

Evaluation of PFAS in Wastewater Treatment Plants (WWTPs) Across the United States

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Table of Contents

| | | |
|-------|--|----|
| 1. | Introduction..... | 1 |
| 2. | Sampling Method and Analysis | 2 |
| 3. | Phase 1 Study | 5 |
| 3.1 | PFAS Percent Detection | 5 |
| 3.2 | PFAS Influent, Effluent, and Final Treated Concentrations..... | 9 |
| 3.3 | Industrial Sources Results..... | 14 |
| 3.4 | PFAS Concentrations for the Three Studies | 15 |
| 4. | Phase 2 Study | 21 |
| 4.1 | WWTP 2 Phase 2 Evaluation | 23 |
| 4.1.1 | Aqueous Fate and Transport Discussion | 24 |
| 4.1.2 | Solid Fate and Transport Discussion | 24 |
| 4.2 | WWTP 8 Phase 2 Evaluation | 27 |
| 4.2.1 | Aqueous Fate and Transport Discussion | 27 |
| 4.3 | WWTP 8 Phase 2 Evaluation | 27 |
| 4.3.1 | Aqueous Fate and Transport Discussion | 28 |
| 4.3.2 | Solid Fate and Transport Discussion | 28 |
| 4.4 | WWTP 9 Phase 2 Evaluation | 31 |
| 4.4.1 | Aqueous Fate and Transport Discussion | 31 |
| 4.4.2 | Solid Fate and Transport Discussion | 31 |
| 4.5 | WWTP 10 Phase 2 Evaluation | 35 |
| 4.5.1 | Aqueous Fate and Transport Discussion | 35 |
| 4.5.2 | Solid Fate and Transport Discussion | 35 |
| 4.6 | WWTP 11 Phase 2 Evaluation | 39 |
| 4.6.1 | Aqueous Fate and Transport Discussion | 39 |
| 4.6.2 | Solid Fate and Transport Discussion | 40 |
| 4.7 | WWTP 13 Phase 2 Evaluation | 43 |
| 4.7.1 | Aqueous Fate and Transport Discussion | 43 |
| 4.7.2 | Solid Fate and Transport Discussion | 43 |
| 4.8 | WWTP14 Phase 2 Evaluation | 46 |
| 4.8.1 | Aqueous Fate and Transport Discussion | 46 |
| 4.8.2 | Solid Fate and Transport Discussion | 47 |
| 4.9 | WWTP 18 Phase 2 Evaluation | 50 |
| 4.9.1 | Aqueous Fate and Transport Discussion | 50 |
| 4.9.2 | Solid Fate and Transport Discussion | 50 |
| 4.10 | PFAS Evaluation of Solid and Aqueous Partition in WWTPs | 54 |
| 5. | Discussion and Conclusions | 62 |
| 6. | References | 65 |

Figures

| | |
|---|----|
| Figure 1. AECOM National Study (Phase 1)..... | 2 |
| Figure 2. Short-chain and long-chain PFCAs and PFSA (ITRC, 2017)..... | 3 |
| Figure 3. Total Oxidizable Precursors Assay (TOPA) (Houtz and Sedlak, 2012)..... | 4 |
| Figure 4. Percent Detection of PFAS – AECOM Phase 1 National Study..... | 6 |
| Figure 5. Percent Detection of PFAS - 2021 California Assessment | 7 |
| Figure 6. Percent Detection of PFAS – 2018 Michigan Assessment | 7 |
| Figure 7. PFAS Influent Percent Detection - All 3 Studies..... | 8 |
| Figure 8. PFAS Effluent Percent Detection - All 3 Studies..... | 8 |
| Figure 9. PFAS Final Treated Solids Percent Detection - All 3 Studies..... | 9 |
| Figure 10. Legend for Box Plot Figures with PFAS Analyte List Grouped by Families | 10 |
| Figure 11. Influent PFAS Detection Frequency and Concentrations – Box Plot..... | 11 |
| Figure 12. Influent PFAS Detection Frequency and Concentrations – Dot Plot | 11 |
| Figure 13. Effluent PFAS Detection Frequency and Concentrations – Box Plot..... | 12 |
| Figure 14. Effluent PFAS Detection Frequency and Concentrations – Dot Plot..... | 12 |
| Figure 15. Final Treated Solids PFAS Detection Frequency and Concentrations – Box Plot..... | 13 |
| Figure 16. Final Treated Solids PFAS Detection Frequency and Concentrations – Dot Plot..... | 13 |
| Figure 17. Final Treated Solids PFOS Concentrations - AECOM Phase 1 National Study..... | 14 |
| Figure 18. Pump Station PFAS Concentrations – WWTP 17 | 15 |
| Figure 19. Influent PFAS Concentrations for All 3 Studies – Box Plot..... | 18 |
| Figure 20. Effluent PFAS Concentrations for All 3 Studies – Box Plot | 19 |
| Figure 21. Final Treated Solids PFAS Concentrations for All 3 Studies – Box Plot | 20 |
| Figure 22. Final Treated Solids PFOS Concentrations - Multiple Published Studies..... | 21 |
| Figure 23. Phase 1 and 2 – Influent and Effluent PFOA Concentrations | 22 |
| Figure 24. Phase 1 and 2 – Influent and Effluent PFOS Concentrations | 22 |
| Figure 25. Phase 1 and 2 – Influent and Effluent Total PFAS Concentrations | 23 |
| Figure 26. PFAS Results and Process Flow Diagram for WWTP 2..... | 25 |
| Figure 27. WWTP 2 PFAS Concentrations in The Aqueous Treatment Process Flow..... | 26 |
| Figure 28. WWTP 2 PFAS Concentrations in The Solid Treatment Process Flow | 26 |
| Figure 29. PFAS Results and Process Flow Diagram for WWTP 8..... | 29 |
| Figure 30. WWTP 8 PFAS Concentrations in The Aqueous Treatment Process Flow..... | 30 |
| Figure 31. WWTP 8 PFAS Concentrations in The Solid Treatment Process Flow | 30 |
| Figure 32. PFAS Results and Process Flow Diagram for WWTP 9..... | 33 |
| Figure 33. WWTP 9 PFAS Concentrations in The Aqueous Treatment Process Flow..... | 34 |
| Figure 34. WWTP 9 PFAS Concentrations in The Solid Treatment Process Flow | 34 |
| Figure 35. PFAS Results and Process Flow Diagram for WWTP 10 | 37 |
| Figure 36. WWTP 10 PFAS Concentrations in The Aqueous Treatment Process Flow..... | 38 |
| Figure 37. WWTP 10 PFAS Concentrations in The Solid Treatment Process Flow | 38 |
| Figure 38. PFAS Results and Process Flow Diagram for WWTP 11 | 41 |
| Figure 39. WWTP 11 PFAS Concentrations in The Aqueous Treatment Process Flow..... | 42 |
| Figure 40. WWTP 11 PFAS Concentrations in The Solid Treatment Process Flow..... | 42 |
| Figure 41. PFAS Results and Process Flow Diagram for WWTP 13 | 44 |
| Figure 42. WWTP 13 PFAS Concentrations in The Aqueous Treatment Process Flow..... | 45 |
| Figure 43. WWTP 13 PFAS Concentrations in The Solid Treatment Process Flow | 45 |
| Figure 44. PFAS Results and Process Flow Diagram for WWTP 14 | 48 |
| Figure 45. WWTP 14 PFAS Concentrations in The Aqueous Treatment Process Flow..... | 49 |
| Figure 46. WWTP 14 PFAS Concentrations in The Solid Treatment Process Flow | 49 |
| Figure 47. PFAS Results and Process Flow Diagram for WWTP 18 | 52 |
| Figure 48. WWTP 18 PFAS Concentrations in The Aqueous Treatment Process Flow..... | 53 |
| Figure 49. WWTP 18 PFAS Concentrations in The Solid Treatment Process Flow | 53 |
| Figure 50. PFAS Concentrations in the Aqueous and Solid Portions of the Primary Clarifier Solids for WWTP 2: Regular Scale (a) and Log Scale (b) | 54 |

Figure 51. PFAS Concentrations in the Aqueous and Solid Portions of the Secondary Clarifier Solids for WWTP 2: Regular Scale (a) and Log Scale (b) 55

Figure 52. PFAS Concentrations in the Aqueous and Solid Portions of the Waste Activated Sludge (Sequence Batch Reactors) Solids for WWTP 13: Regular Scale (a) and Log Scale (b) 55

Figure 53. PFAS Concentrations in the Aqueous and Solid Portions of the Sludge Storage Tanks Solids for WWTP 13: Regular Scale (a) and Log Scale (b) 56

Figure 54. PFAS Concentrations in the Aqueous and Solid Portions of the Thickened Sludge Tanks Solids for WWTP 13: Regular Scale (a) and Log Scale (b) 56

Figure 55. PFAS Concentrations in the Aqueous and Solid Portions of the Oxidation Ditch Anoxic Zone Solids for WWTP 14: Regular Scale (a) and Log Scale (b) 57

Figure 56. PFAS Concentrations in the Aqueous and Solid Portions of the Oxidation Ditch Aerobic Zone Solids for WWTP 14: Regular Scale (a) and Log Scale (b) 57

Figure 57. PFAS Concentrations in the Aqueous and Solid Portions of the Waste Activated Sludge for WWTP 14: Regular Scale (a) and Log Scale (b) 57

Figure 58. PFAS Concentrations in the Aqueous and Solid Portions of the Aerated Holding Storage Tank Solids for WWTP 14: Regular Scale (a) and Log Scale (b) 58

Figure 59. PFAS Concentrations in the Aqueous and Solid Portions of the Primary Clarifier Solids for WWTP 18: Regular Scale (a) and Log Scale (b) 59

Figure 60. PFAS Concentrations in the Aqueous and Solid Portions of Aerated Returned Activated Sludge Influent Solids for WWTP 18: Regular Scale (a) and Log Scale (b)..... 59

Figure 61. PFAS Concentrations in the Aqueous and Solid Portions of the Aerated Returned Activated Sludge Effluent Solids for WWTP 18 Regular Scale (a) and Log Scale (b)..... 60

Figure 62. PFAS Concentrations in the Aqueous and Solid Portions of the DAFT Float Sludge Solids for WWTP 18: Regular Scale (a) and Log Scale (b) 60

Figure 63. PFAS Concentrations in the Aqueous and Solid Portions of the DAFT Bottom Sludge Solids for WWTP 18: Regular Scale (a) and Log Scale (b) 61

Figure 64. PFAS Concentrations in the Aqueous and Solid Portions of the Anaerobic Digester Solids for WWTP 18: Regular Scale (a) and Log Scale (b) 61

Figure 65. PFAS Concentrations in the Aqueous and Solid Portions of the Sludge Storage Tank Solids for WWTP 18: Regular Scale (a) and Log Scale (b) 61

Tables

Table 1. Aqueous PFAS Sample Results 2021 AECOM National Study

Table 2. Solids PFAS Sample Results 2021 AECOM National Study

Appendices

Appendix A. PFAS Analyte List

Appendix B. WWTP Summary Information 2021 AECOM National Study

Appendix C. Power Point Presentation on AECOM's Findings on the Presence & Fate of PFAS in Wastewater Treatment Plants

1. Introduction

Per- and polyfluoroalkyl substances (PFAS) are an emerging contaminant class of human-made chemicals first identified in the late 1930s and developed in the 1940s, which started to be used in commercial products and early 1950s. The term PFAS is attributed to a large class of chemicals composed of many families with vastly different physical and chemical properties (Buck, 2011). A recent survey reported more than 4,700 PFAS identified (OECD, 2018). PFAS were incorporated into components of inks, varnishes, waxes, firefighting foams, metal plating, cleaning solutions, coating formulations due to their unique chemical properties as lubricants, water and oil repellents, paper, and textiles (Paul, 2009). Examples of industries using PFAS include automotive, aviation, aerospace and defense, biocides, cable and wiring, construction, electronics, energy, firefighting, food processing, household products, oil and mining production, metal plating, medical articles, paper and packaging, semiconductors, textiles, leather goods, and apparel (OECD, 2013, UNEP, 2013).

Many PFAS are highly persistent, bioaccumulative, and toxic and have been detected ubiquitously throughout the environment. Some PFAS undergo partial biotic or abiotic degradation to stable PFAS end-compounds that are highly persistent in the environment (Wang, 2017). Perfluoroalkyl carboxylates (PFCAs) and perfluoroalkyl sulfonates (PFSAs) [collectively known as perfluoroalkyl acids (PFAAs)] are known to be resistant to biological and thermal degradation because of the strength of the carbon-fluorine bond; the transformation of PFAAs in Wastewater Treatment Plant (WWTP) processes is not known to occur. By comparison, polyfluorinated compounds, for which some, but not all, carbons are fluorinated, could undergo biotic and abiotic transformation into terminal PFAAs. As a result, these human-made chemicals are expected to be detected for decades in the environment.

Widespread use of fluorinated chemistry at various manufacturing and industrial facilities in conjunction with extreme resistance to degradation has resulted in the presence of PFAS in the environment and at WWTPs. WWTPs are not a source of PFAS, but they can serve as a central collection point to control and mitigate their release into the environment. Effluents discharged from WWTPs and biosolids land-applied to agricultural fields for beneficial reuse have been identified as potential PFAS release pathways into the environment by the Interstate Technology and Regulatory Council (ITRC) (ITRC, 2017). Some regulatory bodies are beginning to establish or have already set limits that could significantly impact wastewater utilities and how they manage effluent, sludge disposal through landfilling or incineration, and/or the beneficial reuse of biosolids through land application practices.

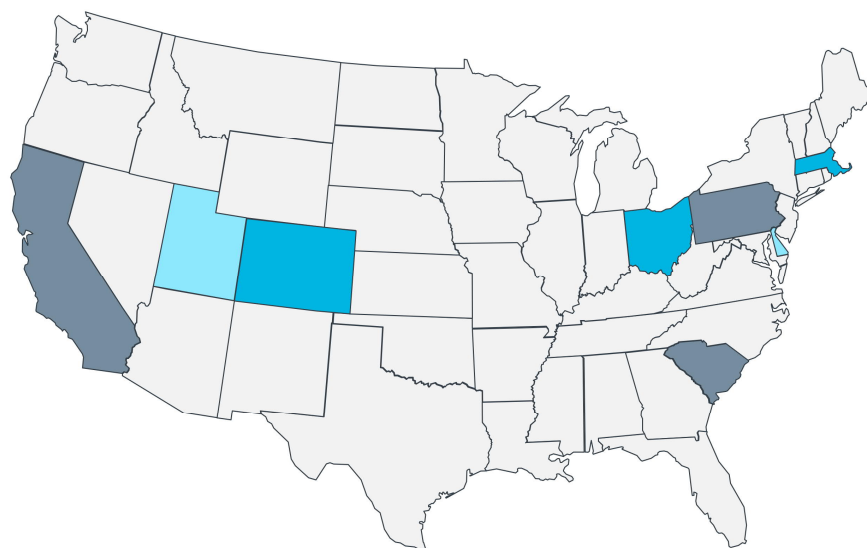
PFAS have been identified in WWTPs since the early 2000s during the 3M-sponsored Multi-City Study from Alabama, Tennessee, Georgia, and Florida. PFAS were also later identified in WWTPs across the United States of America (US) from Minnesota, Iowa, California, Illinois, New York, Kentucky, Georgia, and Michigan (Boulanger, 2005; Higgins, 2005; Schultz, 2006; Sinclair, 2006; Loganathan, 2007; Sepulvado, 2011; Houtz, 2016). PFAS have also been detected worldwide in Switzerland, Australia, and Kenya (Alder, 2008; Alder, 2011; Chirikona, 2015; Gallen, 2016). Some of the most frequently detected PFAS were PFAAs. This makes WWTPs important in managing and mitigating the environmental spread of PFAAs and a key participant in protecting both human and environmental health.

AECOM conducted the first statewide evaluation of 42 WWTPs for the State of Michigan (AECOM, 2021). The Michigan study included the 20 largest WWTPs and 22 WWTPs based on USEPA's 2012 Clean Water Needs Survey List. The additional 22 WWTPs were selected from three (3) main groups based on flows of 0.2 to 0.4 million gallons per day (MGD), 0.5 to 3 MGD,

and 3 to 9 MGD with various treatment processes. To better understand the current data gaps and improve the understanding of PFAS impacts on the WWTPs, including their fate and transport, AECOM implemented an internal national research study for the assessment of 19 WWTPs from 8 different States being a representative number of treatment plants across the US (**Figure 1**). A description of all 19 WWTPs that participated in the study is presented in **Appendix A**. The results expand upon our current dataset that was generated for the State of Michigan. The results will also be compared with results from a California statewide study including three (3) quarters of PFAS data from 2021 collected by 180 WWTPs with a dry weather design flow of 1 million gallons per day (mgd) capacity or higher (Add reference to the California order).

The AECOM National Study was divided into two (2) separate phases. Phase 1 involved reviewing existing analytical data or new sampling of influent, effluent, and final treated solids of 19 WWTPs across the US to identify the presence of PFAS from different geographies, source characteristics, treatment trains, and scale. A total of eight (8) WWTPs were selected for Phase 2 to participate in an in-depth evaluation of the PFAS fate within the WWTPs and the potential impacts to present end uses of the effluent or solids from the facility.

Figure 1. AECOM National Study (Phase 1)



Number of Participants (19 total in 8 states)

■ 1 participant ■ 2 participants ■ 3+ participants

2. Sampling Method and Analysis

All the samples were analyzed by Eurofins – Test America laboratory from West Sacramento using an in-house developed isotope dilution method for a list of 28 PFAS from 9 PFAS families to provide a comprehensive evaluation. The PFAS families included 11 PFCAs, seven (7) PFASs, one (1) Perfluoroalkane Sulfonamides (FASAs), three (3) Fluorotelomer Sulfonic Acids (FTSAs), one (1) N-Ethyl Perfluoroalkane Sulfonamidoacetic Acids (EtFASAAs), and one (1) N-Methyl Perfluoroalkane Sulfonamidoacetic Acids (MeFASAAs) (**Appendix B**). Four (4) of these families (i.e., FASA, FTSA, EtFASAA, and MeFASAA) are precursors which could undergo a

partial abiotic or biotic transformation to persistent end products such as PFCAs and PFSAs families. The FASA, EtFASAA, and MeFASAA families are expected to transform into PFSAs. All the PFAS analyzed in this study from these three (3) families were eight carbon chain length, such as Perfluorooctane Sulfonamide (FOSA), N-methylperfluorooctanesulfonamidoacetic acid (MeFOSAA), and N-ethylperfluorooctanesulfonamidoacetic acid (EtFOSAA) and are expected to eventually degrade to PFOS. The three (3) PFAS from the FTSA family, 4:2 FTSA, 6:2 FTSA, and 8:2 FTSA, are expected to transform into compounds from the PFCAs family. A total of four (4) PFAS (i.e., Hexafluoropropylene Oxide Dimer Acid (HFPO-DA also known as Gen-X); 4,8-Dioxa-3H-perfluorononanoic acid (ADONA); 9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (F53B-Minor); and 11-Chloroeicosafuoro-3-oxaundecane-1-sulfonic acid (F53B-Major)) are known to have been developed to replace other PFAS that have been widely used in the manufacturing process such as PFOA and PFOS. For example, Gen-X and other related compounds have been developed by Chemours (formerly part of DuPont) to replace PFOA for the manufacturing of polymers, ADONA has been developed by 3M and Dyneon (which has been part of 3M since 2011), and finally, F53B-Minor and F53B-Major are compounds that have been developed and used primarily in China as a replacement for PFOS as a wetting agent or mist suppressant. These four (4) compounds from three (3) families are not expected to be detected in the US in high concentrations unless the WWTP is receiving waste from a fluoropolymer plant in the case of Gen-X and ADONA or is situated in China the case of F53B-Minor and F53B-Major.

The analysis of PFCAs and PFSAs included multiple PFAS from the same family of various fluorinated carbon-fluorine chain lengths (**Figure 2**). PFAS with shorter carbon-fluorine chain lengths are referred to as short-chain, and those with a longer chain length are referred to as long-chain. PFSAs with a carbon chain length equal to six (6) and PFCAs of eight (8) or above are considered long-chain, as presented in **Figure 2**. A total of six (6) short-chain and 12 long-chain PFAAs; two (2) short-chain and five (5) long-chain precursors; and two (2) short-chain and two (2) long-chain PFAS replacement chemistry were analyzed as part of the 28 PFAS analyte list (**Appendix B**).

Figure 2. Short-chain and long-chain PFCAs and PFSAs (ITRC, 2017)

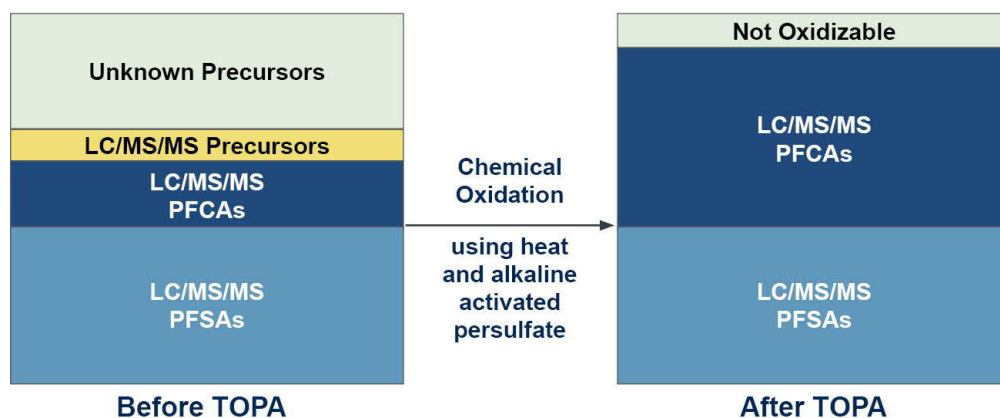
| Number of Carbons | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|-------------------|-------------------|-------|-------|------------------|------------------|------|------|-------|-------|
| PFCAs | Short-chain PFCAs | | | | Long-chain PFCAs | | | | |
| | PFBA | PFPeA | PFHxA | PFHpA | PFOA | PFNA | PFDA | PFUnA | PFDoA |
| PFSAs | PFBS | PFPeS | PFHxS | PFHpS | PFOS | PFNS | PFDS | PFUnS | PFDoS |
| | Short-chain PFSAs | | | Long-chain PFSAs | | | | | |

Total oxidizable precursor assay (TOPA) was developed to assess and quantify the presence of precursors that could potentially transform and partially degrade into PFAAs (**Figure 3**). TOPA uses heat- and alkaline-activated persulfate to generate an excess of hydroxyl radical during the oxidation process resulting in the partial transformation of some of the precursors. TOPA assay has been shown to oxidize a large number (although not all) of known precursors. Most of the oxidation is performed on the functional head or weaker bonds (i.e., C-H) than those that are stronger such as C-F. For example, TOPA assay could be used to understand the predominant precursors present if they are short-chain or long-chain for example. While TOPA assay generates almost exclusively PFCAs, in the environment the precursors might degrade to PFSAs. The fluorinated part of the PFAS for most of the compounds is preserved and long-chain and short-chain precursors could generate both long-chain PFCAs (e.g., PFOA, PFNA, PFDA) and short-chain PFCAs (e.g., PFBA, PFPeA, PFHxA). Long-chain precursors manufactured using electrochemical fluorination used by 3M have been identified to degrade

during TOPA analysis to only long-chain PFCAs. Long-chain precursors, that were created using telomerization, degraded to long-chain and short-chain PFCAs during the TOPA analysis. For example, 8:2 FTSA had 24% long-chain (i.e., 21% as C8 and 3% C9), 27% as C7, 19% as C6, 12% as C5, and 11% as C4. However, short-chain precursors will not be able to degrade to long-chain PFCAs (Houtz and Sedlak, 2012). For samples in which the increase in PFBA and PFPeA would be substantially higher than those of PFHpA and PFOA during the TOPA analysis, it is expected that short-chain PFAS are the predominant form of PFAS in both aqueous and solid samples. It is also thought that short-chain precursors may have a higher tendency to accumulate in solids compared to their short-chain PFAAs. This is important as short-chain PFAS are known to accumulate into crops and the short-chain precursors present in the biosolids could become a constant source of short-chain PFAS when they are land applied onto agricultural fields. While TOPA can be used to evaluate the presence of additional precursors, there are limitations due to the following reasons:

- 1) The transformation pathway during the oxidation does not follow the same transformation pathway that a precursor would undergo into the environment or within a wastewater treatment plant. TOPA results in the generation of only PFCAs, for precursors in the environment would degrade to PFSAs.
- 2) The oxidation conditions used in the TOPA are extreme compare to actual environmental conditions. As a result, the transformation of all precursors present during TOPA does not guarantee that the same number of precursors would degrade in the environment or within waste water treatment plants.
- 3) The transformation during TOPA happens quickly, while the actual transformation in the environment would be a lot slower.
- 4) Due to the extreme oxidation conditions, there is the possibility of some PFAAs also be destroyed. As a result, there may be instances when PFAAs may be degraded in the absence of enough precursors. The total concentrations of PFCAs after TOPA (Post-TOP) may be lower than those before the TOPA analysis (Pre-TOP).
- 5) While standards of various precursors are used to confirm the efficiency of TOPA, there is still a possibility of other precursors being present that may be more difficult to transform. The presence of additional organic compounds may impact oxidation efficiently. However, the precursors analyzed in the current study are expected to be transformed during TOPA.

Figure 3. Total Oxidizable Precursors Assay (TOPA) (Houtz and Sedlak, 2012)



TOPA was used for WWTPs 8, 9, 10, and 11 to further evaluate the presence of precursors, especially those not included in the current analyte list of 28 PFAS. The TOPA analysis and evaluation is performed by first using LC-MS/MS to quantify the PFAS, followed by the oxidation step and one additional quantification using LC-MS/MS.

3. Phase 1 Study

Phase 1 included the sampling of influent, effluent, and final treated solids of select WWTPs across the US to identify the presence of PFAS from different geographies, source characteristics, treatment trains, and scale. The objective of Phase 1 was to evaluate if PFAS are present and at what concentrations. The evaluation included data analysis and interpretation to understand the PFAS signature and those of high concern (i.e., PFOA and PFOS). AECOM performed a data review and confirmed the usability of the data for use in this study. Sampling was performed following AECOM's and the State of Michigan PFAS Sampling Guidance.

During Phase 1 samples were collected from 18 WWTPs in 8 States between May and December of 2020 (**Figure 1**). One WWTP (#19) provided sample results from August of 2019 for 45 PFAS in the effluent only but the analysis was completed by the same commercial laboratory and the results included the same 28 PFAS from the Phase 1 Study (**Appendix B**).

Wastewater and solid samples from WWTPs are some of the most challenging environmental matrices to be analyzed for PFAS due to potential significant matrix interference that can occur, resulting in high detection limits. These high detection limits make the interpretation of PFAS impacts to WWTPs challenging. The aqueous and solid sample results for the Phase 1 Study are presented in **Tables 1** and **2**, respectively.

3.1 PFAS Percent Detection

The percent detection for all 28 PFAS in study Phase 1 are presented in **Figure 4**. PFAS was detected in 89% of the influent, 100% of the effluent, and 83% of the final treated solids sampled. This high detection frequency indicates that PFAS is commonly present at some level in industrial, commercial, or even residential discharges. There were almost no detections of the PFAS replacement chemistry compounds as expected. Some of these compounds are believed to be used only in China or are primarily used at fluoropolymers manufacturing facilities in the US.

The short-chain PFAAs from various PFAS families were more frequently detected in the aqueous samples (e.g., influent and effluent). The long-chain PFCAs were detected more frequently in the solid's samples (i.e., sludge or biosolids), which indicates a higher affinity to the solids for long-chain compounds. For the PFSA family, both short-chain and long-chain were detected in both the aqueous and solid samples, with PFOS being the most detected PFSA in most samples. Generally speaking, the longer the carbon-fluorine chain, the less soluble and higher affinity to solids the PFAS have, with some of the long-chain compounds being detected primarily in the solids.

Figures 5 presents the percent detection the influent, effluent, and final treated solids for all 28 PFAS in the California study and **Figure 6** presents percent detection for 24 PFAS in the Michigan Study. For the Michigan study, a total of 47 influent, 44 effluent, and 44 final treated solids samples were collected from 42 WWTPs, as some facilities had multiple streams for a sample type. PFAS was detected in 100% of the influent, effluent, and final treated solids. The four (4) replacement chemistry PFAS were not analyzed for the Michigan study. The California

statewide study included a total of 193 influent samples collected from 180 WWTPs, 186 effluent samples collected from 179 WWTPs, and 128 solid samples from 122 WWTPs. The highest concentration recorded for each sample type during three (3) 2021 quarters was used in the study as a worst-case scenario. PFAS was detected in 85% of the influent, 86% effluent, and 82% final treated solids. Similar detection trends were observed in both studies, with higher detection frequencies for the Michigan study likely due to the larger number of WWTPs in the California study with a potentially larger percentage having little to no industrial discharge. The Michigan study had fewer WWTPs with 35 of 42 having industrial discharges and two (2) additional WWTPs with known historical aqueous film-forming foams (AFFF) discharges. PFAS are expected to be strongly associated with industrial discharges due to the extensive use of PFAS in a wide range of industries. The percent detection differences for the influent, effluent and final treated solids for all three (3) studies are presented in **Figures 7, 8, and 9.**

Figure 4. Percent Detection of PFAS – AECOM Phase 1 National Study

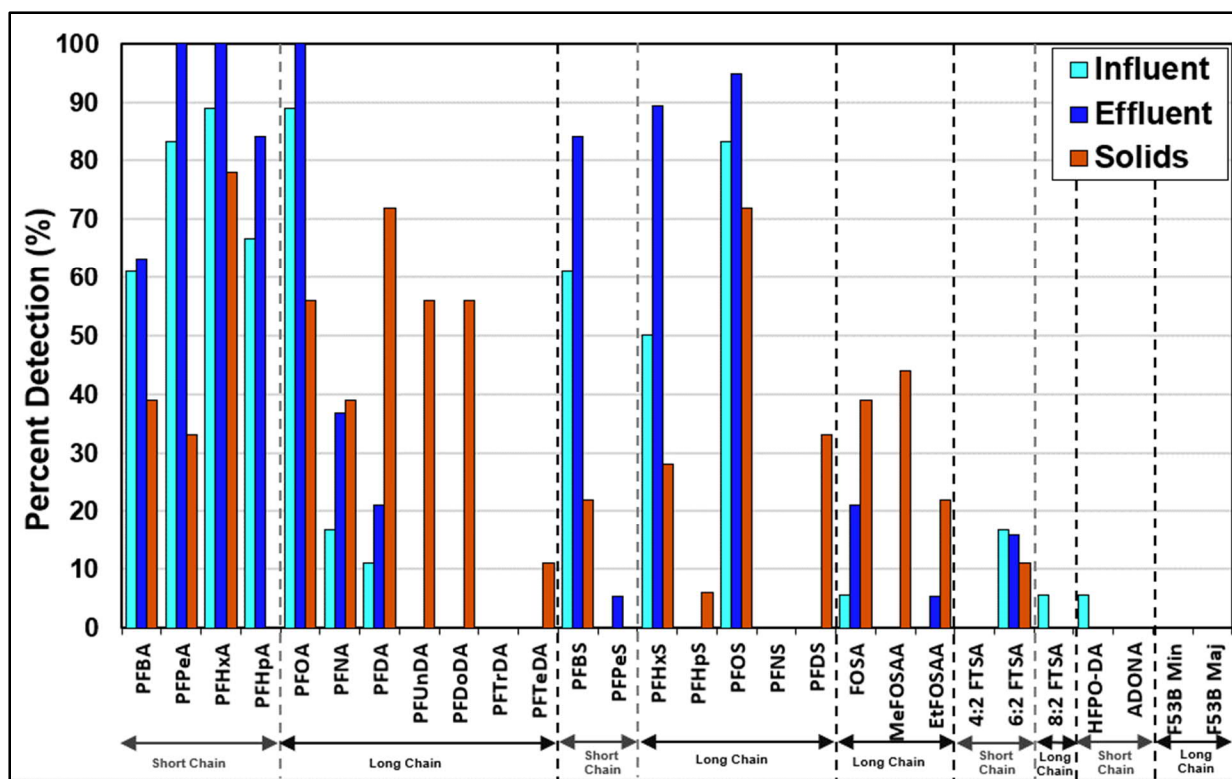


Figure 5. Percent Detection of PFAS - 2021 California Assessment

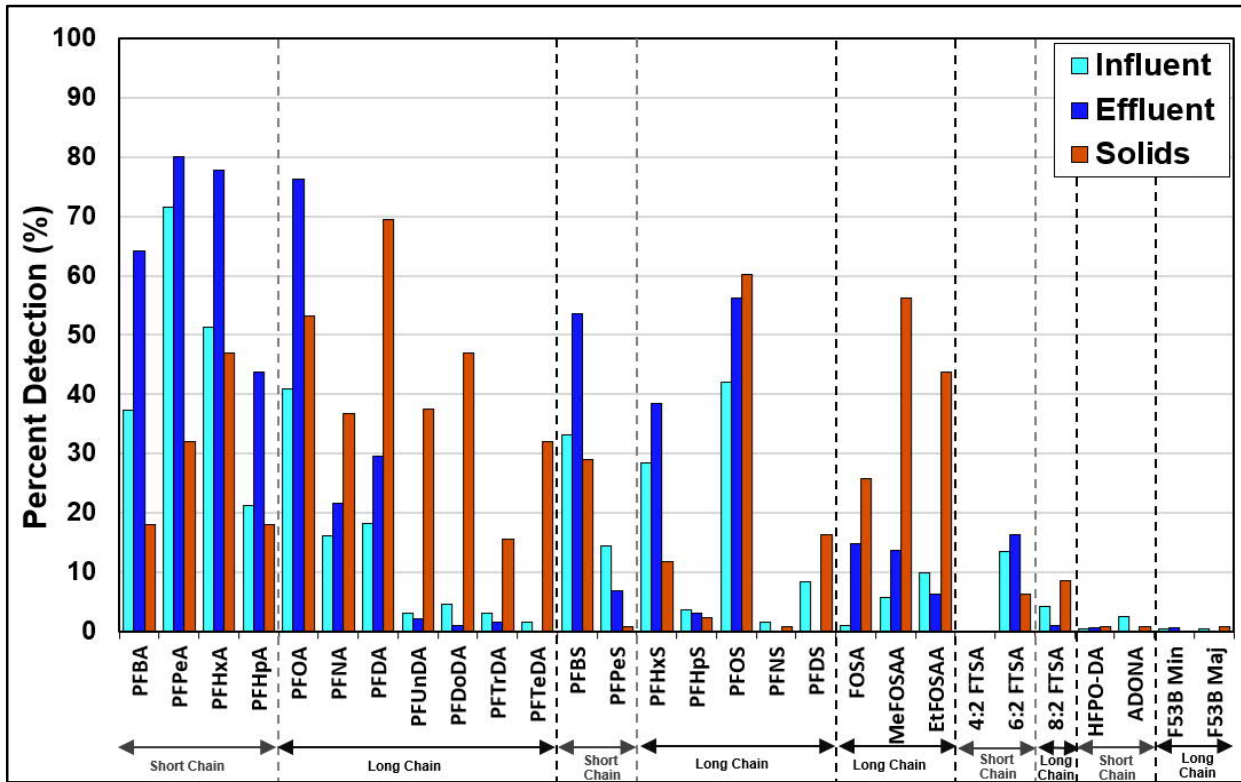


Figure 6. Percent Detection of PFAS – 2018 Michigan Assessment

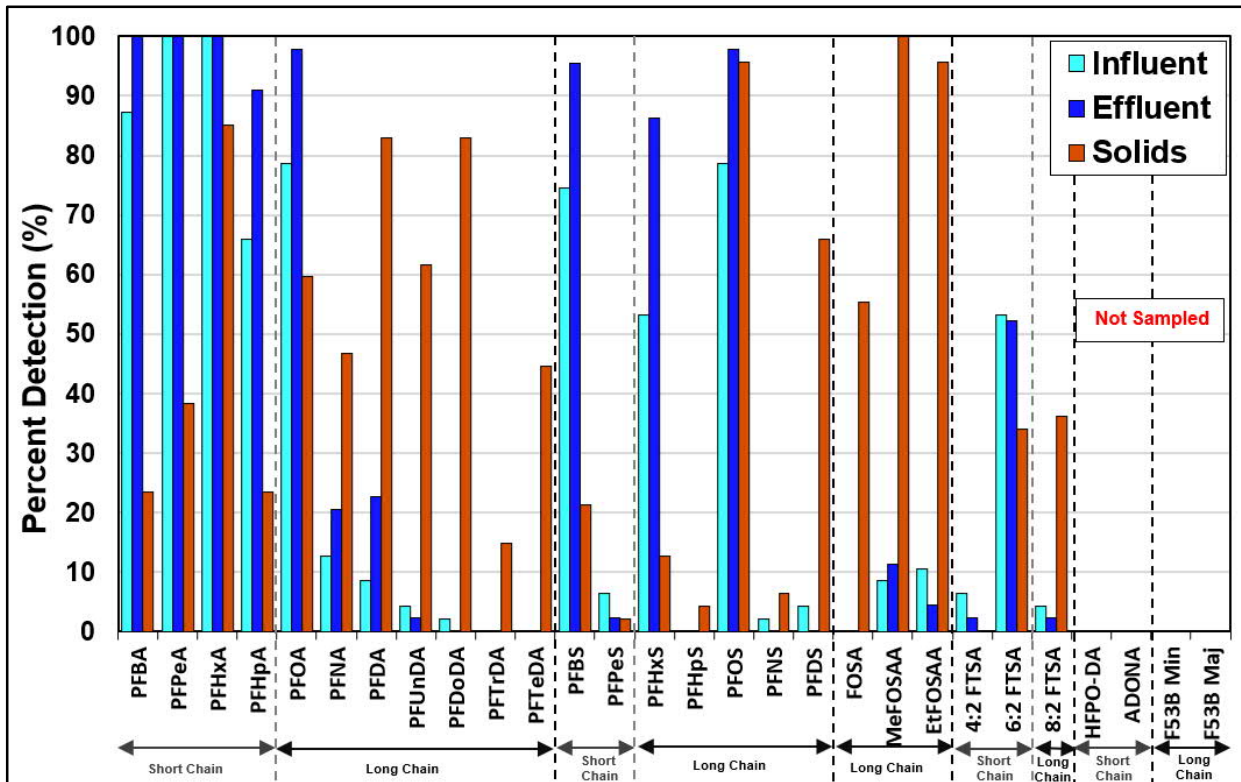


Figure 7. PFAS Influent Percent Detection - All 3 Studies

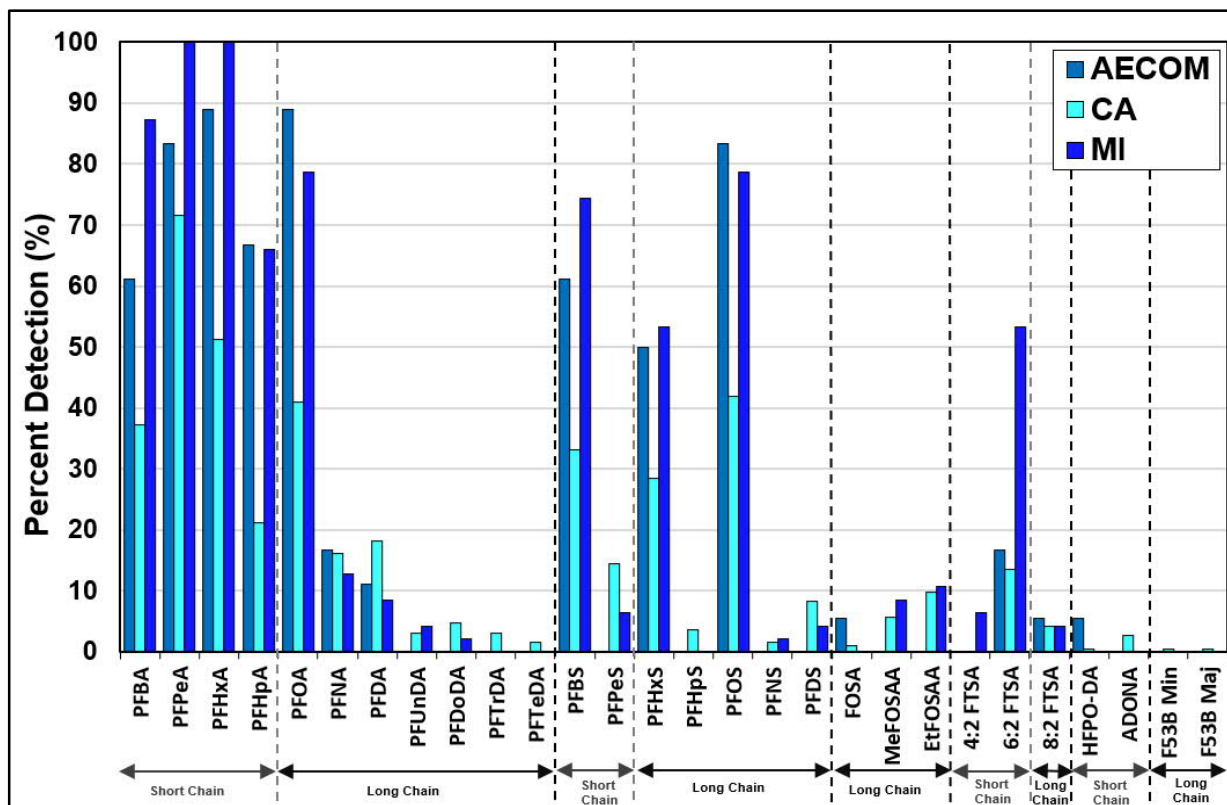


Figure 8. PFAS Effluent Percent Detection - All 3 Studies

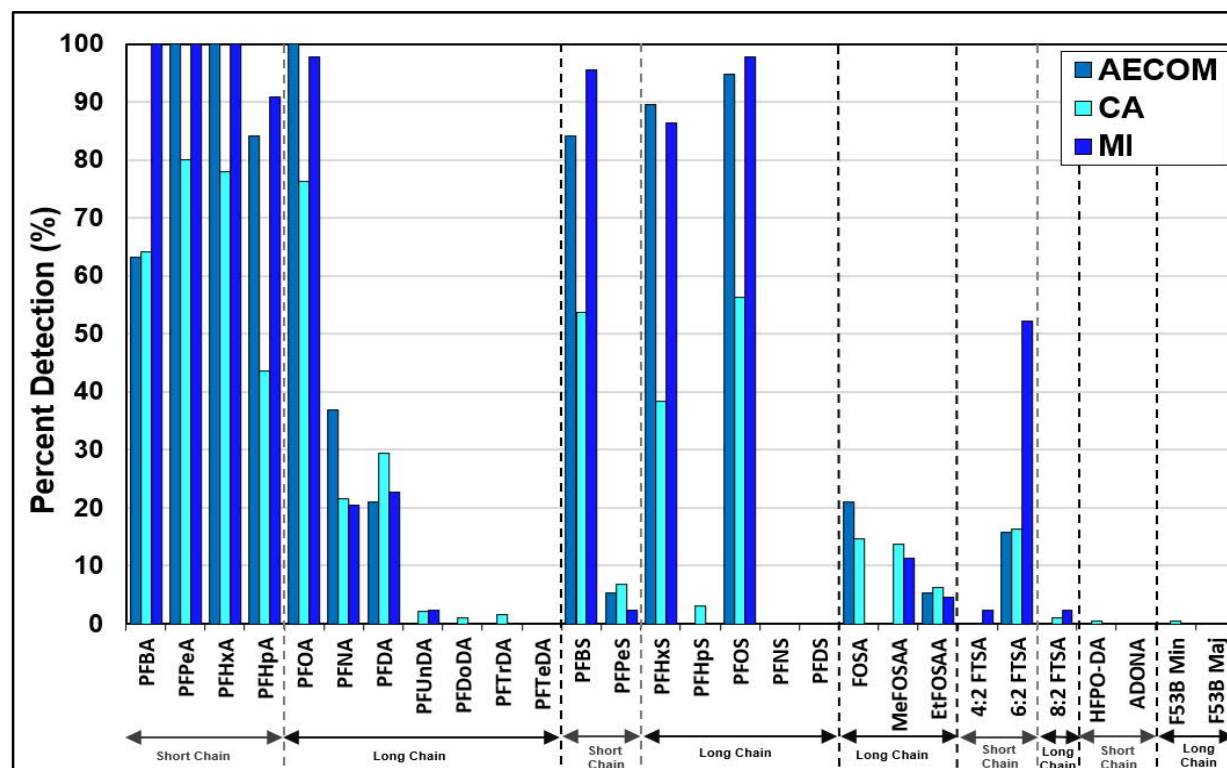
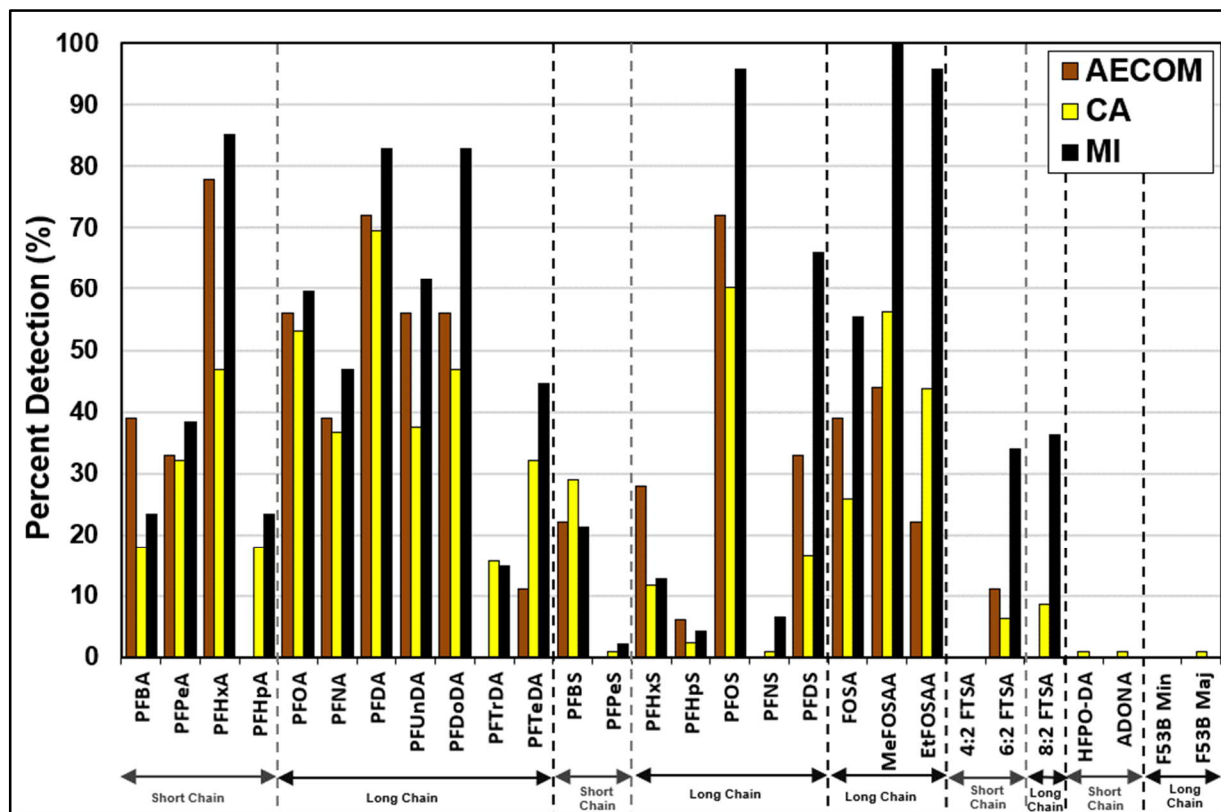


Figure 9. PFAS Final Treated Solids Percent Detection - All 3 Studies

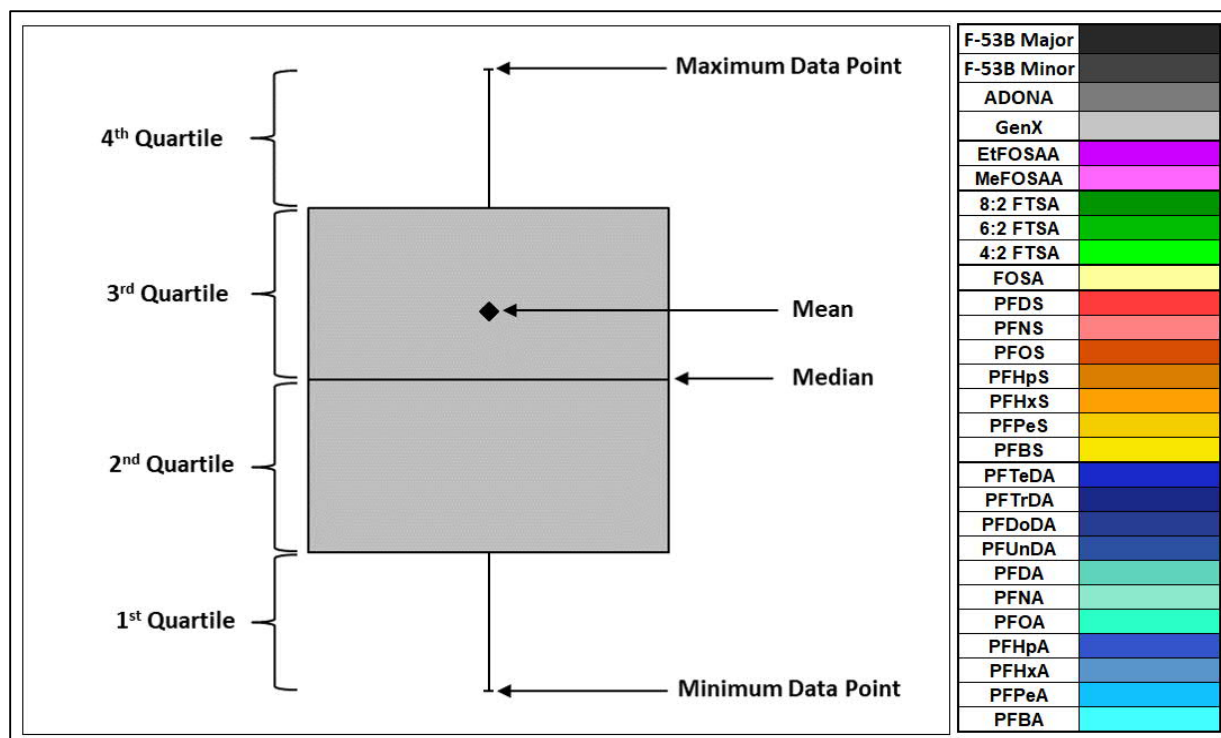


3.2 PFAS Influent, Effluent, and Final Treated Concentrations

The PFAS concentrations and detection frequency for all 28 compounds were plotted as a box plot and dot plot graphs, including color-coding for each PFAS family and increasing chain length from left to right. The box plots also included whiskers for the minimum and maximum concentrations and 25th, 50th, and 75th percentiles, including the mean concentrations (Figure 10). The box and dot plot graphs for influent are presented in Figures 11 and 12, with the effluent presented in Figures 13 and 14 and the final treated solids (sludge and biosolids) presented in Figures 15 and 16. For many PFAS, a wide range of concentrations were detected for most PFAS in influent, effluent, and final treated solids, which resulted in high biased mean concentrations.

There was only one detection for HFPO-DA in the influent. Many influent detections were below the ten (10) ng/L, and almost all were below 30 ng/L. A similar pattern was observed for the effluent in terms of PFAS detected and concentration ranges. However, detection was slightly more frequent for those same PFAS in the effluent than in the influent. Also, the short-chain PFCAs have overall higher concentrations in the effluent compared to the influent. PFAS detected in both the influent and effluent at higher concentrations and with higher detection frequencies include PFPeA, PFHxA, and PFOA from the PFCA family; PFOS in the PFSA family, and 6:2 FTSA in the FTSA family.

Figure 10. Legend for Box Plot Figures with PFAS Analyte List Grouped by Families



The PFAS detection trend in the final treated solids was different than that in the influent and effluent samples. PFOS stood out of all PFAS in the solid samples, and while most of the PFAS detections were below ten (10) $\mu\text{g}/\text{Kg}$, for PFOS many of the results were above the ten (10) $\mu\text{g}/\text{Kg}$. There were no PFCAs, high longer carbon chain length of ten (10) (i.e., PFDA) detected in the influent and effluent samples. However, PFCAs with carbon chain lengths of 11, 12, 13, and 14 were detected in solids. Similarly, for the PFSA family, PFDS which had a carbon chain length of ten (10) was also detected only in the solids. MeFOSAA and, to a later extent EtFOSAA, which are known precursors that could partially degrade to PFOS, were also detected in some of the solid samples only. The PFOS concentrations in all 18 solid samples are presented in **Figure 17**, with the median and average concentrations of 26 and 56 $\mu\text{g}/\text{Kg}$, respectively. Five (5) of the 18 solid samples were non-detect for PFOS. However, due to significant matrix interference, the detection limit for PFOS was elevated to between 13 and 85 $\mu\text{g}/\text{Kg}$. As a result, PFOS may still be present at concentrations below the elevated detection limits. WWTP 4 had a design flow of 206 million gallons per day (mgd). While the WWTP 4 had many industrial discharges, the large flow of the facility offered enough dilution to result in a non-detection for PFOS with a detection limit of 6.1 $\mu\text{g}/\text{Kg}$. WWTP 13 had a PFOS non-detection at 6.4 $\mu\text{g}/\text{Kg}$ but WWTP 13 does not have any industrial discharges and may be the reason for the non-detection for PFOS, even though there were PFAS detections. A total of nine (9) facilities had PFOS concentrations between 10 to 30 $\mu\text{g}/\text{Kg}$, with two (2) facilities having concentrations between 50 to 70 $\mu\text{g}/\text{Kg}$, and two facilities above 100 $\mu\text{g}/\text{Kg}$. The highest PFOS concentration was 390 $\mu\text{g}/\text{Kg}$ for WWTP 14.

Figure 11. Influent PFAS Detection Frequency and Concentrations – Box Plot

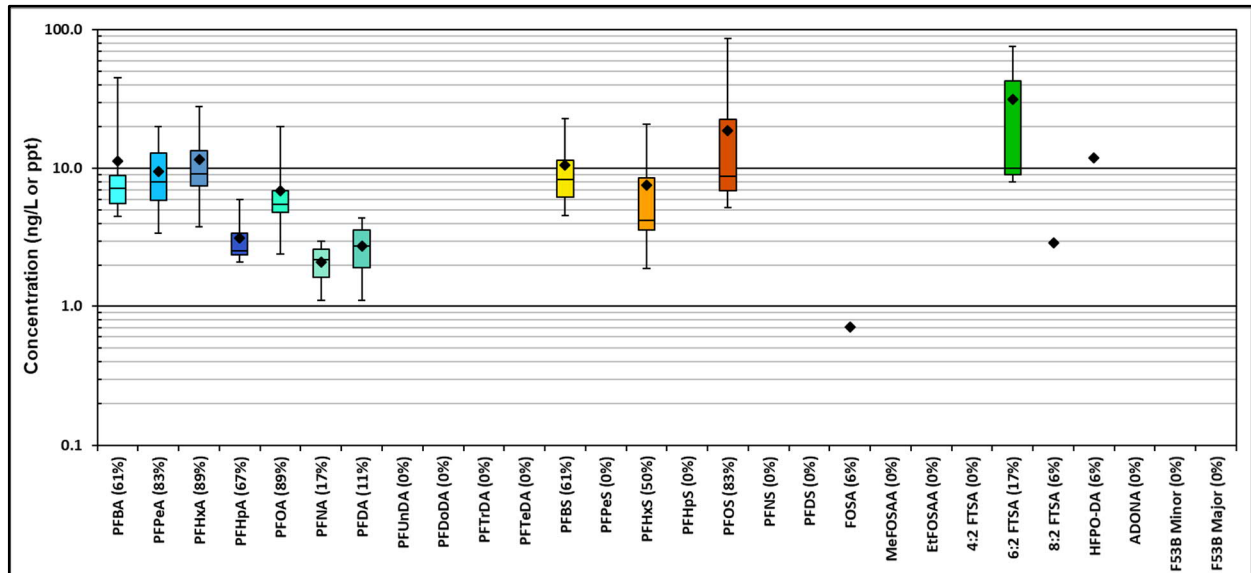


Figure 12. Influent PFAS Detection Frequency and Concentrations – Dot Plot

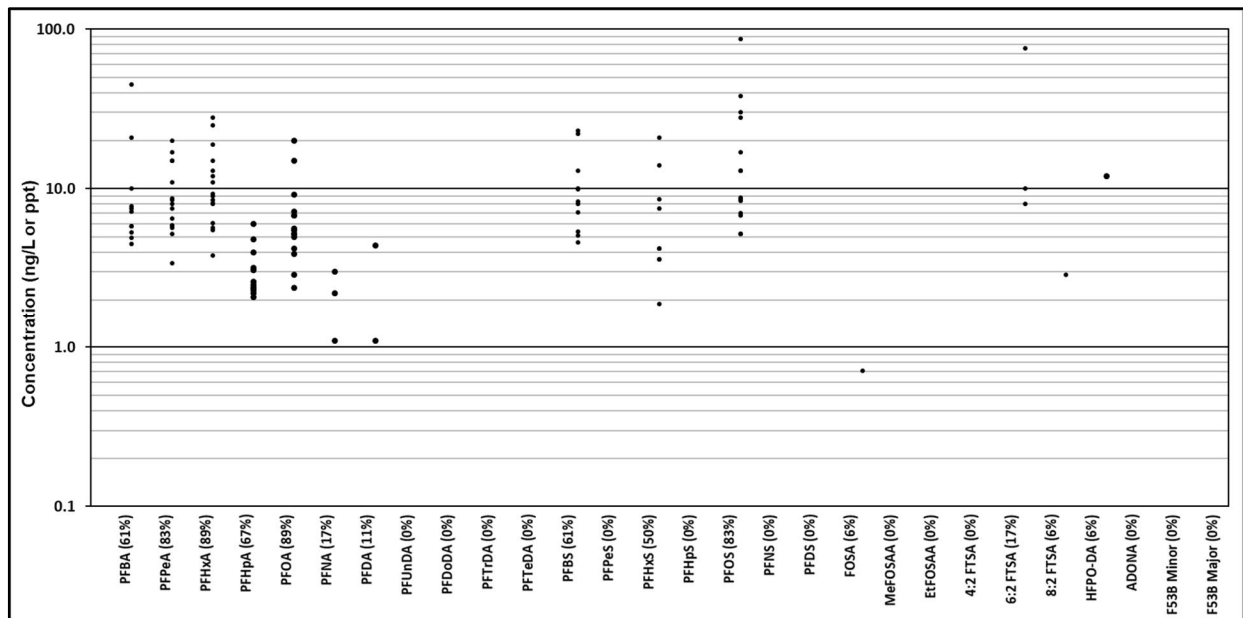


Figure 13. Effluent PFAS Detection Frequency and Concentrations – Box Plot

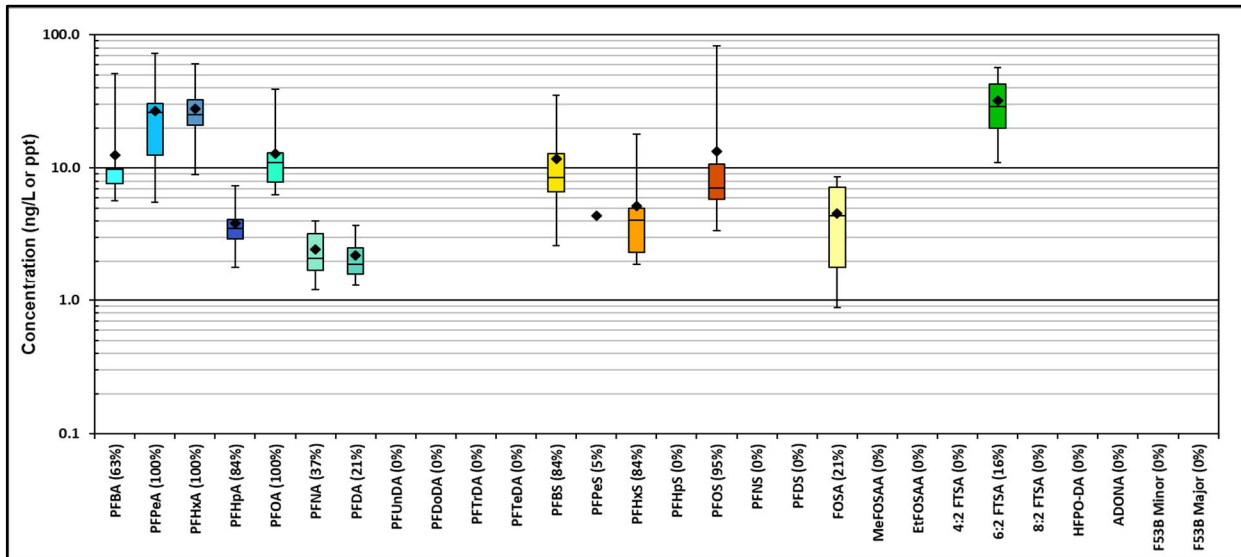


Figure 14. Effluent PFAS Detection Frequency and Concentrations – Dot Plot

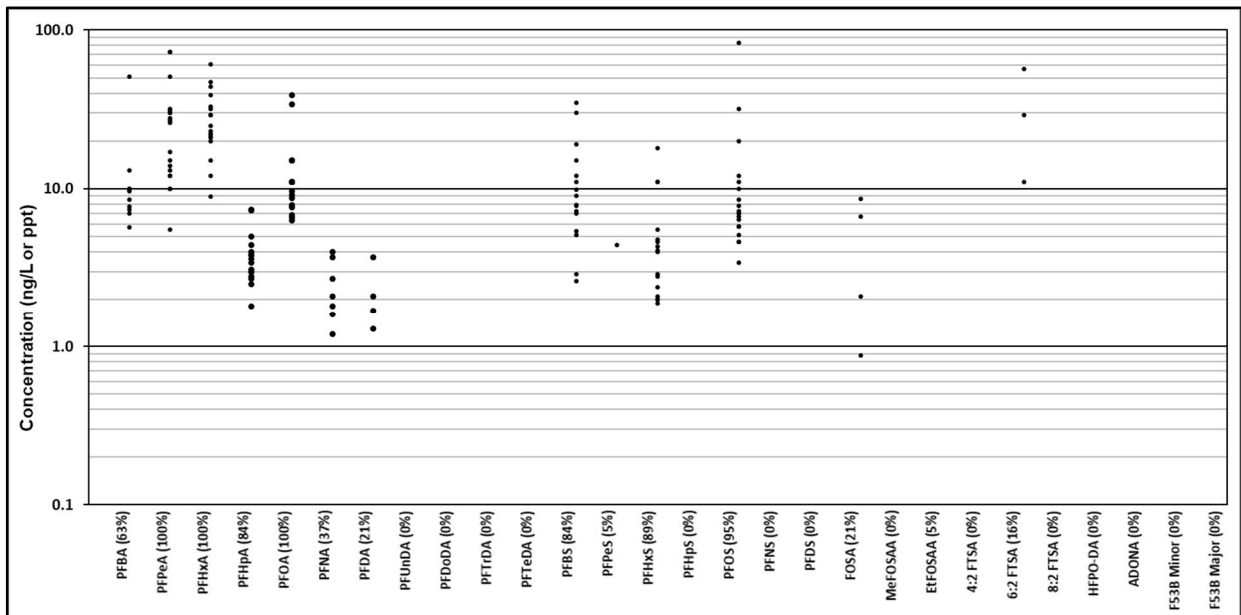


Figure 15. Final Treated Solids PFAS Detection Frequency and Concentrations – Box Plot

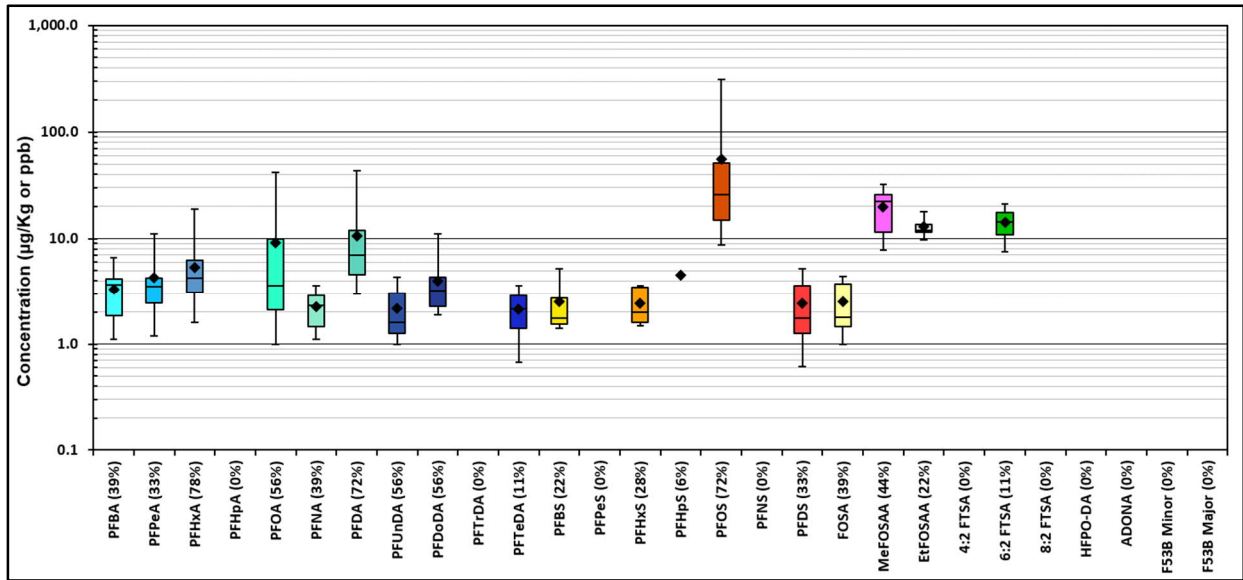


Figure 16. Final Treated Solids PFAS Detection Frequency and Concentrations – Dot Plot

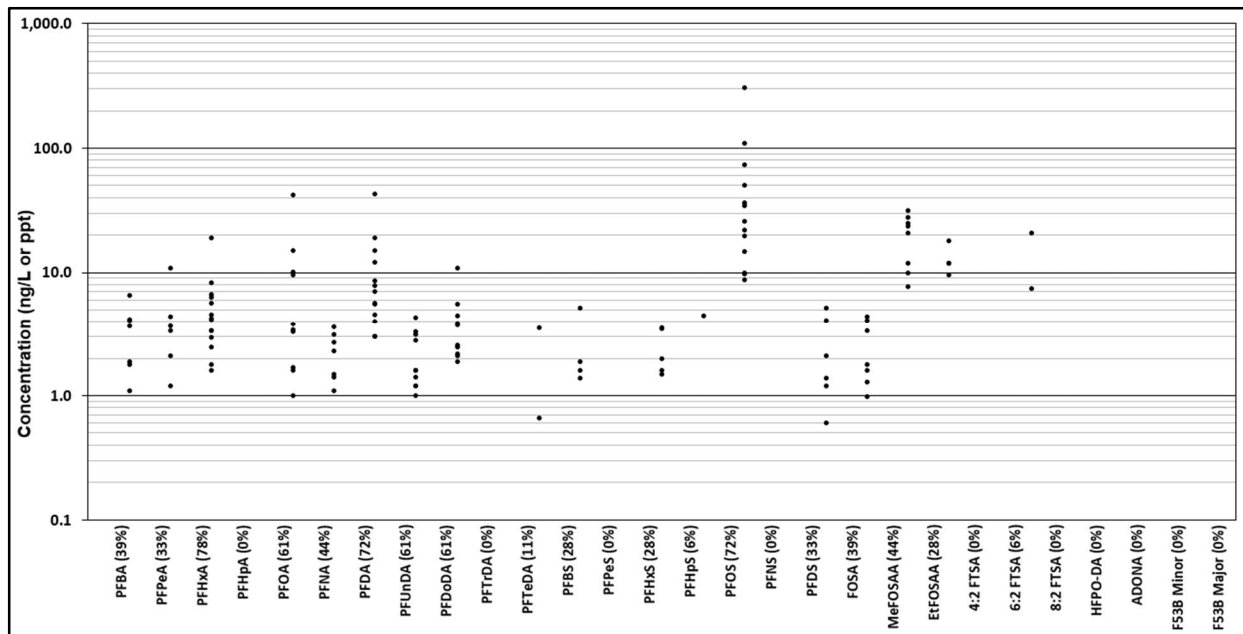
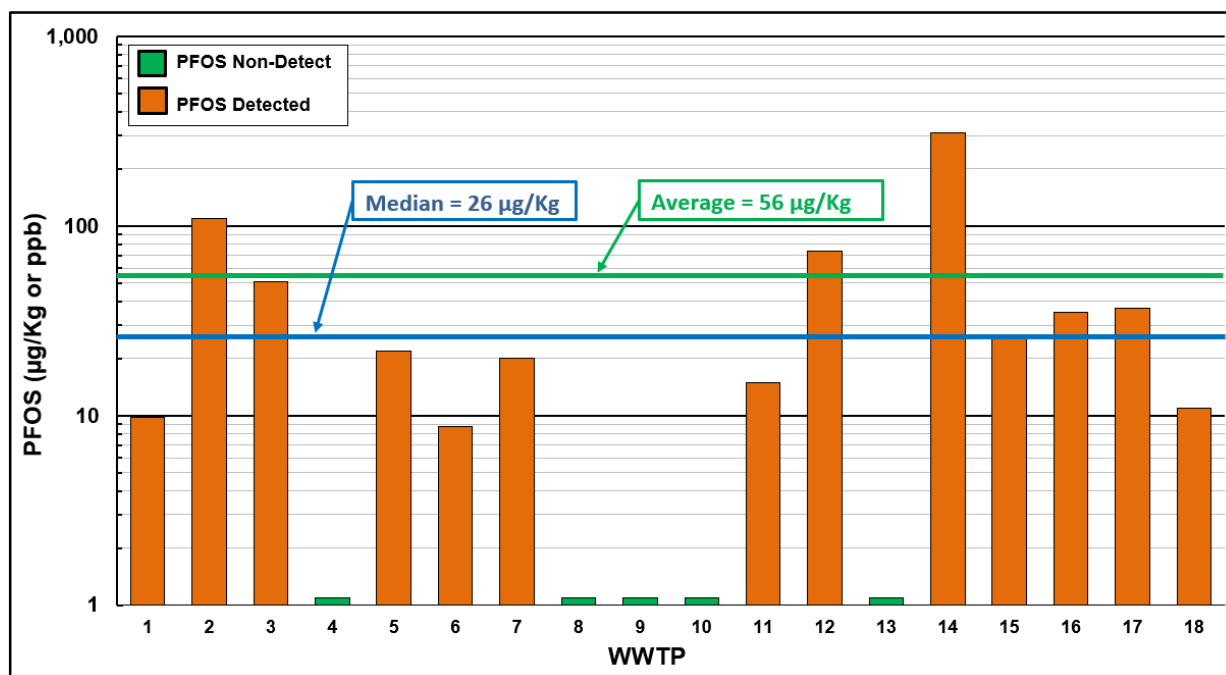


Figure 17. Final Treated Solids PFOS Concentrations - AECOM Phase 1 National Study



3.3 Industrial Sources Results

PFAS could be present in many commercial and residential waste streams. However, due to the extended historical and widespread use of PFAS in many industries, industrial discharges are expected to be the primary sources of PFAS to WWTPs. The design flow of each facility could play a significant role in the PFAS impact as the commercial and primarily residential wastewaters may serve as a dilution of the industrial wastewater streams. Potential sources of PFAS in WWTPs from Switzerland, Germany, and Thailand were identified from industrial discharges of textile, carpet, and paper coatings, AFFFs, electroplating, and semiconductor industries (Kunacheva, 2011; Alder, 2015). In Michigan, many WWTPs with industrial pretreatment programs (IPP) were identified as having a higher likelihood of discharging PFAS because they accept industrial wastewaters. In Michigan, approximately 2,000 samples from 574 industrial dischargers, including Industrial User (IU), Significant Industrial User (SIU), and Categorical Industrial User (CIU) as described in the pretreatment regulations under Title 40 of the Code of Federal Regulations (CFR) 403, were sampled for PFAS. The most significant CIU sources identified in Michigan were categories 413 (Electroplating), 433 (Metal Finishing), 419 (Petroleum Refining), 430 (Pulp, Paper, and Paperboard), and 437 (Centralized Waste Treatment). The most significant IU and SIU facilities identified in Michigan were chemical manufacturing, pulp, and paper manufacturing, AFFF residuals from department of defense (DoD) installations, airports, petroleum terminals and refineries, and fire departments, commercial, industrial laundry facilities, various contaminated sites, textile and leather facilities, and landfills.

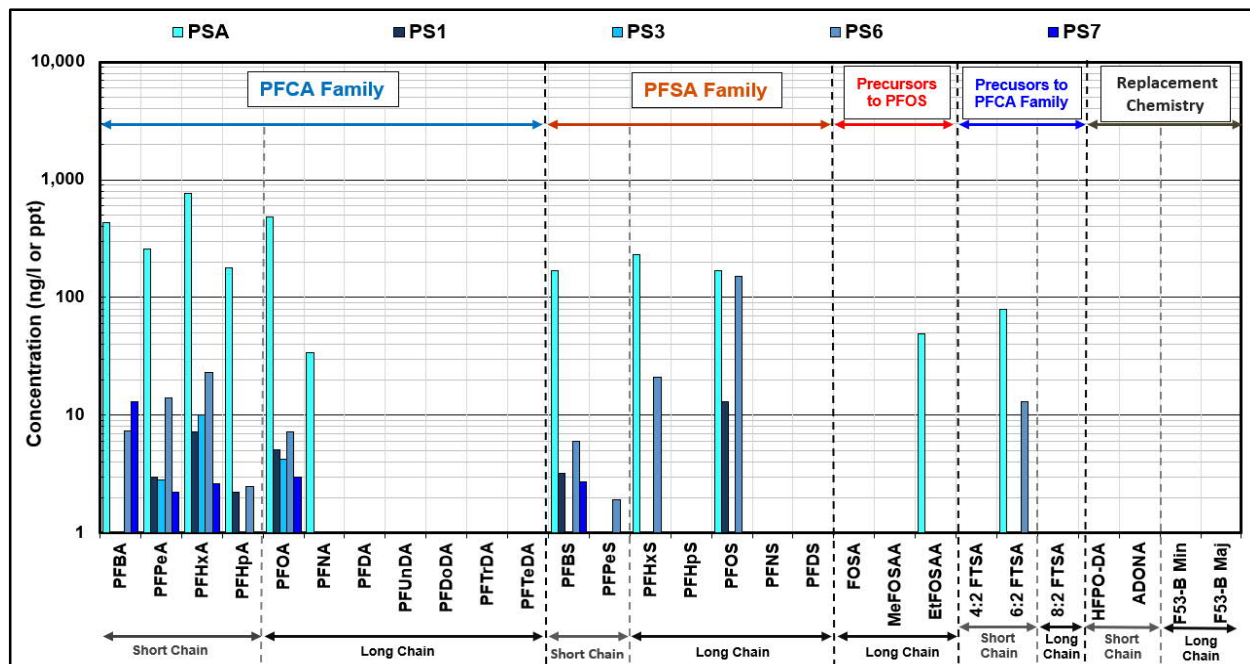
The identification of PFAS sources to the WWTPs was not part of the current study. However, during the AECOM review of the information provided by each WWTPs, when the industrial discharges were provided, AECOM did observe the presence of similar industrial discharges as those identified in Michigan and other studies as being PFAS sources.

Sampling at various points within the wastewater collection system may help identify significant

sources of PFAS and alternatives for source reduction. For example, WWTP 17 sampled five (5) pump stations to understand better potential PFAS sources to their facility with the results presented in **Figure 18**. Pump station A (PSA) had the highest PFAS concentrations with the most compounds detected. The total PFAS concentration was 2,853 ng/L, with the highest concentration of 770 ng/L detected for PFHxA. Pump station 6 (PS6) had the second-highest PFAS concentrations and the number of compounds detected. The total PFAS concentration in PS6 was 245.9 ng/L, with the highest concentration for PFOS of 150 ng/L. The PFAS detections for the other pump stations were mainly below ten (10) ng/L. The most frequent detections were short-chain PFAAs, with PFOA and PFOS being the frequently detected long-chain PFAS. PFAS precursors were only detected in PSA and PS6. The actual impact to the WWTP depends on both PFAS concentration and total discharge volume, however these collection system results provide WWTP 17 more information to identify sources and consider source reduction strategies.

In Michigan, a total PFOS source reduction was achieved between 88% to 99% through source reduction efforts (AECOM, 2021). PFOS is the main regulatory driver in Michigan, having the lowest surface water criterion of 12 ng/L. Metal finishers (e.g., chrome platers) were identified as one of the main industrial dischargers that contributed the most significant mass of PFOS to the WWTPs from Michigan that performed the source reduction. Some WWTPs had only one metal finisher discharging to the WWTP. As a result, in some instances, installing a single pretreatment system on the discharge from the one metal finisher resulted in a significant drop in the PFOS effluent concentrations at the WWTP.

Figure 18. Pump Station PFAS Concentrations – WWTP 17



3.4 PFAS Concentrations for the Three Studies

Box plot graphs for the influent, effluent and final treated solids for all three (3) studies are presented in **Figures 19, 20, and 21**. The PFAS detected in the influent for all three studies were similar in terms of overall compounds detected, with the 25th to 75th percentiles overlapping each other over similar concentration ranges. However, the concentration ranges

for some PFAS in the California and Michigan statewide studies were larger than the those for the AECOM National Study. This is due to the more significant number of WWTPs included in the California and Michigan studies. PFAS detected in only one of the studies but not in the others were detected at low detection frequency and low concentrations. There were almost no detections of the PFAS replacement chemistry compounds as expected. Some of these compounds are believed to be used only in China or are primarily used at fluoropolymers manufacturing facilities in the US. Short-chain PFAAs were the most frequently detected PFAS as presented in **Figure 7**, with concentrations ranging from low ng/L to 100 ng/L. All the PFAS detections had the same similar range from low ng/L to about 100 ng/L, except for PFOA, PFOS, and 6:2 FTSA, which had higher concentrations above the 100 ng/L. PFOA and PFOS have been highly associated with past historical PFAS use, and 6:2 FTSA is one of the precursors used as replacement chemistry for long-chain PFAS.

A similar trend was observed in the effluent results as in the influent with similar overall compounds detected with the 25th to 75th percentiles overlapping with similar concentration ranges. However, some of the long-chain PFAS identified in the influent were not detected in the effluent, indicating that they most likely accumulate in the solids. There were almost no detections of the replacement chemistry compounds. There was an observed increase in overall concentrations for many PFAS, especially short-chain PFCAs, such as PFPeA and PFHxA. The mean concentrations for many PFAS were also higher than those in the influent, indicating that the few facilities with higher concentrations had a more significant effect on the high bias in the effluent.

The PFAS detection observed in solids also had the 25th to 75th percentiles overlapping with similar concentration ranges for almost all the PFAS. However, there were some differences observed in the solids compared to the influent and effluent trends. The majority of PFAS had three-quarters of the data up to the 75th percentile below ten (10) µg/kg. All the long-chain PFAS were detected in all three studies in the solids, except for the long-chain replacement chemistry. PFOS had the highest overall concentrations compared to the rest of the PFAS detected in all three studies, with the 25th to the 75th percentiles above ten (10) µg/kg. Precursors known to degrade to PFOS, such as MeFOSAA and EtFOSAA, which were detected at lower concentrations and frequencies in the influent and effluent samples, were detected more frequently in the solids at higher concentrations compared to other short-chain and long-chain PFAS. This indicates preferential adsorption for the solids of long-chain PFAS, but concentrations in the influent and effluent were very low or non-detect. This indicated that when PFOS is present in the influent is also expected to be the main PFAS detected in solids.

A comparison of the PFOS concentrations for the three studies for final treated solids with other studies published in the literature for WWTPs from the US and around the world is presented in **Figure 22**. Archived biosolids samples (collected in 2001) by USEPA representing 94 wastewater treatment facilities from 32 different States and the District of Columbia were analyzed for 13 PFAS. Solids concentrations from 20 United States WWTPs were also collected in 2004 and 2007, except for one sample collected in 1998 (Venkatesana and Halden, 2013). The PFOS concentrations in the final treated solids from the three (3) studies were compared to those reported in archived biosolids samples from 2001 by USEPA, the US from 2004 and 2007, Switzerland (Alder, 2015), Australia (Gallen, 2016), parts of the United States (Higgins, 2005), and Kenya (Chirikona, 2015) (**Figure 22**).

In May 2000, one of the world's leading producers of PFAS, 3M, announced to voluntarily phase out by 2002 its production chemistry based on perfluorooctane sulfonyl fluoride (POSF). The announcement for the switch in PFAS chemistry was in response to PFAS compounds and perfluorooctane sulfonic acid (PFOS) being detected in various biota across the world, including

remote parts and various environmental factors matrices. Before 2002 PFOS discharges to the WWTPs are expected to have been higher than those detected after 2002 and especially detected today. Products that contained PFOS were sold after 2002, with other countries such as China increase the production of PFOS, and residual PFOS impacts may have been present at many industrial effluents. As a result, PFOS sources were not entirely removed from the environment in 2002. The PFOS concentrations in the solids from multiple studies, including archived biosolids samples, seem to support the overall lower concentration trend since 2002 (**Figure 22**). The archived biosolids samples from 2001 collected by USEPA identified PFOS as the most abundant PFAS analyte detected with a minimum, median, average, and maximum concentrations of 308, 390, 402, and 608 $\mu\text{g}/\text{kg}$, respectively. The mean concentration for PFOS was not statistically significantly different from 2004 and 2007 samples compared to those collected from 2001 (Venkatesana and Halden, 2013). However, the concentration range was larger between 8 to 2,600 $\mu\text{g}/\text{kg}$, including a 65 $\mu\text{g}/\text{kg}$ median. The PFOS concentrations from 2005 presented by Higgins had very similar concentrations to those from 2004 and 2007. The PFOS concentrations in the solids from WWTPs from Switzerland and Australia ranged from 5 to 2,440 $\mu\text{g}/\text{kg}$ with a median ranged from 36 to 130 $\mu\text{g}/\text{kg}$ (Alder, 2015; Gallen, 2016). The mean and median concentrations from Australia, sampled more recently in 2016 than those from Switzerland from 2008 and 2011, were lower than Switzerland. The PFOS concentrations were significantly higher than those reported in WWTPs from Kenya (Chirikona, 2015), where only one (1) out of nine (9) WWTPs had some industrial discharges. The concentrations in the three studies had similar median concentrations of 13, 26, and 16 $\mu\text{g}/\text{kg}$ for the Michigan, AECOM, and California studies, respectively. The median concentrations were like those of Australia from 2016 of 36 $\mu\text{g}/\text{kg}$. However, the concentration range from the AEOC study was not as extensive as that for the Michigan and California studies. This is due to the more significant number of sampled facilities with a broader range of PFAS impacts. Most of the studies, including the three studies, had a high median biased due to high concentrations of few facilities. In conclusion, the median concentrations are more appropriate to be used for comparison between extensive studies. It also indicates that PFAS impacts to the WWTPs vary widely, with historical impacts expected to be higher than those observed today.

Figure 19. Influent PFAS Concentrations for All 3 Studies – Box Plot

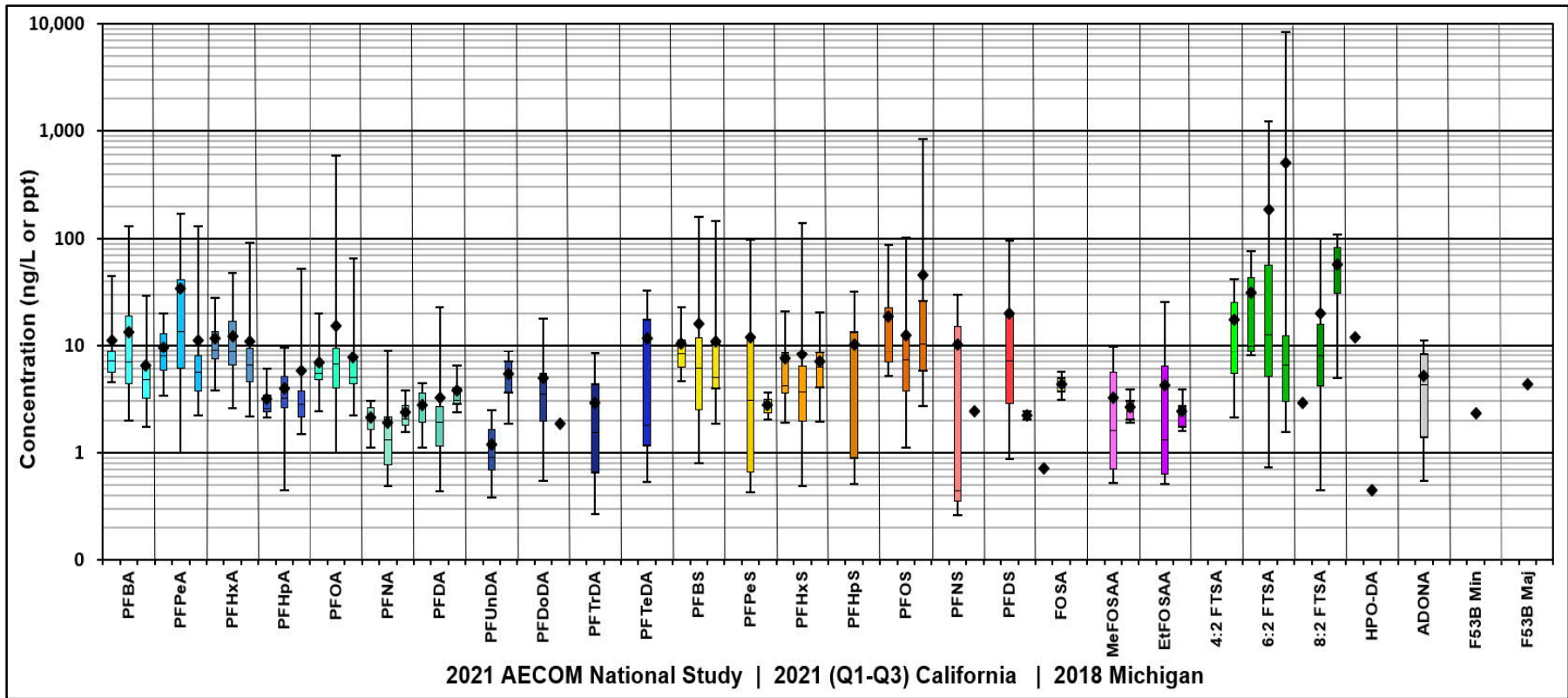


Figure 20. Effluent PFAS Concentrations for All 3 Studies – Box Plot

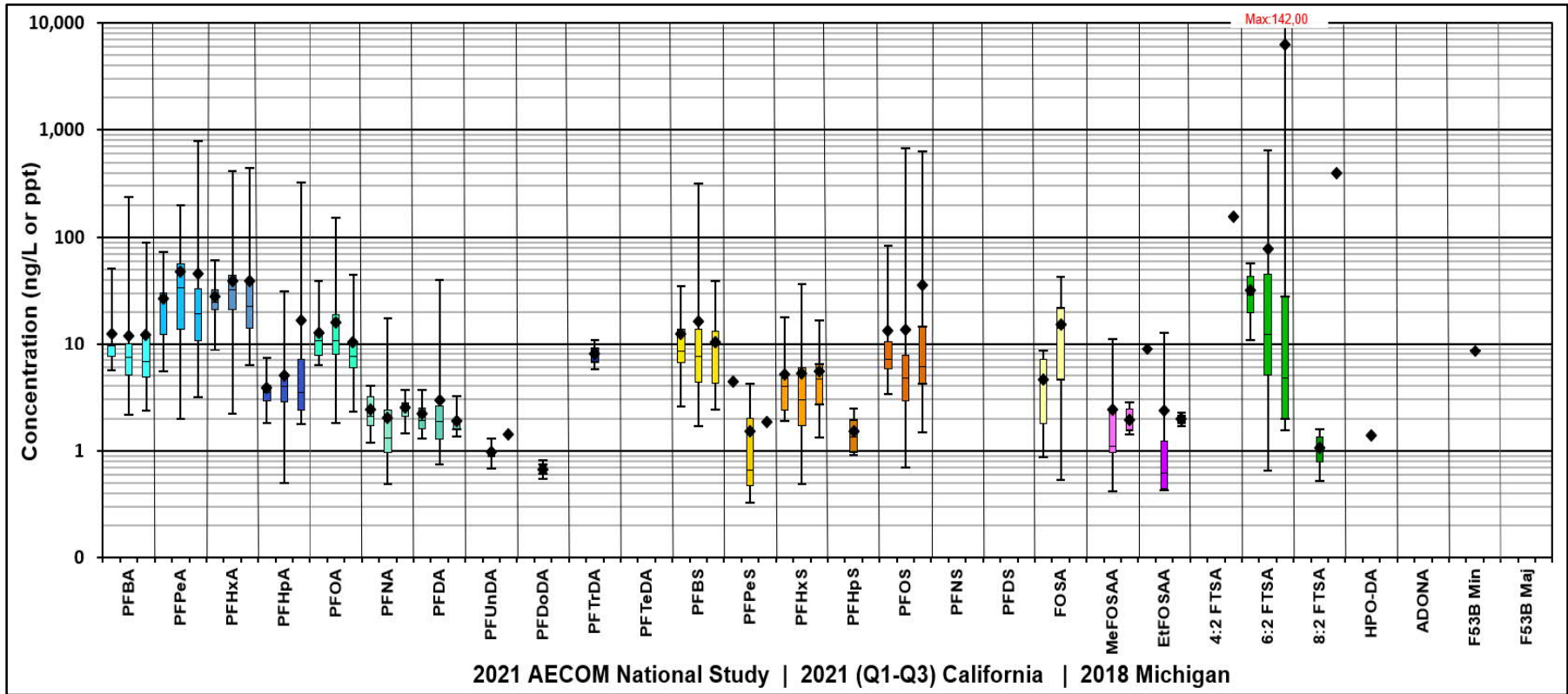


Figure 21. Final Treated Solids PFAS Concentrations for All 3 Studies – Box Plot

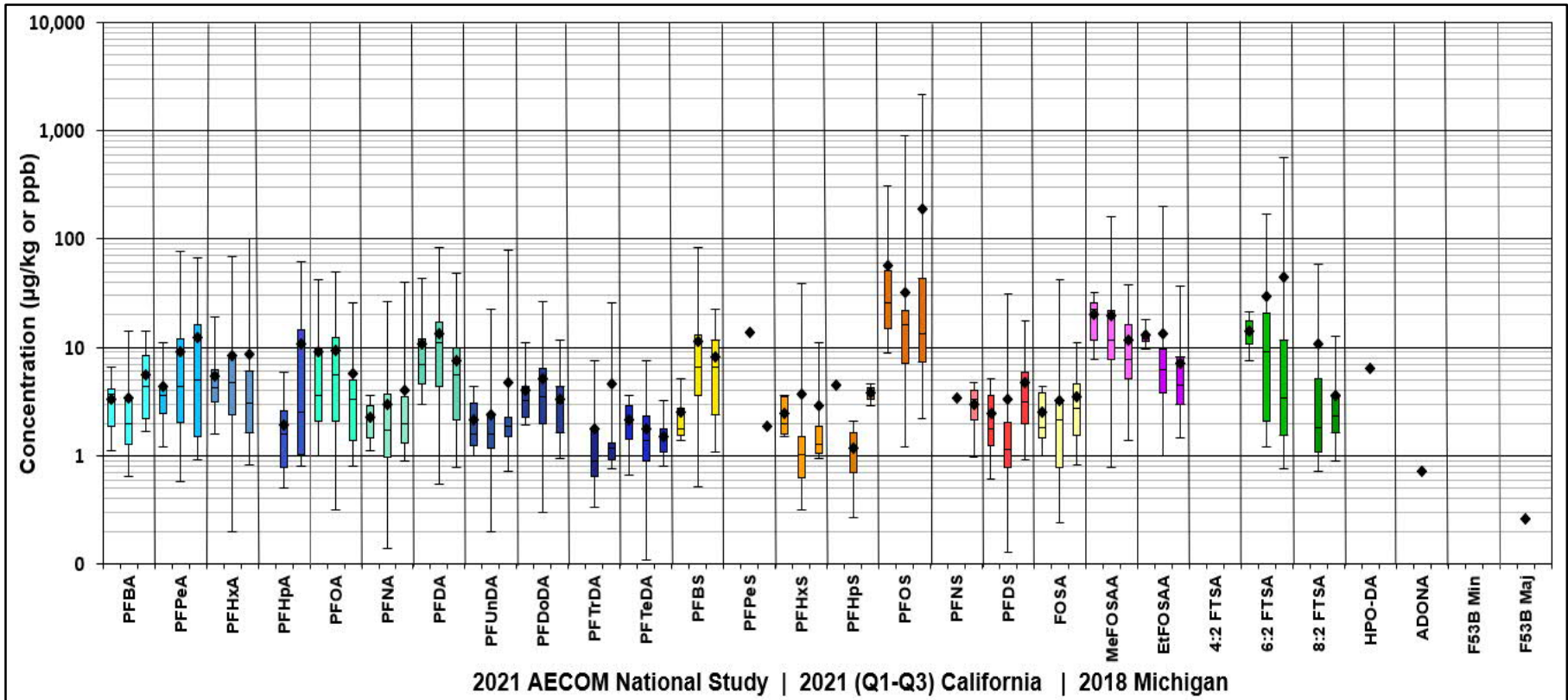
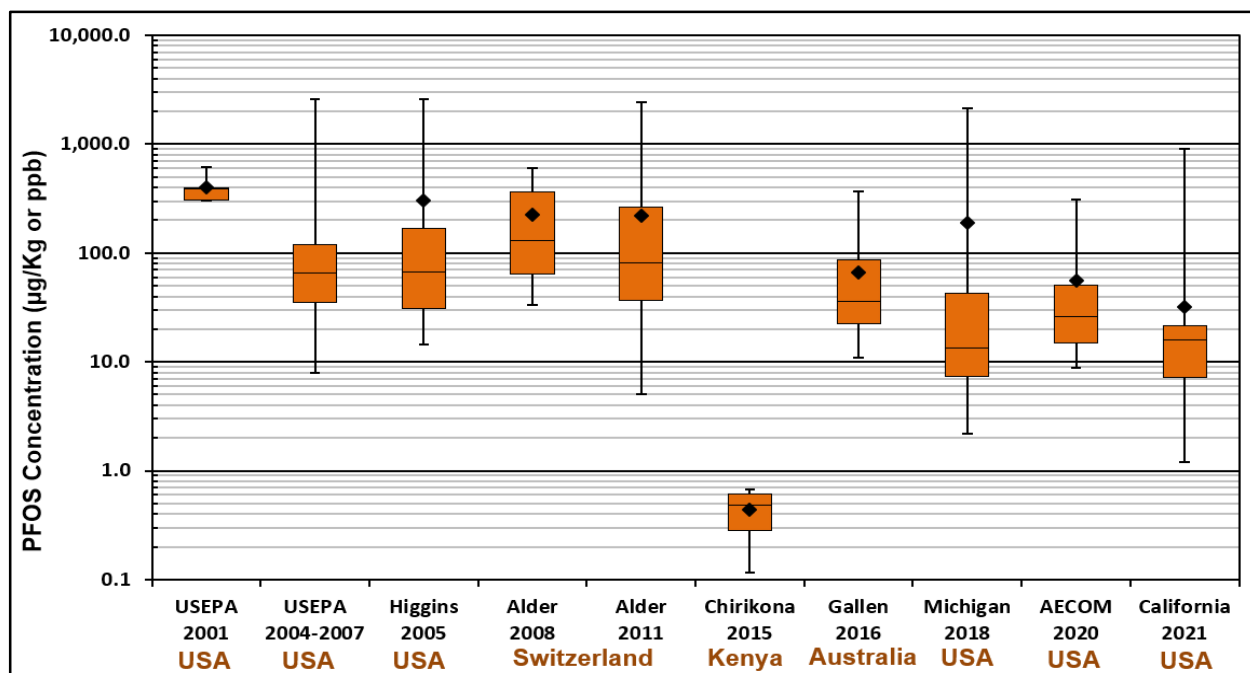


Figure 22. Final Treated Solids PFOS Concentrations - Multiple Published Studies



4. Phase 2 Study

Eight (8) WWTPs were selected for Phase 2 to participate in an in-depth evaluation of the PFAS fate within the WWTPs and the potential impacts to present end uses of the effluent or solids from the facility. Phase 2 samples were collected at several locations along the liquid treatment train and solids management process to evaluate the fate of PFAS within the treatment process. The review of the Phase 2 data also included the evaluation of the potential of precursor degradation or recirculation of PFAS within the WWTPs. The WWTPs selected for Phase 2 were #2, 8, 9, 10, 11, 13, 14, and 18.

As stated earlier in the Phase 1 study evaluation, wastewater and solid samples from WWTPs are some of the most difficult environmental matrices to be analyzed for PFAS due to potential significant matrix interference that can occur which will result in higher detection limits. These high detection limits will make the interpretation of PFAS impacts to WWTPs difficult to make. The aqueous and solid sample results for the Phase 1 Study are presented in **Tables 1** and **2**, respectively. The Phase 2 samples were collected between December 15, 2020, through June 9, 2021. The time difference between Phase 1 and Phase 2 varied from a few weeks to months. To evaluate the potential fluctuation in concentrations, the PFOA for the influent for Phase 1 and Phase 2 were plotted in **Figure 23**; the PFOS for the influent for Phase 1 and Phase 2 were plotted in **Figure 24**, and the total PFAS for the influent from Phase 1 and Phase 2 were plotted on **Figure 25**.

Similar trends and concentrations were observed for WWTPs 2, 8, 9, 10, 11, 13, and 18. Some of the results were difficult to evaluate due to the matrix interference and high detection limits. However, overall, it was observed that the facilities had concentrations within the same range for PFOA, PFOS, and total PFAs in the effluent during Phase 1; the same was observed during Phase 2. WWTP 14 was the only facility that a higher PFAS impact was observed during Phase 2, which was believed to do with a discharge from a facility with AFFF impact, a known PFAS source.

Figure 23. Phase 1 and 2 – Influent and Effluent PFOA Concentrations

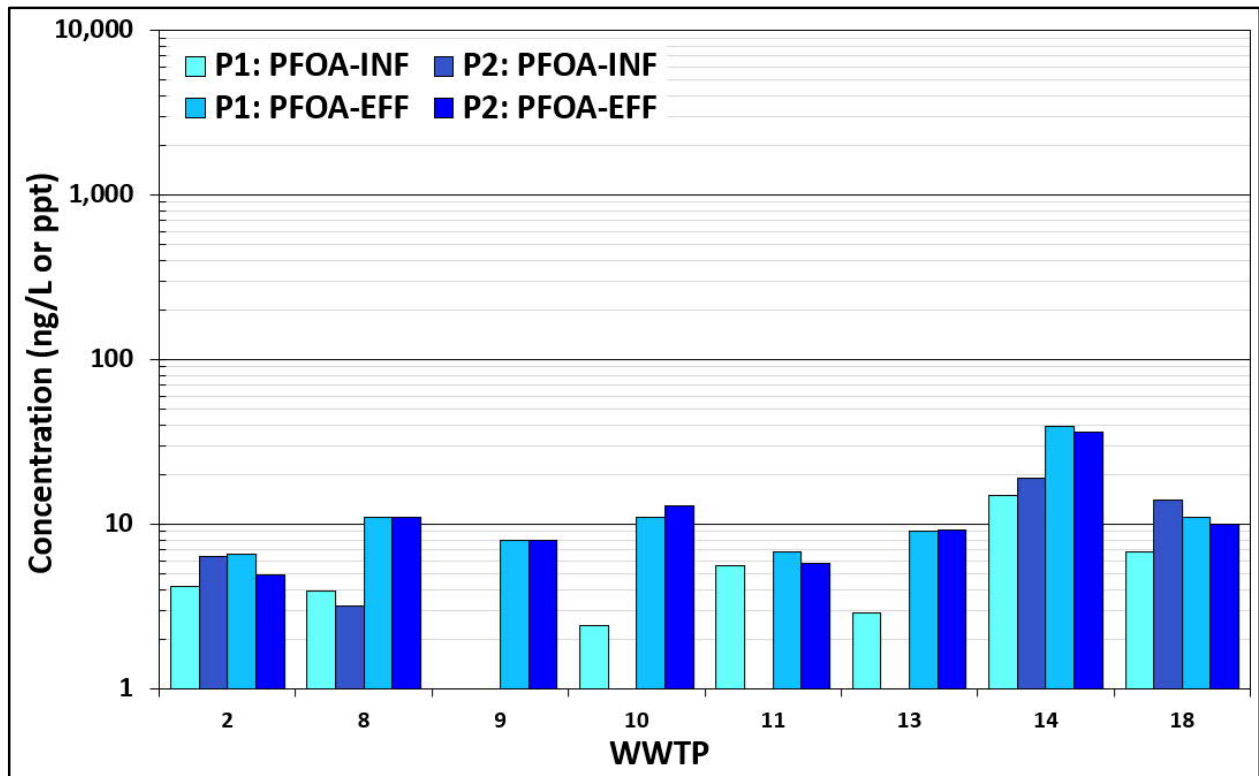


Figure 24. Phase 1 and 2 – Influent and Effluent PFOS Concentrations

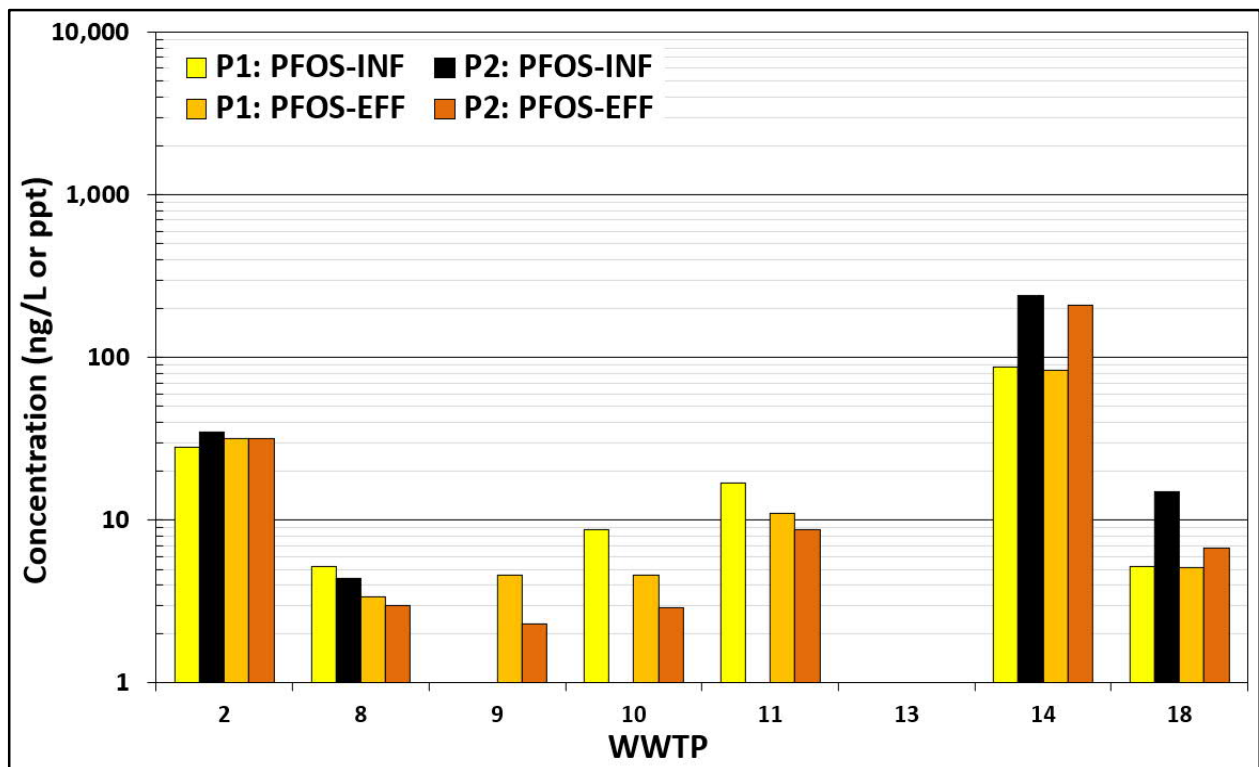
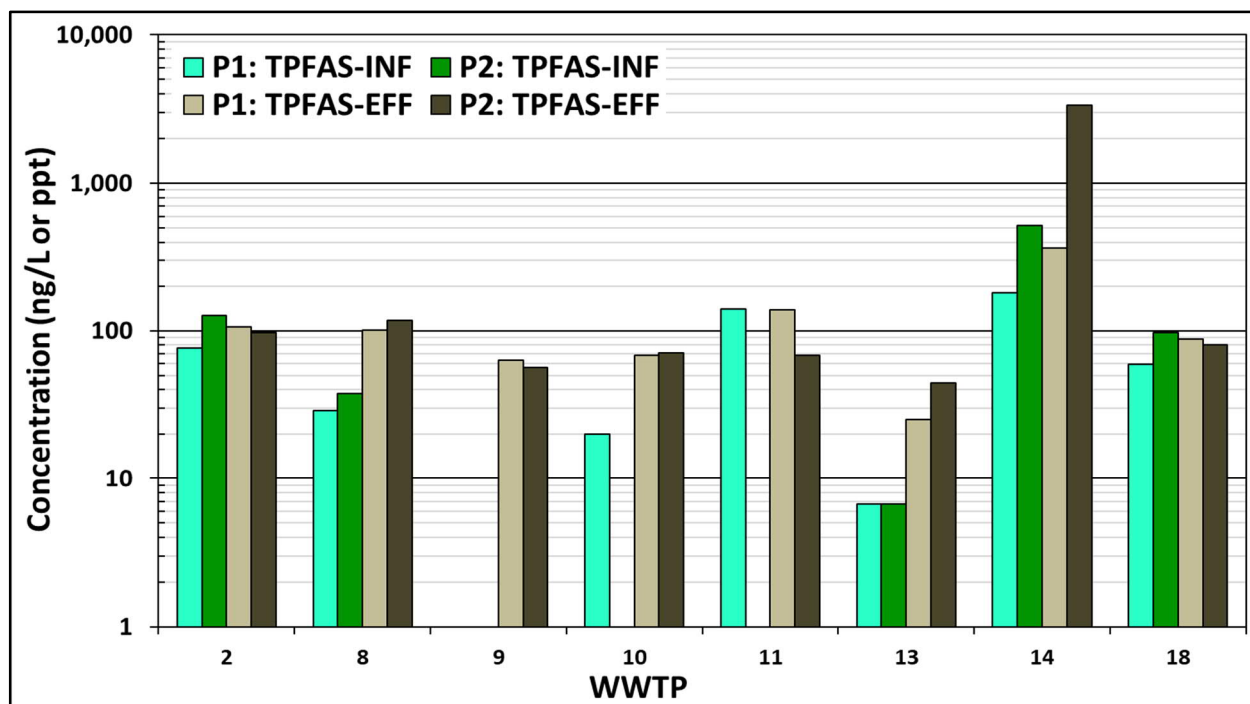


Figure 25. Phase 1 and 2 – Influent and Effluent Total PFAS Concentrations



To properly evaluate the PFAS fate within the WWTPs, a total of three graphs were developed for each WWTP. One figure was presented for the aqueous treatment train and the second figure for the solids process treatment train, with the first samples being from the beginning of the WWTP and the subsequent after the further treatment process. The last sample for both treatment trains was representative of the final treated aqueous and solid sample. Finally, a graph was developed with the process flow diagram (PFD) with the location of each sample. The PFAS on the figures was divide into various families, including various chain-length sections. The graph with the PFD also had a summary table that presented the results for the Total PFAs, PFOA, PFOS, short-chain PFAAs, long-chain PAAAs, short-chain precursors, and finally long-chain precursors. Also, to better understand the partition of PFAS between the aqueous and solids, for solid samples with high aqueous percentage, the aqueous and solid portions of the samples were analyzed separately for PFAS. Finally, a select number of samples were also analyzed using the TOPA for WWTPs 8, 9, 10, and 11. Please note the results for the aqueous samples were in ng/L or parts per trillion (ppt), while the solid samples were reported as µg/Kg of parts per billion (ppb).

4.1 WWTP 2 Phase 2 Evaluation

Five (5) aqueous samples (Aqueous Sample IDs 1 through 5) were collected from the liquid treatment train between raw influent and final effluent. Centrate recirculates back to preliminary treatment and was also sampled. Three additional aqueous samples were collected as the aqueous portion of the solids with high moisture content (Aqueous Sample IDs 7, 8, and 9). Two solid samples were collected from primary sludge and waste active sludge (Solid Sample IDs 1 and 2). Finally, one final cake sample was collected after the final centrifugation step (Solid Sample ID 3). A description of each Sample ID and the location within the treatment plant is presented in **Figure 26** on the process flow diagram.

4.1.1 Aqueous Fate and Transport Discussion

Total PFAS within the aqueous treatment train was shown to be within the same range between 97 to 126 ng/L (**Figure 26**). Similar PFAS were detected within the aqueous treatment train, such as short-chain PFCAs, with PFOA being the only long-chain PFCA (**Figure 27**). For the PFSA family, PFBS was the only short-chain compound detected, and PFHxS and PFOS were the only long-chain compound detected. The absence of odd number carbon chain PFSA was expected based on literature review due to the less frequency of detection related to how the PFAS were produced, which favored the formation of even number carbon chain length PFASs. Precursors were detected earlier in the treatment, either in the influent or in the aeration tank effluent. The concentrations were 5.4 and 6.5 for FOSA, a known PFOS precursor, and 13 ng/L for 6:2 FTSA, a known precursor to PFHxA and PFPeA, and a lesser degree PFBA. There was no replacement chemistry PFAs detected in aqueous treatment train samples. The results indicate that the PFAS are passing through the treatment train without any significant impact for the most part.

PFAS are expected to adsorb and concentrate in the solids, especially long-chain PFAS. The accumulation of PFAS in solids further down the treatment train is expected to be greater due to the longer time PFAS interacts with the solids and recirculated streams. The longer retention time facilitates additional adsorption to solids. Conversely, PFAS concentrations in the aqueous portion of the solids are expected to decrease as the PFAS accumulate more in the solids. Sample results from WWTP 2 supports the expected concentration trends. Total PFAS for the aqueous portion of Primary Clarifier (PC) sludge was 197 ng/L compared to 132 for Return Activated Sludge (RAS) or Waste Activated Sludge (WAS). This was due to the long-chain PFAS, which has a higher affinity to the solids, significantly decreasing in the aqueous portion of the solids in the WAS compared to the PC sludge. PFOS dropped from 120 to 24 ng/L, and long-chain PFAAs dropped from 126 to 45 ng/L. Higher PFAS concentrations were detected in the centrate and aqueous portion of the solids from the sludge storage tanks, with total PFAS concentrations reaching 762 and 818 ng/l, respectively. The highest increase in the total PFAS was due to the increase in the short-chain PFAAs. While the centrate had a significantly higher PFAS concentration, centrate recirculation of 0.001 mgd makes up a low percentage of the overall influent flow of 9.5 mgd. RAS had a higher recirculated flow of 2.1 mgd with increased concentration and mass of PFAS in the solids. While PFAS concentrations in the aqueous portion of RAS were only slightly higher than that in influent and the majority of PFAS present in solids are expected to remain to adsorb to the solids.

4.1.2 Solid Fate and Transport Discussion

A significant increase in the total PFAS further down the treatment process was observed from 28 µg/Kg in the PC Sludge to 188 µg/Kg in the WAS (**Figure 26**). The highest increase in the PFAS was observed as expected in the long-chain PFAAs from 16 to 150 µg/Kg. The PFAS detected in the WAS was higher, with some PFAs detected in the WAS but not detected in the PC Sludge. The overall concentrations in the final treated solids (i.e., Cake) were lower than WAS but higher than the PC Sludge due to the blending of both solid streams. The PC Sludge had the least number of PFAS present, followed by WAS and then Cake. The Cake was the only solid sample that contained precursors, with all three being precursors that could degrade to PFOS. MeFOSAA, one of the PFOS precursors, was detected at the second-highest concentration. Precursors may have only been detected in the Cake because their presence in the influent can vary over time and Cake represents a blend of solids from a period longer than the Phase 2 sampling. Alternatively, the longer retention time may play a partial role in the presence of precursors in the Cake due to the longer retention time in the sludge storage tank, allowing more time for the PFOS precursors to accumulate to the solids.

Figure 26. PFAS Results and Process Flow Diagram for WWTP 2

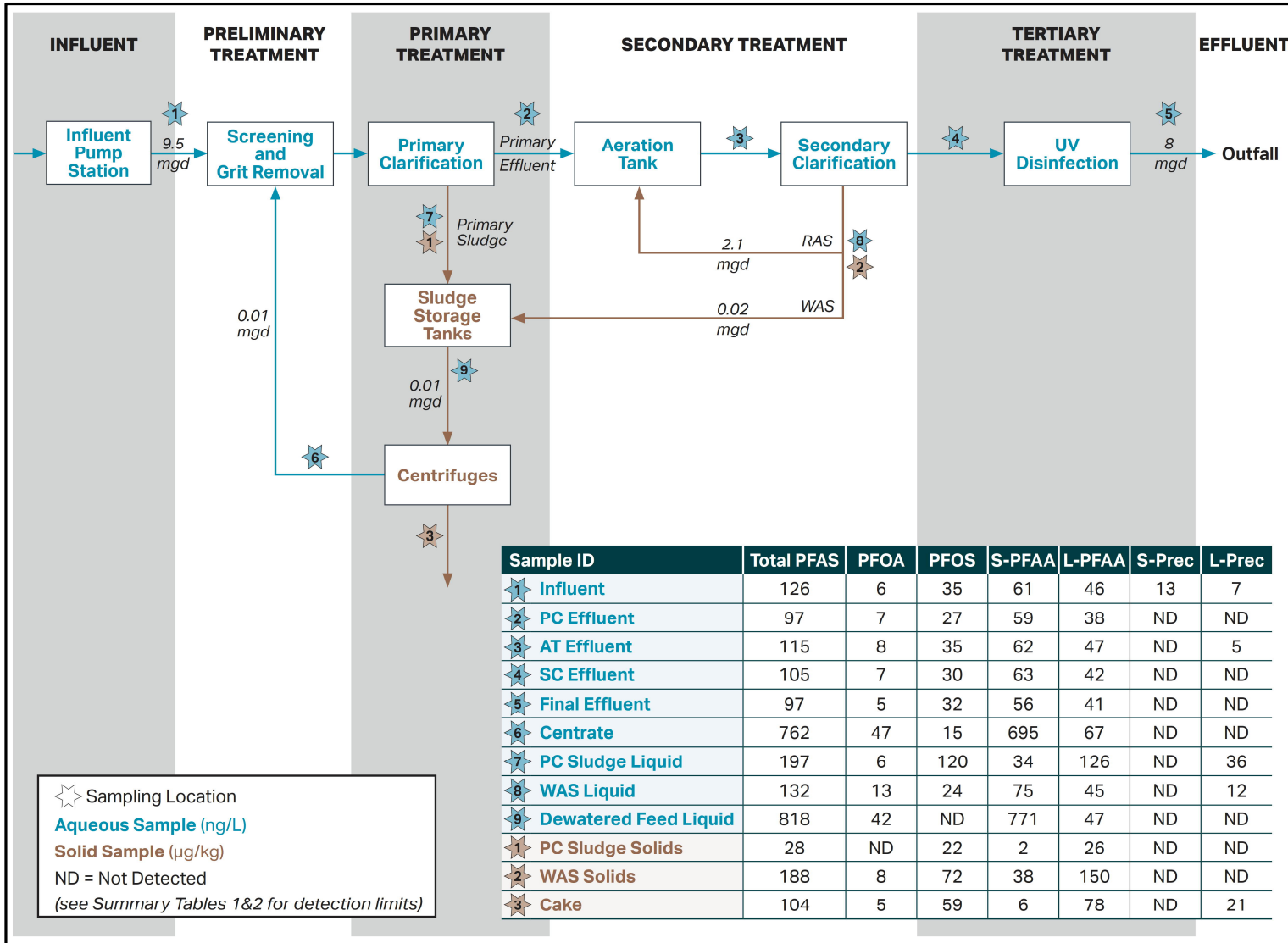


Figure 27. WWTP 2 PFAS Concentrations in The Aqueous Treatment Process Flow

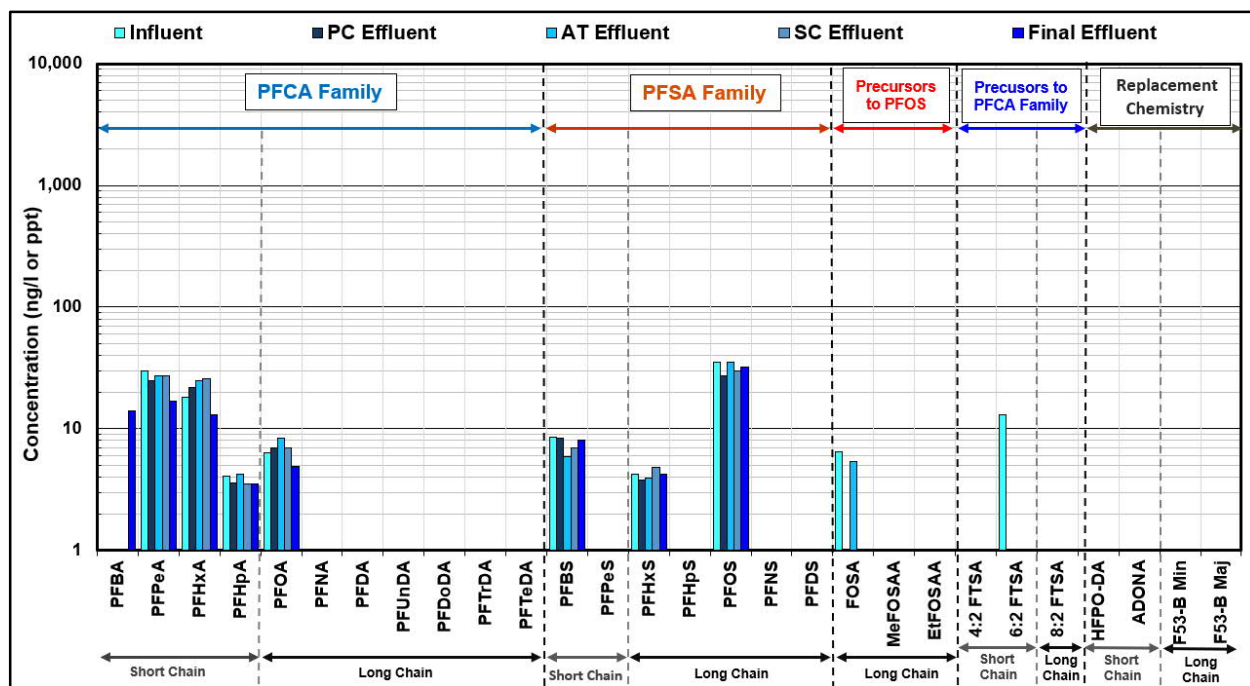
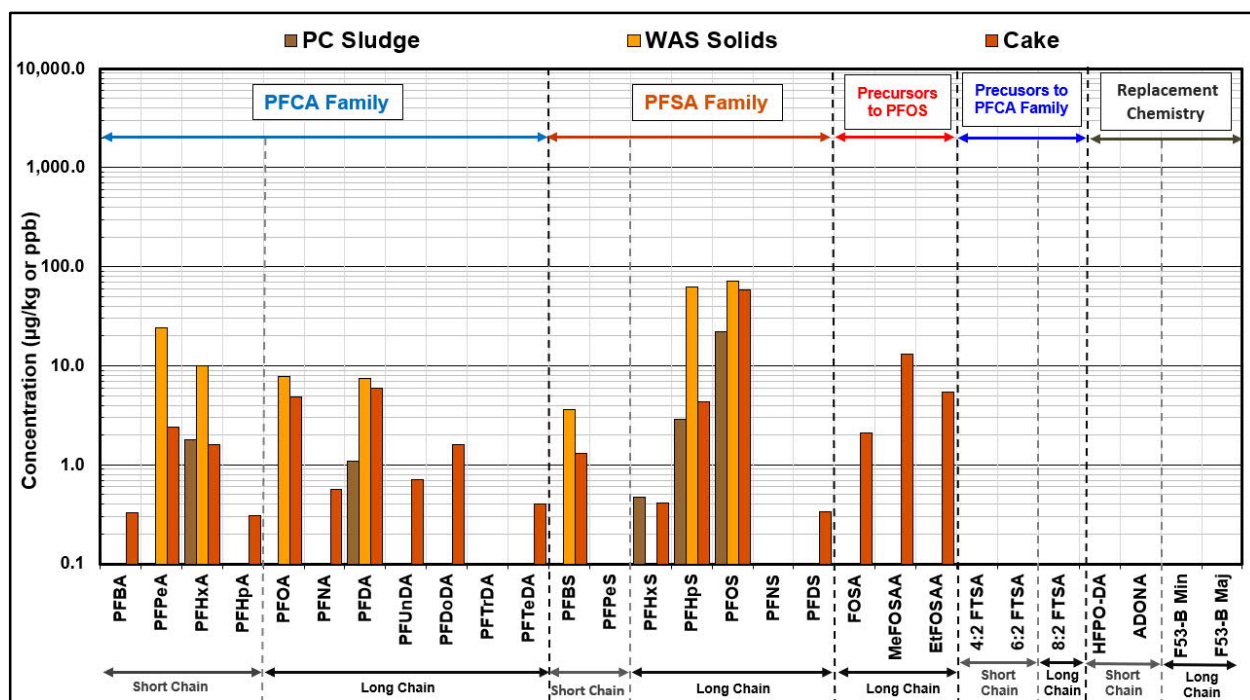


Figure 28. WWTP 2 PFAS Concentrations in The Solid Treatment Process Flow



4.2 WWTP 8 Phase 2 Evaluation

Five (5) aqueous treatment samples (Aqueous Sample IDs 1 through 5) were collected from the liquid treatment train between raw influent and final effluent. Two solid samples with high moisture content were collected from primary and waste active sludge (Solid Sample IDs 1 and 2). A description of each Sample ID and the location within the treatment plant is presented in **Figure 29** on the process flow diagram. One set of samples were collected on December 2, 2020, and the second set on December 16, 2020. The WWTP was first selected for the study based on samples collected before December 2, 2020. The PFAS results for the second event for both the aqueous and solid samples are presented in **Figures 30** and **31**. TOPA was also used to analyze the influent and effluent, and the results are presented as Pre-TOP and Post-TOP.

4.2.1 Aqueous Fate and Transport Discussion

The matrix interference resulted in elevated detection limits and limited the interpretation for each sampling event individually. The influent results for both sampling events had similar detection limits, and the total PFAS concentrations were similar during both events with 29 and 38 ng/L (**Figure 29**). PFAS concentration increased in the secondary treatment after the activated sludge aeration with total PFAS increasing from 40 to 215 ng/L. There was a decrease in PFAS concentrations after the secondary sedimentation in the aqueous stream most likely to partition PFAS to the solids. No significant changes were observed in the PFAS concentration in the tertiary treatment from the dual-medial pressure filtration with overall similar concentrations pre and post-filtration. Precursors were detected only before the secondary sedimentation effluent (**Figure 30**). The short-chain PFCAs were detected at the highest concentrations. FOSA may have been accumulated in the solids in the secondary treatment, which may be why it was not present in the final effluent.

The difference in the Pre-TOP and Post-TOP results for the raw influent for the total PFAS was from 38 to 163 ng/L, with the most significant increase in the short-chain PFAAs from 20 to 151 ng/L. There was no observed increase in the long-chain PFAAs, which indicates that currently, the predominant precursors in the influent are short-chain. The concentrations of short-chain precursors analyzed as part of the 28-analyte list could not account for the increase observed in the Post-TOP results, indicating the presence of additional short-chain precursors not part of the current analysis list. A similar trend was observed in the Pre-TOP, and Post-TOP results in the final effluent, with the majority, increased occurring for the short-chain PFAAs from 64 to 125 ng/L, and the increase for the total PFAS was only from 78 to 136 ng/L. The increase in PFAS concentrations in the Post-TOP sample for the final effluent indicated fewer available short-chain precursors in the final effluent. While the short-chain precursors have a fluorinated fluorine-carbon tail, they have additional hydrogen-carbon bonds subject to degradation. The short-chain precursors, as a result, are expected to have a higher affinity to solids than their short-chain PFAAs, to which they could potentially degrade in the environment. This indicated that there might be an additional accumulation of short-chain precursors in the solids at a higher magnitude than those observed for the short-chain PFAAs.

4.3 WWTP 8 Phase 2 Evaluation

The treatment train for WWTP 9 was like that of WWTP 8. Five (5) aqueous treatment samples (Aqueous Sample IDs 1 through 5) were collected from the liquid treatment train between raw influent and final effluent (**Figure 32**). Two solid samples with high moisture content were collected from primary and waste active sludge (Solid Sample IDs 1 and 2). A description of each Sample ID and the location within the treatment plant is presented in **Figure 32** on the process flow diagram. Two sets of samples were collected, one on December 2, 2020, and the

second on December 16, 2020. The PFAS results for the second event for both the aqueous and solid samples are presented in **Figures 33** and **34**. TOPA was also used to analyze the influent and effluent, and the results are presented as Pre-TOP and Post-TOP.

4.3.1 Aqueous Fate and Transport Discussion

Like WWTP 8, the Matrix interference at WWTP 9 also resulted in elevated detection limits, which made difficult the interpretation of some analytical results. This also limited the interpretation for each sampling event individually. The raw influent results had elevated detection limits in both sampling events and were non-detect, and the first results were from the primary effluent. The primary influent had a total PFAS concentration of 34 ng/L (**Figure 32**). An observed increase in the PFAS concentration in the secondary treatment after the activated sludge aeration with total PFAS increasing from 34 to 110 ng/L. There was a decrease in PFAS concentrations after the secondary sedimentation in the aqueous stream most likely to partition PFAS to the solids. No significant changes were observed in the PFAS concentration in the tertiary treatment from the dual-medial pressure filtration with overall similar concentrations pre and post-filtration. There were no precursors or replacement chemistry compounds detected in the aqueous treatment train (**Figure 33**). The short-chain PFCAs were detected at the highest concentrations.

There was no detection in the Pre-TOP results in the raw influent due to matrix interference. There was a significant difference in the Post-TOP with the total PFAS of 114 and 214 for the first and second sampling events. While during the second sampling event, the PFAS concentration was almost double, the overall ratios were similar for the short-chain PFAAs, which were the predominant PFAS detected. This indicates that there may be a potential higher fluctuation in the influent concentrations or that the elevated detection limits for some compounds limited a robust evaluation of the PFAS fate at WWTP 9. There was a slight increase in the PFAS concentrations in the final effluent between the Pre-TOP and Post-TOP with the total PFAS for sampling event one from 63 to 84 ng/L and sampling event two from 56 to 96 ng/L. The most significant increase was observed in the short-chain PFAAs from 51 to 76 ng/L for sampling event one (1) and 46 to 87 ng/L for sampling event two (2). There was no observed increase in the long-chain PFAAs, which indicates that the influent's predominant precursors are short-chain. Similar to WWTP 8, there may be additional short-chain precursors not part of the current analyte list. The short-chain precursors are expected to have a higher affinity to solids than their short-chain PFAAs, to which they could potentially degrade in the environment. This indicated that there might be an additional accumulation of short-chain precursors in the solids at a higher magnitude than those observed for the short-chain PFAAs.

4.3.2 Solid Fate and Transport Discussion

The matrix interference resulted in high detection limits for the primary sludge samples to be non-detect during both sampling events and slightly elevated detection limits in the RAS. The PFAS concentrations from the second sampling event are more representative as they had lower detection limits than the first. PFOS was detected at the highest concentration of 36 µg/kg, followed by a short-chain PFHxA at 18 µg/Kg, and then another long-chain PFDA at 13 µg/kg. Long-chain PFAS such as PFDA is expected to be present in solids due to its high affinity to solids even though it was non-detect in the aqueous treatment train. The presence of PFHxA in the solids was expected as PFHxA was one of the most frequently detected PFAS in the aqueous treatment stream and at the highest concentration. Also, 6:2 FTSA, a known precursor to PFHxA and PFPeA, was detected in the aqueous stream in the influent only. This may indicate that it could have adsorbed to the solids and potentially degrade to short-chain PFAS such as PFHxA.

Figure 29. PFAS Results and Process Flow Diagram for WWTP 8

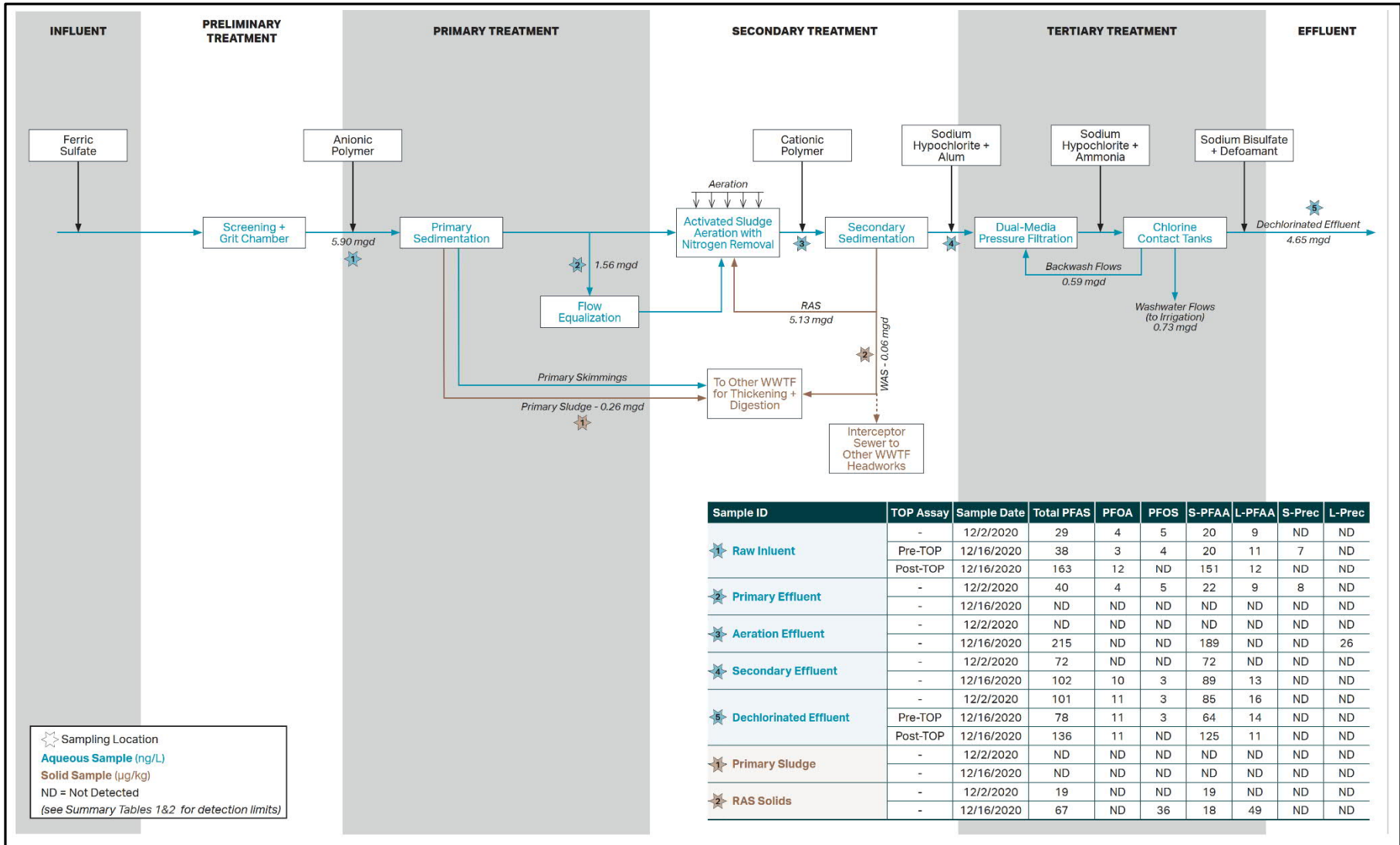


Figure 30. WWTP 8 PFAS Concentrations in The Aqueous Treatment Process Flow

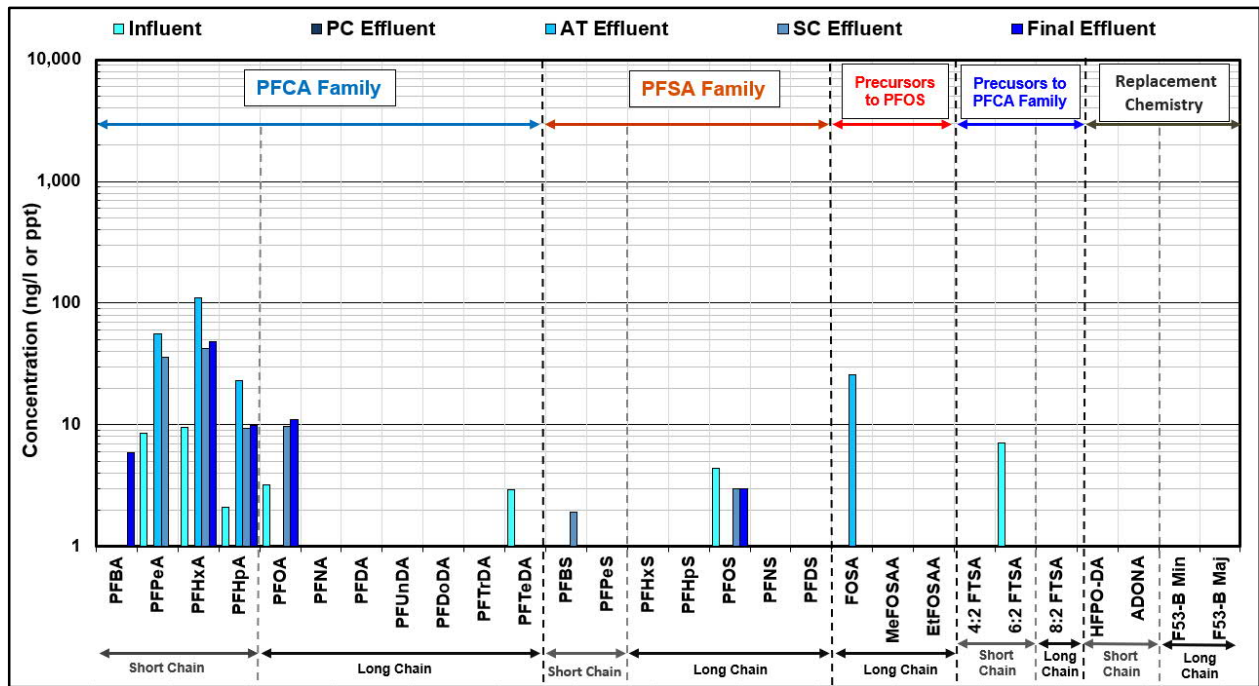
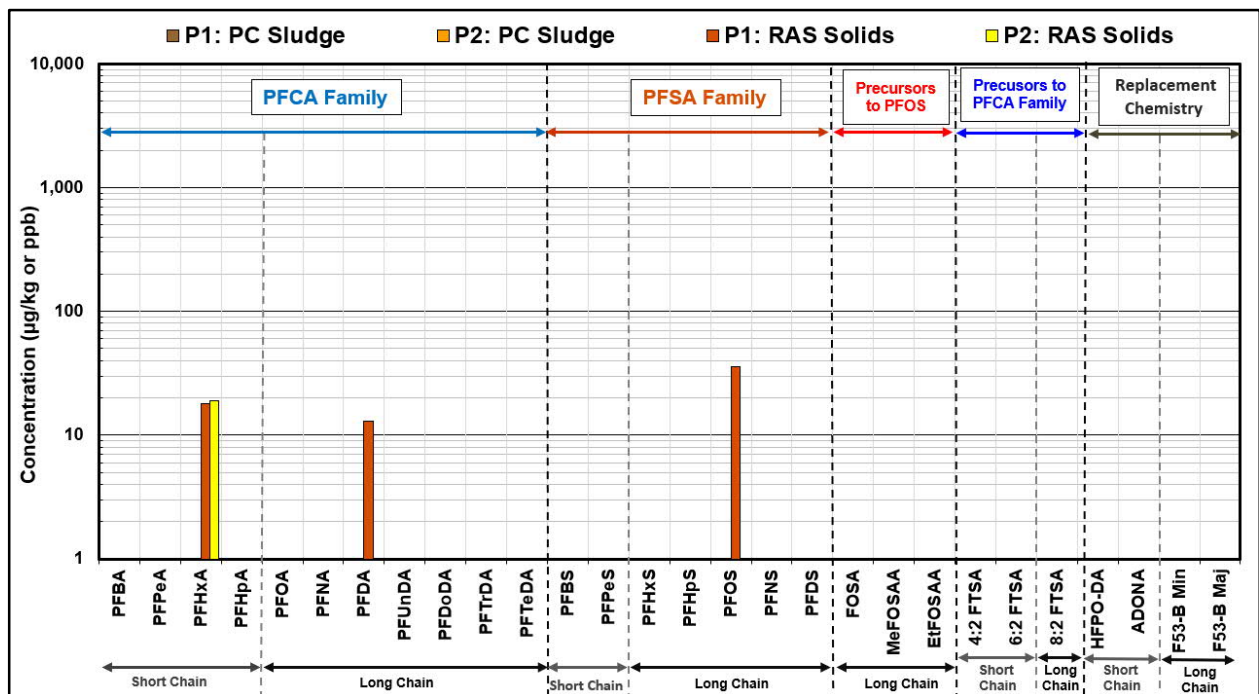


Figure 31. WWTP 8 PFAS Concentrations in The Solid Treatment Process Flow



4.4 WWTP 9 Phase 2 Evaluation

The treatment train for WWTP 9 was like that of WWTP 8. Five (5) aqueous treatment samples (Aqueous Sample IDs 1 through 5) were collected from the liquid treatment train between raw influent and final effluent (**Figure 32**). Two solid samples with high moisture content were collected from primary and waste active sludge (Solid Sample IDs 1 and 2). A description of each Sample ID and the location within the treatment plant is presented in **Figure 32** on the process flow diagram. Two sets of samples were collected, one on December 2, 2020, and the second on December 16, 2020. The PFAS results for the second event for both the aqueous and solid samples are presented in **Figures 33** and **34**. TOPA was also used to analyze the influent and effluent, and the results are presented as Pre-TOP and Post-TOP.

4.4.1 Aqueous Fate and Transport Discussion

Like WWTP 8, the Matrix interference at WWTP 9 also resulted in elevated detection limits, which made difficult the interpretation of some analytical results. This also limited the interpretation for each sampling event individually. The raw influent results had elevated detection limits in both sampling events and were non-detect, and the first results were from the primary effluent. The primary influent had a total PFAS concentration of 34 ng/L (**Figure 32**). An observed increase in the PFAS concentration in the secondary treatment after the activated sludge aeration with total PFAS increasing from 34 to 110 ng/L. There was a decrease in PFAS concentrations after the secondary sedimentation in the aqueous stream most likely to partition PFAS to the solids. No significant changes were observed in the PFAS concentration in the tertiary treatment from the dual-medial pressure filtration with overall similar concentrations pre and post-filtration. There were no precursors or replacement chemistry compounds detected in the aqueous treatment train (**Figure 33**). The short-chain PFCAs were detected at the highest concentrations.

There was no detection in the Pre-TOP results in the raw influent due to matrix interference. There was a significant difference in the Post-TOP with the total PFAS of 114 and 214 for the first and second sampling events. While during the second sampling event, the PFAS concentration was almost double, the overall ratios were similar for the short-chain PFAAs, which were the predominant PFAS detected. This indicates that there may be a potential higher fluctuation in the influent concentrations or that the elevated detection limits for some compounds limited a robust evaluation of the PFAS fate at WWTP 9. There was a slight increase in the PFAS concentrations in the final effluent between the Pre-TOP and Post-TOP with the total PFAS for sampling event one from 63 to 84 ng/L and sampling event two from 56 to 96 ng/L. The most significant increase was observed in the short-chain PFAAs from 51 to 76 ng/L for sampling event one (1) and 46 to 87 ng/L for sampling event two (2). There was no observed increase in the long-chain PFAAs, which indicates that the influent's predominant precursors are short-chain. Similar to WWTP 8, there may be additional short-chain precursors not part of the current analyte list. The short-chain precursors are expected to have a higher affinity to solids than their short-chain PFAAs, to which they could potentially degrade in the environment. This indicated that there might be an additional accumulation of short-chain precursors in the solids at a higher magnitude than those observed for the short-chain PFAAs.

4.4.2 Solid Fate and Transport Discussion

The matrix interference resulted in high detection limits for the primary sludge samples to be non-detect during both sampling events and slightly elevated detection limits in the RAS. The PFAS concentrations from the second sampling event are more representative as they had lower detection limits than the first. PFOS was detected at the highest concentration of 36 µg/kg, followed by a short-chain PFHxA at 18 µg/kg, and then another long-chain PFDA at 13

µg/kg. Long-chain PFAS such as PFDA is expected to be present in solids due to its high affinity to solids even though it was non-detect in the aqueous treatment train. The presence of PFHxA in the solids was expected as PFHxA was one of the most frequently detected PFAS in the aqueous treatment stream and at the highest concentration. Also, 6:2 FTSA, a known precursor to PFHxA and PFPeA, was detected in the aqueous stream in the influent only. This may indicate that it could have adsorbed to the solids and potentially degrade to short-chain PFAS such as PFHxA.

Figure 32. PFAS Results and Process Flow Diagram for WWTP 9

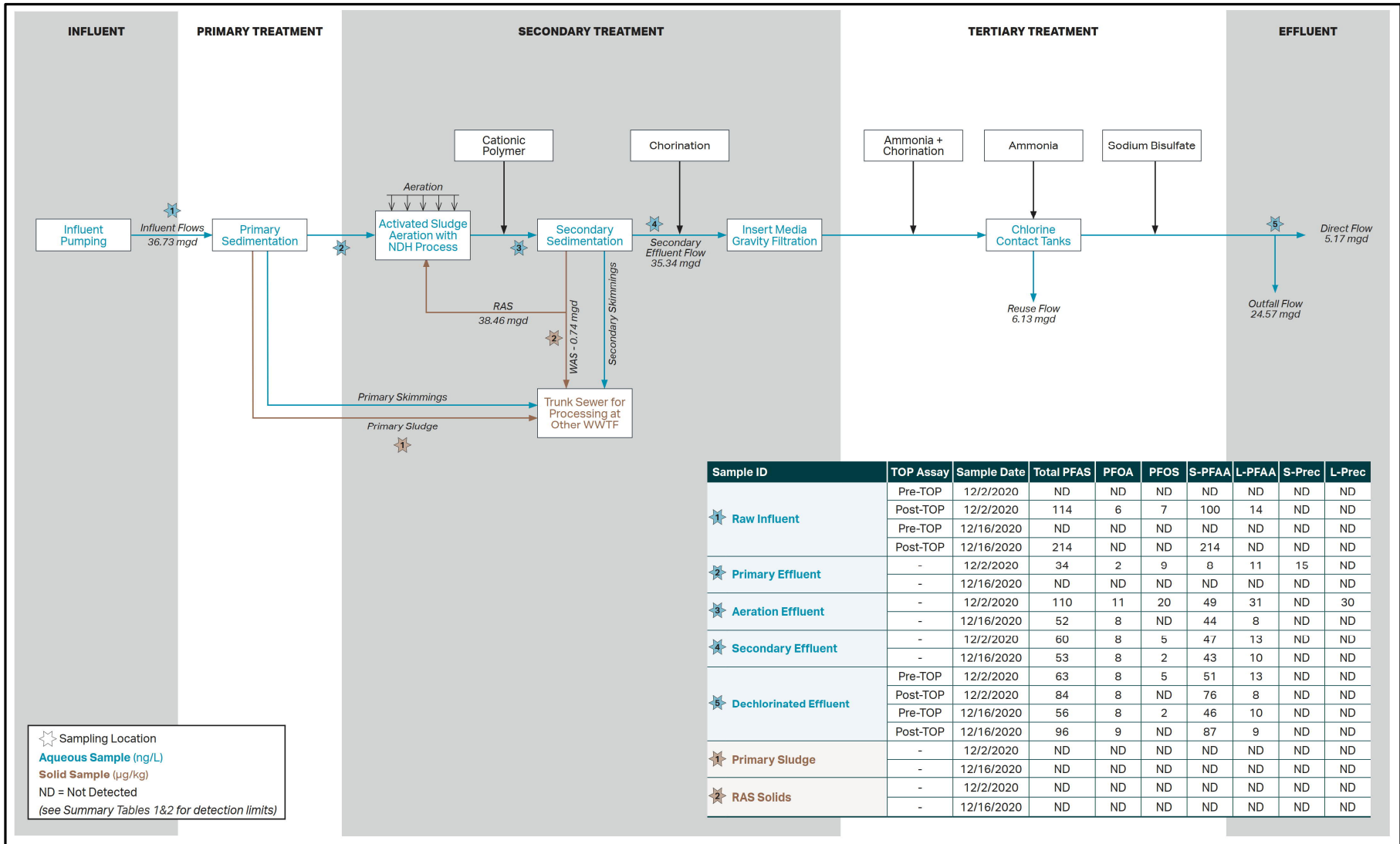


Figure 33. WWTP 9 PFAS Concentrations in The Aqueous Treatment Process Flow

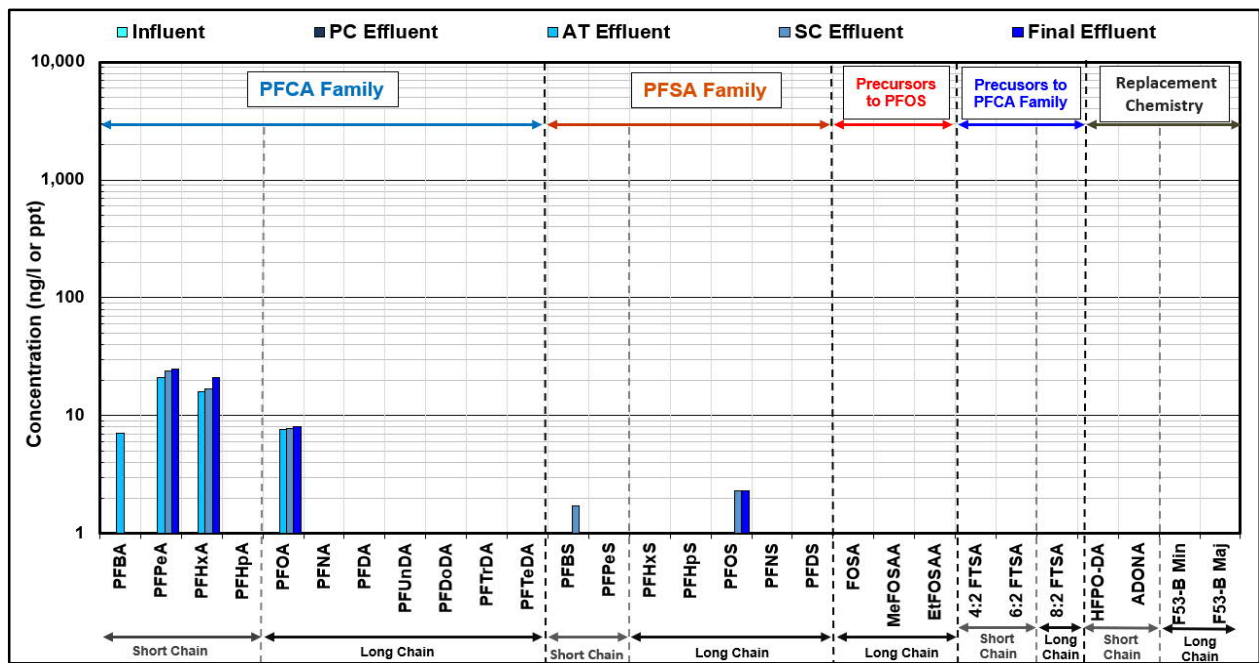
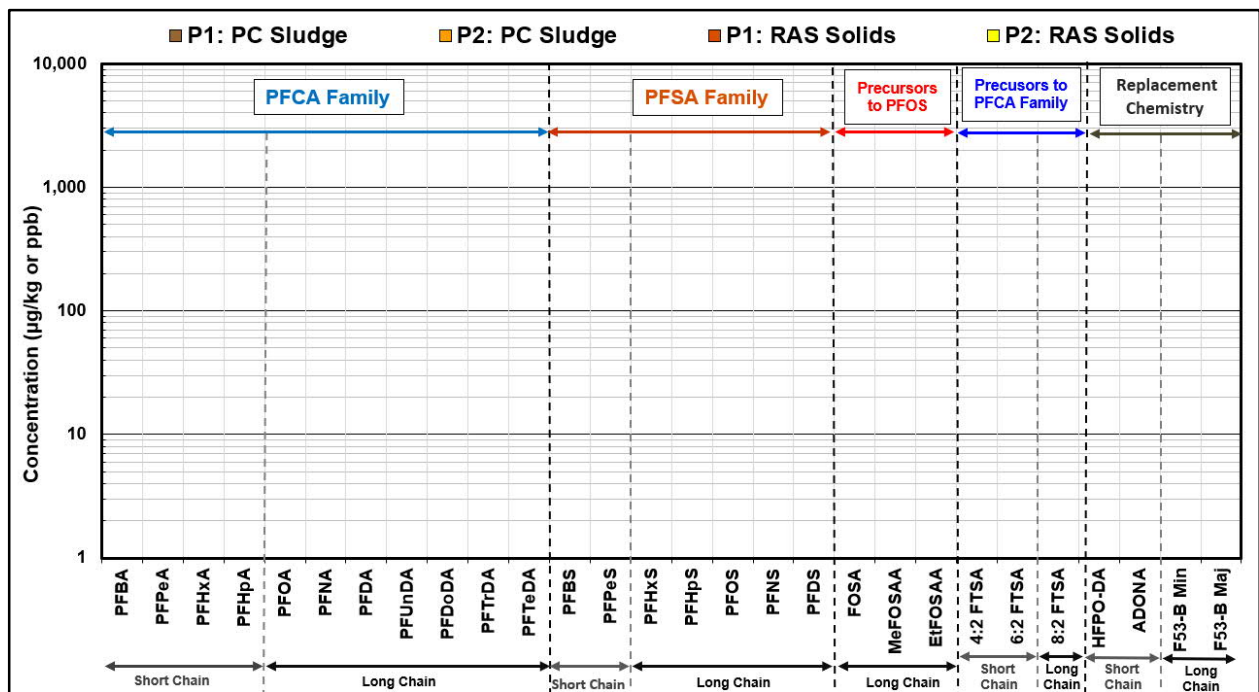


Figure 34. WWTP 9 PFAS Concentrations in The Solid Treatment Process Flow



4.5 WWTP 10 Phase 2 Evaluation

The treatment train for WWTP 10 was almost identical to WWTP 9 and similar to WWTP 8. Five (5) aqueous treatment samples (Aqueous Sample IDs 1 through 5) were collected from the liquid treatment train between raw influent and final effluent. Two solid samples with high moisture content were collected from primary and waste active sludge (Solid Sample IDs 1 and 2). A description of each Sample ID and the location within the treatment plant is presented in **Figure 35** on the process flow diagram. Samples were collected on December 2, 2020, and the second set on December 16, 2020. The PFAS results for the second event for both the aqueous and solid samples are presented in **Figures 36** and **37**. TOPA was also used to analyze the influent and effluent, and the results are presented as Pre-TOP and Post-TOP.

4.5.1 Aqueous Fate and Transport Discussion

The matrix interference resulted in some of the detection limits elevated and limited the interpretation for each sampling event individually. The detection limits in the influent for the second event were elevated, but for the first sampling, events were lower and detected a total PFAS concentration of 20 ng/L (**Figure 35**). The primary effluent had a similar total PFAS concentration of 21 ng/L and a similar signature to the raw influent. Similar to WWTP 8 and 9, there was an observed increase in the PFAS concentration in the secondary treatment after the activated sludge aeration, with total PFAS increasing from 21 to 280 ng/L for the first sampling event and 62 ng/L for the second sampling event. The detection limits for the first sampling event were very high, between 200 and 800 ng/L. As a result, the total PFAS concentrations are expected to possibly have been a lot higher during the first sampling event. This may indicate significant fluctuations in influent concentrations or potential significant matrix interference. There was a decrease in PFAS concentrations after the secondary sedimentation in the aqueous stream most likely to partition PFAS to the solids. No significant changes were observed in the PFAS concentration in the tertiary treatment from the insert media gravitation filter with similar concentrations pre and post-filtration. FOSA was the only precursors detected during the first sampling event in the aerated activated sludge effluent (**Figure 35**). The short-chain PFCAs were detected at the highest concentrations.

The difference in the Pre-TOP and Post-TOP results for the raw influent for the total PFAS was from 20 to 121 ng/L for sampling event one (1), with the most significant increase in the short-chain PFAAs from 9 to 113 ng/L. There was no observed increase in the long-chain PFAAs, which indicates that the influent's predominant precursors are short-chain. The detection limits were high for the Pre-TOP results for the second sampling event. However, the Post-TOP results for the second sampling event and overall signature were similar to that of the initial sampling event. A similar trend was observed in the Pre-TOP, and Post-TOP results in the final effluent, with the majority, increased occurring for the short-chain PFAAs from 51 to 85 ng/L, and the increase for the total PFAS was only from 68 to 95 ng/L for the first sampling event. A very similar trend was observed during the second sampling event. The increase in PFAS concentrations in the Post-TOP sample for the final effluent compared to the influent indicates less available short-chain precursors in the final effluent. While the short-chain precursors have a fluorinated fluorine-carbon tail, they also have additional hydrogen-carbon bonds subject to degradation. The short-chain precursors, as a result, are expected to have a higher affinity to solids than their short-chain PFAAs, to which they could potentially degrade in the environment. This indicated that there might be an additional accumulation of short-chain precursors in the solids at a higher magnitude than those observed for the short-chain PFAAs.

4.5.2 Solid Fate and Transport Discussion

The matrix interference resulted in high detection limits for the primary sludge sample during the

first sampling event to be non-detect during both sampling events and slightly elevated detection limits in the primary sludge and RAS. PFOS was detected at the highest concentration of 31 $\mu\text{g}/\text{Kg}$, followed by a short-chain PFBA at 15 $\mu\text{g}/\text{Kg}$. The presence of PFBA in the solids was expected as short-chain precursors were identified to be abundantly present based on the Post-TOP results.

Figure 35. PFAS Results and Process Flow Diagram for WWTP 10

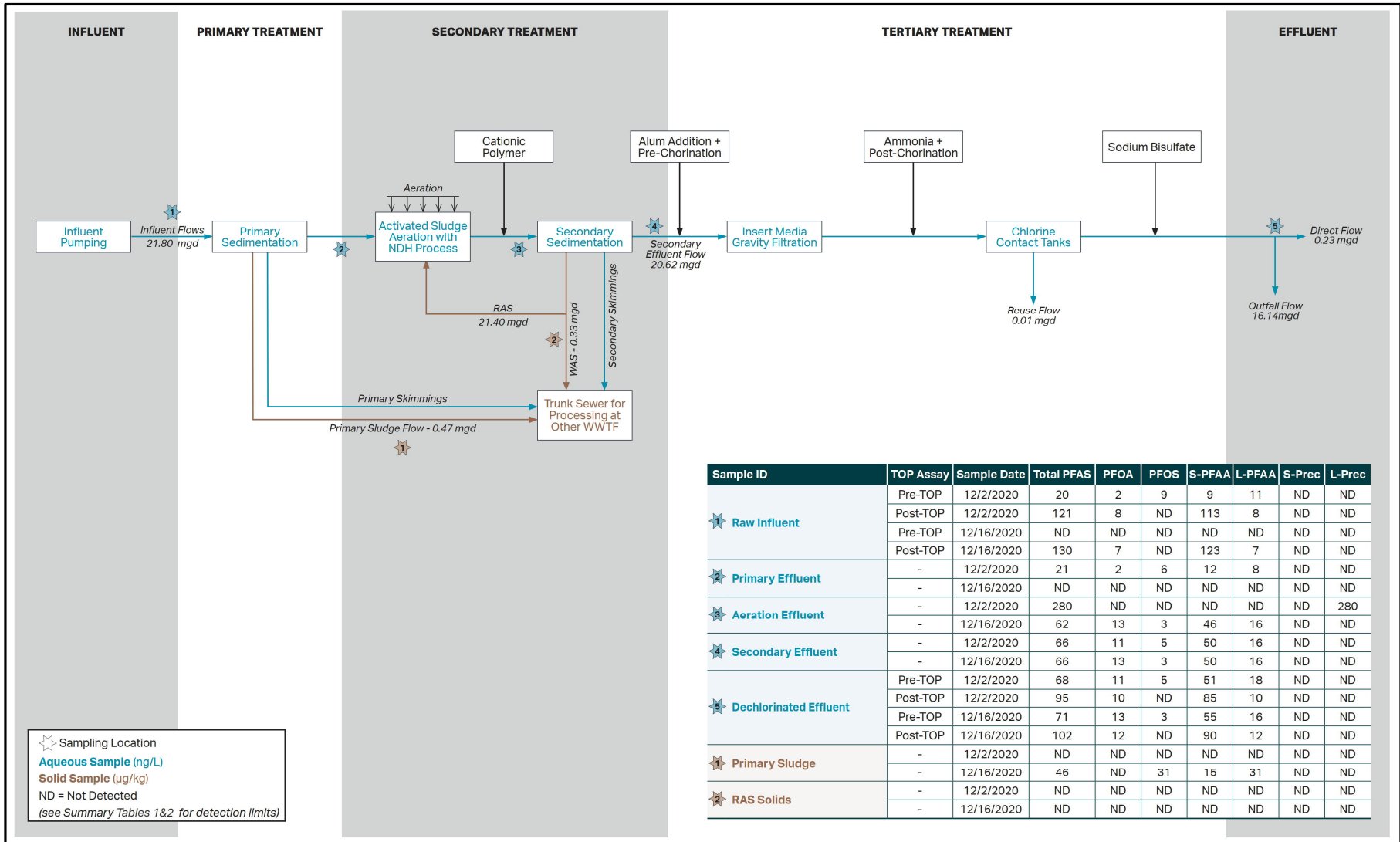


Figure 36. WWTP 10 PFAS Concentrations in The Aqueous Treatment Process Flow

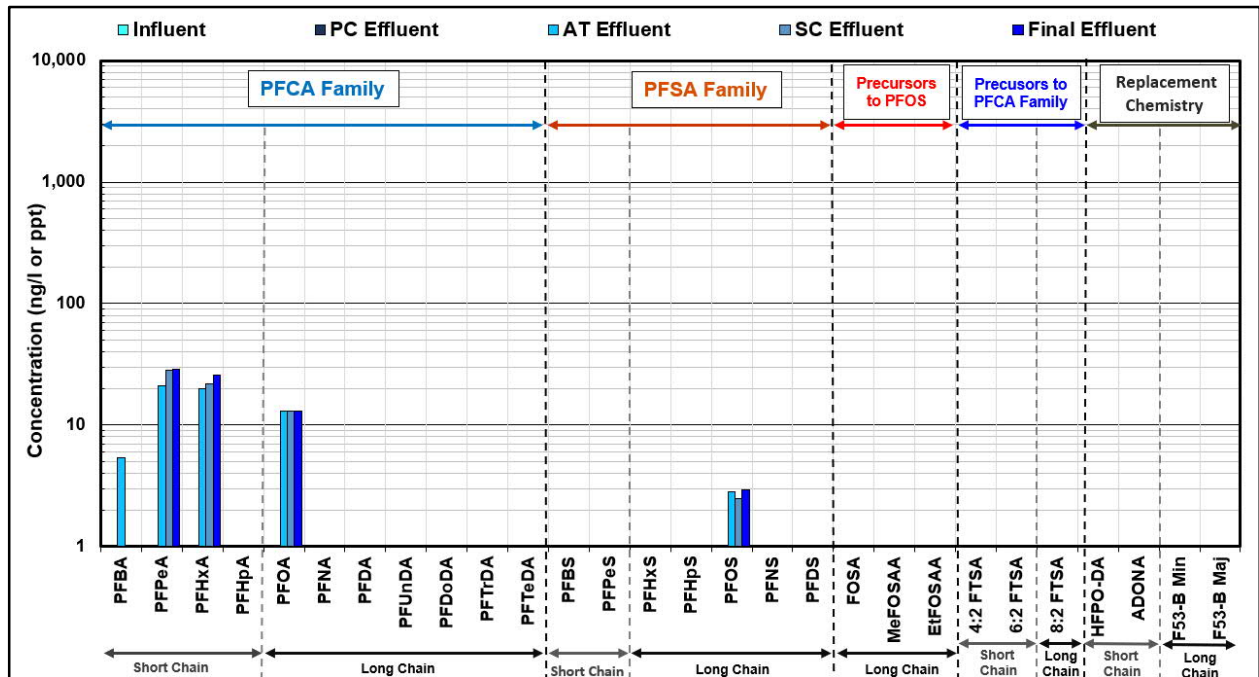
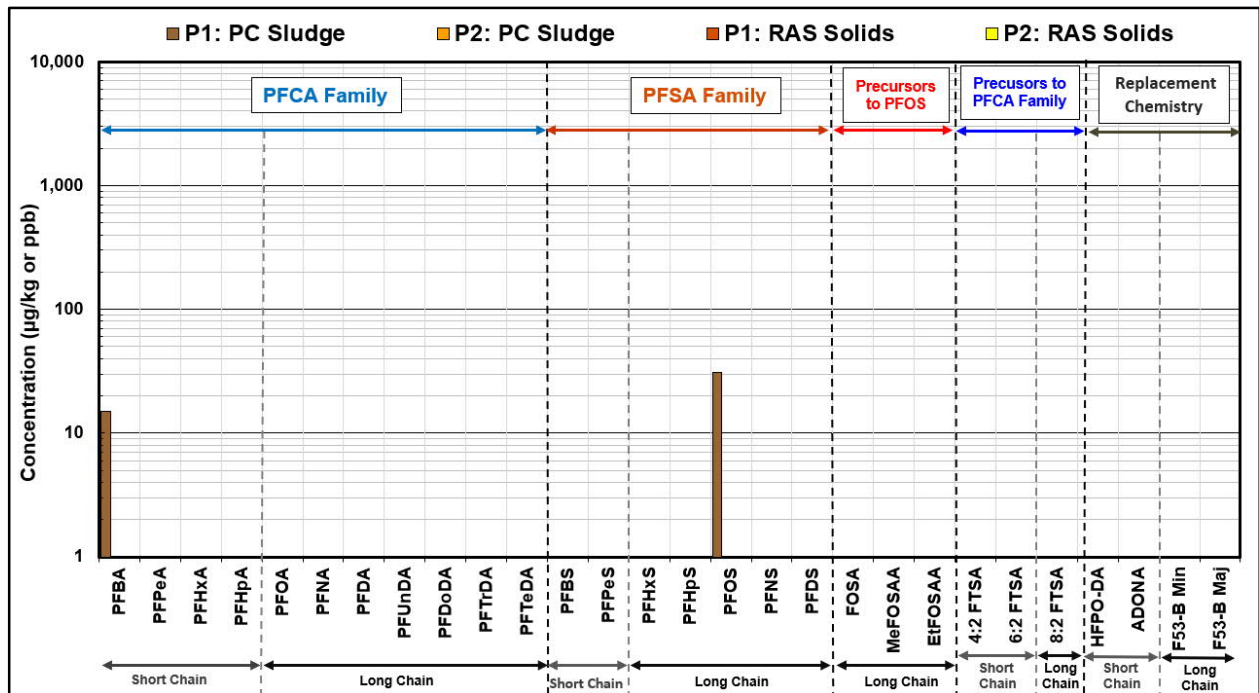


Figure 37. WWTP 10 PFAS Concentrations in The Solid Treatment Process Flow



4.6 WWTP 11 Phase 2 Evaluation

Five (5) aqueous treatment samples (Aqueous Sample IDs 1 through 5) were collected from the liquid treatment train between raw influent and final effluent. Two additional samples were collected from the Dissolved Air Floatation (DAF) supernatant and centrate from the centrifuge recirculated back to preliminary treatment. Four (4) solid samples with high moisture content were collected from the primary sedimentation tanks, WAS, DAF thickened WAS, and digested sludge (Solid Sample IDs 1 through 4). One additional sample with a higher solid percentage was collected after the scroll centrifuges as a Cake (Solid Sample ID 5). A description of each Sample ID and the location within the treatment plant is presented in **Figure 38** on the process flow diagram. Samples were collected on December 1, 2020, and the second set on December 15, 2020. The PFAS results for the second event for both the aqueous and solid samples are presented in **Figures 39** and **40**. TOPA was also used to analyze the influent, effluent, and cake with the results presented as Pre-TOP and Post-TOP.

4.6.1 Aqueous Fate and Transport Discussion

The matrix interference resulted in some of the detection limits elevated and limited the interpretation for each sampling event individually. However, there does seem to show overall higher PFAS concentrations during the first sampling event. The detection limits in the influent for the second event were elevated, but for the first sampling, the event was lower and detected a total PFAS concentration of 140 ng/L (**Figure 38**). The final effluent had a similar total PFAS concentration of 138 ng/L and a similar signature to the raw influent. During the second sampling event, total PFAS concentrations range from about 68 to 81 ng/L. While some lower concentrations were detected, many of the compounds had elevated detection limits due to matrix interference. Overall, there was no significant removal of PFAS in the aqueous treatment train. The short-chain PFCAs were detected at the highest concentrations, with PFHxA being detected at the highest concentration. The only long-chain PFCAs detected was PFOA. The only precursors detected was EtFOSAA, which is known to degrade to PFOS. There were no detections of PFAS replacement chemistry (**Figure 39**).

The additional aqueous samples from the DAF Subnatant of 70 ng/L and centrate of 131 ng/L had PFAS concentrations within similar ranges that those detected in the aqueous treatment train. Due to the small volume of return of these wastewater streams to the overall operational flow of the WWTP, the PFAS concentrations in WWTP 11 are not expected to significantly change the overall PFAS impact to the facility.

The difference in the Pre-TOP and Post-TOP results for the raw influent for the total PFAS was from 140 to 206 ng/L for sampling event one (1), with the most significant increase in the short-chain PFAAs from 41 to 180 ng/L. However, a large portion of the short-chain increase could be attributed to the degradation of 76 ng/L during the TOPA analysis. There was no observed increase in the long-chain PFAAs, which indicates that the influent's predominant precursors are short-chain. The detection limits were high for the Pre-TOP results for the second sampling event. However, the Post-TOP results for the second sampling event and overall signature were similar to that of the initial sampling event. There was an apparent decrease in concentration for the effluent sample during the first sampling event after the TOPA analysis. The matrix interference resulted in some compounds having a higher detection limit. For the second sampling event, a similar trend was observed in the Pre-TOP, and Post-TOP results in the final effluent, with the majority, increased occurring for the short-chain PFAAs from 50 to 93 ng/L. The increase for the total PFAS was only from 68 to 108 ng/L for the first sampling event. The increase in PFAS concentrations in the Post-TOP sample for the final effluent compared to the influent indicates less available short-chain precursors in the final effluent. While the short-chain precursors have a fluorine-carbon tail, they have additional hydrogen-carbon bonds subject to degradation. The short-chain precursors, as a result, are expected to have a higher

affinity to solids than their short-chain PFAAs, to which they could potentially degrade in the environment. This indicated that there might be an additional accumulation of short-chain precursors in the solids at a higher magnitude than those observed for the short-chain PFAAs.

4.6.2 Solid Fate and Transport Discussion

The matrix interference resulted in high detection limits for some PFAS and samples during the first sampling event to be non-detect. PFOS was detected at the highest concentration of 60 µg/kg and was the most often detected PFAS in the solids. The second-highest concentration was a short-chain PFHxA, at ten (10) µg/kg (Figure 40). There were also some low single-digit µg/kg detections of few additional long-chain PFCAs and one detection of MeFOSAA at 7.8 µg/kg, a known PFOS precursor. The presence of PFHxA in the solids was expected as short-chain precursors were identified to be abundantly present based on the Post-TOP results. There was no significant increase in concentrations observed after a particular solid treatment. The difference in concentrations may be due mostly to the potential PFAS fluctuations in the influent and retention times for various treatment processes, which will allow the PFAS to accumulate in the solids.

TOPA was also used on the Cake to understand better the potential of precursors adsorbed to the solids. Due to matrix interference, the second sampling event's detection limit was elevated, but the Post-TOP for both sampling events was similar. There was an increase in the Total PFAS from 34 to 228 µg/kg for the first sampling, with most of the increase occurred for the short-chain PFAAs. This again supports the observation that short-chain precursors have a preference to adsorb to solids. There was no increase in the long-chain PFAAs, indicating that currently, no significant long-chain PFAS precursors present in the wastewater.

Figure 38. PFAS Results and Process Flow Diagram for WWTP 11

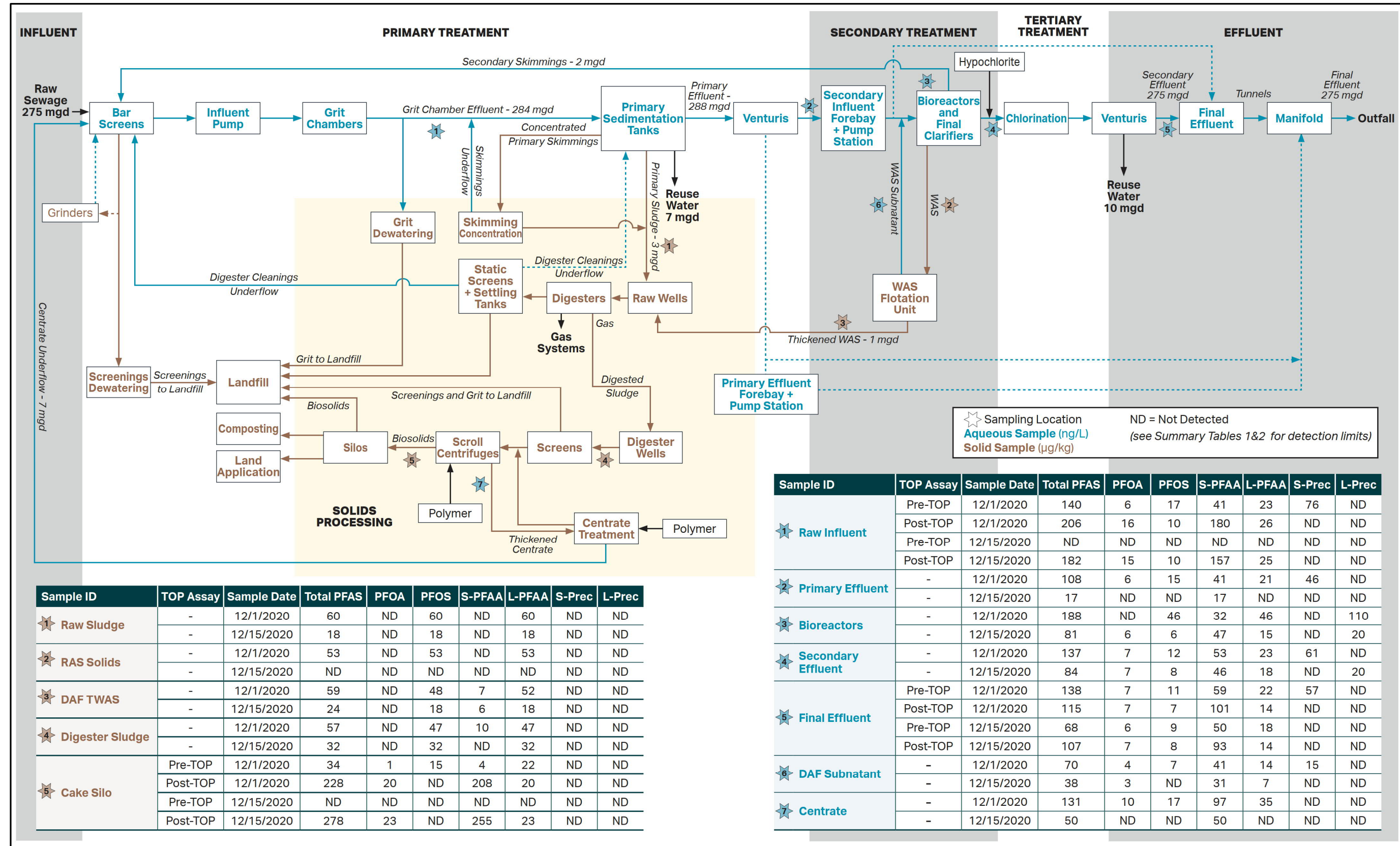


Figure 39. WWTP 11 PFAS Concentrations in The Aqueous Treatment Process Flow

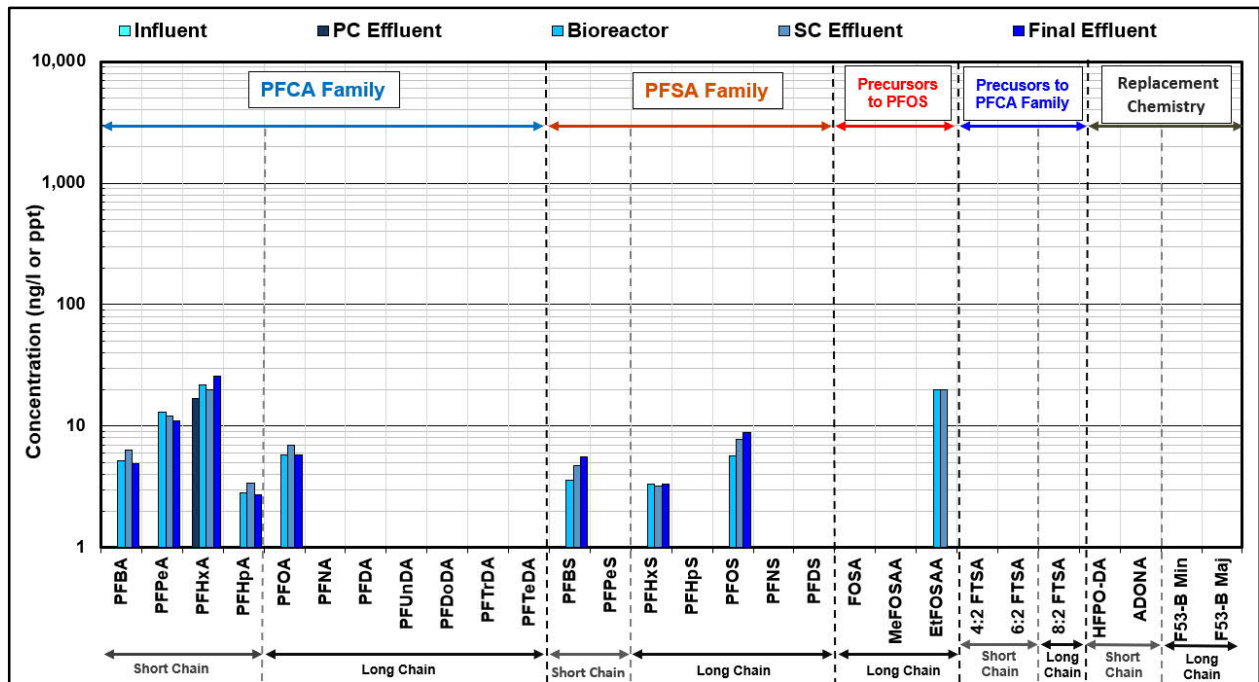
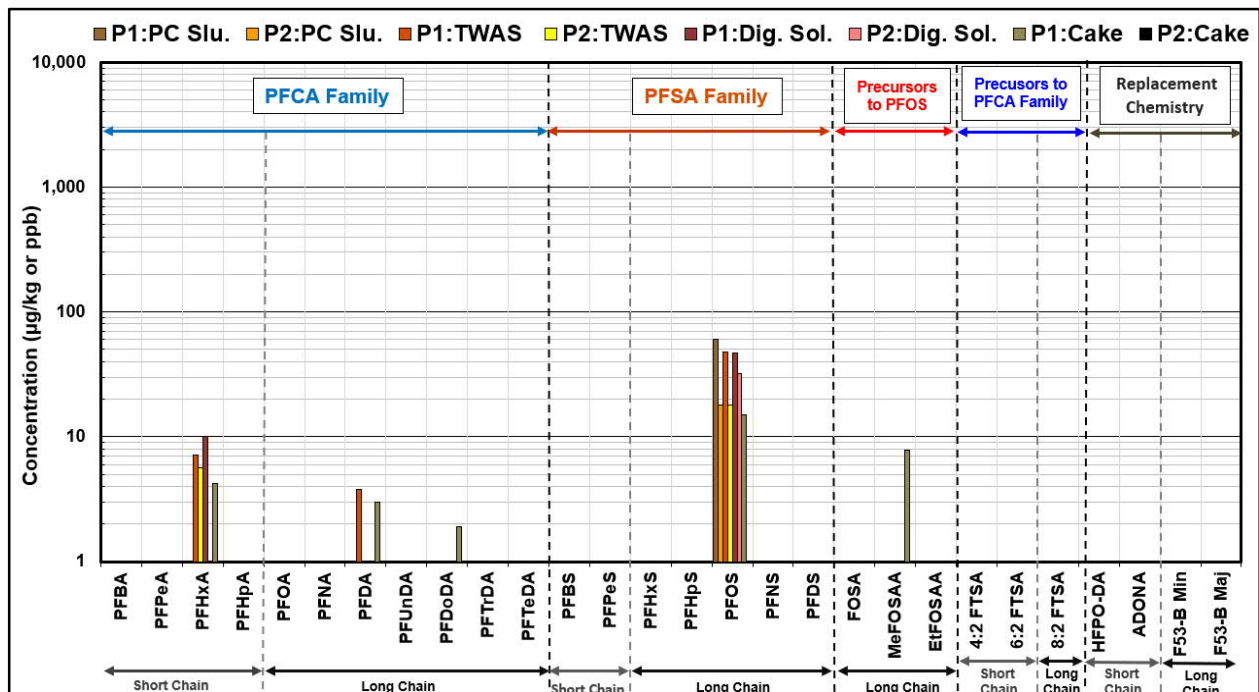


Figure 40. WWTP 11 PFAS Concentrations in The Solid Treatment Process Flow



4.7 WWTP 13 Phase 2 Evaluation

Four (4) aqueous treatment samples (Aqueous Sample IDs 1 through 4) were collected from the liquid treatment train between raw influent and final effluent. Three additional aqueous samples were collected as the aqueous portion of the solids with high moisture content (Aqueous Sample IDs 5, 6, and 7). Finally, two additional samples were collected as the filtrate from the rotary drum thickener and the backwash from the disc filters (Aqueous Sample IDs 8 and 9). Both the filtrate and backwash are recirculated back into the WWTP 13 in the equalization tank influent. Two solid samples with high moisture were collected as WAS and sludge storage tanks (Solid Sample IDs 1 and 2). Finally, one final solids sample was collected from the thickened sludge tank (Solid Sample ID 3). A description of each Sample ID and the location within the treatment plant is presented in **Figure 41** on the process flow diagram.

4.7.1 Aqueous Fate and Transport Discussion

There was an increase in the total PFAS within the aqueous treatment train from 7 ng/L in the influent to 44 ng/L after the sequence batch reactor in secondary treatment (**Figure 41**). The total PFAS concentrations remained the same, with a total PFAS concentration of 44 ng/L in the effluent. The disc filters from the tertiary treatment did not show any significant impact on the removal of PFAS. Short-chain PFCAs such as PFPeA and PFHxA were detected at the highest concentrations up to 24 ng/L. Long-chain PFCAs such as PFOA and PFDA were also detected, with PFOA having the highest concentration of 9.2 and PFDA of 2.2 ng/L (**Figure 42**). There were no compounds detected from the PFSA family. There were also low ng/L detections of PFOS precursors, such as 2.5 ng/L for FOSA and 1.2 for MeFOSAA. The PFAS concentrations and signature in the disc backwash were similar to the one detected in the aqueous treatment train. There was a slight increase in the total PFAS concentration in the filtrate to 69 ng/L, with very similar PFAS detected in the rest of the aqueous samples. The recirculation of waste streams is unlikely to significantly affect the PFAS concentrations within the aqueous treatment train due to similar PFAS concentrations as in the aqueous treatment train and small recirculation volume.

The matrix interference resulted in high detection limits for some PFAS and no detections in the aqueous portion of the WAS solids. The highest PFAS concentrations were detected in the aqueous portion of rotary drum thickener with the total PFAS concentration of 86 ng/L and having the same PFAS signature.

4.7.2 Solid Fate and Transport Discussion

PFDA was the only PFAS detected in the solid samples, with the highest concentration being 12 µg/kg in the storage tank. This may indicate that WWTP 13 is very likely that it had very low or no impact on PFSA family compounds such as PFOS.

Figure 41. PFAS Results and Process Flow Diagram for WWTP 13

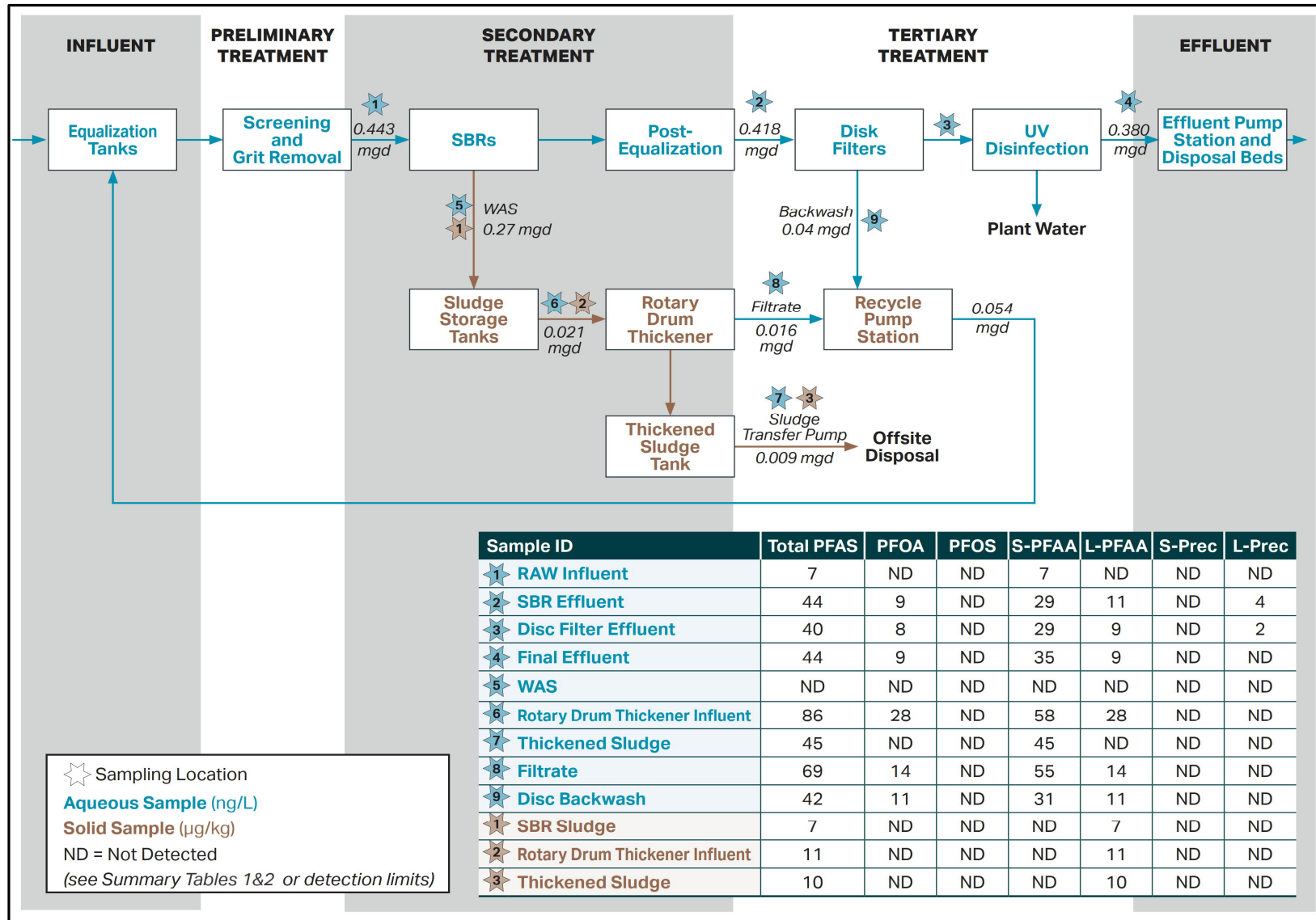


Figure 42. WWTP 13 PFAS Concentrations in The Aqueous Treatment Process Flow

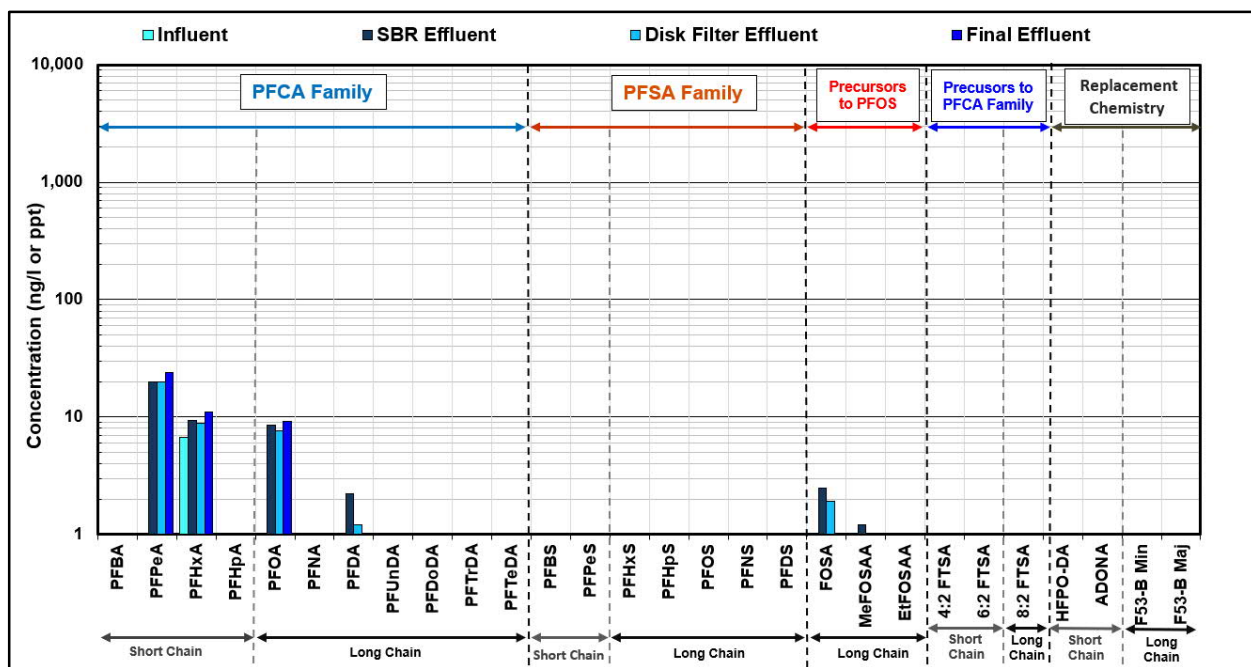
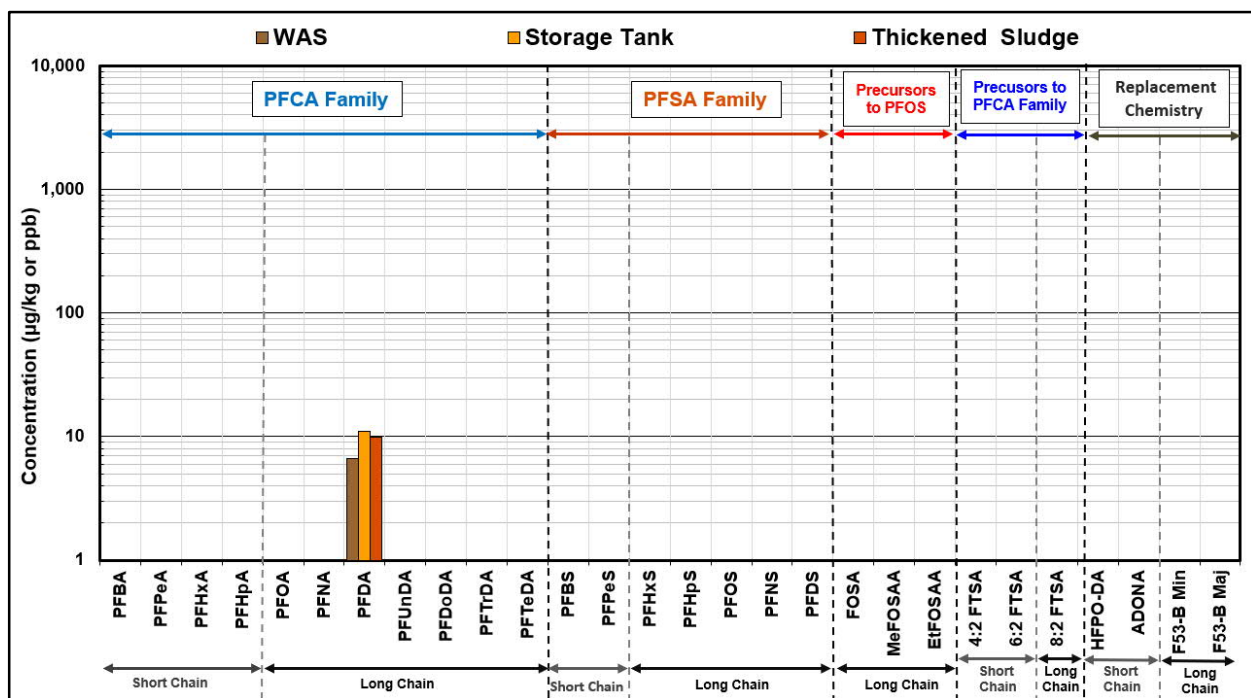


Figure 43. WWTP 13 PFAS Concentrations in The Solid Treatment Process Flow



4.8 WWTP14 Phase 2 Evaluation

Four (4) aqueous treatment samples (Aqueous Sample IDs 1 through 4) were collected from the liquid treatment train between raw influent and final effluent. Four (4) additional aqueous samples were collected as the aqueous portion of the solids with high moisture content (Aqueous Sample IDs 5, 6, 7, and 8). Four (4) solid samples with high moisture were collected from the anoxic and aerobic zones from the oxidation ditch, WAS, and Aerated Holding Tanks (Solid Sample IDs 1 through 4). Finally, the dewatering belt press collected one final solid sample (Solid Sample ID 5). A description of each Sample ID and the location within the treatment plant is presented in **Figure 44** on the process flow diagram.

4.8.1 Aqueous Fate and Transport Discussion

There was an increase in the total PFAS within the aqueous treatment train from 519 ng/L in the influent to 3,352 ng/L after the oxidation ditch in secondary treatment (**Figure 44**). The total PFAS concentrations remained within this range through the rest of the aqueous treatment train, with a total PFAS concentration of 3,368 ng/L in the effluent. The disc filter did not show any significant impact on the removal of PFAS. The short-chain and long-chain PFAAs and precursors had similar PFAS signatures and concentrations after the oxidation ditch through the rest of the aqueous treatment train. The highest concentrations were detected for 6:2 FTSA in all the treatment trains with the highest concentration of 2,800 ng/L. The second-highest concentrations were detected for short-chain PFCAs such as PFPeA and PFHxA, between 200 and 510 ng/L. PFOS had concentrations between 140 and 240 ng/L. Long-chain PFCAs such as PFOA PFNA and PFDA were also detected, with PFOA having the highest concentration of 70 ng/L (**Figure 45**). Even chain PFSAAs such as PFBS, PFHxS, and PFOS were detected at higher concentrations than odd chain length PFSAAs such as PFPeS and PFHpS. Odd chain PFSAAs are not typically detected in many industrial streams, including wastewater, due to the lower concentrations in the products than the even chain PFSAAs. However, odd chain PFSAAs have been frequently correlated with AFFFs. Long-chain FTSA (i.e., 8:2 FTSA) was also detected at low concentrations with the highest concentration of 5 ng/L. There were also low ng/L detections of PFOS precursors, such as 6.8 ng/L for FOSA.

The increase in PFAS concentrations right after the influent from a total PFAS of 519 ng/L, early in the oxidation ditch in the anoxic zone where the total PFAS increases to 3,877 ng/L. The anoxic and aerobic zones analysis was for the aqueous portion of the solid samples with a high moisture content of about 95%. The PFAS signature in the oxidation ditch samples was like that identified in the aqueous treatment train. However, there was a significant change in the total PFAS in the aqueous portion of the aerated sludge tank's total PFAS concentration more than doubled to 9,635 ng/L. The most significant changes were for 6:2 FTSA, where the concentrations reduced from about 2,500 to 1,300 ng/L. However, there was a significant increase in the short-chain PFAAs from about 600 ng/L to 7,967 ng/L. While 6:2, FTSA is a known precursor that is known to degrade to short-chain PFCAs partially. The highest increases were for PFPeA from 360 to 6,100 ng/L, for PFHxA from 230 to 1,300 ng/L. The increase in long-chain PFCAs was less significant for PFOA from 63 to 110 ng/L and for PFNA from 2.2 to 4.5 ng/L. The increase in the short-chain PFCAs indicates that additional short-chain PFAS are present other than 6:2 FTSA. As stated earlier in the report, short-chain PFAS are expected to accumulate stronger than short-chain PFCAs to which they degrade. Partial degradation and transformation of PFAS precursors under aerobic conditions have been well documented in the literature.

There was an increase in the total PFAS concentrations and, in particular, 6:2 FTSA in Phase 2 results for samples collected on March 16, 2021, and Phase 1 results collected on September 16, 2020. The 6:2 FTSA increased from Phase 1 to Phase 2 in the influent from 8 to 83 ng/L

and effluent from 29 to 2,400 ng/L. This significant increase is likely a point source release that occurred recently and is probably associated most likely with AFFF impacts.

4.8.2 Solid Fate and Transport Discussion

The highest detectable PFAS was PFOS, with concentrations ranging between 360 to 480 $\mu\text{g}/\text{kg}$ (**Figure 46**). There was an observable trend within the solid treatment train, and the variation in concentrations may be due to fluctuations in the influent concentrations. The second-highest concentrations were detected for 6:2 FTSA, for which the concentration from the oxidation ditch decreased from 260 $\mu\text{g}/\text{kg}$ to 120 $\mu\text{g}/\text{kg}$ in the aerated sludge. The decrease in the concentrations for 6:2 FTSA in the solid's treatment train may indicate potential partial degradation of 6:2 FTSA. Precursors transformation in the aerated sludge is also supported by the increase of PFPeA, PFHxA, PFHpA, and PFOA in the aerated sludge with no increase in the PFDA. The 6:2 FTSA main transformation pathway is for PFPeA and secondary for PFHxA. The pathway transformation for 8:2 FTSA is PFHpA and PFOA, which had a lower increase in concentrations. This was expected as the concentrations of 6:2 FTSA were a lot higher than those of 8:2 FTSA, and none of these compounds would degrade to PFDA.

Figure 44. PFAS Results and Process Flow Diagram for WWTP 14

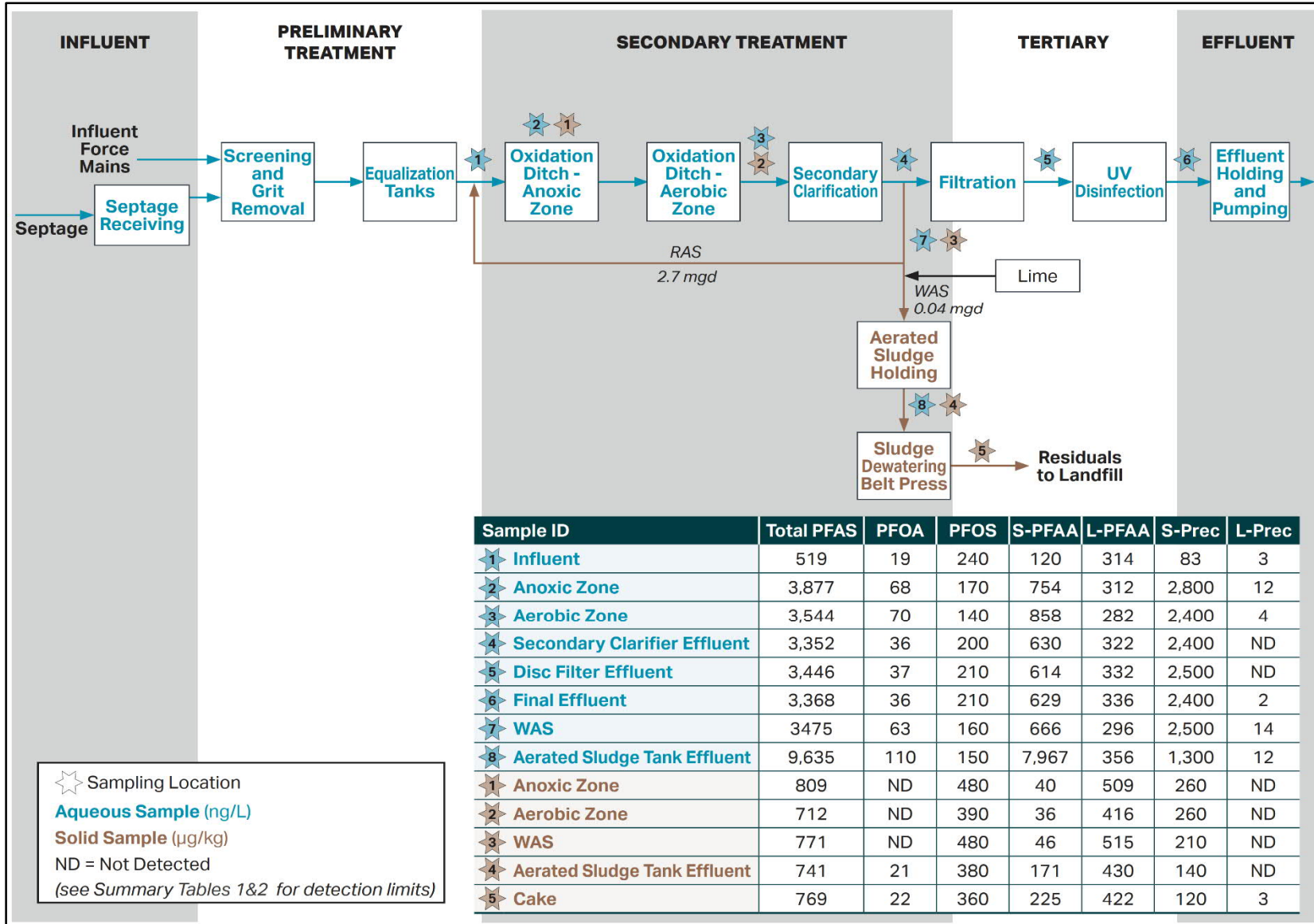


Figure 45. WWTP 14 PFAS Concentrations in The Aqueous Treatment Process Flow

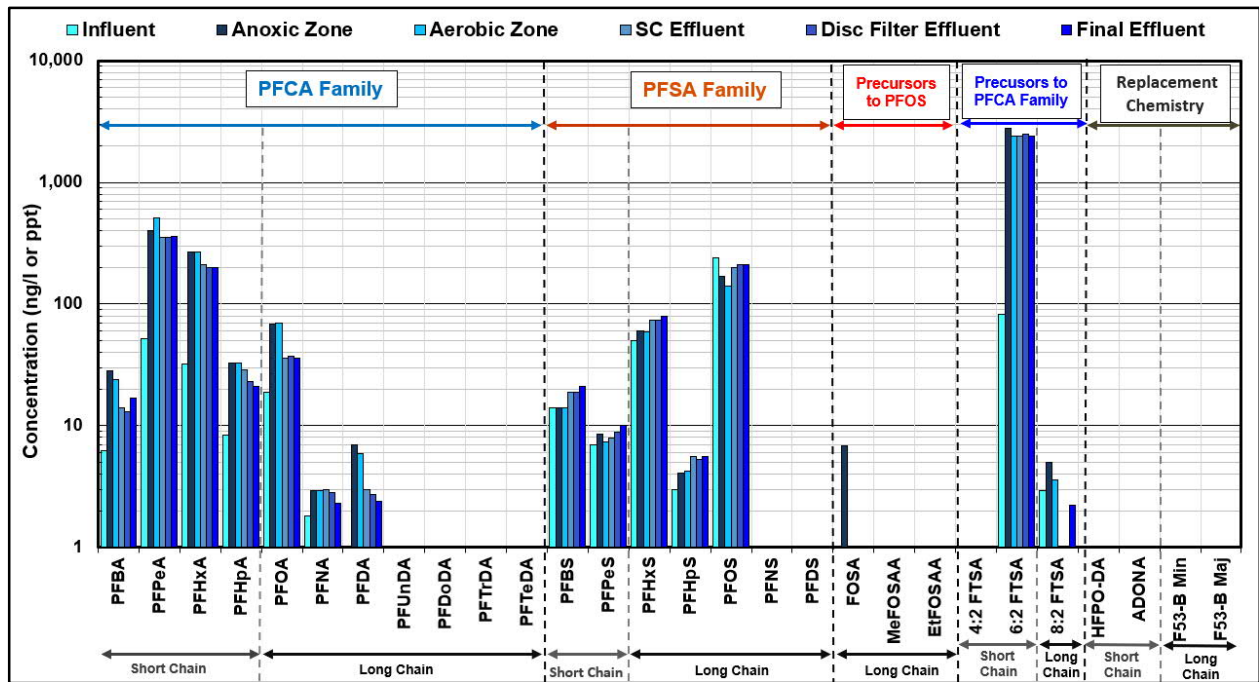
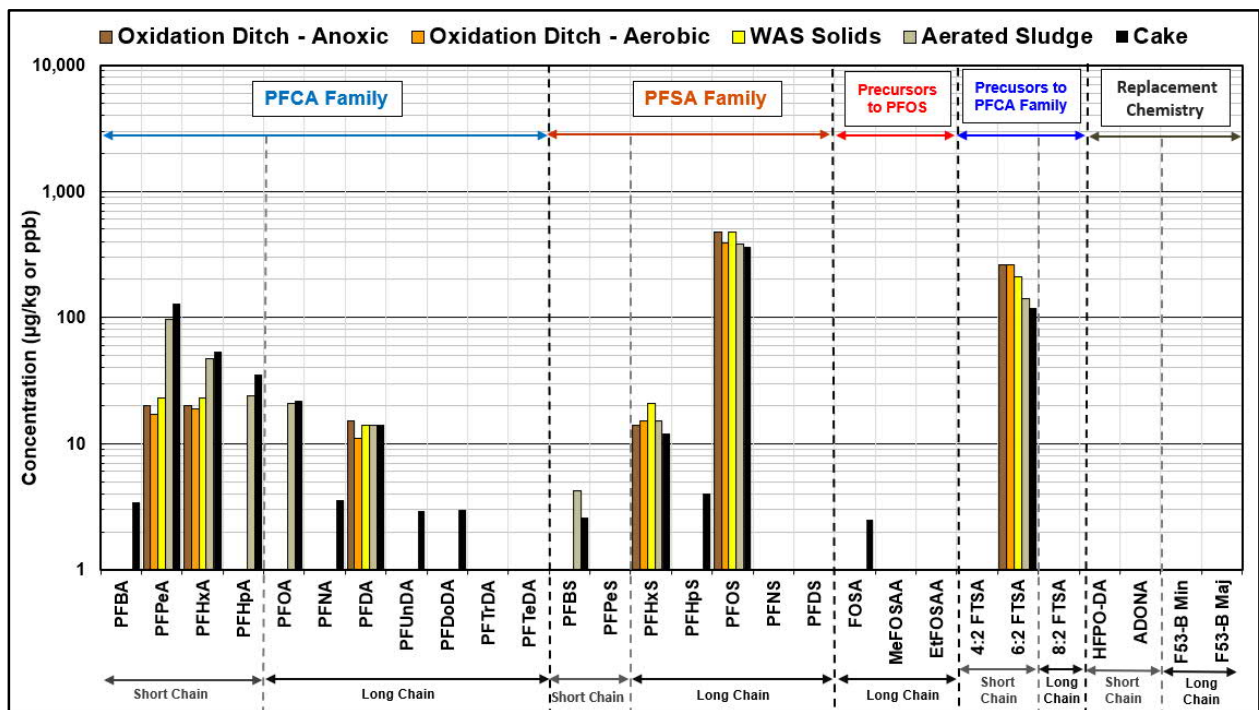


Figure 46. WWTP 14 PFAS Concentrations in The Solid Treatment Process Flow



4.9 WWTP 18 Phase 2 Evaluation

A total of 13 aqueous treatment samples (Aqueous Sample IDs 1, 2A, 2B, and 3 through 12) were collected from the liquid treatment train between raw influent and final effluent. The dissolved aeration flotation tanks (DAFT) supernatant was also collected, recirculated back to the trickling filters (Aqueous Sample ID 16). Centrate recirculated back to either the headworks or trickling filters, was also collected (Aqueous Sample ID 17). Eight (8) additional aqueous samples were collected as the aqueous portion of the solids with high moisture content (Aqueous Sample IDs 13, 14, 15, 18, 19, 20A, 20B, and 21). A total of eight (8) solid samples with high moisture were collected as the primary sludge, WAS/RAs, aerated RAS, DAFT bottom sludge, DAFT float sludge, two individual samples from two digestors, and dewatered digested sludge (Solid Sample IDs 2, 3, 4, 5, 6, 7A, 7B, and 8). Finally, three solid samples were collected as grit, Class A, and Class B biosolids (Solid Sample IDs 1, 9A, and 9B). A description of each Sample ID and the location within the treatment plant is presented in **Figure 47** on the process flow diagram.

4.9.1 Aqueous Fate and Transport Discussion

The total PFAS and signature remain consistent throughout the aqueous treatment train ranging between 70 to 88 ng/L, with short-chain PFAAs being about 60-65% of the total PFAS and long-chain PFAAs being about 40-35% (**Figure 48**). This indicates that PFAS passes through the system with no treatment. No precursors were detected in the aqueous treatment train. There was a slight increase in the DAFT supernatant concentrations to total PFAS of 108 ng/L, increasing both short-chain and long-chain PFAAs. There was a considerable increase in concentrations with a total PFAS of 209 ng/L with an observer higher increase in the short-chain PFAAs than the increase of long-chain PFAAs.

There was no observable increase in PFAS concentrations in the aqueous portion of the high moisture solids such as primary sludge, RAS, and aerated RAS. Some increases were observed in the DAFT float in the total PFAS sludge of 133 ng/L, including the detection of 10 ng/L of long-chain precursors. The concentrations were slightly lower in the DAFT bottom sludge with the total PFAS of about 100 ng/L, most likely due to the adsorption of PFAS to solids.

There was a significant increase in the total PFAS in the digested solids of 288 ng/L and thickened sludge after digestion with total PFAS concentrations of 347 ng/L. There were very similar results in both digestors samples, indicating that the waste streams are well mixed and homogenized. There were some detections of short-chain precursors between 4 and 6 ng/L and those of long-chain precursors between 66 and 91 ng/L. This indicates the presence of additional precursors that currently are not part of the analyte list.

The PFAS signature within the aqueous treatment train was similarly observed at many other facilities with short-chain PFCAs having higher PFOA concentrations. There was also even carbon number PFSA detected at the facility.

4.9.2 Solid Fate and Transport Discussion

The highest detectable PFAS was PFOS, with concentrations ranging between 11 to 610 µg/kg (**Figure 49**). PFOS precursors were detected as the second-highest concentrations of 27 to 600 µg/kg for MeFOSAA and 12 to 250 for EfFOSAA. Both PFOS precursors are known to transform in the environment to PFOS; however, the transformation process is slow. As the use of PFOS and PFOS precursors have significantly been reduced since 2002, the presence of these compounds indicates that residual legacy impact may be the source of these PFAS. Additional detections of long-chain PFCAs were also detected, as was expected since these

compounds have a high affinity to solids. The PFOS precursors were never detected in the aqueous treatment train. There were some short-chain PFAs also detected in solid such as PFHxA and PFBS. There is a decrease in concentrations for all PFAS as the solids are treated from primary treatment up to DAFT float, most likely due to the mass transfer of PFAS from the solids phase to the aqueous phase.

Figure 47. PFAS Results and Process Flow Diagram for WWTP 18

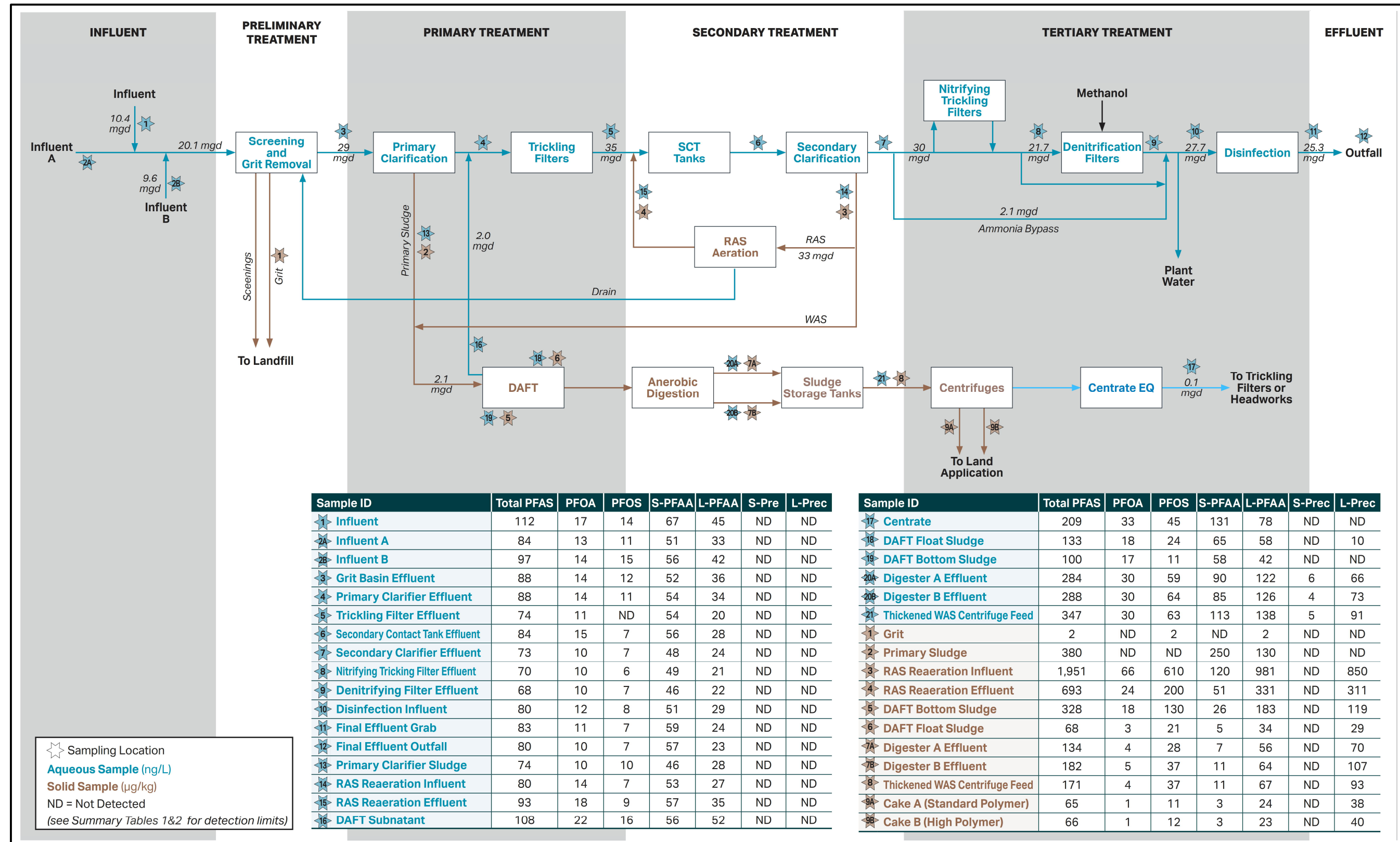


Figure 48. WWTP 18 PFAS Concentrations in The Aqueous Treatment Process Flow

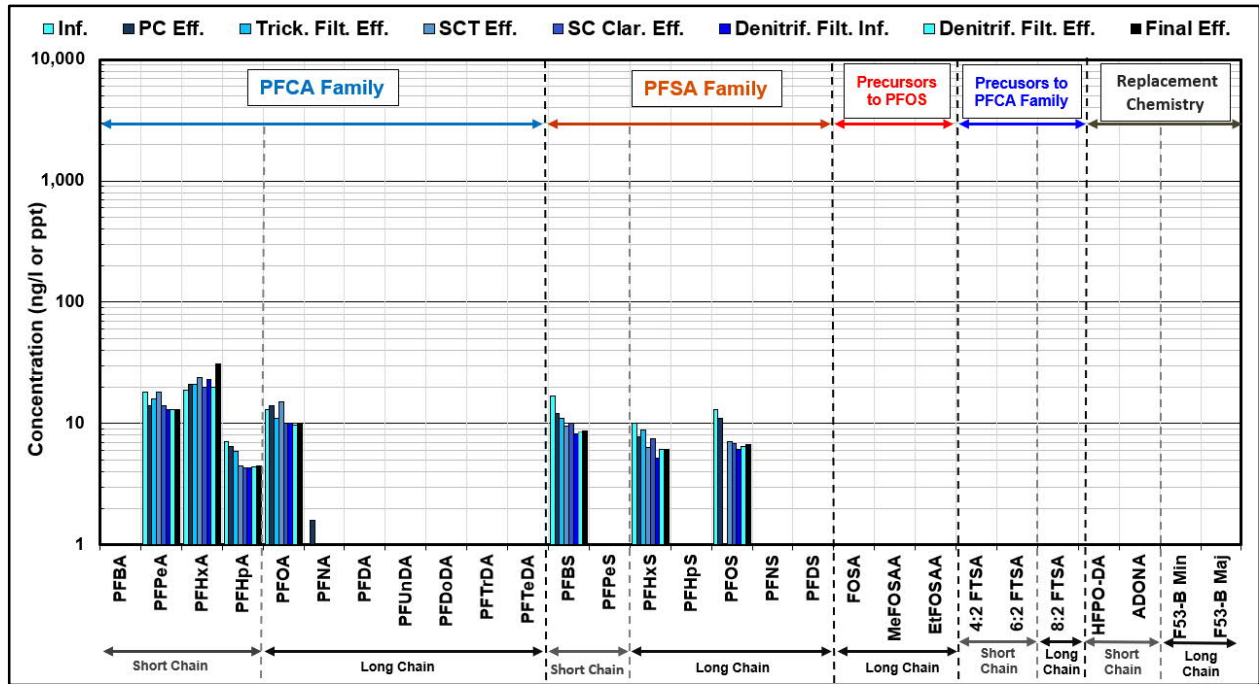
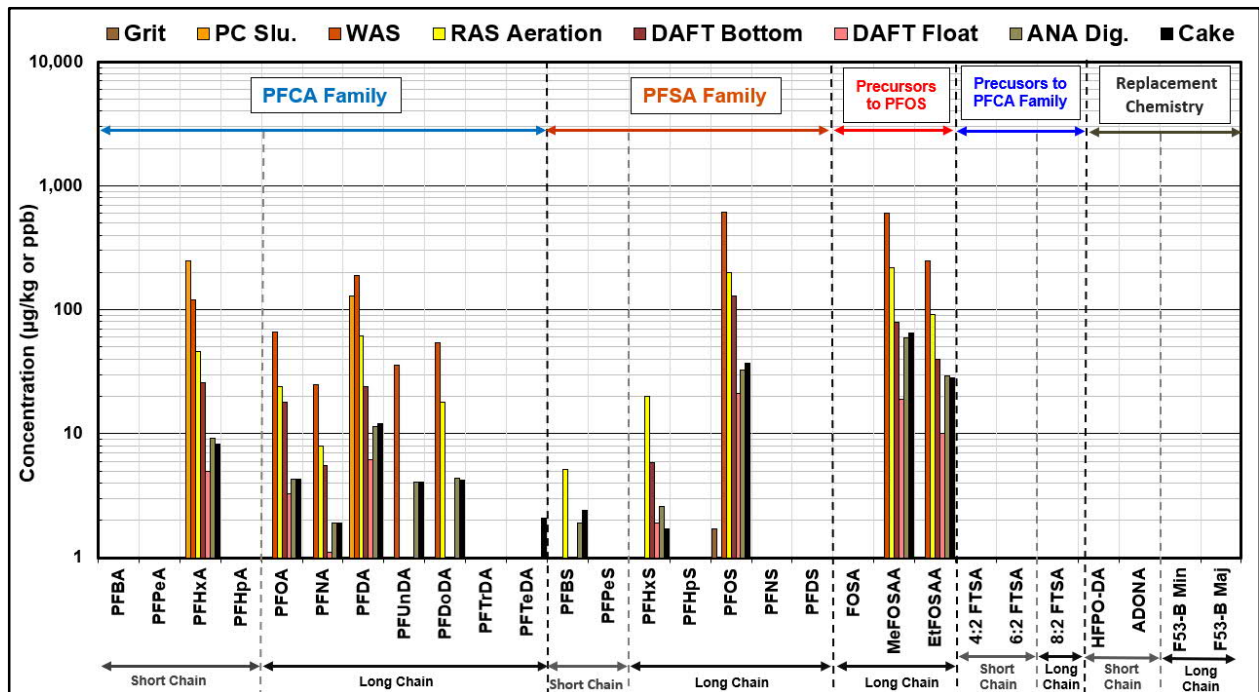


Figure 49. WWTP 18 PFAS Concentrations in The Solid Treatment Process Flow



4.10 PFAS Evaluation of Solid and Aqueous Partition in WWTPs

At select WWTPs (i.e., WWTP 2, 13, 14, and 18), the solids samples with very low solids percentage (i.e., ~5% or lower) from various treatment processes were collected. The analysis for the aqueous and solid portion was performed separately to evaluate the PFAS partition into the aqueous and solid phases. The PFAS results for the aqueous and solid portion of each sample from the four (4) WWTPs from multiple treatment processes are regular and loghramic scales in Figures 50 through 53. The detection limits for solids are in low $\mu\text{g}/\text{Kg}$ or ppb, which is significantly higher than the aqueous detection limit phase, which is low ng/L or ppt. As a result, PFAS are expected to be more frequently detected in the aqueous phase compared to the solid phase. In some instances, the concentrations of the short-chain compounds may be below the detection limit in the solid phase but still detected in the aqueous phase, which indicates that analyzing only the solid phase may show the absence of short-chain compounds, but they could still be present. Long-chain PFAS are known to adsorb to solids; as a result, preferentially, certain long-chain PFAS may still be detected more frequently in the solids than in the aqueous phase. The main reason for the difference in detections in the solid and aqueous phases is that

Two (2) solid samples with low solids percentage were collected from WWTP 2 with sludge collected from the primary clarifier (**Figure 50**) and the second sample as waste activated sludge (WAS) from the secondary clarifier (**Figure 51**). There were additional PFAS detected in the WAS sample compared to those detected in the primary sludge. Also, higher concentrations were detected for all PFAS detected in the WAS compared to that of primary sludge. The majority of the PFAS were associated with the solid phase. Low concentrations of a couple of PFOS precursors such as FOSA, MeFOSAA, and EtFOSAA were detected in the primary sludge, and only FOSA was detected in the WAS. MeFOSAA and EtFOSAA may have partition predominantly in the solids at concentrations below the detection limit or partially degraded into other PFAS. It is known that the final degradation product for both compounds is PFOS.

Figure 50. PFAS Concentrations in the Aqueous and Solid Portions of the Primary Clarifier Solids for WWTP 2: Regular Scale (a) and Log Scale (b)

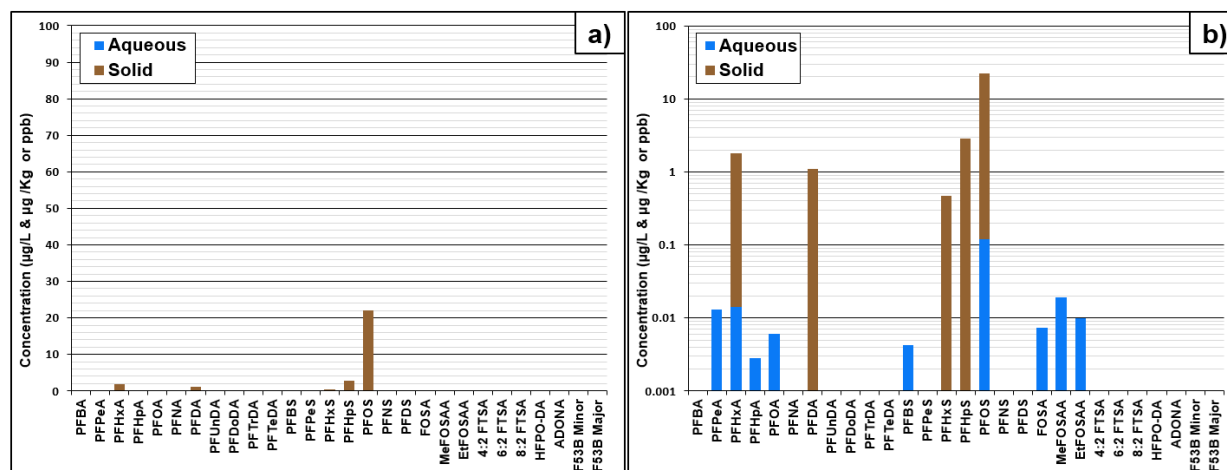
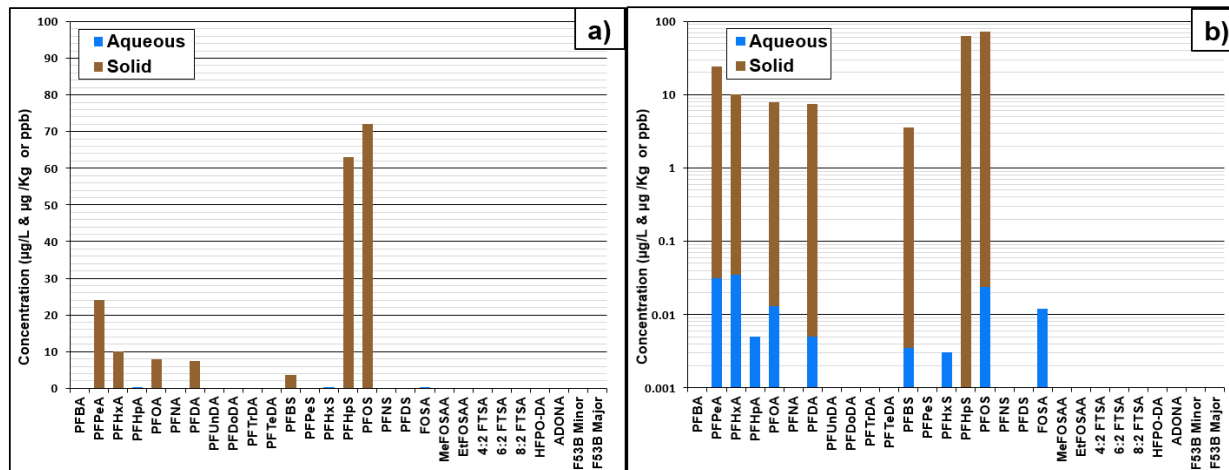


Figure 51. PFAS Concentrations in the Aqueous and Solid Portions of the Secondary Clarifier Solids for WWTP 2: Regular Scale (a) and Log Scale (b)



Three (3) solid samples with low solids percentage were collected from WWTP 13 with sludge collected from the sequence batch reactors (**Figure 52**), sludge storage tank (**Figure 53**), and Thickened Sludge Tanks (**Figure 54**). The highest number of PFAS detected were in the sludge storage tanks. However, the PFAS signature was similar in all three samples, and the difference in the PFAS detected was due to the low detection of the compounds. PFDA was the main PFAS detected in the solids, with slightly higher concentrations in the sludge tanks or thickened sludge tanks.

Figure 52. PFAS Concentrations in the Aqueous and Solid Portions of the Waste Activated Sludge (Sequence Batch Reactors) Solids for WWTP 13: Regular Scale (a) and Log Scale (b)

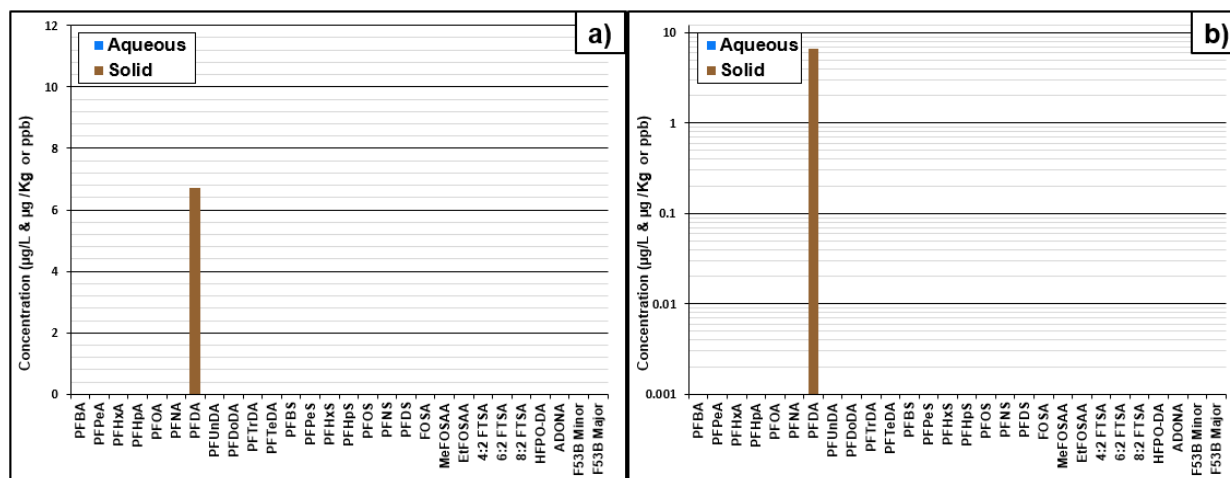


Figure 53. PFAS Concentrations in the Aqueous and Solid Portions of the Sludge Storage Tanks Solids for WWTP 13: Regular Scale (a) and Log Scale (b)

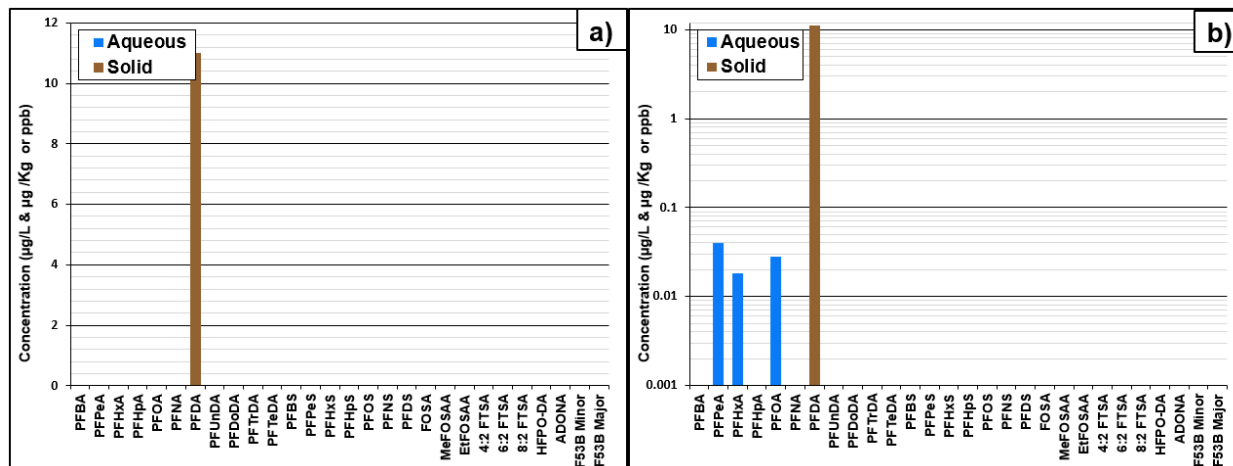
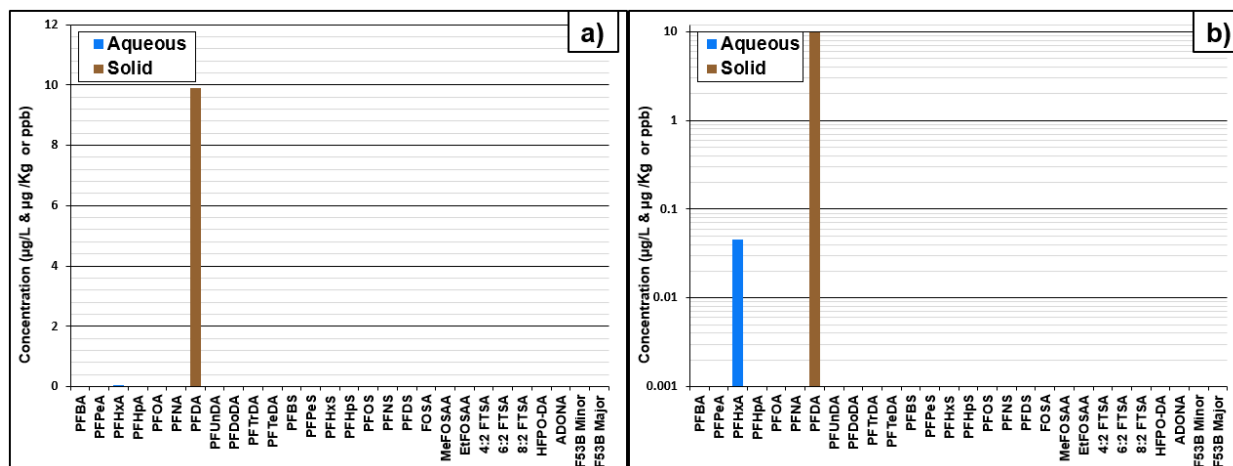


Figure 54. PFAS Concentrations in the Aqueous and Solid Portions of the Thickened Sludge Tanks Solids for WWTP 13: Regular Scale (a) and Log Scale (b)



Four (4) solid samples with low solids percentage were collected from WWTP 14 with sludge collected from the oxidation ditch anoxic zone (**Figure 55**), oxidation ditch aerobic zone (**Figure 56**), waste activated sludge (WAS) (**Figure 57**), and aerated holding storage tank (**Figure 58**). The overall trend in terms of PFAS detected, and signature was similar in all samples, with some fluctuations for PFOS. The PFOS concentrations fluctuated from 360 to 480 µg/Kg which was most likely due to fluctuations in the PFOS concentrations at the wastewater and collecting grab samples. It is likely for a point source of PFOS to be present that has highly fluctuated PFOS concentrations. PFOS was detected at the highest concentrations followed by 6:2 FTSA. The partition of PFAS was predominantly occurring in the solid phase. The signature observed in the aqueous and solids samples is like that expected at from facilities where AFFF from multiple manufacturers were used.

Figure 55. PFAS Concentrations in the Aqueous and Solid Portions of the Oxidation Ditch Anoxic Zone Solids for WWTP 14: Regular Scale (a) and Log Scale (b)

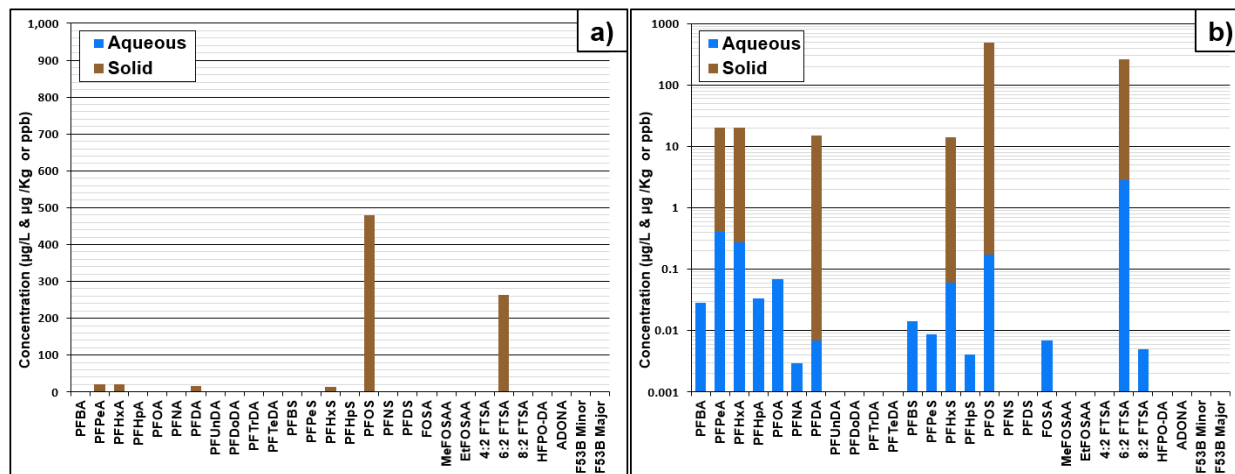


Figure 56. PFAS Concentrations in the Aqueous and Solid Portions of the Oxidation Ditch Aerobic Zone Solids for WWTP 14: Regular Scale (a) and Log Scale (b)

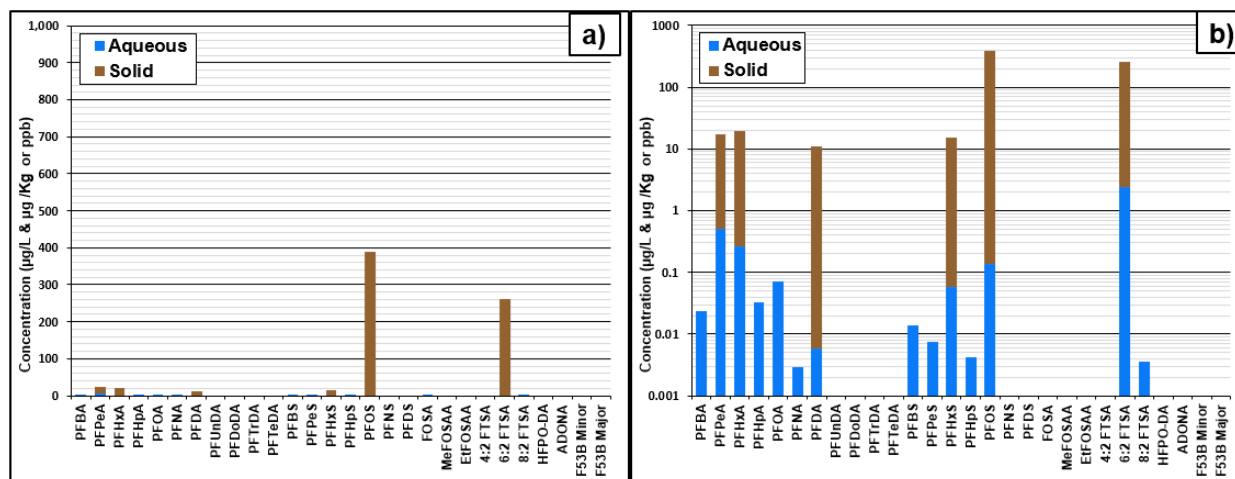


Figure 57. PFAS Concentrations in the Aqueous and Solid Portions of the Waste Activated Sludge for WWTP 14: Regular Scale (a) and Log Scale (b)

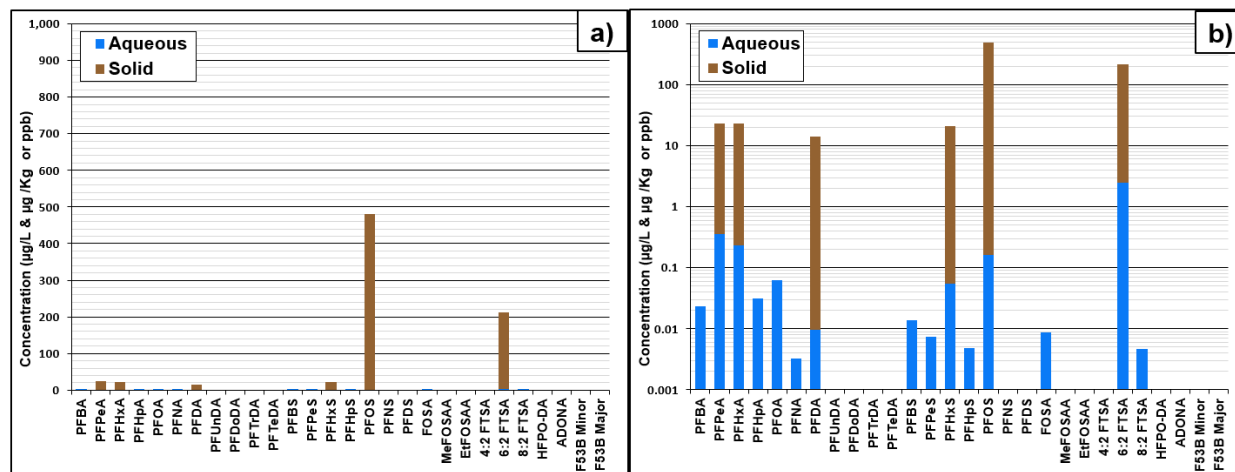
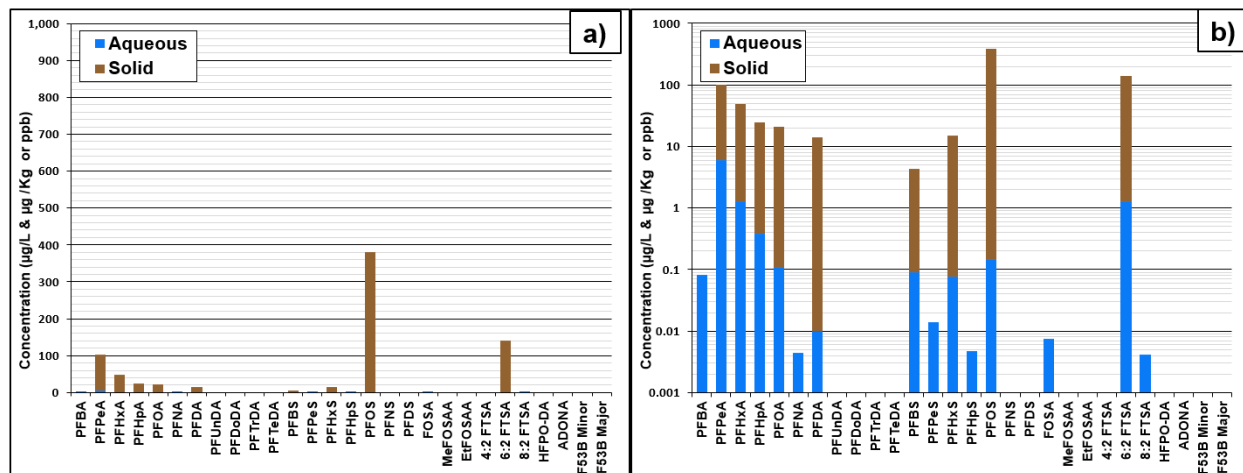


Figure 58. PFAS Concentrations in the Aqueous and Solid Portions of the Aerated Holding Storage Tank Solids for WWTP 14: Regular Scale (a) and Log Scale (b)



A total of seven (7) solid samples with low solids percentage were collected from WWTP 18 with sludge collected as primary treatment sludge (**Figure 59**), waste activated sludge (WAS) (**Figure 60**), aerated return activated sludge (RAS) (**Figure 61**), DAFT bottom sludge (**Figure 62**), DAFT float sludge (**Figure 63**), anaerobic digested solids (**Figure 64**) and sludge storage tanks (**Figure 65**). One additional sample was collected from a second anaerobic digester to evaluate potential difference in concentrations as the anaerobic digesters were operated in parallel. There was only a 30 % in the total difference between the two digester samples within expected concentrations fluctuations given that the samples were also collected as grab and expected variations from the lab analysis as well.

There was an apparent difference between the primary treatment sludge (**Figure 59**), and the influent for the Aerated RAS (i.e., WAS) (**Figure 60**), and Aerated RAS samples (**Figure 61**), with an increase in the number of PFAS detected and concentrations after the primary treatment. The results indicate that secondary biological treatment has a significant effect on the fate of PFAS in the WWTP compared to that of the primary treatment. While the same PFAS at similar low ng/L concentrations were detected in all three samples, there were additional long-chain PFCAs and PFOS precursors present in the WAS and Aerated RAS samples. The accumulation of the long-chain precursors into the solids may be partially due to the degradation of precursors that are not part of the analyte list, but most likely in big part due to the solid's recirculation. PFAS have more opportunity to come into contact and accumulate into the solids as the aerated RAS is recirculated within the WWTP. The increase in PFAS concentrations in the WAS compared to the Aerated RAS may be due to the fluctuations with the WWTP, lab analysis interface and grab sample collection. Many of the detection limits for the Aerated RAS are elevated due to matrix interference and the PFAS detections in the influent are below the elevated reporting limits. The three (3) dominant PFAS identified later in the solid treatment train PFOS, MeFOSAA, and EtFOSAA were non-detect in the primary treatment sludge. Out of three only one PFAS, PFOS was detected in the aqueous treatment process flow. All three PFAS (i.e., PFOS, MeFOSAA, and EtFOSAA) are expected to preferentially partition to the solids and this may indicate that they may still be present in the aqueous process flow at concentrations lower than the detection limits. It may also indicate the presence of additional PFAS precursors that are not in the analyte list that could degrade to MeFOSAA and EtFOSAA.

The primary sludge and WAS are mixed and feed to a DAFT. Solid samples were collected

from the float (top solids) (Figure 62) and bottom sludges (Figure 63). The solids that do not float to the top are settling to the bottom. The bottom sludges had the highest PFAS concentrations for all compounds and types (i.e., short and long chain PFAAs and precursors). Based on this limited data set is not clear if the type of solids contributed to the preferential accumulation of PFAS to the bottom sludge. The PFAS concentrations in the digested solids (Figure 64), and storage tanks (Figure 65) further down the solid process treatment flow had concentrations between those detected in the bottom and float sludges, which may indicate potential fluctuations in the concentrations. This is also supported by the fact that they had similar PFAS signature while the concentrations fluctuated.

Figure 59. PFAS Concentrations in the Aqueous and Solid Portions of the Primary Clarifier Solids for WWTP 18: Regular Scale (a) and Log Scale (b)

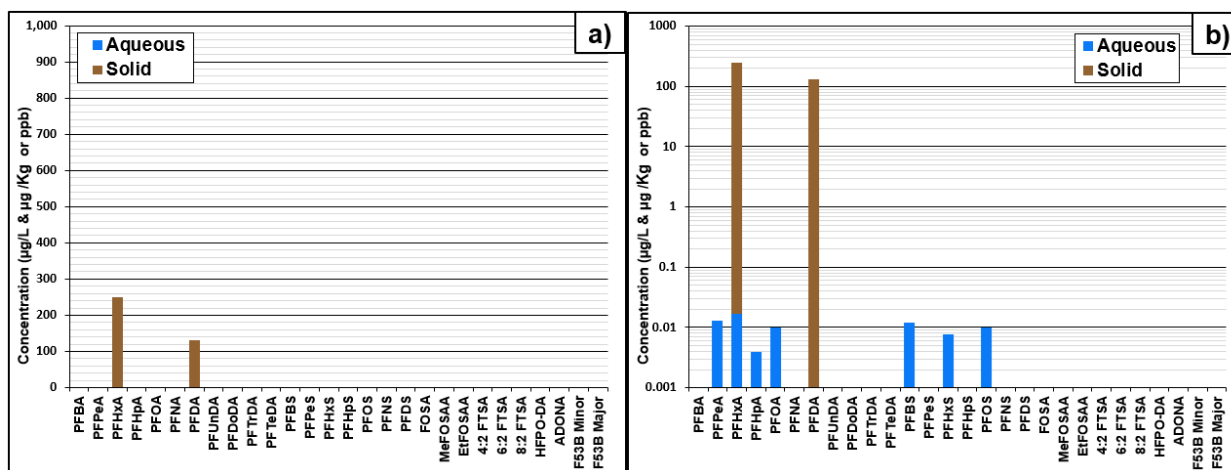


Figure 60. PFAS Concentrations in the Aqueous and Solid Portions of Aerated Returned Activated Sludge Influent Solids for WWTP 18: Regular Scale (a) and Log Scale (b)

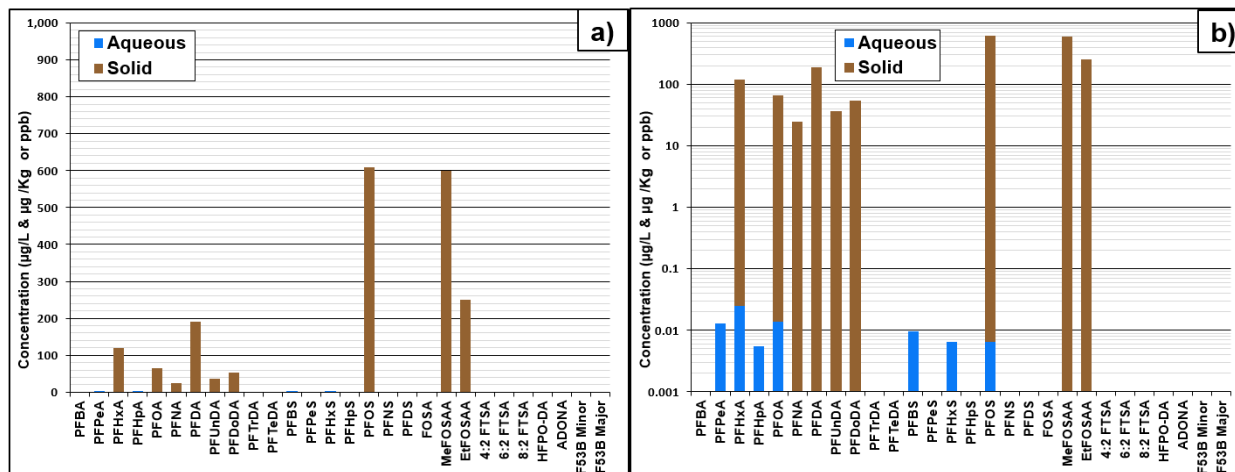


Figure 61. PFAS Concentrations in the Aqueous and Solid Portions of the Aerated Returned Activated Sludge Effluent Solids for WWTP 18 Regular Scale (a) and Log Scale (b)

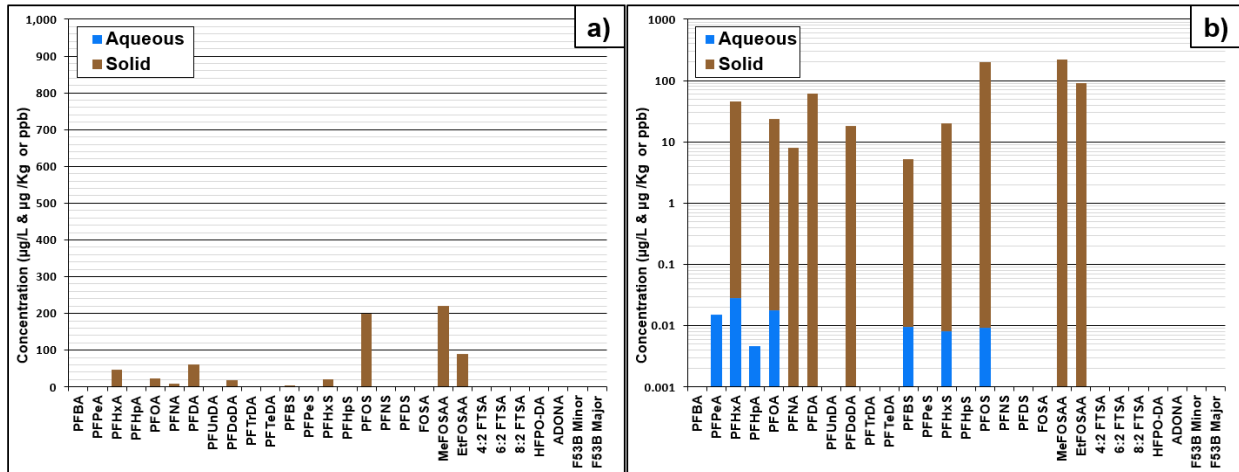


Figure 62. PFAS Concentrations in the Aqueous and Solid Portions of the DAFT Float Sludge Solids for WWTP 18: Regular Scale (a) and Log Scale (b)

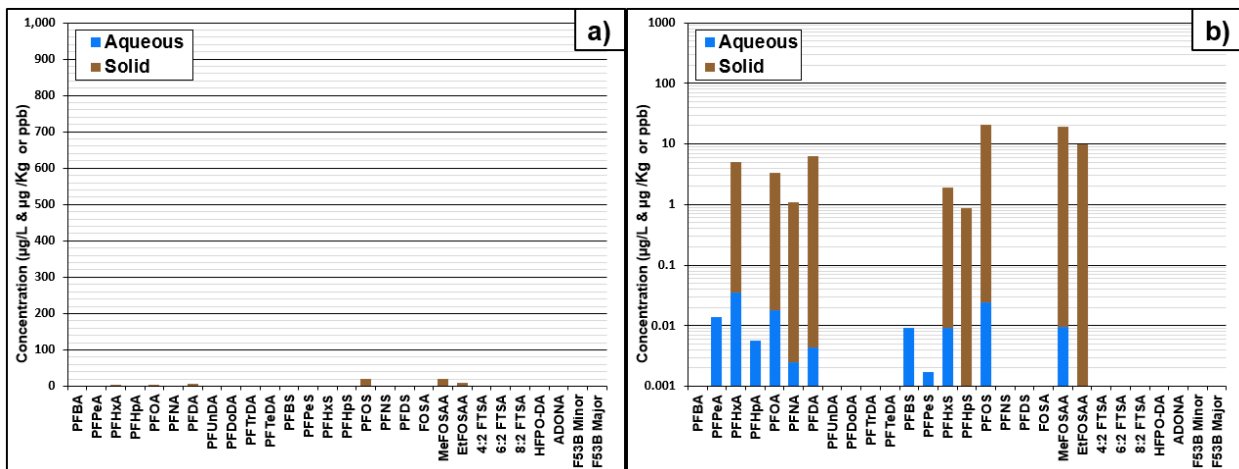


Figure 63. PFAS Concentrations in the Aqueous and Solid Portions of the DAFT Bottom Sludge Solids for WWTP 18: Regular Scale (a) and Log Scale (b)

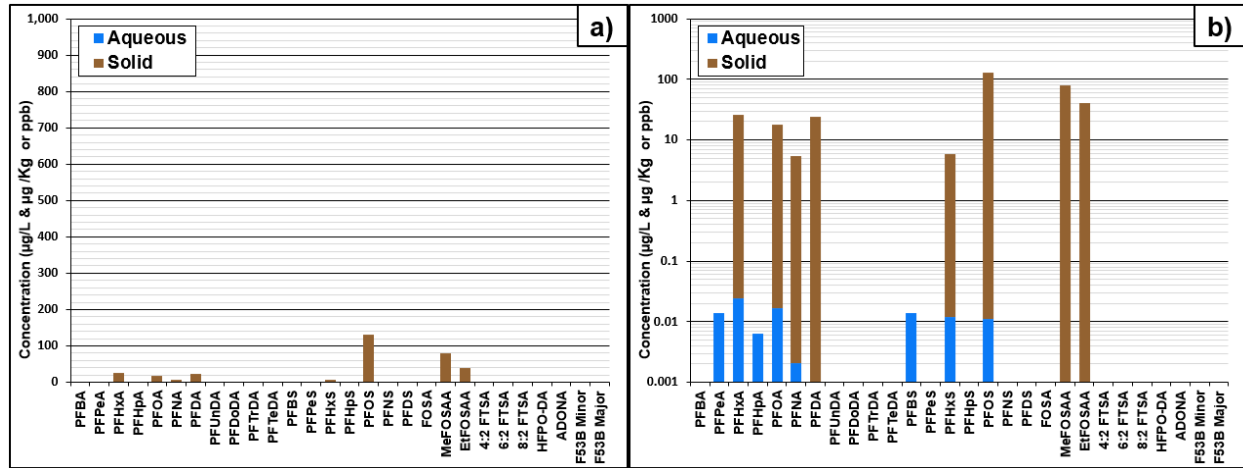


Figure 64. PFAS Concentrations in the Aqueous and Solid Portions of the Anaerobic Digester Solids for WWTP 18: Regular Scale (a) and Log Scale (b)

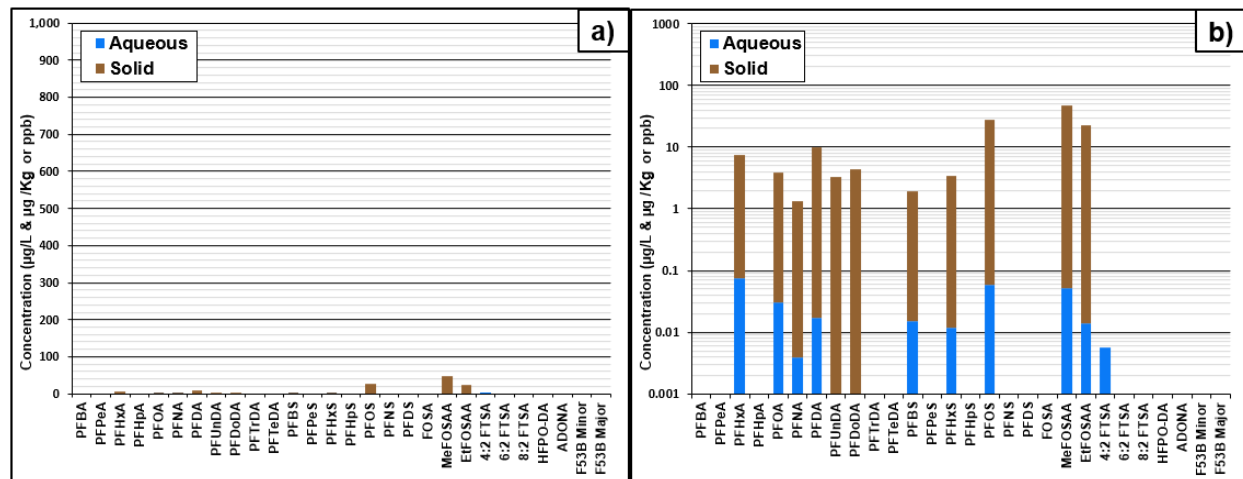
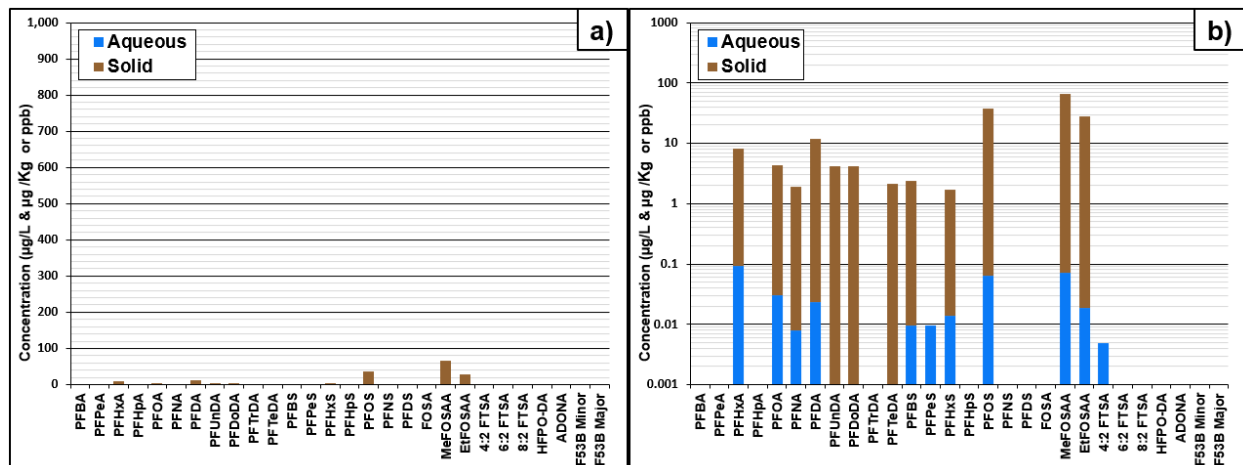


Figure 65. PFAS Concentrations in the Aqueous and Solid Portions of the Sludge Storage Tank Solids for WWTP 18: Regular Scale (a) and Log Scale (b)



5. Discussion and Conclusions

Widespread use of PFAS in a wide range of manufacturing and industrial facilities since at least early 1950s in conjunction with extreme resistance to degradation has resulted in the presence of PFAS in the environment and at many WWTPs. While WWTPs are not the source of PFAS, they are a central point of collection. Effluents discharged from WWTPs and biosolids applied to the agricultural land for beneficial reuse have been identified as potential PFAS release pathways into the environment. PFAS have been identified in WWTPs since the early 2000s in many states across the US. Recent statewide evaluations of WWTPs identified widespread PFAS impacts with a wide range in concentrations. To provide additional evaluation in the US the current national study included 19 WWTPs across the US from 8 different states. The study was divided into separate Phases. Phase 1 included the screening for PFAS in the influent, effluent, and final treated solids. Based on the results from the Phase 1, a subgroup of eight (8) WWTPs were selected for an in-depth assessment with the collection of multiple samples from the liquid and solid treatment process flows to better understand PFAS fate within WWTPs. All the samples were analyzed by Eurofins – Test America laboratory from West Sacramento using an in-house developed isotope dilution method for a list of 28 PFAS from 9 PFAS families to provide a comprehensive evaluation (Appendix B). One WWTP provide the results for 45 PFAS which included the 28 PFAs analyses for this study to be used during the Phase 1 evaluation.

The percent detection for all 28 PFAS during the Phase 1 are presented in **Figure 4**. PFAS was detected in 89% of the influent, 100% of the effluent, and 83% of the final treated solids sampled. PFAS were detected in all WWTPs, but the concentrations varied significantly. Also, the signature of various compounds varied as well. The short-chain PFCAs and PFSA were the most frequently detected PFAS in the aqueous process treatment flow. While short-chain and long-chain PFAS were detected in the solids, with many of long-chain PFAS preferentially only detected in the solids. The Phase 1 results were also compared to statewide studies performed in Michigan and California. For the Michigan study, a total of 47 influent, 44 effluent, and 44 final treated solids samples were collected from 42 WWTPs. The California statewide study included a total of 193 influent samples collected from 180 WWTPs, 186 effluent samples collected from 179 WWTPs, and 128 solid samples from 122 WWTPs. For the California study the highest concentration recorded for each sample type during three (3) 2021 quarters was used in the study as a worst-case scenario. The percent detection differences for the influent, effluent and final treated solids for all three (3) studies are presented in **Figures 7, 8, and 9**. A similar trend to that of the Phase 1 was observed in both statewide Michigan and California studies in terms of wide range of PFAS concentrations and signature of various compounds in the aqueous and solids treatment process flows. This indicates that similar trends are expected to be observed across the US with PFAS being detected in most of the WWTPs. However, the PFAS concentrations could vary significantly from one facility to another. The concentrations were summarized as box plots for the influent, effluent, and final treated solids in **Figures 11, 13, and 15**. The most frequently detected PFAS in the influent, above 80% were PFPeA, PFHxA, PFOA, and PFOS. In the effluent the detection frequency increased for many of the PFAS detected in the influent including those that were above 80%, with additional PFAS detected above 80% in the effluent were PFHpA, PFBS, and PFHxS. The detection ranges were similar for the influent and effluent, but they were slightly higher for couple of PFAS especially short-chain PFCAs. The detection of PFOS were overall more significant with the highest concentrations and concentrations range in the final treated solids with one of the highest detection frequency of 72%. However, due to the significant matrix interference the detection limit in many of the final treated solids were elevated. This indicates that PFOS may potentially be at least one of the most frequently detected PFAS in final treated solids, including biosolids, and also detected at some of the highest concentrations. An evaluation of the sewershed was conducted for WWTP 17 which showed that the majority of the PFAS mass may be associated

with a limited area of the sewershed (**Figure 18**). This indicates that source reductions as conducted in Michigan could identify significant sources of PFAS from limited sources. Addressing a small number of highly impacted sources may significantly decrease the overall PFAS mass to the WWTPs. Box plot graphs for the influent, effluent and final treated solids for all three (3) studies are presented in **Figures 19, 20, and 21**. Similar trends were observed in the statewide studies compared to the Phase 1 with a wider concentration ranges for the statewide studies. This indicates that the PFAS impact vary significantly and is very specific to each facility, and when a large study is conducted the concentration ranges could also be very large. PFOS as mentioned earlier, was identified at the highest concentrations in the final treated solids. However, due to the transition from long-chain PFAS by 3M in 2002, the concentrations are expected to have reduce in the environment. As a result, overall PFOS concentrations detected in the AECOM National Study in the Phase 1 were like those detected in both recent statewide studies, but lower to those detected in the early 2000s (**Figure 22**).

A total of eight (8) WWTPs were selected for the Phase 2 evaluation. The matrix interference resulted in elevated detection limits and limited the interpretation for each sampling event individually. The difference between Phase 1 and Phase 2 results for PFOA, PFOS, and Total PFAS is presented in **Figures 23, 24, and 25**, respectively. There were no significant changes between Phase 1 and Phase 2 results with the exception for WWTP 14 and for PFOS in WWTP 18. Detailed summaries for all eight (8) WWTPs is presented in **Section 4.2**. Many of the trends observed during the Phase 1 were also observed in the Phase 2 int terms of compounds detected and overall concentrations ranges. Some of the main observations from the Phase 2 are that there were no detections of the PFAS used as replacement chemistry. The replacement chemistry compounds are expected to be most likely detected in areas where PFAS manufacturing plants are using these PFAS, but to not be widely detected in WWTPs at this time. The concentrations of precursors varied significantly including the type from one facility to another. While the PFCAs and PFSA were detected in all WWTPs and similar signatures were detected in the aqueous and solid treatment process flow. The short-chain PFAS were associated more strongly with the aqueous treatment process flow, while long-chain PFAS were associated more strongly with the solids treatment process flow. There was no indication that degradation of PFCAs and PFSA was occurring in the aqueous or solid treatment process flows. An increase in the effluent concentrations compared to those in the influent of especially short-chain PFAS were observed at some WWTPs. The increase in PFAS concentrations were due in part degradation of precursors, with the highest increase observed after the first biological treatment or due to the recirculation waste streams within the WWTPs. The increase in PFAS concentrations was facility specific and it depended on the type of precursors present, biological treatments, and type of recirculation streams. As a result, it indicates that comprehensive evaluation of WWTPs should be conducted when the PFAS fate is studies. Also, during future expansions or modifications in the treatment, the PFAS fate and potential impacts should be taken into consideration. PFOS was identified as one the main PFAS associated with final treated solids in terms of concentrations and detection frequency. The number of PFAS detected in solids increased typically further down the treatment train and in some instances in concentrations. Evaluations of solids disposal and potential changes in the processing of solids should take into consideration potential PFAS impacts and especially those of PFOS.

The evaluation of aqueous and solid phases separately of solids with high aqueous percentage (i.e., aqueous percentage above 90 %) for multiple solids within various treatment processes flow. Most of the PFAS mass was associated with the solids. It also indicates that many times while PFAS are present in the solids phase are associated with the aqueous phase and at concentrations below the detection limit for the solids.

The current studies identified a high prevalence of PFAS within WWTPs across the US. While some overall trends were observed, it was determined that potential PFAS impacts to WWTPs

could vary significantly and each facility should be evaluated individually. Due to the prevalence of PFAS, it is expected that future regulatory actions to impact the reuse of and discharge of final treated effluents and solids disposal.

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Tables

Table 1
Aqueous PFAS Sample Results
2021 AECOM National Study

| Facility # | Sample ID | Sample Date | Task | PFD | TOP Analysis | Total PFAS | S-PFAAs | L-PFAAs | S-Prec | L-Prec | Repl. | PFBA | PFPeA | PFHxA | PFHpA | PFOA | PFNA | PFDA | PFUnDA | PFDoDA | PFTrDA | PFTeDA | PFBS | PFPeS | PFHxS | PFHpS | PFOS | PFNS | PFDS | FOSA | MeFOSAA | EtFOSAA | 4:2 FTSA | 6:2 FTSA | 8:2 FTSA | HFPO-DA | ADONA | F53B Min | F53B Maj | |
|------------|-------------------------------|-------------|------|-----|--------------|------------|---------|---------|--------|--------|-------|-------|-------|-------|-------|-------|--------|--------|--------|--------|--------|--------|-------|--------|--------|--------|-------|--------|--------|--------|---------|---------|----------|----------|----------|---------|--------|----------|----------|-------|
| 1 | Final Effluent | 9/2/2020 | P1E | n/a | n/a | 138 | 104 | 25 | 0 | 9 | 0 | 7.7 | 51 | 32 | 3.6 | 15 | 1.8 | < 0.28 | < 0.98 | < 0.49 | < 1.2 | < 0.26 | 9.9 | < 0.27 | 2.8 | < 0.17 | 5.8 | < 0.14 | < 0.29 | 8.6 | < 2.8 | < 1.7 | < 4.7 | < 1.8 | < 1.8 | < 1.3 | < 0.16 | < 0.21 | < 0.29 | |
| 1 | Raw Influent | 9/2/2020 | P1I | n/a | n/a | 153 | 82 | 71 | 0 | 0 | 0 | 21 | 17 | 25 | 6 | 20 | < 0.53 | 4.4 | < 2.1 | < 1.1 | < 2.5 | < 0.56 | 13 | < 0.58 | 8.6 | < 0.37 | 38 | < 0.31 | < 0.62 | < 0.68 | < 6.0 | < 3.7 | < 10 | < 3.9 | < 2.9 | < 2.9 | < 0.35 | < 0.47 | < 0.62 | |
| 2 | Raw Influent | 6/9/2021 | P2I | 1 | n/a | 126 | 61 | 46 | 13 | 7 | 0 | < 12 | 30 | 18 | 4.1 | 6.4 | < 1.4 | < 1.6 | < 5.5 | < 2.8 | < 6.5 | < 3.7 | 8.0 | < 1.5 | 4.2 | < 0.95 | 35 | < 1.9 | < 1.6 | 6.5 | < 6.0 | < 6.5 | < 1.2 | 13 | < 2.3 | < 7.5 | < 2.0 | < 1.2 | < 1.6 | |
| 2 | Primary Clarifier Effluent | 6/9/2021 | P2 | 2 | n/a | 97 | 56 | 41 | 0 | 0 | 0 | 14 | 17 | 13 | 3.5 | 4.9 | < 1.4 | < 1.6 | < 5.5 | < 2.8 | < 6.5 | < 3.7 | 8.1 | < 1.5 | 4.2 | < 0.95 | 32 | < 1.9 | < 1.6 | 4.9 | < 6.0 | < 6.5 | < 1.2 | < 13 | < 2.3 | < 7.5 | < 2.0 | < 1.2 | < 1.6 | |
| 2 | Aeration Tank Effluent | 6/9/2021 | P2 | 3 | n/a | 115 | 62 | 47 | 0 | 5 | 0 | < 12 | 27 | 25 | 4.2 | 8.3 | < 1.4 | < 1.6 | < 5.5 | < 2.8 | < 6.5 | < 3.7 | 5.9 | < 1.5 | 3.9 | < 0.95 | 35 | < 1.9 | < 1.6 | 5.4 | < 6.0 | < 6.5 | < 1.2 | < 13 | < 2.3 | < 7.5 | < 2.0 | < 1.2 | < 1.6 | |
| 2 | Secondary Clarifier Effluent | 6/9/2021 | P2 | 4 | n/a | 105 | 63 | 42 | 0 | 0 | 0 | < 12 | 27 | 26 | 3.5 | 6.9 | < 1.4 | < 1.6 | < 5.5 | < 2.8 | < 6.5 | < 3.7 | 6.9 | < 1.5 | 4.8 | < 0.95 | 30 | < 1.9 | < 1.6 | 4.9 | < 6.0 | < 6.5 | < 1.2 | < 13 | < 2.3 | < 7.5 | < 2.0 | < 1.2 | < 1.6 | |
| 2 | Final Effluent | 6/9/2021 | P2E | 5 | n/a | 97 | 59 | 38 | 0 | 0 | 0 | < 12 | 25 | 22 | 3.6 | 7 | < 1.4 | < 1.6 | < 5.5 | < 2.8 | < 6.5 | < 3.7 | 8.4 | < 1.5 | 3.8 | < 0.95 | 27 | < 1.9 | < 1.6 | 4.9 | < 6.0 | < 6.5 | < 1.2 | < 13 | < 2.3 | < 7.5 | < 2.0 | < 1.2 | < 1.6 | |
| 2 | Centrate | 6/9/2021 | P2 | 6 | n/a | 762 | 695 | 67 | 0 | 0 | 0 | 44 | 410 | 140 | 11 | 47 | < 1.4 | < 1.6 | < 5.5 | < 2.8 | < 6.5 | < 3.7 | 90 | < 1.5 | 5 | < 0.95 | 15 | < 1.9 | < 1.6 | 4.9 | < 6.0 | < 6.5 | < 1.2 | < 13 | < 2.3 | < 7.5 | < 2.0 | < 1.2 | < 1.6 | |
| 2 | Primary Clarifier Sludge | 6/9/2021 | P2 | 7 | n/a | 197 | 34 | 126 | 0 | 36 | 0 | < 12 | 13 | 14 | 2.8 | 6.1 | < 1.4 | < 1.6 | < 5.5 | < 2.8 | < 6.5 | < 3.7 | 4.2 | < 1.5 | < 2.9 | < 0.95 | 120 | < 1.9 | < 1.6 | 7.4 | 19 | 10 | < 1.2 | < 13 | < 2.3 | < 7.5 | < 2.0 | < 1.2 | < 1.6 | |
| 2 | WAS | 6/9/2021 | P2 | 8 | n/a | 132 | 75 | 45 | 0 | 12 | 0 | < 12 | 31 | 35 | 5 | 13 | < 1.4 | < 1.6 | < 5.5 | < 2.8 | < 6.5 | < 3.7 | 3.5 | < 1.5 | 3.1 | < 0.95 | 24 | < 1.9 | < 1.6 | 12 | < 6.0 | < 6.5 | < 1.2 | < 13 | < 2.3 | < 7.5 | < 2.0 | < 1.2 | < 1.6 | |
| 2 | TWAS Centrifuge Feed | 6/9/2021 | P2 | 9 | n/a | 818 | 771 | 47 | 0 | 0 | 0 | 58 | 450 | 150 | 13 | 42 | < 1.4 | < 1.6 | < 5.5 | < 2.8 | < 6.5 | < 3.7 | 100 | < 1.5 | 4.9 | < 0.95 | < 2.7 | < 1.9 | < 1.6 | 4.9 | < 6.0 | < 6.5 | < 1.2 | < 13 | < 2.3 | < 7.5 | < 2.0 | < 1.2 | < 1.6 | |
| 2 | Final Effluent | 7/24/2020 | P1E | n/a | n/a | 107 | 66 | 41 | 0 | 0 | 0 | 7 | 27 | 21 | 3.8 | 6.6 | < 0.23 | < 0.26 | < 0.92 | < 0.46 | < 1.1 | < 0.24 | 7.2 | < 0.25 | 2 | < 0.16 | 32 | < 0.13 | < 0.27 | < 0.29 | < 2.6 | < 1.6 | < 4.4 | < 1.7 | < 1.7 | < 1.3 | < 0.15 | < 0.20 | < 0.27 | |
| 2 | Raw Influent | 7/24/2020 | P1I | n/a | n/a | 76 | 42 | 34 | 0 | 0 | 0 | 5.8 | 15 | 13 | 3.2 | 4.2 | < 0.23 | < 0.27 | < 0.95 | < 0.48 | < 1.1 | < 0.25 | 5.1 | < 0.26 | 1.9 | < 0.16 | 28 | < 0.14 | < 0.28 | < 0.30 | < 2.7 | < 1.6 | < 4.5 | < 1.7 | < 1.7 | < 1.3 | < 0.16 | < 0.21 | < 0.28 | |
| 3 | Final Effluent | 7/24/2020 | P1E | n/a | n/a | 104 | 79 | 22 | 0 | 2 | 0 | 10 | 32 | 25 | 4.4 | 11 | < 0.22 | < 0.25 | < 0.89 | < 0.45 | < 1.1 | < 0.23 | 7.8 | < 0.24 | 5.5 | < 0.15 | 5.8 | < 0.13 | < 0.26 | 2.1 | < 2.5 | < 1.5 | < 4.2 | < 1.6 | < 1.2 | < 0.15 | < 0.19 | < 0.26 | | |
| 3 | Raw Influent | 7/24/2020 | P1I | n/a | n/a | 59 | 33 | 26 | 0 | 0 | 0 | 5.8 | 8 | 8.5 | 2.4 | 5.2 | < 0.26 | < 0.26 | < 0.92 | < 0.46 | < 1.1 | < 0.24 | 8.3 | < 0.25 | 7.5 | < 0.16 | 13 | < 0.13 | < 0.27 | < 0.29 | < 2.6 | < 1.6 | < 4.4 | < 1.7 | < 1.7 | < 1.3 | < 0.15 | < 0.20 | < 0.27 | |
| 4 | Raw Influent | 8/10/2020 | P1I | n/a | n/a | 41 | 29 | 12 | 0 | 0 | 0 | 7.2 | 5.9 | 8.1 | 2.1 | 5 | < 0.24 | < 0.27 | < 0.97 | < 0.48 | < 1.1 | < 0.26 | 5.4 | < 0.26 | < 0.15 | < 0.17 | 7 | < 0.14 | < 0.28 | < 0.31 | < 2.7 | < 1.7 | < 4.6 | < 1.8 | < 1.8 | < 1.3 | < 0.16 | < 0.21 | < 0.28 | |
| 4 | Final Effluent | 8/10/2020 | P1E | n/a | n/a | 60 | 41 | 19 | 0 | 0 | 0 | 5.7 | 12 | 15 | 2.5 | 6.3 | < 0.24 | < 0.24 | < 0.99 | < 0.50 | < 1.2 | < 0.26 | 5.4 | < 0.27 | 2.9 | < 0.17 | 7.8 | < 0.14 | < 0.29 | < 0.32 | < 2.8 | < 1.7 | < 4.7 | < 1.8 | < 1.8 | < 1.4 | < 0.16 | < 0.22 | < 0.29 | |
| 5 | Raw Influent | 7/23/2020 | P1I | n/a | n/a | 0 | 0 | 0 | 0 | 0 | 0 | < 2.9 | < 4.1 | < 4.8 | < 2.1 | < 7.0 | < 0.22 | < 0.26 | < 0.91 | < 0.45 | < 1.1 | < 0.24 | < 1.7 | < 0.25 | < 1.4 | < 1.6 | < 4.5 | < 1.3 | < 2.6 | < 2.9 | < 2.6 | < 1.6 | < 4.3 | < 1.7 | < 1.7 | < 1.2 | < 0.15 | < 0.20 | < 0.26 | |
| 5 | Final Effluent | 7/23/2020 | P1E | n/a | n/a | 57 | 39 | 19 | 0 | 0 | 0 | < 2.9 | 13 | 23 | 2.8 | 7.6 | 1.6 | < 0.25 | < 0.90 | < 0.45 | < 1.1 | < 0.24 | < 1.6 | < 0.24 | 2.4 | < 0.15 | 7 | < 0.13 | < 0.26 | < 0.29 | < 2.5 | < 1.5 | < 4.2 | < 1.6 | < 1.6 | < 1.2 | < 0.15 | < 0.20 | < 0.26 | |
| 6 | Final Effluent | 6/18/2020 | P1E | n/a | n/a | 112 | 90 | 22 | 0 | 0 | 0 | < 5.0 | 14 | 61 | < 2.0 | 15 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | 15 | < 2.0 | < 2.0 | < 2.0 | 6.7 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 |
| 6 | Raw Influent | 6/18/2020 | P1I | n/a | n/a | 50 | 25 | 12 | 0 | 0 | 12 | < 4.9 | 7.5 | 8 | < 2.0 | 5.5 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | 6.8 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 |
| 7 | Final Effluent | 9/14/2020 | P1E | n/a | n/a | 195 | 155 | 29 | 11 | 0 | 0 | 5.1 | 30 | 39 | 5 | 11 | 4 | < 0.29 | < 1.0 | < 0.51 | < 1.2 | < 0.68 | 30 | < 0.28 | 4 | < 0.18 | 10 | < 0.34 | < 0.30 | < 0.91 | < 1.1 | < 1.2 | < 0.22 | 11 | < 0.43 | < 1.4 | < 0.37 | < 0.22 | < 0.30 | |
| 7 | Raw Influent | 9/14/2020 | P1I | n/a | n/a | 153 | 119 | 24 | 10 | 0 | 0 | 4.5 | 20 | 28 | 4 | 9.2 | 3 | < 0.29 | < 1.0 | < 0.51 | < 1.2 | < 0.67 | 22 | < 0.28 | 3.6 | < 0.18 | 8.4 | < 0.34 | < 0.30 | < 0.91 | < 1.1 | < 1.2 | < 0.22 | 10 | < 0.42 | < 1.4 | < 0.37 | < 0.22 | < 0.30 | |
| 8 | Raw Effluent | 12/2/2020 | P1I | 1 | n/a | 29 | 20 | 9 | 0 | 0 | 0 | < 4.5 | 6.5 | 11 | 2.3 | 3.9 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | 5.2 | < 1.8 | < 1.8 | < 1.8 | < 4.5 | < 4.5 | < 4.7 | < 7.3 | < 1.8 | < 3.6 | < 1.8 | < 1.8 | < 1.8 | |
| 8 | Primary Effluent | 12/2/2020 | P2 | 2 | n/a | 40 | 22 | 9 | 8 | 0 | 0 | < 4.5 | 6.8 | 11 | 2.5 | 4 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | 4.8 | < 1.8 | < 1.8 | < 1.8 | < 4.5 | < 4.5 | < 4.7 | 8.4 | < 1.8 | < 3.6 | < 1.8 | < 1.8 | < 1.8 | |
| 8 | Aeration Effluent | 12/2/2020 | P2 | 3 | n/a | 0 | 0 | 0 | 0 | 0 | 0 | < 500 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 |
| 8 | Secondary Effluent | 12/2/2020 | P2 | 4 | n/a | 72 | 72 | 0 | 0 | 0 | 0 | < 4.7 | 28 | 44 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 |
| 8 | Chlorinated Tertiary Effluent | 12/2/2020 | P1E | 5 | n/a | 101 | 85 | 16 | 0 | 0 | 0 | < 4.6 | 31 | 44 | 7.4 | 11 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 |
| 8 | Raw Effluent | 12/16 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Table 1
Aqueous PFAS Sample Results
2021 AECOM National Study

| Facility # | Sample ID | Sample Date | Task | PFD | TOP Analysis | Total PFAS | S-PFAAs | L-PFAAs | S-Prec | L-Prec | Repl. | PFBA | PFPeA | PFHxA | PFHpA | PFOA | PFNA | PFDA | PFUnDA | PFDoDA | PFTrDA | PFTeDA | PFBS | PFPeS | PFHxS | PFHpS | PFOS | PFNS | PFDS | FOSA | MeFOSAA | EtFOSAA | 4:2 FTSA | 6:2 FTSA | 8:2 FTSA | HFPO-DA | ADONA | F53B Min | F53B Maj | | |
|------------|--------------------------------|-------------|------|-----|--------------|------------|---------|---------|--------|--------|-------|-------|-------|-------|-------|------|-------|-------|--------|--------|--------|--------|-------|-------|-------|-------|-------|-------|-------|-------|---------|---------|----------|----------|----------|---------|-------|----------|----------|------|------|
| 11 | Bioreactors | 12/15/2020 | P2 | 3 | n/a | 81 | 47 | 15 | 20 | 0 | 0 | 5.2 | 13 | 22 | 2.8 | 5.8 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | 3.6 | <1.9 | 3.3 | <1.9 | 5.7 | <1.9 | <1.9 | <4.9 | 20 | <1.9 | <4.7 | <4.7 | <1.9 | <1.9 | <3.8 | <1.9 | |
| 11 | Raw Effluent | 12/15/2020 | P2I | 1 | Pre-TOP | 0 | 0 | 0 | 0 | 0 | 0 | <44 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <44 | <44 | <18 | <44 | <18 | <18 | <18 | <18 | <18 | <18 | |
| 11 | Raw Effluent | 12/15/2020 | P2IT | 1T | Post-TOP | 182 | 157 | 25 | 0 | 0 | 0 | 61 | 39 | 42 | 15 | 15 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | |
| 11 | Primary Effluent | 12/15/2020 | P2 | 2 | n/a | 17 | 17 | 0 | 0 | 0 | 0 | <43 | <17 | 17 | <17 | <17 | <17 | <17 | <17 | <17 | <17 | <17 | <17 | <17 | <17 | <17 | <17 | <17 | <17 | <17 | <17 | <17 | <17 | <17 | <17 | <17 | <17 | <17 | <17 | <17 | <17 |
| 11 | Secondary Effluent | 12/15/2020 | P2 | 4 | n/a | 84 | 46 | 18 | 20 | 0 | 0 | 6.3 | 12 | 20 | 3.4 | 6.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | |
| 11 | DAF Underflow | 12/15/2020 | P2 | 6 | n/a | 38 | 31 | 7 | 0 | 0 | 0 | <4.7 | 10 | 16 | <1.9 | 2.8 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 | <1.9 |
| 11 | Chlorinated Effluent | 12/15/2020 | P2E | 5 | Pre-TOP | 68 | 50 | 18 | 0 | 0 | 0 | 4.9 | 11 | 26 | 2.7 | 5.8 | <1.8 | <1.8 | <1.8 | <1.8 | <1.8 | <1.8 | <1.8 | <1.8 | <1.8 | 5.6 | <1.8 | 3.3 | <1.8 | 8.8 | <1.8 | <1.8 | <4.7 | <45 | <1.8 | <4.5 | <4.5 | <1.8 | <1.8 | <3.6 | <1.8 |
| 11 | Chlorinated Effluent | 12/15/2020 | P2ET | 5T | Post-TOP | 107 | 93 | 14 | 0 | 0 | 0 | 39 | 22 | 32 | <5.0 | 6.6 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | |
| 11 | Centrate | 12/15/2020 | P2 | 7 | n/a | 50 | 50 | 0 | 0 | 0 | 0 | <44 | <18 | 50 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | <18 | |
| 12 | Final Effluent | 10/26/2020 | P1E | n/a | n/a | 94 | 44 | 41 | 9 | 0 | 0 | <2.2 | 10 | 20 | 2.7 | 7.8 | 2.1 | <0.29 | <1.0 | <0.51 | <1.2 | <0.68 | 11 | <0.28 | 11 | <0.18 | 20 | <0.33 | <0.30 | <0.91 | <1.1 | <1.2 | <0.22 | 9 | <0.43 | <1.4 | <0.37 | <0.22 | <0.30 | | |
| 12 | Raw Influent | 10/25/2020 | P1I | n/a | n/a | 84 | 31 | 53 | 0 | 0 | 0 | 4.5 | 5.7 | 9 | 2.2 | 6.8 | 2.2 | <0.28 | <0.99 | <0.50 | <1.2 | <0.66 | 10 | <0.27 | 14 | <0.17 | 30 | <0.33 | <0.29 | <0.89 | <1.1 | <1.2 | <0.22 | <2.3 | <0.42 | <1.4 | <0.36 | <0.22 | <0.29 | | |
| 13 | Raw Influent | 6/30/2021 | P2I | 1 | n/a | 7 | 7 | 0 | 0 | 0 | 0 | <12 | <2.5 | 6.7 | <1.3 | <4.3 | <1.4 | <1.6 | <5.5 | <2.8 | <6.5 | <3.7 | <1.0 | <1.5 | <2.9 | <0.95 | <2.7 | <1.9 | <1.6 | <4.9 | <6.0 | <6.5 | <1.2 | <13 | <2.3 | <1.4 | <0.37 | <0.22 | <0.30 | | |
| 13 | SBR Effluent | 6/30/2021 | P2 | 2 | n/a | 44 | 29 | 11 | 0 | 4 | 0 | <2.2 | 20 | 9.3 | <0.23 | 8.6 | <0.25 | 2.2 | <1.0 | <0.51 | <1.2 | <0.68 | <0.19 | <0.28 | <0.53 | <0.18 | <0.50 | <0.35 | <0.30 | 2.5 | 1.2 | <1.2 | <0.22 | <2.3 | <0.43 | <1.4 | <0.37 | <0.22 | <0.30 | | |
| 13 | Disc Filter Effluent | 6/30/2021 | P2 | 3 | n/a | 40 | 29 | 9 | 0 | 2 | 0 | <2.2 | 20 | 8.8 | <0.23 | 7.7 | 0.51 | 1.2 | <1.0 | <0.51 | <1.2 | <0.68 | <4.0 | <0.28 | <0.53 | <0.18 | <0.50 | <0.34 | <0.30 | 1.9 | <1.1 | <1.2 | <0.22 | <2.3 | <0.43 | <1.4 | <0.37 | <0.22 | <0.30 | | |
| 13 | Final Effluent | 6/30/2021 | P2E | 4 | n/a | 44 | 35 | 9 | 0 | 0 | 0 | <23 | 24 | 11 | <2.4 | 9.2 | <2.6 | <3.0 | <1.0 | <5.2 | <1.2 | <6.9 | <1.9 | <2.9 | <5.4 | <1.8 | <5.1 | <3.5 | <3.0 | <9.3 | <11 | <12 | <2.3 | <2.4 | <4.4 | <1.4 | <3.8 | <2.3 | <3.0 | | |
| 13 | WAS | 6/30/2021 | P2 | 5 | n/a | 0 | 0 | 0 | 0 | 0 | 0 | <60 | <12 | <15 | <6.3 | <21 | <6.8 | <7.8 | <28 | <14 | <33 | <18 | <5.0 | <7.5 | <14 | <4.8 | <14 | <9.3 | <8.0 | <25 | <30 | <33 | <6.0 | <6.3 | <12 | <38 | <10 | <6.0 | <8.0 | | |
| 13 | Rotary Drum Thickener Influent | 6/30/2021 | P2 | 6 | n/a | 86 | 58 | 28 | 0 | 0 | 0 | <60 | 40 | 18 | <6.3 | 28 | <6.8 | <7.8 | <28 | <14 | <33 | <18 | <5.0 | <7.5 | <14 | <4.8 | <14 | <9.3 | <8.0 | <25 | <30 | <33 | <6.0 | <6.3 | <12 | <38 | <10 | <6.0 | <8.0 | | |
| 13 | Thickened Sludge | 6/30/2021 | P2 | 7 | n/a | 45 | 45 | 0 | 0 | 0 | 0 | <120 | <25 | 45 | <13 | <43 | <14 | <16 | <55 | <28 | <65 | <37 | <10 | <15 | <29 | <9.5 | <27 | <19 | <16 | <49 | <60 | <65 | <12 | <130 | <23 | <75 | <20 | <12 | <16 | | |
| 13 | Filtrate | 6/30/2021 | P2 | 8 | n/a | 69 | 55 | 14 | 0 | 0 | 0 | <24 | 36 | 17 | <2.5 | 14 | <2.7 | <3.1 | <11 | <5.5 | <13 | <7.3 | <2.1 | <3.0 | <2.9 | <1.9 | <5.4 | <3.7 | <3.2 | <9.8 | <12 | <13 | <2.4 | <25 | <4.6 | <15 | <4.0 | <2.4 | <3.2 | | |
| 13 | Disc Filter Backwash | 6/30/2021 | P2 | 9 | n/a | 42 | 31 | 11 | 0 | 0 | 0 | <24 | 20 | 11 | <2.5 | 11 | <2.7 | <3.1 | <11 | <5.5 | <13 | <7.3 | <2.0 | <3.0 | <5.7 | <1.9 | <5.4 | <3.7 | <3.2 | <9.8 | <12 | <13 | <2.4 | <25 | <4.6 | <15 | <4.0 | <2.4 | <3.2 | | |
| 13 | Final Effluent | 7/29/2020 | P1E | n/a | n/a | 25 | 14 | 11 | 0 | 0 | 0 | <0.30 | 5.5 | 8.9 | <0.21 | 9.1 | <0.23 | 1.7 | <0.93 | <0.47 | <1.1 | <0.25 | <2.7 | <0.25 | <0.14 | <0.16 | <0.46 | <0.14 | <0.27 | <0.30 | <2.6 | <1.6 | <4.4 | <1.7 | <1.7 | <1.3 | <0.15 | <0.20 | <0.27 | | |
| 13 | Raw Influent | 7/29/2020 | P1I | n/a | n/a | 7 | 4 | 3 | 0 | 0 | 0 | <0.30 | <0.42 | 3.8 | <0.21 | 2.9 | <0.23 | <0.26 | <0.93 | <0.47 | <1.1 | <0.25 | <0.17 | <4.9 | <0.14 | <0.16 | <4.7 | <0.14 | <4.2 | <0.30 | <2.6 | <1.6 | <4.4 | <1.7 | <1.7 | <1.3 | <0.15 | <0.20 | <0.27 | | |
| 14 | Influent | 3/16/2021 | P2I | 1 | n/a | 519 | 120 | 314 | 83 | 3 | 0 | 6.2 | 52 | 32 | 8.4 | 19 | 1.8 | <0.27 | <0.96 | <0.48 | <1.1 | <0.64 | 14 | 6.9 | 50 | 3 | 240 | <0.32 | <0.28 | <0.86 | <1.0 | <1.1 | <0.21 | 83 | 2.9 | <1.3 | <0.35 | <0.21 | <0.28 | | |
| 14 | Anoxic Zone | 3/16/2021 | P2 | 2 | n/a | 3,877 | 754 | 312 | 2,800 | 12 | 0 | 28 | 400 | 270 | 33 | 68 | 2.9 | 6.9 | <0.94 | <0.47 | <1.1 | <0.63 | 14 | 8.6 | 60 | 4.1 | 170 | <0.32 | <0.27 | 6.8 | <1.0 | <1.1 | <0.21 | 2800 | 5 | <1.3 | <0.34 | <0.21 | <0.27 | | |
| 14 | Aerobic Zone | 3/16/2021 | P2 | 3 | n/a | 3,544 | 858 | 282 | 2,400 | 4 | 0 | 24 | 510 | 270 | 33 | 70 | 2.9 | 5.9 | <5.5 | <2.8 | <6.5 | <3.7 | 14 | 7.4 | 59 | 4.2 | 140 | <1.9 | <1.6 | <4.9 | <6.0 | <3.3 | <1.2 | 2400 | 3.6 | <7.5 | <2.0 | <1.2 | <1.6 | | |
| 14 | Secondary Clarifier Effluent | 3/16/2021 | P2 | 4 | n/a | 3,352 | 630 | 322 | 2,400 | 0 | 0 | 14 | 350 | 210 | 29 | 36 | 3 | <0.92 | <0.46 | <1.1 | <0.61 | 19 | 7.9 | 74 | 5.6 | 200 | <0.31 | <0.27 | <0.82 | <1.0 | <1.1 | <0.20 | 2400 | <0.38 | <1.2 | <0.36 | <0.20 | <0.27 | | | |
| 14 | Disc Filter Effluent | 3/16/2021 | P2 | 5 | n/a | 3,446 | 614 | 332 | 2,500 | 0 | 0 | 13 | 350 | 200 | 23 | 37 | 2.8 | 2.7 | <5.5 | <2.8 | <6.5 | <3.7 | 19 | 8.8 | 74 | 5.3 | 210 | <1.9 | <1.6 | <4.9 | <6.0 | <3.3 | <1.2 | 2500 | <2.3 | <7.5 | <2.0 | <1.2 | <1.6 | | |
| 14 | Final Effluent | 3/16/2021 | P2E | 6 | n/a | 3,368 | 629 | 336 | 2,400 | 2 | 0 | 17 | 360 | 200 | 21 | 36 | 2.3 | 2.4 | <5.5 | <2.8 | <6.5 | <3.7 | 21 | 10 | 80 | 5.6 | 210 | <1.9 | <1.6 | <4.9 | <6.0 | <3.3 | <1.2 | 2400 | 2.2 | <7.5 | <2.0 | <1.2 | <1.6 | | |
| 14 | WAS | 3/16/2021 | P2 | 7 | n/a | 3,475 | 666 | 296 | 2,500 | 14 | 0 | 23 | 360 | 230 | 31 | 63 | 3.3 | 9.5 | <0.94 | <0.47 | <1.1 | <0.63 | 14 | 7.5 | 55 | 4.9 | 160 | <0.32 | <0.27 | 8.8 | <1.0 | <1.1 | <0.21 | 2500 | 4.7 | <1.3 | <0.34 | <0.21 | <0.27 | | |
| 14 | Aerated Sludge Tank Effluent | 3/16/2021 | P2 | 8 | n/a | 9,635 | 7,967 | 356 | 1,300 | 12 | 0 | 82 | 6100 | 1300 | 380 | 110 | | | | | | | | | | | | | | | | | | | | | | | | | |

Table 2
Solids PFAS Sample Results
2021 AECOM National Study

| Facility # | Sample ID | Sample Date | Task | PFD | TOP Analysis | Total PFAS | S-PFAAs | L-PFAAs | S-Prec | L-Prec | Repl. | PFBA | PFPeA | PFHxA | PFHpA | PFOA | PFNA | PFDA | PFUnDA | PFDoDA | PFTrDA | PFTeDA | PFBS | PFPeS | PFHxS | PFHpS | PFOS | PFNS | PFDS | FOSA | MeFOSAA | EtFOSAA | 4:2 FTSA | 6:2 FTSA | 8:2 FTSA | HFPO-DA | ADONA | F53B Min | F53B Maj | | |
|------------|-----------------|-------------|------|-----|--------------|------------|---------|---------|--------|--------|-------|--------|--------|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|---------|---------|----------|----------|----------|---------|---------|----------|----------|--------|--------|
| 1 | Cake | 9/2/2020 | P1 | n/a | n/a | 37 | 12 | 25 | 0 | 0 | 0 | 4.1 | 4.4 | 3.4 | < 0.46 | 3.8 | < 0.57 | 7.8 | < 0.57 | < 1.1 | < 0.81 | < 0.85 | < 0.40 | < 0.32 | 3.6 | < 0.55 | 9.8 | < 0.32 | < 0.62 | < 1.3 | < 6.2 | < 5.9 | < 5.9 | < 2.4 | < 4.0 | < 1.7 | < 0.28 | < 0.43 | < 0.35 | | |
| 2 | Cake | 7/23/2020 | P1 | n/a | n/a | 204 | 8 | 151 | 0 | 44 | 0 | < 6.0 | 2.1 | 4.3 | < 0.14 | 10 | 1.1 | 15 | 1.6 | 5.6 | < 0.25 | < 1.2 | 1.6 | < 0.10 | 1.5 | 4.5 | 110 | < 0.10 | 2.1 | 4.4 | 28 | 12 | < 1.8 | < 0.75 | < 1.2 | < 0.55 | < 0.090 | < 0.13 | < 0.11 | | |
| 2 | Cake | 6/9/2021 | P2 | 3 | n/a | 104 | 6 | 78 | 0 | 21 | 0 | 0.33 | 2.4 | 1.6 | 0.31 | 4.8 | 0.57 | 5.9 | 0.71 | 1.6 | < 0.29 | 0.4 | 1.3 | < 0.11 | 0.41 | 4.3 | 59 | < 0.10 | 0.34 | 2.1 | 13 | 5.4 | < 2.1 | < 0.86 | < 1.4 | < 0.63 | < 0.10 | < 0.15 | < 0.13 | | |
| 2 | WAS Solids | 6/9/2021 | P2 | 2 | n/a | 188 | 38 | 150 | 0 | 0 | 0 | < 1.6 | 2.4 | 10 | < 1.6 | 7.8 | < 2.0 | 7.4 | < 2.0 | < 3.8 | < 2.9 | < 3.1 | 3.6 | < 1.1 | < 1.8 | 6.3 | 72 | < 1.1 | < 2.2 | < 4.7 | < 2.2 | < 2.1 | < 2.1 | < 8.5 | < 1.4 | < 6.3 | < 1.0 | < 1.5 | < 1.3 | | |
| 2 | Primary Sludge | 6/9/2021 | P2 | 1 | n/a | 28 | 2 | 26 | 0 | 0 | 0 | < 0.38 | < 1.1 | 1.8 | < 0.40 | < 1.2 | < 0.49 | 1.1 | < 0.49 | < 0.92 | < 0.70 | < 0.74 | < 0.34 | < 0.27 | 0.47 | 2.9 | 22 | < 0.27 | < 0.53 | < 1.1 | < 5.3 | < 5.1 | < 5.1 | < 2.1 | < 3.4 | < 1.5 | < 0.25 | < 0.37 | < 0.30 | | |
| 3 | Cake | 7/23/2020 | P1 | n/a | n/a | 145 | 10 | 89 | 0 | 46 | 0 | 1.9 | 3.7 | 4.6 | < 0.16 | 9.6 | 3.6 | 19 | 1.6 | 3.8 | < 0.28 | < 1.4 | < 0.14 | < 0.11 | < 4.5 | < 0.20 | 51 | < 0.11 | < 0.22 | 1.8 | 32 | 12 | < 2.1 | < 0.84 | < 1.4 | < 0.61 | < 0.10 | < 0.15 | < 0.12 | | |
| 4 | Cake | 8/11/2020 | P1 | n/a | n/a | 0 | 0 | 0 | 0 | 0 | 0 | < 0.85 | < 2.3 | < 1.3 | < 0.88 | < 2.6 | < 1.1 | < 0.67 | < 1.1 | < 2.0 | < 1.6 | < 1.6 | < 0.76 | < 0.61 | < 0.94 | < 1.1 | < 6.1 | < 0.61 | < 1.2 | < 2.5 | < 12 | < 11 | < 11 | < 4.6 | < 7.6 | < 3.3 | < 0.55 | < 0.82 | < 0.67 | | |
| 5 | Cake | 7/23/2020 | P1 | n/a | n/a | 70 | 3 | 40 | 0 | 27 | 0 | 1.1 | < 0.44 | 1.6 | < 0.17 | < 0.49 | 1.5 | 4.6 | 3.3 | 3.9 | < 0.29 | < 2.6 | < 0.14 | < 0.11 | 3.5 | < 0.20 | 22 | < 0.11 | 1.2 | 3.4 | 24 | < 2.1 | < 2.1 | < 0.86 | < 1.4 | < 0.63 | < 0.10 | < 0.15 | < 0.13 | | |
| 6 | Cake | 6/19/2020 | P1 | n/a | n/a | 50 | 2 | 26 | 0 | 23 | 0 | < 8.1 | < 2.4 | 1.8 | < 2.4 | 1.7 | 2.3 | 4 | 1.4 | 2.2 | < 2.4 | < 2.4 | < 1.9 | < 2.4 | < 2.4 | < 2.4 | 8.8 | < 2.4 | 5.2 | 1.3 | 12 | 9.7 | < 8.1 | < 8.1 | < 1.4 | < 12 | < 8.1 | < 12 | < 8.1 | < 2.4 | |
| 7 | Cake | 9/15/2020 | P1 | n/a | n/a | 55 | 24 | 31 | 0 | 0 | 0 | 4.2 | 11 | 6.7 | < 0.27 | < 0.81 | 3.1 | 3 | 2.8 | 2.1 | < 0.48 | < 0.51 | < 1.9 | < 0.19 | < 0.14 | < 0.33 | 20 | < 0.19 | < 0.37 | < 0.78 | < 3.7 | < 3.5 | < 3.5 | < 1.4 | < 2.4 | < 1.0 | < 0.080 | < 0.26 | < 0.21 | | |
| 8 | Primary Sludge | 12/16/2020 | P2 | 1 | n/a | 0 | 0 | 0 | 0 | 0 | 0 | < 41 | < 41 | < 41 | < 41 | < 41 | < 41 | < 41 | < 41 | < 41 | < 41 | < 41 | < 41 | < 41 | < 41 | < 41 | < 100 | < 41 | < 41 | < 41 | < 410 | < 410 | < 410 | < 410 | < 410 | < 410 | < 410 | < 410 | < 410 | < 410 | < 410 |
| 8 | RAS Solids | 12/16/2020 | P2 | 2 | n/a | 67 | 18 | 49 | 0 | 0 | 0 | < 10 | < 10 | 18 | < 10 | < 10 | 13 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | 36 | < 10 | < 10 | < 100 | < 100 | < 100 | < 100 | < 100 | < 100 | < 100 | < 100 | < 100 | < 100 | < 100 | < 100 |
| 8 | Primary Sludge | 12/2/2020 | P1 | 1 | n/a | 0 | 0 | 0 | 0 | 0 | 0 | < 29 | < 29 | < 29 | < 29 | < 29 | < 29 | < 29 | < 29 | < 29 | < 29 | < 29 | < 29 | < 29 | < 29 | < 29 | < 29 | < 29 | < 29 | < 290 | < 290 | < 290 | < 290 | < 290 | < 290 | < 290 | < 290 | < 290 | < 290 | < 290 | < 290 |
| 8 | RAS Solids | 12/2/2020 | P1 | 2 | n/a | 19 | 19 | 0 | 0 | 0 | 0 | < 13 | < 13 | 19 | < 13 | < 13 | < 13 | < 13 | < 13 | < 13 | < 13 | < 13 | < 13 | < 13 | < 13 | < 13 | < 13 | < 13 | < 130 | < 130 | < 130 | < 130 | < 130 | < 130 | < 130 | < 130 | < 130 | < 130 | < 130 | < 130 | < 130 |
| 9 | Primary Sludge | 12/2/2020 | P1 | 1 | n/a | 0 | 0 | 0 | 0 | 0 | 0 | < 18 | < 18 | < 18 | < 18 | < 18 | < 18 | < 18 | < 18 | < 18 | < 18 | < 18 | < 18 | < 18 | < 18 | < 18 | < 18 | < 18 | < 180 | < 180 | < 180 | < 180 | < 180 | < 180 | < 180 | < 180 | < 180 | < 180 | < 180 | < 180 | |
| 9 | RAS Solids | 12/2/2020 | P1 | 2 | n/a | 0 | 0 | 0 | 0 | 0 | 0 | < 85 | < 85 | < 85 | < 85 | < 85 | < 85 | < 85 | < 85 | < 85 | < 85 | < 85 | < 85 | < 85 | < 85 | < 85 | < 85 | < 210 | < 85 | < 85 | < 85 | < 850 | < 850 | < 850 | < 850 | < 850 | < 850 | < 850 | < 850 | < 850 | < 850 |
| 9 | Primary Sludge | 12/16/2020 | P2 | 1 | n/a | 0 | 0 | 0 | 0 | 0 | 0 | < 11 | < 11 | < 11 | < 11 | < 11 | < 11 | < 11 | < 11 | < 11 | < 11 | < 11 | < 11 | < 11 | < 11 | < 11 | < 26 | < 11 | < 11 | < 110 | < 110 | < 110 | < 110 | < 110 | < 110 | < 110 | < 110 | < 110 | < 110 | < 110 | |
| 9 | RAS Solids | 12/16/2020 | P2 | 2 | n/a | 0 | 0 | 0 | 0 | 0 | 0 | < 20 | < 20 | < 20 | < 20 | < 20 | < 20 | < 20 | < 20 | < 20 | < 20 | < 20 | < 20 | < 20 | < 20 | < 20 | < 49 | < 20 | < 20 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 |
| 10 | Primary Sludge | 12/2/2020 | P1 | 1 | n/a | 0 | 0 | 0 | 0 | 0 | 0 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 500 | < 200 | < 200 | < 2000 | < 2000 | < 2000 | < 2000 | < 2000 | < 2000 | < 2000 | < 2000 | < 2000 | < 2000 | < 2000 | < 2000 |
| 10 | RAS Solids | 12/2/2020 | P1 | 2 | n/a | 0 | 0 | 0 | 0 | 0 | 0 | < 20 | < 20 | < 20 | < 20 | < 20 | < 20 | < 20 | < 20 | < 20 | < 20 | < 20 | < 20 | < 20 | < 20 | < 20 | < 49 | < 20 | < 20 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 | < 200 |
| 10 | Primary Sludge | 12/16/2020 | P2 | 1 | n/a | 46 | 15 | 31 | 0 | 0 | 0 | 15 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 31 | < 10 | < 10 | < 100 | < 100 | < 100 | < 100 | < 100 | < 100 | < 100 | < 100 | < 100 | < 100 | < 100 | < 100 |
| 10 | RAS Solids | 12/16/2020 | P2 | 2 | n/a | 0 | 0 | 0 | 0 | 0 | 0 | < 30 | < 30 | < 30 | < 30 | < 30 | < 30 | < 30 | < 30 | < 30 | < 30 | < 30 | < 30 | < 30 | < 30 | < 30 | < 30 | < 30 | < 300 | < 300 | < 300 | < 300 | < 300 | < 300 | < 300 | < 300 | < 300 | < 300 | < 300 | < 300 | < 300 |
| 11 | RAS Solids | 12/1/2020 | P1 | 2 | n/a | 53 | 0 | 53 | 0 | 0 | 0 | < 18 | < 18 | < 18 | < 18 | < 18 | < 18 | < 18 | < 18 | < 18 | < 18 | < 18 | < 18 | < 18 | < 18 | < 18 | < 56 | < 18 | < 180 | < 180 | < 180 | < 180 | < 180 | < 180 | < 180 | < 180 | < 180 | < 180 | < 180 | < 180 | < 180 |
| 11 | Raw Sludge | 12/1/2020 | P1 | 1 | n/a | 60 | 0 | 60 | 0 | 0 | 0 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 | < 7.8 |
| 11 | DAF TWAS | 12/1/2020 | P1 | 3 | n/a | 59 | 7 | 52 | 0 | 0 | 0 | < 3.8 | < 3.8 | 7.2 | < 3.8 | < 3.8 | 3.8 | < 3.8 | < 3.8 | < 3.8 | < 3.8 | < 3.8 | < 3.8 | < 3.8 | < 3.8 | < 3.8 | < 3.8 | < 3.8 | < 3.8 | < 3.8 | < 3.8 | < 3.8 | < 3.8 | < 3.8 | < 3.8 | < 3.8 | < 3.8 | < 3.8 | < 3.8 | < 3.8 | < 3.8 |
| 11 | Digester Sludge | 12/1/2020 | P1 | 4 | n/a | 57 | 10 | 47 | 0 | 0 | 0 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 100 | < 100 | < 100 | < 100 | < 100 | < 100 | < 100 | < 100 | < 100 | < 100 | < 100 | < 100 | < 100 |
| 11 | Cake Silo | 12/1/2020 | P1 | 5 | Pre-TOP | 34 | 4 | 22 | 0 | 8 | 0 | < 0.70 | < 0.70 | 4.2 | < 0.70 | 1 | < 0.70 | 3 | 1 | 1.9 | < 0.70 | < 0.70 | < 0.70 | < 0.70 | < 0.70 | 15 | < 0.70 | < 0.70 | < 0.70 | 7.8 | < 7.0 | < 7.0 | < 7.0 | < 7.0 | < 0.88 | < 0.70 | < 0.70 | < 0.70 | < 0.70 | | |
| 11 | Cake Silo | 12/1/2020 | P1 | 5T | Post-TOP | 228 | 208 | 20 | 0 | 0 | 0 | 120 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |



Appendix A

PFAS Analyte List

PFAS Analyte List

| # | PFAS Name | Acronym | CAS # | (Carbon #) Chain Length |
|--|--|------------|-------------|----------------------------|
| Perfluoroalkyl carboxylic acids (PFCAs) | | | | |
| 1 | Perfluorobutanoic Acid | PFBA | 375-22-4 | (4) Short-chain |
| 2 | Perfluoropentanoic Acid | PFPeA | 2706-90-3 | (5) Short-chain |
| 3 | Perfluorohexanoic Acid | PFHxA | 307-24-4 | (6) Short-chain |
| 4 | Perfluoroheptanoic Acid | PFHpA | 375-85-9 | (7) Short-chain |
| 5 | Perfluorooctanoic Acid | PFOA | 335-67-1 | (8) Long-chain |
| 6 | Perfluorononanoic Acid | PFNA | 375-95-1 | (9) Long-chain |
| 7 | Perfluorodecanoic Acid | PFDA | 335-76-2 | (10) Long-chain |
| 8 | Perfluoroundecanoic Acid | PFUnDA | 2058-94-8 | (11) Long-chain |
| 9 | Perfluorododecanoic Acid | PFDoDA | 307-55-1 | (12) Long-chain |
| 10 | Perfluorotridecanoic Acid | PFTTrDA | 72629-94-8 | (13) Long-chain |
| 11 | Perfluorotetradecanoic Acid | PFTeDA | 376-06-7 | (14) Long-chain |
| Perfluoroalkane sulfonic acids (PFSAs) | | | | |
| 12 | Perfluorobutane Sulfonic acid | PFBS | 375-73-5 | (4) Short-chain |
| 13 | Perfluoropentanesulfonic acid | PFPeS | 2706-91-4 | (5) Short-chain |
| 14 | Perfluorohexane Sulfonic acid | PFHxS | 355-46-4 | (6) Long-chain |
| 15 | Perfluoroheptane Sulfonic acid | PFHpS | 375-92-8 | (7) Long-chain |
| 16 | Perfluorooctane Sulfonic acid | PFOS | 1763-23-1 | (8) Long-chain |
| 17 | Perfluorononanesulfonic acid | PFNS | 68259-12-1 | (9) Long-chain |
| 18 | Perfluorodecane Sulfonic acid | PFDS | 335-77-3 | (10) Long-chain |
| Precursors to PFOS | | | | |
| 19 | Perfluorooctane sulfonamide ¹ | FOSA | 754-91-6 | (8) Long-chain |
| 20 | N-methylperfluorooctanesulfonamidoacetic acid ² | MeFOSAA | 2355-31-9 | (8) Long-chain |
| 21 | N-ethylperfluorooctanesulfonamidoacetic acid ³ | EtFOSAA | 2991-50-6 | (8) Long-chain |
| Precursors to PFCA Family | | | | |
| 22 | 4:2 Fluorotelomer Sulfonic Acid ⁴ | 4:2 FTS | 757124-72-4 | (6) Short-chain |
| 23 | 6:2 Fluorotelomer sulfonic acid ⁴ | 6:2 FTSA | 27619-97-2 | (8) Long-chain |
| 24 | 8:2 Fluorotelomer sulfonic acid ⁴ | 8:2 FTSA | 39108-34-4 | (10) Long-chain |
| PFAS Replacement Chemistry | | | | |
| 25 | Hexafluoropropylene Oxide Dimer Acid | HFPO-DA | 13252-13-6 | (6) Short-chain |
| 26 | 4,8-Dioxa-3H-perfluorononanoic acid | ADONA | 919005-14-4 | (7) Short-chain |
| 27 | 9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid | F53B Minor | 756426-58-1 | (8) Long-chain |
| 28 | 11-Chloroeicosafuoro-3-oxaundecane-1-sulfonic acid | F53B Major | 763051-92-9 | (10) Long-chain |

¹FOSA is part of Perfluoroalkane Sulfonamides (FASAs) PFAS family:

²MeFOSAA is part of N-Methyl Perfluoroalkane Sulfonamidoacetic Acids (MeFASAs) PFAS family.

³EtFOSAA is part of N-Ethyl Perfluoroalkane Sulfonamidoacetic Acids (EtFASAs) PFAS family.

⁴4:2 FTSA, 6:2 FTSA, and 8:2 FTSA are part of (n:2) Fluorotelomer Sulfonic Acids (FTSAs) PFAS family.



Appendix B

**WWTP Summary
Information 2021
AECOM National
Study**

**WWTP Summary Information
2021 AECOM National Study**

| Facility Information | | | | | Liquid Process Flow | | | | | Solid Process Flow | | | | |
|----------------------|-------|------------------------------------|-----------------|-----------------------------------|-----------------------------------|--|-----------------------|---|-------------------|--|--|--|--|--|
| Facility # | State | Solids Retention Time (SRT) (days) | WWTP Flow (MGD) | Wastewater Sources | Primary Treatment | Secondary Treatment | Secondary Type | Tertiary Treatment | Disinfection Type | Preliminary Operations | Thickening | Stabilization | Dewatering | Disposal |
| 1 | MA | - | 8 | Commercial Residential | Screen, Grit, Settling Clarifiers | Anaerobic Selector Basin, Oxidation, Settling Clarifiers | BNR | - | Ultra Violet | Screening | Gravity | Composting | Belt-Filter Press | Landfill |
| 2 | OH | 13 | 10 | Industrial Commercial Residential | Screen, Grit, Settling Clarifiers | Extended Aeration, Anoxic/Aerobic Stages, Settling Clarifiers | BNR | - | Ultra Violet | Storage | - | Aerobic Digestion | Centrifuge | Landfill, Thermophilic Digester Facility |
| 3 | OH | 8 | 6 | Industrial Commercial Residential | Screen, Grit | Anoxic/Aerobic Stages, Settling Clarifiers | BNR | - | Ultra Violet | Storage | - | Aerobic Digestion | Centrifuge | Landfill, Thermophilic Digester Facility |
| 4 | PA | 10 | 206 | Industrial Commercial Residential | Screen, Grit, Settling Clarifiers | Conventional Aeration, Settling Clarifiers | Conventional Aeration | - | Chlorination | Grinding, Storage | - | Alkaline | Centrifuge | Landfill, Incineration, Land Application |
| 5 | PA | - | 25 | Commercial Residential | Screen, Grit, Settling Clarifiers | HPO aeration, "Ludzack-Ettinger-Wuhrmann" Process, RAS Regen, secondary clarifiers | BNR | Chemically Enhanced Primary/Secondary Treatment | Chlorination | Storage | Gravity | Anaerobic Digestion | Belt-Filter Press | Sludge Disposal Facility |
| 6 | PA | - | 11 | Residential | Screen, Grit, Settling Clarifiers | Conventional Aeration, Settling Clarifiers | Conventional Aeration | Trickling Filters, Final Clarifiers | Chlorination | Storage | Gravity Belth Thickeners | Anaerobic Digestion | Centrifuge | Land Application |
| 7 | PA | - | 32 | Industrial Commercial Residential | Screen, Grit, Settling Clarifiers | Plastic Media Trickling Filters/Settling Clarifiers | Trickling Filters | Fixed Nozzle Recok Media/Settling Clarifiers | Chlorination | Storage | Gravity | Anaerobic Digestion | Belt-Filter Press | Landfill, Land Application |
| 8 | CA | - | 6 | Industrial Residential | Screen, Grit, Settling Clarifiers | Activated Sludge Aeration with Nitrogen Removal | Conventional Aeration | Dual-Media Pressure Filtraion - Chlorination | Chloramination | To other WWTF for Thickening + Digestion | To other WWTF for Thickening + Digestion | To other WWTF for Thickening + Digestion | To other WWTF for Thickening + Digestion | To other WWTF for Thickening + Digestion |
| 9 | CA | - | 37 | Industrial Residential | Settling Clarifiers | Activated Sludge Aeration with NDH Process | Conventional Aeration | Insert Media Gravity Filtration + Chlorination | Chloramination | Trunk Sewer for Processing at Other WWTF | Trunk Sewer for Processing at Other WWTF | Trunk Sewer for Processing at Other WWTF | Trunk Sewer for Processing at Other WWTF | Trunk Sewer for Processing at Other WWTF |
| 10 | CA | - | 22 | Industrial Residential | Settling Clarifiers | Activated Sludge Aeration with NDH Process | Conventional Aeration | Insert Media Gravity Filtration + Chlorination | Chloramination | Trunk Sewer for Processing at Other WWTF | Trunk Sewer for Processing at Other WWTF | Trunk Sewer for Processing at Other WWTF | Trunk Sewer for Processing at Other WWTF | Trunk Sewer for Processing at Other WWTF |
| 11 | CA | - | 275 | Industrial Residential | Screen, Grit, Settling Clarifiers | Secondary Influent Forebay + Pump Station + Bioreactors | Bioreactors | - | Chlorination | Storage | Dissolved Air Flotation Thickening | Anaerobic Digestion | Centrifuge | Landfill, Composting, Land Application |
| 12 | UT | 6 | 33 | Industrial Commercial Residential | Screen, Grit, Settling Clarifiers | Trickling Filter / Activated Sludge | Trickling Filters | - | Chlorination | Screening | Gravity, Rotary-Drum | Anaerobic Digestion | Belt-Filter Press | Landfill, Land Application |
| 13 | MA | 12 | 0.4 | Commercial Residential | Screen, Grit, Flow Equalization | SBR | SBR | Cloth Media Filter | Ultra Violet | Storage | Rotary-Drum | - | - | Pumped to Incineration Facility |
| 14 | SC | 30 | 3 | Industrial Commercial Residential | Screen, Grit | Extended Aeration, Anoxic/Aerobic Stages, Settling Clarifiers | BNR | Cloth Media Filter | Ultra Violet | - | - | Aerobic Digestion | Belt-Filter Press | Landfill |
| 15 | SC | 30 | 6 | Industrial Commercial Residential | Screen, Grit | Extended Aeration, Anoxic/Aerobic Stages, Settling Clarifiers | BNR | Cloth Media Filter | Ultra Violet | - | - | Aerobic Digestion | Belt-Filter Press | Landfill |
| 16 | SC | 8-12 | 5 | Industrial Commercial Residential | Screen, Grit | Conventional Aeration, Settling Clarifiers | Conventional Aeration | Settling Clarifiers | Chlorination | Storage | - | Aerobic Digestion | Centrifuge | Landfill |
| 17 | DE | - | 16 | Industrial Commercial Residential | screen, grit | extended aeration lagoon | Conventional Aeration | Denitrification | Ultra Violet | Storage | - | Alkaline | Belt-Filter Press / Dryer | Land Application |
| 18 | CO | - | 20 | Industrial Commercial Residential | Screen, Grit, Settling Clarifiers | Secondary Settling, SCT Tanks | SCT | Nitrifying Trickling Filters, Denitrification Filters | Chlorination | - | Dissolved Air Flotation Thickening | Aerobic Digestion | Centrifuge | Land Application |
| 19 | CO | - | 5 | Residential | Screen, Settling Clarifiers | Johannesburg configuration - Anaerobic/Anoxic/Aerobic | BNR | Sand Filter | Ultra Violet | - | - | - | - | - |



Appendix C

Power Point Presentation
on AECOM's Findings
on the Presence & Fate
of PFAS in Wastewater
Treatment Plants



IDENTIFY. RESOLVE.

AECOM's Findings on the Presence & Fate of PFAS in Wastewater Treatment Plants

Rosa Gwinn, Ph.D., P.G.
PFAS Global Technical Lead

Christopher Curran, P.E.
PFAS Lead, Water Business Line

Dorin Bogdan, Ph.D.
PFAS Technical Lead

Zachary Keegan, PE,
Project Manager

Safety Moment – Fall Driving Safety

- Leaves:
 - Allow greater stopping distance / right turn time
 - Landscapers near roadways
 - Never drive through leaf piles
- Adjust for Fewer Hours of Daylight:
 - Children playing in the dark
 - Joggers, evening walkers
- Sun Glare/Frost:
 - Allow greater stopping distance
 - Sunglasses in your vehicle
 - Clean inside of windshield
 - Replace wiper blades



Uses of PFAS in the Industries



AUTOMOTIVE



FIRST
RESPONDERS



OIL & GAS



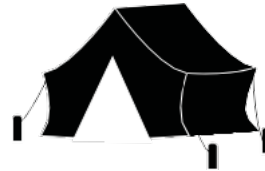
MILITARY



CHEMICAL/
PHARMACEUTICAL
MANUFACTURING



ELECTRONICS



OUTDOOR
APPAREL/
EQUIPMENT



HEALTHCARE



AEROSPACE/
DEFENSE



ALTERNATIVE
ENERGY

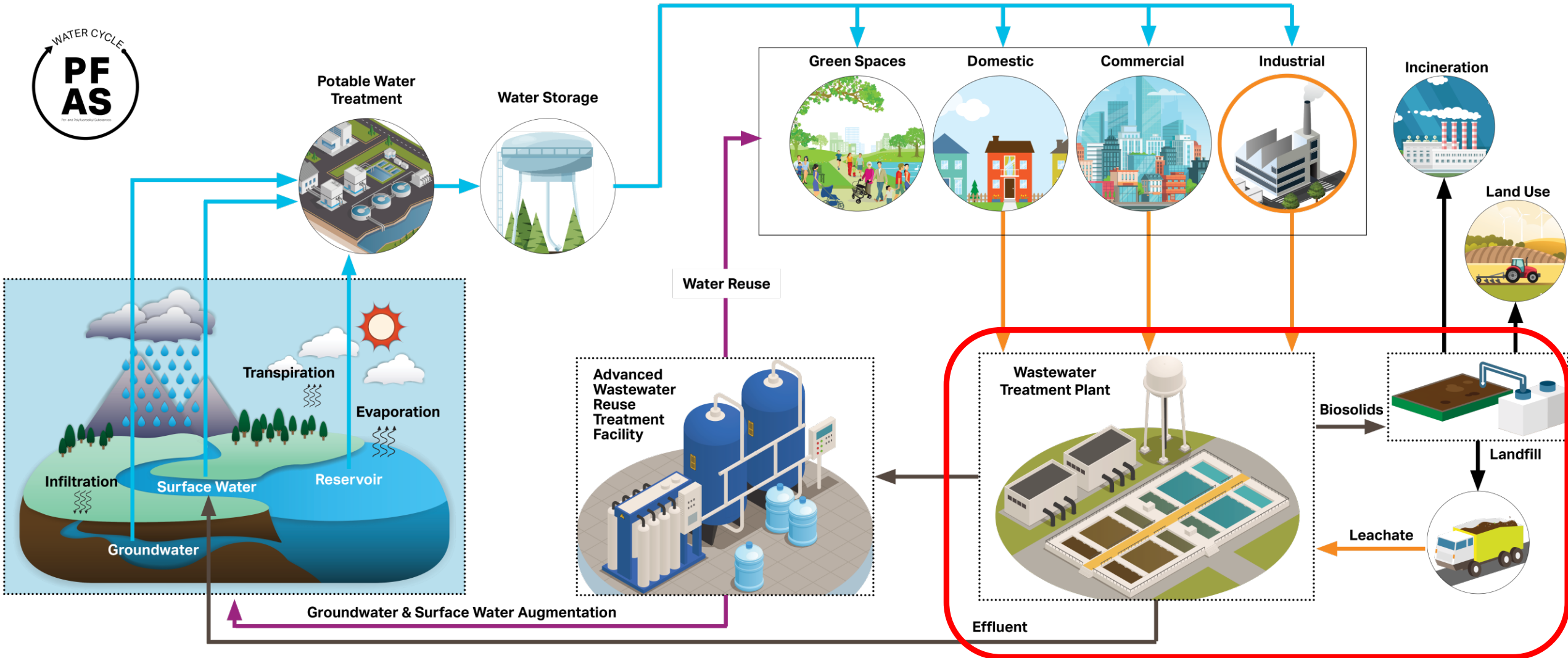


SEMICONDUCTORS



BUILDING/
CONSTRUCTION

PFAS – One Water Perspective



EPA Strategic Roadmap Considerations



Restrict PFAS discharges from industrial sources through a multi-faceted Effluent Limitations Guidelines program
Expected 2022 and Ongoing

Leverage NPDES permitting to reduce PFAS discharges to waterways
Expected Winter 2022

Publish final recommended ambient water quality criteria for PFAS
Expected Winter 2022 and Fall 2024

Publish multi-laboratory validated analytical method for 40 PFAS
Expected Fall 2022

Finalize risk assessment for PFOA and PFOS in biosolids
Expected Winter 2024

Build the technical foundation to address PFAS air emissions
Expected Fall 2022 and Ongoing

Propose to designate certain PFAS as CERCLA hazardous substances
Proposed rule expected Spring 2022; Final rule expected Summer 2023

RESEARCH

Invest in research, development, and innovation to increase understanding of PFAS exposures and toxicities, human health and ecological effects, and effective interventions that incorporate the best available science.

Objectives

- Build the evidence base on individual PFAS and define categories of PFAS to establish toxicity values and methods.
- Increase scientific understanding on the universe of PFAS, sources of environmental contamination, exposure pathways, and human health and ecological effects.
- Expand research on current and emerging PFAS treatment, remediation, destruction, disposal, and control technologies.
- Conduct research to understand how PFAS contribute to the cumulative burden of pollution in communities with environmental justice concerns.

RESTRICT

Pursue a comprehensive approach to proactively prevent PFAS from entering air, land, and water at levels that can adversely impact human health and the environment.

Objectives

- Use and harmonize actions under all available statutory authorities to control and prevent PFAS contamination and minimize exposure to PFAS during consumer and industrial uses.
- Place responsibility for limiting exposures and addressing hazards of PFAS on manufacturers, processors, distributors, importers, industrial and other significant users, dischargers, and treatment and disposal facilities.
- Establish voluntary programs to reduce PFAS use and release.
- Prevent or minimize PFAS discharges and emissions in all communities, regardless of income, race, or language barriers.

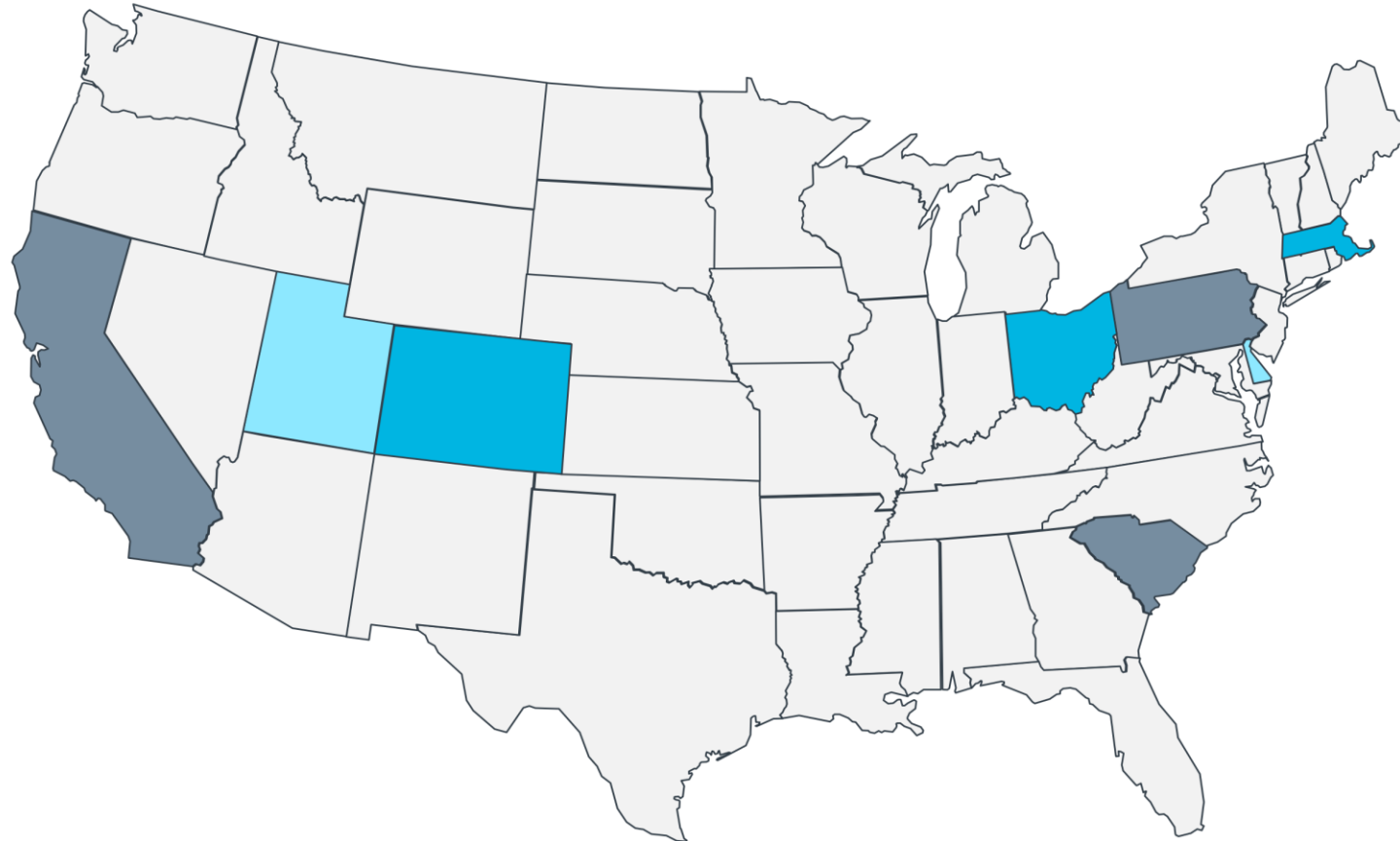
REMEDiate

Broaden and accelerate the cleanup of PFAS contamination to protect human health and ecological systems.

Objectives

- Harmonize actions under all available statutory authorities to address PFAS contamination to protect people, communities, and the environment.
- Maximize responsible party performance and funding for investigations and cleanup of PFAS contamination.
- Help ensure that communities impacted by PFAS receive resources and assistance to address contamination, regardless of income, race, or language barriers.
- Accelerate the deployment of treatment, remediation, destruction, disposal, and mitigation technologies for PFAS, and ensure that disposal and destruction activities do not create new pollution problems in communities with environmental justice concerns.

AECOM WWTP Study Objectives



Number of Participants (19 total in 8 states)

■ 1 participant ■ 2 participants ■ 3+ participants

Phase 1

- Large group of compounds (>4,700)
- 28 PFAS Analyte List
 - 18 PFAS/2 Families – Do not degrade
 - 3 PFAS / 3 Families – PFOS Precursors
 - 3 PFAS / 1 Family – PFCAs Family Precursors
 - 4 PFAS / 3 Families – Replacement Chemistry

PFAS Analyte List

| # | PFAS Name | Acronym | CAS # | (Carbon #) Chain Length |
|--|--|------------|-------------|----------------------------|
| Perfluoroalkyl carboxylic acids (PFCAs) | | | | |
| 1 | Perfluorobutanoic Acid | PFBA | 375-22-4 | (4) Short-chain |
| 2 | Perfluoropentanoic Acid | PFPeA | 2706-90-3 | (5) Short-chain |
| 3 | Perfluorohexanoic Acid | PFHxA | 307-24-4 | (6) Short-chain |
| 4 | Perfluoroheptanoic Acid | PFHpA | 375-85-9 | (7) Short-chain |
| 5 | Perfluorooctanoic Acid | PFOA | 335-67-1 | (8) Long-chain |
| 6 | Perfluorononanoic Acid | PFNA | 375-95-1 | (9) Long-chain |
| 7 | Perfluorodecanoic Acid | PFDA | 335-76-2 | (10) Long-chain |
| 8 | Perfluoroundecanoic Acid | PFUnDA | 2058-94-8 | (11) Long-chain |
| 9 | Perfluorododecanoic Acid | PFDoDA | 307-55-1 | (12) Long-chain |
| 10 | Perfluorotridecanoic Acid | PFTrDA | 72629-94-8 | (13) Long-chain |
| 11 | Perfluorotetradecanoic Acid | PFTeDA | 376-06-7 | (14) Long-chain |
| Perfluoroalkane sulfonic acids (PFSA) | | | | |
| 12 | Perfluorobutane Sulfonic acid | PFBS | 375-73-5 | (4) Short-chain |
| 13 | Perfluoropentanesulfonic acid | PFPeS | 2706-91-4 | (5) Short-chain |
| 14 | Perfluorohexane Sulfonic acid | PFHxS | 355-46-4 | (6) Long-chain |
| 15 | Perfluoroheptane Sulfonic acid | PFHpS | 375-92-8 | (7) Long-chain |
| 16 | Perfluorooctane Sulfonic acid | PFOS | 1763-23-1 | (8) Long-chain |
| 17 | Perfluorononanesulfonic acid | PFNS | 68259-12-1 | (9) Long-chain |
| 18 | Perfluorodecane Sulfonic acid | PFDS | 335-77-3 | (10) Long-chain |
| Precursors to PFOS | | | | |
| 19 | Perfluorooctane sulfonamide ¹ | FOSA | 754-91-6 | (8) Long-chain |
| 20 | N-methylperfluorooctanesulfonamidoacetic acid ² | MeFOSAA | 2355-31-9 | (8) Long-chain |
| 21 | N-ethylperfluorooctanesulfonamidoacetic acid ³ | EtFOSAA | 2991-50-6 | (8) Long-chain |
| Precursors to PFCA Family | | | | |
| 22 | 4:2 Fluorotelomer Sulfonic Acid ⁴ | 4:2 FTS | 757124-72-4 | (6) Short-chain |
| 23 | 6:2 Fluorotelomer sulfonic acid ⁴ | 6:2 FTSA | 27619-97-2 | (8) Long-chain |
| 24 | 8:2 Fluorotelomer sulfonic acid ⁴ | 8:2 FTSA | 39108-34-4 | (10) Long-chain |
| PFAS Replacement Chemistry | | | | |
| 25 | Hexafluoropropylene Oxide Dimer Acid | HFPO-DA | 13252-13-6 | (6) Short-chain |
| 26 | 4,8-Dioxa-3H-perfluorononanoic acid | ADONA | 919005-14-4 | (7) Short-chain |
| 27 | 9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid | F53B Minor | 756426-58-1 | (8) Long-chain |
| 28 | 11-Chloroicosadecafluoro-3-oxaundecane-1-sulfonic acid | F53B Major | 763051-92-9 | (10) Long-chain |

WWTP Summary Information

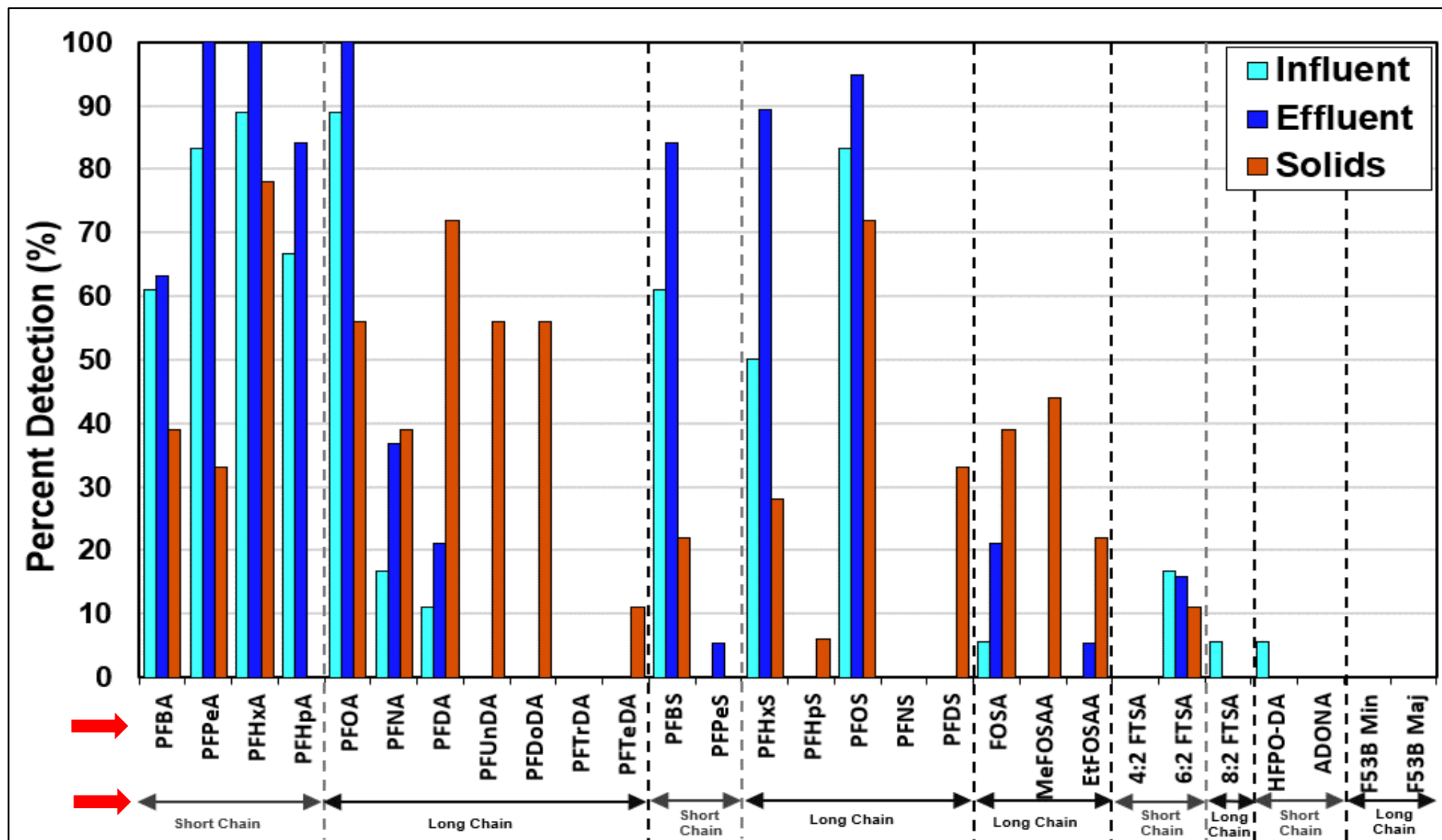
| WWTP Information | | Number of Facilities |
|--|--------------------------------------|---|
| Design Flow (million gallons per day) | < 1 | 1 |
| | 1 to 10 | 7 |
| | 10 to 40 | 9 |
| | 200 - 300 | 2 |
| Wastewater Sources | Residential & Commercial | 3 |
| | Residential, Commercial & Industrial | 16 |
| Primary Treatment Types | | Screen, Grit, Settling Clarifiers |
| Secondary Treatment Types | | Aeration, Extended Aeration, Anoxic/Aerobic Stages, Settling Clarifiers, Trickling Filters |
| Tertiary Treatment Types (13 out of 18 Facilities) | | Chemically Enhancement, Trickling Filters, Insert Media Gravity Filtration, Cloth Media Filter, Nitrifying/Denitrification Filters, and Sand Filter |
| Disinfection Type | Chlorination | 11 |
| | Ultraviolet | 8 |

WWTP Summary Information cont.

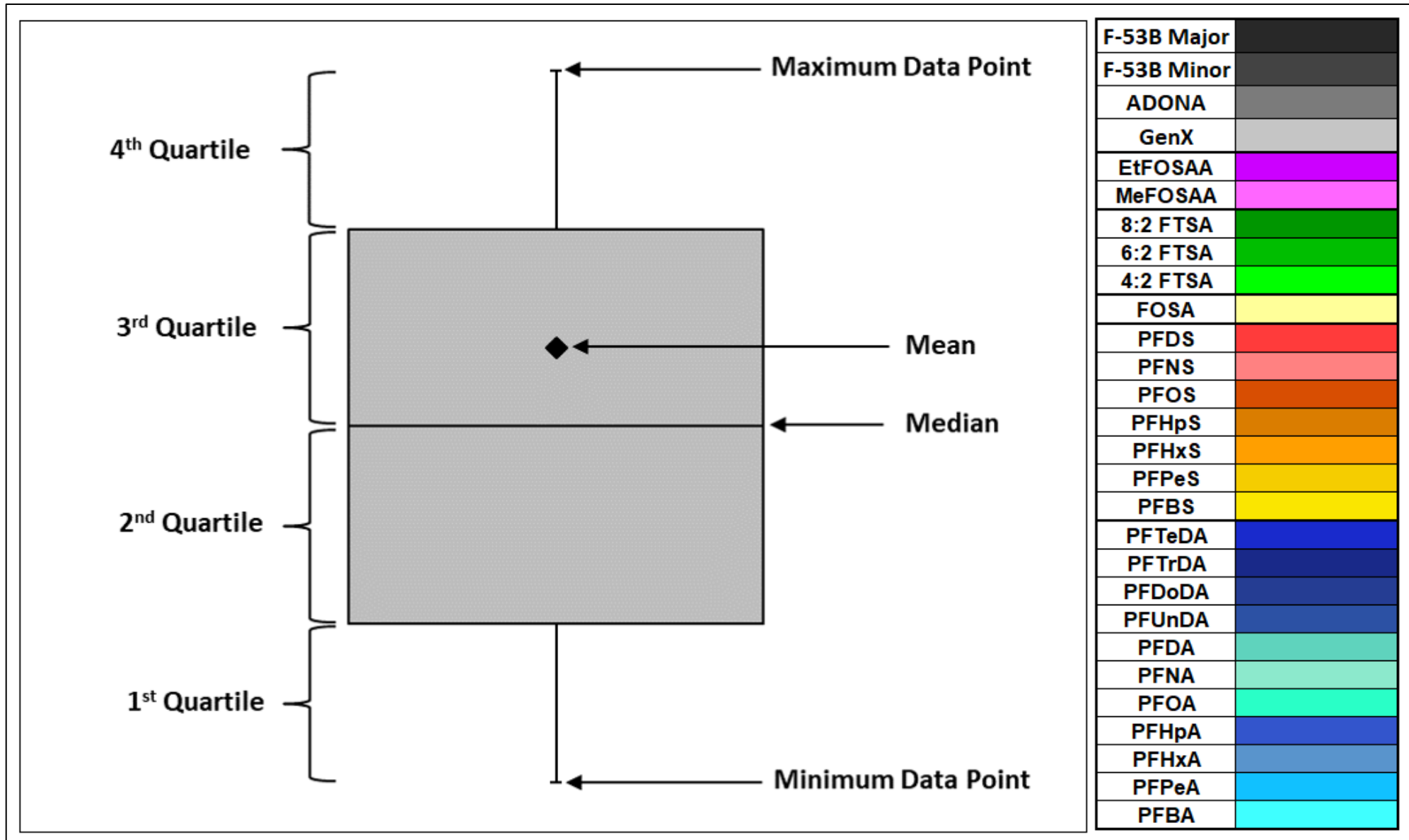
| WWTP Information | | Number of Facilities |
|----------------------|--|----------------------|
| Stabilization | None | 5 |
| | Composting | 1 |
| | Anaerobic | 5 |
| | Aerobic | 6 |
| | Alkaline | 2 |
| Dewatering | None | 5 |
| | Centrifuge | 7 |
| | Belt-Filter Press (BFP) & BFP/Dryer | 7 |
| Disposal | Off-Site Disposal Facility | 5 |
| | Landfill | 4 |
| | Land Application | 3 |
| | Incineration | 1 |
| | Multiple: Landfill, Land Application, Incineration | 6 |

Phase 1 Results Summary

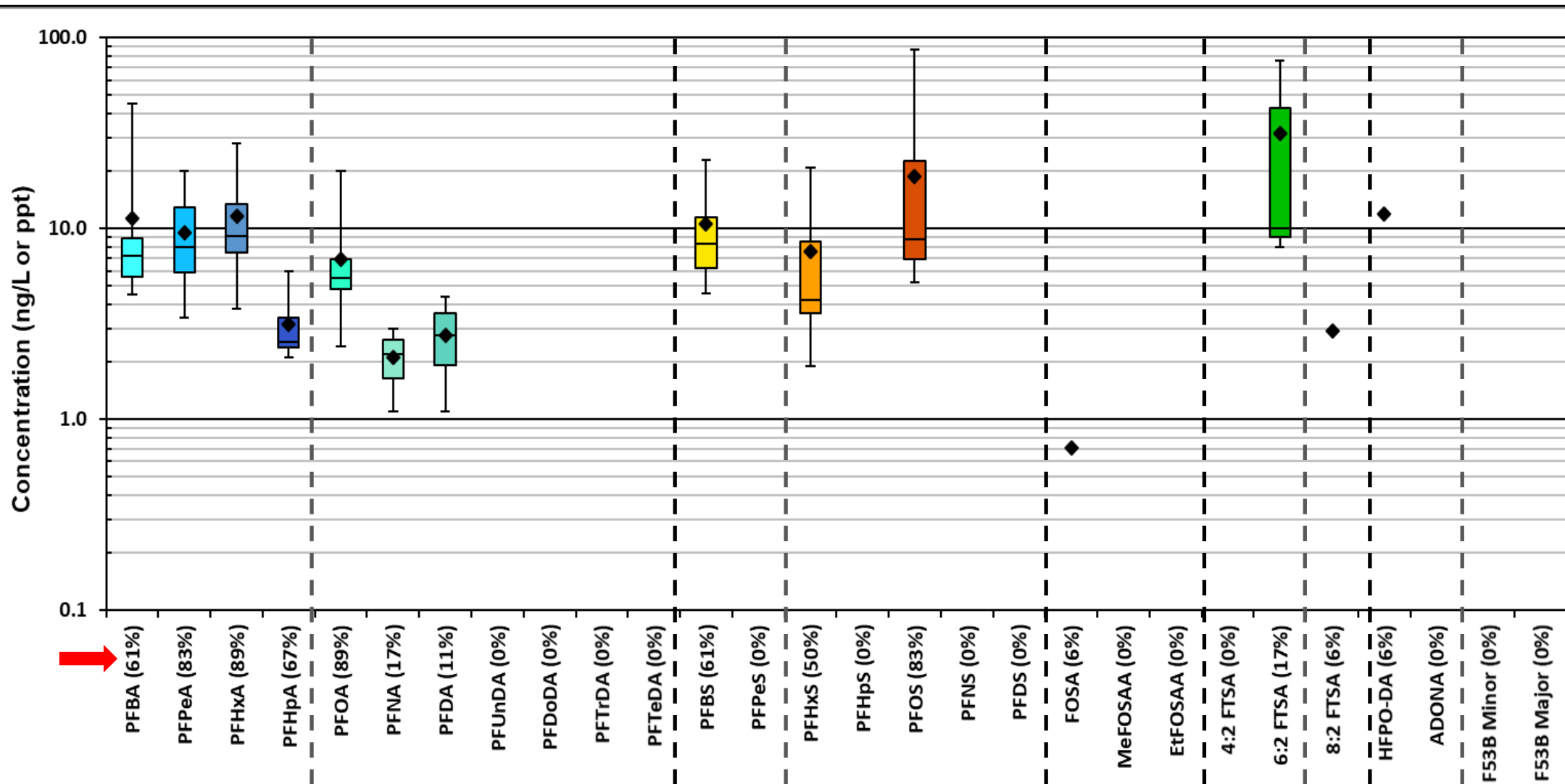
Percent Detection of PFAS



PFAS Legend – Box Plot



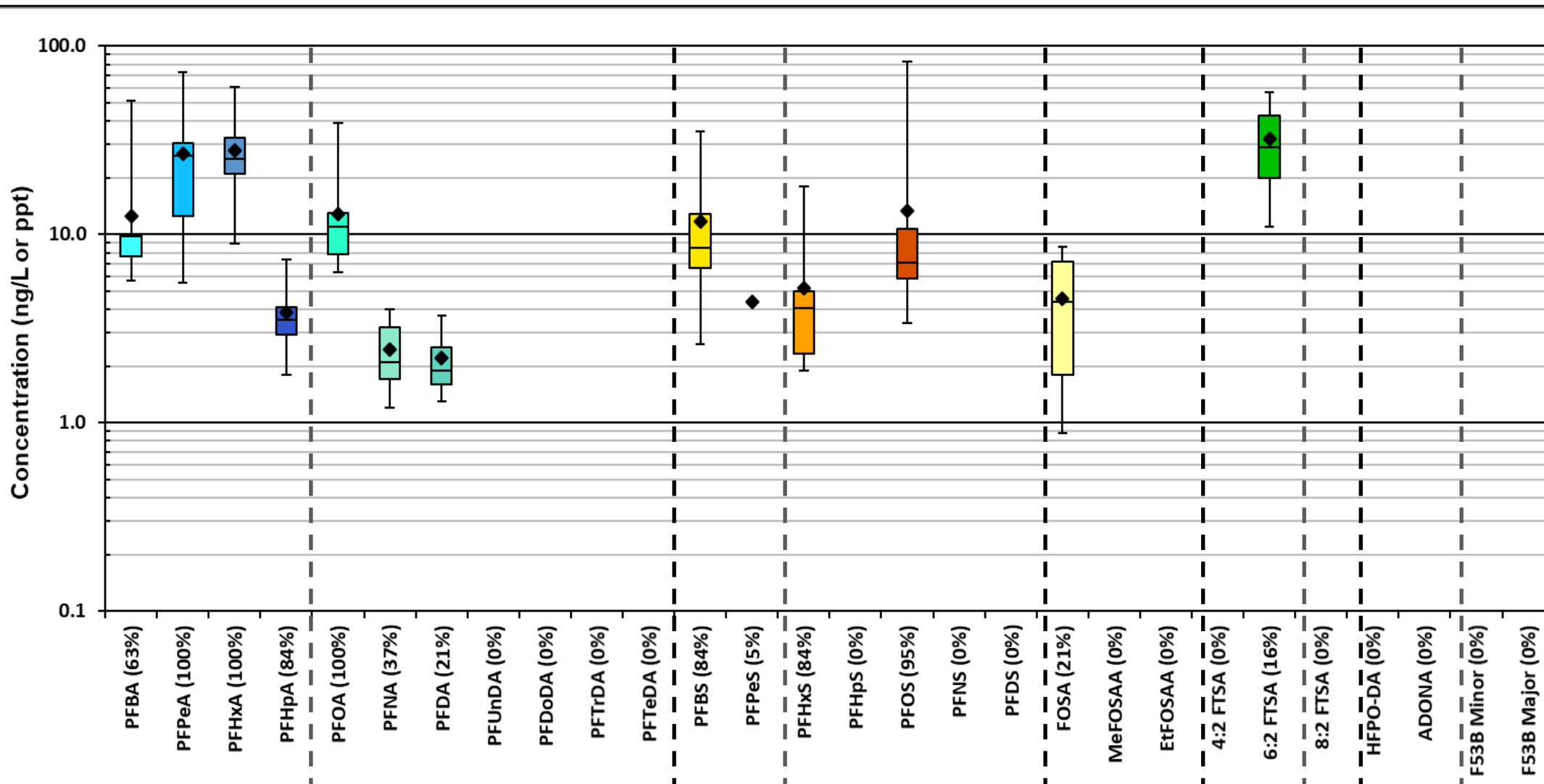
Influent PFAS Detection Frequency and Concentrations



| | |
|-------------|--|
| F-53B Major | |
| F-53B Minor | |
| ADONA | |
| GenX | |
| EtFOSAA | |
| MeFOSAA | |
| 8:2 FTSA | |
| 6:2 FTSA | |
| 4:2 FTSA | |
| FOSA | |
| PFDS | |
| PFNS | |
| PFOS | |
| PFHpS | |
| PFHxS | |
| PFPeS | |
| PFBS | |
| PFTeDA | |
| PFTrDA | |
| PFDoDA | |
| PFUnDA | |
| PFDA | |
| PFNA | |
| PFOA | |
| PFHpA | |
| PFHxA | |
| PFPeA | |
| PFBA | |

Short Chain | Long Chain | Short Chain | Long Chain | Long Chain | Short Chain | Long Chain | Short Chain | Long Chain

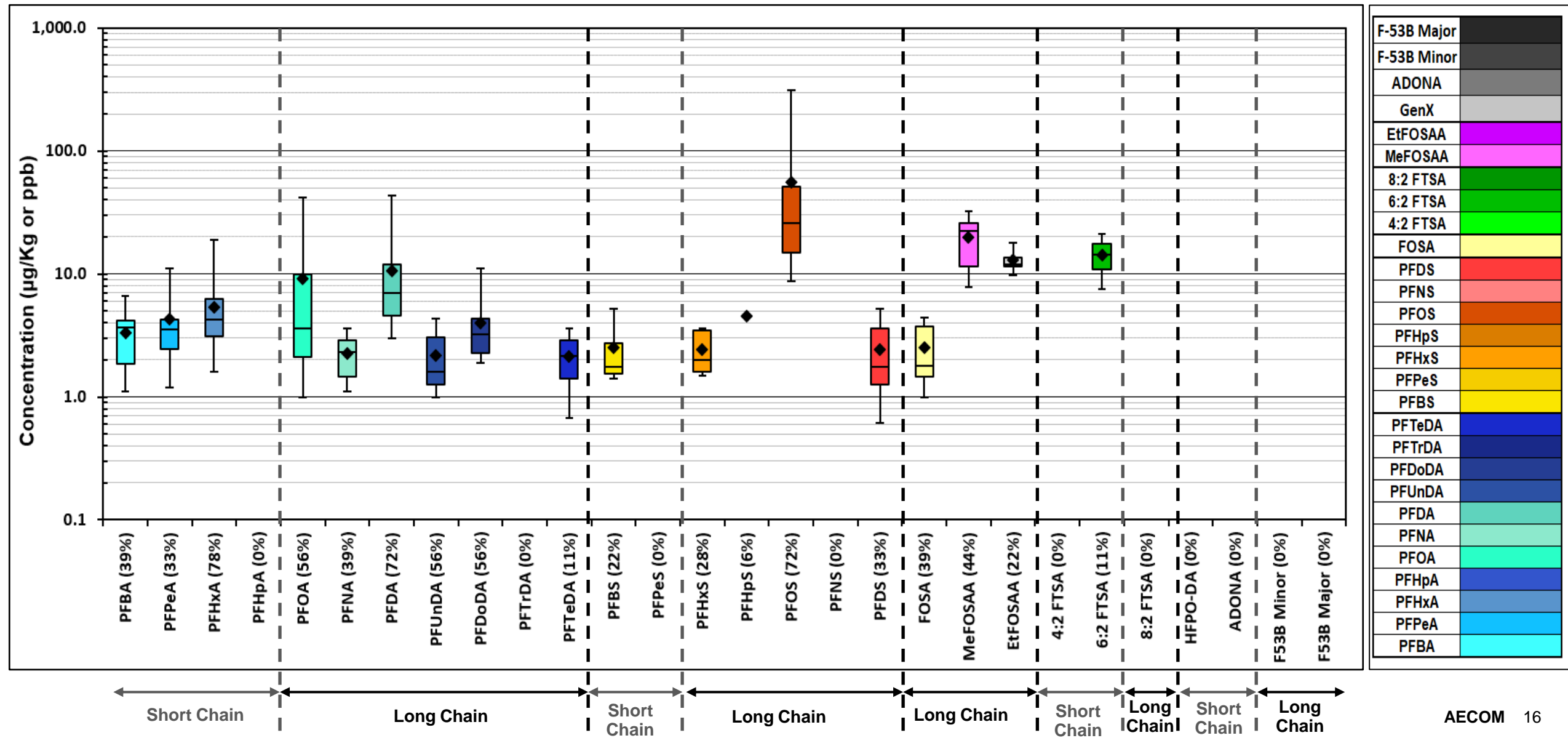
Effluent PFAS Detection Frequency and Concentrations



| | |
|-------------|--|
| F-53B Major | |
| F-53B Minor | |
| ADONA | |
| GenX | |
| EtFOSAA | |
| MeFOSAA | |
| 8:2 FTSA | |
| 6:2 FTSA | |
| 4:2 FTSA | |
| FOSA | |
| PFDS | |
| PFNS | |
| PFOS | |
| PFHpS | |
| PFHxS | |
| PFPeS | |
| PFBS | |
| PFTeDA | |
| PFTrDA | |
| PFDoDA | |
| PFUnDA | |
| PFDA | |
| PFNA | |
| PFOA | |
| PFHpA | |
| PFHxA | |
| PFPeA | |
| PFBA | |

Short Chain Long Chain Short Chain Long Chain Long Chain Short Chain Long Chain Short Chain Long Chain

Final Treated Solids PFAS Detection Frequency and Concentrations



Michigan's Interim Strategy to Land Application of Biosolids Containing PFAS

- **Tier 3: PFOS \geq 150 $\mu\text{g}/\text{kg}$.**
 - Cannot be land applied
 - Investigate potential sources to develop a source reduction program
- **Tier 2: PFOS \geq 50 $\mu\text{g}/\text{kg}$ & $<$ 150 $\mu\text{g}/\text{kg}$**
 - Investigate potential sources to develop a source reduction program
 - Reduce land application rates to no more than 1.5 dry tons per acre (or submit an alternative risk mitigation strategy)
- **Tier 1: PFOS $>$ 20 $\mu\text{g}/\text{kg}$ & $<$ 50 $\mu\text{g}/\text{kg}$**
 - Consider investigating sources and sampling the WWTP effluent for PFAS

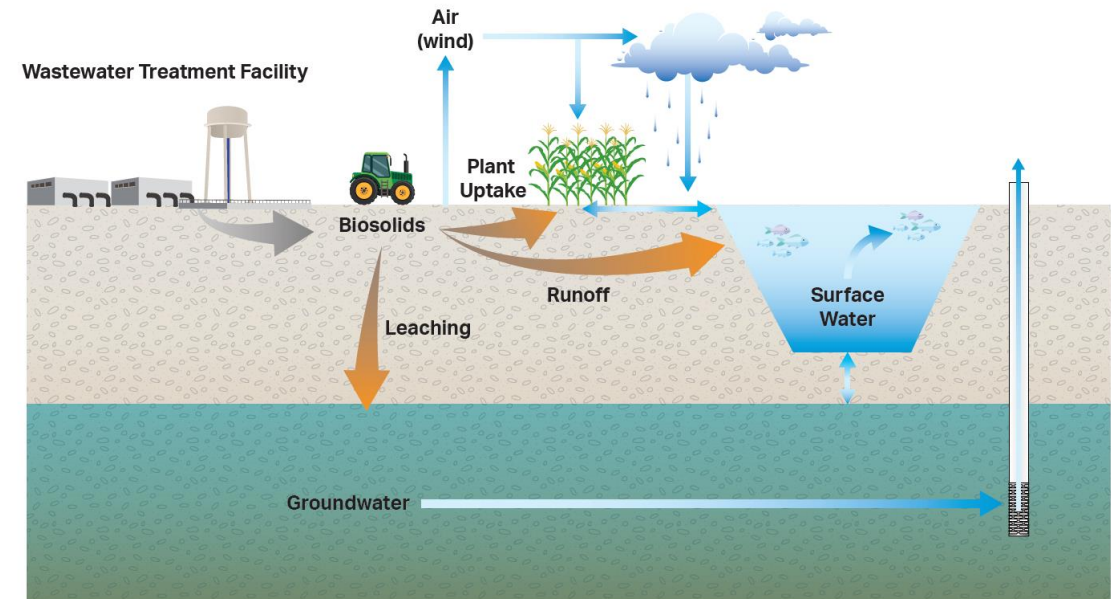


MICHIGAN DEPARTMENT OF
ENVIRONMENT, GREAT LAKES, AND ENERGY

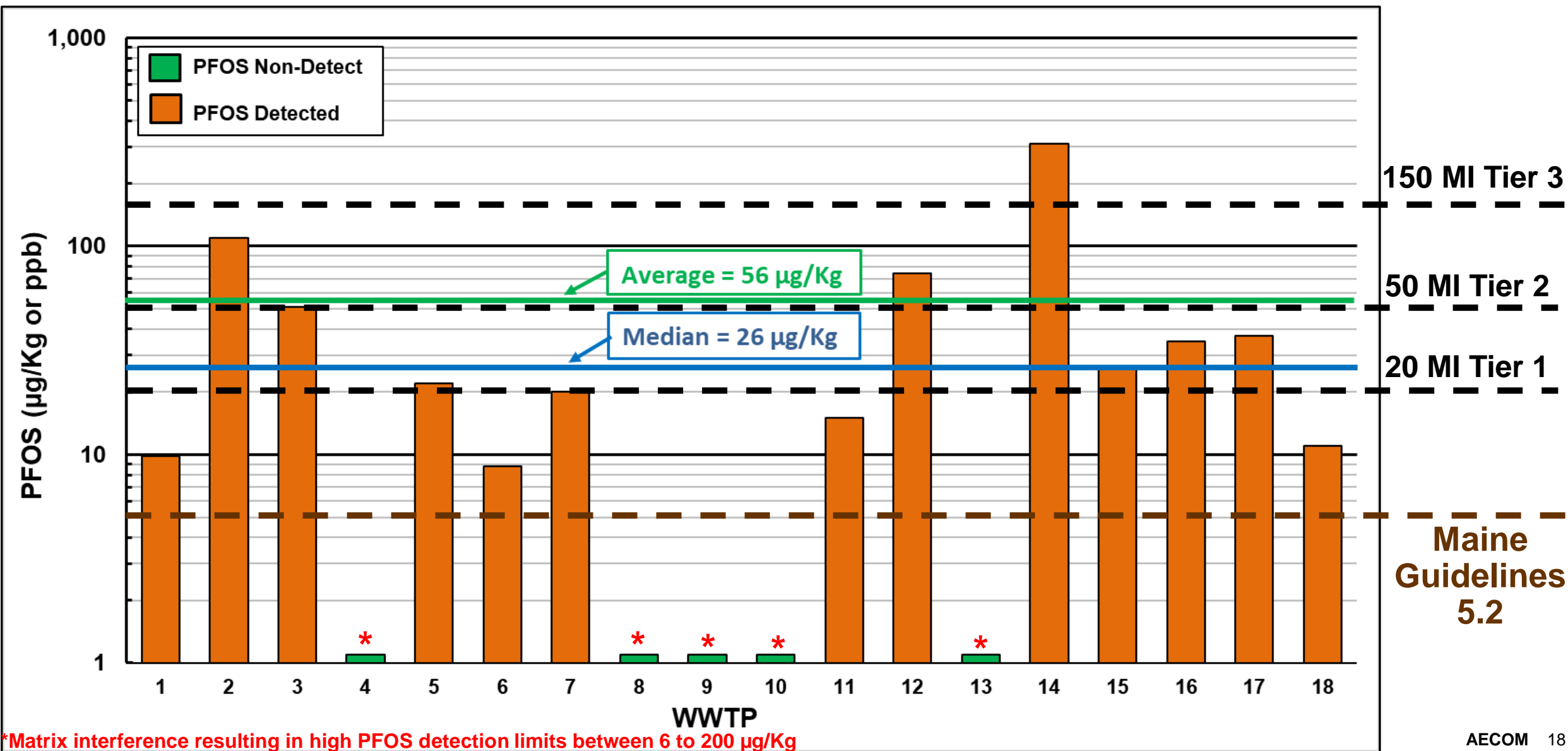
LAND APPLICATION OF BIOSOLIDS CONTAINING PFAS

Interim Strategy

March 2021



Final Treated Solids PFOS Concentrations

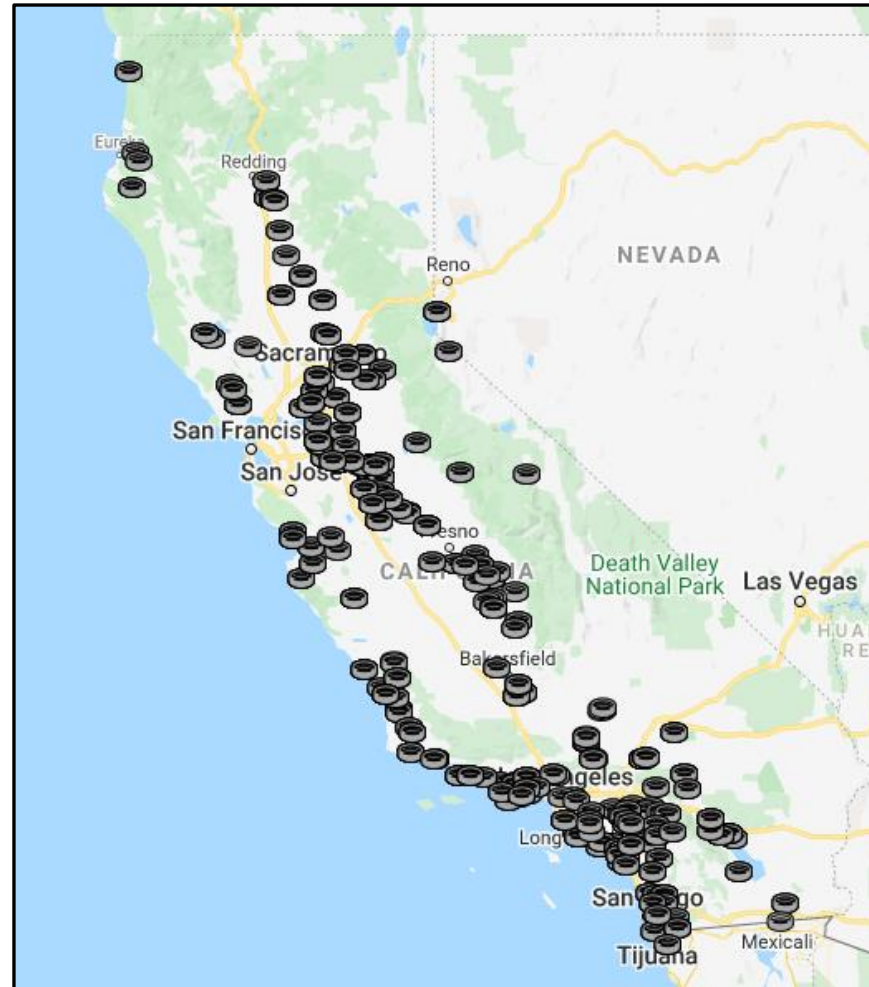


Phase 1 vs. Statewide Michigan & California Studies

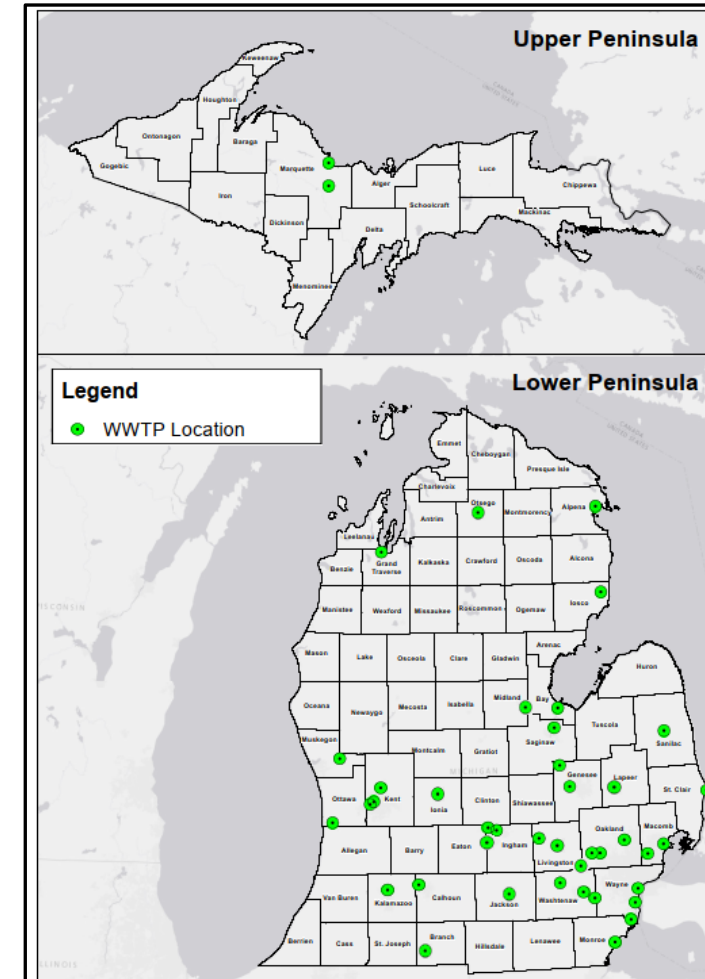
Statewide Michigan and California Studies

- California Study - 2021
 - 180 WWTPs
 - 1 MGD dry weather design
- Michigan Study - 2018
 - 42 WWTP
 - 20 largest (10-930 MGD)
 - 22 various treatment processes (0.2-9 MGD)

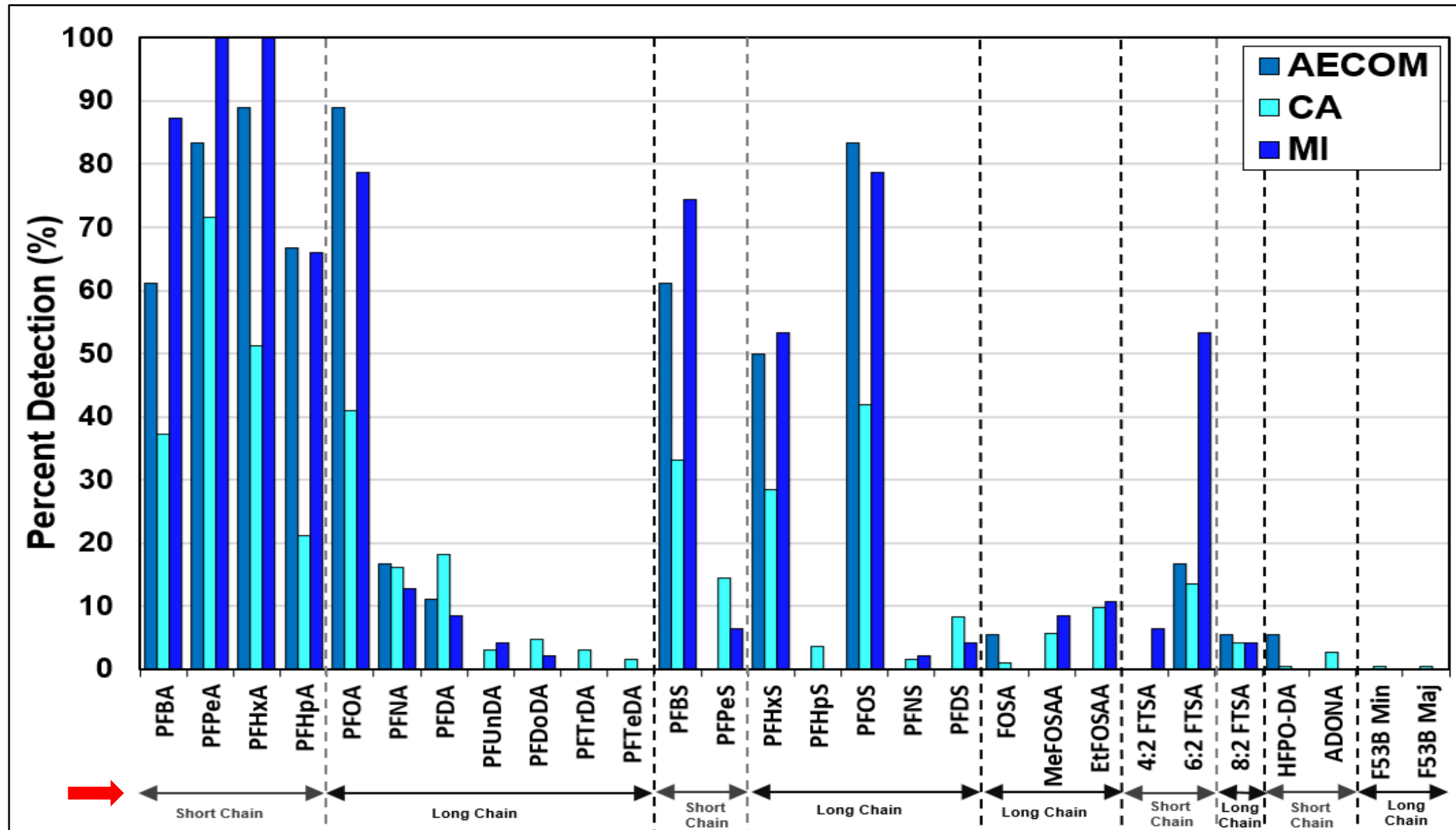
California WWTPs



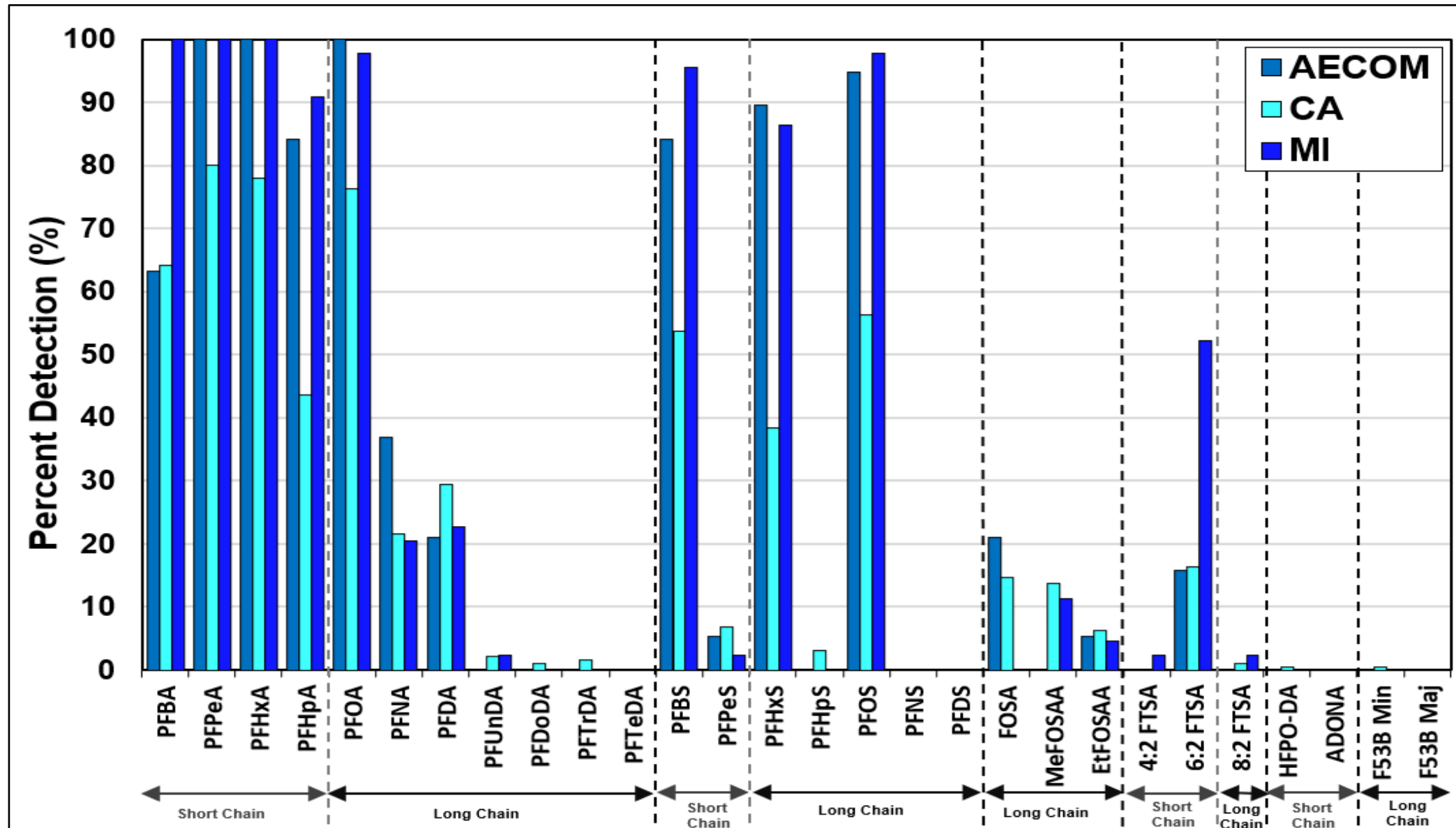
Michigan WWTPs



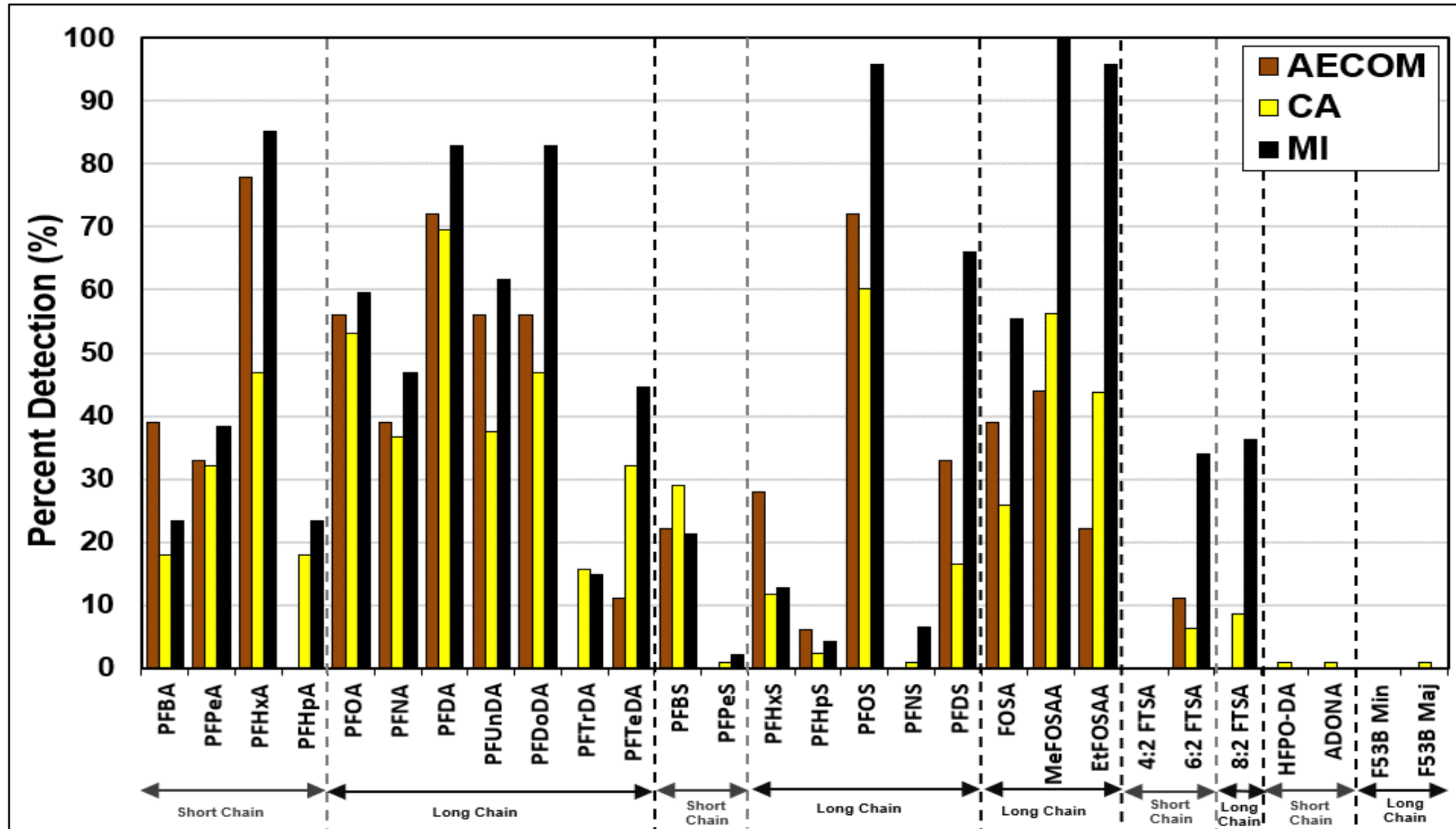
PFAS Influent Percent Detection - All 3 Studies



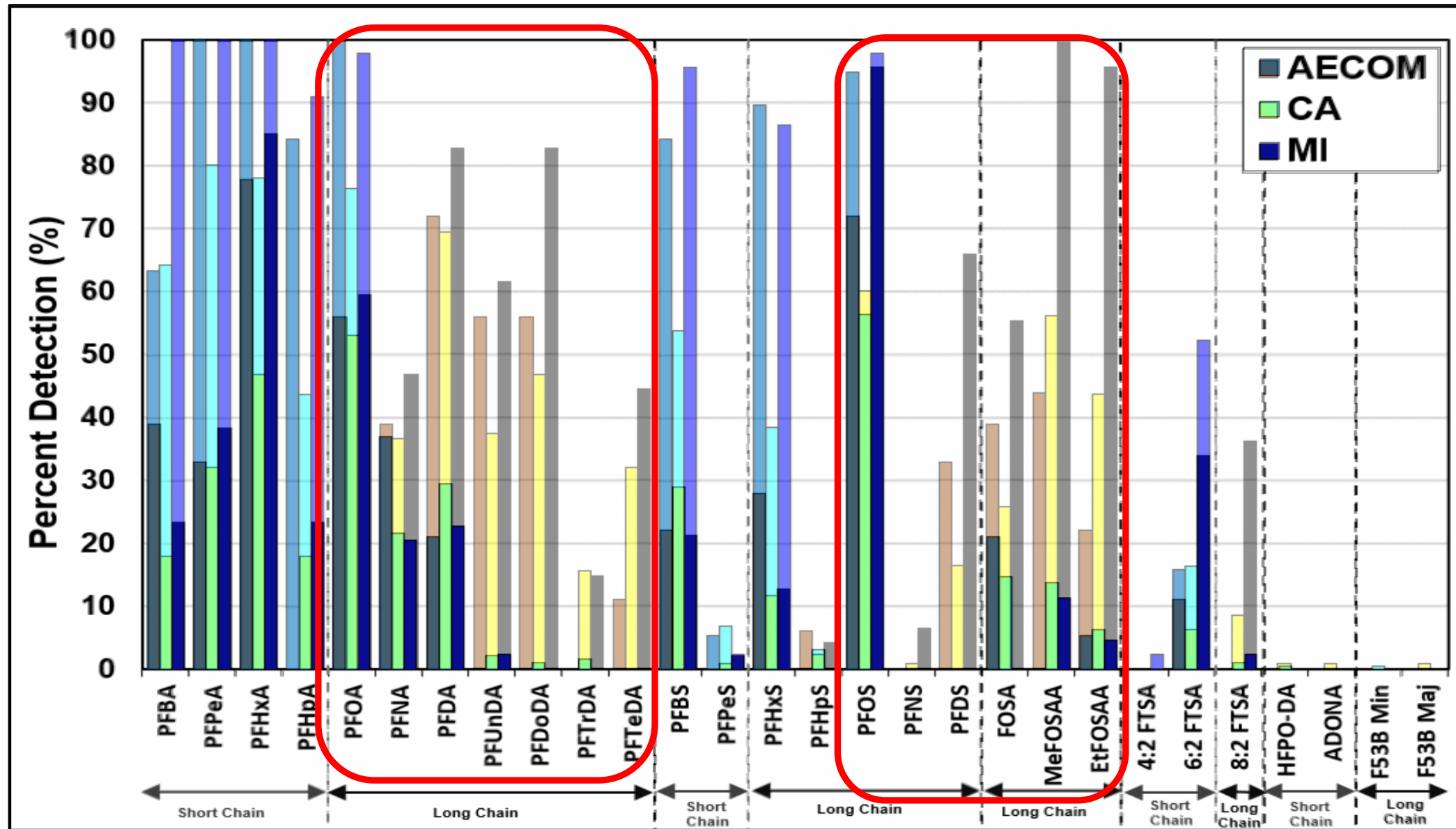
PFAS Effluent Percent Detection - All 3 Studies



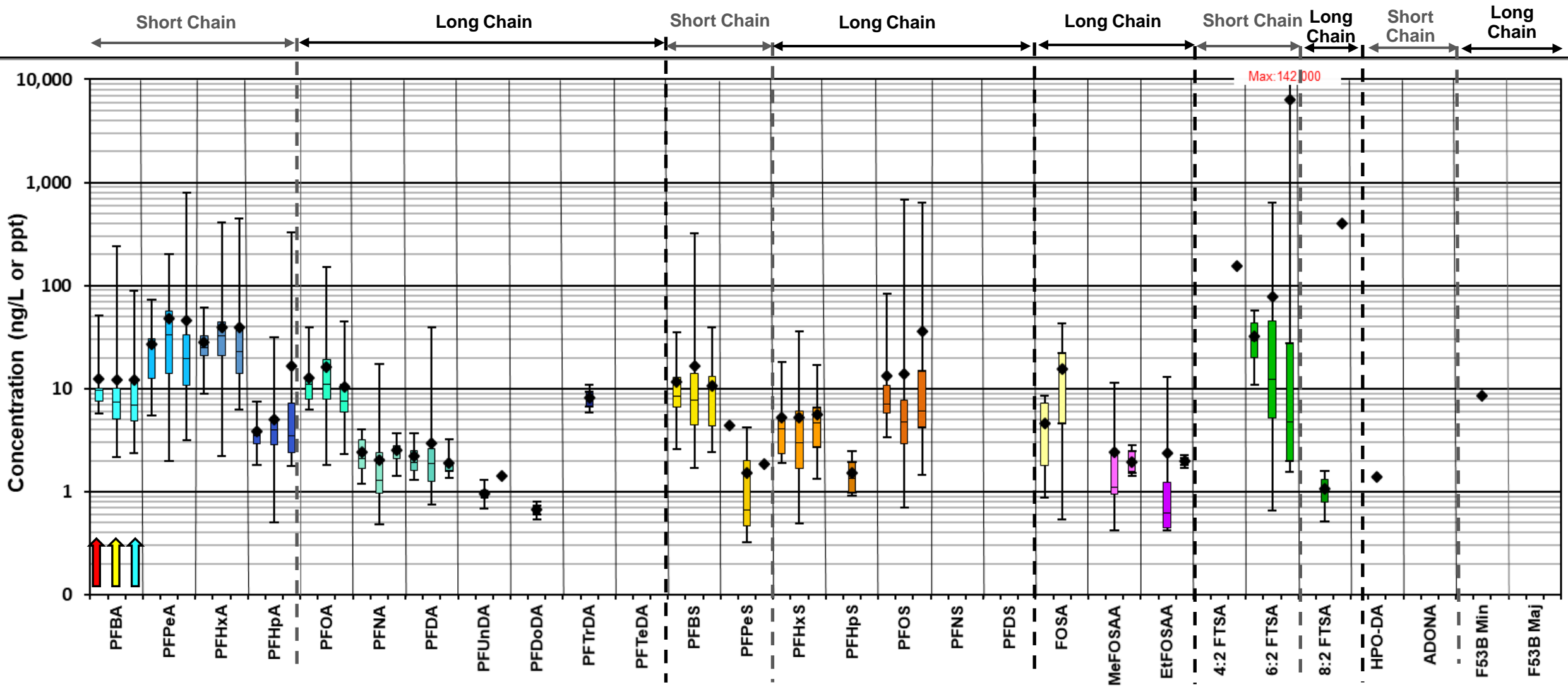
PFAS Final Treated Solids Percent Detection - All 3 Studies



PFAS Effluent & Final Treated Solids Percent Detection - All 3 Studies



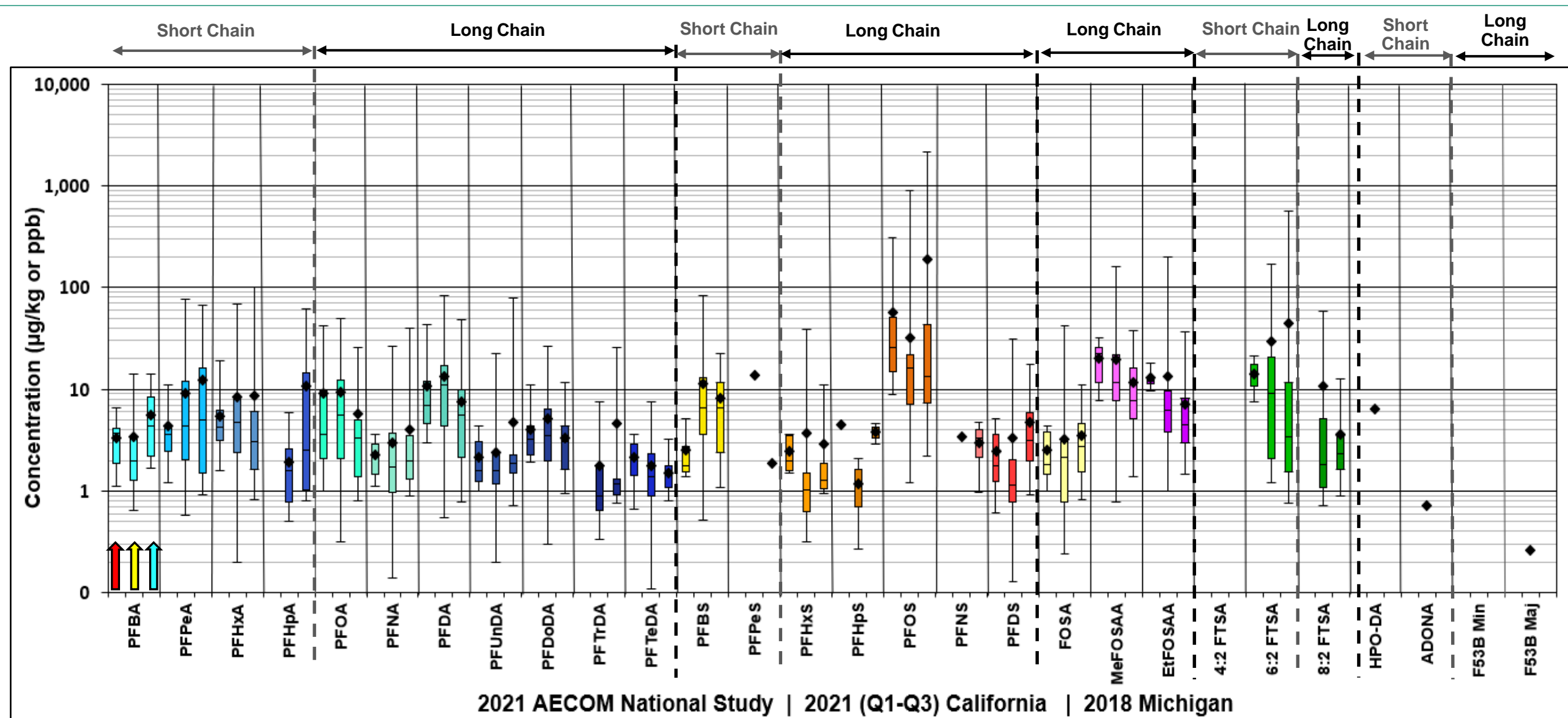
Effluent PFAS Concentrations – All 3 Studies



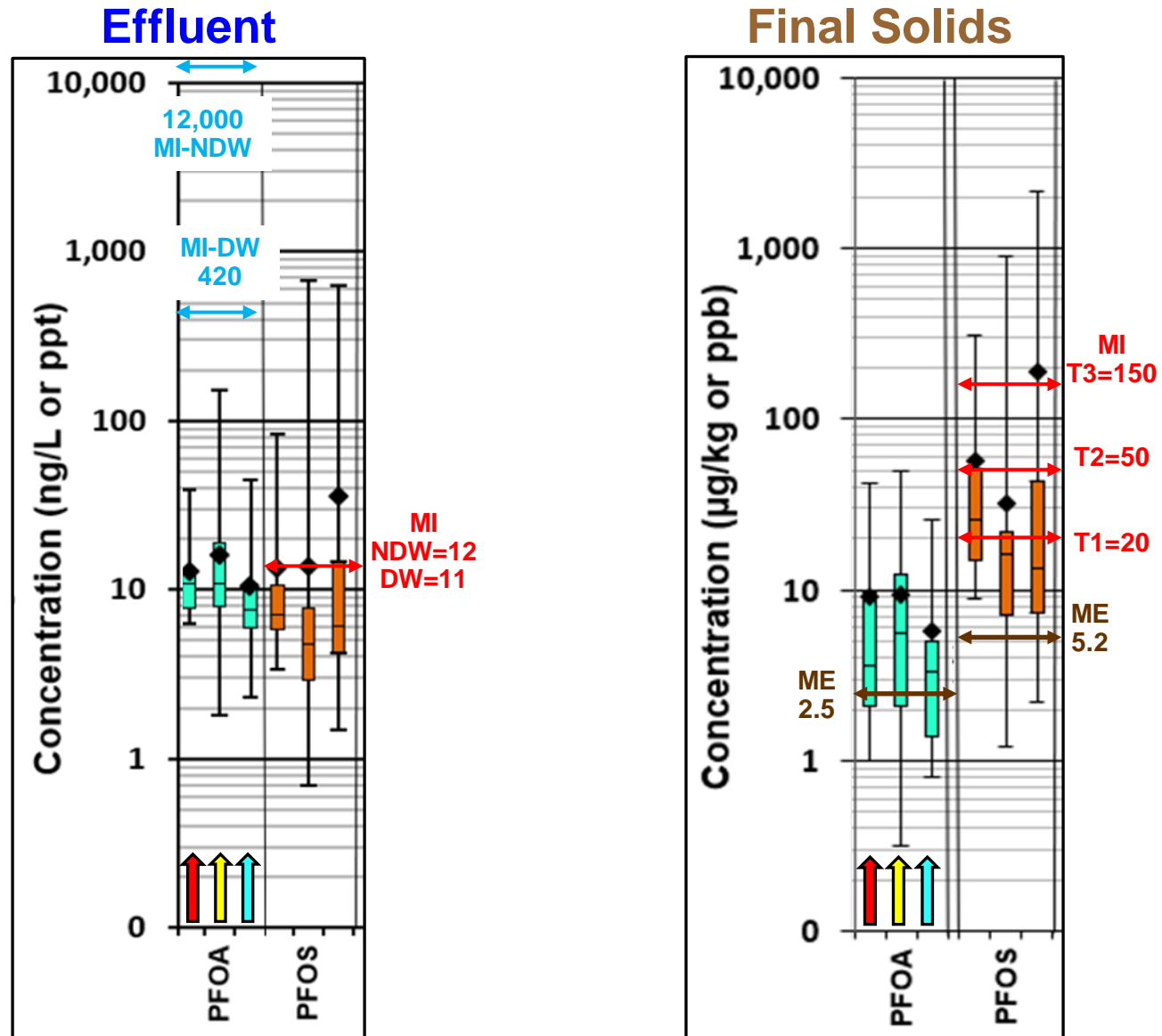
2021 AECOM National Study | 2021 (Q1-Q3) California | 2018 Michigan



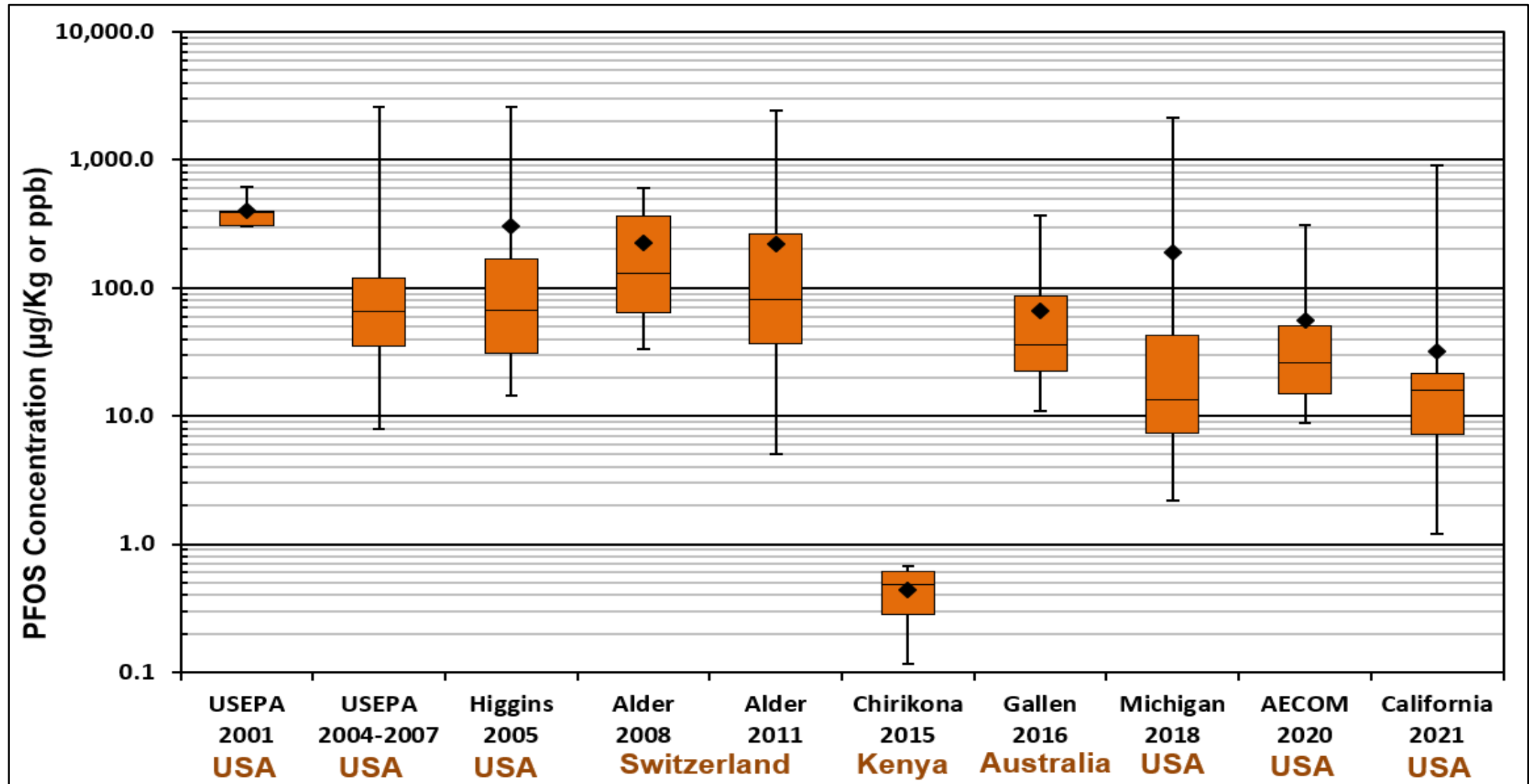
Final Treated Solids PFAS Concentrations – All 3 Studies



Focus on PFOA/PFOS Concentrations – All 3 Studies

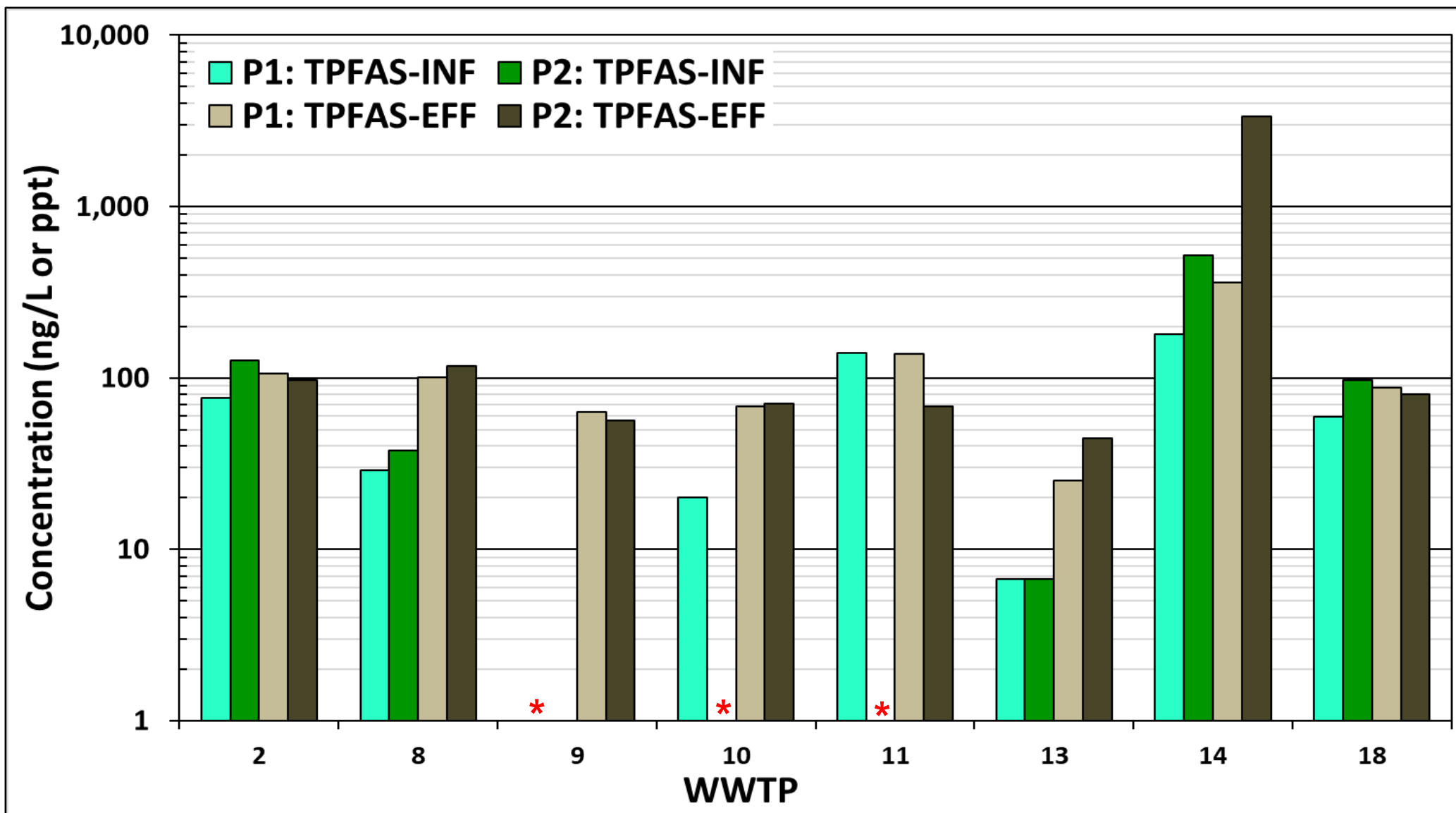


Final Treated Solids PFOS Concentrations - Published Studies



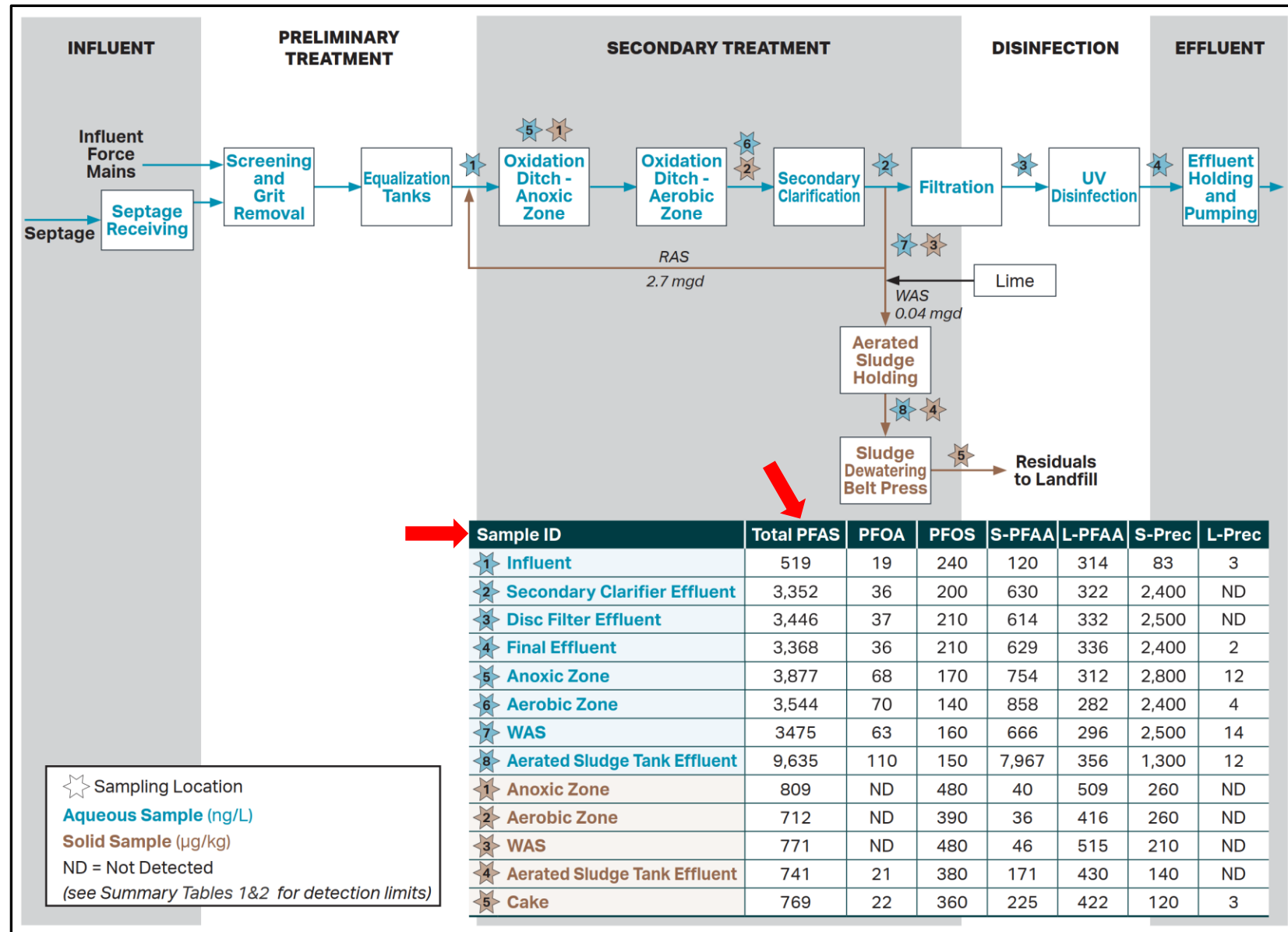
Phase 2

Phase 1 & 2 WWTPs – Total PFAS



*Matrix interference resulting in high detection limits for individual compounds between 16 to 46 ng/L

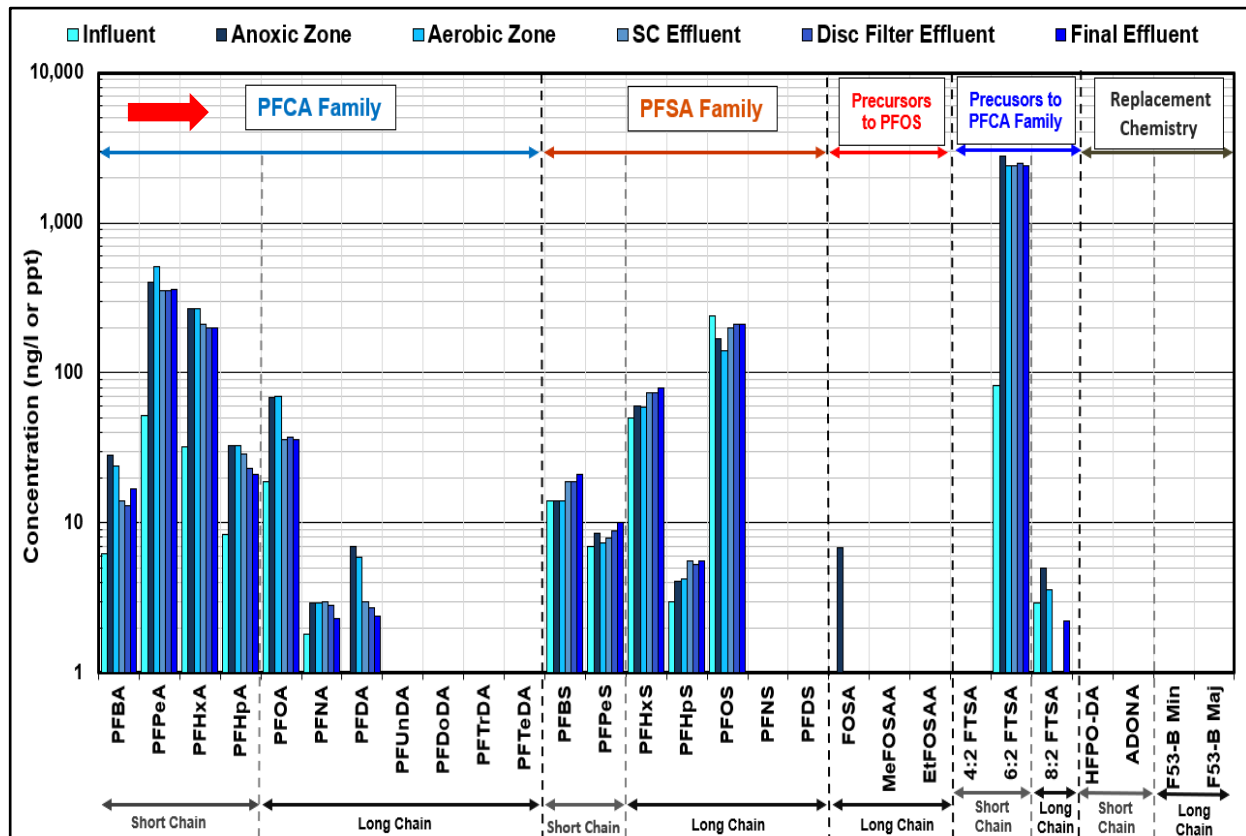
Phase 2 – Example of WWTP 14 PFD (3 MGD)



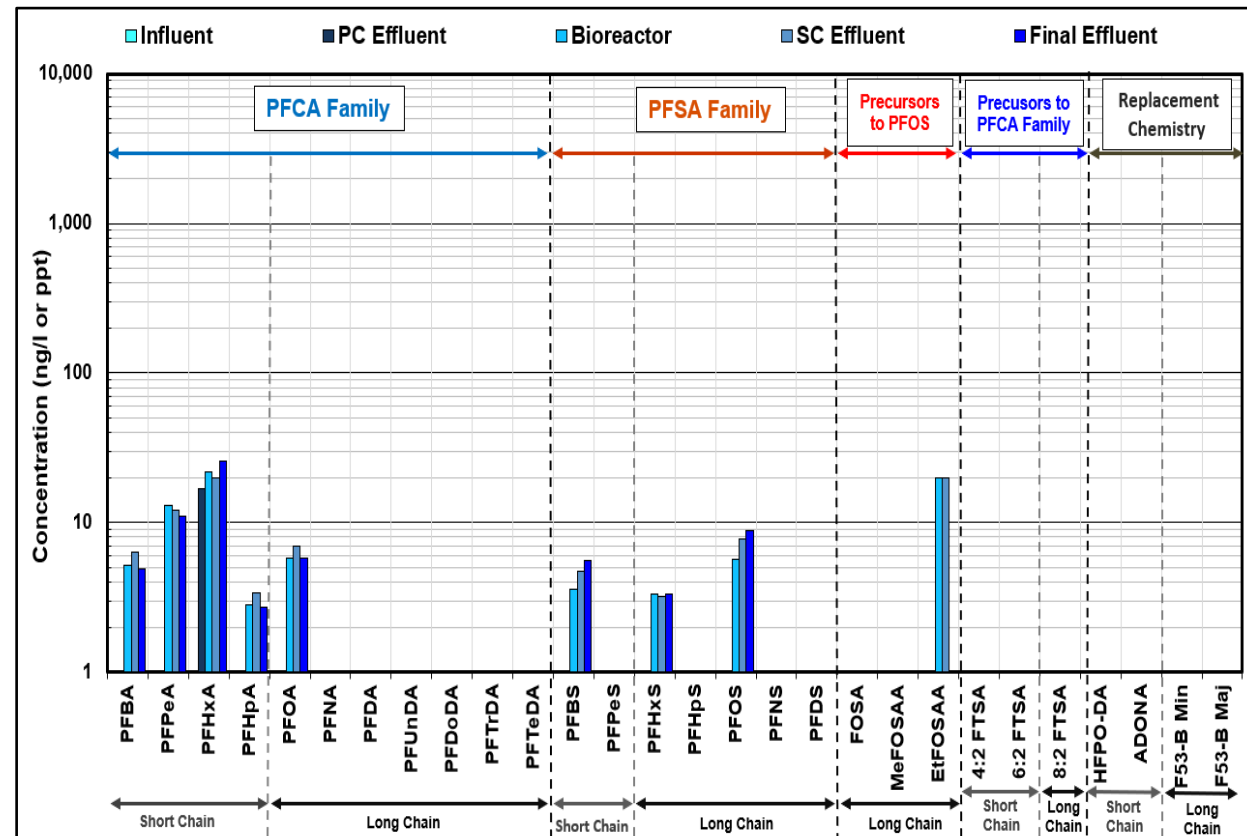
PFAS Concentrations in The Aqueous Process Flow



Low Flow with Industrial Impact

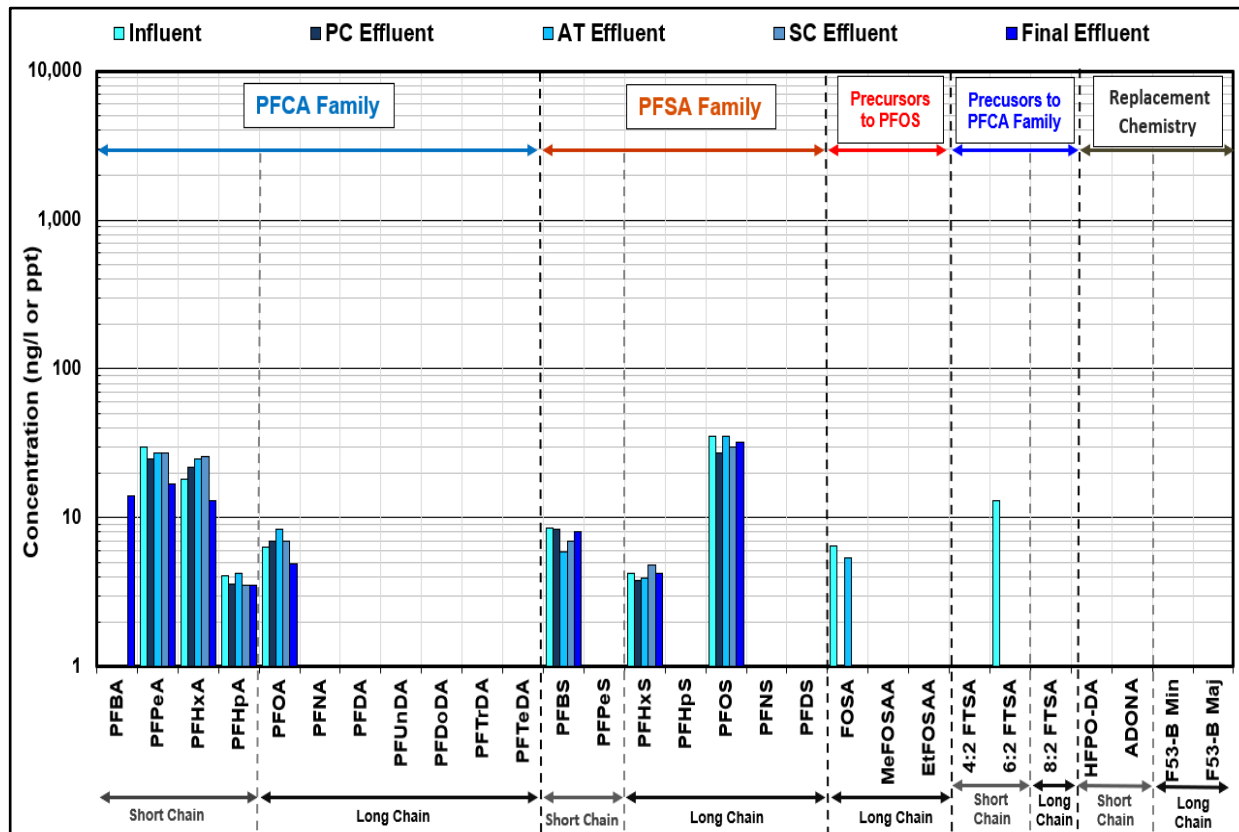


High Flow with Industrial Impact

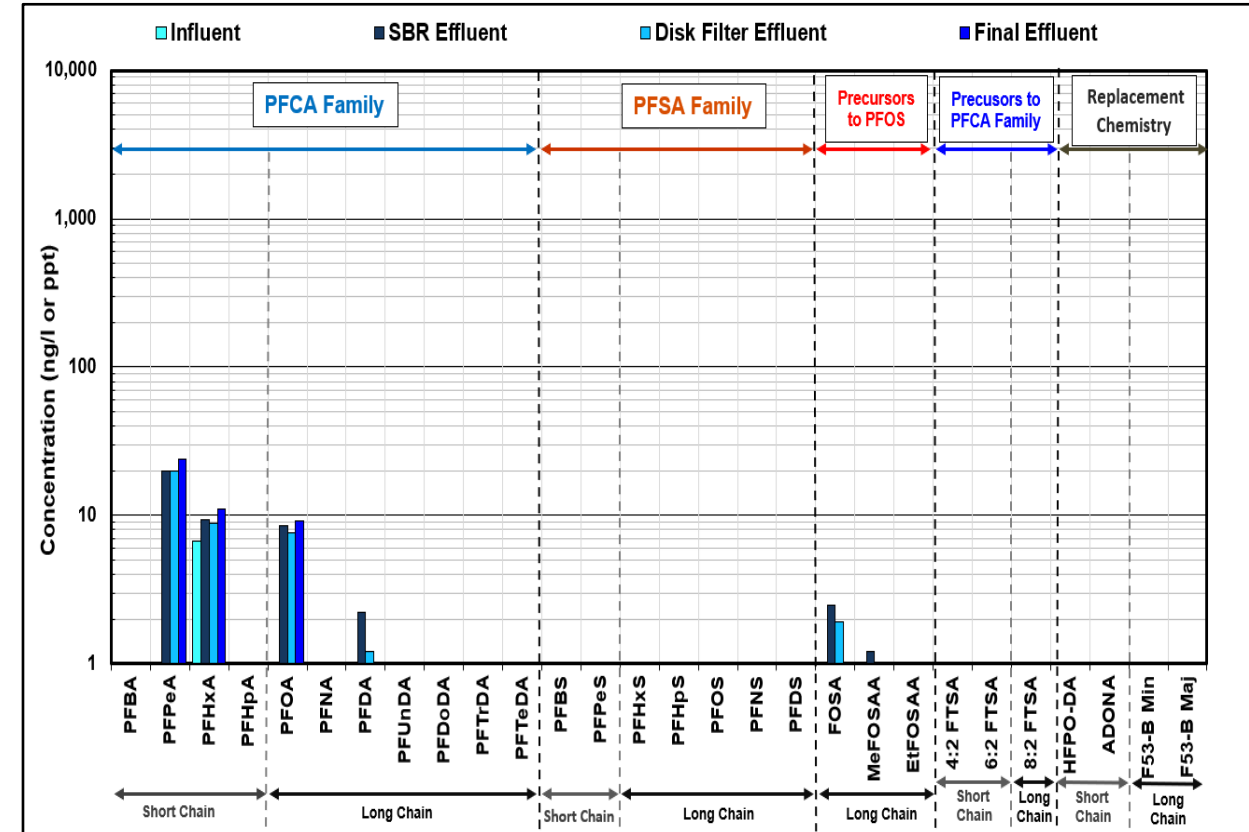


PFAS Concentrations in The Aqueous Process Flow cont.

Medium Flow with Industrial Impact

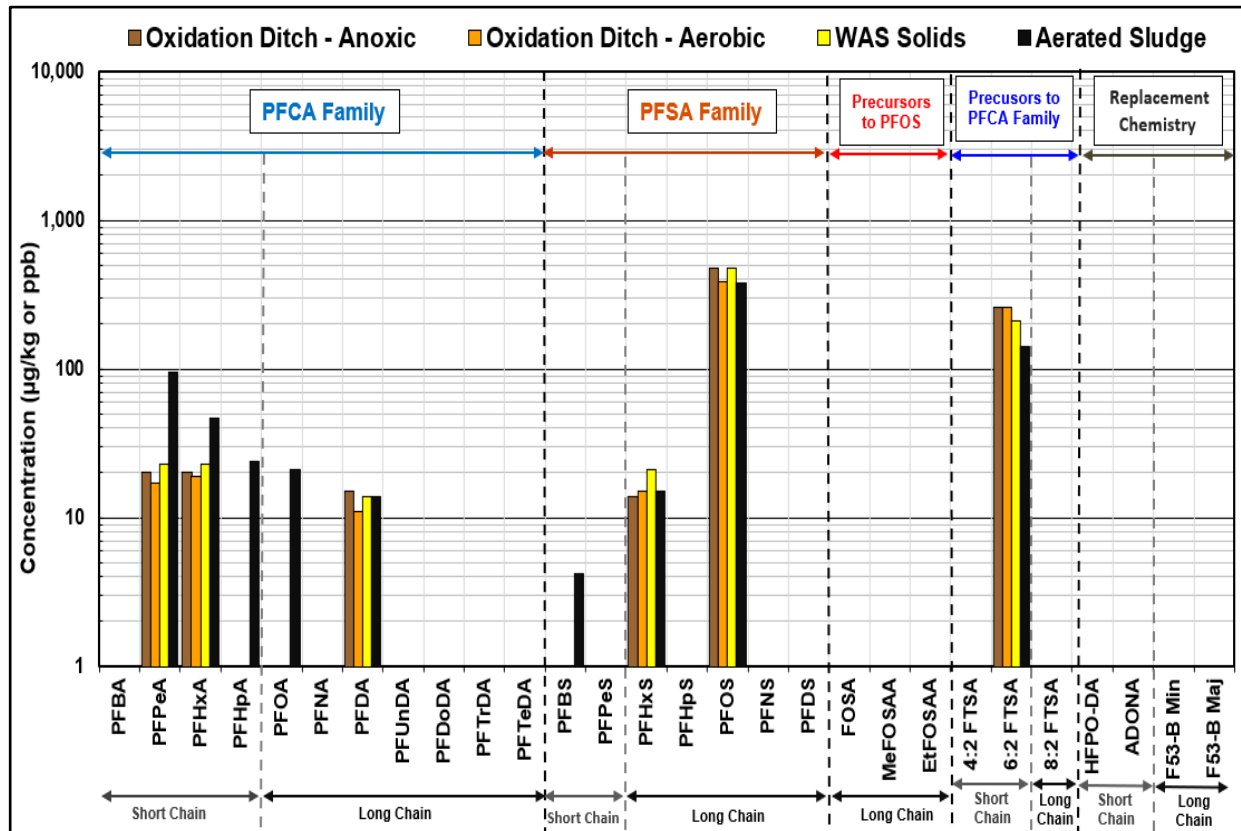


Low Flow with Commercial and Residential

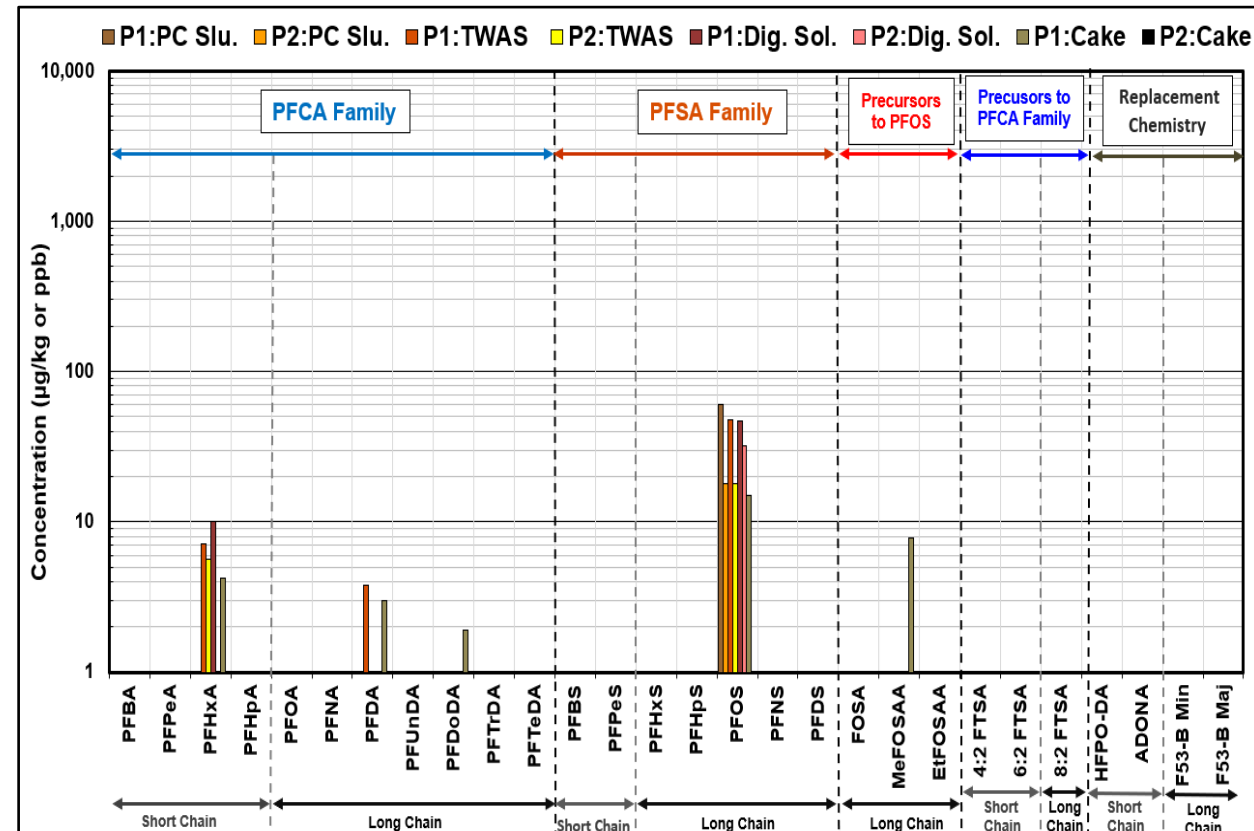


PFAS Concentrations in The Solids Process Flow

Low Flow with Industrial Impact

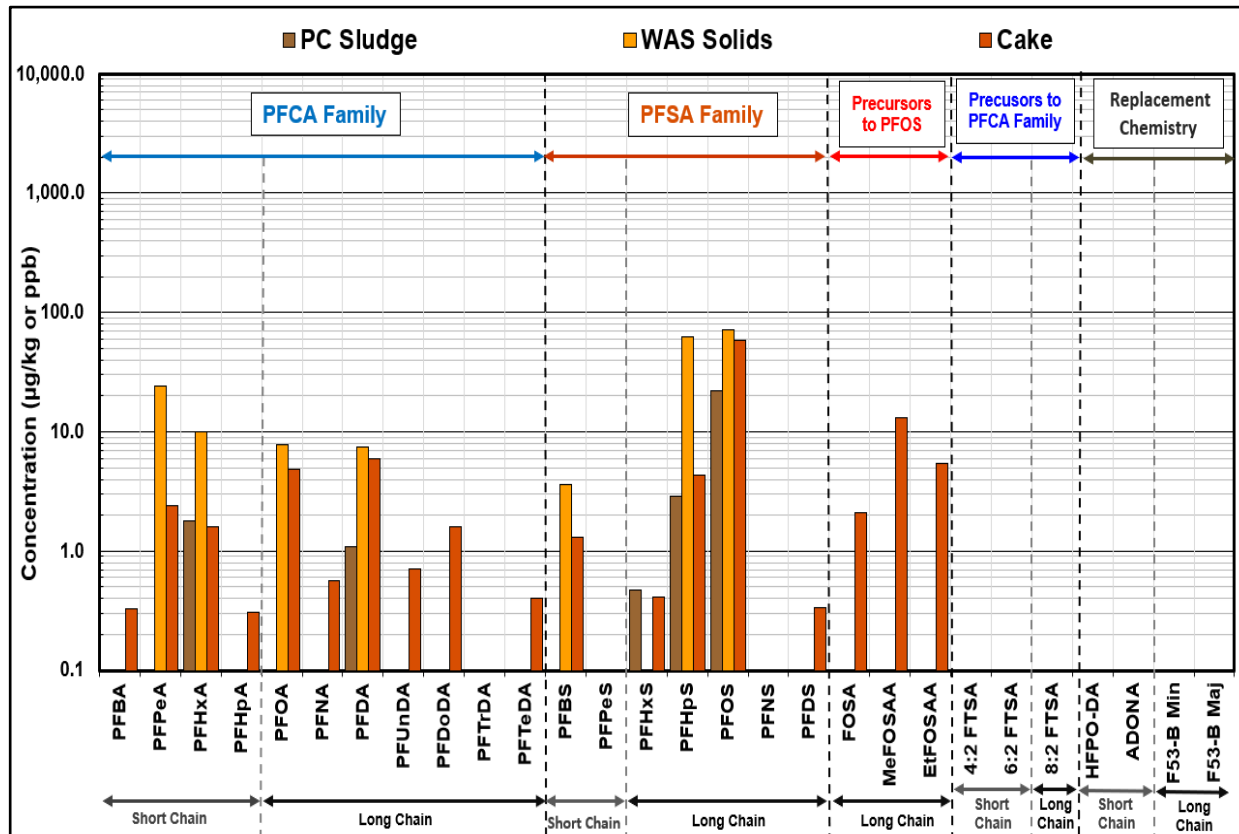


High Flow with Industrial Impact

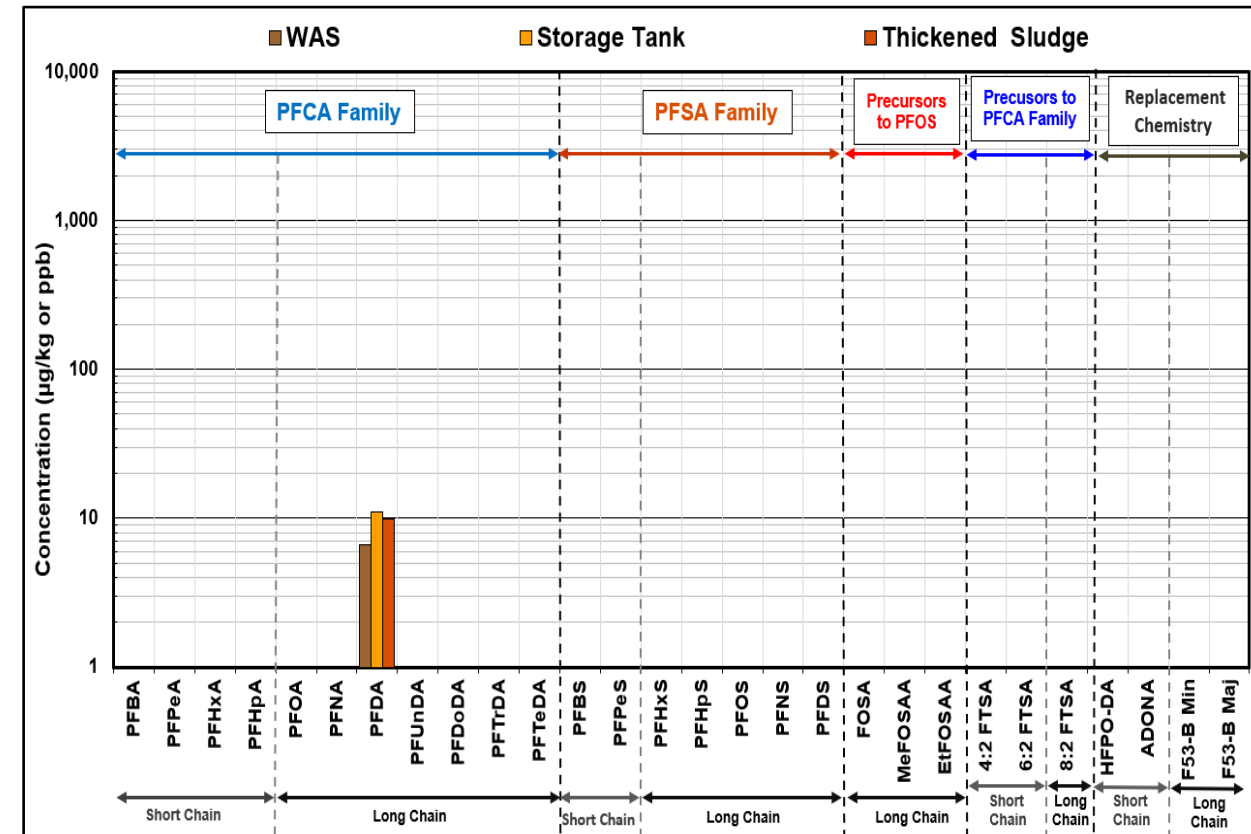


PFAS Concentrations in The Solids Process Flow cont.

Medium Flow with Industrial Impact

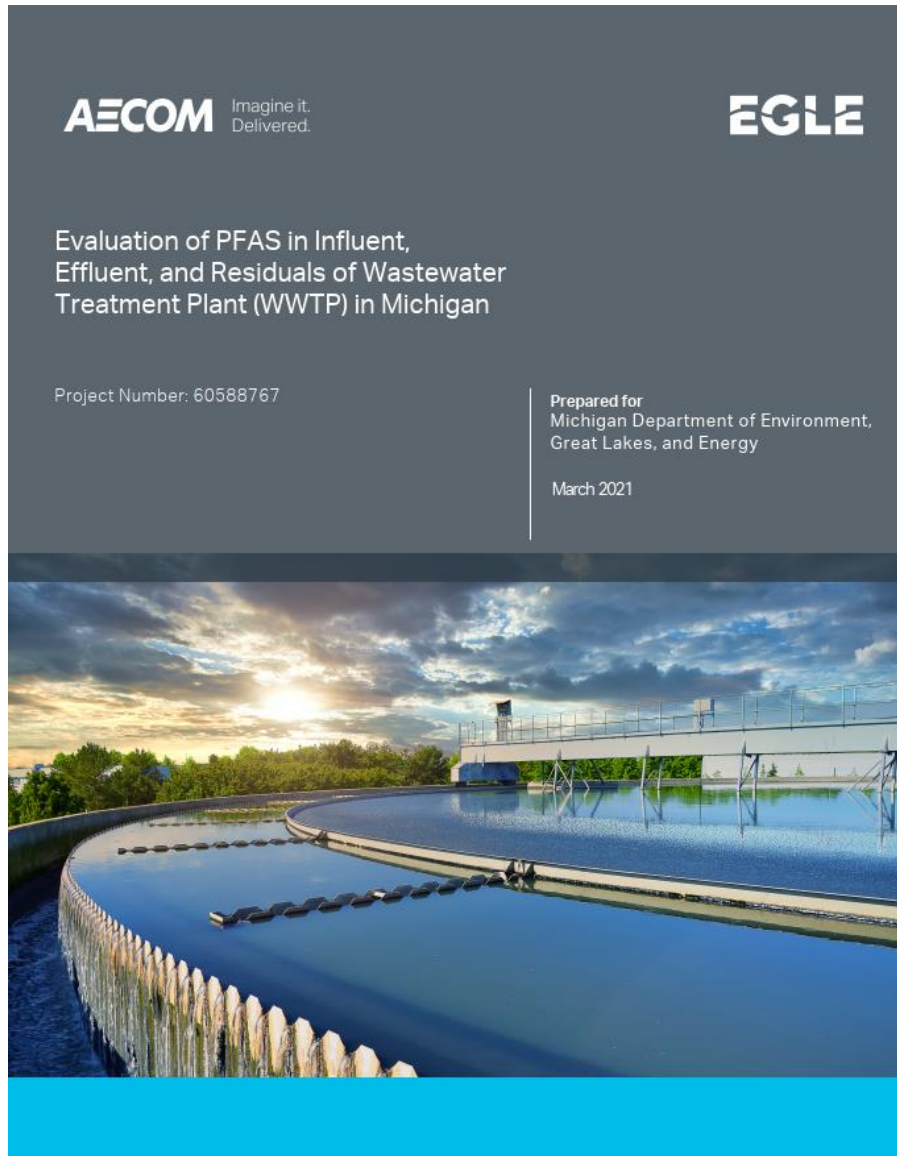


Low Flow with Commercial and Residential



Source Controls

PFAS Sources in WWTPs from Michigan



- 2,000 PFAS industrial effluent samples
- 574 industrial facilities
- Many PFAS sources identified

| Industry/Category/Type | # Sampled | % Detection | PFOS Range (ng/L) |
|--|-----------|-------------|-------------------|
| Metal Finishing | 212 | 33 % | 0.7 – 240,000 |
| Electroplating | 44 | 66 % | 0.4 – 50,000 |
| Centralized Waste Treaters | 17 | 86% | 1 – 53,000 |
| AFFF-Contaminated Sewers | 5 | 100% | 5 – 45,000 |
| Type II Sanitary Landfills | 48 | 94% | 6 – 5,000 |
| Type III Sanitary Landfills | 7 | 57% | 4 – 4,000 |
| Pulp, Paper and Paperboard | 4 | 100% | 2 – 190 |
| Commercial Industrial Laundry Facilities | 12 | 42% | 6 – 69 |

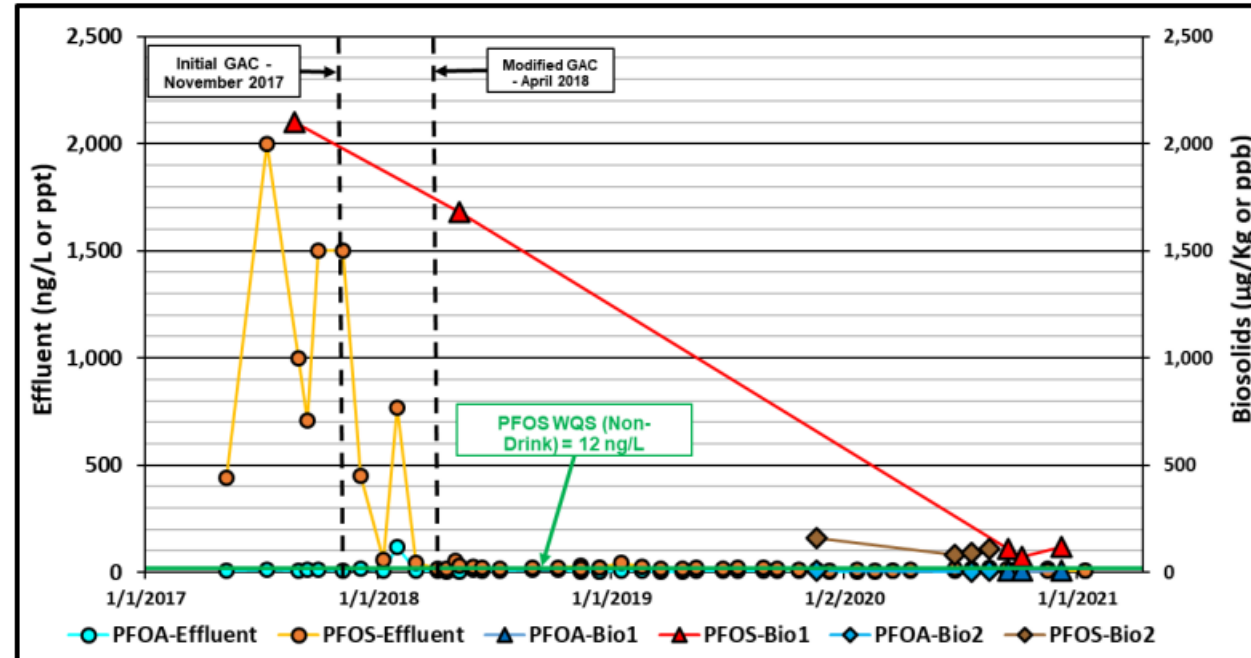
Source Reductions Examples - Michigan

Table 9. Substantial PFOS Reduction at WWTPs with Exceedances

| Municipal WWTP | Recent PFOS, Effluent* (ng/L) | PFOS Reduction (highest to most recent) | Actions Taken to Reduce PFOS |
|----------------|-------------------------------|---|---|
| Bronson WWTP | 5 | 99% | Treatment (GAC) at source (1) |
| Howell WWTP | 5 | 96% | Treatment (GAC/Resin) at source (1) |
| Ionia WWTP | <6 | 99% | Treatment (GAC) at source (1) |
| Kalamazoo WWTP | 5 | 90% | Treatment (GAC) at source (2), change of water supply |
| KI Sawyer WWTP | 9 | 96% | Eliminated leak of AFFF |
| Lapeer WWTP | 8.2 | 99% | Treatment (GAC) at source (1) |
| Wixom WWTP | 34 | 99% | Treatment (GAC) at source (1) |

*Data received as of December 31, 2020

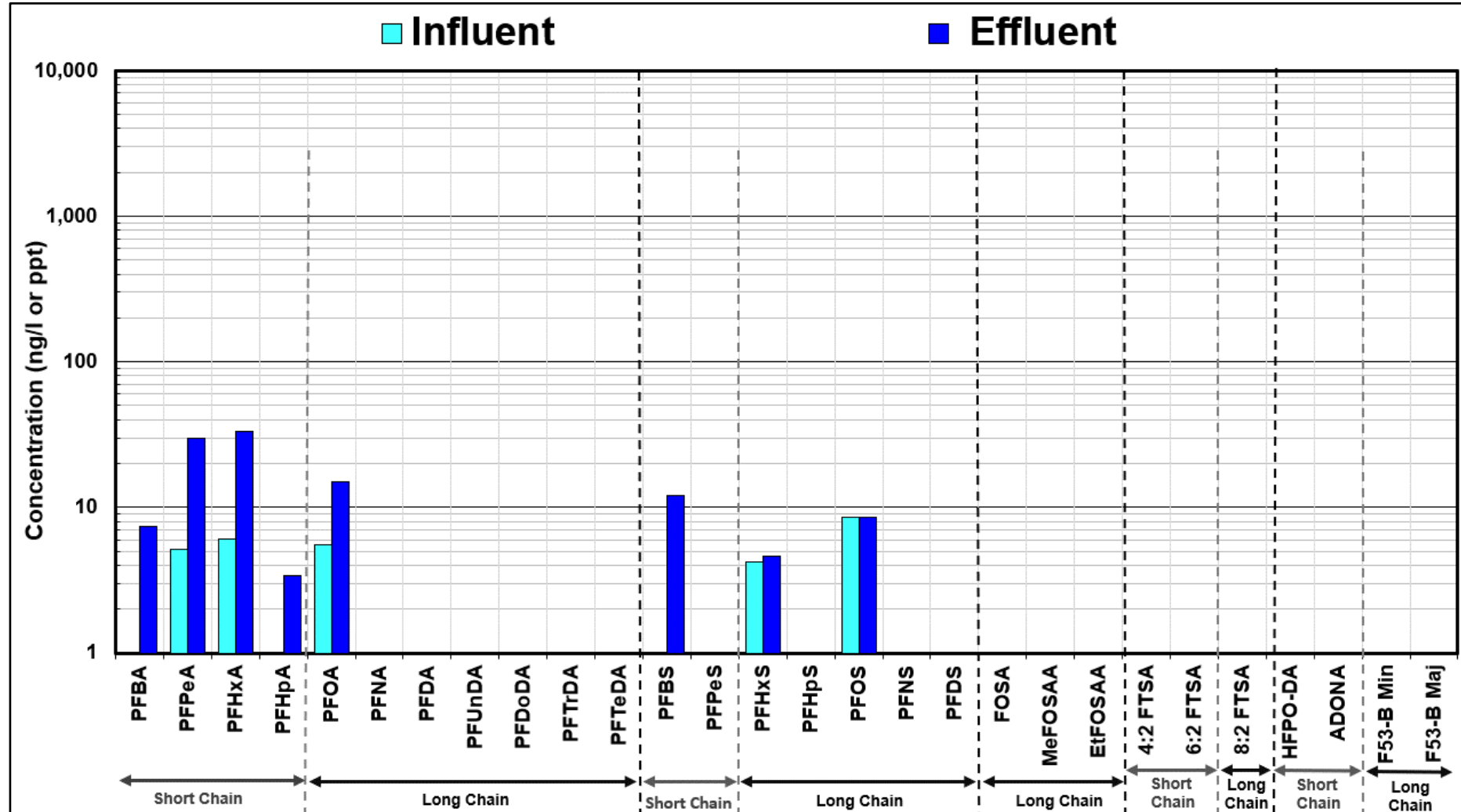
Figure 12. Temporal PFOA and PFOS Effluent and Biosolids Concentrations in Lapeer WWTP



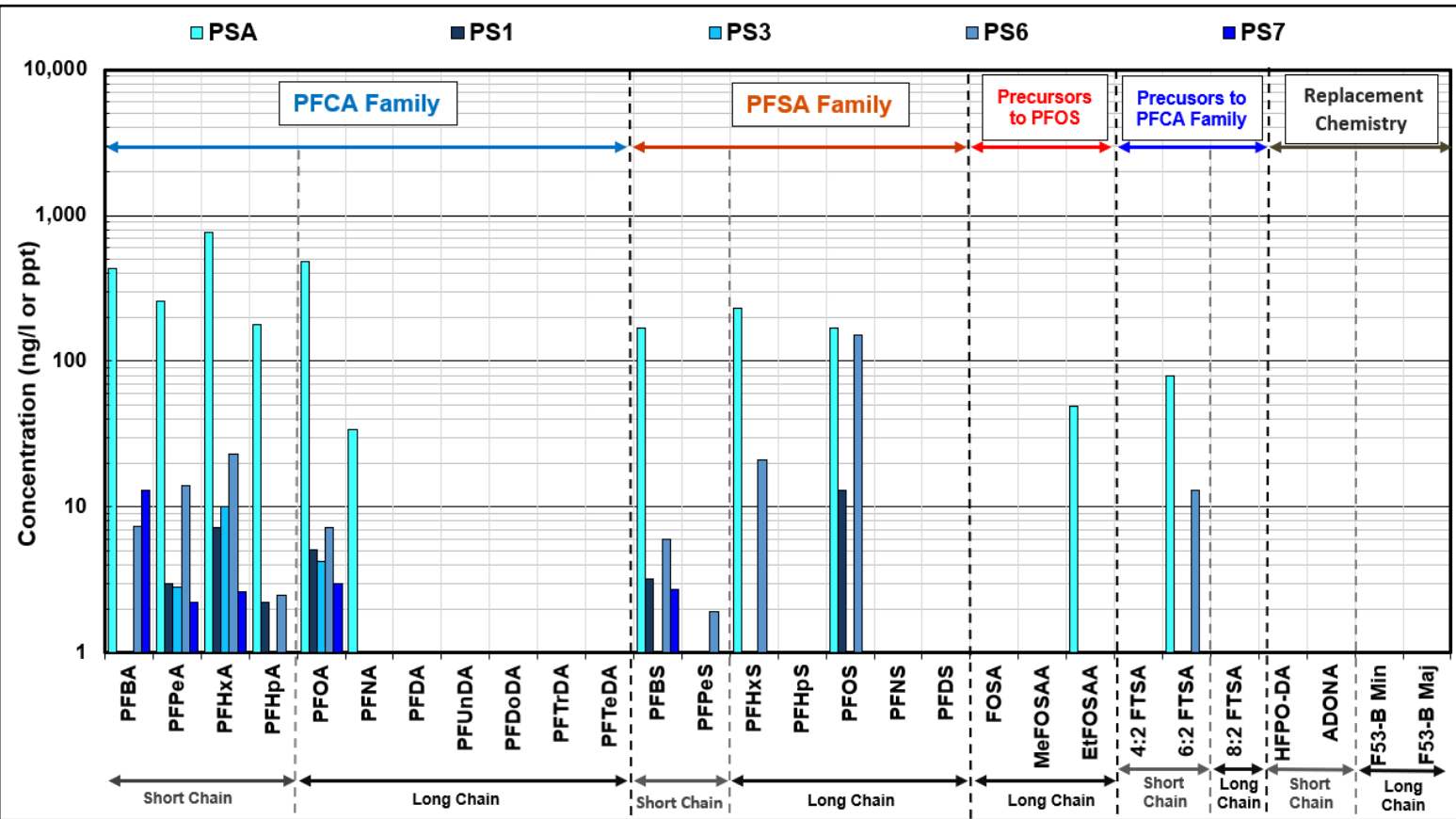
Example of Effectiveness of Source Reduction Strategies with Industrial Discharges to the System Resulting in PFOS Decreases over Time (AECOM Study, 2018-2019)

WWTP 17: Example of Source Investigation

- Design Flow - 16 MGD
- Service area Characteristics:
 - Domestic / Commercial
 - Moderate Industrial
 - Airport / DOD
 - Landfill Leachate
- Contact stabilization process with tertiary denitrification filters



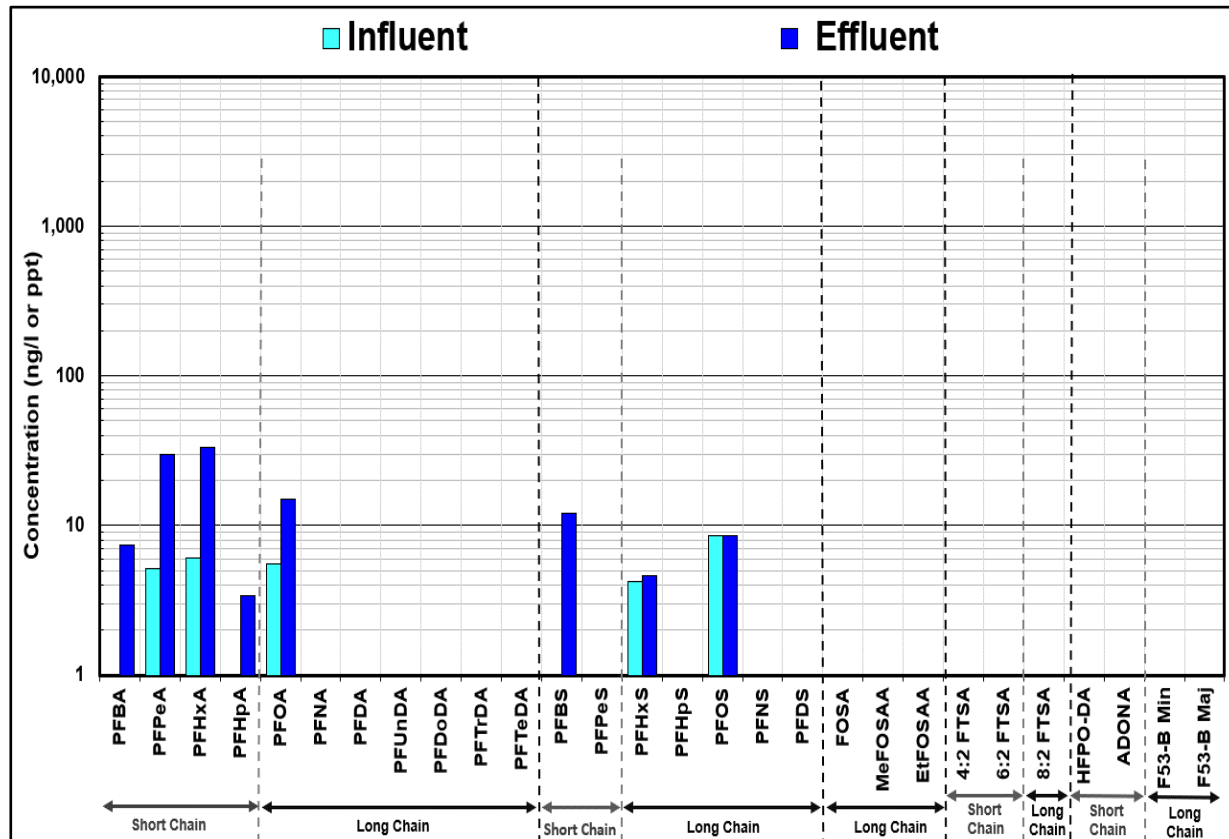
Pump Station PFAS Concentrations – WWTP 17



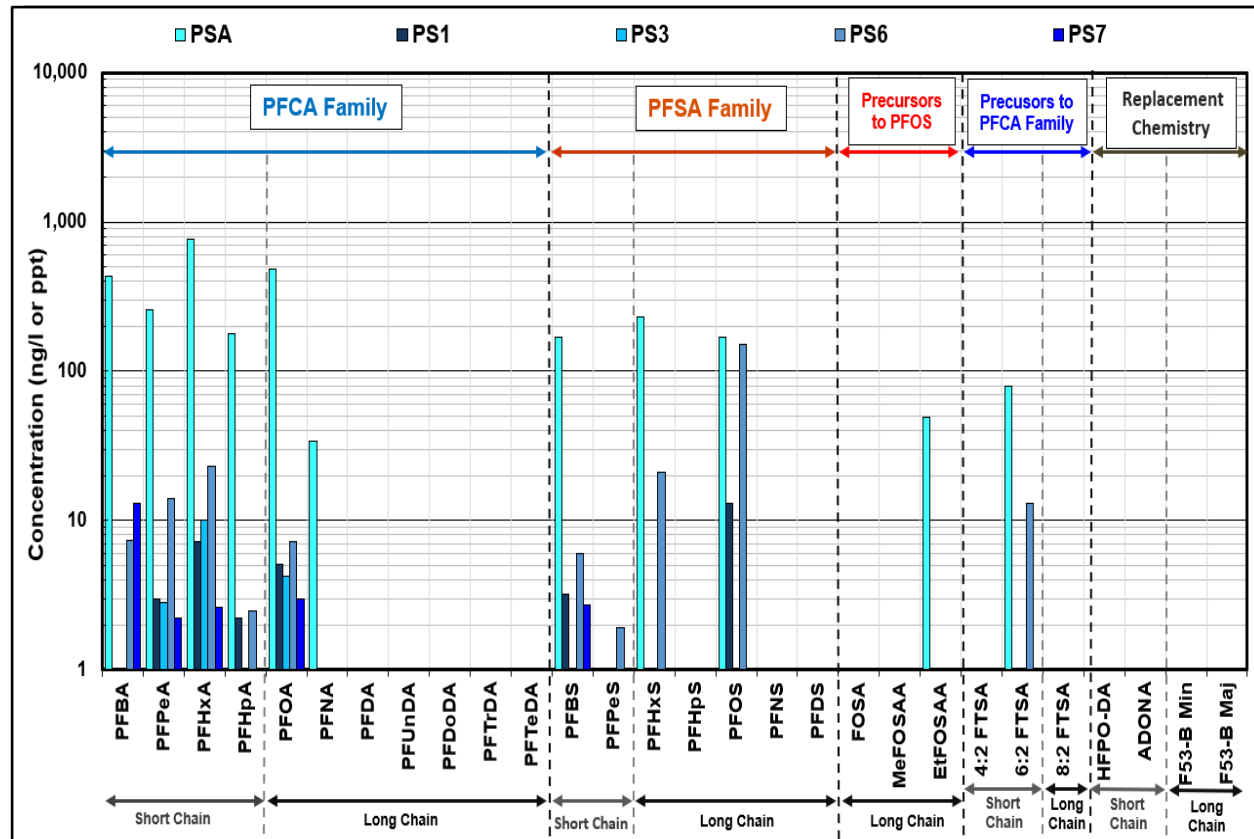
- Additional Testing Can Further Pinpoint PFAS Sources to WWTP
- Pump Stations Selected by Utility to better understand Sources and Contribution
- PSA and PS6 indicate potential sources to the WWTP and opportunities to investigate source controls
- PS1 and PS7 not contributing significantly to the WWTP

WWTP PFAS Concentrations in The Aqueous Process Flow

WWTP 17 - Concentrations



WWTP 17 – Contributing Pump Stations



Concluding Thoughts

Conclusions

- PFAS were detected in all sampled WWTPs
- Short-chain PFAS: tendency to remain in liquid
Long-chain PFAS: higher affinity to the biosolids
- Each facility is unique as variance observed between facilities and benchmarked studies
- Industrial influence on PFAS load evident in smaller facilities
- PFOS is likely to be the primary driver in the final effluent and beneficial reuse
 - Integrate strategies now (source controls, master planning)
- EPA strategic roadmap identifies upcoming considerations for wastewater utilities





IDENTIFY. RESOLVE.

Questions?

Thank You!

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