4380.0	0.0583	0.0553
	Block 2		0.0582	0.0596	0.0573	0.0584	0.0795	0.0795	0.2487			4380.0		
	Block 3		0.0597	0.0588	0.0581	0.0589	0.0850	0.0850	0.2686			4380.0		
MB ₈	Block 1	96	0.0564	0.0587	0.0568	0.0573	0.0676	0.0676	0.2127	0.2535	7.04	5760.0	0.0553	0.0525
	Block 2		0.0570	0.0585	0.0581	0.0579	0.0739	0.0739	0.2313			5760.0		
	Block 3		0.0614	0.0604	0.0589	0.0602	0.1001	0.1001	0.3165			5760.0		

Table 36 - Brilliant Blue FCF Desorption Data

BB Trial Results			Starting Volume (mL)	Ending Volume (mL)	Volume Delta (mL)	Final Temperature (°C)	Final pH	Saturation Volume (mL)	Saturation Concentration (ppm)	Saturation Concentration (mg/L)	Mass of Dye in Contaminant (mg)	8-Dec-21		
Brilliant Blue Dye			Block 1	3500	3195	305	12.6	9.16	225	39.6	39.6	8.919		
			Block 2	3500	1615	1885	12.9	8.72						
			Block 3	3500	3125	375	12.7	8.96						
			Average	3500	2645.0	855.0	12.7	8.95						
						Initial RO values	10.3	5.34						
Group ID		Time (hrs.)	Absorption 1 (abs.)	Absorption 2 (abs.)	Absorption 3 (abs.)	Average Absorption (abs.)	Runoff Concentration (ppm)	Runoff Concentration (mg/L)	Mass of Dye in Runoff (mg)	Average Mass of Dye in Runoff (mg)	Average Percent Contaminant Desorbed (%)	Time (min)	Standard Deviation of Mass in Runoff (σ)	90% Confidence Interval
BB ₁	Block 1	0.5	0.0469	0.0466	0.0481	0.0472	0.0080	0.0080	0.0256	0.5144	5.77	30.0	0.7302	0.6935
	Block 2		0.0538	0.0536	0.0517	0.0530	0.1015	0.1015	0.1639			30.0		
	Block 3		0.0730	0.0742	0.0740	0.0737	0.4332	0.4332	1.3538			30.0		
BB ₂	Block 1	1	0.0468	0.0478	0.0469	0.0472	0.0075	0.0075	0.0239	0.5577	6.25	60.0	0.7985	0.7584
	Block 2		0.0538	0.0531	0.0533	0.0534	0.1074	0.1074	0.1734			60.0		
	Block 3		0.0756	0.0766	0.0763	0.0762	0.4722	0.4722	1.4757			60.0		
BB ₃	Block 1	3	0.0506	0.0490	0.0500	0.0499	0.0507	0.0507	0.1621	0.6778	7.60	180.0	0.8109	0.7702
	Block 2		0.0557	0.0563	0.0581	0.0567	0.1603	0.1603	0.2588			180.0		
	Block 3		0.0789	0.0781	0.0797	0.0789	0.5160	0.5160	1.6126			180.0		
BB ₄	Block 1	13	0.0576	0.0569	0.0500	0.0548	0.1303	0.1303	0.4164	0.9297	10.42	780.0	0.8363	0.7943
	Block 2		0.0657	0.0648	0.0650	0.0652	0.2959	0.2959	0.4779			780.0		
	Block 3		0.0846	0.0854	0.0836	0.0845	0.6063	0.6063	1.8947			780.0		
BB ₅	Block 1	24	0.0620	0.0614	0.0626	0.0620	0.2452	0.2452	0.7834	1.1069	12.41	1440.0	0.6858	0.6514
	Block 2		0.0712	0.0715	0.0719	0.0715	0.3980	0.3980	0.6427			1440.0		
	Block 3		0.0846	0.0854	0.0836	0.0845	0.6063	0.6063	1.8947			1440.0		
BB ₆	Block 1	48	0.0620	0.0665	0.0678	0.0654	0.3002	0.3002	0.9592	1.2432	13.94	2880.0	0.7324	0.6955
	Block 2		0.0736	0.0735	0.0736	0.0736	0.4306	0.4306	0.6953			2880.0		
	Block 3		0.0882	0.0879	0.0883	0.0881	0.6640	0.6640	2.0750			2880.0		
BB ₇	Block 1	72	0.0730	0.0725	0.0724	0.0726	0.4156	0.4156	1.3278	1.5280	17.13	4320.0	0.7168	0.6808
	Block 2		0.0836	0.0822	0.0824	0.0827	0.5775	0.5775	0.9326			4320.0		
	Block 3		0.0935	0.0933	0.0925	0.0931	0.7436	0.7436	2.3237			4320.0		
BB ₈	Block 1	96	0.0758	0.0760	0.0751	0.0756	0.4637	0.4637	1.4814	1.8767	21.04	5760.0	0.5590	0.5309
	Block 2		N/A	N/A	N/A	N/A	N/A	N/A	N/A			5760.0		
	Block 3		0.0911	0.0928	0.0923	0.0921	0.7270	0.7270	2.2720			5760.0		

Appendix C

Table 37 - Allura Red AC Calibration Curve Data

Calibration Curve Data															21-Oct-21
Allura Red Dye	Wavelength	Molecular Weight		Starting Weight											
C ₁₈ H ₁₄ N ₂ Na ₂ O ₈ S ₂	504 nm	496.42	g/mol	24.8 mg											
Sample ID	Type	Molarity (mM)	Concentration (%)	Concentration (ppx)	Formulation					Absorption 1 (abs.)	Absorption 2 (abs.)	Average Absorption	Concentration (ppm)		
RO	Blank	0.0000	0%	0 ppm	2.0000	mL	RO	+	0.0	mL	RO	0.0570	0.0583	0.0577	0.00
AR ₀	Stock	0.0500	100%	24.8 ppm	2.0000	mL	AR ₀	+	0.0	mL	RO	0.5680	0.5653	0.5667	24.8
AR ₁	Standard	0.0250	50%	12.4 ppm	1.0000	mL	AR ₀	+	1.0	mL	RO	0.3157	0.3159	0.3158	12.4
AR ₂	Standard	0.0050	10%	2.48 ppm	0.4000	mL	AR ₁	+	1.6	mL	RO	0.1242	0.1142	0.1141	2.48
AR ₃	Standard	0.0005	1%	0.248 ppm	0.2000	mL	AR ₂	+	1.8	mL	RO	0.0715	0.0687	0.0701	0.248
AR ₄	Standard	2.50E-04	0.5%	12.4 ppb	0.0100	mL	AR ₀	+	1.99	mL	RO	0.0613	0.0601	0.0607	0.124
AR ₅	Standard	5.00E-05	0.1%	2.48 ppb	0.0200	mL	AR ₂	+	1.98	mL	RO	0.0583	0.0589	0.0586	0.0248

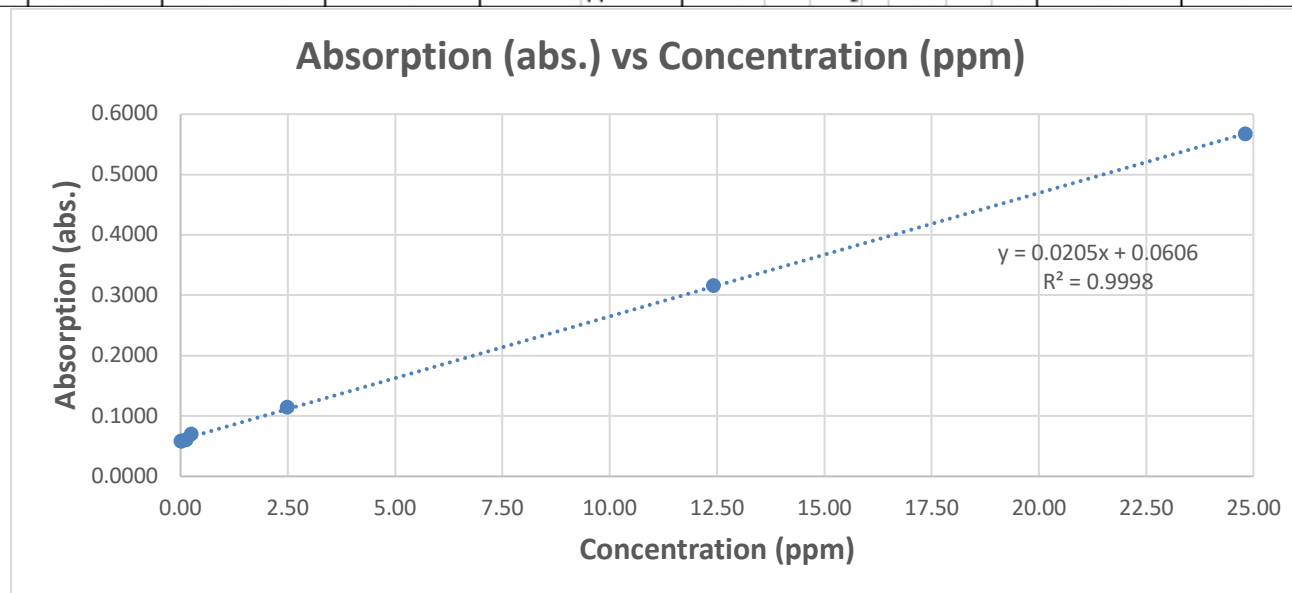


Figure 24 - Allura Red AC Calibration Curve

Table 38 - Methylene Blue Calibration Curve Data

Calibration Curve Data														21-Oct-21	
Methylene Blue Dye	Wavelength	Molecular Weight		Starting Weight											
C ₁₆ H ₁₈ ClN ₃ S	664 nm	319.85	g/mol	16	mg										
Sample ID	Type	Molarity (mM)	Concentration (%)	Concentration (ppx)	Formulation				Absorption 1 (abs.)	Absorption 2 (abs.)	Average Absorption	Concentration (ppm)			
RO	Blank	0.0000	0%	0 ppm	2.0000	mL	RO	+	0.0	mL	RO	0.0551	0.0549	0.0550	0.0
AR ₀	Stock	0.0500	100%	16 ppm	2.0000	mL	MB ₀	+	0.0	mL	RO	1.4663	1.4948	1.4806	16.0
AR ₁	Standard	0.0250	50%	8 ppm	1.0000	mL	MB ₀	+	1.0	mL	RO	0.8059	0.8071	0.8065	8.0
AR ₂	Standard	0.0050	10%	1.6 ppm	0.4000	mL	MB ₁	+	1.6	mL	RO	0.1739	0.1715	0.1727	1.6
AR ₃	Standard	0.0005	1%	0.16 ppm	0.2000	mL	MB ₂	+	1.8	mL	RO	0.0617	0.0602	0.0610	0.16
AR ₄	Standard	2.50E-04	0.5%	8 ppb	0.0100	mL	MB ₀	+	1.99	mL	RO	0.0593	0.0581	0.0587	0.08
AR ₅	Standard	5.00E-05	0.1%	1.6 ppb	0.0200	mL	MB ₂	+	1.98	mL	RO	0.0573	0.0569	0.0571	0.016

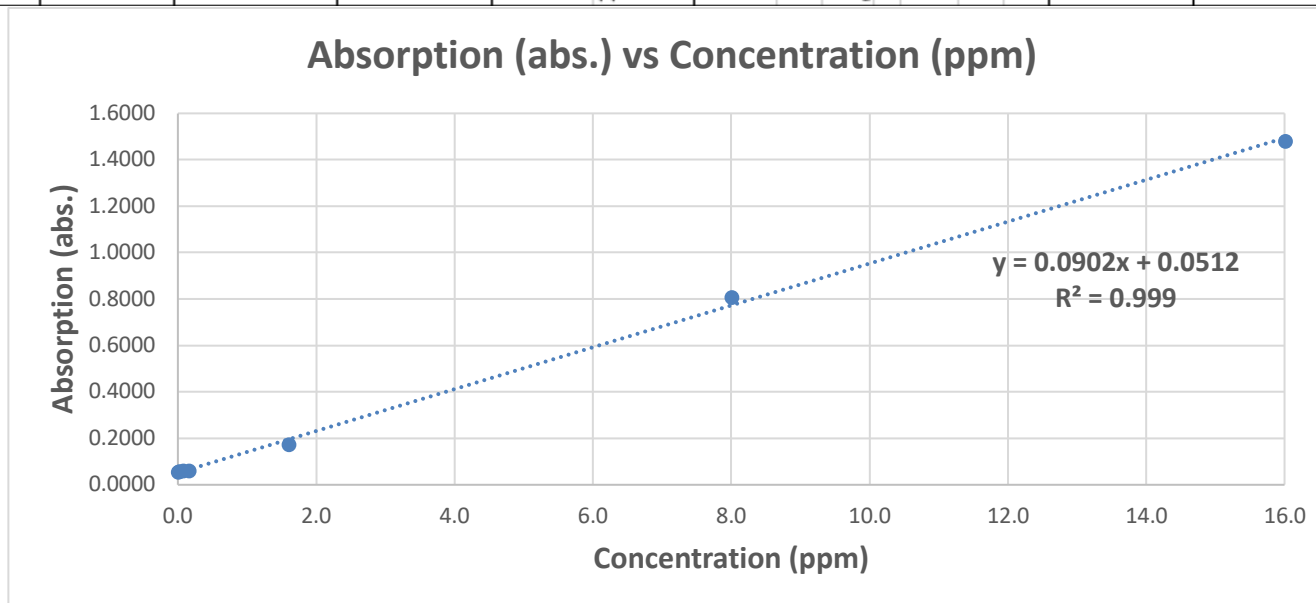


Figure 25 - Methylene Blue Calibration Curve

Table 39 - Brilliant Blue FCF Calibration Curve Data

Calibration Curve Data													15-Nov-21		
Brilliant Blue Dye	Wavelength	Molecular Weight		Starting Weight											
C ₃₇ H ₃₆ N ₂ Na ₂ O ₉ S ₃	630 nm	792.86	g/mol	39.64	mg										
Sample ID	Type	Molarity (mM)	Concentration (%)	Concentration (ppx)	Formulation					Absorption 1 (abs.)	Absorption 2 (abs.)	Average Absorption	Concentration (ppm)		
RO	Blank	0.0000	0%	0 ppm	2.0000	mL	RO	+	0.0	mL	RO	0.0372	0.0389	0.0381	0.0
BB ₀	Stock	0.0500	100%	39.64 ppm	2.0000	mL	MB ₀	+	0.0	mL	RO	2.5522	2.4516	2.5019	39.6
BB ₁	Standard	0.0250	50%	19.82 ppm	1.0000	mL	MB ₀	+	1.0	mL	RO	1.3223	1.3202	1.3213	19.8
BB ₂	Standard	0.0050	10%	3.964 ppm	0.4000	mL	MB ₁	+	1.6	mL	RO	0.3057	0.3099	0.3078	4.0
BB ₃	Standard	0.0005	1%	0.3964 ppm	0.2000	mL	MB ₂	+	1.8	mL	RO	0.0639	0.0647	0.0643	0.3964
BB ₄	Standard	2.50E-04	0.5%	19.82 ppb	0.0100	mL	MB ₀	+	1.99	mL	RO	0.0517	0.0515	0.0516	0.1982
BB ₅	Standard	5.00E-05	0.1%	3.964 ppb	0.0200	mL	MB ₂	+	1.98	mL	RO	0.0418	0.0415	0.0417	0.0396

Absorption (abs.) vs Concentration (ppm)

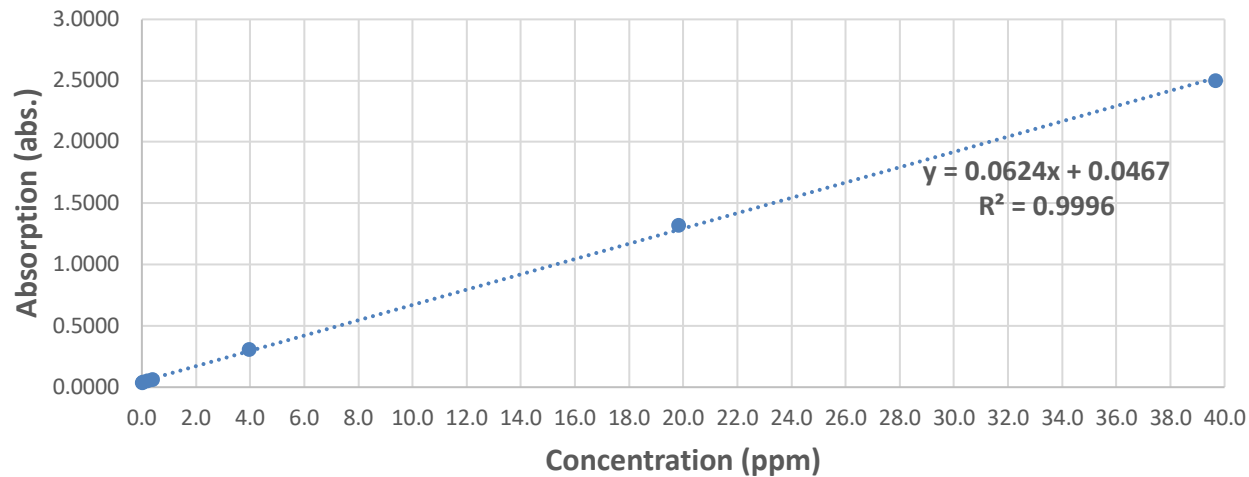


Figure 26 - Brilliant Blue FCF Calibration Curve

Appendix D

Python Script 1 – Dye plots

```
#generate the curve fit plots for the dye data
import os
import pandas as pd
import matplotlib.pyplot as plt
import numpy as np

from numpy import exp
from sklearn import metrics as skm

parent = os.path.join(os.path.abspath(__file__), os.pardir)

filename = os.path.abspath(os.path.join(parent,
                                         'pfas_data_final.xlsx'))

data = pd.read_excel(filename, sheet_name = 'BB_plotting')

#Brilliant Blue
x_values = np.concatenate( (data['t (hrs)'],data['t (hrs)'],data['t (hrs)']), axis = 0)
y_values = np.concatenate( (data['conc1'],data['conc2'],data['conc3']), axis = 0)

#Title
valuetouse = 'Brilliant Blue'

# objective function
def fit_equation(x, a, b):

    return a*(1 - exp(-b*x ) )

from scipy.optimize import curve_fit

# fit curve
popt, pcov = curve_fit(fit_equation, x_values, y_values)

x_line = np.linspace(0,max(x_values), num = len(y_values))
a = popt[0]
b = popt[1]

y_line = a*(1 - 2.718281828459045**(-(b*x_line) ) )
colors = ['b', 'g', 'm']*int((len(y_values)/3))
```

```

#Title
valuetouse = 'Brilliant Blue'

# objective function
def fit_equation(x, a, b):

    return a*(1 - exp(-(b*x) ))

from scipy.optimize import curve_fit

# fit curve
popt, pcov = curve_fit(fit_equation, x_values, y_values)

x_line = np.linspace(0,max(x_values), num = len(y_values))
a = pop[0]
b = pop[1]

y_line = a*(1 - 2.718281828459045**(-(b*x_line) ))
colors = ['b', 'g', 'm']*int((len(y_values)/3))

ax = plt.subplot(111)
plt.subplots_adjust(left=0.15, bottom=0.15, right=.8, top=0.8)

plt.scatter(x_values, y_values, color = colors)

plt.plot(x_line, y_line, color = 'r', marker = 'None')
plt.show()

#for y we need measurements at each time point, rather than a smooth plot of the whole line
y_r2 = a*(1 - 2.718281828459045**(-(b*x_values) ))

r_square = round(skm.r2_score(y_values, y_r2), 3)

plt.text(10,0,'R^2 value = '+ str(r_square), fontsize =16 )
plt.text(10,max(y_values)/10, str(round(a, 3))+ '(1- '+ 'e^(-t*'+ str(round(b,3))+ '))', fontsize = 16
)
plt.xticks(fontsize=14 )
plt.yticks(fontsize=14 )

ax.set_xlabel('Hours', fontsize=14, labelpad = 14)
ax.set_ylabel('Absorbtion', fontsize=14, labelpad =14 )
plt.title(valuetouse, fontsize = 20)

```


Python Script 2 – for generating PFAS array plots

```
import os
import pandas as pd
import matplotlib.pyplot as plt
import numpy as np
from numpy import exp
from sklearn import metrics as skm
from scipy.optimize import curve_fit

# objective function
def fit_equation(x, a, b):

    return a*(1 - exp(-b*x ) )

parent = os.path.join(os.path.abspath(__file__), os.pardir)
filename = os.path.abspath(os.path.join(parent,
                                         'pfas_data_final.xlsx'))
data = pd.read_excel(filename, sheet_name = 'PFAS_plotting')

x_values = np.array( data['t (hrs)'])
possible_headers = list(data.columns)[1:]

fig = plt.figure(figsize = (8,10))

i = 1
for h in possible_headers:
    y_values = np.array( data[h])

    # fit curve
    popt, pcov = curve_fit(fit_equation, x_values, y_values)

    x_line_plot = np.linspace(0,max(x_values), num = 100)
    x_line = np.array([0,1,3,36])

    a = popt[0]
    b = popt[1]

    y_line_plot = a*(1 - 2.718281828459045**(-(b*x_line_plot) ) )
    colors = ['b', 'g', 'm']*int((len(y_values)/3))
    colors = ['b']*int(len(y_values))

    plt.subplot( 4,3,i)
    plt.scatter(x_values, y_values, color = colors)
```

```

#up-sample to be able to do a better job here.

plt.plot(x_line_plot, y_line_plot, color = 'r', marker = 'None', linestyle = '--' )

ax = plt.gca()
(xmin, xmax) = ax.get_xlim()
(ymin, ymax) = ax.get_ylim()
ax.set_xlim([xmin, xmax])
ax.set_ylim([ymin, ymax*1.1])

#for y we need measurments at each time point, rather than a smooth plot of the whole line
y_r2 = a*(1 - 2.718281828459045**(-(b*x_line) ) )

r_square = round(skm.r2_score(y_values, y_r2), 3)

plt.text(8,0,'R^2 value = '+ str(r_square), fontsize=8 )
plt.text(8,max(y_values)/7, str(round(a, 3))+*(1-'+' 'e^(-t*'+ str(round(b,2))+ '))', fontsize = 8 )
plt.xticks(fontsize=8 )
plt.yticks(fontsize=8 )

plt.title(h, fontsize = 8)

i +=1

fig.subplots_adjust(top=0.85, hspace = 0.5)

```

Appendix E

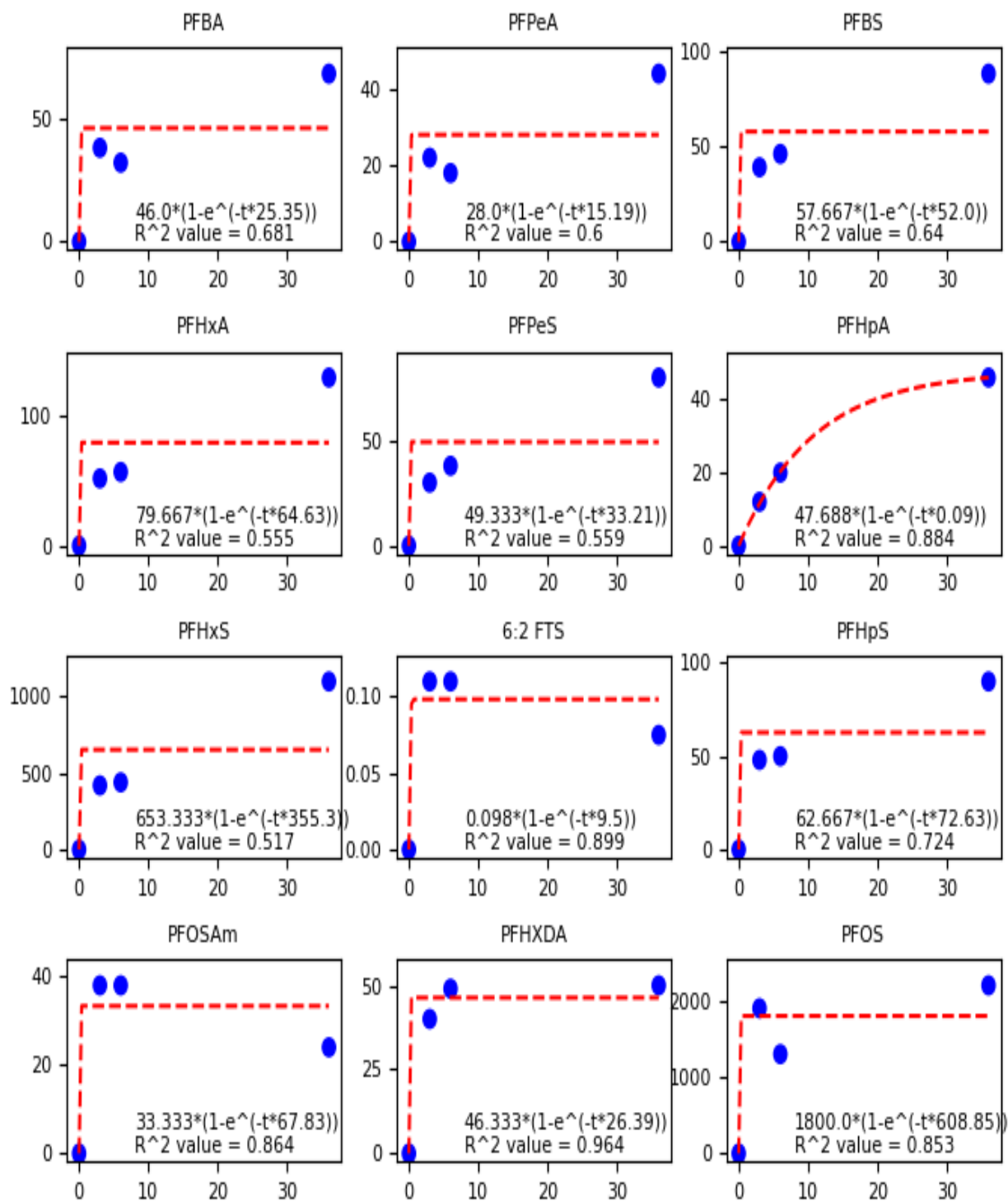


Figure 27 - PFAS Compound Decay Curves

Appendix F



Pace Analytical Services, LLC.
1700 Elm Street
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444

Report Prepared for:

Jason McDonald
WPAFB - AFIT
2950 Hobson Way
Dayton OH 45433

REPORT OF LABORATORY ANALYSIS FOR PFAAs

Report Information:

Pace Project #: 10590162
Sample Receipt Date: 12/07/2021
Client Project #: WPAFB AFIT PFAS STORMW
Client Sub PO #: N/A
State Cert #: MN300001

Invoicing & Reporting Options:

The report provided has been invoiced as a Level 2 PFAA Report. If an upgrade of this report package is requested, an additional charge may be applied.

Please review the attached invoice for accuracy and forward any questions to Kirsten Hogberg, your Pace Project Manager.

This report has been reviewed by:

January 14, 2022

Kirsten Hogberg, Project Manager
(612) 607-6407
(612) 607-6444 (fax)
kirsten.hogberg@pacelabs.com



Report of Laboratory Analysis

This report should not be reproduced, except in full, without the written consent of Pace Analytical Services, Inc.

The results relate only to the samples included in this report.

Report Prepared Date:

January 14, 2022

DISCUSSION

This report presents the results from the analyses performed on eight samples submitted by a representative of WPAFB-AFIT. The samples were analyzed for thirty-six perfluorinated compounds using DOD QSM 5.3 for PFAS. Reporting limits were set to MDL levels. Revision 1 was generated to correct the sample volumes and update the reporting limits to MDL.

A laboratory method blank was prepared and analyzed with each sample batch as part of our routine quality control procedures. The results show the blank was free of the target perfluorinated compounds at the reporting limits. This indicates that the sample processing procedures did not significantly contribute to the analyte content determined for the sample material.

Laboratory spike samples were also prepared with each sample batch using clean reference matrix that had been fortified with native standards. The recovery results were within the method limits. The RPDs (relative percent differences) between one designated spike and its duplicate were within the method limits. These spikes indicate that extraction performed as expected. Matrix spikes were prepared with the sample batch using sample material from a separate project; results from that analysis will be provided upon request.

Diminished/elevated extracted internal standard (EIS) recovery ("R" flagged) were present in samples, however, the use of the isotope dilution method generally precludes any adverse impact on those individual native compounds that have a directly associated standard.

The four injection internal standards (13C4 PFOA, 13C4 PFOS, 13C2_PFDA, and 13C2_PFHxA) pass for each analysis in the batch verifying that the instrument detector is working as expected.

Results for selected analytes were taken from secondary dilutions of the sample extracts in order to bring the results within the calibration range or to reduce the impact of matrix effects. The affected values were flagged "D" on the results tables.

Concentrations below the calibration range were flagged "J" and should be regarded as estimates.

Values were flagged "I" where incorrect isotope ratios were obtained.



Pace Analytical Services, LLC
1700 Elm Street - Suite 200
Minneapolis, MN 55414

Tel: 612-607-1700
Fax: 612-607-6444

Minnesota Laboratory Certifications

Authority	Certificate #	Authority	Certificate #
A2LA	2926.01	Missouri	10100
Alabama	40770	Montana	CERT0092
Alaska-DW	MN00064	Nebraska	NE-OS-18-06
Alaska-UST	17-009	Nevada	MN00064
Arizona	AZ0014	New Hampshire	2081
Arkansas - WW	88-0680	New Jersey	MN002
Arkansas-DW	MN00064	New York	11647
California	2929	North Carolina-	27700
Colorado	MN00064	North Carolina-	530
Connecticut	PH-0256	North Dakota	R-036
Florida	E87605	Ohio-DW	41244
Georgia	959	Ohio-VAP (170	CL101
Hawaii	MN00064	Ohio-VAP (180	CL110
Idaho	MN00064	Oklahoma	9507
Illinois	200011	Oregon- rimary	MN300001
Indiana	C-MN-01	Oregon-Second	MN200001
Iowa	368	Pennsylvania	68-00563
Kansas	E-10167	Puerto Rico	MN00064
Kentucky-DW	90062	South Carolina	74003
Kentucky-WW	90062	Tennessee	TN02818
Louisiana-DEQ	AI-84596	Texas	T104704192
Louisiana-DW	MN00064	Utah	MN00064
Maine	MN00064	Vermont	VT-027053137
Maryland	322	Virginia	460163
Michigan	9909	Washington	C486
Minnesota	027-053-137	West Virginia-D	382
Minnesota-Ag	via MN 027-053	West Virginia-D	9952C
Minnesota-Petr	1240	Wisconsin	999407970
Mississippi	MN00064	Wyoming-UST	via A2LA 2926.

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, Inc.

Appendix A

Sample Management

CHAIN-OF-CUSTODY Analytical Request Document

Chain-of-Custody is a LEGAL DOCUMENT - Complete all relevant fields

Company: **WPAFB - AFIT** Billing Information: **ALISSA.MASON@AFIT.EDU**

Address: **2950 HOBSON WAY** Email To: **JASON.MCDONALD@AFIT.EDU**

Report To: **JASON MCDONALD** Site Collection Info/Address:

Copy To: **TREVOR SLIECHT**

Customer Project Name/Number: **PFAS STORMWATER & CONCRETE TESTING** State: **OH / MONTGOMERY** County/City: **[] PT [] MT [] CT [X] ET**

Phone: **503 347 1552** Site/Facility ID #: **WPAFB AFIT** Compliance Monitoring? **[] Yes [X] No**

Email: **JASON.MCDONALD@AFIT.EDU** Purchase Order #: **20100836** DW PWS ID #:

Collected By (print): **JASON MCDONALD** Quote #: **20100836** DW Location Code:

Collected By (signature): **[Signature]** Turnaround Date Required: **21 DEC 21** Immediately Packed on Ice: **[X] Yes [] No**

Sample Disposal: **[X] Dispose as appropriate [] Return** Rush: **[] Same Day [] Next Day** Field Filtered (if applicable): **[] Yes [X] No**

[] Archive: [] 2 Day [] 3 Day [] 4 Day [] 5 Day (Expedite Charges Apply) Analysis:

[] Hold:

* Matrix Codes (Insert in Matrix box below): Drinking Water (DW), Ground Water (GW), Wastewater (WW), Product (P), Soil/Solid (SL), Oil (OL), Wipe (WP), Air (AR), Tissue (TS), Bioassay (B), Vapor (V), Other (OT)

Customer Sample ID	Matrix *	Comp / Grab	Collected (or Composite Start)		Composite End		Res CI	# of Ctns
			Date	Time	Date	Time		
PR ₀ (AS PREPARED)	OT/P		3 DEC 21	1130	3 DEC 21	1155		1
BLANK (TEST)	OT/P		29 DEC 21	1020	29 DEC 21	1025		1
CB ₁ (POWDER)	SL		4 DEC 21	1000	4 DEC 21	1030		1
CB ₂ (POWDER)	SL		4 DEC 21	1000	4 DEC 21	1030		1
CB ₃ (POWDER)	SL		4 DEC 21	1000	4 DEC 21	1030		1
PR ₁ (3 hr)	P		3 DEC 21	1315	3 DEC 21	1315		1
PR ₂ (5 hr)	P		3 DEC 21	1315	3 DEC 21	1315		1
PR ₃ (25 hr)	P		5 DEC 21	0015	5 DEC 21	0015		1

Customer Remarks / Special Conditions / Possible Hazards: **PR₀ IS A 3.97 RATIO OF 3M LIGHTWATER TO RW WATER SOLUTION (HIGH CONCENTRATION)**

Type of Ice Used: **[X] Wet Blue Dry None** SHORT HOLDS PRESENT (<72 hours): **Y N N/A**

Packing Material Used: Lab Tracking #: **2701063**

Radchem sample(s) screened (<500 cpm): **Y N NA** Samples received via: **FEDEX UPS Client Courier Pace Courier**

Relinquished by/Company: **WPAFB - AFIT / JASON MCDONALD** Date/Time: **6 DEC 21 / 1130** Received by/Company: **[Signature]** Date/Time: **12/7/21 0850**


Relinquished by/Company: Date/Time: Received by/Company: Date/Time:

Relinquished by/Company: Date/Time: Received by/Company: Date/Time:

Lab Sample Temperature Info: Temp Blank Received: **0 N NA** Therm ID#: **1** Cooler 1 Temp Upon Receipt: **0.7 oC** Cooler 1 Therm Corr. Factor: **0.7 oC** Cooler 1 Corrected Temp: **0.7 oC** Comments:

Trip Blank Received: **Y N NA** HCL MeOH TSP Other

Non Conformance(s): **YES / NO** Page: of:

	Document Name: Sample Condition Upon Receipt (SCUR) - MN	Document Revised: 02Dec2021
	Document No.: ENV-FRM-MIN4-0150 Rev.03	Page 1 of 1
	Pace Analytical Services - Minneapolis	

Sample Condition Upon Receipt	Client Name: <u>WPAFB - AFIT</u>	Project #: <u>WO# : 10590162</u>
Courier: <input checked="" type="checkbox"/> Fed Ex <input type="checkbox"/> UPS <input type="checkbox"/> USPS <input type="checkbox"/> Client <input type="checkbox"/> Pace <input type="checkbox"/> Speedee <input type="checkbox"/> Commercial	PM: KNH Due Date: 12/29/21 CLIENT: WPAFB - AFIT	
Tracking Number: <u>5150 1598 1681</u>	See Exceptions <input type="checkbox"/> ENV-FRM-MIN4-0142	

Custody Seal on Cooler/Box Present? ☒ Yes ☐ No **Seals Intact?** ☒ Yes ☐ No **Biological Tissue Frozen?** ☐ Yes ☐ No ☒ N/A

Packing Material: ☒ Bubble Wrap ☐ Bubble Bags ☐ None ☐ Other: _____ **Temp Blank?** ☒ Yes ☐ No

Thermometer: ☒ T1(0461) ☐ T2(1336) ☐ T3(0459) ☐ T4(0254)
☐ T5(0489) ☐ 01339252/1710 ☐ 122639816 ☐ 140792808 **Type of Ice:** ☒ Wet ☐ Blue ☐ None ☐ Dry ☐ Melted

Did Samples Originate in West Virginia? ☐ Yes ☒ No **Were All Container Temps Taken?** ☐ Yes ☐ No ☒ N/A

Temp should be above freezing to 6°C **Cooler Temp Read w/temp blank:** 0.7 °C **Average Corrected Temp (no temp blank only):** _____ °C ☐ See Exceptions ENV-FRM-MIN4-0142 ☐ 1 Container

Correction Factor: True **Cooler Temp Corrected w/temp blank:** 0.7 °C

USDA Regulated Soil: (☐ N/A, water sample/Other: _____) **Date/Initials of Person Examining Contents:** CBSI 12/7/21

Did samples originate in a quarantine zone within the United States: AL, AR, CA, FL, GA, ID, LA, MS, NC, NM, NY, OK, OR, SC, TN, TX or VA (check maps)? ☐ Yes ☒ No Did samples originate from a foreign source (internationally, including Hawaii and Puerto Rico)? ☐ Yes ☒ No

If Yes to either question, fill out a Regulated Soil Checklist ENV-FRM-MIN4-0154 and include with SCUR/COC paperwork.

	COMMENTS:
Chain of Custody Present and Filled Out? <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	1.
Chain of Custody Relinquished? <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	2.
Sampler Name and/or Signature on COC? <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> N/A	3.
Samples Arrived within Hold Time? <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	4. If Fecal: <input type="checkbox"/> <8 hrs <input type="checkbox"/> >8hr, <24 hrs, <input type="checkbox"/> >24 hrs
Short Hold Time Analysis (<72 hr)? <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No	5. <input type="checkbox"/> Fecal Coliform <input type="checkbox"/> HPC <input type="checkbox"/> Total Coliform/E coli <input type="checkbox"/> BOD/cBOD <input type="checkbox"/> Hex Chrome <input type="checkbox"/> Turbidity <input type="checkbox"/> Nitrate <input type="checkbox"/> Nitrite <input type="checkbox"/> Orthophos <input type="checkbox"/> Other
Rush Turn Around Time Requested? <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No	6.
Sufficient Volume? <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	7.
Correct Containers Used? <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	8.
-Pace Containers Used? <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	
Containers Intact? <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	9.
Field Filtered Volume Received for Dissolved Tests? <input type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> N/A	10. Is sediment visible in the dissolved container? <input type="checkbox"/> Yes <input type="checkbox"/> No
Is sufficient information available to reconcile the samples to the COC? <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No Matrix: <input checked="" type="checkbox"/> Water <input checked="" type="checkbox"/> Soil <input type="checkbox"/> Oil <input checked="" type="checkbox"/> Other-	11. If no, write ID/ Date/Time on Container Below: <input type="checkbox"/> See Exception ENV-FRM-MIN4-0142
All containers needing acid/base preservation have been checked? <input type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> N/A All containers needing preservation are found to be in compliance with EPA recommendation? (HNO₃, H₂SO₄, <2pH, NaOH >9 Sulfide, NaOH >10 Cyanide) <input type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> N/A	12. Sample # <input type="checkbox"/> NaOH <input type="checkbox"/> HNO ₃ <input type="checkbox"/> H ₂ SO ₄ <input type="checkbox"/> Zinc Acetate
Exceptions: VOA, Coliform, TOC/DOC Oil and Grease, DRO/8015 (water) and Dioxin (FA) <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> N/A	Positive for Res. <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No pH Paper Lot# _____ <input type="checkbox"/> See Exception ENV-FRM-MIN4-0142 Res. Chlorine 0-6 Roll 0-6 Strip 0-14 Strip
Headspace in Methyl Mercury Container? <input type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> N/A	
Extra labels present on soil VOA or WIDRO containers? <input type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> N/A	13. <input type="checkbox"/> See Exception ENV-FRM-MIN4-0140
Headspace in VOA Vials (greater than 6mm)? <input type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> N/A	
Trip Blank Present? <input type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> N/A	14. Pace Trip Blank Lot # (if purchased):
Trip Blank Custody Seals Present? <input type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> N/A	

CLIENT NOTIFICATION/RESOLUTION **Field Data Required?** ☐ Yes ☐ No

Person Contacted: _____ **Date/Time:** _____

Comments/Resolution: Required method - PFAS by Isotope Dilution.

Project Manager Review: Kristen Hogberg **Date:** 12/8/2021

Note: Whenever there is a discrepancy affecting North Carolina compliance samples, a copy of this form will be sent to the North Carolina DEHNR Certification Office (i.e., out of hold, incorrect preservative, out of temp, incorrect containers).

Reporting Flags

- A = Reporting Limit based on signal to noise (EDL)
- B = Less than 10x higher than method blank level
- C = Result obtained from confirmation analysis
- D = Result obtained from analysis of diluted sample
- E = Exceeds calibration range
- I = Interference present
- J = Estimated value
- L = Suppressive interference, analyte may be biased low
- Nn = Value obtained from additional analysis
- P = PCDE Interference
- R = Recovery outside target range
- S = Peak saturated
- U = Analyte not detected
- V = Result verified by confirmation analysis
- X = %D Exceeds limits
- Y = Calculated using average of daily RFs
- * = See Discussion

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, Inc.
Revision 1

Appendix B

Sample Analysis Summary



Pace Analytical Services, LLC
1700 Elm Street, Suite 200
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444
www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 1 of 4

Client Sample ID PRo (as prepared)
Lab Sample ID 10590162001
Lab File ID A211229A_013
Matrix Non_Potable_Water
Collected 12/03/2021 11:35
Received 12/07/2021 08:50

Extraction Date 12/27/2021 14:48
Total Amount Extracted 1.00uL
Ical ID 211228A03
CCal File A211229A_005
Ending CCal File A211229A_020
Blank File A211229A_008

Compound	Concentration (ug/L)	QL (ug/L)	RL (ug/L)	DL (ug/L)	Dil.	CAS No.	Qual.
PFBA	840	500	0.11	0.11	1	375-22-4	
PFPeA	640	500	0.11	0.11	1	2706-90-3	
HFPO-DA	ND	500	0.13	0.13	1	13252-13-6	
PFBS	1800	440	0.12	0.12	1	375-73-5	
PFHxA	2300	500	0.11	0.11	1	307-24-4	
4:2 FTS	ND	470	0.14	0.14	1	757124-72-4	
PFPeS	1900	470	0.12	0.12	1	2706-91-4	
PFHpA	410 J	500	0.14	0.14	1	375-85-9	
DONA	ND	470	0.13	0.13	1	919005-14-4	
PFHxS	25000	460	0.13	0.13	1	355-46-4	
PFOA	1300	500	0.15	0.15	1	335-67-1	
6:2 FTS	81 IJ	480	0.16	0.16	1	27619-97-2	
PFHpS	2500	480	0.10	0.10	1	375-92-8	
PFNA	ND	500	0.18	0.18	1	375-95-1	
PFOSAm	160 J	500	0.20	0.20	1	754-91-6	
PFOS	130000 D	4600	1.4	1.4	10	1763-23-1	
MeFOSA	ND	500	0.13	0.13	1	31506-32-8	
PFDA	ND	500	0.14	0.14	1	335-76-2	
EtFOSAm	ND	500	0.15	0.15	1	4151-50-2	
8:2 FTS	ND	480	0.16	0.16	1	39108-34-4	
9-CI-PF3ON	ND	470	0.076	0.076	1	756426-58-1	
PFNS	140 IJ	480	0.11	0.11	1	68259-12-1	
PFUnDA	ND	500	0.14	0.14	1	2058-94-8	
NMeFOSAA	ND	500	0.11	0.11	1	2355-31-9	
NEtFOSAA	ND	500	0.14	0.14	1	2991-50-6	
PFDS	83 J	480	0.11	0.11	1	335-77-3	
PFDOA	ND	500	0.12	0.12	1	307-55-1	
MeFOSE	ND	500	0.082	0.082	1	24448-09-7	
10:2 FTS	ND	480	0.18	0.18	1	120226-60-0	
EtFOSE	ND	500	0.12	0.12	1	1691-99-2	
11-CI-PF3OUdS	ND	470	0.11	0.11	1	763051-92-9	
PFTrDA	ND	500	0.16	0.16	1	72629-94-8	
PFDoS	40 J	480	0.12	0.12	1	79780-39-5	
PFTDA	ND	500	0.12	0.12	1	376-06-7	
PFHXDA	40 J	500	0.091	0.091	1	67905-19-5	
PFODA	ND	500	0.15	0.15	1	16517-11-6	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 2 of 4

Client Sample ID	PRo (as prepared)	Extraction Date	12/27/2021 14:48
Lab Sample ID	10590162001	Total Amount Extracted	1.00uL
Lab File ID	A211229A_013	Ical ID	211228A03
Matrix	Non_Potable_Water	CCal File	A211229A_005
Collected	12/03/2021 11:35	Ending CCal File	A211229A_020
Received	12/07/2021 08:50	Blank File	A211229A_008

Injection Internal Standards

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers
13C2_PFHxA	5000	5500	109	50-150	
13C4_PFOA	5000	5200	103	50-150	
13C2_PFDA	5000	5400	109	50-150	
13C4_PFOS	4800	5200	109	50-150	

Extracted Internal Standards

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers
13C4_PFBA	5000	5500	110	50-150	
13C5_PFPeA	5000	5400	109	50-150	
13C3_PFBs	4600	4500	97	50-150	
13C2_4:2FTS	4700	4800	102	50-150	
13C5_PFHxA	5000	5300	105	50-150	
13C4_PFHpA	5000	5500	109	50-150	
13C3_PFHxS	4700	5200	109	50-150	
13C2_6:2FTS	4700	5600	118	50-150	
13C8_PFOA	5000	5200	103	50-150	
13C9_PFNA	5000	5300	106	50-150	
13C8_PFOS	4800	6900	144	50-150	D
13C2_8:2FTS	4800	4900	102	50-150	
13C6_PFDA	5000	5100	102	50-150	
d3-MeFOSAA	5000	4800	95	50-150	
13C8_PFOA	5000	4100	82	50-150	
d5-EtFOSAA	5000	4600	92	50-150	
13C7_PFHdA	5000	5100	103	50-150	
13C2_PFDaA	5000	5100	101	50-150	
13C2_PFTeDA	5000	4900	99	50-150	
13C3_HFPO-DA	5000	5400	107	50-150	
13C2_PFHxDA	5000	4800	97	50-150	
d7-N-MeFOSE	5000	3600	73	10-150	
d9-N-EtFOSE	5000	3700	75	10-150	
d3-N-MeFOSA	5000	2500	50	10-150	
d5-N-EtFOSA	5000	2600	52	10-150	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

Sample Analysis Summary
 PFAS by Isotope Dilution

Page 3 of 4

Client Sample ID	PRo (as prepared)	Extraction Date	12/27/2021 14:48
Lab Sample ID	10590162001	Total Amount Extracted	1.00uL
Lab File ID	A211229A_013	Ical ID	211228A03
Matrix	Non_Potable_Water	CCal File	A211229A_005
Collected	12/03/2021 11:35	Ending CCal File	A211229A_020
Received	12/07/2021 08:50	Blank File	A211229A_008

Injection Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
13C2 PFHxA	N/A	N/A	4.92	4.93	2502	
13C4 PFOA	N/A	N/A	5.88	5.89	2041	
13C2 PFDA	N/A	N/A	6.75	6.77	1788	
13C4 PFOS	N/A	N/A	7.06	7.08	1425	

Extracted Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
13C4 PFBA	N/A	N/A	3.50	3.52	2425	
13C5 PFPeA	N/A	N/A	4.34	4.35	2032	
13C3 PFBS	N/A	N/A	5.10	5.11	2313	
13C2 4:2FTS	N/A	N/A	4.71	4.72	351	
13C5 PFHxA	N/A	N/A	4.92	4.93	438	
13C4 PFHpA	N/A	N/A	5.42	5.43	2036	
13C3 PFHxS	N/A	N/A	6.15	6.17	1625	
13C2 6:2FTS	N/A	N/A	5.66	5.66	580	
13C8 PFOA	N/A	N/A	5.88	5.89	2316	
13C9 PFNA	N/A	N/A	6.32	6.33	2218	
13C8 PFOS	N/A	N/A	7.05	7.08	537	D
13C2 8:2FTS	N/A	N/A	6.51	6.52	943	
13C6 PFDA	N/A	N/A	6.75	6.77	2281	
d3-MeFOSAA	N/A	N/A	6.71	6.72	1170	
13C8 PFOSA	N/A	N/A	8.64	8.65	2395	
d5-EtFOSAA	N/A	N/A	6.92	6.93	928	
13C7 PFUdA	N/A	N/A	7.19	7.20	1828	
13C2 PFDoA	N/A	N/A	7.62	7.64	1908	
13C2 PFTeDA	N/A	N/A	8.47	8.48	1547	
13C3 HFPO-DA	N/A	N/A	5.13	5.14	1599	
13C2 PFHxDA	N/A	N/A	9.22	9.24	2115	
d7-N-MeFOSE	N/A	N/A	9.94	9.95	192	
d9-N-EtFOSE	N/A	N/A	10.55	10.56	469	
d3-N-MeFOSA	N/A	N/A	10.19	10.20	816	
d5-N-EtFOSA	N/A	N/A	10.86	10.87	757	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
1700 Elm Street, Suite 200
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444
www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 4 of 4

Client Sample ID	PRo (as prepared)	Extraction Date	12/27/2021 14:48
Lab Sample ID	10590162001	Total Amount Extracted	1.00uL
Lab File ID	A211229A_013	Ical ID	211228A03
Matrix	Non_Potable_Water	CCal File	A211229A_005
Collected	12/03/2021 11:35	Ending CCal File	A211229A_020
Received	12/07/2021 08:50	Blank File	A211229A_008

Native Analytes

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
PFBA	N/A	N/A	3.51	3.52	361	
PFPeA	N/A	N/A	4.34	4.35	279	
HFPO-DA	0.000	0.470	0.00	5.15	ND	
PFBS	0.330	0.340	5.10	5.12	618	
PFHxA	0.065	0.0640	4.93	4.94	409	
4:2 FTS	0.000	0.560	0.00	4.72	ND	
PFPeS	0.340	0.310	5.66	5.68	559	
PFHpA	0.270	0.310	5.43	5.44	85	J
DONA	0.000	0.480	0.00	5.61	ND	
PFHxS	0.300	0.290	6.16	6.17	1511	
PFOA	0.420	0.370	5.89	5.90	125	
6:2 FTS	0.900	0.510	5.66	5.67	13	IJ
PFHpS	0.240	0.230	6.62	6.64	64	
PFNA	0.000	0.190	0.00	6.34	ND	
PFOSAm	N/A	N/A	8.65	8.65	402	J
PFOS	0.220	0.200	7.06	7.09	326	D
MeFOSA	0.000	0.930	0.00	10.22	ND	
PFDA	0.000	0.110	0.00	6.77	ND	
EtFOSAm	0.000	0.700	0.00	10.90	ND	
8:2 FTS	0.000	0.650	0.00	6.52	ND	
9-Cl-PF3ON	0.000	0.0210	0.00	7.40	ND	
PFNS	0.380	0.240	7.50	7.52	49	IJ
PFUnDA	0.000	0.120	0.00	7.21	ND	
NMeFOSAA	0.000	0.530	0.00	6.73	ND	
NEtFOSAA	0.000	0.870	0.00	6.94	ND	
PFDS	0.300	0.250	7.93	7.95	58	J
PFDOA	0.000	0.130	0.00	7.64	ND	
MeFOSE	N/A	N/A	0.00	9.99	ND	
10:2 FTS	0.000	0.700	0.00	7.39	ND	
EtFOSE	0.000	0.000	0.00	10.62	ND	
11-Cl-PF3OUdS	0.000	0.0140	0.00	8.25	ND	
PFTTrDA	0.000	0.150	0.00	8.07	ND	
PFDoS	0.290	0.220	8.73	8.75	82	J
PFTDA	0.000	0.160	0.00	8.49	ND	
PFHXDA	0.150	0.130	9.23	9.24	53	J
PFODA	0.000	0.0990	0.00	10.20	ND	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
1700 Elm Street, Suite 200
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444
www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 1 of 4

Client Sample ID BLANK (TEST)
Lab Sample ID 10590162002
Lab File ID A211229A_014
Matrix Non_Potable_Water
Collected 11/29/2021 12:25
Received 12/07/2021 08:50

Extraction Date 12/27/2021 14:48
Total Amount Extracted 213mL
Ical ID 211228A03
CCal File A211229A_005
Ending CCal File A211229A_020
Blank File A211229A_008

Compound	Concentration (ng/L)	QL (ng/L)	RL (ng/L)	DL (ng/L)	Dil.	CAS No.	Qual.
PFBA	73	2.4	0.52	0.52	1	375-22-4	
PFPeA	56	2.4	0.51	0.51	1	2706-90-3	
HFPO-DA	ND	2.4	0.62	0.62	1	13252-13-6	
PFBS	160	2.1	0.56	0.56	1	375-73-5	
PFHxA	210	2.4	0.51	0.51	1	307-24-4	
4:2 FTS	ND	2.2	0.66	0.66	1	757124-72-4	
PFPeS	190	2.2	0.56	0.56	1	2706-91-4	
PFHpA	36	2.4	0.65	0.65	1	375-85-9	
DONA	ND	2.2	0.60	0.60	1	919005-14-4	
PFHxS	1300 D	110	30	30	50	355-46-4	
PFOA	100	2.4	0.69	0.69	1	335-67-1	
6:2 FTS	1.6 J	2.2	0.76	0.76	1	27619-97-2	
PFHpS	210	2.2	0.48	0.48	1	375-92-8	
PFNA	2.7	2.4	0.87	0.87	1	375-95-1	
PFOSAm	3.8	2.4	0.96	0.96	1	754-91-6	
PFOS	6300 D	110	32	32	50	1763-23-1	
MeFOSA	ND	2.4	0.60	0.60	1	31506-32-8	
PFDA	1.4 J	2.4	0.66	0.66	1	335-76-2	
EtFOSAm	ND	2.4	0.71	0.71	1	4151-50-2	
8:2 FTS	ND	2.3	0.77	0.77	1	39108-34-4	
9-CI-PF3ON	ND	2.2	0.36	0.36	1	756426-58-1	
PFNS	5.9	2.3	0.52	0.52	1	68259-12-1	
PFUnDA	ND	2.4	0.63	0.63	1	2058-94-8	
NMeFOSAA	ND	2.4	0.51	0.51	1	2355-31-9	
NEtFOSAA	ND	2.4	0.65	0.65	1	2991-50-6	
PFDS	2.1 J	2.3	0.53	0.53	1	335-77-3	
PFDOA	ND	2.4	0.57	0.57	1	307-55-1	
MeFOSE	ND	2.4	0.39	0.39	1	24448-09-7	
10:2 FTS	ND	2.3	0.87	0.87	1	120226-60-0	
EtFOSE	ND	2.4	0.58	0.58	1	1691-99-2	
11-CI-PF3OUdS	ND	2.2	0.51	0.51	1	763051-92-9	
PFTTrDA	ND	2.4	0.73	0.73	1	72629-94-8	
PFDoS	ND	2.3	0.54	0.54	1	79780-39-5	
PFTDA	ND	2.4	0.56	0.56	1	376-06-7	
PFHXDA	ND	2.4	0.43	0.43	1	67905-19-5	
PFODA	ND	2.4	0.69	0.69	1	16517-11-6	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
1700 Elm Street, Suite 200
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444
www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 2 of 4

Client Sample ID	BLANK (TEST)	Extraction Date	12/27/2021 14:48
Lab Sample ID	10590162002	Total Amount Extracted	213mL
Lab File ID	A211229A_014	Ical ID	211228A03
Matrix	Non_Potable_Water	CCal File	A211229A_005
Collected	11/29/2021 12:25	Ending CCal File	A211229A_020
Received	12/07/2021 08:50	Blank File	A211229A_008

Injection Internal Standards

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers
13C2_PFHxA	24	25	107	50-150	
13C4_PFOA	24	26	111	50-150	
13C2_PFDA	24	28	120	50-150	
13C4_PFOS	22	20	88	50-150	

Extracted Internal Standards

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers
13C4_PFBA	24	26	111	50-150	
13C5_PFPeA	24	25	106	50-150	
13C3_PFBS	22	22	99	50-150	
13C2_4:2FTS	22	22	101	50-150	
13C5_PFHxA	24	23	98	50-150	
13C4_PFHpA	24	27	113	50-150	
13C3_PFHxS	22	41	185	50-150	RD
13C2_6:2FTS	22	25	110	50-150	
13C8_PFOA	24	25	106	50-150	
13C9_PFNA	24	25	106	50-150	
13C8_PFOS	22	28	124	50-150	D
13C2_8:2FTS	23	23	104	50-150	
13C6_PFDA	24	25	104	50-150	
d3-MeFOSAA	24	21	89	50-150	
13C8_PFOSA	24	20	84	50-150	
d5-EtFOSAA	24	17	71	50-150	
13C7_PFUdA	24	24	101	50-150	
13C2_PFDaA	24	23	96	50-150	
13C2_PFTeDA	24	15	65	50-150	
13C3_HFPO-DA	24	24	104	50-150	
13C2_PFHxDA	24	14	58	50-150	
d7-N-MeFOSE	24	16	66	10-150	
d9-N-EtFOSE	24	15	63	10-150	
d3-N-MeFOSA	24	10	43	10-150	
d5-N-EtFOSA	24	9.9	42	10-150	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
1700 Elm Street, Suite 200
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444
www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 3 of 4

Client Sample ID	BLANK (TEST)	Extraction Date	12/27/2021 14:48
Lab Sample ID	10590162002	Total Amount Extracted	213mL
Lab File ID	A211229A_014	Ical ID	211228A03
Matrix	Non_Potable_Water	CCal File	A211229A_005
Collected	11/29/2021 12:25	Ending CCal File	A211229A_020
Received	12/07/2021 08:50	Blank File	A211229A_008

Injection Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
13C2 PFHxA	N/A	N/A	4.92	4.93	1487	
13C4 PFOA	N/A	N/A	5.88	5.89	2352	
13C2 PFDA	N/A	N/A	6.75	6.77	2138	
13C4 PFOS	N/A	N/A	7.05	7.08	1129	

Extracted Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
13C4 PFBA	N/A	N/A	3.50	3.52	3188	
13C5 PFPeA	N/A	N/A	4.34	4.35	1535	
13C3 PFBS	N/A	N/A	5.10	5.11	1511	
13C2 4:2FTS	N/A	N/A	4.71	4.72	129	
13C5 PFHxA	N/A	N/A	4.92	4.93	281	
13C4 PFHpA	N/A	N/A	5.42	5.43	1992	
13C3 PFHxS	N/A	N/A	6.16	6.17	229	RD
13C2 6:2FTS	N/A	N/A	5.65	5.66	487	
13C8 PFOA	N/A	N/A	5.88	5.89	1815	
13C9 PFNA	N/A	N/A	6.32	6.33	2269	
13C8 PFOS	N/A	N/A	7.06	7.08	145	D
13C2 8:2FTS	N/A	N/A	6.51	6.52	662	
13C6 PFDA	N/A	N/A	6.75	6.77	1691	
d3-MeFOSAA	N/A	N/A	6.71	6.72	1156	
13C8 PFOSA	N/A	N/A	8.64	8.65	1606	
d5-EtFOSAA	N/A	N/A	6.92	6.93	720	
13C7 PFUdA	N/A	N/A	7.18	7.20	1843	
13C2 PFDoA	N/A	N/A	7.62	7.64	1637	
13C2 PFTeDA	N/A	N/A	8.46	8.48	1508	
13C3 HFPO-DA	N/A	N/A	5.13	5.14	1557	
13C2 PFHxDA	N/A	N/A	9.21	9.24	1944	
d7-N-MeFOSE	N/A	N/A	9.93	9.95	205	
d9-N-EtFOSE	N/A	N/A	10.54	10.56	452	
d3-N-MeFOSA	N/A	N/A	10.18	10.20	743	
d5-N-EtFOSA	N/A	N/A	10.85	10.87	746	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
1700 Elm Street, Suite 200
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444
www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 4 of 4

Client Sample ID BLANK (TEST)
Lab Sample ID 10590162002
Lab File ID A211229A_014
Matrix Non_Potable_Water
Collected 11/29/2021 12:25
Received 12/07/2021 08:50

Extraction Date 12/27/2021 14:48
Total Amount Extracted 213mL
Ical ID 211228A03
CCal File A211229A_005
Ending CCal File A211229A_020
Blank File A211229A_008

Native Analytes

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
PFBA	N/A	N/A	3.51	3.52	719	
PFPeA	N/A	N/A	4.34	4.35	823	
HFPO-DA	2.50	0.470	5.13	5.15	ND	
PFBS	0.340	0.340	5.10	5.12	1428	
PFHxA	0.067	0.0640	4.93	4.94	711	
4:2 FTS	0.000	0.560	0.00	4.72	ND	
PFPeS	0.370	0.310	5.66	5.68	831	
PFHpA	0.300	0.310	5.43	5.44	318	
DONA	0.000	0.480	0.00	5.61	ND	
PFHxS	0.310	0.230	6.16	6.15	1406	D
PFOA	0.400	0.370	5.88	5.90	362	
6:2 FTS	0.590	0.510	5.65	5.67	27	J
PFHpS	0.260	0.230	6.62	6.64	55	
PFNA	0.200	0.190	6.32	6.34	147	
PFOSAm	N/A	N/A	8.64	8.65	376	
PFOS	0.210	0.200	7.07	7.09	273	D
MeFOSA	0.000	0.930	0.00	10.22	ND	
PFDA	0.100	0.110	6.76	6.77	79	J
EtFOSAm	0.000	0.700	0.00	10.90	ND	
8:2 FTS	0.000	0.650	0.00	6.52	ND	
9-Cl-PF3ON	0.000	0.0210	7.38	7.40	ND	
PFNS	0.310	0.240	7.50	7.52	76	
PFUnDA	0.110	0.120	7.19	7.21	ND	
NMeFOSAA	0.000	0.530	6.67	6.73	ND	
NEtFOSAA	1.30	0.870	6.93	6.94	ND	
PFDS	0.300	0.250	7.92	7.95	104	J
PFDOA	0.110	0.130	7.62	7.64	ND	
MeFOSE	N/A	N/A	0.00	9.99	ND	
10:2 FTS	0.000	0.700	0.00	7.39	ND	
EtFOSE	0.000	0.000	0.00	10.62	ND	
11-Cl-PF3OUdS	0.000	0.0140	0.00	8.25	ND	
PFTTrDA	0.000	0.150	0.00	8.07	ND	
PFDoS	0.290	0.220	8.72	8.75	ND	
PFTDA	0.000	0.160	0.00	8.49	ND	
PFHXDA	0.130	0.130	9.22	9.24	ND	
PFODA	0.000	0.0990	0.00	10.20	ND	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
1700 Elm Street, Suite 200
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444
www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 1 of 4

Client Sample ID <B1 (POWDER)
Lab Sample ID 10590162003
Lab File ID A211214A_026
Matrix Soil
Collected 12/04/2021 10:30
Received 12/07/2021 08:50

Extraction Date 12/10/2021 08:52
Total Amount Extracted 5.04g
Ical ID 211210A03
CCal File A211214A_023
Ending CCal File A211214A_033
Blank File A211214A_013

Compound	Concentration (ug/Kg)	QL (ug/Kg)	RL (ug/Kg)	DL (ug/Kg)	Dil.	CAS No.	Qual.
PFBA	37 D	0.99	0.24	0.24	10	375-22-4	
PFPeA	34 D	0.99	0.26	0.26	10	2706-90-3	
HFPO-DA	ND	0.099	0.029	0.029	1	13252-13-6	
PFBS	79 D	0.88	0.22	0.22	10	375-73-5	
PFHxA	140 D	9.9	3.0	3.0	100	307-24-4	
4:2 FTS	ND	0.093	0.032	0.032	1	757124-72-4	
PFPeS	95 D	9.3	1.8	1.8	100	2706-91-4	
PFHpA	17 D	0.99	0.22	0.22	10	375-85-9	
DONA	ND	0.094	0.038	0.038	1	919005-14-4	
PFHxS	1200 D	18	4.4	4.4	200	355-46-4	
PFOA	48 D	0.99	0.22	0.22	10	335-67-1	
6:2 FTS	ND	0.094	0.032	0.032	1	27619-97-2	
PFHpS	57 D	0.94	0.25	0.25	10	375-92-8	
PFNA	0.18	0.099	0.028	0.028	1	375-95-1	
PFOSAm	22 D	0.99	0.23	0.23	10	754-91-6	
PFOS	950 D	18	5.5	5.5	200	1763-23-1	
MeFOSA	ND	0.099	0.025	0.025	1	31506-32-8	
PFDA	0.12	0.099	0.022	0.022	1	335-76-2	
EtFOSAm	ND	0.099	0.023	0.023	1	4151-50-2	
8:2 FTS	ND	0.095	0.026	0.026	1	39108-34-4	
9-CI-PF3ON	ND	0.092	0.014	0.014	1	756426-58-1	
PFNS	1.8	0.095	0.018	0.018	1	68259-12-1	
PFUnDA	ND	0.099	0.028	0.028	1	2058-94-8	
NMeFOSAA	ND	0.099	0.023	0.023	1	2355-31-9	
NEtFOSAA	ND	0.099	0.025	0.025	1	2991-50-6	
PFDS	0.84	0.096	0.025	0.025	1	335-77-3	
PFDOA	0.054 J	0.099	0.026	0.026	1	307-55-1	
MeFOSE	0.13	0.099	0.024	0.024	1	24448-09-7	
10:2 FTS	ND	0.096	0.037	0.037	1	120226-60-0	
EtFOSE	0.14	0.099	0.025	0.025	1	1691-99-2	
11-CI-PF3OUdS	ND	0.093	0.016	0.016	1	763051-92-9	
PFTTrDA	ND	0.099	0.021	0.021	1	72629-94-8	
PFDoS	0.60	0.096	0.030	0.030	1	79780-39-5	
PFTDA	ND	0.099	0.032	0.032	1	376-06-7	
PFHXDA	ND	0.099	0.035	0.035	1	67905-19-5	
PFODA	ND	0.099	0.025	0.025	1	16517-11-6	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
1700 Elm Street, Suite 200
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444
www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 2 of 4

Client Sample ID <B1 (POWDER)
Lab Sample ID 10590162003
Lab File ID A211214A_026
Matrix Soil
Collected 12/04/2021 10:30
Received 12/07/2021 08:50

Extraction Date 12/10/2021 08:52
Total Amount Extracted 5.04g
Ical ID 211210A03
CCal File A211214A_023
Ending CCal File A211214A_033
Blank File A211214A_013

Injection Internal Standards

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers
13C2 PFHxA	0.99	1.1	106	50-150	
13C4 PFOA	0.99	1.1	106	50-150	
13C2 PFDA	0.99	1.0	105	50-150	
13C4 PFOS	0.95	0.66	70	50-150	

Extracted Internal Standards

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers
13C4 PFBA	0.99	0.28	28	50-150	RD
13C5 PFPeA	0.99	0.25	26	50-150	RD
13C3 PFBS	0.92	0.30	32	50-150	RD
13C2 4:2FTS	0.93	0.13	14	50-150	R
13C5 PFHxA	0.99	0.29	29	50-150	RD
13C4 PFHpA	0.99	0.32	32	50-150	RD
13C3 PFHxS	0.94	0.29	31	50-150	RD
13C2 6:2FTS	0.94	0.15	16	50-150	R
13C8 PFOA	0.99	0.32	32	50-150	RD
13C9 PFNA	0.99	0.30	30	50-150	R
13C8 PFOS	0.95	1.1	111	50-150	D
13C2 8:2FTS	0.95	0.15	16	50-150	R
13C6 PFDA	0.99	0.28	28	50-150	R
d3-MeFOSAA	0.99	0.092	9	50-150	R
13C8 PFOSA	0.99	0.22	22	50-150	RD
d5-EtFOSAA	0.99	0.087	9	50-150	R
13C7 PFUdA	0.99	0.30	30	50-150	R
13C2 PFDoA	0.99	0.28	28	50-150	R
13C2 PFTeDA	0.99	0.27	27	50-150	R
13C3 HFPO-DA	0.99	0.41	42	50-150	R
13C2 PFHxDA	0.99	0.29	30	50-150	R
d7-N-MeFOSE	0.99	0.74	75	10-150	
d9-N-EtFOSE	0.99	0.73	73	10-150	
d3-N-MeFOSA	0.99	0.39	39	10-150	
d5-N-EtFOSA	0.99	0.53	53	10-150	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
1700 Elm Street, Suite 200
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444
www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 3 of 4

Client Sample ID <B1 (POWDER)
Lab Sample ID 10590162003
Lab File ID A211214A_026
Matrix Soil
Collected 12/04/2021 10:30
Received 12/07/2021 08:50

Extraction Date 12/10/2021 08:52
Total Amount Extracted 5.04g
Ical ID 211210A03
CCal File A211214A_023
Ending CCal File A211214A_033
Blank File A211214A_013

Injection Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
13C2 PFHxA	N/A	N/A	5.19	5.16	1284	
13C4 PFOA	N/A	N/A	6.19	6.16	1605	
13C2 PFDA	N/A	N/A	7.03	7.00	1315	
13C4 PFOS	N/A	N/A	7.32	7.30	233	

Extracted Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
13C4 PFBA	N/A	N/A	3.71	3.68	801	RD
13C5 PFPeA	N/A	N/A	4.60	4.57	469	RD
13C3 PFBS	N/A	N/A	5.37	5.33	1118	RD
13C2 4:2FTS	N/A	N/A	4.97	4.94	81	R
13C5 PFHxA	N/A	N/A	5.19	5.16	73	RD
13C4 PFHpA	N/A	N/A	5.71	5.68	1093	RD
13C3 PFHxS	N/A	N/A	6.16	6.17	17	RD
13C2 6:2FTS	N/A	N/A	5.95	5.92	43	R
13C8 PFOA	N/A	N/A	6.20	6.16	3318	RD
13C9 PFNA	N/A	N/A	6.61	6.59	1090	R
13C8 PFOS	N/A	N/A	6.97	6.97	53	D
13C2 8:2FTS	N/A	N/A	6.80	6.77	115	R
13C6 PFDA	N/A	N/A	7.03	7.01	917	R
d3-MeFOSAA	N/A	N/A	6.98	6.96	155	R
13C8 PFOSA	N/A	N/A	8.74	8.75	117	RD
d5-EtFOSAA	N/A	N/A	7.17	7.15	90	R
13C7 PFUdA	N/A	N/A	7.45	7.43	675	R
13C2 PFDoA	N/A	N/A	7.87	7.85	918	R
13C2 PFTeDA	N/A	N/A	8.69	8.67	1123	R
13C3 HFPO-DA	N/A	N/A	5.40	5.37	943	R
13C2 PFHxDA	N/A	N/A	9.44	9.43	1600	R
d7-N-MeFOSE	N/A	N/A	10.14	10.11	186	
d9-N-EtFOSE	N/A	N/A	10.75	10.71	321	
d3-N-MeFOSA	N/A	N/A	10.37	10.34	542	
d5-N-EtFOSA	N/A	N/A	11.04	11.00	940	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
1700 Elm Street, Suite 200
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444
www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 4 of 4

Client Sample ID <B1 (POWDER)
Lab Sample ID 10590162003
Lab File ID A211214A_026
Matrix Soil
Collected 12/04/2021 10:30
Received 12/07/2021 08:50

Extraction Date 12/10/2021 08:52
Total Amount Extracted 5.04g
Ical ID 211210A03
CCal File A211214A_023
Ending CCal File A211214A_033
Blank File A211214A_013

Native Analytes

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
PFBA	N/A	N/A	3.71	3.71	844	D
PFPeA	N/A	N/A	4.61	4.57	734	D
HFPO-DA	0.000	0.460	0.00	5.38	ND	
PFBS	0.360	0.330	5.37	5.34	3564	D
PFHxA	0.066	0.0680	5.20	5.17	343	D
4:2 FTS	0.000	0.530	0.00	4.95	ND	
PFPeS	0.340	0.290	5.95	5.91	585	D
PFHpA	0.290	0.270	5.72	5.72	327	D
DONA	0.000	0.500	0.00	5.85	ND	
PFHxS	0.330	0.260	6.17	6.17	1328	D
PFOA	0.360	0.360	6.20	6.07	299	D
6:2 FTS	0.000	0.540	0.00	5.93	ND	
PFHpS	0.270	0.250	6.89	6.86	473	D
PFNA	0.200	0.190	6.62	6.59	60	
PFOSAm	N/A	N/A	8.75	8.70	530	D
PFOS	0.240	0.220	7.08	7.09	227	D
MeFOSA	0.740	0.860	10.40	10.36	ND	
PFDA	0.085	0.0840	7.03	7.02	38	
EtFOSAm	0.000	0.680	11.06	11.03	ND	
8:2 FTS	0.000	0.700	0.00	6.78	ND	
9-Cl-PF3ON	0.000	0.0200	0.00	7.62	ND	
PFNS	0.240	0.240	7.75	7.74	48	
PFUnDA	0.000	0.100	0.00	7.44	ND	
NMeFOSAA	0.000	0.590	0.00	6.96	ND	
NEtFOSAA	0.000	0.720	0.00	7.15	ND	
PFDS	0.280	0.250	8.16	8.15	60	
PFDOA	0.120	0.140	7.87	7.86	27	J
MeFOSE	N/A	N/A	10.18	10.15	161	
10:2 FTS	0.000	0.640	0.00	7.61	ND	
EtFOSE	0.000	0.000	10.81	10.77	129	
11-Cl-PF3OUdS	0.000	0.0130	0.00	8.44	ND	
PFTTrDA	0.000	0.150	0.00	8.27	ND	
PFDOS	0.260	0.230	8.94	8.93	108	
PFTDA	0.000	0.140	0.00	8.68	ND	
PFHXDA	0.120	0.120	9.44	9.43	ND	
PFODA	0.000	0.0950	0.00	10.39	ND	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
1700 Elm Street, Suite 200
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444
www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 1 of 4

Client Sample ID <B2 (POWDER)
Lab Sample ID 10590162004
Lab File ID A211214A_027
Matrix Soil
Collected 12/04/2021 10:30
Received 12/07/2021 08:50

Extraction Date 12/10/2021 08:52
Total Amount Extracted 5.09g
Ical ID 211210A03
CCal File A211214A_023
Ending CCal File A211214A_033
Blank File A211214A_013

Compound	Concentration (ug/Kg)	QL (ug/Kg)	RL (ug/Kg)	DL (ug/Kg)	Dil.	CAS No.	Qual.
PFBA	4.8	0.098	0.023	0.023	1	375-22-4	
PFPeA	4.0	0.098	0.026	0.026	1	2706-90-3	
HFPO-DA	ND	0.098	0.029	0.029	1	13252-13-6	
PFBS	12 D	0.87	0.22	0.22	10	375-73-5	
PFHxA	24 D	0.98	0.29	0.29	10	307-24-4	
4:2 FTS	ND	0.092	0.031	0.031	1	757124-72-4	
PFPeS	15 D	0.92	0.18	0.18	10	2706-91-4	
PFHpA	3.0	0.098	0.022	0.022	1	375-85-9	
DONA	ND	0.093	0.038	0.038	1	919005-14-4	
PFHxS	160 D	8.9	2.2	2.2	100	355-46-4	
PFOA	9.0	0.098	0.022	0.022	1	335-67-1	
6:2 FTS	0.24	0.093	0.031	0.031	1	27619-97-2	
PFHpS	9.2	0.093	0.025	0.025	1	375-92-8	
PFNA	0.057 J	0.098	0.028	0.028	1	375-95-1	
PFOSAm	8.4	0.098	0.023	0.023	1	754-91-6	
PFOS	560 D	9.1	2.7	2.7	100	1763-23-1	
MeFOSA	ND	0.098	0.024	0.024	1	31506-32-8	
PFDA	ND	0.098	0.021	0.021	1	335-76-2	
EtFOSAm	ND	0.098	0.023	0.023	1	4151-50-2	
8:2 FTS	0.15	0.094	0.025	0.025	1	39108-34-4	
9-Cl-PF3ON	ND	0.092	0.014	0.014	1	756426-58-1	
PFNS	0.76	0.094	0.018	0.018	1	68259-12-1	
PFUnDA	ND	0.098	0.028	0.028	1	2058-94-8	
NMeFOSAA	ND	0.098	0.023	0.023	1	2355-31-9	
NEtFOSAA	ND	0.098	0.024	0.024	1	2991-50-6	
PFDS	0.34	0.095	0.025	0.025	1	335-77-3	
PFDOA	ND	0.098	0.026	0.026	1	307-55-1	
MeFOSE	0.045 J	0.098	0.023	0.023	1	24448-09-7	
10:2 FTS	ND	0.095	0.036	0.036	1	120226-60-0	
EtFOSE	0.058 J	0.098	0.024	0.024	1	1691-99-2	
11-Cl-PF3OUdS	ND	0.093	0.016	0.016	1	763051-92-9	
PFTrDA	ND	0.098	0.021	0.021	1	72629-94-8	
PFDoS	0.29	0.095	0.029	0.029	1	79780-39-5	
PFTDA	ND	0.098	0.032	0.032	1	376-06-7	
PFHXDA	ND	0.098	0.035	0.035	1	67905-19-5	
PFODA	ND	0.098	0.025	0.025	1	16517-11-6	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
1700 Elm Street, Suite 200
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444
www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 2 of 4

Client Sample ID	<B2 (POWDER)	Extraction Date	12/10/2021 08:52
Lab Sample ID	10590162004	Total Amount Extracted	5.09g
Lab File ID	A211214A_027	Ical ID	211210A03
Matrix	Soil	CCal File	A211214A_023
Collected	12/04/2021 10:30	Ending CCal File	A211214A_033
Received	12/07/2021 08:50	Blank File	A211214A_013

Injection Internal Standards

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers
13C2 PFHxA	0.98	1.2	118	50-150	
13C4 PFOA	0.98	1.1	114	50-150	
13C2 PFDA	0.98	1.0	106	50-150	
13C4 PFOS	0.94	0.88	93	50-150	

Extracted Internal Standards

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers
13C4 PFBA	0.98	0.44	45	50-150	R
13C5 PFPeA	0.98	0.45	46	50-150	R
13C3 PFBS	0.91	0.37	40	50-150	RD
13C2 4:2FTS	0.92	0.30	33	50-150	R
13C5 PFHxA	0.98	0.39	39	50-150	RD
13C4 PFHpA	0.98	0.48	48	50-150	R
13C3 PFHxS	0.93	0.50	54	50-150	D
13C2 6:2FTS	0.93	0.29	31	50-150	R
13C8 PFOA	0.98	0.48	49	50-150	R
13C9 PFNA	0.98	0.44	45	50-150	R
13C8 PFOS	0.94	0.42	45	50-150	RD
13C2 8:2FTS	0.94	0.29	31	50-150	R
13C6 PFDA	0.98	0.45	46	50-150	R
d3-MeFOSAA	0.98	0.19	20	50-150	R
13C8 PFOSA	0.98	0.31	31	50-150	R
d5-EtFOSAA	0.98	0.19	19	50-150	R
13C7 PFUdA	0.98	0.43	43	50-150	R
13C2 PFDoA	0.98	0.43	44	50-150	R
13C2 PFTeDA	0.98	0.43	44	50-150	R
13C3 HFPO-DA	0.98	0.58	59	50-150	
13C2 PFHxDA	0.98	0.43	44	50-150	R
d7-N-MeFOSE	0.98	0.71	72	10-150	
d9-N-EtFOSE	0.98	0.66	67	10-150	
d3-N-MeFOSA	0.98	0.48	49	10-150	
d5-N-EtFOSA	0.98	0.58	59	10-150	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 3 of 4

Client Sample ID <B2 (POWDER)
 Lab Sample ID 10590162004
 Lab File ID A211214A_027
 Matrix Soil
 Collected 12/04/2021 10:30
 Received 12/07/2021 08:50

Extraction Date 12/10/2021 08:52
 Total Amount Extracted 5.09g
 Ical ID 211210A03
 CCal File A211214A_023
 Ending CCal File A211214A_033
 Blank File A211214A_013

Injection Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
13C2 PFHxA	N/A	N/A	5.18	5.16	1869	
13C4 PFOA	N/A	N/A	6.19	6.16	1517	
13C2 PFDA	N/A	N/A	7.03	7.00	1136	
13C4 PFOS	N/A	N/A	7.31	7.30	788	

Extracted Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
13C4 PFBA	N/A	N/A	3.70	3.69	2174	R
13C5 PFPeA	N/A	N/A	4.59	4.57	1842	R
13C3 PFBS	N/A	N/A	5.36	5.33	912	RD
13C2 4:2FTS	N/A	N/A	4.97	4.94	199	R
13C5 PFHxA	N/A	N/A	5.19	5.16	716	RD
13C4 PFHpA	N/A	N/A	5.70	5.68	1347	R
13C3 PFHxS	N/A	N/A	6.46	6.42	318	D
13C2 6:2FTS	N/A	N/A	5.95	5.92	131	R
13C8 PFOA	N/A	N/A	6.19	6.16	1775	R
13C9 PFNA	N/A	N/A	6.61	6.59	1390	R
13C8 PFOS	N/A	N/A	7.33	7.29	88	RD
13C2 8:2FTS	N/A	N/A	6.80	6.77	172	R
13C6 PFDA	N/A	N/A	7.03	7.01	1219	R
d3-MeFOSAA	N/A	N/A	6.98	6.96	296	R
13C8 PFOSA	N/A	N/A	8.73	8.70	309	R
d5-EtFOSAA	N/A	N/A	7.17	7.15	193	R
13C7 PFUdA	N/A	N/A	7.45	7.43	1019	R
13C2 PFDaA	N/A	N/A	7.87	7.85	987	R
13C2 PFTeDA	N/A	N/A	8.69	8.67	1191	R
13C3 HFPO-DA	N/A	N/A	5.40	5.37	1128	
13C2 PFHxDA	N/A	N/A	9.43	9.43	1876	R
d7-N-MeFOSE	N/A	N/A	10.14	10.11	176	
d9-N-EtFOSE	N/A	N/A	10.75	10.71	291	
d3-N-MeFOSA	N/A	N/A	10.37	10.34	626	
d5-N-EtFOSA	N/A	N/A	11.04	11.00	1024	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
1700 Elm Street, Suite 200
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444
www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 4 of 4

Client Sample ID <B2 (POWDER)
Lab Sample ID 10590162004
Lab File ID A211214A_027
Matrix Soil
Collected 12/04/2021 10:30
Received 12/07/2021 08:50

Extraction Date 12/10/2021 08:52
Total Amount Extracted 5.09g
Ical ID 211210A03
CCal File A211214A_023
Ending CCal File A211214A_033
Blank File A211214A_013

Native Analytes

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
PFBA	N/A	N/A	3.70	3.69	1135	
PFPeA	N/A	N/A	4.60	4.58	855	
HFPO-DA	0.000	0.460	0.00	5.38	ND	
PFBS	0.340	0.330	5.37	5.34	1527	D
PFHxA	0.055	0.0600	5.20	5.17	424	D
4:2 FTS	0.000	0.530	0.00	4.95	ND	
PFPeS	0.320	0.310	5.95	5.95	764	D
PFHpA	0.300	0.290	5.71	5.68	305	
DONA	0.000	0.500	0.00	5.85	ND	
PFHxS	0.320	0.310	6.46	6.43	368	D
PFOA	0.390	0.380	6.20	6.27	351	
6:2 FTS	0.690	0.540	5.96	5.93	26	
PFHpS	0.280	0.240	6.89	6.87	56	
PFNA	0.230	0.190	6.61	6.59	41	J
PFOSAm	N/A	N/A	8.74	8.71	346	
PFOS	0.230	0.260	7.33	7.15	313	D
MeFOSA	0.530	0.860	10.40	10.36	ND	
PFDA	0.000	0.0840	0.00	7.02	ND	
EtFOSAm	0.000	0.680	0.00	11.03	ND	
8:2 FTS	0.400	0.700	6.80	6.78	43	
9-Cl-PF3ON	0.000	0.0200	0.00	7.62	ND	
PFNS	0.250	0.240	7.74	7.74	44	
PFUnDA	0.000	0.100	0.00	7.44	ND	
NMeFOSAA	0.000	0.590	0.00	6.96	ND	
NEtFOSAA	0.000	0.720	0.00	7.15	ND	
PFDS	0.310	0.250	8.16	8.15	46	
PFDOA	0.000	0.140	0.00	7.86	ND	
MeFOSE	N/A	N/A	10.18	10.15	90	J
10:2 FTS	0.000	0.640	0.00	7.61	ND	
EtFOSE	0.000	0.000	10.81	10.77	84	J
11-Cl-PF3OUdS	0.000	0.0130	8.46	8.44	ND	
PFTTrDA	0.000	0.150	0.00	8.27	ND	
PFDoS	0.250	0.230	8.94	8.93	99	
PFTDA	0.000	0.140	0.00	8.68	ND	
PFHXDA	0.000	0.120	9.44	9.43	ND	
PFODA	0.000	0.0950	0.00	10.39	ND	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
1700 Elm Street, Suite 200
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444
www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 1 of 4

Client Sample ID <B3 (POWDER)
Lab Sample ID 10590162005
Lab File ID A211214A_028
Matrix Soil
Collected 12/04/2021 10:30
Received 12/07/2021 08:50

Extraction Date 12/10/2021 08:52
Total Amount Extracted 5.11g
Ical ID 211210A03
CCal File A211214A_023
Ending CCal File A211214A_033
Blank File A211214A_013

Compound	Concentration (ug/Kg)	QL (ug/Kg)	RL (ug/Kg)	DL (ug/Kg)	Dil.	CAS No.	Qual.
PFBA	2.1	0.098	0.023	0.023	1	375-22-4	
PFPeA	1.7	0.098	0.026	0.026	1	2706-90-3	
HFPO-DA	ND	0.098	0.029	0.029	1	13252-13-6	
PFBS	4.0	0.087	0.022	0.022	1	375-73-5	
PFHxA	8.9	0.098	0.029	0.029	1	307-24-4	
4:2 FTS	ND	0.092	0.031	0.031	1	757124-72-4	
PFPeS	5.2	0.092	0.018	0.018	1	2706-91-4	
PFHpA	1.2	0.098	0.022	0.022	1	375-85-9	
DONA	ND	0.092	0.038	0.038	1	919005-14-4	
PFHxS	69 D	4.5	1.1	1.1	50	355-46-4	
PFOA	4.5	0.098	0.022	0.022	1	335-67-1	
6:2 FTS	ND	0.093	0.031	0.031	1	27619-97-2	
PFHpS	5.4	0.093	0.024	0.024	1	375-92-8	
PFNA	0.031 J	0.098	0.028	0.028	1	375-95-1	
PFOSAm	3.3	0.098	0.023	0.023	1	754-91-6	
PFOS	260 D	4.5	1.4	1.4	50	1763-23-1	
MeFOSA	ND	0.098	0.024	0.024	1	31506-32-8	
PFDA	ND	0.098	0.021	0.021	1	335-76-2	
EtFOSAm	ND	0.098	0.023	0.023	1	4151-50-2	
8:2 FTS	ND	0.094	0.025	0.025	1	39108-34-4	
9-Cl-PF3ON	ND	0.091	0.014	0.014	1	756426-58-1	
PFNS	0.40	0.094	0.018	0.018	1	68259-12-1	
PFUnDA	ND	0.098	0.028	0.028	1	2058-94-8	
NMeFOSAA	ND	0.098	0.023	0.023	1	2355-31-9	
NEtFOSAA	ND	0.098	0.024	0.024	1	2991-50-6	
PFDS	0.20	0.094	0.025	0.025	1	335-77-3	
PFDOA	ND	0.098	0.026	0.026	1	307-55-1	
MeFOSE	ND	0.098	0.023	0.023	1	24448-09-7	
10:2 FTS	ND	0.094	0.036	0.036	1	120226-60-0	
EtFOSE	ND	0.098	0.024	0.024	1	1691-99-2	
11-Cl-PF3OUdS	ND	0.092	0.016	0.016	1	763051-92-9	
PFTrDA	ND	0.098	0.021	0.021	1	72629-94-8	
PFDoS	0.14	0.095	0.029	0.029	1	79780-39-5	
PFTDA	ND	0.098	0.031	0.031	1	376-06-7	
PFHXDA	ND	0.098	0.035	0.035	1	67905-19-5	
PFODA	ND	0.098	0.025	0.025	1	16517-11-6	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
1700 Elm Street, Suite 200
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444
www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 2 of 4

Client Sample ID <B3 (POWDER)
Lab Sample ID 10590162005
Lab File ID A211214A_028
Matrix Soil
Collected 12/04/2021 10:30
Received 12/07/2021 08:50

Extraction Date 12/10/2021 08:52
Total Amount Extracted 5.11g
Ical ID 211210A03
CCal File A211214A_023
Ending CCal File A211214A_033
Blank File A211214A_013

Injection Internal Standards

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers
13C2 PFHxA	0.98	1.1	109	50-150	
13C4 PFOA	0.98	1.0	106	50-150	
13C2 PFDA	0.98	0.99	101	50-150	
13C4 PFOS	0.94	0.93	99	50-150	

Extracted Internal Standards

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers
13C4 PFBA	0.98	0.41	42	50-150	R
13C5 PFPeA	0.98	0.43	44	50-150	R
13C3 PFBS	0.91	0.40	45	50-150	R
13C2 4:2FTS	0.92	0.25	27	50-150	R
13C5 PFHxA	0.98	0.43	44	50-150	R
13C4 PFHpA	0.98	0.44	45	50-150	R
13C3 PFHxS	0.93	0.53	57	50-150	D
13C2 6:2FTS	0.93	0.30	32	50-150	R
13C8 PFOA	0.98	0.42	43	50-150	R
13C9 PFNA	0.98	0.43	44	50-150	R
13C8 PFOS	0.94	0.36	39	50-150	RD
13C2 8:2FTS	0.94	0.20	22	50-150	R
13C6 PFDA	0.98	0.43	44	50-150	R
d3-MeFOSAA	0.98	0.19	20	50-150	R
13C8 PFOSA	0.98	0.31	32	50-150	R
d5-EtFOSAA	0.98	0.20	21	50-150	R
13C7 PFUdA	0.98	0.45	46	50-150	R
13C2 PFDoA	0.98	0.41	42	50-150	R
13C2 PFTeDA	0.98	0.45	46	50-150	R
13C3 HFPO-DA	0.98	0.52	53	50-150	
13C2 PFHxDA	0.98	0.42	43	50-150	R
d7-N-MeFOSE	0.98	0.45	46	10-150	
d9-N-EtFOSE	0.98	0.38	38	10-150	
d3-N-MeFOSA	0.98	0.49	50	10-150	
d5-N-EtFOSA	0.98	0.61	62	10-150	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
1700 Elm Street, Suite 200
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444
www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 3 of 4

Client Sample ID <B3 (POWDER)
Lab Sample ID 10590162005
Lab File ID A211214A_028
Matrix Soil
Collected 12/04/2021 10:30
Received 12/07/2021 08:50

Extraction Date 12/10/2021 08:52
Total Amount Extracted 5.11g
Ical ID 211210A03
CCal File A211214A_023
Ending CCal File A211214A_033
Blank File A211214A_013

Injection Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
13C2 PFHxA	N/A	N/A	5.19	5.16	2165	
13C4 PFOA	N/A	N/A	6.19	6.16	1594	
13C2 PFDA	N/A	N/A	7.03	7.00	1484	
13C4 PFOS	N/A	N/A	7.31	7.30	515	

Extracted Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
13C4 PFBA	N/A	N/A	3.70	3.69	1925	R
13C5 PFPeA	N/A	N/A	4.59	4.57	2094	R
13C3 PFBS	N/A	N/A	5.36	5.33	1193	R
13C2 4:2FTS	N/A	N/A	4.97	4.94	138	R
13C5 PFHxA	N/A	N/A	5.19	5.16	233	R
13C4 PFHpA	N/A	N/A	5.70	5.68	788	R
13C3 PFHxS	N/A	N/A	6.46	6.42	196	D
13C2 6:2FTS	N/A	N/A	5.95	5.92	155	R
13C8 PFOA	N/A	N/A	6.19	6.16	1754	R
13C9 PFNA	N/A	N/A	6.61	6.59	1178	R
13C8 PFOS	N/A	N/A	7.33	7.29	548	RD
13C2 8:2FTS	N/A	N/A	6.79	6.77	241	R
13C6 PFDA	N/A	N/A	7.03	7.01	1406	R
d3-MeFOSAA	N/A	N/A	6.98	6.96	455	R
13C8 PFOSA	N/A	N/A	8.73	8.70	486	R
d5-EtFOSAA	N/A	N/A	7.18	7.15	280	R
13C7 PFUdA	N/A	N/A	7.45	7.43	770	R
13C2 PFDoA	N/A	N/A	7.87	7.85	1241	R
13C2 PFTeDA	N/A	N/A	8.69	8.67	1750	R
13C3 HFPO-DA	N/A	N/A	5.40	5.37	1541	
13C2 PFHxDA	N/A	N/A	9.43	9.43	1471	R
d7-N-MeFOSE	N/A	N/A	10.14	10.11	190	
d9-N-EtFOSE	N/A	N/A	10.74	10.71	173	
d3-N-MeFOSA	N/A	N/A	10.37	10.34	553	
d5-N-EtFOSA	N/A	N/A	11.04	11.00	1134	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
1700 Elm Street, Suite 200
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444
www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 4 of 4

Client Sample ID <B3 (POWDER)
Lab Sample ID 10590162005
Lab File ID A211214A_028
Matrix Soil
Collected 12/04/2021 10:30
Received 12/07/2021 08:50

Extraction Date 12/10/2021 08:52
Total Amount Extracted 5.11g
Ical ID 211210A03
CCal File A211214A_023
Ending CCal File A211214A_033
Blank File A211214A_013

Native Analytes

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
PFBA	N/A	N/A	3.70	3.69	561	
PFPeA	N/A	N/A	4.60	4.58	559	
HFPO-DA	0.000	0.460	0.00	5.38	ND	
PFBS	0.340	0.340	5.36	5.34	582	
PFHxA	0.062	0.0560	5.19	5.17	638	
4:2 FTS	0.000	0.530	0.00	4.95	ND	
PFPeS	0.340	0.310	5.94	5.92	352	
PFHpA	0.280	0.290	5.71	5.68	285	
DONA	0.000	0.500	0.00	5.85	ND	
PFHxS	0.280	0.310	6.46	6.43	323	D
PFOA	0.380	0.380	6.20	6.27	298	
6:2 FTS	0.000	0.540	0.00	5.93	ND	
PFHpS	0.290	0.240	6.89	6.87	53	
PFNA	0.230	0.190	6.61	6.59	26	J
PFOSAm	N/A	N/A	8.74	8.71	298	
PFOS	0.230	0.260	7.34	7.15	256	D
MeFOSA	0.000	0.860	0.00	10.36	ND	
PFDA	0.000	0.0840	0.00	7.02	ND	
EtFOSAm	0.000	0.680	0.00	11.03	ND	
8:2 FTS	0.000	0.700	0.00	6.78	ND	
9-Cl-PF3ON	0.000	0.0200	0.00	7.62	ND	
PFNS	0.270	0.240	7.74	7.74	42	
PFUnDA	0.000	0.100	0.00	7.44	ND	
NMeFOSAA	0.000	0.590	0.00	6.96	ND	
NEtFOSAA	0.000	0.720	0.00	7.15	ND	
PFDS	0.300	0.250	8.16	8.15	42	
PFDOA	0.000	0.140	0.00	7.86	ND	
MeFOSE	N/A	N/A	0.00	10.15	ND	
10:2 FTS	0.000	0.640	0.00	7.61	ND	
EtFOSE	0.000	0.000	0.00	10.77	ND	
11-Cl-PF3OUdS	0.000	0.0130	0.00	8.44	ND	
PFTDA	0.000	0.150	0.00	8.27	ND	
PFDoS	0.250	0.230	8.93	8.93	88	
PFTDA	0.000	0.140	0.00	8.68	ND	
PFHXDA	0.170	0.120	9.44	9.43	ND	
PFODA	0.000	0.0950	0.00	10.39	ND	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
1700 Elm Street, Suite 200
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444
www.pacelabs.com

Sample Analysis Summary PFAS by Isotope Dilution

Page 1 of 4

Client Sample ID PR1 (3 hr)
Lab Sample ID 10590162006
Lab File ID A211229A_015
Matrix Non_Potable_Water
Collected 12/03/2021 13:15
Received 12/07/2021 08:50

Extraction Date 12/27/2021 14:48
Total Amount Extracted 1.00uL
Ical ID 211228A03
CCal File A211229A_005
Ending CCal File A211229A_020
Blank File A211229A_008

Compound	Concentration (ug/L)	QL (ug/L)	RL (ug/L)	DL (ug/L)	Dil.	CAS No.	Qual.
PFBA	38 J	500	0.11	0.11	1	375-22-4	
PFPeA	22 J	500	0.11	0.11	1	2706-90-3	
HFPO-DA	ND	500	0.13	0.13	1	13252-13-6	
PFBS	39 J	440	0.12	0.12	1	375-73-5	
PFHxA	ND	500	0.11	0.11	1	307-24-4	
4:2 FTS	ND	470	0.14	0.14	1	757124-72-4	
PFPeS	30 J	470	0.12	0.12	1	2706-91-4	
PFHpA	12 J	500	0.14	0.14	1	375-85-9	
DONA	ND	470	0.13	0.13	1	919005-14-4	
PFHxS	420 J	460	0.13	0.13	1	355-46-4	
PFOA	ND	500	0.15	0.15	1	335-67-1	
6:2 FTS	110 J	480	0.16	0.16	1	27619-97-2	
PFHpS	48 J	480	0.10	0.10	1	375-92-8	
PFNA	ND	500	0.18	0.18	1	375-95-1	
PFOSAm	38 J	500	0.20	0.20	1	754-91-6	
PFOS	1900	460	0.14	0.14	1	1763-23-1	
MeFOSA	ND	500	0.13	0.13	1	31506-32-8	
PFDA	ND	500	0.14	0.14	1	335-76-2	
EtFOSAm	ND	500	0.15	0.15	1	4151-50-2	
8:2 FTS	ND	480	0.16	0.16	1	39108-34-4	
9-CI-PF3ON	ND	470	0.076	0.076	1	756426-58-1	
PFNS	ND	480	0.11	0.11	1	68259-12-1	
PFUnDA	ND	500	0.14	0.14	1	2058-94-8	
NMeFOSAA	ND	500	0.11	0.11	1	2355-31-9	
NEtFOSAA	ND	500	0.14	0.14	1	2991-50-6	
PFDS	ND	480	0.11	0.11	1	335-77-3	
PFDOA	ND	500	0.12	0.12	1	307-55-1	
MeFOSE	ND	500	0.082	0.082	1	24448-09-7	
10:2 FTS	ND	480	0.18	0.18	1	120226-60-0	
EtFOSE	ND	500	0.12	0.12	1	1691-99-2	
11-CI-PF3OUdS	ND	470	0.11	0.11	1	763051-92-9	
PFTTrDA	ND	500	0.16	0.16	1	72629-94-8	
PFDoS	ND	480	0.12	0.12	1	79780-39-5	
PFTDA	ND	500	0.12	0.12	1	376-06-7	
PFHXDA	40 J	500	0.091	0.091	1	67905-19-5	
PFODA	ND	500	0.15	0.15	1	16517-11-6	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 2 of 4

Client Sample ID	PR1 (3 hr)	Extraction Date	12/27/2021 14:48
Lab Sample ID	10590162006	Total Amount Extracted	1.00uL
Lab File ID	A211229A_015	Ical ID	211228A03
Matrix	Non_Potable_Water	CCal File	A211229A_005
Collected	12/03/2021 13:15	Ending CCal File	A211229A_020
Received	12/07/2021 08:50	Blank File	A211229A_008

Injection Internal Standards

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers
13C2_PFHxA	5000	5600	112	50-150	
13C4_PFOA	5000	5300	106	50-150	
13C2_PFDA	5000	5700	114	50-150	
13C4_PFOS	4800	5300	112	50-150	

Extracted Internal Standards

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers
13C4_PFBA	5000	5300	106	50-150	
13C5_PFPeA	5000	5200	105	50-150	
13C3_PFBs	4600	4500	96	50-150	
13C2_4:2FTS	4700	4600	98	50-150	
13C5_PFHxA	5000	5300	106	50-150	
13C4_PFHpA	5000	5200	103	50-150	
13C3_PFHxS	4700	5100	108	50-150	
13C2_6:2FTS	4700	5500	116	50-150	
13C8_PFOA	5000	5100	101	50-150	
13C9_PFNA	5000	5300	105	50-150	
13C8_PFOS	4800	4700	99	50-150	
13C2_8:2FTS	4800	4700	98	50-150	
13C6_PFDA	5000	4900	98	50-150	
d3-MeFOSAA	5000	3900	77	50-150	
13C8_PFOA	5000	3900	78	50-150	
d5-EtFOSAA	5000	3500	70	50-150	
13C7_PFUdA	5000	4100	82	50-150	
13C2_PFDaA	5000	3700	73	50-150	
13C2_PFTeDA	5000	3700	74	50-150	
13C3_HFPO-DA	5000	5200	105	50-150	
13C2_PFHxDA	5000	4100	81	50-150	
d7-N-MeFOSE	5000	3300	66	10-150	
d9-N-EtFOSE	5000	3300	66	10-150	
d3-N-MeFOSA	5000	2200	45	10-150	
d5-N-EtFOSA	5000	2300	45	10-150	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 3 of 4

Client Sample ID	PR1 (3 hr)	Extraction Date	12/27/2021 14:48
Lab Sample ID	10590162006	Total Amount Extracted	1.00uL
Lab File ID	A211229A_015	Ical ID	211228A03
Matrix	Non_Potable_Water	CCal File	A211229A_005
Collected	12/03/2021 13:15	Ending CCal File	A211229A_020
Received	12/07/2021 08:50	Blank File	A211229A_008

Injection Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
13C2 PFHxA	N/A	N/A	4.92	4.93	2205	
13C4 PFOA	N/A	N/A	5.87	5.89	1357	
13C2 PFDA	N/A	N/A	6.75	6.77	1818	
13C4 PFOS	N/A	N/A	7.05	7.08	1638	

Extracted Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
13C4 PFBA	N/A	N/A	3.50	3.52	3083	
13C5 PFPeA	N/A	N/A	4.33	4.35	2122	
13C3 PFBS	N/A	N/A	5.09	5.11	1968	
13C2 4:2FTS	N/A	N/A	4.70	4.72	370	
13C5 PFHxA	N/A	N/A	4.92	4.93	470	
13C4 PFHpA	N/A	N/A	5.42	5.43	2283	
13C3 PFHxS	N/A	N/A	6.15	6.17	1986	
13C2 6:2FTS	N/A	N/A	5.65	5.66	500	
13C8 PFOA	N/A	N/A	5.87	5.89	1787	
13C9 PFNA	N/A	N/A	6.31	6.33	1866	
13C8 PFOS	N/A	N/A	7.05	7.08	1298	
13C2 8:2FTS	N/A	N/A	6.51	6.52	1002	
13C6 PFDA	N/A	N/A	6.75	6.77	2239	
d3-MeFOSAA	N/A	N/A	6.71	6.72	1156	
13C8 PFOSA	N/A	N/A	8.64	8.65	2201	
d5-EtFOSAA	N/A	N/A	6.91	6.93	673	
13C7 PFUdA	N/A	N/A	7.18	7.20	2145	
13C2 PFDaA	N/A	N/A	7.61	7.64	2182	
13C2 PFTeDA	N/A	N/A	8.46	8.48	1268	
13C3 HFPO-DA	N/A	N/A	5.12	5.14	1820	
13C2 PFHxDA	N/A	N/A	9.21	9.24	1565	
d7-N-MeFOSE	N/A	N/A	9.93	9.95	208	
d9-N-EtFOSE	N/A	N/A	10.54	10.56	429	
d3-N-MeFOSA	N/A	N/A	10.18	10.20	709	
d5-N-EtFOSA	N/A	N/A	10.84	10.87	730	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
1700 Elm Street, Suite 200
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444
www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 4 of 4

Client Sample ID	PR1 (3 hr)	Extraction Date	12/27/2021 14:48
Lab Sample ID	10590162006	Total Amount Extracted	1.00uL
Lab File ID	A211229A_015	Ical ID	211228A03
Matrix	Non_Potable_Water	CCal File	A211229A_005
Collected	12/03/2021 13:15	Ending CCal File	A211229A_020
Received	12/07/2021 08:50	Blank File	A211229A_008

Native Analytes

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
PFBA	N/A	N/A	3.50	3.52	58	J
PFPeA	N/A	N/A	4.33	4.35	20	J
HFPO-DA	0.000	0.470	0.00	5.15	ND	
PFBS	0.350	0.340	5.10	5.12	83	J
PFHxA	0.000	0.0640	0.00	4.94	ND	
4:2 FTS	0.000	0.560	0.00	4.72	ND	
PFPeS	0.340	0.310	5.66	5.68	80	J
PFHpA	0.340	0.310	5.42	5.44	10	J
DONA	0.000	0.480	0.00	5.61	ND	
PFHxS	0.280	0.290	6.15	6.17	407	J
PFOA	0.000	0.370	0.00	5.90	ND	
6:2 FTS	0.690	0.510	5.65	5.67	22	J
PFHpS	0.270	0.230	6.61	6.64	53	J
PFNA	0.000	0.190	0.00	6.34	ND	
PFOSAm	N/A	N/A	8.64	8.65	177	J
PFOS	0.220	0.220	7.06	7.09	162	
MeFOSA	0.000	0.930	0.00	10.22	ND	
PFDA	0.000	0.110	0.00	6.77	ND	
EtFOSAm	0.000	0.700	0.00	10.90	ND	
8:2 FTS	0.000	0.650	0.00	6.52	ND	
9-Cl-PF3ON	0.000	0.0210	0.00	7.40	ND	
PFNS	0.000	0.240	0.00	7.52	ND	
PFUnDA	0.000	0.120	0.00	7.21	ND	
NMeFOSAA	0.000	0.530	0.00	6.73	ND	
NEtFOSAA	0.000	0.870	0.00	6.94	ND	
PFDS	0.000	0.250	0.00	7.95	ND	
PFDOA	0.000	0.130	0.00	7.64	ND	
MeFOSE	N/A	N/A	0.00	9.99	ND	
10:2 FTS	0.000	0.700	0.00	7.39	ND	
EtFOSE	0.000	0.000	0.00	10.62	ND	
11-Cl-PF3OUdS	0.000	0.0140	0.00	8.25	ND	
PFTTrDA	0.000	0.150	0.00	8.07	ND	
PFDoS	0.000	0.220	0.00	8.75	ND	
PFTDA	0.000	0.160	0.00	8.49	ND	
PFHXDA	0.140	0.130	9.21	9.24	50	J
PFODA	0.000	0.0990	0.00	10.20	ND	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

Sample Analysis Summary
 PFAS by Isotope Dilution

Page 1 of 4

Client Sample ID PR2 (6 hr)
 Lab Sample ID 10590162007
 Lab File ID A211229A_016
 Matrix Non_Potable_Water
 Collected 12/03/2021 18:15
 Received 12/07/2021 08:50

Extraction Date 12/27/2021 14:48
 Total Amount Extracted 1.00uL
 Ical ID 211228A03
 CCal File A211229A_005
 Ending CCal File A211229A_020
 Blank File A211229A_008

Compound	Concentration (ug/L)	QL (ug/L)	RL (ug/L)	DL (ug/L)	Dil.	CAS No.	Qual.
PFBA	32 J	500	0.11	0.11	1	375-22-4	
PFPeA	18 J	500	0.11	0.11	1	2706-90-3	
HFPO-DA	ND	500	0.13	0.13	1	13252-13-6	
PFBS	46 J	440	0.12	0.12	1	375-73-5	
PFHxA	ND	500	0.11	0.11	1	307-24-4	
4:2 FTS	ND	470	0.14	0.14	1	757124-72-4	
PFPeS	38 J	470	0.12	0.12	1	2706-91-4	
PFHpA	20 J	500	0.14	0.14	1	375-85-9	
DONA	ND	470	0.13	0.13	1	919005-14-4	
PFHxS	440 J	460	0.13	0.13	1	355-46-4	
PFOA	ND	500	0.15	0.15	1	335-67-1	
6:2 FTS	110 J	480	0.16	0.16	1	27619-97-2	
PFHpS	50 IJ	480	0.10	0.10	1	375-92-8	
PFNA	ND	500	0.18	0.18	1	375-95-1	
PFOSAm	38 J	500	0.20	0.20	1	754-91-6	
PFOS	1300	460	0.14	0.14	1	1763-23-1	
MeFOSA	ND	500	0.13	0.13	1	31506-32-8	
PFDA	ND	500	0.14	0.14	1	335-76-2	
EtFOSAm	ND	500	0.15	0.15	1	4151-50-2	
8:2 FTS	ND	480	0.16	0.16	1	39108-34-4	
9-CI-PF3ON	ND	470	0.076	0.076	1	756426-58-1	
PFNS	ND	480	0.11	0.11	1	68259-12-1	
PFUnDA	ND	500	0.14	0.14	1	2058-94-8	
NMeFOSAA	ND	500	0.11	0.11	1	2355-31-9	
NEtFOSAA	ND	500	0.14	0.14	1	2991-50-6	
PFDS	ND	480	0.11	0.11	1	335-77-3	
PFDOA	ND	500	0.12	0.12	1	307-55-1	
MeFOSE	ND	500	0.082	0.082	1	24448-09-7	
10:2 FTS	ND	480	0.18	0.18	1	120226-60-0	
EtFOSE	ND	500	0.12	0.12	1	1691-99-2	
11-CI-PF3OUdS	ND	470	0.11	0.11	1	763051-92-9	
PFTTrDA	ND	500	0.16	0.16	1	72629-94-8	
PFDoS	ND	480	0.12	0.12	1	79780-39-5	
PFTDA	ND	500	0.12	0.12	1	376-06-7	
PFHXDA	49 J	500	0.091	0.091	1	67905-19-5	
PFODA	ND	500	0.15	0.15	1	16517-11-6	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 2 of 4

Client Sample ID	PR2 (6 hr)	Extraction Date	12/27/2021 14:48
Lab Sample ID	10590162007	Total Amount Extracted	1.00uL
Lab File ID	A211229A_016	Ical ID	211228A03
Matrix	Non_Potable_Water	CCal File	A211229A_005
Collected	12/03/2021 18:15	Ending CCal File	A211229A_020
Received	12/07/2021 08:50	Blank File	A211229A_008

Injection Internal Standards

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers
13C2_PFHxA	5000	5100	101	50-150	
13C4_PFOA	5000	5100	103	50-150	
13C2_PFDA	5000	5400	108	50-150	
13C4_PFOS	4800	5100	108	50-150	

Extracted Internal Standards

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers
13C4_PFBA	5000	5000	100	50-150	
13C5_PFPeA	5000	5200	104	50-150	
13C3_PFBs	4600	4300	93	50-150	
13C2_4:2FTS	4700	4300	92	50-150	
13C5_PFHxA	5000	5000	100	50-150	
13C4_PFHpA	5000	5000	99	50-150	
13C3_PFHxS	4700	4900	103	50-150	
13C2_6:2FTS	4700	5100	107	50-150	
13C8_PFOA	5000	5000	99	50-150	
13C9_PfNA	5000	4800	97	50-150	
13C8_PFOS	4800	4300	90	50-150	
13C2_8:2FTS	4800	4200	88	50-150	
13C6_PFDA	5000	4700	94	50-150	
d3-MeFOSAA	5000	4400	88	50-150	
13C8_PFOA	5000	4000	80	50-150	
d5-EtFOSAA	5000	4300	86	50-150	
13C7_PFHdA	5000	4600	93	50-150	
13C2_PFDaA	5000	4700	93	50-150	
13C2_PFTeDA	5000	4200	83	50-150	
13C3_HFPO-DA	5000	5200	104	50-150	
13C2_PFHxDA	5000	3600	71	50-150	
d7-N-MeFOSE	5000	3500	70	10-150	
d9-N-EtFOSE	5000	3600	72	10-150	
d3-N-MeFOSA	5000	1900	38	10-150	
d5-N-EtFOSA	5000	1900	39	10-150	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 3 of 4

Client Sample ID	PR2 (6 hr)	Extraction Date	12/27/2021 14:48
Lab Sample ID	10590162007	Total Amount Extracted	1.00uL
Lab File ID	A211229A_016	Ical ID	211228A03
Matrix	Non_Potable_Water	CCal File	A211229A_005
Collected	12/03/2021 18:15	Ending CCal File	A211229A_020
Received	12/07/2021 08:50	Blank File	A211229A_008

Injection Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
13C2 PFHxA	N/A	N/A	4.92	4.93	1735	
13C4 PFOA	N/A	N/A	5.88	5.89	1524	
13C2 PFDA	N/A	N/A	6.75	6.77	1656	
13C4 PFOS	N/A	N/A	7.05	7.08	1798	

Extracted Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
13C4 PFBA	N/A	N/A	3.50	3.52	2409	
13C5 PFPeA	N/A	N/A	4.34	4.35	1908	
13C3 PFBS	N/A	N/A	5.10	5.11	1311	
13C2 4:2FTS	N/A	N/A	4.71	4.72	353	
13C5 PFHxA	N/A	N/A	4.92	4.93	319	
13C4 PFHpA	N/A	N/A	5.42	5.43	1357	
13C3 PFHxS	N/A	N/A	6.15	6.17	1707	
13C2 6:2FTS	N/A	N/A	5.65	5.66	855	
13C8 PFOA	N/A	N/A	5.88	5.89	1969	
13C9 PFNA	N/A	N/A	6.32	6.33	2012	
13C8 PFOS	N/A	N/A	7.06	7.08	1731	
13C2 8:2FTS	N/A	N/A	6.51	6.52	623	
13C6 PFDA	N/A	N/A	6.75	6.77	1815	
d3-MeFOSAA	N/A	N/A	6.71	6.72	1294	
13C8 PFOSA	N/A	N/A	8.64	8.65	1823	
d5-EtFOSAA	N/A	N/A	6.92	6.93	715	
13C7 PFUdA	N/A	N/A	7.18	7.20	1843	
13C2 PFDaA	N/A	N/A	7.62	7.64	1557	
13C2 PFTeDA	N/A	N/A	8.46	8.48	1897	
13C3 HFPO-DA	N/A	N/A	5.13	5.14	1341	
13C2 PFHxDA	N/A	N/A	9.21	9.24	2461	
d7-N-MeFOSE	N/A	N/A	9.94	9.95	219	
d9-N-EtFOSE	N/A	N/A	10.55	10.56	453	
d3-N-MeFOSA	N/A	N/A	10.19	10.20	641	
d5-N-EtFOSA	N/A	N/A	10.85	10.87	734	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 4 of 4

Client Sample ID	PR2 (6 hr)	Extraction Date	12/27/2021 14:48
Lab Sample ID	10590162007	Total Amount Extracted	1.00uL
Lab File ID	A211229A_016	Ical ID	211228A03
Matrix	Non_Potable_Water	CCal File	A211229A_005
Collected	12/03/2021 18:15	Ending CCal File	A211229A_020
Received	12/07/2021 08:50	Blank File	A211229A_008

Native Analytes

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
PFBA	N/A	N/A	3.51	3.52	43	J
PFPeA	N/A	N/A	4.34	4.35	28	J
HFPO-DA	0.000	0.470	0.00	5.15	ND	
PFBS	0.210	0.340	5.10	5.12	105	J
PFHxA	0.000	0.0640	0.00	4.94	ND	
4:2 FTS	0.000	0.560	0.00	4.72	ND	
PFPeS	0.300	0.310	5.66	5.68	126	J
PFHpA	0.210	0.310	5.42	5.44	11	J
DONA	0.000	0.480	0.00	5.61	ND	
PFHxS	0.310	0.290	6.15	6.17	586	J
PFOA	0.000	0.370	0.00	5.90	ND	
6:2 FTS	0.500	0.510	5.65	5.67	20	J
PFHpS	0.370	0.230	6.62	6.64	50	IJ
PFNA	0.000	0.190	0.00	6.34	ND	
PFOSAm	N/A	N/A	8.65	8.65	192	J
PFOS	0.210	0.220	7.06	7.09	150	
MeFOSA	0.000	0.930	0.00	10.22	ND	
PFDA	0.000	0.110	0.00	6.77	ND	
EtFOSAm	0.000	0.700	0.00	10.90	ND	
8:2 FTS	0.000	0.650	0.00	6.52	ND	
9-Cl-PF3ON	0.000	0.0210	0.00	7.40	ND	
PFNS	0.000	0.240	0.00	7.52	ND	
PFUnDA	0.000	0.120	0.00	7.21	ND	
NMeFOSAA	0.000	0.530	0.00	6.73	ND	
NEtFOSAA	0.000	0.870	0.00	6.94	ND	
PFDS	0.000	0.250	0.00	7.95	ND	
PFDOA	0.000	0.130	0.00	7.64	ND	
MeFOSE	N/A	N/A	0.00	9.99	ND	
10:2 FTS	0.000	0.700	0.00	7.39	ND	
EtFOSE	0.000	0.000	0.00	10.62	ND	
11-Cl-PF3OUdS	0.000	0.0140	0.00	8.25	ND	
PFTTrDA	0.000	0.150	0.00	8.07	ND	
PFDoS	0.000	0.220	0.00	8.75	ND	
PFTDA	0.000	0.160	0.00	8.49	ND	
PFHXDA	0.120	0.130	9.22	9.24	46	J
PFODA	0.000	0.0990	0.00	10.20	ND	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 1 of 4

Client Sample ID PR3 (36 hr)
 Lab Sample ID 10590162008
 Lab File ID A211229A_017
 Matrix Non_Potable_Water
 Collected 12/05/2021 00:15
 Received 12/07/2021 08:50

Extraction Date 12/27/2021 14:48
 Total Amount Extracted 1.00uL
 Ical ID 211228A03
 CCal File A211229A_005
 Ending CCal File A211229A_020
 Blank File A211229A_008

Compound	Concentration (ug/L)	QL (ug/L)	RL (ug/L)	DL (ug/L)	Dil.	CAS No.	Qual.
PFBA	68 J	500	0.11	0.11	1	375-22-4	
PFPeA	44 J	500	0.11	0.11	1	2706-90-3	
HFPO-DA	ND	500	0.13	0.13	1	13252-13-6	
PFBS	88 J	440	0.12	0.12	1	375-73-5	
PFHxA	130 J	500	0.11	0.11	1	307-24-4	
4:2 FTS	ND	470	0.14	0.14	1	757124-72-4	
PFPeS	80 J	470	0.12	0.12	1	2706-91-4	
PFHpA	46 J	500	0.14	0.14	1	375-85-9	
DONA	ND	470	0.13	0.13	1	919005-14-4	
PFHxS	1100	460	0.13	0.13	1	355-46-4	
PFOA	61 J	500	0.15	0.15	1	335-67-1	
6:2 FTS	75 J	480	0.16	0.16	1	27619-97-2	
PFHpS	90 J	480	0.10	0.10	1	375-92-8	
PFNA	ND	500	0.18	0.18	1	375-95-1	
PFOSAm	24 J	500	0.20	0.20	1	754-91-6	
PFOS	2200	460	0.14	0.14	1	1763-23-1	
MeFOSA	ND	500	0.13	0.13	1	31506-32-8	
PFDA	ND	500	0.14	0.14	1	335-76-2	
EtFOSAm	ND	500	0.15	0.15	1	4151-50-2	
8:2 FTS	ND	480	0.16	0.16	1	39108-34-4	
9-CI-PF3ON	ND	470	0.076	0.076	1	756426-58-1	
PFNS	ND	480	0.11	0.11	1	68259-12-1	
PFUnDA	ND	500	0.14	0.14	1	2058-94-8	
NMeFOSAA	ND	500	0.11	0.11	1	2355-31-9	
NEtFOSAA	ND	500	0.14	0.14	1	2991-50-6	
PFDS	ND	480	0.11	0.11	1	335-77-3	
PFDOA	ND	500	0.12	0.12	1	307-55-1	
MeFOSE	ND	500	0.082	0.082	1	24448-09-7	
10:2 FTS	ND	480	0.18	0.18	1	120226-60-0	
EtFOSE	ND	500	0.12	0.12	1	1691-99-2	
11-CI-PF3OUdS	ND	470	0.11	0.11	1	763051-92-9	
PFTTrDA	ND	500	0.16	0.16	1	72629-94-8	
PFDoS	ND	480	0.12	0.12	1	79780-39-5	
PFTDA	ND	500	0.12	0.12	1	376-06-7	
PFHXDA	50 J	500	0.091	0.091	1	67905-19-5	
PFODA	ND	500	0.15	0.15	1	16517-11-6	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
1700 Elm Street, Suite 200
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444
www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 2 of 4

Client Sample ID	PR3 (36 hr)	Extraction Date	12/27/2021 14:48
Lab Sample ID	10590162008	Total Amount Extracted	1.00uL
Lab File ID	A211229A_017	Ical ID	211228A03
Matrix	Non_Potable_Water	CCal File	A211229A_005
Collected	12/05/2021 00:15	Ending CCal File	A211229A_020
Received	12/07/2021 08:50	Blank File	A211229A_008

Injection Internal Standards

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers
13C2_PFHxA	5000	5400	107	50-150	
13C4_PFOA	5000	5400	109	50-150	
13C2_PFDA	5000	5300	106	50-150	
13C4_PFOS	4800	5100	107	50-150	

Extracted Internal Standards

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers
13C4_PFBA	5000	5300	106	50-150	
13C5_PFPeA	5000	5100	102	50-150	
13C3_PFBs	4600	4400	95	50-150	
13C2_4:2FTS	4700	4600	99	50-150	
13C5_PFHxA	5000	5200	104	50-150	
13C4_PFHpA	5000	5200	104	50-150	
13C3_PFHxS	4700	4800	102	50-150	
13C2_6:2FTS	4700	5300	112	50-150	
13C8_PFOA	5000	4700	95	50-150	
13C9_PFNA	5000	4800	96	50-150	
13C8_PFOS	4800	4500	94	50-150	
13C2_8:2FTS	4800	4300	89	50-150	
13C6_PFDA	5000	4800	95	50-150	
d3-MeFOSAA	5000	4000	81	50-150	
13C8_PFOA	5000	4000	80	50-150	
d5-EtFOSAA	5000	4000	80	50-150	
13C7_PFUdA	5000	5000	100	50-150	
13C2_PFDaA	5000	4600	92	50-150	
13C2_PFTeDA	5000	4500	91	50-150	
13C3_HFPO-DA	5000	5200	105	50-150	
13C2_PFHxDA	5000	4600	92	50-150	
d7-N-MeFOSE	5000	3600	72	10-150	
d9-N-EtFOSE	5000	3700	75	10-150	
d3-N-MeFOSA	5000	2100	41	10-150	
d5-N-EtFOSA	5000	2100	42	10-150	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

Sample Analysis Summary

PFAS by Isotope Dilution

Page 3 of 4

Client Sample ID PR3 (36 hr)	Extraction Date 12/27/2021 14:48
Lab Sample ID 10590162008	Total Amount Extracted 1.00uL
Lab File ID A211229A_017	Ical ID 211228A03
Matrix Non_Potable_Water	CCal File A211229A_005
Collected 12/05/2021 00:15	Ending CCal File A211229A_020
Received 12/07/2021 08:50	Blank File A211229A_008

Injection Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
13C2 PFHxA	N/A	N/A	4.92	4.93	2280	
13C4 PFOA	N/A	N/A	5.87	5.89	1847	
13C2 PFDA	N/A	N/A	6.74	6.77	1505	
13C4 PFOS	N/A	N/A	7.05	7.08	1864	

Extracted Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
13C4 PFBA	N/A	N/A	3.50	3.52	2178	
13C5 PFPeA	N/A	N/A	4.33	4.35	1886	
13C3 PFBS	N/A	N/A	5.09	5.11	1646	
13C2 4:2FTS	N/A	N/A	4.70	4.72	262	
13C5 PFHxA	N/A	N/A	4.92	4.93	295	
13C4 PFHpA	N/A	N/A	5.42	5.43	2419	
13C3 PFHxS	N/A	N/A	6.14	6.17	1600	
13C2 6:2FTS	N/A	N/A	5.65	5.66	492	
13C8 PFOA	N/A	N/A	5.87	5.89	2270	
13C9 PFNA	N/A	N/A	6.31	6.33	1800	
13C8 PFOS	N/A	N/A	7.05	7.08	1796	
13C2 8:2FTS	N/A	N/A	6.51	6.52	940	
13C6 PFDA	N/A	N/A	6.75	6.77	1640	
d3-MeFOSAA	N/A	N/A	6.70	6.72	1154	
13C8 PFOSA	N/A	N/A	8.63	8.65	1854	
d5-EtFOSAA	N/A	N/A	6.91	6.93	677	
13C7 PFUdA	N/A	N/A	7.18	7.20	1622	
13C2 PFDaA	N/A	N/A	7.61	7.64	1630	
13C2 PFTeDA	N/A	N/A	8.45	8.48	1579	
13C3 HFPO-DA	N/A	N/A	5.12	5.14	1496	
13C2 PFHxDA	N/A	N/A	9.21	9.24	2819	
d7-N-MeFOSE	N/A	N/A	9.93	9.95	217	
d9-N-EtFOSE	N/A	N/A	10.54	10.56	513	
d3-N-MeFOSA	N/A	N/A	10.18	10.20	894	
d5-N-EtFOSA	N/A	N/A	10.84	10.87	732	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

Sample Analysis Summary
 PFAS by Isotope Dilution

Page 4 of 4

Client Sample ID	PR3 (36 hr)	Extraction Date	12/27/2021 14:48
Lab Sample ID	10590162008	Total Amount Extracted	1.00uL
Lab File ID	A211229A_017	Ical ID	211228A03
Matrix	Non_Potable_Water	CCal File	A211229A_005
Collected	12/05/2021 00:15	Ending CCal File	A211229A_020
Received	12/07/2021 08:50	Blank File	A211229A_008

Native Analytes

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
PFBA	N/A	N/A	3.50	3.52	88	J
PFPeA	N/A	N/A	4.33	4.35	48	J
HFPO-DA	0.000	0.470	0.00	5.15	ND	
PFBS	0.400	0.340	5.10	5.12	190	J
PFHxA	0.083	0.0640	4.92	4.94	68	J
4:2 FTS	0.000	0.560	0.00	4.72	ND	
PFPeS	0.420	0.310	5.66	5.68	158	J
PFHpA	0.390	0.310	5.42	5.44	20	J
DONA	0.000	0.480	0.00	5.61	ND	
PFHxS	0.320	0.290	6.15	6.17	725	
PFOA	0.390	0.370	5.88	5.90	14	J
6:2 FTS	0.530	0.510	5.65	5.67	13	J
PFHpS	0.260	0.230	6.61	6.64	57	J
PFNA	0.000	0.190	0.00	6.34	ND	
PFOSAm	N/A	N/A	8.64	8.65	145	J
PFOS	0.210	0.220	7.02	7.09	155	
MeFOSA	0.000	0.930	0.00	10.22	ND	
PFDA	0.000	0.110	0.00	6.77	ND	
EtFOSAm	0.000	0.700	0.00	10.90	ND	
8:2 FTS	0.000	0.650	0.00	6.52	ND	
9-Cl-PF3ON	0.000	0.0210	0.00	7.40	ND	
PFNS	0.000	0.240	0.00	7.52	ND	
PFUnDA	0.000	0.120	0.00	7.21	ND	
NMeFOSAA	0.000	0.530	0.00	6.73	ND	
NEtFOSAA	0.000	0.870	0.00	6.94	ND	
PFDS	0.000	0.250	0.00	7.95	ND	
PFDOA	0.000	0.130	0.00	7.64	ND	
MeFOSE	N/A	N/A	0.00	9.99	ND	
10:2 FTS	0.000	0.700	0.00	7.39	ND	
EtFOSE	0.000	0.000	0.00	10.62	ND	
11-Cl-PF3OUdS	0.000	0.0140	0.00	8.25	ND	
PFTTrDA	0.000	0.150	0.00	8.07	ND	
PFDoS	0.000	0.220	0.00	8.75	ND	
PFTDA	0.000	0.160	0.00	8.49	ND	
PFHXDA	0.130	0.130	9.21	9.24	62	J
PFODA	0.000	0.0990	0.00	10.20	ND	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

Method Blank Analysis Summary
 PFAS by Isotope Dilution

Page 1 of 4

Client Sample ID BLKUY
 Lab Sample ID BLANK-94971
 Lab File ID A211214A_013
 Matrix Soil
 Collected 12/08/2021 08:33
 Received 12/08/2021 08:33

Extraction Date 12/10/2021 08:52
 Total Amount Extracted 5.00g
 Ical ID 211210A03
 CCal File A211214A_012
 Ending CCal File A211214A_023
 Blank File

Compound	Concentration (ug/Kg)	QL (ug/Kg)	RL (ug/Kg)	DL (ug/Kg)	Dil.	CAS No.	Qual.
PFBA	ND	0.10	0.024	0.024	1	375-22-4	
PFPeA	ND	0.10	0.026	0.026	1	2706-90-3	
HFPO-DA	ND	0.10	0.030	0.030	1	13252-13-6	
PFBS	ND	0.088	0.022	0.022	1	375-73-5	
PFHxA	ND	0.10	0.030	0.030	1	307-24-4	
4:2 FTS	ND	0.094	0.032	0.032	1	757124-72-4	
PFPeS	ND	0.094	0.019	0.019	1	2706-91-4	
PFHpA	ND	0.10	0.022	0.022	1	375-85-9	
DONA	ND	0.095	0.038	0.038	1	919005-14-4	
PFHxS	ND	0.091	0.022	0.022	1	355-46-4	
PFOA	ND	0.10	0.023	0.023	1	335-67-1	
6:2 FTS	ND	0.095	0.032	0.032	1	27619-97-2	
PFHpS	ND	0.095	0.025	0.025	1	375-92-8	
PFNA	ND	0.10	0.029	0.029	1	375-95-1	
PFOSAm	ND	0.10	0.023	0.023	1	754-91-6	
PFOS	ND	0.092	0.028	0.028	1	1763-23-1	
MeFOSA	ND	0.10	0.025	0.025	1	31506-32-8	
PFDA	ND	0.10	0.022	0.022	1	335-76-2	
EtFOSA	ND	0.10	0.024	0.024	1	4151-50-2	
8:2 FTS	ND	0.096	0.026	0.026	1	39108-34-4	
9-CI-PF3ON	ND	0.093	0.015	0.015	1	756426-58-1	
PFNS	ND	0.096	0.018	0.018	1	68259-12-1	
PFUnDA	ND	0.10	0.028	0.028	1	2058-94-8	
NMeFOSAA	ND	0.10	0.023	0.023	1	2355-31-9	
NEtFOSAA	ND	0.10	0.025	0.025	1	2991-50-6	
PFDS	ND	0.096	0.025	0.025	1	335-77-3	
PFDOA	ND	0.10	0.027	0.027	1	307-55-1	
MeFOSE	ND	0.10	0.024	0.024	1	24448-09-7	
10:2 FTS	ND	0.096	0.037	0.037	1	120226-60-0	
EtFOSE	ND	0.10	0.025	0.025	1	1691-99-2	
11-CI-PF3OUdS	ND	0.094	0.016	0.016	1	763051-92-9	
PFTrDA	ND	0.10	0.021	0.021	1	72629-94-8	
PFDoS	ND	0.097	0.030	0.030	1	79780-39-5	
PFTDA	ND	0.10	0.032	0.032	1	376-06-7	
PFHXDA	ND	0.10	0.036	0.036	1	67905-19-5	
PFODA	ND	0.10	0.025	0.025	1	16517-11-6	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

Method Blank Analysis Summary
 PFAS by Isotope Dilution

Page 2 of 4

Client Sample ID	BLKUY	Extraction Date	12/10/2021 08:52
Lab Sample ID	BLANK-94971	Total Amount Extracted	5.00g
Lab File ID	A211214A_013	Ical ID	211210A03
Matrix	Soil	CCal File	A211214A_012
Collected	12/08/2021 08:33	Ending CCal File	A211214A_023
Received	12/08/2021 08:33	Blank File	

Injection Internal Standards

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers
13C2 PFHxA	1.0	1.1	106	50-150	
13C4 PFOA	1.0	1.0	103	50-150	
13C2 PFDA	1.0	1.1	111	50-150	
13C4 PFOS	0.96	1.1	111	50-150	

Extracted Internal Standards

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers
13C4 PFBA	1.0	0.84	84	50-150	
13C5 PFPeA	1.0	0.87	87	50-150	
13C3 PFBS	0.93	0.81	87	50-150	
13C2 4:2FTS	0.94	0.76	81	50-150	
13C5 PFHxA	1.0	0.87	87	50-150	
13C4 PFHpA	1.0	0.84	84	50-150	
13C3 PFHxS	0.95	0.76	80	50-150	
13C2 6:2FTS	0.95	0.80	84	50-150	
13C8 PFOA	1.0	0.82	82	50-150	
13C9 PFNA	1.0	0.79	79	50-150	
13C8 PFOS	0.96	0.79	82	50-150	
13C2 8:2FTS	0.96	0.84	88	50-150	
13C6 PFDA	1.0	0.83	83	50-150	
d3-MeFOSAA	1.0	0.86	86	50-150	
13C8 PFOSA	1.0	0.79	79	50-150	
d5-EtFOSAA	1.0	0.78	78	50-150	
13C7 PFUdA	1.0	0.85	85	50-150	
13C2 PFDoA	1.0	0.84	84	50-150	
13C2 PFTeDA	1.0	0.88	88	50-150	
13C3 HFPO-DA	1.0	0.85	85	50-150	
13C2 PFHxDA	1.0	0.89	89	50-150	
d7-N-MeFOSE	1.0	0.47	47	10-150	
d9-N-EtFOSE	1.0	0.49	49	10-150	
d3-N-MeFOSA	1.0	0.39	39	10-150	
d5-N-EtFOSA	1.0	0.39	39	10-150	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
1700 Elm Street, Suite 200
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444
www.pacelabs.com

Method Blank Analysis Summary

PFAS by Isotope Dilution

Page 3 of 4

Client Sample ID BLKUY
Lab Sample ID BLANK-94971
Lab File ID A211214A_013
Matrix Soil
Collected 12/08/2021 08:33
Received 12/08/2021 08:33

Extraction Date 12/10/2021 08:52
Total Amount Extracted 5.00g
Ical ID 211210A03
CCal File A211214A_012
Ending CCal File A211214A_023
Blank File

Injection Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
13C2 PFHxA	N/A	N/A	5.18	5.16	1416	
13C4 PFOA	N/A	N/A	6.18	6.16	1557	
13C2 PFDA	N/A	N/A	7.02	7.00	1575	
13C4 PFOS	N/A	N/A	7.31	7.30	1018	

Extracted Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
13C4 PFBA	N/A	N/A	3.70	3.69	2097	
13C5 PFPeA	N/A	N/A	4.59	4.57	1930	
13C3 PFBS	N/A	N/A	5.35	5.33	580	
13C2 4:2FTS	N/A	N/A	4.96	4.94	178	
13C5 PFHxA	N/A	N/A	5.18	5.16	270	
13C4 PFHpA	N/A	N/A	5.70	5.68	1554	
13C3 PFHxS	N/A	N/A	6.44	6.42	669	
13C2 6:2FTS	N/A	N/A	5.94	5.92	577	
13C8 PFOA	N/A	N/A	6.18	6.16	1643	
13C9 PFNA	N/A	N/A	6.61	6.59	1516	
13C8 PFOS	N/A	N/A	7.31	7.30	772	
13C2 8:2FTS	N/A	N/A	6.79	6.77	495	
13C6 PFDA	N/A	N/A	7.02	7.01	1500	
d3-MeFOSAA	N/A	N/A	6.97	6.96	1128	
13C8 PFOSA	N/A	N/A	8.73	8.70	1433	
d5-EtFOSAA	N/A	N/A	7.17	7.15	558	
13C7 PFUdA	N/A	N/A	7.45	7.43	1141	
13C2 PFDoA	N/A	N/A	7.86	7.85	900	
13C2 PFTeDA	N/A	N/A	8.68	8.67	1303	
13C3 HFPO-DA	N/A	N/A	5.39	5.37	1239	
13C2 PFHxDA	N/A	N/A	9.43	9.43	1938	
d7-N-MeFOSE	N/A	N/A	10.14	10.11	171	
d9-N-EtFOSE	N/A	N/A	10.74	10.71	267	
d3-N-MeFOSA	N/A	N/A	10.37	10.34	497	
d5-N-EtFOSA	N/A	N/A	11.04	11.00	860	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

Method Blank Analysis Summary
 PFAS by Isotope Dilution

Page 4 of 4

Client Sample ID BLKUY
 Lab Sample ID BLANK-94971
 Lab File ID A211214A_013
 Matrix Soil
 Collected 12/08/2021 08:33
 Received 12/08/2021 08:33

Extraction Date 12/10/2021 08:52
 Total Amount Extracted 5.00g
 Ical ID 211210A03
 CCal File A211214A_012
 Ending CCal File A211214A_023
 Blank File

Native Analytes

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
PFBA	N/A	N/A	3.70	3.69	ND	
PFPeA	N/A	N/A	0.00	4.58	ND	
HFPO-DA	0.000	0.430	0.00	5.38	ND	
PFBS	0.000	0.320	5.37	5.34	ND	
PFHxA	0.000	0.0620	0.00	5.17	ND	
4:2 FTS	0.000	0.540	0.00	4.95	ND	
PFPeS	0.000	0.290	0.00	5.92	ND	
PFHpA	0.000	0.280	0.00	5.68	ND	
DONA	0.000	0.490	0.00	5.85	ND	
PFHxS	0.000	0.270	0.00	6.43	ND	
PFOA	0.000	0.370	0.00	6.27	ND	
6:2 FTS	0.000	0.500	0.00	5.93	ND	
PFHpS	0.000	0.230	0.00	6.87	ND	
PFNA	0.000	0.180	0.00	6.59	ND	
PFOSAm	N/A	N/A	8.74	8.71	ND	
PFOS	0.000	0.200	0.00	7.31	ND	
MeFOSA	0.000	0.900	0.00	10.36	ND	
PFDA	0.000	0.0850	0.00	7.02	ND	
EtFOSAm	0.000	0.680	0.00	11.03	ND	
8:2 FTS	0.000	0.620	0.00	6.78	ND	
9-Cl-PF3ON	0.000	0.0200	0.00	7.62	ND	
PFNS	0.000	0.230	0.00	7.74	ND	
PFUnDA	0.000	0.110	0.00	7.44	ND	
NMeFOSAA	0.000	0.530	0.00	6.96	ND	
NEtFOSAA	0.000	0.650	0.00	7.15	ND	
PFDS	0.000	0.230	0.00	8.15	ND	
PFDOA	0.000	0.140	0.00	7.86	ND	
MeFOSE	N/A	N/A	0.00	10.15	ND	
10:2 FTS	0.000	0.660	0.00	7.61	ND	
EtFOSE	0.000	0.000	0.00	10.77	ND	
11-Cl-PF3OUdS	0.000	0.0140	8.45	8.44	ND	
PFTTrDA	0.000	0.150	0.00	8.27	ND	
PFDOS	0.000	0.240	0.00	8.93	ND	
PFTDA	0.000	0.130	0.00	8.68	ND	
PFHXDA	0.150	0.120	9.43	9.43	ND	
PFODA	0.000	0.0960	0.00	10.39	ND	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
1700 Elm Street, Suite 200
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444
www.pacelabs.com

Method Blank Analysis Summary

PFAS by Isotope Dilution

Page 1 of 4

Client Sample ID BLKYT
Lab Sample ID BLANK-95271
Lab File ID A211229A_008
Matrix Water
Collected 12/21/2021 22:27
Received 12/21/2021 22:27

Extraction Date 12/27/2021 14:48
Total Amount Extracted 265mL
Ical ID 211228A03
CCal File A211229A_005
Ending CCal File A211229A_020
Blank File

Compound	Concentration (ng/L)	QL (ng/L)	RL (ng/L)	DL (ng/L)	Dil.	CAS No.	Qual.
PFBA	ND	1.9	0.42	0.42	1	375-22-4	
PFPeA	ND	1.9	0.41	0.41	1	2706-90-3	
HFPO-DA	ND	1.9	0.50	0.50	1	13252-13-6	
PFBS	ND	1.7	0.45	0.45	1	375-73-5	
PFHxA	ND	1.9	0.41	0.41	1	307-24-4	
4:2 FTS	ND	1.8	0.53	0.53	1	757124-72-4	
PFPeS	ND	1.8	0.45	0.45	1	2706-91-4	
PFHpA	ND	1.9	0.52	0.52	1	375-85-9	
DONA	ND	1.8	0.49	0.49	1	919005-14-4	
PFHxS	ND	1.7	0.48	0.48	1	355-46-4	
PFOA	ND	1.9	0.55	0.55	1	335-67-1	
6:2 FTS	ND	1.8	0.61	0.61	1	27619-97-2	
PFHpS	ND	1.8	0.39	0.39	1	375-92-8	
PFNA	ND	1.9	0.70	0.70	1	375-95-1	
PFOSAm	ND	1.9	0.77	0.77	1	754-91-6	
PFOS	ND	1.7	0.52	0.52	1	1763-23-1	
MeFOSA	ND	1.9	0.48	0.48	1	31506-32-8	
PFDA	ND	1.9	0.53	0.53	1	335-76-2	
EtFOSAm	ND	1.9	0.57	0.57	1	4151-50-2	
8:2 FTS	ND	1.8	0.62	0.62	1	39108-34-4	
9-Cl-PF3ON	ND	1.8	0.29	0.29	1	756426-58-1	
PFNS	ND	1.8	0.42	0.42	1	68259-12-1	
PFOUnDA	ND	1.9	0.51	0.51	1	2058-94-8	
NMeFOSAA	ND	1.9	0.41	0.41	1	2355-31-9	
NEtFOSAA	ND	1.9	0.52	0.52	1	2991-50-6	
PFDS	ND	1.8	0.43	0.43	1	335-77-3	
PFDOA	ND	1.9	0.46	0.46	1	307-55-1	
MeFOSE	ND	1.9	0.31	0.31	1	24448-09-7	
10:2 FTS	ND	1.8	0.70	0.70	1	120226-60-0	
EtFOSE	ND	1.9	0.47	0.47	1	1691-99-2	
11-Cl-PF3OUdS	ND	1.8	0.41	0.41	1	763051-92-9	
PFTDA	ND	1.9	0.59	0.59	1	72629-94-8	
PFDoS	ND	1.8	0.43	0.43	1	79780-39-5	
PFTDA	ND	1.9	0.45	0.45	1	376-06-7	
PFHXDA	ND	1.9	0.34	0.34	1	67905-19-5	
PFODA	ND	1.9	0.55	0.55	1	16517-11-6	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
1700 Elm Street, Suite 200
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444
www.pacelabs.com

Method Blank Analysis Summary

PFAS by Isotope Dilution

Page 2 of 4

Client Sample ID	BLKYT	Extraction Date	12/27/2021 14:48
Lab Sample ID	BLANK-95271	Total Amount Extracted	265mL
Lab File ID	A211229A_008	Ical ID	211228A03
Matrix	Water	CCal File	A211229A_005
Collected	12/21/2021 22:27	Ending CCal File	A211229A_020
Received	12/21/2021 22:27	Blank File	

Injection Internal Standards

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers
13C2_PFHxA	19	21	110	50-150	
13C4_PFOA	19	21	113	50-150	
13C2_PFDA	19	22	117	50-150	
13C4_PFOS	18	21	116	50-150	

Extracted Internal Standards

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers
13C4_PFBA	19	21	112	50-150	
13C5_PFPeA	19	22	114	50-150	
13C3_PFBs	18	18	104	50-150	
13C2_4:2FTS	18	21	116	50-150	
13C5_PFHxA	19	21	112	50-150	
13C4_PFHpA	19	22	115	50-150	
13C3_PFHxS	18	20	114	50-150	
13C2_6:2FTS	18	21	118	50-150	
13C8_PFOA	19	20	107	50-150	
13C9_PFNA	19	20	104	50-150	
13C8_PFOS	18	21	114	50-150	
13C2_8:2FTS	18	20	110	50-150	
13C6_PFDA	19	20	103	50-150	
d3-MeFOSAA	19	18	98	50-150	
13C8_PFOSA	19	17	90	50-150	
d5-EtFOSAA	19	17	90	50-150	
13C7_PFUdA	19	20	107	50-150	
13C2_PFDaA	19	21	111	50-150	
13C2_PFTeDA	19	19	102	50-150	
13C3_HFPO-DA	19	21	111	50-150	
13C2_PFHxDA	19	18	96	50-150	
d7-N-MeFOSE	19	14	72	10-150	
d9-N-EtFOSE	19	14	74	10-150	
d3-N-MeFOSA	19	8.6	45	10-150	
d5-N-EtFOSA	19	8.9	47	10-150	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
1700 Elm Street, Suite 200
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444
www.pacelabs.com

Method Blank Analysis Summary

PFAS by Isotope Dilution

Page 3 of 4

Client Sample ID BLKYT
Lab Sample ID BLANK-95271
Lab File ID A211229A_008
Matrix Water
Collected 12/21/2021 22:27
Received 12/21/2021 22:27

Extraction Date 12/27/2021 14:48
Total Amount Extracted 265mL
Ical ID 211228A03
CCal File A211229A_005
Ending CCal File A211229A_020
Blank File

Injection Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
13C2 PFHxA	N/A	N/A	4.92	4.93	1890	
13C4 PFOA	N/A	N/A	5.88	5.89	1685	
13C2 PFDA	N/A	N/A	6.76	6.77	2432	
13C4 PFOS	N/A	N/A	7.06	7.08	1358	

Extracted Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
13C4 PFBA	N/A	N/A	3.50	3.52	3076	
13C5 PFPeA	N/A	N/A	4.34	4.35	2005	
13C3 PFBS	N/A	N/A	5.10	5.11	1607	
13C2 4:2FTS	N/A	N/A	4.71	4.72	314	
13C5 PFHxA	N/A	N/A	4.92	4.93	289	
13C4 PFHpA	N/A	N/A	5.42	5.43	2579	
13C3 PFHxS	N/A	N/A	6.15	6.17	2198	
13C2 6:2FTS	N/A	N/A	5.66	5.66	603	
13C8 PFOA	N/A	N/A	5.88	5.89	1548	
13C9 PFNA	N/A	N/A	6.32	6.33	1814	
13C8 PFOS	N/A	N/A	7.06	7.08	1303	
13C2 8:2FTS	N/A	N/A	6.51	6.52	726	
13C6 PFDA	N/A	N/A	6.76	6.77	2467	
d3-MeFOSAA	N/A	N/A	6.71	6.72	1374	
13C8 PFOSA	N/A	N/A	8.64	8.65	2144	
d5-EtFOSAA	N/A	N/A	6.92	6.93	949	
13C7 PFUdA	N/A	N/A	7.19	7.20	2023	
13C2 PFDaA	N/A	N/A	7.62	7.64	2014	
13C2 PFTeDA	N/A	N/A	8.47	8.48	1537	
13C3 HFPO-DA	N/A	N/A	5.13	5.14	1304	
13C2 PFHxDA	N/A	N/A	9.22	9.24	1950	
d7-N-MeFOSE	N/A	N/A	9.94	9.95	240	
d9-N-EtFOSE	N/A	N/A	10.55	10.56	397	
d3-N-MeFOSA	N/A	N/A	10.19	10.20	679	
d5-N-EtFOSA	N/A	N/A	10.85	10.87	729	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
1700 Elm Street, Suite 200
Minneapolis, MN 55414
Phone: 612.607.1700
Fax: 612.607.6444
www.pacelabs.com

Method Blank Analysis Summary

PFAS by Isotope Dilution

Page 4 of 4

Client Sample ID BLKYT
Lab Sample ID BLANK-95271
Lab File ID A211229A_008
Matrix Water
Collected 12/21/2021 22:27
Received 12/21/2021 22:27

Extraction Date 12/27/2021 14:48
Total Amount Extracted 265mL
Ical ID 211228A03
CCal File A211229A_005
Ending CCal File A211229A_020
Blank File

Native Analytes

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Signal to Noise	Qualifiers
PFBA	N/A	N/A	3.51	3.52	ND	
PFPeA	N/A	N/A	4.34	4.35	ND	
HFPO-DA	0.000	0.470	0.00	5.15	ND	
PFBS	0.000	0.340	5.11	5.12	ND	
PFHxA	0.000	0.0640	4.93	4.94	ND	
4:2 FTS	0.000	0.560	0.00	4.72	ND	
PFPeS	0.000	0.310	0.00	5.68	ND	
PFHpA	0.000	0.310	0.00	5.44	ND	
DONA	0.000	0.480	0.00	5.61	ND	
PFHxS	0.000	0.290	6.16	6.17	ND	
PFOA	0.000	0.370	0.00	5.90	ND	
6:2 FTS	0.550	0.510	5.65	5.67	ND	
PFHpS	0.000	0.230	0.00	6.64	ND	
PFNA	0.000	0.190	0.00	6.34	ND	
PFOSAm	N/A	N/A	8.65	8.65	ND	
PFOS	0.000	0.220	0.00	7.09	ND	
MeFOSA	0.000	0.930	0.00	10.22	ND	
PFDA	0.000	0.110	0.00	6.77	ND	
EtFOSAm	0.000	0.700	0.00	10.90	ND	
8:2 FTS	0.000	0.650	0.00	6.52	ND	
9-Cl-PF3ON	0.000	0.0210	0.00	7.40	ND	
PFNS	0.000	0.240	0.00	7.52	ND	
PFUnDA	0.000	0.120	0.00	7.21	ND	
NMeFOSAA	0.000	0.530	0.00	6.73	ND	
NEtFOSAA	0.000	0.870	0.00	6.94	ND	
PFDS	0.000	0.250	0.00	7.95	ND	
PFDOA	0.000	0.130	0.00	7.64	ND	
MeFOSE	N/A	N/A	0.00	9.99	ND	
10:2 FTS	0.000	0.700	0.00	7.39	ND	
EtFOSE	0.000	0.000	0.00	10.62	ND	
11-Cl-PF3OUdS	0.000	0.0140	0.00	8.25	ND	
PFTTrDA	0.000	0.150	0.00	8.07	ND	
PFDoS	0.000	0.220	0.00	8.75	ND	
PFTDA	0.000	0.160	0.00	8.49	ND	
PFHXDA	0.120	0.130	9.22	9.24	ND	
PFODA	0.000	0.0990	0.00	10.20	ND	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

LCS Analysis Summary
 PFAS by Isotope Dilution

Page 1 of 4

Lab Sample ID LCS-94972
 Run File Name A211214A_014
 Analyzed 12/14/2021 13:53
 Injected By NH

Instrument ID 10LCMS03
 Column ID 118AB10133
 Ical ID 211210A03
 Level L

Injection Internal Standards

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers
13C2_PFHxA	1.0	0.98	98	50-150	
13C4_PFOA	1.0	0.98	98	50-150	
13C2_PFDA	1.0	1.0	101	50-150	
13C4_PFOS	0.96	1.0	107	50-150	

Extracted Internal Standards

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers
13C4_PFBa	1.0	0.88	88	50-150	
13C5_PFPeA	1.0	0.90	90	50-150	
13C3_PFBs	0.93	0.83	90	50-150	
13C2_4:2FTS	0.94	0.83	88	50-150	
13C5_PFHxA	1.0	0.87	87	50-150	
13C4_PFHpA	1.0	0.86	86	50-150	
13C3_PFHxS	0.95	0.79	83	50-150	
13C2_6:2FTS	0.95	0.85	89	50-150	
13C8_PFOA	1.0	0.89	89	50-150	
13C9_PFNA	1.0	0.83	83	50-150	
13C8_PFOS	0.96	0.85	89	50-150	
13C2_8:2FTS	0.96	0.86	90	50-150	
13C6_PFDA	1.0	0.86	86	50-150	
d3-MeFOSAA	1.0	0.94	94	50-150	
13C8_PFOSA	1.0	0.80	80	50-150	
d5-EtFOSAA	1.0	0.85	85	50-150	
13C7_PFUdA	1.0	0.90	90	50-150	
13C2_PFDaA	1.0	0.87	87	50-150	
13C2_PFTeDA	1.0	0.91	91	50-150	
13C3_HFPO-DA	1.0	0.88	88	50-150	
13C2_PFHxDA	1.0	0.91	91	50-150	
d7-N-MeFOSE	1.0	0.63	63	10-150	
d9-N-EtFOSE	1.0	0.64	64	10-150	
d3-N-MeFOSA	1.0	0.61	61	10-150	
d5-N-EtFOSA	1.0	0.60	60	10-150	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

LCS Analysis Summary
 PFAS by Isotope Dilution

Page 2 of 4

Lab Sample ID LCS-94972
 Run File Name A211214A_014
 Analyzed 12/14/2021 13:53
 Injected By NH

Instrument ID 10LCMS03
 Column ID 118AB10133
 Ical ID 211210A03
 Level L

Native Analytes

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers	CAS No.
PFBA	0.20	0.22	108	71-135		375-22-4
PFPeA	0.20	0.22	112	69-132		2706-90-3
HFPO-DA	0.20	0.22	109	70-140		13252-13-6
PFBS	0.18	0.19	108	72-128		375-73-5
PFHxA	0.20	0.22	112	70-132		307-24-4
4:2 FTS	0.19	0.22	115	62-145		757124-72-4
PFPeS	0.19	0.21	110	73-123		2706-91-4
PFHpA	0.20	0.22	109	71-131		375-85-9
DONA	0.19	0.22	116	70-140		919005-14-4
PFHxS	0.18	0.20	111	67-130		355-46-4
PFOA	0.20	0.22	108	69-133		335-67-1
6:2 FTS	0.19	0.19	100	64-140		27619-97-2
PFHpS	0.19	0.20	106	70-132		375-92-8
PFNA	0.20	0.22	108	72-129		375-95-1
PFOSAm	0.20	0.22	109	67-137		754-91-6
PFOS	0.18	0.21	111	68-136		1763-23-1
MeFOSA	0.20	0.22	110	70-140		31506-32-8
PFDA	0.20	0.20	102	69-133		335-76-2
EtFOSAm	0.20	0.22	110	70-140		4151-50-2
8:2 FTS	0.19	0.16	84	65-137		39108-34-4
9-Cl-PF3ON	0.19	0.21	111	70-140		756426-58-1
PFNS	0.19	0.23	118	69-125		68259-12-1
PFUnDA	0.20	0.22	111	64-136		2058-94-8
NMeFOSAA	0.20	0.18	89	63-144		2355-31-9
NEtFOSAA	0.20	0.26	130	61-139		2991-50-6
PFDS	0.19	0.23	120	59-134		335-77-3
PFDOA	0.20	0.22	110	69-135		307-55-1
MeFOSE	0.20	0.23	115	70-140		24448-09-7
10:2 FTS	0.19	0.21	107	70-140		120226-60-0
EtFOSE	0.20	0.23	116	70-140		1691-99-2
11-Cl-PF3OUdS	0.19	0.21	114	70-140		763051-92-9
PFTrDA	0.20	0.20	102	66-139		72629-94-8
PFDoS	0.19	0.23	119	70-140		79780-39-5
PFTDA	0.20	0.21	105	69-133		376-06-7
PFHXDA	0.20	0.23	113	70-140		67905-19-5
PFODA	0.20	0.21	107	70-140		16517-11-6

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

LCS Analysis Summary
 PFAS by Isotope Dilution

Page 3 of 4

Lab Sample ID LCS-94972
 Run File Name A211214A_014
 Analyzed 12/14/2021 13:53
 Injected By NH

Instrument ID 10LCMS03
 Column ID 118AB10133
 Ical ID 211210A03
 Level L

Injection Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Qualifiers
13C2 PFHxA	N/A	N/A	5.19	5.16	
13C4 PFOA	N/A	N/A	6.19	6.16	
13C2 PFDA	N/A	N/A	7.03	7.00	
13C4 PFOS	N/A	N/A	7.32	7.30	

Extracted Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Qualifiers
13C4 PFBA	N/A	N/A	3.70	3.69	
13C5 PFPeA	N/A	N/A	4.59	4.57	
13C3 PFBS	N/A	N/A	5.36	5.33	
13C2 4:2FTS	N/A	N/A	4.97	4.94	
13C5 PFHxA	N/A	N/A	5.19	5.16	
13C4 PFHpA	N/A	N/A	5.70	5.68	
13C3 PFHxS	N/A	N/A	6.44	6.42	
13C2 6:2FTS	N/A	N/A	5.95	5.92	
13C8 PFOA	N/A	N/A	6.19	6.16	
13C9 PFNA	N/A	N/A	6.61	6.59	
13C8 PFOS	N/A	N/A	7.32	7.30	
13C2 8:2FTS	N/A	N/A	6.79	6.77	
13C6 PFDA	N/A	N/A	7.03	7.01	
d3-MeFOSAA	N/A	N/A	6.98	6.96	
13C8 PFOSA	N/A	N/A	8.74	8.70	
d5-EtFOSAA	N/A	N/A	7.18	7.15	
13C7 PFUdA	N/A	N/A	7.45	7.43	
13C2 PFDoA	N/A	N/A	7.87	7.85	
13C2 PFTeDA	N/A	N/A	8.69	8.67	
13C3 HFPO-DA	N/A	N/A	5.40	5.37	
13C2 PFHxDA	N/A	N/A	9.44	9.43	
d7-N-MeFOSE	N/A	N/A	10.14	10.11	
d9-N-EtFOSE	N/A	N/A	10.75	10.71	
d3-N-MeFOSA	N/A	N/A	10.37	10.34	
d5-N-EtFOSA	N/A	N/A	11.04	11.00	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

LCS Analysis Summary
 PFAS by Isotope Dilution

Page 4 of 4

Lab Sample ID LCS-94972
 Run File Name A211214A_014
 Analyzed 12/14/2021 13:53
 Injected By NH

Instrument ID 10LCMS03
 Column ID 118AB10133
 Ical ID 211210A03
 Level L

Native Analytes

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Qualifiers
PFBA	N/A	N/A	3.70	3.69	
PFPeA	N/A	N/A	4.60	4.58	
HFPO-DA	0.44	0.43	5.41	5.38	
PFBS	0.30	0.32	5.36	5.34	
PFHxA	0.05	0.06	5.19	5.17	
4:2 FTS	0.50	0.54	4.97	4.95	
PFPeS	0.30	0.29	5.94	5.92	
PFHpA	0.28	0.28	5.71	5.68	
DONA	0.47	0.49	5.89	5.85	
PFHxS	0.27	0.27	6.45	6.43	
PFOA	0.41	0.37	6.20	6.27	
6:2 FTS	0.52	0.50	5.95	5.93	
PFHpS	0.22	0.23	6.89	6.87	
PFNA	0.17	0.18	6.62	6.59	
PFOSAm	N/A	N/A	8.75	8.71	
PFOS	0.19	0.20	7.33	7.31	
MeFOSA	0.85	0.90	10.39	10.36	
PFDA	0.11	0.08	7.04	7.02	
EtFOSAm	0.69	0.68	11.07	11.03	
8:2 FTS	0.82	0.62	6.80	6.78	
9-Cl-PF3ON	0.01	0.02	7.63	7.62	
PFNS	0.24	0.23	7.75	7.74	
PFUnDA	0.10	0.11	7.46	7.44	
NMeFOSAA	0.67	0.53	6.99	6.96	
NEtFOSAA	0.48	0.65	7.18	7.15	
PFDS	0.23	0.23	8.16	8.15	
PFDOA	0.12	0.14	7.88	7.86	
MeFOSE	N/A	N/A	10.18	10.15	
10:2 FTS	0.62	0.66	7.63	7.61	
EtFOSE	0.00	0.00	10.81	10.77	
11-Cl-PF3OUdS	0.01	0.01	8.45	8.44	
PFTTrDA	0.15	0.15	8.29	8.27	
PFDoS	0.22	0.24	8.94	8.93	
PFTDA	0.13	0.13	8.69	8.68	
PFHXDA	0.12	0.12	9.44	9.43	
PFODA	0.09	0.09	10.41	10.39	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

LCS Analysis Summary
 PFAS by Isotope Dilution

Page 1 of 4

Lab Sample ID LCS-95272
 Run File Name A211229A_009
 Analyzed 12/29/2021 15:48
 Injected By NH

Instrument ID 10LCMS03
 Column ID 112EB00094
 Ical ID 211228A03
 Level L

Injection Internal Standards

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers
13C2_PFHxA	19	21	113	50-150	
13C4_PFOA	19	21	110	50-150	
13C2_PFDA	19	21	111	50-150	
13C4_PFOS	18	21	115	50-150	

Extracted Internal Standards

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers
13C4_PFBA	19	21	109	50-150	
13C5_PFPeA	19	21	111	50-150	
13C3_PFBS	18	18	103	50-150	
13C2_4:2FTS	18	19	109	50-150	
13C5_PFHxA	19	21	110	50-150	
13C4_PFHpA	19	20	105	50-150	
13C3_PFHxS	18	20	111	50-150	
13C2_6:2FTS	18	23	127	50-150	
13C8_PFOA	19	20	103	50-150	
13C9_PFNA	19	20	103	50-150	
13C8_PFOS	18	20	112	50-150	
13C2_8:2FTS	18	17	94	50-150	
13C6_PFDA	19	20	105	50-150	
d3-MeFOSAA	19	17	89	50-150	
13C8_PFOSA	19	18	95	50-150	
d5-EtFOSAA	19	16	87	50-150	
13C7_PFUdA	19	20	105	50-150	
13C2_PFDaA	19	20	105	50-150	
13C2_PFTeDA	19	18	97	50-150	
13C3_HFPO-DA	19	20	107	50-150	
13C2_PFHxDA	19	17	91	50-150	
d7-N-MeFOSE	19	16	84	10-150	
d9-N-EtFOSE	19	16	84	10-150	
d3-N-MeFOSA	19	10	56	10-150	
d5-N-EtFOSA	19	12	62	10-150	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

LCS Analysis Summary
 PFAS by Isotope Dilution

Page 2 of 4

Lab Sample ID LCS-95272
 Run File Name A211229A_009
 Analyzed 12/29/2021 15:48
 Injected By NH

Instrument ID 10LCMS03
 Column ID 112EB00094
 Ical ID 211228A03
 Level L

Native Analytes

Compound	Known Conc.	Conc. Found	%Recovery	Recovery Limits	Qualifiers	CAS No.
PFBA	3.8	4.3	113	73-129		375-22-4
PFPeA	3.8	4.1	108	72-129		2706-90-3
HFPO-DA	3.8	4.4	116	70-140		13252-13-6
PFBS	3.3	3.9	117	72-130		375-73-5
PFHxA	3.8	4.3	112	72-129		307-24-4
4:2 FTS	3.5	4.0	113	63-143		757124-72-4
PFPeS	3.6	4.2	119	71-127		2706-91-4
PFHpA	3.8	4.6	120	72-130		375-85-9
DONA	3.6	4.1	115	70-140		919005-14-4
PFHxS	3.4	4.1	120	68-131		355-46-4
PFOA	3.8	4.2	110	71-133		335-67-1
6:2 FTS	3.6	4.6	127	64-140		27619-97-2
PFHpS	3.6	3.8	106	69-134		375-92-8
PFNA	3.8	4.3	113	69-130		375-95-1
PFOSAm	3.8	4.2	111	67-137		754-91-6
PFOS	3.5	3.9	111	65-140		1763-23-1
MeFOSA	3.8	4.3	114	68-141		31506-32-8
PFDA	3.8	4.3	115	71-129		335-76-2
EtFOSA	3.8	4.1	109	70-140		4151-50-2
8:2 FTS	3.6	4.3	120	67-138		39108-34-4
9-CI-PF3ON	3.5	4.0	112	70-130		756426-58-1
PFNS	3.6	3.9	109	69-127		68259-12-1
PFUnDA	3.8	4.1	108	69-133		2058-94-8
NMeFOSAA	3.8	4.3	113	65-136		2355-31-9
NEtFOSAA	3.8	4.4	116	61-135		2991-50-6
PFDS	3.7	3.9	106	53-142		335-77-3
PFDOA	3.8	4.2	112	72-134		307-55-1
MeFOSE	3.8	4.3	113	70-140		24448-09-7
10:2 FTS	3.6	3.9	107	70-140		120226-60-0
EtFOSE	3.8	4.0	105	70-140		1691-99-2
11-CI-PF3OUdS	3.6	3.8	107	70-140		763051-92-9
PFTTrDA	3.8	4.1	108	65-144		72629-94-8
PFDdS	3.7	3.8	105	70-140		79780-39-5
PFTDA	3.8	4.3	114	71-132		376-06-7
PFHXDA	3.8	4.6	123	70-140		67905-19-5
PFODA	3.8	4.0	107	70-140		16517-11-6

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

LCS Analysis Summary
 PFAS by Isotope Dilution

Page 3 of 4

Lab Sample ID LCS-95272
 Run File Name A211229A_009
 Analyzed 12/29/2021 15:48
 Injected By NH

Instrument ID 10LCMS03
 Column ID 112EB00094
 Ical ID 211228A03
 Level L

Injection Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Qualifiers
13C2 PFHxA	N/A	N/A	4.92	4.93	
13C4 PFOA	N/A	N/A	5.87	5.89	
13C2 PFDA	N/A	N/A	6.75	6.77	
13C4 PFOS	N/A	N/A	7.05	7.08	

Extracted Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Qualifiers
13C4 PFBA	N/A	N/A	3.50	3.52	
13C5 PFPeA	N/A	N/A	4.33	4.35	
13C3 PFBS	N/A	N/A	5.09	5.11	
13C2 4:2FTS	N/A	N/A	4.70	4.72	
13C5 PFHxA	N/A	N/A	4.92	4.93	
13C4 PFHpA	N/A	N/A	5.42	5.43	
13C3 PFHxS	N/A	N/A	6.15	6.17	
13C2 6:2FTS	N/A	N/A	5.65	5.66	
13C8 PFOA	N/A	N/A	5.87	5.89	
13C9 PFNA	N/A	N/A	6.31	6.33	
13C8 PFOS	N/A	N/A	7.05	7.08	
13C2 8:2FTS	N/A	N/A	6.51	6.52	
13C6 PFDA	N/A	N/A	6.75	6.77	
d3-MeFOSAA	N/A	N/A	6.71	6.72	
13C8 PFOSA	N/A	N/A	8.63	8.65	
d5-EtFOSAA	N/A	N/A	6.91	6.93	
13C7 PFUdA	N/A	N/A	7.18	7.20	
13C2 PFDoA	N/A	N/A	7.62	7.64	
13C2 PFTeDA	N/A	N/A	8.46	8.48	
13C3 HFPO-DA	N/A	N/A	5.12	5.14	
13C2 PFHxDA	N/A	N/A	9.21	9.24	
d7-N-MeFOSE	N/A	N/A	9.93	9.95	
d9-N-EtFOSE	N/A	N/A	10.54	10.56	
d3-N-MeFOSA	N/A	N/A	10.18	10.20	
d5-N-EtFOSA	N/A	N/A	10.85	10.87	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

LCS Analysis Summary
 PFAS by Isotope Dilution

Page 4 of 4

Lab Sample ID LCS-95272
 Run File Name A211229A_009
 Analyzed 12/29/2021 15:48
 Injected By NH

Instrument ID 10LCMS03
 Column ID 112EB00094
 Ical ID 211228A03
 Level L

Native Analytes

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Qualifiers
PFBA	N/A	N/A	3.50	3.52	
PFPeA	N/A	N/A	4.34	4.35	
HFPO-DA	0.47	0.47	5.13	5.15	
PFBS	0.31	0.34	5.10	5.12	
PFHxA	0.05	0.06	4.92	4.94	
4:2 FTS	0.52	0.56	4.71	4.72	
PFPeS	0.30	0.31	5.66	5.68	
PFHpA	0.28	0.31	5.42	5.44	
DONA	0.49	0.48	5.59	5.61	
PFHxS	0.26	0.29	6.15	6.17	
PFOA	0.38	0.37	5.88	5.90	
6:2 FTS	0.54	0.51	5.65	5.67	
PFHpS	0.25	0.23	6.61	6.64	
PFNA	0.20	0.19	6.32	6.34	
PFOSAm	N/A	N/A	8.64	8.65	
PFOS	0.23	0.22	7.06	7.09	
MeFOSA	0.86	0.93	10.20	10.22	
PFDA	0.09	0.11	6.75	6.77	
EtFOSAm	0.67	0.70	10.88	10.90	
8:2 FTS	0.70	0.65	6.51	6.52	
9-Cl-PF3ON	0.01	0.02	7.38	7.40	
PFNS	0.23	0.24	7.50	7.52	
PFUnDA	0.11	0.12	7.19	7.21	
NMeFOSAA	0.50	0.53	6.71	6.73	
NEtFOSAA	0.76	0.87	6.92	6.94	
PFDS	0.24	0.25	7.92	7.95	
PFDOA	0.13	0.13	7.62	7.64	
MeFOSE	N/A	N/A	9.97	9.99	
10:2 FTS	0.71	0.70	7.37	7.39	
EtFOSE	0.00	0.00	10.60	10.62	
11-Cl-PF3OUdS	0.01	0.01	8.23	8.25	
PFTTrDA	0.14	0.15	8.04	8.07	
PFDoS	0.23	0.22	8.72	8.75	
PFTDA	0.15	0.16	8.46	8.49	
PFHXDA	0.12	0.13	9.22	9.24	
PFODA	0.11	0.09	10.15	10.20	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

LCSD Analysis Summary
 PFAS by Isotope Dilution

Page 1 of 4

Lab Sample ID LCSD-95273
 Run File Name A211229A_010
 Analyzed 12/29/2021 16:03
 Injected By NH

Instrument ID 10LCMS03
 Column ID 112EB00094
 Ical ID 211228A03
 Level L

Injection Internal Standards

Compound	Known Conc.	LCS Conc. Found	LCS Rec. %	LCSD Conc. Found	LCSD Rec. %	RPD %	Recovery Limits	Qualifiers
13C2 PFHxA	19	21	113	20	108	4.7	50-150	
13C4 PFOA	19	21	110	21	113	2.2	50-150	
13C2 PFDA	19	21	111	21	114	2.5	50-150	
13C4 PFOS	18	21	115	21	120	4.1	50-150	

Extracted Internal Standards

Compound	Known Conc.	LCS Conc. Found	LCS Rec. %	LCSD Conc. Found	LCSD Rec. %	RPD %	Recovery Limits	Qualifiers
13C4 PFBA	19	21	109	20	107	2.2	50-150	
13C5 PFPeA	19	21	111	20	106	4.5	50-150	
13C3 PFBS	17	18	103	18	102	0.9	50-150	
13C2 4:2FTS	17	19	109	19	107	1.5	50-150	
13C5 PFHxA	19	21	110	20	108	2.0	50-150	
13C4 PFHpA	19	20	105	20	108	3.1	50-150	
13C3 PFHxS	18	20	111	20	113	2.1	50-150	
13C2 6:2FTS	18	23	127	21	117	8.1	50-150	
13C8 PFOA	19	20	103	20	108	4.2	50-150	
13C9 PFNA	19	20	103	20	108	4.5	50-150	
13C8 PFOS	18	20	112	19	104	7.2	50-150	
13C2 8:2FTS	18	17	94	19	105	10.5	50-150	
13C6 PFDA	19	20	105	19	104	0.3	50-150	
d3-MeFOSAA	19	17	89	18	98	9.9	50-150	
13C8 PFOSA	19	18	95	17	92	3.9	50-150	
d5-EtFOSAA	19	16	87	17	90	3.9	50-150	
13C7 PFUdA	19	20	105	20	109	3.4	50-150	
13C2 PFDoA	19	20	105	20	109	3.1	50-150	
13C2 PFTeDA	19	18	97	19	102	5.3	50-150	
13C3 HFPO-DA	19	20	107	20	109	1.4	50-150	
13C2 PFHxDA	19	17	91	18	96	5.3	50-150	
d7-N-MeFOSE	19	16	84	15	81	3.7	10-150	
d9-N-EtFOSE	19	16	84	15	79	5.8	10-150	
d3-N-MeFOSA	19	10	56	9.0	48	13.8	10-150	
d5-N-EtFOSA	19	12	62	9.3	50	22.5	10-150	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

LCSD Analysis Summary
 PFAS by Isotope Dilution

Page 2 of 4

Lab Sample ID LCSD-95273
 Run File Name A211229A_010
 Analyzed 12/29/2021 16:03
 Injected By NH

Instrument ID 10LCMS03
 Column ID 112EB00094
 Ical ID 211228A03
 Level L

Native Analytes

Compound	Known Conc.	LCS Conc. Found	LCS Rec. %	LCSD Conc. Found	LCSD Rec. %	RPD %	Recovery Limits	Qualifiers
PFBA	3.7	4.3	113	4.4	118	3.9	73-129	
PFPeA	3.7	4.1	108	4.3	115	6.0	72-129	
HFPO-DA	3.7	4.4	116	4.2	112	3.4	70-140	
PFBS	3.3	3.9	117	3.8	116	0.8	72-130	
PFHxA	3.7	4.3	112	4.1	110	2.2	72-129	
4:2 FTS	3.5	4.0	113	3.9	112	1.3	63-143	
PFPeS	3.5	4.2	119	4.0	114	4.5	71-127	
PFHpA	3.7	4.6	120	4.5	119	0.8	72-130	
DONA	3.5	4.1	115	3.8	107	7.3	70-140	
PFHxS	3.4	4.1	120	3.7	110	8.9	68-131	
PFOA	3.7	4.2	110	4.1	111	0.5	71-133	
6:2 FTS	3.6	4.6	127	4.9	137	7.4	64-140	
PFHpS	3.6	3.8	106	3.9	110	3.7	69-134	
PFNA	3.7	4.3	113	4.2	113	0.3	69-130	
PFOSAm	3.7	4.2	111	4.2	112	1.2	67-137	
PFOS	3.5	3.9	111	4.2	122	8.9	65-140	
MeFOSA	3.7	4.3	114	4.0	106	6.8	68-141	
PFDA	3.7	4.3	115	4.0	108	5.9	71-129	
EtFOSAm	3.7	4.1	109	4.0	106	2.8	70-140	
8:2 FTS	3.6	4.3	120	4.4	123	3.1	67-138	
9-CI-PF3ON	3.5	4.0	112	4.0	115	2.8	70-130	
PFNS	3.6	3.9	109	4.1	114	5.1	69-127	
PFUnDA	3.7	4.1	108	4.3	114	6.0	69-133	
NMeFOSAA	3.7	4.3	113	4.1	110	2.7	65-136	
NEtFOSAA	3.7	4.4	116	4.3	116	0.2	61-135	
PFDS	3.6	3.9	106	3.8	106	0.5	53-142	
PFDOA	3.7	4.2	112	4.0	108	3.9	72-134	
MeFOSE	3.7	4.3	113	4.0	106	5.8	70-140	
10:2 FTS	3.6	3.9	107	3.8	104	3.1	70-140	
EtFOSE	3.7	4.0	105	3.9	105	0.2	70-140	
11-CI-PF3OUdS	3.5	3.8	107	3.9	110	3.1	70-140	
PFTTrDA	3.7	4.1	108	3.8	101	6.2	65-144	
PFDoS	3.6	3.8	105	4.0	111	6.0	70-140	
PFTDA	3.7	4.3	114	4.0	107	6.4	71-132	
PFHXDA	3.7	4.6	123	4.2	113	7.9	70-140	
PFODA	3.7	4.0	107	3.9	104	2.8	70-140	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

LCSD Analysis Summary

PFAS by Isotope Dilution

Page 3 of 4

Lab Sample ID LCSD-95273
 Run File Name A211229A_010
 Analyzed 12/29/2021 16:03
 Injected By NH

Instrument ID 10LCMS03
 Column ID 112EB00094
 Ical ID 211228A03
 Level L

Injection Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Qualifiers
13C2 PFHxA	N/A	N/A	4.92	4.93	
13C4 PFOA	N/A	N/A	5.88	5.89	
13C2 PFDA	N/A	N/A	6.76	6.77	
13C4 PFOS	N/A	N/A	7.06	7.08	

Extracted Internal Standards

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Qualifiers
13C4 PFBA	N/A	N/A	3.50	3.52	
13C5 PFPeA	N/A	N/A	4.34	4.35	
13C3 PFBS	N/A	N/A	5.10	5.11	
13C2 4:2FTS	N/A	N/A	4.71	4.72	
13C5 PFHxA	N/A	N/A	4.92	4.93	
13C4 PFHpA	N/A	N/A	5.42	5.43	
13C3 PFHxS	N/A	N/A	6.15	6.17	
13C2 6:2FTS	N/A	N/A	5.65	5.66	
13C8 PFOA	N/A	N/A	5.88	5.89	
13C9 PFNA	N/A	N/A	6.32	6.33	
13C8 PFOS	N/A	N/A	7.06	7.08	
13C2 8:2FTS	N/A	N/A	6.51	6.52	
13C6 PFDA	N/A	N/A	6.76	6.77	
d3-MeFOSAA	N/A	N/A	6.71	6.72	
13C8 PFOSA	N/A	N/A	8.64	8.65	
d5-EtFOSAA	N/A	N/A	6.92	6.93	
13C7 PFUdA	N/A	N/A	7.19	7.20	
13C2 PFDoA	N/A	N/A	7.62	7.64	
13C2 PFTeDA	N/A	N/A	8.46	8.48	
13C3 HFPO-DA	N/A	N/A	5.13	5.14	
13C2 PFHxDA	N/A	N/A	9.22	9.24	
d7-N-MeFOSE	N/A	N/A	9.94	9.95	
d9-N-EtFOSE	N/A	N/A	10.54	10.56	
d3-N-MeFOSA	N/A	N/A	10.18	10.20	
d5-N-EtFOSA	N/A	N/A	10.85	10.87	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.



Pace Analytical Services, LLC
 1700 Elm Street, Suite 200
 Minneapolis, MN 55414
 Phone: 612.607.1700
 Fax: 612.607.6444
 www.pacelabs.com

LCSD Analysis Summary
 PFAS by Isotope Dilution

Page 4 of 4

Lab Sample ID LCSD-95273
 Run File Name A211229A_010
 Analyzed 12/29/2021 16:03
 Injected By NH

Instrument ID 10LCMS03
 Column ID 112EB00094
 Ical ID 211228A03
 Level L

Native Analytes

Compound	Ion Abund. Ratio	Reference Ratio	Retention Time	Reference Time	Qualifiers
PFBA	N/A	N/A	3.51	3.52	
PFPeA	N/A	N/A	4.34	4.35	
HFPO-DA	0.48	0.47	5.14	5.15	
PFBS	0.32	0.34	5.11	5.12	
PFHxA	0.06	0.06	4.93	4.94	
4:2 FTS	0.53	0.56	4.71	4.72	
PFPeS	0.29	0.31	5.67	5.68	
PFHpA	0.31	0.31	5.43	5.44	
DONA	0.51	0.48	5.60	5.61	
PFHxS	0.26	0.29	6.16	6.17	
PFOA	0.34	0.37	5.89	5.90	
6:2 FTS	0.42	0.51	5.66	5.67	
PFHpS	0.26	0.23	6.62	6.64	
PFNA	0.17	0.19	6.33	6.34	
PFOSAm	N/A	N/A	8.65	8.65	
PFOS	0.21	0.22	7.07	7.09	
MeFOSA	0.92	0.93	10.20	10.22	
PFDA	0.09	0.11	6.76	6.77	
EtFOSAm	0.68	0.70	10.88	10.90	
8:2 FTS	0.61	0.65	6.52	6.52	
9-Cl-PF3ON	0.02	0.02	7.38	7.40	
PFNS	0.23	0.24	7.50	7.52	
PFUnDA	0.10	0.12	7.19	7.21	
NMeFOSAA	0.54	0.53	6.72	6.73	
NEtFOSAA	0.66	0.87	6.93	6.94	
PFDS	0.26	0.25	7.93	7.95	
PFDOA	0.14	0.13	7.63	7.64	
MeFOSE	N/A	N/A	9.98	9.99	
10:2 FTS	0.71	0.70	7.37	7.39	
EtFOSE	0.00	0.00	10.60	10.62	
11-Cl-PF3OUdS	0.01	0.01	8.23	8.25	
PFTDA	0.14	0.15	8.05	8.07	
PFDoS	0.23	0.22	8.72	8.75	
PFTDA	0.14	0.16	8.47	8.49	
PFHXDA	0.13	0.13	9.22	9.24	
PFODA	0.10	0.09	10.15	10.20	

REPORT OF LABORATORY ANALYSIS

This report shall not be reproduced, except in full,
 without the written consent of Pace Analytical Services, LLC.

Bibliography

- 3M. (1999). *3M Light Water (TM) Material Safety Data Sheet*. 1999.
- 3M. (2000). *Phase-out plan for POSF-based products*.
- Adamson, D. T., Nickerson, A., Kulkarni, P. R., Higgins, C. P., Popovic, J., Field, J., Rodowa, A., Newell, C., Deblanc, P., & Kornuc, J. J. (2020). Mass-Based, Field-Scale Demonstration of PFAS Retention within AFFF-Associated Source Areas. *Environmental Science Technologies*, 54, 15768–15777. <https://doi.org/10.1021/acs.est.0c04472>
- Agency for Toxic Substances and Disease Registry. (2021). Toxicological Profile for Perfluoroalkyls. *Atsdr*, 205, 24. <http://dx.doi.org/10.1155/2013/286524>
- Ahrens, L. (2011). Polyfluoroalkyl compounds in the aquatic environment: A review of their occurrence and fate. *Journal of Environmental Monitoring*, 13(1), 20–31. <https://doi.org/10.1039/c0em00373e>
- Ahrens, L., & Bundschuh, M. (2014). Fate and effects of poly- and perfluoroalkyl substances in the aquatic environment: A review. *Environmental Toxicology and Chemistry*, 33(9), 1921–1929. <https://doi.org/10.1002/etc.2663>
- Askeland, M., Clarke, B., & Paz-Ferreiro, J. (2020). A serial PFASs sorption technique coupled with adapted high volume direct aqueous injection LCMS method. *MethodsX*, 7. <https://doi.org/10.1016/j.mex.2020.100886>
- Ateia, M., Maroli, A., Tharayil, N., & Karanfil, T. (2019). The overlooked short- and ultrashort-chain poly- and perfluorinated substances: A review. *Chemosphere*, 220, 866–882. <https://doi.org/10.1016/J.CHEMOSPHERE.2018.12.186>
- Attallah, O. A., Al-Ghobashy, M. A., Nebesen, M., & Salem, M. Y. (2016). Removal of cationic and anionic dyes from aqueous solution with magnetite/pectin and magnetite/silica/pectin hybrid nanocomposites: Kinetic, isotherm and mechanism analysis. *RSC Advances*, 6(14), 11461–11480. <https://doi.org/10.1039/c5ra23452b>
- Azzolini, D. C. (2014). *Desorptive Behavior of Perfluoroalkyl Acids and Perfluoroalkyl Acid Precursors from Aqueous Film-Forming Foam Impacted Soils and Aquifer Materials*. Colorado School of Mines.
- Backe, W J, Day, T. C., & Field, J. A. (2013). Zwitterionic, cationic, and anionic fluorinated chemicals in aqueous film forming foam formulations and groundwater from US. military bases by nonaqueous large-volume injection HPLC-MS/MS. *Environmental Science and Technology*, 47(10), 5226–5234. <https://doi.org/10.1021/es3034999>
- Backe, Will J., Day, T. C., & Field, J. A. (2013). Zwitterionic, cationic, and anionic fluorinated chemicals in aqueous film forming foam formulations and groundwater from U.S. military bases by nonaqueous large-volume injection HPLC-MS/MS. *Environmental Science and Technology*, 47(10), 5226–5234.

<https://doi.org/10.1021/es3034999>

- Baduel, C., Paxman, C. J., & Mueller, J. F. (2015). Perfluoroalkyl substances in a firefighting training ground (FTG), distribution and potential future release. *Journal of Hazardous Materials*, 296, 46–53. <https://doi.org/10.1016/j.jhazmat.2015.03.007>
- Barzen-Hanson, K. A., Davis, S. E., Kleber, M., & Field, J. A. (2017). Sorption of Fluorotelomer Sulfonates, Fluorotelomer Sulfonamido Betaines, and a Fluorotelomer Sulfonamido Amine in National Foam Aqueous Film-Forming Foam to Soil. *Environmental Science and Technology*, 51(21), 12394–12404. <https://doi.org/10.1021/acs.est.7b03452>
- Barzen-Hanson, K. A., & Field, J. A. (2015). *Discovery and Implications of C 2 and C 3 Perfluoroalkyl Sulfonates in Aqueous Film-Forming Foams and Groundwater*. <https://doi.org/10.1021/acs.estlett.5b00049>
- Bikos, D. A., & Mason, T. G. (2019). Band-collision gel electrophoresis. *Nature Communications*, 10(1). <https://doi.org/10.1038/s41467-019-11438-9>
- Bolan, N., Sarkar, B., Yan, Y., Li, Q., Wijesekara, H., Kannan, K., Tsang, D. C. W., & Schauerte, M. (2021). Remediation of poly- and perfluoroalkyl substances (PFAS) contaminated soils - To mobilize or immobilize or to degrade? *Journal of Hazardous Materials*, 401. <https://doi.org/10.1016/j.jhazmat.2020.123892>
- Bolan, Nanthi, Sarkar, B., Yan, Y., Li, Q., Wijesekara, H., Kannan, K., Tsang, D. C. W., Schauerte, M., Bosch, J., Noll, H., Ok, Y. S., Scheckel, K., Kumpiene, J., Gobindlal, K., Kah, M., Sperry, J., Kirkham, M. B., Wang, H., Tsang, Y. F., ... Rinklebe, J. (2021). Remediation of poly- and perfluoroalkyl substances (PFAS) contaminated soils – To mobilize or to immobilize or to degrade? *Journal of Hazardous Materials*, 401(September 2020). <https://doi.org/10.1016/j.jhazmat.2020.123892>
- Bossi, R. C., Rigel, F. F., Dietz, R., Sonne, C., Fauser, P., Dam, M., & Vorkamp, K. (2005). Preliminary screening of perfluorooctane PFOS) and other fluorochemicals in fish, burds and marine mammals from Greenland to the Faroe Islands. *Environmental Pollution*, 136, 323–329.
- Brusseau, M. L. (2018). Assessing the potential contributions of additional retention processes to PFAS retardation in the subsurface. *Science of The Total Environment*, 613–614, 176–185. <https://doi.org/10.1016/J.SCITOTENV.2017.09.065>
- Brusseau, M. L., Yan, N., van Glubt, S., Wang, Y., Chen, W., Lyu, Y., Dungan, B., Carroll, K. C., & Holguin, F. O. (2019). Comprehensive retention model for PFAS transport in subsurface systems. *Water Research*, 148, 41–50. <https://doi.org/10.1016/j.watres.2018.10.035>
- Buck, R. C., Franklin, J., Berger, U., Conder, J. M., Cousins, I. T., & de Voogt, P. (2011). Perfluoroalkyl and Polyfluoroalkyl Substances in the Environment: Terminology, Classification, and Origins. *Integrated Environmental Assessment Management*, 7, 513–541. <https://doi.org/10.1002/ieam.258>
- by David Kempisty, E. M., & Racz, L. (2021). *Forever Chemicals: Environmental*,

Economic, and Social Equity Concerns with PFAS in the Environment.
<https://www.crcpress.com/Environmental->

- Calafat, A. M., Wong, L. Y., Kuklenyik, Z., Reidy, J. A., & Needham, L. L. (2007). Polyfluoroalkyl chemicals in the U.S. population: Data from the national health and nutrition examination survey (NHANES) 2003-2004 and comparisons with NHANES 1999-2000. *Environmental Health Perspectives*, 115(11), 1596–1602. <https://doi.org/10.1289/ehp.10598>
- Chen, Y. C., Lo, S. L., Li, N. H., Lee, Y. C., & Kuo, J. (2013). Sorption of perfluoroalkyl substances (PFASs) onto wetland soils. *Desalination and Water Treatment*, 51(40-42), 7469–7475. <https://doi.org/10.1080/19443994.2013.792145>
- Chin, D. A. (2019). Estimating Peak Runoff Rates Using the Rational Method. *Journal of Irrigation and Drainage Engineering*, 145(6), 04019006. [https://doi.org/10.1061/\(asce\)ir.1943-4774.0001387](https://doi.org/10.1061/(asce)ir.1943-4774.0001387)
- Climate-Data. (2021). *Climate Ginowan (Japan)*.
- Davis, M. L. (Michigan S. U., & Masten, S. J. (Michigan S. U. (2014). *Principles of Enviromental Engineering and Science* (3rd ed.). McGraw-Hill.
- Domingo, J. L., & Nadal, M. (2019). Human exposure to per- and polyfluoroalkyl substances (PFAS) through drinking water: A review of the recent scientific literature. *Environmental Research*, 177(August). <https://doi.org/10.1016/j.envres.2019.108648>
- Du, Z., Deng, S., Bei, Y., Huang, Q., Wang, B., Huang, J., & Yu, G. (2014). Adsorption behavior and mechanism of perfluorinated compounds on various adsorbents-A review. *Journal of Hazardous Materials*, 274, 443–454. <https://doi.org/10.1016/j.jhazmat.2014.04.038>
- Eldridge, R. D. (2012). *The Okinawa “Base Problem” Today*. Nippon.Com. <https://www.nippon.com/en/in-depth/a00501>
- Gagliano, E., Sgroi, M., Falciglia, P. P., Vagliasindi, F. G. A., & Roccaro, P. (2020). Removal of poly- and perfluoroalkyl substances (PFAS) from water by adsorption: Role of PFAS chain length, effect of organic matter and challenges in adsorbent regeneration. *Water Research*, 171. <https://doi.org/10.1016/J.WATRES.2019.115381>
- Glüge, J., Scheringer, M., Cousins, I. T., Dewitt, J. C., Goldenman, G., Herzke, D., Lohmann, R., Ng, C. A., Trier, X., & Wang, Z. (2020). An overview of the uses of per- And polyfluoroalkyl substances (PFAS). *Environmental Science: Processes and Impacts*, 22(12), 2345–2373. <https://doi.org/10.1039/d0em00291g>
- GoogleMaps. (2021). *MCAS Futenma, 1:1,500*.
- Guelfo, J. L., & Higgins, C. P. (2013). Subsurface transport potential of perfluoroalkyl acids at aqueous film-forming foam (AFFF)-impacted sites. *Environmental Science and Technology*, 47(9), 4164–4171. <https://doi.org/10.1021/es3048043>
- Hayes, J., & Faber, S. (2019). *Mapping PFAS Chemical Contamination at 206 U.S.*

Military Sites. EWG.Org. <https://www.ewg.org/research/pfas-chemicals-contaminate-us-military-sites>

- Higgins, C. P., & Luthy, R. G. (2006). Sorption of perfluorinated surfactants on sediments. *Environmental Science and Technology*, 40(23), 7251–7256. <https://doi.org/10.1021/es061000n>
- Houtz, E. F., Higgins, C. P., Field, J. A., & Sedlak, D. L. (2013). *Persistence of Perfluoroalkyl Acid Precursors in AFFF-Impacted Groundwater and Soil*. Persistence of Perfluoroalkyl Acid Precursors in AFFF-Impacted Groundwater and Soil. <https://doi.org/10.1021/es4018877>
- Interstate Technology Regulatory Council. (2017). *History and Use of Per- and Polyfluoroalkyl Substances*. https://pfas-1.itrcweb.org/fact_sheets_page/PFAS_Fact_Sheet_History_and_Use_April2020.pdf
- Kah, M., Oliver, D., & Kookana, R. (2021). Sequestration and potential release of PFAS from spent engineered sorbents. *Science of the Total Environment*, 765, 142770. <https://doi.org/10.1016/j.scitotenv.2020.142770>
- Kakade, A. M. (2014). Measuring Concrete Surface pH - a Proposed Test Method. *Concrete Repair Bulletin*, April, 16–20.
- Kempisty, D., Xing, Y., & Racz, L. (2018). *Perfluoroalkyl Substances in the Environment: Theory, Practice, and Innovation*.
- Kim, S., & Cho, Y. I. (2003). The effect of dye concentration on the viscosity of water in a scanning capillary-tube viscometer. *Journal of Non-Newtonian Fluid Mechanics*, 111(1), 63–68. [https://doi.org/10.1016/S0377-0257\(03\)00009-0](https://doi.org/10.1016/S0377-0257(03)00009-0)
- Kwok, K. Y., Wang, X. H., Ya, M., Li, Y., Zhang, X. H., Yamashita, N., Lam, J. C. W., & Lam, P. K. S. (2015). Occurrence and distribution of conventional and new classes of per- and polyfluoroalkyl substances (PFASs) in the South China Sea. *Journal of Hazardous Materials*, 285, 389–397. <https://doi.org/10.1016/j.jhazmat.2014.10.065>
- Landrigan, P. J., Stegeman, J. J., Fleming, L. E., Allemand, D., Anderson, D. M., Backer, L. C., Brucker-Davis, F., Chevalier, N., Corra, L., Czerucka, D., Bottein, M. Y. D., Demeneix, B., Depledge, M., Deheyn, D. D., Dorman, C. J., Fénichel, P., Fisher, S., Gaill, F., Galgani, F., ... Rampal, P. (2020). Human health and ocean pollution. *Annals of Global Health*, 86(1), 1–64. <https://doi.org/10.5334/aogh.2831>
- Larson, R., Hostetler, R. P., & Edwards, B. H. (2010). *College Algebra: A Graphing Approach*. Brooks/Cole, Cengage Learning.
- Lee, Y. C., Lo, S. L., Kuo, J., & Lin, Y. L. (2012). Persulfate oxidation of perfluorooctanoic acid under the temperatures of 20–40°C. *Chemical Engineering Journal*, 198–199, 27–32. <https://doi.org/10.1016/j.cej.2012.05.073>
- Li, Y., Oliver, D. P., & Kookana, R. S. (2018). A critical analysis of published data to discern the role of soil and sediment properties in determining sorption of per and polyfluoroalkyl substances (PFASs). In *Science of the Total Environment* (Vols.

- 628–629, pp. 110–120). <https://doi.org/10.1016/j.scitotenv.2018.01.167>
- Lim, H. S. (2018). Open channel flow friction factor: Logarithmic law. *Journal of Coastal Research*, 34(1), 229–237. <https://doi.org/10.2112/JCOASTRES-D-17-00030.1>
- MasterFlex(TM). (2020). *Pump Tubing Selection Guide*.
- McCormac, J. C., & Brown, R. H. (2014). *Design of Reinforced Concrete* (Ninth). John Wiley & Sons, Inc.
- Michigan Department of Environmental Quality. (2018). *General Pfas Sampling*. 24.
- Moody, C. A., & Field, J. A. (2000). *Critical Review Perfluorinated Surfactants and the Environmental Implications of Their Use in Fire-Fighting Foams*. <https://doi.org/10.1021/es991359u>
- National Center for Biotechnology Information. (2004a). *PubChem Compound Summary for CID 33258, Allura Red AC*. National Library of Medicine. <https://pubchem.ncbi.nlm.nih.gov/compound/Allura-Red-AC>
- National Center for Biotechnology Information. (2004b). *PubChem Compound Summary for CID 6099, Methylene Blue*. National Library of Medicine. <https://pubchem.ncbi.nlm.nih.gov/compound/Methylene-blue>
- National Center for Biotechnology Information. (2020). *PubChem Compound Summary for CID 19700, Brilliant Blue*. National Library of Medicine. <https://pubchem.ncbi.nlm.nih.gov/compound/Brilliant-Blue>
- Naval Sea Systems Command. (2017). *MIL-PRF-24385F2*.
- Nickerson, A., Rodowa, A. E., Adamson, D. T., Field, J. A., Kulkarni, P. R., Kornuc, J. J., & Higgins, C. P. (2021). Spatial Trends of Anionic, Zwitterionic, and Cationic PFASs at an AFFF-Impacted Site. *Environmental Science and Technology*, 55, 313–323. <https://doi.org/10.1021/acs.est.0c04473>
- NIST/SEMATECH. (2012). *Nonlinear Least Squares Regression*. <https://doi.org/10.18434/M32189>
- Olsen, G. W., Mair, D. C., Lange, C. C., Harrington, L. M., Church, T. R., Goldberg, C. L., Herron, R. M., Hanna, H., Nobiletti, J. B., Rios, J. A., Reagen, W. K., & Ley, C. A. (2017). Per- and polyfluoroalkyl substances (PFAS) in {A}merican Red Cross adult blood donors, 200012015. *Environmental Research*, 157, 87–95. <https://doi.org/10.1016/J.ENVRES.2017.05.013>
- Omo-Okoro, P. N., Curtis, C. J., Karásková, P., Melymuk, L., Oyewo, O. A., & Okonkwo, J. O. (2020). Kinetics, Isotherm, and Thermodynamic Studies of the Adsorption Mechanism of PFOS and PFOA Using Inactivated and Chemically Activated Maize Tassel. *Water, Air, and Soil Pollution*, 231(9). <https://doi.org/10.1007/s11270-020-04852-z>
- Pace Analytical. (2021). *Selected 36 Per- and Polyfluoroalkyl Substances (PFAS) by LC/MS/MS*.

- Pace Analytical. (2022). *Department of Defense (DOD) Test Methods*.
<https://pfas.com/pfas-testing/dod-pfas-testing/>
- Place, B. J., & Field, J. A. (2012). *Identification of Novel Fluorochemicals in Aqueous Film-Forming Foams Used by the US Military*. <https://doi.org/10.1021/es301465n>
- Rice, P. (2019). Human Health Risk Assessment of Perfluorinated Chemicals. *Perfluoroalkyl Substances in the Environment*, 123–170.
<https://doi.org/10.1201/9780429487125-8>
- Saavedra-Labastida, E., Díaz-Nava, M. C., Illescas, J., & Muro, C. (2019). Comparison of the Removal of an Anionic Dye from Aqueous Solutions by Adsorption with Organically Modified Clays and their Composites. *Water, Air, and Soil Pollution*, 230(4). <https://doi.org/10.1007/s11270-019-4131-z>
- Schaefer, C., Drennan, D., Nickerson, A., Maizel, A., & Higgins, C. (2021). Diffusion of perfluoroalkyl acids through clay-rich soil. *Journal of Contaminant Hydrology*, 241. <https://doi-org.afil.idm.oclc.org/10.1016/j.jconhyd.2021.103814>
- Sepulvado, J. G., Blaine, A. C., Hundal, L. S., & Higgins, C. P. (2011). Occurrence and Fate of Perfluorochemicals in Soil Following the Land Application of Municipal Biosolids. *Environmental Science and Technology*, 45, 8106–8112.
<https://doi.org/10.1021/es103903d>
- Sheinson, R. S., Williams, B. A., Green, C., Fleming, J. W., Anleitner, R., Ayers, S., Maranghides, A., & Barylski, D. (2002). *THE FUTURE OF AQUEOUS FILM FORMING FOAM (AFFF): PERFORMANCE PARAMETERS AND REQUIREMENTS* Ronald S. Sheinson, Bradley A. Williams, Christian Green, James W. Fleming, Robert Anleitner.
- Silva, J. A. K., Martin, W. A., Johnson, J. L., & McCray, J. E. (2019). Evaluating air-water and NAPL-water interfacial adsorption and retention of Perfluorocarboxylic acids within the Vadose zone. *Journal of Contaminant Hydrology*, 223.
<https://doi.org/10.1016/j.jconhyd.2019.03.004>
- Sima, M. W., & Jaffe, P. R. (2021). *A critical review of modeling Poly- and Perfluoroalkyl Substances (PFAS) in the soil-water environment* (Vol. 757). Science of the Total Environment. <https://doi.org/10.1016/j.scitotenv.2020.143793>
- Simon, J. A., Abrams, S., Bradburne, T., Bryant, D., Burns, M., Newell, C. J., Parker, B. L., Singh, T., Tomiczek, P., & Wice, R. (2019). PFAS Experts Symposium: Statements on regulatory policy, chemistry and analytics, toxicology, transport/fate, and remediation for per-and polyfluoroalkyl substances (PFAS) contamination issues. *Remediation*, 29. <https://doi.org/10.1002/rem.21624>
- Söregård, M., Östblom, E., Köhler, S., & Ahrens, L. (2020). Adsorption behavior of per- And polyfluoroalkyl substances (PFASs) to 44 inorganic and organic sorbents and use of dyes as proxies for PFAS sorption. *Journal of Environmental Chemical Engineering*, 8(3), 103744. <https://doi.org/10.1016/j.jece.2020.103744>
- Sullivan, T. F. P. (2001). Environmental Law Handbook Updated. In *Chief Engineer*

(Vol. 66, Issue 7). Bernan Press.

- Thompson, M. (2014). *CHEMICAL DIFFUSION THROUGH CONCRETE A Study Showing That Concrete Is Highly Porous, Allowing the Penetration and Diffusion of Chemicals, Notably Pesticides* (Issue January) [University of Western Sydney]. <https://www.researchgate.net/publication/232808597%0ACHEMICAL>
- U.S. Environmental Protection Agency. (2009). Provisional Health Advisories for Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS). In *Environmental Protection*.
- U.S. Environmental Protection Agency. (2015). *The Third Unregulated Contaminant Monitoring Rule (UCMR 3): Data Summary June 2015 UCMR 3 Data Field Names and Definitions*. June, 1–12. <https://www.epa.gov/sites/production/files/2017-02/documents/ucmr3-data-summary-january-2017.pdf>
- U.S. Environmental Protection Agency. (2016). *FACT SHEET PFOA and PFOS Drinking Water Health Advisories* (Issue May).
- U.S. Environmental Protection Agency. (2017). *Risk Management for Per- and Polyfluoroalkyl Substances (PFAS) under TSCA*. U.S. Environmental Protection Agency, PFOA Stewardship Program. <https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-management-and-polyfluoroalkyl-substances-pfas#tab-3>
- U.S. Environmental Protection Agency. (2020). *Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) Technical Brief*. January, 2. https://www.epa.gov/sites/production/files/2019-02/documents/pfas_methods_tech_brief_28feb19_update.pdf
- USACE. (1995). *Structural Design of Concrete Lined Flood Control Channels*. U.S. Army Corps of Engineers.
- USFJ. (2020). *Japanese officials work with U.S. Marines at MCAS Futenma*. U.S. Forces Japan. <https://www.usfj.mil/Media/Press-Releases/Article-View/Article/2163347/japanese-officials-work-with-us-marines-at-mcas-futenma>
- USMC. (2012). *MCRP 3-40D.4, Concrete and masonry structures*.
- Vo, P., N., H., Ngo, H. H., Guo, W., Nguyen, H., M., T., Li, J., Liang, H., Deng, L., Chen, Z., & Hang Nguyen, T. A. (2020). Poly?and perfluoroalkyl substances in water and wastewater: A comprehensive review from sources to remediation. *Journal of Water Process Engineering*, 36. <https://doi.org/10.1016/J.JWPE.2020.101393>
- Vu, C. T., & Wu, T. (2020). *Recent progress in adsorptive removal of per- and polyfluoroalkyl substances (PFAS) from water/wastewater*. Critical Reviews in Environmental Science and Technology. <https://doi.org/10.1080/10643389.2020.1816125>
- Wang, F., & Shih, K. (2011). *Adsorption of perfluorooctanesulfonate (PFOS) and perfluorooctanoate (PFOA) on alumina: Influence of solution pH and cations*.

<https://doi.org/10.1016/j.watres.2011.03.007>

- Wang, Y., & Liu, A. (2020). Carbon-fluorine bond cleavage mediated by metalloenzymes. *Chemical Society Reviews*, 49(14), 4906–4925. <https://doi.org/10.1039/c9cs00740g>
- Xiao, F., Jin, B., Golovko, S. A., Golovko, M. Y., & Xing, B. (2019). Sorption and Desorption Mechanisms of Cationic and Zwitterionic Per- And Polyfluoroalkyl Substances in Natural Soils: Thermodynamics and Hysteresis. *Environmental Science and Technology*, 53(20). <https://doi.org/10.1021/acs.est.9b05379>
- Xie, S., Wen, Z., Zhan, H., & Jin, M. (2018). An Experimental Study on the Adsorption and Desorption of Cu(II) in Silty Clay. *Geofluids*, 2018. <https://doi.org/10.1155/2018/3610921>
- Xu, Y., Fletcher, T., Pineda, D., Lindh, C. H., Nilsson, C., Glynn, A., Vogs, C., Norström, K., Lilja, K., Jakobsson, K., & Li, Y. (2020). Serum half-lives for short- and long-chain perfluoroalkyl acids after ceasing exposure from drinking water contaminated by firefighting foam. *Environmental Health Perspectives*, 128(7), 1–11. <https://doi.org/10.1289/EHP6785>
- Yang, J., Du, Q., & Bao, Y. (2011). Concrete with recycled concrete aggregate and crushed clay bricks. *Construction and Building Materials*, 25(4), 1935–1945. <https://doi.org/10.1016/j.conbuildmat.2010.11.063>
- Yi, S., Harding-Marjanovic, K. C., Houtz, E. F., Gao, Y., Lawrence, J. E., Nichiporuk, R. v, Iavarone, A. T., Zhuang, W.-Q., Hansen, M., Field, J. A., Sedlak, D. L., & Alvarez-Cohen, L. (2018). Biotransformation of AFFF Component: Fluorotelomer Thioether Amido Sulfonate Generates 6:2 Fluorotelomer Thioether Carboxylate under Sulfate-Reducing Conditions. 6(2). <https://doi.org/10.1021/acs.estlett.8b00148>
- Yin, P., Hu, Z., Song, X., Liu, J., & Lin, N. (2016). Activated persulfate oxidation of perfluorooctanoic acid (PFOA) in groundwater under acidic conditions. *International Journal of Environmental Research and Public Health*, 13(6). <https://doi.org/10.3390/ijerph13060602>
- Young, D. F., Munson, B. R., Okiishi, T. H., & Huebsch, W. W. (2011). *A Brief Introduction of Fluid Mechanics* (Fifth). John Wiley & Sons, Inc.
- Zareitalabad, P., Siemens, J., Hamer, M., & Amelung, W. (2013). Perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS) in surface waters, sediments, soils and wastewater - A review on concentrations and distribution coefficients. In *Chemosphere* (Vol. 91, Issue 6, pp. 725-732). <https://doi.org/10.1016/j.chemosphere.2013.02.024>
- Zhang, W., Zhang, D., Zagorevski, D. v., & Liang, Y. (2019). Exposure of *Juncus effusus* to seven perfluoroalkyl acids: Uptake, accumulation and phytotoxicity. *Chemosphere*, 233, 300–308. <https://doi.org/10.1016/J.CHEMOSPHERE.2019.05.258>
- Zhao, L., Bian, J., Zhang, Y., Zhu, L., & Liu, Z. (2014). Comparison of the sorption

behaviors and mechanisms of perfluorosulfonates and perfluorocarboxylic acids on three kinds of clay minerals. *Chemosphere*, 114, 51–58.
<https://doi.org/10.1016/j.chemosphere.2014.03.098>

REPORT DOCUMENTATION PAGE				<i>Form Approved</i> <i>OMB No. 0704-0188</i>							
<small>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</small> PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.											
1. REPORT DATE (DD-MM-YYYY) 24-03-2022		2. REPORT TYPE Master's Thesis		3. DATES COVERED (From - To) Aug 2020 - Mar 2022							
4. TITLE AND SUBTITLE Persistence and Mitigation of PFAS within Concrete Stormwater Drainage Infrastructure				5a. CONTRACT NUMBER							
				5b. GRANT NUMBER							
				5c. PROGRAM ELEMENT NUMBER							
6. AUTHOR(S) McDonald, Jason R., Capt, USMC				5d. PROJECT NUMBER 21V179							
				5e. TASK NUMBER							
				5f. WORK UNIT NUMBER							
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/EN) 2950 Hobson Way Wright-Patterson AFB OH 45433-7765				8. PERFORMING ORGANIZATION REPORT NUMBER AFIT-ENV-MS-22-M-234							
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Environmental Protection Agency Dr. Matthew Magnuson 26 West Martin Luther King Jr. Drive Cincinnati, OH 45268 magnuson.matthew@epa.gov				10. SPONSOR/MONITOR'S ACRONYM(S) EPA							
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)							
12. DISTRIBUTION/AVAILABILITY STATEMENT DISTRUBTION STATEMENT A. APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.											
13. SUPPLEMENTARY NOTES This material is declared a work of the U.S. Government and is not subject to copyright protection in the United States.											
14. ABSTRACT The persistence, fate, and transport of per- and poly-fluoroalkyl substances have been previously studied in environmental media such as soils and groundwater. This study investigates concrete, a medium that is rarely studied but frequently present in instances where PFAS originating from AFFF releases and spills have occurred. This work discusses the development of a fate and transport model that can be applied to PFAS contaminated concrete including stormwater channels that may drain from AFFF release points. The study used AFFF to investigate retention of PFAS by the concrete, as well as the ability of chemical dyes to trace the hydraulics of flowing water through small mock channels. A desorption model developed from this data incorporates properties of the concrete and simulated hydrological runoff, along with mechanistic terms for both diffusion and adsorption kinetics. This model can be used to estimate the length of time PFAS may remain above a given action level and provide a model that can be easily adapted to DoD and civilian installations to better manage and mitigate PFAS.											
15. SUBJECT TERMS PFAS, AFFF, Stormwater Drainage, Concrete, Desorption, Kinetic Modeling											
16. SECURITY CLASSIFICATION OF: <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 33%; padding: 2px;">a. REPORT</td> <td style="width: 33%; padding: 2px;">b. ABSTRACT</td> <td style="width: 33%; padding: 2px;">c. THIS PAGE</td> </tr> <tr> <td style="text-align: center; padding: 2px;">U</td> <td style="text-align: center; padding: 2px;">U</td> <td style="text-align: center; padding: 2px;">U</td> </tr> </table>			a. REPORT	b. ABSTRACT	c. THIS PAGE	U	U	U	17. LIMITATION OF ABSTRACT UU		18. NUMBER OF PAGES 188
a. REPORT	b. ABSTRACT	c. THIS PAGE									
U	U	U									
			19a. NAME OF RESPONSIBLE PERSON Dr. Eric Mbonimpa AFIT/ENV								
			19b. TELEPHONE NUMBER (Include area code) (937) 255-3636 x7405 eric.mbonimpa@afit.edu								