Utilities Department Water Treatment Plant

TECHNICAL MEMORANDUM

PFAS Treatment Feasibility Evaluation

March 2025 / Final (Revised March 20, 2025)

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Abbreviations

AACE	AACE International
$CaCO_3$	calcium carbonate
Carollo	Carollo Engineers
City	City of Pembroke Pines
CU	color units
DIW	deep injection well
DOM	dissolved organic matter
EBCT	empty bed contact time
FIX	fixed-bed ion exchange
FS200	Fluoro-Sorb 200
FTS	fluorotelomer sulfonate
GAC	granular activated carbon
gpm	gallons per minute
HBWC	health-based water concentration
HFPO-DA	Hexafluoropropylene Oxide Dimer Acid
HI	Hazard Index
HLR	hydraulic loading rate
IX	ion exchange
MCLs	maximum contaminant level
MCLGs	maximum contaminant level goals
MDL	method detection limit
MG	million gallons
mgd	million gallons per day
mg/L	milligrams per liter
mL/min	milliliters per minute
MRL	method reporting limit
ng/L	nanograms per liter
NF	nanofiltration
NPDWR	National Primary Drinking Water Regulations
NPV	net present value
O&M	operations and maintenance
PFAS	per- and polyfluoroalkyl substance
PFBA	perfluorobutanoic acid
PFBS	perfluorobutanesulfonic acid
PFCAs	perfluoroalkyl carboxylic acids
PFD	process flow diagram
PFDA	perfluorodecanoic acid
PFHpA	perfluoroheptanoic acid

PFHpS	perfluoroheptane sulfonic acid
PFHxA	perfluorohexanoic acid
PFHxS	perfluorohexane sulfonic acid
PFNA	perfluorononanoic acid
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonic acid
PFPeA	perfluoropentanoic acid
PFPeS	perfluoropentanesulfonic acid
PFSAs	perfluoroalkyl sulfonic acids
psi	pounds per square inch
RAA	running annual average
RCRA	Resource Conservation and Recovery Act
RO	reverse osmosis
RSSCT	Rapid Small-Scale Column Test
SFWMD	South Florida Water Management District
SU	standard units
T&O	taste and odor
TOC	total organic carbon
UCMR5	Unregulated Contaminant Monitoring Rule
USEPA	United States Environmental Protection Agency
Water ARC®	Carollo's Water Applied Research Center
WTP	water treatment plant
WUP	Water Use Permit

EXECUTIVE SUMMARY

ES.1 Overview

The City of Pembroke Pines (City) requested Carollo Engineers (Carollo) to provide a feasibility evaluation and economics analysis study for treatment of per- and polyfluoroalkyl substance (PFAS) at the City's Water Treatment Plant (WTP). The study's overarching goal is to identify the most cost-effective treatment approach to address PFAS contamination in the City's groundwater supply and help the City comply with the upcoming National Primary Drinking Water Regulations (NPDWR) for PFAS that are being promulgated by the US Environmental Protection Agency (USEPA).

The USEPA is requiring that public water systems meet these new regulatory requirements by April 26, 2029. In addition, compliance monitoring and public notification will start as soon as April 26, 2027. This means that the City will be required to report PFAS levels in its annual Consumer Confidence Reports (CCRs).

For this evaluation, a range of treatment alternatives, including granular activated carbon (GAC), single-reuse ion exchange (IX) resin, a novel PFAS-specific adsorbent, and high-pressure membranes, such as nanofiltration (NF) or reverse osmosis (RO) were evaluated. Conceptual designs and cost estimates were then developed to identify the most cost-effective alternative while also meeting the City's water quality and operation goals.

The recommended treatment alternative is to expand the existing City WTP's regenerable fixed-bed ion exchange (FIX) system to provide for more total organic carbon (TOC) removal and to add a PFAS treatment process, consisting of 10 lead-lag trains of IX pressure vessels. The estimated capital cost for the regenerable FIX system expansion and the addition of a PFAS treatment facility using IX resin is $54.5 million dollars. This is the least costly alternative of the four treatment options considered. NF or RO was not recommended due to the high capital and operating costs, concerns with the potential variability of treatment performance, and South Florida Water Management District (SFWMD) withdrawal permitting issues that will be discussed further in the study.

In order to meet EPA's compliance deadline, the City should proceed without delay in the procurement, design, and construction process of the treatment enhancements to its WTP. A detailed schedule is discussed further in the study.

Note: The costs shown in this study reflect an accuracy range from (-30 percent to +50 percent) in accordance with AACE. The applicable cost level classification for this evaluation was selected as a Class 4 Estimate, which reflects an order of magnitude estimate and is customarily used for screening and preliminary budget allocations before a detailed design is developed. Refer to Section 6, Cost Estimates for details.

SECTION 1 INTRODUCTION

The overarching goal of this study is to provide the required analysis and information for the City to make a sound decision on a treatment approach that will meet the City's water quality and operation goals to comply with the upcoming NPDWR for PFAS.

1.1 Project Objectives

The key objectives of this feasibility study were to:

- Determine the extent of PFAS treatment needed to meet the compliance requirements.
- Identify the most appropriate and cost-effective treatment and pretreatment approach to meet the City's water quality and operation goals.
- Define the next steps in the implementation of the selected PFAS treatment process through conceptual system design.
- Conduct life-cycle cost analysis to inform PFAS treatment economics at the City's WTP.

1.2 Background

1.2.1 Pembroke Pines Water Treatment Plant

The City owns and operates the Pembroke Pines WTP, which consists of lime softening, granular media filtration, side-stream regenerable FIX, disinfection, and finished water storage. A process flow diagram (PFD) of the existing treatment train is shown in Figure 1.1. An aerial view of the WTP and the main facilities is shown in Figure 1.2. The WTP's rated treatment capacity is 18 million gallons per day (mgd). The Water Use Permit (WUP) No. 06-00135-W issued by the South Florida Water Management District (SFWMD) permits the City an average Biscayne Aquifer groundwater allocation of 15.6 mgd, of which, 3.12 mgd is for the Central Wellfield and 12.48 mgd is for the Eastern Wellfield. In this study, the assumed design capacity for the PFAS treatment process is 18 mgd so as to match the current WTP capacity rating.

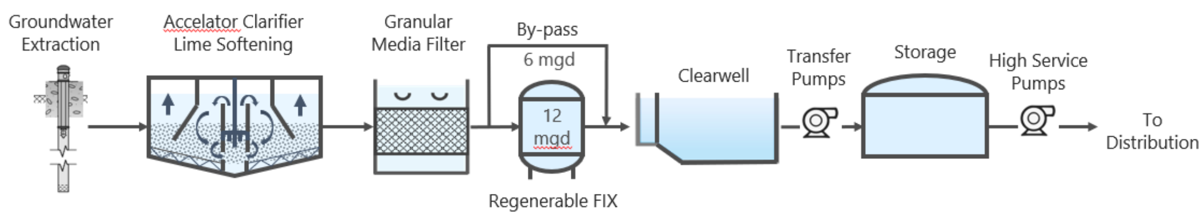


Figure 1.1 PFD of the Existing Treatment Train at the City's WTP

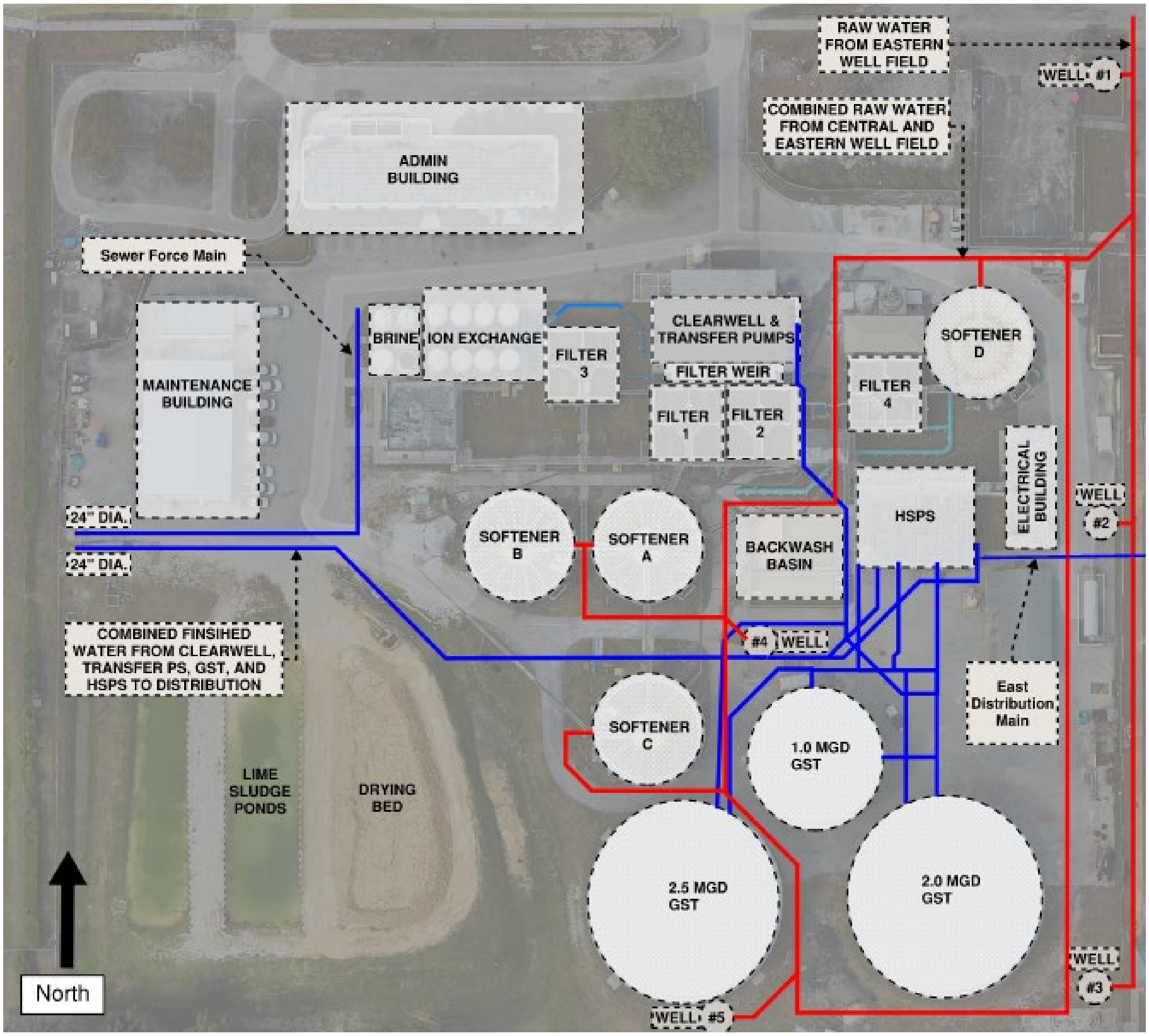


Figure 1.2 Aerial View of the City's WTP and Main Treatment Facilities

1.2.1.1 Raw Water System Overview

The WTP obtains its groundwater supply from two wellfields. The Eastern Wellfield is located about one mile east of the WTP and consists of four wells, while the Central Wellfield is located onsite at the WTP and consists of five wells. According to the SFWMD WUP, all nine wells are equipped with vertical turbine pumps, and the pumping capacities are as listed in Table 1.1.

Table 1.1 Summary of Raw Groundwater Extraction Wells and Pumping Capacities for the East and Central Wellfields

Wellfield	Well No.	Well Diameter (inch)	Well Depth (feet)	Pump Capacity (gpm)	Rated Total Dynamic Head (feet)
Central	1	12	112.5	2,000	45
	2	12	112	1,000	32
	3	12	111	525	58
	4	16	144	2,100	43
	5	16	115	2,350	57
East	6	10	94	1,580	52
	9	18	125	3,000	60
	10	18	123	2,800	60
	11	18	125	2,800	60

Notes:
gpm - gallons per minute

1.2.1.2 Regenerable Fixed-Bed Ion Exchange System Overview

Dissolved organic matter (DOM), often characterized by TOC or dissolved organic carbon, can negatively impact PFAS treatability of adsorption processes, such as GAC and IX resin. Historically, the City's WTP has been challenged with color from DOM present in the groundwater supply. As a result, a regenerable FIX system was implemented at the WTP for color (i.e., DOM or TOC) removal following conventional lime softening and granular media filtration.

The regenerable FIX system is located downstream of the granular media filters and consists of eight 12-foot diameter pressure vessels. The FIX system is divided into two treatment trains. Each train consists of four treatment units (i.e., pressure vessels) and three dedicated feed pumps. The feed water for the regenerable FIX system primarily comes from filter No. 3. However, system piping allows for effluent from any filters to feed the regenerable FIX system. A schematic of the flow configurations among the filters, the regenerable FIX system, and the clearwell is depicted in Figure 1.3. The regenerable FIX system design criteria are summarized in Table 1.2.

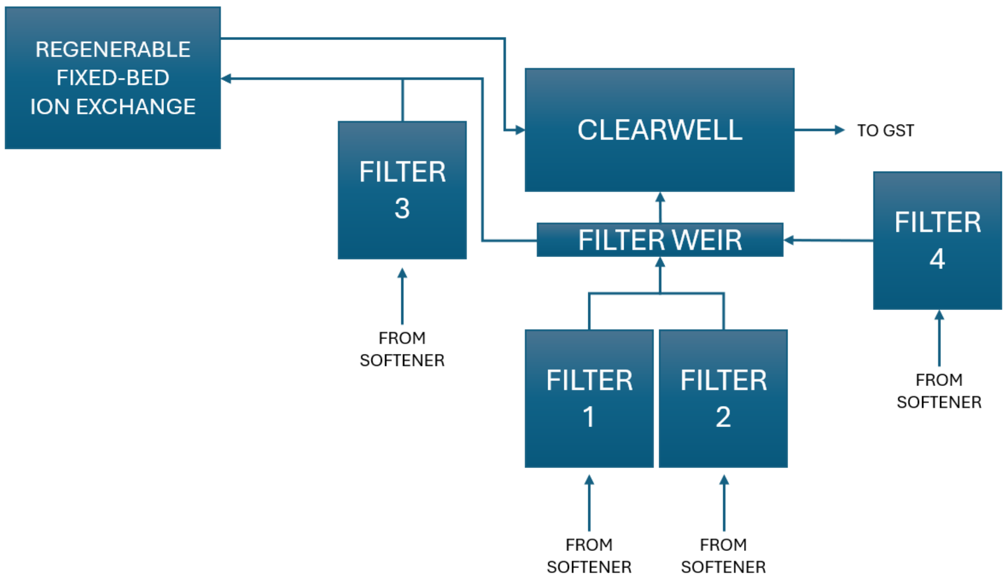


Figure 1.3 Flow Configurations Among Granular Media Filters, Regenerable FIX System, and the Clearwell at the WTP

Table 1.2 Critical Design Criteria for the Existing Regenerable FIX System

Parameter	Units	Value
Number of Treatment Trains	-	2
Number of Pressure Vessels per Treatment Train	-	4
Total Number of Pressure Vessels	-	8
Design Treatment Capacity	mgd	12
Design Treatment Flow per Vessel	mgd	1.5
Vessel Internal Diameter	feet	12
HLR at Design Flow	gpm/square feet	9.2
Resin Type	-	Type I Strong Base Anion Exchange
Resin Volume per Vessel	cubic feet	424
EBCT at Design Flow	minute	3.0
Resin Bed Depth	feet	3.75
Design Regeneration Waste Volume per Vessel	gallons/regeneration	20,300
Design Backwash Flow Rate	gpm	340
Design Slow Rinse Flow Rate	gpm	107
Design Fast Rinse Flow Rate	gpm	1,050
Design Salt Usage per Regeneration Cycle	pounds	4,200

Notes:
EBCT - empty bed contact time; HLR - hydraulic loading rate

For color or TOC removal, the spent FIX resin needs to be regenerated once the target effluent color or TOC concentration is reached. Alternatively, spent resin is regenerated based on system throughput or the total volume of water treated between two regeneration cycles. According to the resin analysis performed by Kurita® in February 2024, the existing strong base anion exchange resin was moderately fouled by DOM, and only 68 percent total resin capacity remained. Due to concerns about resin fouling and potential deterioration in resin performance, each vessel is currently scheduled to regenerate after a system throughput of 8 million gallons (MG) of water treated. This regeneration frequency is greater than the initial throughput (i.e., 10 MG) recommended by the resin manufacturer, aiming at maintaining the performance of the FIX system and the treated water quality. In addition to regenerating the resin at a higher frequency, the City also performed a "caustic squeeze" in August 2024, which is a cleaning procedure with a more aggressive regenerant chemical (i.e., sodium hydroxide) to restore the resin capacity lost from organic fouling. Follow-up resin analysis performed by Kurita® in December 2024 indicated a slight increase in total resin capacity but is expected to continue to degrade. Although the resin capacity was not fully restored, the treatment performance remains acceptable. Therefore, continued performance monitoring, subsequent cleaning when required, and proactive planning for resin replacement are recommended. A phased schedule for resin replacement (e.g., replace resin in one to two vessels at a time) are recommended as the resin approaches its typical life expectancy (i.e., 10 years).

1.2.2 PFAS

1.2.2.1 Background

PFAS constitute a large family of manufactured chemicals that have been used in a wide range of consumer, commercial, and industrial products such as nonstick cookware, waterproof clothing, and firefighting foams since the 1940s. PFAS are chemically, biologically, and thermally stable and can accumulate in humans, animals, and the environment over time. Today, PFAS are ubiquitous in every stage of the water cycle at trace concentrations (i.e., parts per trillion or nanograms per liter [ng/L]). Exposure to PFAS can result in adverse health outcomes, such as developmental effects, cancer, liver effects, immune effects, and thyroid effects, among others.

1.2.2.2 National Primary Drinking Water Regulations for PFAS

In April 2024, the United States Environmental Protection Agency (USEPA) announced the NPDWRs for six PFAS. Table 1.3 lists the finalized MCLs and maximum contaminant level goals (MCLG) for individual PFAS.

Table 1.3 National Primary Drinking Water Regulation for Six PFAS

Compound	MCL (Enforceable Levels)	MCLG (Health-Based, Non-Enforceable Levels)
PFOS	4.0 ng/L (1)	Zero
PFOA	4.0 ng/L	Zero
PFHxS	10 ng/L	10 ng/L
PFNA	10 ng/L	10 ng/L
HFPO-DA (commonly referred to as GenX chemicals)	10 ng/L	10 ng/L
Mixtures containing two or more of PFHxS, PFNA, HFPO-DA, and PFBS	1.0 (unitless) HI	1.0 (unitless) HI

Notes:
HFPO-DA - hexafluoropropylene oxide dimer acid; HI - hazard index; PFBS - perfluorobutanesulfonic acid; PFHxS - perfluorohexane sulfonic acid; PFNA - perfluorononanoic acid; PFOA - perfluorooctanoic acid; PFOS - perfluorooctane sulfonic acid
(1) All MCL compliance will be determined based on running annual average (RAA) concentrations from quarterly sampling.

The HI is calculated as a sum of fractions of the measured concentration of each of the four PFAS divided by its corresponding health reference value (i.e., health-based water concentration, [HBWC]), as shown in the following equation.

$$HI = \frac{[PFBS]}{2{,}000\ ng/L} + \frac{[PFHxS]}{10\ ng/L} + \frac{[PFNA]}{10\ ng/L} + \frac{[HFPO\text{-}DA]}{10\ ng/L}$$

In addition, the final rule requires public water systems to monitor these PFAS, notify the public of their levels in drinking water by April 26, 2027, and comply with the MCLs by April 26, 2029.

1.2.3 Existing Water Supply Assessment

1.2.3.1 South Florida Water Management Water Use Permit

The WTP water supply is permitted under WUP No. 06-00135-W issued by the SFWMD in 2010 with an annual groundwater allocation of 5,696 MG, or an average of 15.6 mgd from the Biscayne Aquifer. The permit specifies the following key withdrawal limitations and will expire on August 18, 2030:

- Maximum annual withdrawal of 1,139 MG (3.12 mgd) from the Central Wellfield (on-site).
- Maximum monthly withdrawal of 103.29 MG (0.28 mgd) from the Central Wellfield (on-site).
- Maximum annual withdrawal of 4,556 MG (12.48 mgd) from the East Wellfield (off-site).
- Maximum monthly withdrawal of 413.16 MG (1.13 mgd) from the East Wellfield (off-site).

According to the City of Pembroke Pines Utilities Comprehensive Master Plan (Jacobs, 2023), records of daily raw and treated water flows between 2015 and 2020 showed an average finished water production rate of 13.4 mgd, which is below the current groundwater allocation of 15.6 mgd. In addition, the most recent maximum day demand was recorded at 16.42 mgd, which is below the plant's rated capacity of 18 mgd. However, if a high-pressure membrane-based technology is implemented, such as NF (with typical 85 percent recovery), the raw water supply required would have to be increased to 21.2 mgd. This conversion would affect the City's capability to stay within the current groundwater allocation without considering an increase to the current withdrawal permit, alternative water supplies, such as aquifer storage and recharge, increased water conservation measures, or reuse.

SECTION 2 WATER QUALITY ASSESSMENT

2.1 Raw Water Quality

The historical raw water quality data are reported in this section to document the key characteristics of the source water as they relate to the current finished water quality goals and how these will impact future PFAS treatment performance. Table 2.1 summarizes the concentration distributions for pH, alkalinity, calcium hardness, magnesium hardness, total hardness, iron, and color in the raw groundwater supply.

Table 2.1 Summary of Historical Raw Groundwater Quality

Parameter	Units	5th Percentile	Median, or 50th Percentile	95th Percentile
pH	SU	7.1	7.5	7.8
Calcium Hardness	mg/L as $CaCO_3$	175	208	245
Magnesium Hardness	mg/L as $CaCO_3$	8	24	59
Total Hardness	mg/L as $CaCO_3$	207	232	270
Alkalinity	mg/L as $CaCO_3$	179	209	256
Iron	mg/L	0.77	0.97	1.3
Apparent Color	CU	40	51	66

Notes:
$CaCO_3$ - calcium carbonate; CU - color units; mg/L - milligrams per liter; SU - standard units

PFAS occurrence in the raw groundwater supply was characterized once for individual wells on October 17, 2023. Table 2.2 summarizes the PFAS sampling results for each groundwater well from the October 2023 sampling event. Among the six regulated PFAS, PFOA and PFOS were found at concentrations exceeding their respective MCLs of 4.0 ng/L. Therefore, a treatment process is required for the City to comply with the upcoming NPDWR for PFAS.

Table 2.2 PFAS Sampling Results for Individual Wells From the October 2023 Sampling Event

PFAS	Units	Raw Groundwater Wells								
		PW-1	PW-2	PW-3	PW-4	PW-5	PW-6	PW-9	PW-10	PW-11
PFBA	ng/L	9	5.4	4.1	8.3	7.7	14	18	11	17
PFPeA	ng/L	16	9.2	8.1	16	15	22	45	18	40
PFHxA	ng/L	12	7.1	6.3	11	11	13	35	13	28
PFHpA	ng/L	6.1	4.1	3.3	6.1	5.8	6	14	7.1	14
PFOA	**ng/L**	**11**	**8**	**6**	**8.7**	**9.6**	**15**	**12**	**15**	**16**
PFNA	**ng/L**	**1.7**	**1.6 J**	**1.6**	**1.8**	**1.7**	**3.4**	**2.8**	**2.9**	**3**
PFDA	ng/L	1.0 J (1)	<1.7 (2)	<1.6	<1.7	<1.6	2.3	1.2 J	1.6 J	1.3 J
PFBS	**ng/L**	**6.8**	**3.6**	**2.7**	**8.1**	**6.6**	**16**	**11**	**14**	**12**
PFPeS	ng/L	<1.7	<1.7	<1.6	<1.7	<1.6	<1.7	<1.7	<1.7	0.98 J
PFHxS	**ng/L**	**6.8**	**4.3**	**3.6**	**7.4**	**6.2**	**5.4**	**6.2**	**8.1**	**8.3**

PFAS	Units	Raw Groundwater Wells								
		PW-1	PW-2	PW-3	PW-4	PW-5	PW-6	PW-9	PW-10	PW-11
PFHpS	ng/L	<1.7	<1.7	<1.6	<1.7	<1.6	<1.7	<1.7	1.0 J	0.88 J
PFOS	ng/L	32	23	21	34	29	61	37	64	53
6:2 FTS	ng/L	9.5	7.3	10	4.4	11	<4.2	77	2.4 J	64
8:2 FTS	ng/L	<1.7	<1.7	<1.6	<1.7	1.1 J	<1.7	7.8	<1.7	6.2

Notes:
FTS - fluorotelomer sulfonate; PFBA - perfluorobutanoic acid; PFDA - perfluorodecanoic acid; PFHpA - perfluoroheptanoic acid; PFHpS - perfluoroheptane sulfonic acid; PFHxA - perfluorohexanoic acid; PFPeA - perfluoropentanoic acid; PFPeS - perfluoropentanesulfonic acid
(1) A J-flagged value, indicating an estimated concentration above the laboratory method detection limit (MDL) but below the method reporting limit (MRL).
(2) Values with "<" represent less than the MRL for a specific PFAS.
(3) Regulated PFAS are highlighted in bold, with HFPO-DA or GenX not shown because it was not detected in any of the raw groundwater wells.

2.2 Finished Water Quality

As the PFAS treatment process is typically integrated at the end of a treatment train, preceding disinfection and finished water storage, the finished water quality can be considered as representative of the feed water quality for the required PFAS treatment process. Historical finished water quality is listed below in Table 2.3.

Table 2.3 Summary of Historical Finished Water Quality for the City's WTP

Parameter	Units	5th Percentile	Median or 50th Percentile	95th Percentile
pH	SU	8.5	9.0	9.7
Calcium Hardness	mg/L as $CaCO_3$	53	69	90
Total Hardness	mg/L as $CaCO_3$	64	79	100
Alkalinity	mg/L as $CaCO_3$	30	46	70
Iron	mg/L	0.01	0.06	0.21
Apparent Color	CU	2	8	18
Total Chlorine	mg/L as chlorine	3.2	3.9	4.5
Turbidity	nephelometric turbidity unit	0.09	0.24	0.84

Regarding PFAS, two finished water samples were collected and analyzed in March and September 2023 as part of the fifth Unregulated Contaminant Monitoring Rule (UCMR5) requirements. Detectable PFAS results from the two UCMR5 sampling events are summarized in Table 2.4. Although no paired raw and finished water samples have been collected and analyzed for PFAS, their concentrations were generally comparable between the raw groundwater and the finished water from different sampling events, indicating no significant PFAS removal by the existing treatment processes at the WTP.

Based on the available PFAS occurrence data, PFOA and PFOS are the driving PFAS elements in the City's groundwater supply, requiring approximately 70 percent and 90 percent removal to meet their respective MCLs. Given the high levels of PFAS removal required, the treatment for the entire WTP flow is required and a blended approach where only part of the flow is treated is not adequate to meet the finished water PFAS goals.

Table 2.4 Summary of UCMR5 Finished Water PFAS Sampling Results

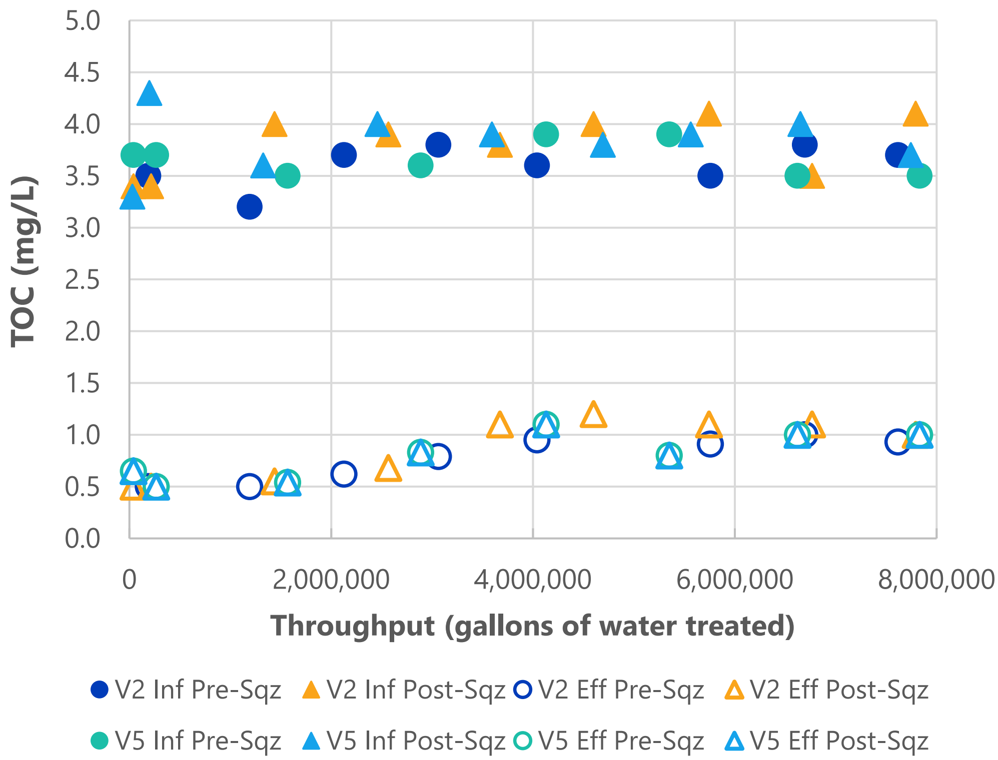
PFAS	Units	Sampling Date	Result	MCL
PFBA	ng/L	3/17/2023	12.2	-
	ng/L	9/12/2023	9.2	
PFBS	ng/L	3/17/2023	9.8	-
	ng/L	9/12/2023	7.1	
PFPeA	ng/L	3/17/2023	23.9	-
	ng/L	9/12/2023	17.7	
PFHxA	ng/L	3/17/2023	18.4	-
	ng/L	9/12/2023	13.4	
PFHxS	ng/L	3/17/2023	9.1	10
	ng/L	9/12/2023	6.1	
PFHpA	ng/L	3/17/2023	10.0	-
	ng/L	9/12/2023	6.7	
PFOA	ng/L	3/17/2023	14.4	4.0
	ng/L	9/12/2023	10.2	
PFOS	ng/L	3/17/2023	34.7	4.0
	ng/L	9/12/2023	23.3	
6:2 FTS	ng/L	3/17/2023	39.1	-
	ng/L	9/12/2023	28.0	

2.3 Total Organic Carbon Treatment Performance by the Existing Regenerable Fixed-Bed Ion Exchange System

The design capacity for the regenerable FIX system is 12 mgd, which is two-thirds of the WTP's rated treatment capacity (i.e., 18 mgd). Treated effluent from the regenerable FIX system and bypass flow from the filters are blended at an approximate ratio of 2:1 in the clearwell for final disinfection.

In addition to regenerating the spent resin at a higher frequency, targeting a system throughput of 8 MG, the City performed a "caustic squeeze" in August 2024, which is a cleaning procedure to restore the resin capacity from organic fouling. As part of this study, Carollo systematically evaluated the TOC treatment performance of the regenerable FIX system before and after the caustic squeeze to determine the effectiveness of this cleaning procedure.

Carollo sampled TOC in the FIX system feed and in Vessels 2 and 5 effluents on a daily basis between two regeneration cycles as well as before and after caustic squeeze. The resulting TOC sampling data are listed in Figure 2.1. The results are used to determine if current resin generation frequency is optimal and if the fouled resin capacity is restored by a caustic squeeze.



Notes: Influent (solid symbols) and effluent (empty symbols) TOC concentrations for Vessel 2 (train 1) and Vessel 5 (train 2) before (circles) and after (triangles) caustic squeeze.

Figure 2.1 FIX Influent and Effluent TOC Concentrations as a Function of Throughput (Total Volume of Water Treated per Vessel) Before and After Caustic Squeeze

Key observations from the TOC characterization task are noted as follows:

- Results indicated that filter effluent (i.e., feed water for the two FIX treatment trains) TOC was stable, with an average TOC concentration of approximately 4 mg/L.
- Effluent TOC increased as a function of system throughput or total volume of water treated per vessel, ranging from 0.5 mg/L right after regeneration up to 1.0 mg/L at the end of the operation time (or after 8 MG of water treated by each vessel). This is consistent with typical regenerable FIX performance since it is a non-steady state treatment process.
- High TOC percent removal (i.e., 80 percent at the beginning of a new service cycle to 70 percent before the next regeneration cycle) was achieved despite the loss of resin capacity due to organic fouling. Subsequent resin testing by Kurita in December 2024, indicated a slight increase in resin capacity, however, this is expected to continue to degrade. Continued monitoring, cleaning, and phased replacement of resin is recommended.
- The post-caustic squeeze effluent TOC concentrations overlapped with those obtained before the resin cleaning procedure, which indicates that caustic squeeze had no impact on TOC treatment performance by the regenerable FIX system.

The level of TOC pretreatment attained by the existing regenerable FIX system makes the downstream PFAS treatment more viable and cost-effective. This will be discussed in detail in the following section.

SECTION 3 TREATMENT TECHNOLOGY EVALUATION

PFAS treatment technologies are rapidly evolving, and a variety of treatment technologies have been evaluated for PFAS treatment in drinking water. The conventional treatment processes commonly used for drinking water treatment, such as lime softening, granular media filtration, and chlorination, cannot effectively remove PFAS. Currently, only a few treatment technologies are mature enough and appropriate for full-scale drinking water treatment. However, novel or proprietary adsorbents have emerged in recent years and have demonstrated efficient PFAS removal. Advanced treatment processes that can effectively remove PFAS from drinking water include:

- GAC.
- IX resin.
- Novel adsorbent such as Fluoro-Sorb® 200 (FS200).
- High-pressure membranes (i.e., NF or RO).

Each of these technologies has its unique advantages and challenges for PFAS treatment, which are discussed in the following sections. It should be noted that the USEPA has only designated GAC, IX resin, and high-pressure membranes as best available technologies for PFAS treatment in drinking water.

3.1 Granular Activated Carbon

GAC is a porous material with a very high specific surface area that is effective for the adsorption of many dissolved contaminants. Studies and full-scale installations have shown GAC can effectively remove PFAS from drinking water. In general, GAC adsorbs PFOA, PFOS, and other long-chain PFAS better than shorter-chain PFAS. GAC also provides secondary benefits as a treatment barrier for other contaminants, such as disinfection byproduct precursors (i.e., TOC), taste and odor (T&O) compounds, and volatile organic compounds. GAC performance for PFAS treatment can vary widely depending on carbon type, EBCT, adsorber configuration (lead-lag vs. staged-parallel), influent PFAS concentration and speciation, and the presence of competing adsorbates such as TOC.

GAC can be installed in gravity contactors or pressure vessels. Typically, gravity contactors are better suited to large-scale systems (e.g., surface water treatment facilities) and when large pressure drops are undesirable because of their effect on existing plant hydraulics. Pressure vessels enclose the GAC and can be operated over a wide range of flow rates. Pressure vessels are modular and thus provide high operation flexibility, particularly for small-scale systems or applications where treatment flows are highly variable. The limiting factor is that vessel volumes are standardized, and large number of treatment units would be required as the treatment capacity increases. Lastly, gravity contactors or water retaining concrete structures are more complex to design and construct than pressure vessels and will take longer to implement.

While GAC is four to five times less expensive than IX resin on a unit volume basis, a longer EBCT is required (typically, 10 to 20 minutes) for post-filter GAC adsorbers, resulting in a larger system footprint and higher capital costs. GAC backwashing and rinsing are critical during system startup and in the period following GAC changeout to remove fines from the virgin or reactivated GAC. Additionally, arsenic can leach from bituminous coal-based GAC during startup, which can be addressed by sufficient backwashing or providing the facility with ability to waste initial adsorber effluent (i.e., filter-to-waste). Alternatively, pre-acid-rinsed or pre-conditioned GAC can be used to strip arsenic prior to GAC installation, but pre-treated GAC often has a higher unit cost than non-acid-rinsed or non-pretreated GAC.

PFAS treatment by GAC is a non-destructive process and will generate a treatment residual that contains PFAS. For this reason, GAC replacement requires proper disposal of the spent media. The hazardous classification of PFAS-laden spent media and its disposal requirements are uncertain. However, the current best practice is to utilize turnkey service providers (e.g., Calgon Carbon, Evoqua, Aqueous Vet, etc.) to haul away the spent GAC while supplying virgin GAC for replacement. The spent GAC is typically regenerated, reactivated, and then re-sold to non-potable users instead of being returned to the treatment facility for reuse. If PFAS-laden GAC is classified as hazardous waste under Resource Conservation and Recovery Act (RCRA), the spent GAC will need to be thermally regenerated and reactivated at a RCRA Subtitle C permitted hazardous GAC reactivation facility, resulting in an increase in long-term operations and maintenance (O&M) costs associated with GAC changeouts.

3.2 Ion Exchange

The IX treatment process typically consists of pressure vessels filled with IX resin that removes dissolved contaminants as water passes through the resin bed. Non-regenerable (or single-use) strong base anion exchange resin in the chloride form is commonly used for PFAS treatment. Contaminant removal occurs when the anionic contaminant, such as PFAS, exchanges with the chloride counter ion. PFAS removal by IX resin occurs through dual mechanisms, including classic "exchange" reactions and via PFAS adsorption to the resin beads. A visualization of the IX mechanism is presented in Figure 3.1. Depending on the presence of co-contaminants (e.g., TOC, nitrate, etc.), competition for adsorption sites can be observed, decreasing PFAS removal efficiency.

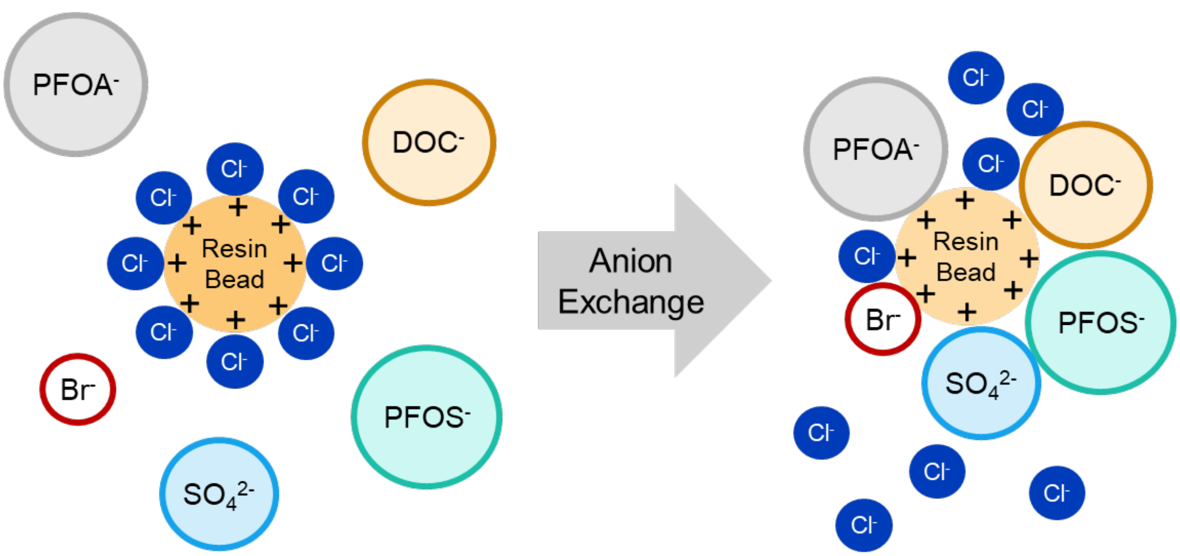


Figure 3.1 Visualization of PFOA, PFOS, and Other Anionic Contaminant Removal Through IX

While IX resin is four to five times the cost of GAC on a unit volume basis, shorter EBCT is required (typically, 2 to 3 minutes per vessel), resulting in fewer treatment units required, a smaller system footprint, and lower capital investments. However, PFAS-adsorbing IX resin does not remove other contaminants of concern and therefore does not provide secondary water quality benefits as GAC does.

It is noteworthy that IX resin is sensitive to chlorine and other oxidants, which can cause resin degradation before exhaustion. IX resin is also susceptible to solids fouling so the reliable removal of influent TOC is critical for this process.If present, residual chlorine will need to be quenched prior to the PFAS-adsorbing IX process to protect the resin from potential oxidation and degradation, like in the existing regenerable FIX system used for TOC removal.

Following exhaustion of the PFAS removal capacity, the spent single-use IX resin will also require proper disposal. The current best practice is to utilize turnkey service providers (e.g., Calgon Carbon, Evoqua, AqueoUS Vets, etc.) to haul away the spent resin while supplying virgin resin for replacement. The spent resin is typically incinerated at an RCRA Subtitle C permitted hazardous waste incineration facility instead of being landfilled, even though PFAS-laden IX resin has not been classified as hazardous water treatment residual under RCRA.

3.3 Novel Adsorbent Fluoro-Sorb 200

In addition to GAC and IX resin, novel adsorbents, such as CETCO FS200, are under development for drinking water PFAS treatment. FS200 is a National Science Foundation 61 certified, proprietary, surface-modified bentonite clay material. FS200 has shown promise in removing both long- and short-chain PFAS in pilot-scale treatment studies, and there are approximately 20 ongoing pilot studies in the Northeast US and in the state of California for PFAS treatment in surface and groundwater supplies.

FS200 also has been claimed to be less susceptible to chlorine oxidation and organic fouling than GAC or IX resin, which are desirable characteristics for the application in this study. However, there currently is only one full-scale drinking water treatment installation of FS200, located at the New Jersey American Water's 1.2-mgd Beckett Station groundwater treatment facility in Swedesboro, New Jersey (installed in 2023). FS200 was selected over GAC and IX resin at this facility because it is more chlorine tolerant and avoids a dechlorination step between the existing greensand filters for manganese removal and PFAS treatment. Due to the one single installation, there is limited understanding of the operational requirements for FS200 and its long-term performance and life-cycle cost for PFAS treatment.

Due to limited full-scale installations, FS200 media has not been replaced and the best practice for spent FS200 disposal remains unknown. However, based on personal communications with turnkey service providers, the spent FS200 could be incinerated at an RCRA Subtitle C permitted hazardous waste incineration facility due to the similarity between FS200 and IX resin in media volume.

While novel adsorbents have limited records in full-scale drinking water applications, both GAC and IX pressure vessels can be designed to accommodate alternative adsorbents in the future if they prove advantageous as the technology matures.

3.4 Nanofiltration and Reverse Osmosis Membranes

Pressure membranes, such as NF and RO, broadly remove both long- and short-chain PFAS and other dissolved constituents, including TOC, hardness, salts, and pathogens. NF/RO systems are currently used in many communities in Florida mainly for groundwater softening or desalination, such as brackish groundwater supplies from the Floridan Aquifer.

It is noteworthy that different NF/RO membranes have varying treatment effectiveness for PFAS. Currently, there is a lack of full-scale performance data for various membrane products in PFAS treatment. Since treatment performance depends on site-specific water quality conditions, bench and pilot-scale NF/RO testing would be recommended if membrane-based treatment technologies are selected for further consideration for full-scale implementation at the City’s WTP.

Membrane systems typically carry high capital and operating costs relative to other treatment technologies but also provide benefits and levels of treatment unattainable by other technologies. For example, hardness and total dissolved solids reduction can also be accomplished with pressure membranes, but not with the other evaluated technologies.

The pumping requirements for NF/RO systems typically result in high energy costs. Perhaps most importantly, reject stream (or "brine") management and disposal is often a limiting factor that determines the feasibility of this technology. Water recovery of two- to three-stage NF/RO systems typically ranges from 70 to 85 percent, with brine compromising the remaining 15 to 30 percent of the total treatment flow. Innovative RO technologies, such as closed-circuit RO and flow reversal RO with multiple stages, can bring overall water recovery rates upwards of 90 to 95 percent. However, this still results in approximately 5 to 10 percent of the total treatment flow as waste streams, which is costly from a water resources perspective as well as from a brine management and disposal perspective.

Sewer discharge permitting of PFAS-laden brine could be extremely challenging thus limiting the application of NF/RO for PFAS treatment. Deep injection well (DIW) disposal, while high in capital and O&M costs, has previously proven to be a viable option in Florida for brine disposal at several facilities. There are increasing concerns about PFAS being recycled back into the aquatic environment and the regulatory landscape for disposal of PFAS laden concentrate and solids is uncertain at this time.

If a high-pressure membrane-based technology is implemented to produce 18 mgd permeate flow, at a hypothetical 85 percent recovery rate, the raw water supply required (21.2 mgd) will exceed the permit allocation (15.6 mgd) as early as 2025. Alternative water supplies, such as additional Biscayne Aquifer allocations, new extraction wells for supplies from the Floridan Aquifer, and other strategies as potable reuse would need to be further investigated to make up the identified water shortfall. Based on recent experience on similar projects, SFWMD may not approve additional withdrawal allocations from the Biscayne Aquifer needed to implement membrane technology.

3.5 Summary of Treatment Technology Evaluation

Table 3.1 presents a comparison of PFAS treatment technologies mentioned above and their respective advantages and disadvantages.

Table 3.1 Comparison of Available Treatment Technologies for PFAS

Technology	Advantages	Disadvantages
GAC	▪ Proven advanced water treatment technology for PFAS removal. ▪ Provides a treatment barrier for other contaminants (e.g., disinfection byproduct precursors, T&O compounds, etc.). ▪ Lower head loss than IX, which requires lower energy use from pumping and standby generation power perspectives. ▪ Upstream process upsets and water quality changes that result in particulates accumulating in the GAC can be easily backwashed out. ▪ Spent GAC can be regenerated, reactivated, and re-sold to non-potable water sectors to lower media costs. ▪ Treatment units (e.g., pressure vessels) can be readily retrofit with either IX resin or novel adsorbents, maximizing flexibility for changing water quality, treatment goals, or treatment technology in the future.	▪ Longer EBCT is required, resulting in a larger system footprint. ▪ Less effective in short-chain PFAS removal. ▪ GAC fouling by competing contaminants (e.g., TOC) can lead to early PFAS breakthrough or frequent GAC changeout. ▪ Non-steady state treatment process, requiring attentive monitoring of PFAS breakthrough from treatment units to schedule GAC replacements.
IX	▪ Proven advanced water treatment technology for PFAS removal. ▪ Faster adsorption kinetics, shorter EBCT, and a smaller system footprint. ▪ Treatment units (i.e., pressure vessels) can be designed to accommodate novel adsorbents (but not GAC due to smaller vessel size), providing flexibility for changing water quality, treatment goals, or treatment technology in the future.	▪ Resin fouling by competing contaminants (e.g., TOC) can lead to early PFAS breakthrough or frequent resin changeout. ▪ Greater head loss than GAC, which requires higher energy use from pumping and standby generation power perspectives. ▪ Upstream process upsets and water quality changes that result in particulates accumulating in the IX resin bed require removal of the top layer of resin, which is maintenance intensive. Backwashing during normal operation is strictly not recommended by resin suppliers. ▪ Does not remove TOC or other dissolved constituents and does not provide secondary water quality benefits. ▪ Non-steady state treatment process, requiring attentive monitoring of contaminant breakthroughs from treatment units to schedule resin replacements. ▪ PFAS-specific IX resin is non-regenerable. Disposal of spent resin through high-temperature incineration is the only water treatment residual handling approach at present.

Technology	Advantages	Disadvantages
Novel Adsorbents	▪ Pilot studies have shown effectiveness in removing both long- and short-chain PFAS. ▪ Less impacted by chlorine oxidation and TOC fouling than GAC and IX resin. ▪ Faster adsorption kinetics and shorter EBCT, which are comparable to that of IX systems (typically 3 minutes). ▪ Lower unit media cost ($/cubic feet) than IX resin.	▪ Limited full-scale installations for PFAS drinking water treatment (one installation at a 1.2-mgd groundwater well facility in 2023). ▪ Limited understanding of long-term performance, system O&M, spent media disposal, and life-cycle costs due to limited number of full-scale installations.
High-Pressure Membranes	▪ Broadly removes both long- and short-chain PFAS. ▪ Removes other constituents, including TOC, hardness, salinity, and pathogens. ▪ Produces excellent treated water quality. ▪ Steady-state treatment process. ▪ Has potential to remove a wider range of contaminants including future regulated contaminants. However, these are not identified at this time and is difficult to quantify expected performance.	▪ Highest capital and O&M costs among all treatment alternatives. ▪ Produces a large volume of concentrate that is challenging and costly to dispose of via a DIW. ▪ Result in a potential shortfall of raw water supplies that is challenging and costly to make up (e.g. additional allocations from the Biscayne Aquifer, new extraction wells to withdraw supply from the Floridan Aquifer, or other strategies such as potable reuse). ▪ Requires post-membrane treatment to ensure stable finished water quality.

SECTION 4 RAPID SMALL-SCALE COLUMN TEST

4.1 Rapid Small-Scale Column Test Background and Objectives

Rapid Small-Scale Column Tests (RSSCTs) can assess PFAS breakthrough behavior in a small fraction (i.e., one to 10 percent) of the time and cost required for a pilot study. This short operation time of the bench-scale miniature columns enables a quick turnaround of the testing results to facilitate expeditious decision making. The cost of RSSCT is less compared to pilot testing because they require less time, media, sample volume, and less PFAS sampling and analysis. Overall, RSSCTs are a small investment compared to the potential cost implications of technology implementation at the full-scale.

As part of this study, RSSCTs were conducted at Carollo's Water Applied Research Center (Water ARC®) to provide an expedited evaluation of the most suitable and cost-effective PFAS treatment technology to meet the City's PFAS treatment goals. The key objectives of bench-scale RSSCTs were to:

- Inform PFAS treatment technology selection.
- Determine TOC pretreatment needs.
- Determine critical design criteria.
- Estimate media use rate and the resulting O&M costs associated with media changeout.

Detailed RSSCT system setup, column design, feed water characterization, testing results, and conclusions are contained in Appendix A. A summary of the key RSSCT findings is provided in this section.

4.2 Rapid Small-Scale Column Test Design

RSSCTs were designed to simulate full-scale design criteria for GAC, IX, and FS200 systems. System throughput is expressed in the number of days a single GAC, IX, or FS200 adsorber will be in service rather than number of bed volumes to account for the different design EBCTs for GAC, IX resin, and FS200.

System throughput can be calculated using the following equation:

$$Throughput\ (days) = \frac{No.of\ Bed\ Volumes\ (unitless) \times Design\ EBCT (minutes)}{24 \frac{hours}{day} \times 60 \frac{minutes}{hour}}$$

Effluent from each GAC column was sampled every 4,000 to 7,000 bed volumes for PFAS and every 10,000 to 25,000 bed volumes for IX resin or FS200. The TOC breakthrough was monitored in each column effluent at the same time as PFAS to determine if TOC could be used as a performance indicator for PFAS. Detailed RSSCT design parameters are listed in Table 4.1.

Table 4.1 RSSCT Column Designs for GAC, IX Resin, and FS200

<table>
<tr><th></th><th>Parameter</th><th>Units</th><th>GAC</th><th>IX</th><th>Fluoro-Sorb</th></tr>
<tr><td rowspan="8">Full-Scale Adsorber</td><td>Feed Water</td><td></td><td colspan="3">High and Low TOC Feed(1)</td></tr>
<tr><td>Supplier</td><td>--</td><td>Calgon</td><td>Purolite</td><td>CETCO</td></tr>
<tr><td>Product</td><td>--</td><td>Filtrasorb 400</td><td>PFA694E</td><td>FS200</td></tr>
<tr><td>Sieve Size</td><td>--</td><td>12×40</td><td>20×35</td><td>20×40</td></tr>
<tr><td>RSSCT Design Model</td><td>--</td><td>Hybrid</td><td>Constant Diffusivity</td><td>Constant Diffusivity</td></tr>
<tr><td>Diffusivity Factor, X</td><td>--</td><td>0.25</td><td>0</td><td>0</td></tr>
<tr><td>EBCT</td><td>minute</td><td>12.5</td><td>2.0</td><td>3.0</td></tr>
<tr><td>HLR</td><td>gpm/square feet</td><td>6.3</td><td>12.6</td><td>12.6</td></tr>
<tr><td rowspan="8">Bench-Scale RSSCT Column</td><td>Ground Particle Sieve Size</td><td>--</td><td>100×200</td><td>100×200</td><td>100×200</td></tr>
<tr><td>Scaling Factor</td><td>--</td><td>8.5</td><td>6.1</td><td>5.7</td></tr>
<tr><td>HLR</td><td>gpm/square feet</td><td>6.3</td><td>12.6</td><td>12.6</td></tr>
<tr><td>Volumetric Flow Rate</td><td>mL/min</td><td>4.6</td><td>9.1</td><td>9.1</td></tr>
<tr><td>EBCT for Miniature Columns</td><td>minute</td><td>0.297</td><td>0.059</td><td>0.094</td></tr>
<tr><td>RSSCT Duration in Bed Volumes</td><td>bed volume</td><td>65,000</td><td>350,000</td><td>280,000</td></tr>
<tr><td rowspan="2">Simulated Media Service Time</td><td>days</td><td>564</td><td>535</td><td>583</td></tr>
<tr><td>years</td><td>1.5</td><td>1.5</td><td>1.5</td></tr>
</table>

Notes:
mL/min - milliliters per minute
(1) In order to evaluate the impact of TOC on PFAS treatment performance by GAC, IX resin, and FS200, two samples were collected from the City's WTP for bench-scale RSSCTs. The first sample was the feed water to the regenerable FIX system (or FIX influent), and the other sample was the FIX effluent after TOC pretreatment.

4.3 Feed Water Quality Characterization

RSSCT feed water samples were collected at the City's WTP upstream and downstream of the regenerable FIX process on September 17, 2024. The collected sample was shipped to Carollo's Water ARC®, and all samples were filtered using a 0.45-µm cartridge filter upon sample receiving. Cartridge filtration was performed to prevent particulate fouling of the high-pressure liquid chromatography pumps used for feeding the miniature bench-scale columns. Table 4.2 summarizes the feed water quality and PFAS characterization results. Notably, PFOS concentration was shown to be much lower in the FIX effluent (i.e., 18 ng/L) than in the FIX influent (i.e., 53 ng/L), indicating potential PFOS removal by the regenerable FIX process. Even though the extent of PFOS removal (i.e., 66 percent) is not high enough to meet the PFOS MCL of 4.0 ng/L, the regenerable FIX process could lower the PFOS mass loading, thus improving PFOS adsorption performance by the downstream adsorption process. Although limited full-scale performance data are currently available, PFOS removal through the regenerable IX processes (either in fixed-bed ion change or suspended IX configuration) has been reported before, and its removal is likely due to the high hydrophobicity of PFOS and its strong bonding with the resin via hydrophobic interactions.

Table 4.2 RSSCT Feed Water Quality Characterization Results

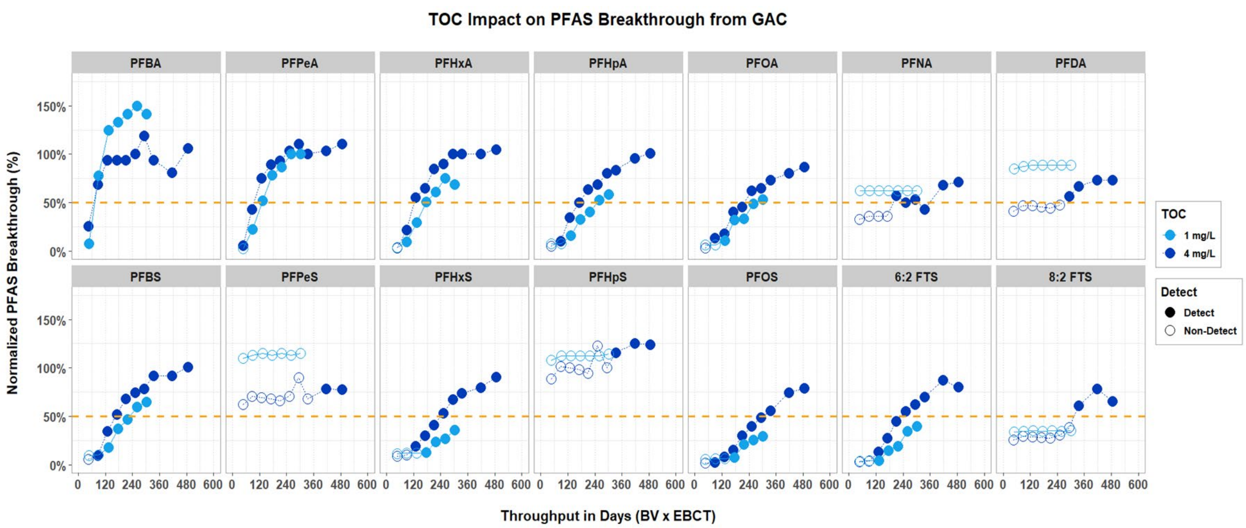
Class	Parameter	Units	FIX Influent	FIX Effluent
General Water Quality	pH	SU	8.5	8.3
	UV Absorbance at 254 nm	cm^{-1}	0.125	0.022
	TOC	mg/L	4.1	1.0
PFCAs	PFBA (C4)	ng/L	18	17
	PFPeA (C5)	ng/L	28	25
	PFHxA (C6)	ng/L	21	16
	PFHpA (C7)	ng/L	9.8	8.2
	PFOA (C8)	ng/L	14	11
	PFNA (C9)	ng/L	2.5	1.9 J (1)
	PFDA (C10)	ng/L	1.4 J	1.3 J
PFSAs	PFBS (C4)	ng/L	10	6.7
	PFPeS (C5)	ng/L	1.1 J	0.9 J
	PFHxS (C6)	ng/L	8.5	6.0
	PFHpS (C7)	ng/L	1.2 J	0.7 J
	PFOS (C8)	ng/L	53	18
FTS	6:2 FTS	ng/L	44	35
	8:2 FTS	ng/L	3.1	2.3

Note:
PFCAs - perfluoroalkyl carboxylic acids; PFSAs - perfluoroalkyl sulfonic acids
(1) A J flagged value, indicating an estimated concentration above the laboratory MDL but below the MRL for the specific PFAS.

4.4 Rapid Small-Scale Column Test Results

4.4.1 Granular Activated Carbon

Breakthrough curves for a total of 14 detectable PFAS, including seven PFCAs (C4 to C10 PFCAs), five PFSAs (C4 to C8 PFSAs), and two FTS (6:2 FTS and 8:2 FTS), are presented in Figure 4.1 for Calgon F400 GAC between the low-TOC (i.e., 1 mg/L) FIX effluent and the high-TOC (i.e., 4 mg/L) FIX influent. As discussed above, DOM (characterized by TOC) can compete with PFAS for active adsorption sites within the GAC, causing earlier PFAS breakthrough. Results of the RSSCTs demonstrated the rapid fouling of GAC by TOC as an earlier PFAS breakthrough was observed across all detectable compounds in the presence of 4 mg/L of TOC. Moreover, the impact of TOC on PFAS breakthrough was relatively consistent across all PFAS, including C4 to C10 PFCAs, C4 to C8 PFSAs, and two FTS, suggesting relatively uniform selectivity of GAC towards various PFAS in these two feed waters.

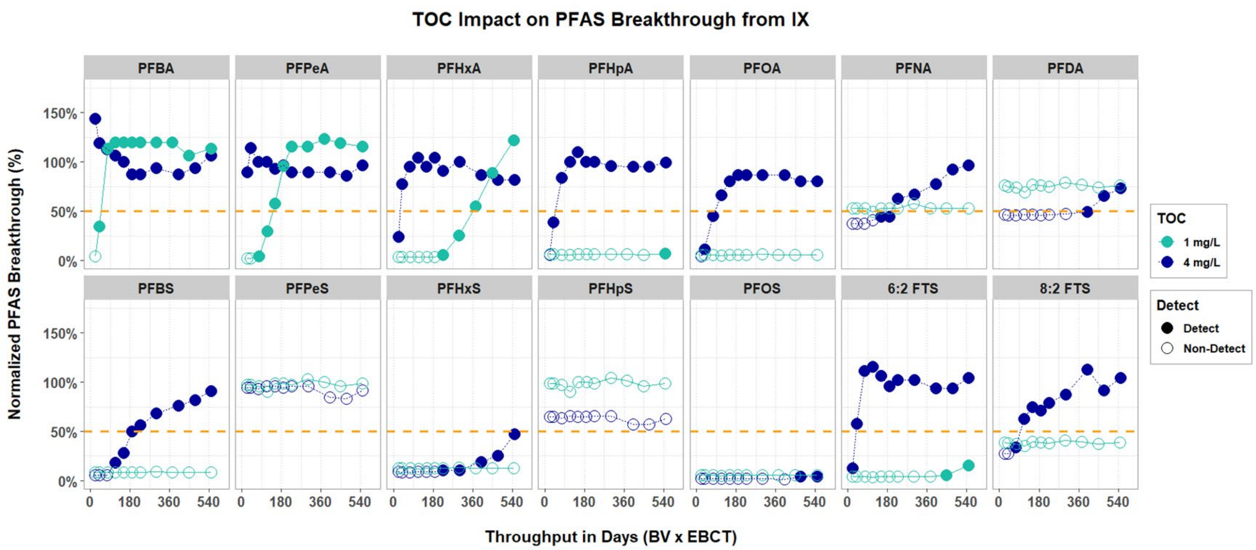


Notes: Normalized PFAS breakthrough curves were shown as a function of system throughput in number of days in operation. RSSCT results for the low-TOC FIX effluent sample are represented in light-blue circles, whereas results for the high-TOC FIX influent sample are represented in dark-blue circles. Any detectable (i.e., >MDL) PFAS concentrations are shown in solid symbols. In contrast, non-detect results are shown in open circles at the corresponding MDLs for the specific PFAS as well as the specific sample. The orange dashed line indicates 50 percent PFAS breakthrough, and the resulting throughputs (i.e., BV50) are often used to indicate GAC adsorption capacity for the contaminant of interest.

Figure 4.1 Normalized PFAS (C/C_0) Breakthrough Curves From Calgon F400 GAC Columns

4.4.2 Ion Exchange

Breakthrough curves for 14 detectable PFAS are presented in Figure 4.2 for Purolite PFA694E IX resin between the low-TOC (i.e., 1 mg/L) FIX effluent and the high-TOC (i.e., 4 mg/L) FIX influent. Following the same trends observed for GAC, PFAS were shown to break through much faster from the IX columns in the presence of higher concentration of TOC. More importantly, adsorption performance deteriorated more significantly for IX resin than for GAC when TOC increased from 1 mg/L to 4 mg/L, particularly for PFCAs. For instance, PFOA remained non-detectable in the column effluent in the presence of 1 mg/L of background TOC, while PFOA reached 100 percent or complete breakthrough after 180 days when background TOC was increased to 4 mg/L. Similar trends were observed for PFHpA, PFNA, PFDA, PFBS, PFHxS, PFOS, 6:2 FTS, and 8:2 FTS. The significant decrease in resin performance at higher TOC concentration suggests that IX resin is more susceptible to TOC fouling than GAC, and the impact of TOC fouling is more apparent for less-adsorbing PFAS, such as the PFCAs.

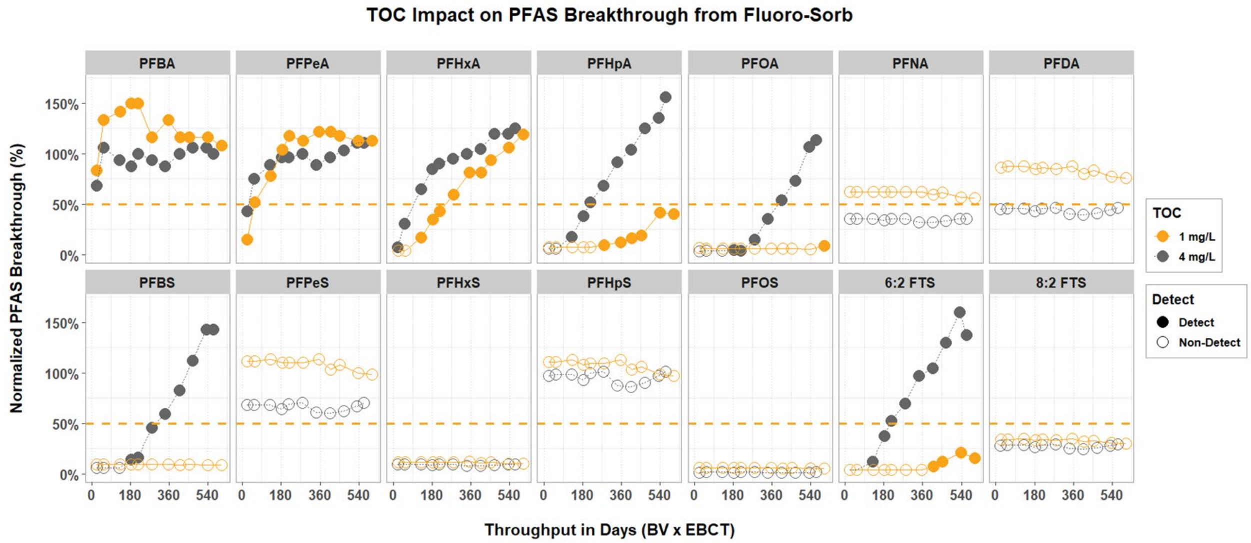


Notes: Normalized PFAS breakthrough curves were shown as a function of system throughput in number of days in operation. RSSCT results for the low-TOC FIX effluent sample are represented in turquoise circles, whereas results for the high-TOC FIX influent sample are represented in navy circles. Any detectable (i.e., >MDL) PFAS concentrations are shown in solid symbols. In contrast, non-detect results are shown in open circles at the corresponding MDLs for the specific PFAS as well as the specific sample. The orange dashed line indicates 50 percent PFAS breakthrough, and the resulting throughputs (i.e., BV50) are often used to indicate IX resin adsorption capacity for the contaminant of interest.

Figure 4.2 Normalized PFAS (C/C_0) Breakthrough Curves From Purolite PFA694E IX Resin Columns

4.4.3 FS200

Breakthrough curves for 14 detectable PFAS are presented in Figure 4.3 for CETCO FS200 between the low-TOC (i.e., 1 mg/L) FIX effluent and the high-TOC (i.e., 4 mg/L) FIX influent. In general, FS200 outperformed GAC and IX resin in the removal of all PFAS at both background TOC concentrations. In fact, long-chain PFCAs (i.e., PFNA and PFDA), and most PFSAs (i.e., PFPeS, PFHxS, PFHpS, and PFOS), as well as 8:2 FTS remained non-detect in all FS200 column effluents under both TOC conditions. The RSSCT results generally suggest that FS200 is less susceptible to TOC fouling than GAC and IX resin, and FS200 has high selectivity and adsorption capacity for PFSAs.

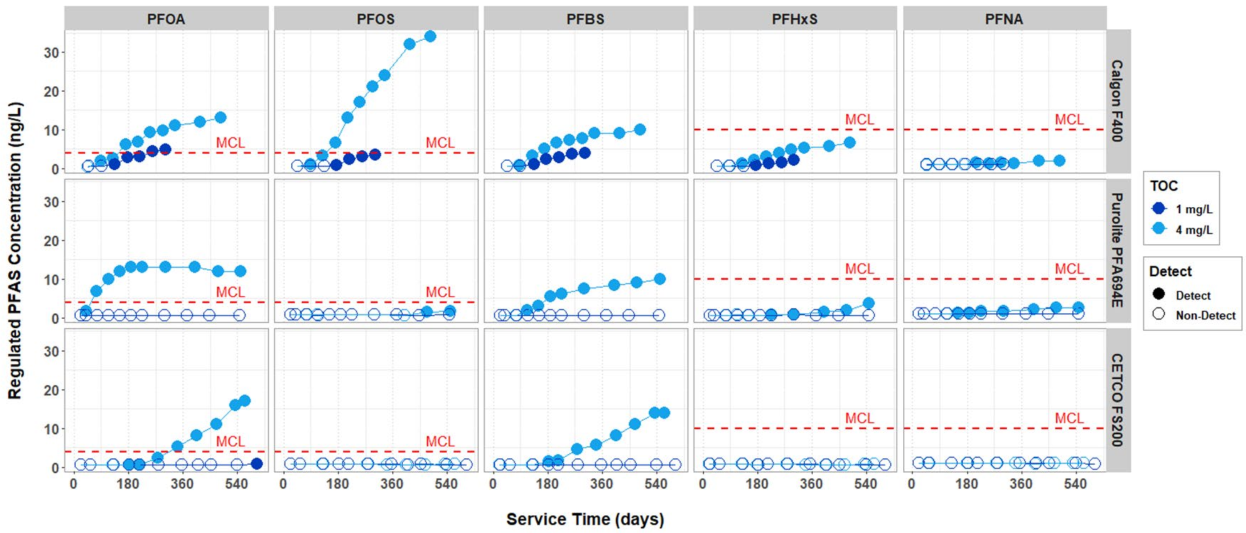


Notes: Normalized PFAS breakthrough curves were shown as a function of system throughput in number of days in operation. RSSCT results for the low-TOC FIX effluent sample are represented in orange circles, whereas results for the high-TOC FIX influent sample are represented in dark-grey circles. Any detectable (i.e., >MDL) PFAS concentrations are shown in solid symbols. In contrast, non-detect results are shown in open circles at the corresponding MDLs for the specific PFAS as well as the specific sample. The orange dashed line indicates 50 percent PFAS breakthrough, and the resulting throughputs (i.e., BV50) are often used to indicate FS200 adsorption capacity for the contaminant of interest.

Figure 4.3 Normalized PFAS (C/C_0) Breakthrough Curves From CETCO Fluoro-Sorb 200 (FS200) Columns

4.4.4 Regulated PFAS and Media Use Rate

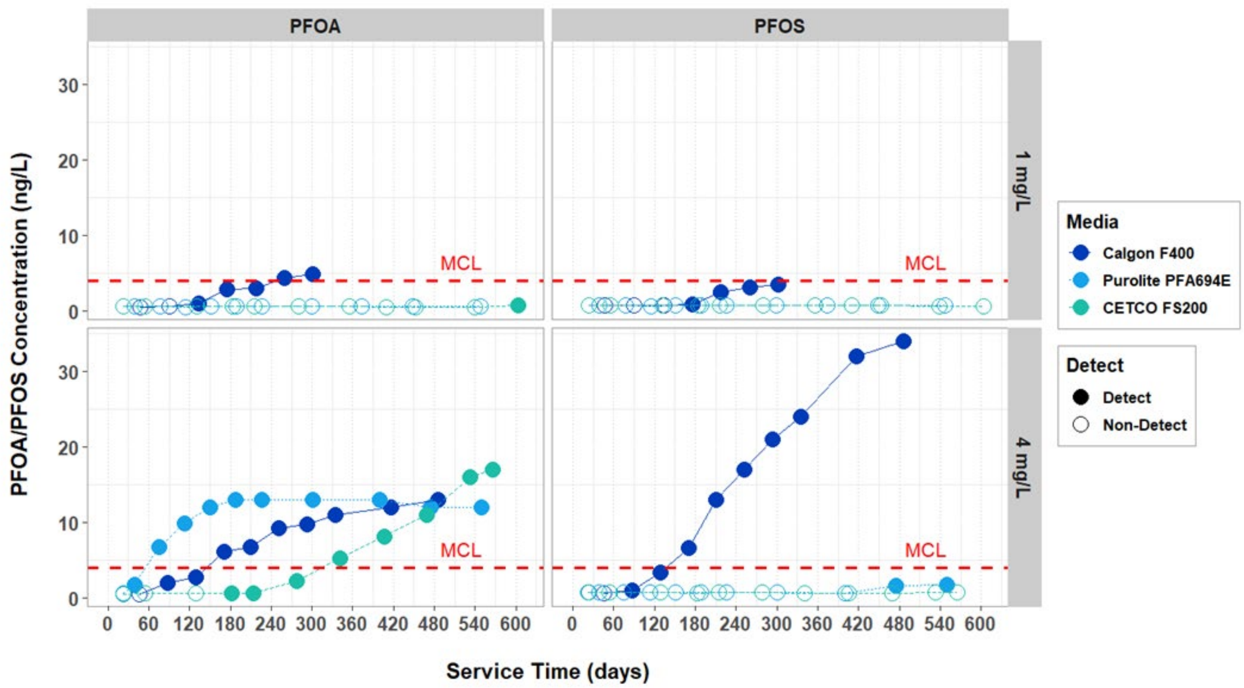
Regulated PFAS breakthrough under low- and high-TOC conditions from GAC, IX resin, and FS200 are compared below in Figure 4.4. Among the six regulated PFAS, HFPO-DA (or GenX) was not detected in the feed water, and thus, results are not shown for this PFAS. RSSCT results indicated that PFHxS and PFNA concentrations in the RSSCT column effluents remained below their respective MCLs of 10 ng/L, regardless of media type and background TOC concentrations. Although PFBS breakthrough was observed, there is no proposed MCL for this PFAS, and the corresponding concentration that would impact HI calculations (HBWC for PFBS is 2,000 ng/L) is well above that found in the feed water. For these reasons, only PFOA and PFOS would drive media selection and change out frequency for the City to meet the compliance requirements for PFAS.



Notes: Regulated PFAS breakthrough curves from Calgon F400 GAC, Purolite PFA694E IX resin, and CETCO FS200 as a function of system throughput in number of days in operation. RSSCT results for the low-TOC FIX effluent sample are represented in dark-blue circles, whereas results for the high-TOC FIX influent sample are represented in light-blue circles. Any detectable (i.e., >MDL) PFAS concentrations are shown in solid symbols. In contrast, non-detect results are shown in open circles at the corresponding MDLs for the specific PFAS as well as the specific sample. The red dashed lines indicate respective MCLs for the regulated PFAS.

Figure 4.4 Regulated PFAS Breakthrough Curves

Figure 4.5 summarizes the treatment performance of Calgon F400 GAC, Purolite PFA694E IX resin, and CETCO FS200 for PFOA and PFOS removal only. The top panel compares PFOA and PFOS breakthroughs from the three types of media in the presence of 1 mg/L of background TOC, whereas the bottom panel compares PFOA and PFOS breakthroughs in the presence of 4 mg/L of background TOC. Setting the treatment targets for PFOA and PFOS at their respective MCLs of 4.0 ng/L, the resulting service times for a single adsorber (e.g., lead pressure vessel containing GAC, IX resin, or FS200) are summarized in Table 4.3.



Notes: PFOA and PFOS breakthrough curves from Calgon F400 GAC (dark-blue circles), Purolite PFA694E IX resin (light-blue circles), and CETCO FS200 (turquoise circles) as a function of system throughput in number of days in operation. PFOA and PFOS breakthroughs for the low-TOC FIX effluent sample are shown in the top panel, whereas breakthrough curves for the high-TOC FIX influent sample are shown in the bottom panel. Any detectable (i.e., >MDL) PFOA and PFOS concentrations are shown in solid symbols. In contrast, non-detect results are shown in open circles at the corresponding MDLs for the specific PFAS as well as the specific sample. The red dashed lines indicate respective MCLs for PFOA and PFOS.

Figure 4.5 PFOA and PFOS Breakthrough Curves

Table 4.3 Estimated Single-Adsorber Media Changeout Frequency

Feed Water TOC	Media	Driving PFAS (The PFAS That Breaks Through Earlier)	Single-Adsorber Service Time in Meeting PFOA and PFOS MCLs of 4.0 ng/L	
			Days	Months
1 mg/L	GAC	PFOA	240	8
	IX Resin	PFOA	540	18
	FS200	PFOA	600	20
4 mg/L	GAC	PFOS	120	4
	IX Resin	PFOA	60	2
	FS200	PFOA	300	10

In general, IX resin and FS200 significantly outperformed GAC in treating PFAS in the presence of low concentration of TOC (i.e., 1 mg/L). According to the RSSCT breakthrough curves shown in Figure 4.5, it is estimated that IX resin can last for approximately 18 months in a single adsorber (e.g., a lead pressure vessel), while FS200 can last for about 20 months. This compares to eight months of estimated service time for a single GAC adsorber, treating the same feed water to meet effluent PFOA goal of 4.0 ng/L. When background TOC concentration increased to 4 mg/L, IX became a non-viable treatment technology as resin was estimated to be changed out once every two months. The estimated service times for GAC and FS200 under high TOC conditions were five months and 10 months, respectively.

Overall, GAC was shown to be a non-viable PFAS treatment option for the City due to moderate PFOA and PFOS concentrations in the feed water (i.e., requires high extents of treatment) and GAC fouling by TOC. IX resin is a cost-effective PFAS treatment option, but only when treating low-TOC feed water. In contrast, FS200 showed the most promising PFAS treatment results as it outperformed both GAC and IX resin at both TOC concentrations evaluated. Estimated single adsorber FS200 service times ranging from 10 to 20 months, treating low- and high-TOC feed water, respectively.

Overall, RSSCT results revealed the critical role of TOC levels in determining PFAS treatment feasibility and economics. IX resin or FS200 can last over a year in the lead adsorbers at design EBCT when treating FIX effluent with low TOC interference. When background TOC concentration was high (i.e., 4 mg/L) without the regenerable FIX process, only the novel adsorbent FS200 resulted in acceptable PFAS treatment performance and reasonable media changeout frequency. For this reason, it is recommended that the City expand the existing regenerable FIX system from side-stream to full-stream treatment to further reduce TOC loading onto the downstream PFAS treatment process to prolong media life and lower PFAS treatment costs as a result of media changeout.

SECTION 5 TREATMENT ALTERNATIVES ANALYSIS AND CONCEPTUAL SYSTEM DESIGN

5.1 Short-Listed Treatment Alternatives

Based on the above testing results from RSSCTs, the treatment alternatives that include expanding the existing regenerable FIX process were shortlisted for further evaluation and conceptual design in this section. In addition, high-pressure membranes, such as NF, were also shortlisted for alternatives analysis. The four short-listed treatment alternatives for conceptual design are summarized in Figure 5.1.

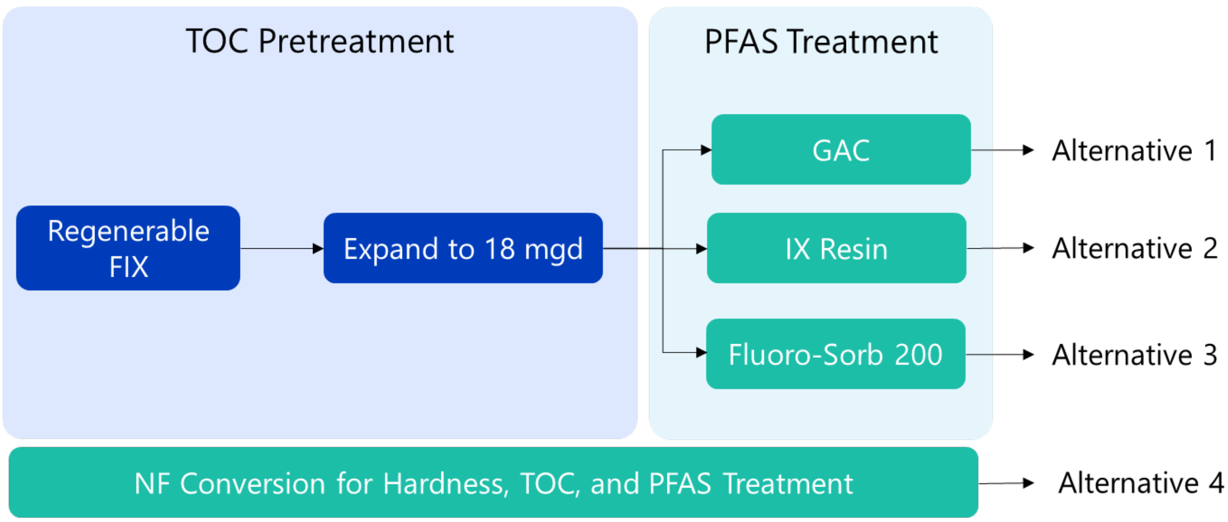


Figure 5.1 Short-Listed Treatment Alternatives

5.2 Site Utilization

During conceptual design, multiple siting options within the WTP were considered for potential use for the proposed PFAS treatment facility. Figure 5.2 shows a map of all potential siting locations outlined below.

- Location No. 1 - Existing Front Admin Parking Lot (Northwest).
- Location No. 2 - Existing Maintenance Building (East).
- Location No. 3 - Front Gate Entrance (Northeast).
- Location No. 4 - Existing 1 MG Ground Storage Tank Area (South).

As shown in Figure 5.2, Location No. 2 is proposed on and around the existing maintenance building and parking area used by plant staff. The existing maintenance building will require relocation if Location No. 2 is utilized for any proposed treatment alternative. Locations No. 1, 3, and 4 have been identified as potential options for a new maintenance building and parking area if Location No. 2 is utilized. If the maintenance building is proposed to be relocated to Location No. 1, additional information is needed for building setback requirements, utility conflicts, structural information on the existing building adjacent to Location No.1 or permitting requirements regarding the canal adjacent to the WTP and east of N. University Boulevard. Similarly, if the maintenance building requires relocation within Location No. 3, additional information is needed for building setback requirements and utility conflicts. Lastly, if the maintenance building and parking area require relocation to Location No. 4, the existing 1 MG storage tank will need to be demolished, and the existing subsurface WTP piping in this area will require concrete encasement for protection against building settlement or other structural or geotechnical concerns. It is not recommended to relocate the 1 MG storage tank, and if Location No. 4 is to be utilized, the overall finished water storage capacity at the WTP will be reduced.

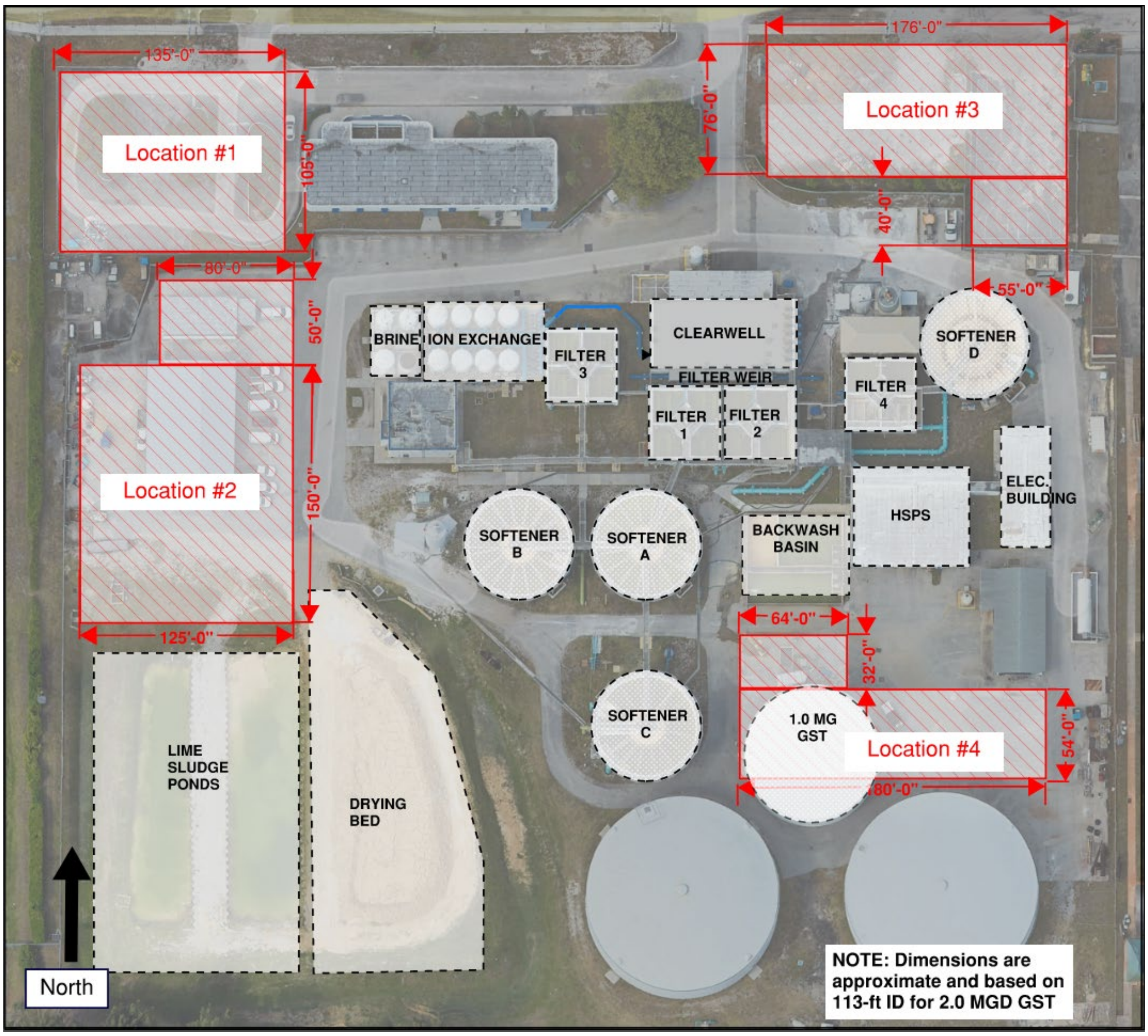


Figure 5.2 Potential Siting Options Within the WTP That Were Considered During Conceptual Design for the Proposed PFAS Treatment Facility

5.3 Treatment Alternatives Analysis and Conceptual Design

5.3.1 Alternative 1 - Expand Existing Regenerable Fixed Ion Exchange System + PFAS Treatment by Granular Activated Carbon

5.3.1.1 Process Flow Diagram

Alternative 1 will include expanding the existing regenerable FIX system from 12 mgd to 18 mgd treatment capacity, removing the 6 mgd filter effluent bypass around the regenerable FIX system, and adding intermediate transfer pumps and GAC adsorbers in lead-lag pressure vessel configuration. A PFD for Alternative 1 is provided in Figure 5.3.

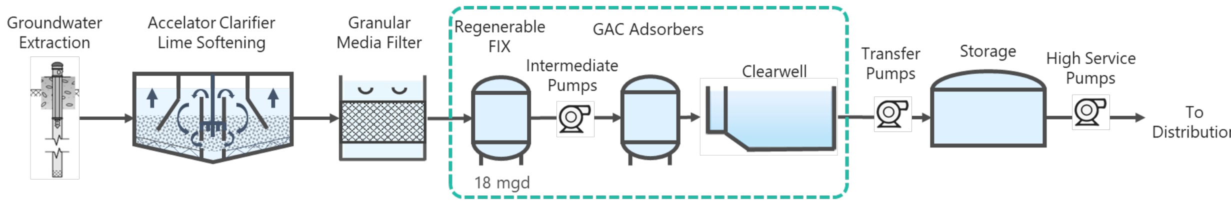
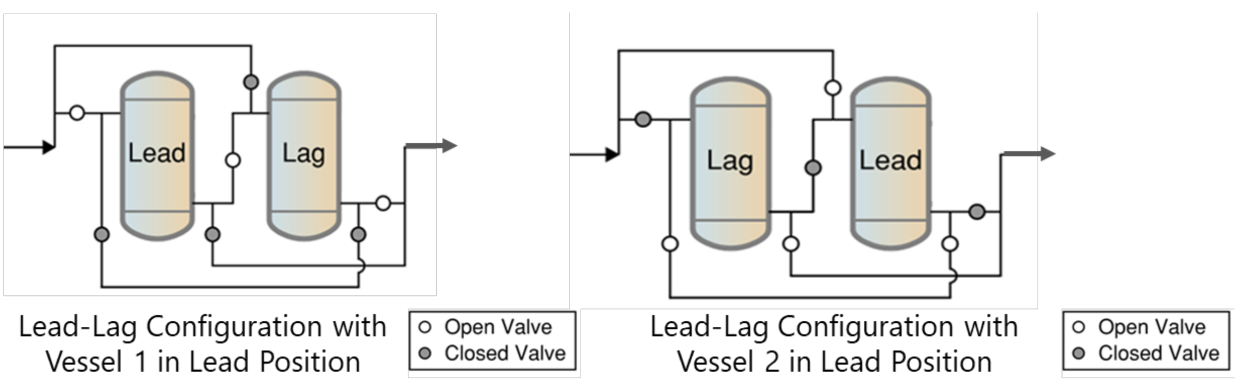


Figure 5.3 PFD for Treatment Alternative 1

5.3.1.2 Granular Activated Carbon Pressure Vessels in Lead-Lag Configuration

Lead-lag treatment configuration increases the amount of GAC inventory available and provides system redundancy during the GAC changeout period to maintain the City's PFAS treatment goals. However, lead-lag treatment configuration requires higher capital investments (i.e., more treatment units required) and a larger system footprint.

The PFD for lead-lag GAC pressure vessels is presented in Figure 5.4, where vessel 1 can be in the lead position, or vessel 2 can be in the lead position when spent GAC in vessel 1 is changed out.



Notes: The diagram on the left shows vessel 1 in the lead position, while the diagram on the right shows vessel 2 in the lead position.

Figure 5.4 PFD for Pressure Vessels in Lead-Lag Configuration

5.3.1.3 Design Criteria

Table 5.1 outlines the design criteria for expanding the existing regenerable FIX treatment system from 12 mgd to 18 mgd or with 6 mgd additional treatment capacity. Table 5.2 outlines the proposed design criteria for GAC pressure vessels in lead-lag configuration.

Table 5.1 Regenerable FIX System Design Criteria for 6 mgd Expansion

Parameter	Units	Value
Treatment Flow	mgd	18
Number of Vessels, Existing	No.	8
Number of Vessels, Expansion	No.	4
Total number of Vessels	No.	12 (8 Existing + 4 Expansion)
Treatment Configuration	-	Staged-Parallel
Design Treatment Flow per Vessel	mgd	1.5
Vessel Internal Diameter	feet	12
HLR at Design Flow	gpm/square feet	9.2
Resin Type	-	Type I Strong Base Anion Exchange
Resin Volume per Vessel	cubic feet	424
EBCT at Design Flow	minute	3.0
Resin Bed Depth	feet	3.75
Design Regeneration Waste Volume per Vessel	gallons	20,300
Design Backwash Flow Rate	gpm	340
Design Slow Rinse Flow Rate	gpm	107
Design Fast Rinse Flow Rate	gpm	1050
Design Salt Usage per Regeneration Cycle	pounds	4,200

Table 5.2 Design Criteria for GAC Pressure Vessels for PFAS Treatment

Parameter	Unit	Value		
		Average Day Flow	Maximum Day Flow	Rated Capacity
Design Treatment Flow	mgd	13.7	16.4	18.0
	gpm	9,521	11,389	12,500
Number of Treatment Trains	No.	16	16	16
Configuration	-	Lead-Lag		
Total No. of Vessels	No.	32	32	32
Flow per Treatment Train/Vessel	mgd	0.9	1.0	1.1
	gpm	595	712	781
Vessel Diameter	feet	12	12	12
Vessel Area	square feet	113	113	113
HLR (N)	gpm/square feet	5.3	6.3	6.9

Parameter	Unit	Value		
		Average Day Flow	Maximum Day Flow	Rated Capacity
Media Type	-	Calgon F400 or Equivalent GAC		
GAC Apparent Density	pounds/cubic feet	33.71	33.71	33.71
GAC Volume per Vessel	cubic feet	1,187	1,187	1,187
	gallons	8,876	8,876	8,876
GAC Bed Depth	feet	10.5	10.5	10.5
EBCT per Vessel	minute	14.9	12.5	11.4
EBCT per Train	minute	29.8	24.9	22.7

5.3.1.4 Conceptual Layout for Treatment Alternative 1

This GAC system conceptual design allows each GAC pressure vessel to serve as the lead or lag vessel. However, the large number of vessels required results in a large system footprint. A conceptual layout has been developed, as shown in Figure 5.5 and indicates the GAC treatment facility may fit within Location No. 1 and Location No. 2.

To expand the regenerable FIX system, it is proposed that the brine tanks be relocated to the south of the existing FIX vessels so that the additional four vessels could be added to the west side of the existing FIX facility. A blending tank is also proposed, which is intended to equalize effluent from all four granular media filters to allow for the treatment of the entire plant flow by regenerable FIX, followed by GAC for PFAS removal. The GAC effluent will be returned to the clearwell for final disinfection. This modification will alleviate the reliance on the clearwell influent weir for flow equalization and simplify the flow configuration from filtration to final disinfection processes.

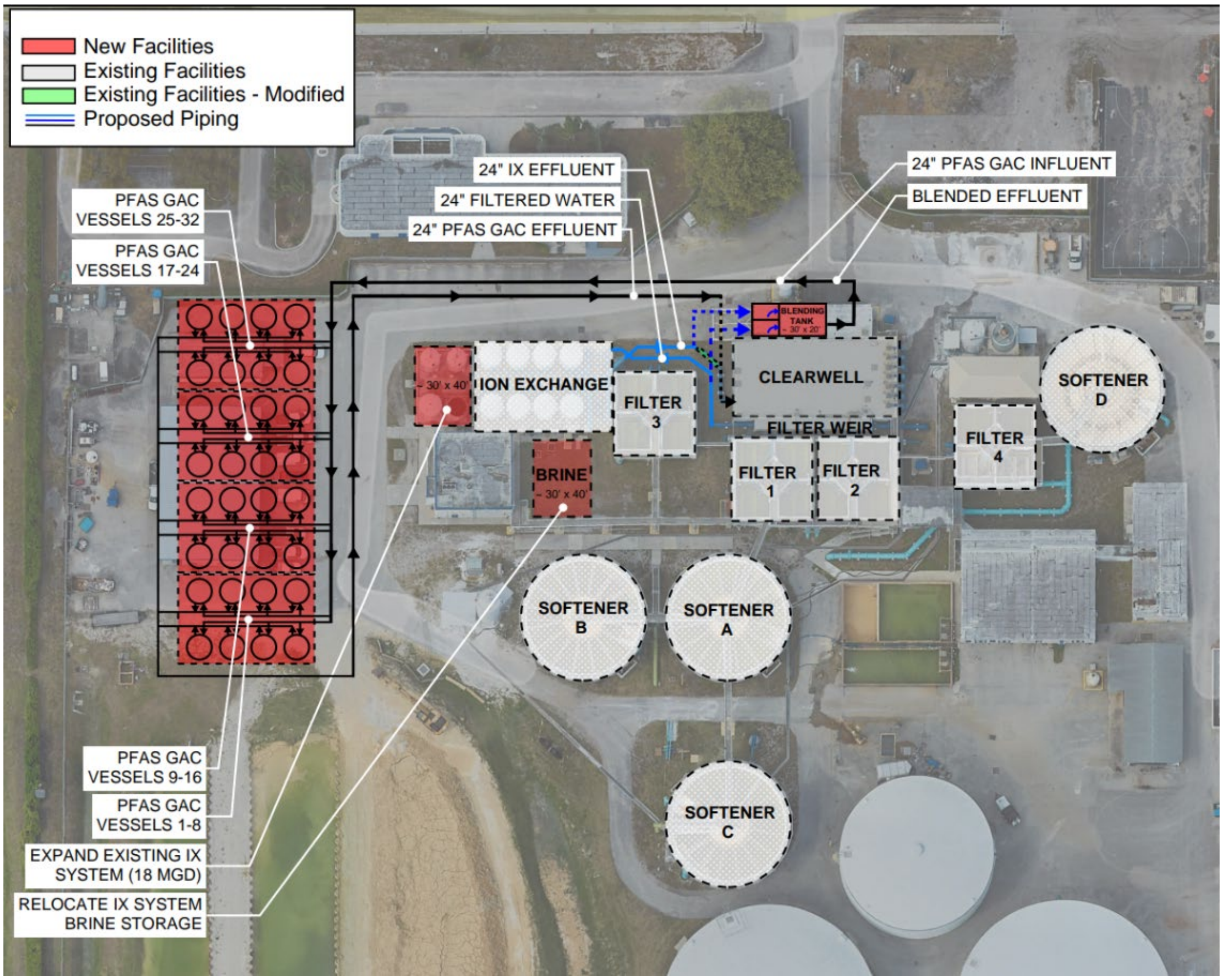


Figure 5.5 Potential Site Layout for Treatment Alternative 1 - Regenerable FIX Process Expansion and the Addition of GAC Pressure Vessels for PFAS Treatment

5.3.2 Alternative 2 - Expand Existing Regenerable Fixed-Bed Ion Exchange System + PFAS Treatment by Ion Exchange Resin

5.3.2.1 Process Flow Diagram

Alternative 2 will include expanding the existing regenerable FIX system from 12 mgd to 18 mgd treatment capacity, removing the 6 mgd filter effluent bypass around the regenerable FIX system, and adding intermediate transfer pumps and IX adsorbers in lead-lag pressure vessel configuration. A PFD for Alternative 2 is provided in Figure 5.6.

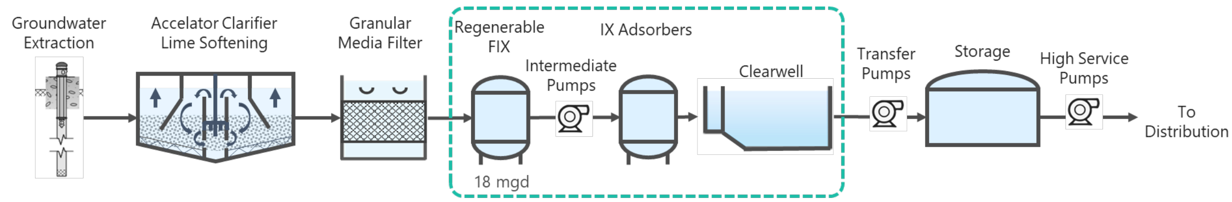


Figure 5.6 PFD for Treatment Alternative 2

5.3.2.2 Design Criteria

The design criteria for the expansion of the existing regenerable FIX treatment system from 12 mgd to 18 mgd, or with 6 mgd additional treatment capacity, were outlined previously in Table 5.1. Table 5.3 outlines the proposed design criteria for IX pressure vessels in lead-lag configuration. It is noteworthy that the pressure vessels are convertible and can be used to accommodate the novel adsorbent, FS200, if this adsorbent is to be tested in one or several full-scale treatment trains or for future media conversion as the technology matures.

Table 5.3 Design Criteria for IX Pressure Vessels for PFAS Treatment

Parameter	Units	Value		
		Average Day Flow	Maximum Day Flow	Rated Capacity
Design Treatment Flow	mgd	13.7	16.4	18.0
Number of Treatment Trains	No.	10	10	10
Treatment Configuration		Lead/Lag		
Total No. of Vessels	No.	20	20	20
Flow per Treatment Train/Vessel	mgd	1.4	1.6	1.8
	gpm	952	1,139	1,250
Vessel Diameter	feet	12	12	12
Vessel Area	square feet	113	113	113
HLR	gpm/square feet	8.4	10.1	11.1
Media Type	--	Single-use Strong Base IX Resin for PFAS		

Parameter	Units	Value		
		Average Day Flow	Maximum Day Flow	Rated Capacity
Media Volume per Vessel	cubic feet	420	420	420
	gallons	3,142	3,142	3,142
Media Bed Depth	feet	3.7	3.7	3.7
EBCT per Vessel	minute	3.3	2.8	2.5
EBCT per Train	minute	6.6	5.5	5.0

5.3.2.3 Conceptual Layout for Treatment Alternative 2

Similar to Alternative 1, each pressure vessel can be in the lead or the lag position. A conceptual site layout has been developed, as shown in Figure 5.7 for Alternative 2. Due to the smaller number of treatment trains required, the PFAS treatment facility may fit within Location No. 3, which will cause minimal disturbances to the existing WTP from a constructability perspective.

To expand the regenerable FIX system, it is proposed that the brine tanks be relocated to the south of the existing FIX vessels so that the additional four vessels could be added to the west side of the existing FIX facility. A blending tank is also proposed to equalize effluent from all four granular media filters. This will allow the treatment of the entire plant flow by regenerable FIX, followed by IX resin for PFAS removal before the treated effluent is returned to the clearwell for final disinfection. This modification will alleviate the reliance on the clearwell influent weir for flow equalization and simplify the flow configuration from filtration to final disinfection processes.

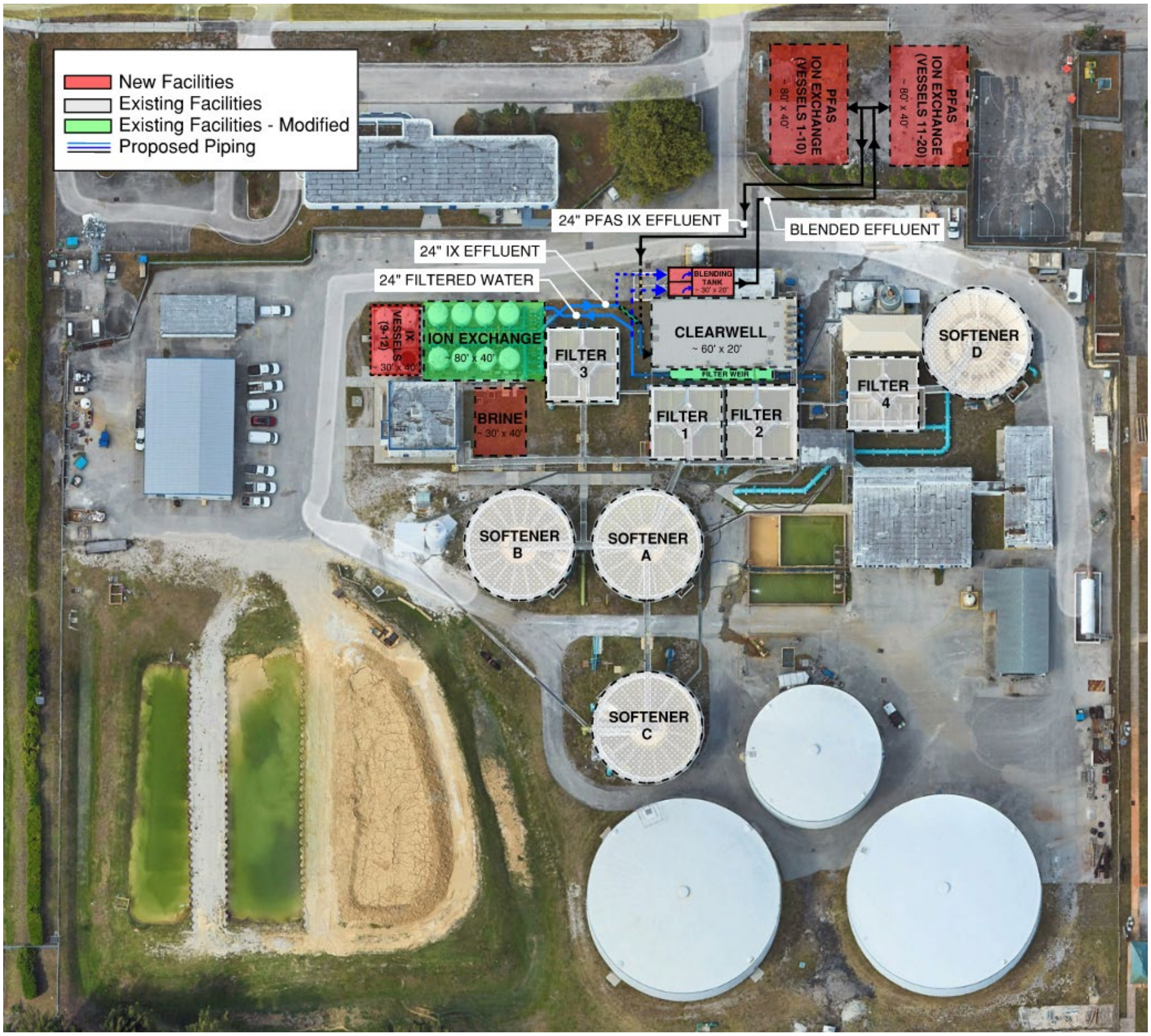


Figure 5.7 Potential Site Layout for Treatment Alternative 2 - Regenerable FIX Process Expansion and the Addition of Pressure Vessels for PFAS Treatment Using IX Resin

5.3.3 Alternative 3 - Expand Existing Regenerable Fixed-Bed Ion Exchange System + PFAS Treatment by FS200

5.3.3.1 Process Flow Diagram

Alternative 3 will include expanding the existing regenerable FIX system from 12 mgd to 18 mgd treatment capacity, removing the 6 mgd filter effluent bypass around the regenerable FIX system, and adding intermediate transfer pumps and FS200 adsorbers in lead lag pressure vessel configuration. The PFD for Alternative 3 is the same as that for Alternative 2, which is shown in Figure 5.6.

5.3.3.2 Design Criteria

The design criteria for the expansion of the existing regenerable FIX treatment system from 12 mgd to 18 mgd, or with 6 mgd additional treatment capacity, were outlined previously in Table 5.1. Table 5.4 outlines the proposed design criteria for FS200 pressure vessels in lead-lag configuration. As mentioned in Section 5.3.2.2, IX pressure vessels are convertible and can be used to accommodate the novel adsorbent, FS200. Theoretically, FS200 pressure vessels would follow the same critical design criteria as those established for IX pressure vessels. However, due to the lack of full-scale implementations, limited data is available regarding the maximum HLR for FS200 without causing head loss or other operation issues. In fact, prior to a pilot study in the state of California, CETCO noted that they had observed media compaction and rapid head loss accumulation at higher HLRs, prompting them to recommend a maximum HLR of 9.5 gpm/square feet for FS200. For this reason, the pressure vessel system was more conservatively designed in this study for FS200 with a lower maximum HLR. Vessel convertibility from IX resin to FS200 warrants further investigation and validation, including bench- and/or pilot-scale studies if this treatment alternative is selected for full-scale implementation at the City's WTP.

Table 5.4 Design Criteria for FS200 Pressure Vessels for PFAS Treatment

Parameter	Units	Value		
		Average Day Flow	Maximum Day Flow	Rated Capacity
Design Treatment Flow	mgd	13.7	16.4	18.0
Number of Treatment Trains	No.	12	12	12
Treatment Configuration		Lead/Lag		
Total No. of Vessels	No.	24	24	24
Flow per Treatment Train/Vessel	mgd	1.1	1.4	1.5
	gpm	793	949	1,042
Vessel Diameter	feet	12	12	12
Vessel Area	square feet	113	113	113
HLR	gpm/square feet	7.0	8.4	9.2
Media Type	--	CETCO FS200		
Media Volume per Vessel	cubic feet	420	420	420
	Gallons	3,142	3,142	3,142
Media Bed Depth	feet	3.7	3.7	3.7
EBCT per Vessel	minute	4.0	3.3	3.0
EBCT per Train	minute	7.9	6.6	6.0

5.3.3.3 Conceptual Layout for Treatment Alternative 3

Same as Alternatives 1 and 2, each pressure vessel can be in the lead or the lag position. A conceptual site layout has been developed, as shown in Figure 5.8 for Alternative 3. Similar to Alternative 2, the PFAS treatment facility may fit within Location No. 3, which will cause minimal disturbances to the existing WTP from a constructability perspective.

Figure 5.8 Potential Site Layout for Treatment Alternative 3 - Regenerable FIX Process Expansion and the Addition of Pressure Vessels for PFAS Treatment Using FS200

5.3.4 Alternative 4 - Converting From Lime Softening and Regenerable Fixed-Bed Ion Exchange to Nanofiltration

5.3.4.1 Process Flow Diagram

In this treatment alternative, the conventional lime softening, granular media filtration, and regenerable FIX processes will be replaced with NF (or RO). The NF facility will be designed for a total permeate flow of 18 mgd with N+1 redundancy. To produce 18 mgd of treated water, the required feed water flow will be 21.2 mgd (refer to Section 2 for more detailed discussion on raw water supply limitations).

Ancillary components to the membrane system include cartridge filters for particulate removal, chemical systems including sulfuric acid, sodium hydroxide, and anti-scalant, and a clean-in-place system for membrane cleaning. A separate electrical room will be located in the proposed membrane treatment building for the required pump drives and new electrical distribution equipment.

Additional components to be designed will include a series of degassifiers, a blending chamber for permeate flow prior to entering the existing clearwell, and a DIW for membrane concentrate disposal. The high-pressure membrane process will likely require electrical power distribution upgrades to operate at much higher pressure.

A PFD for Alternatives 4 is provided in Figure 5.9, assuming the use of NF membrane.

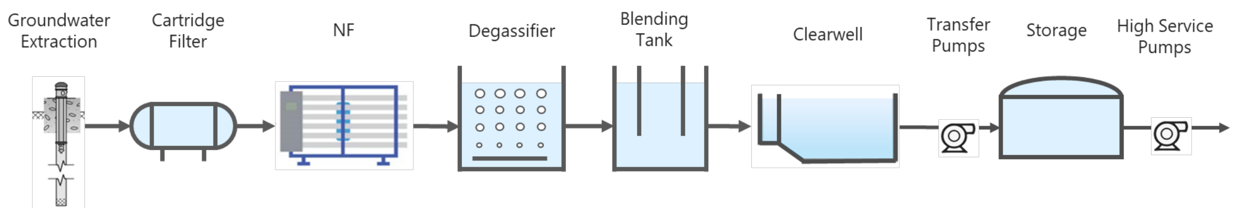


Figure 5.9 PFD for Treatment Alternative 4

5.3.4.2 Design Criteria

To achieve the design permeate flow of 18 mgd, the proposed design criteria for the membrane system are outlined in Table 5.5.

Table 5.5 High-Pressure Membrane System Design Criteria

Parameter	Units	Value
Design Permeate Flow	mgd	18
Number of Treatment Trains (N)	No.	5
Number of Redundant Trains (N+1)	No.	1
Treatment Flow per Train (N)	mgd	3.6
Projected Recovery	%	85%
Number of Treatment Stages	No.	2
Estimated Operating Pressure	psi	75-100 psi
Number of Feed Pumps	No.	5+1
Number of Cartridge Filters	No.	3+1

Notes:
psi - pounds per square inch

5.3.4.3 Conceptual Layout for Treatment Alternative 4

It is proposed that the membrane treatment facility be at the location of the existing maintenance building. This location provides the necessary footprint for the new membrane facility and the accessibility for construction, and it minimizes potential impacts on plant operation during start-up and commissioning. The associated DIW will be located north of the treatment building in the existing administration building parking lot. With the addition of the membrane treatment facility, the following facilities could be relocated or repurposed for other uses:

- The existing maintenance building and parking lot are to be relocated.

- The perimeter fence for the west and north of the property will need to be aligned.

After the successful commissioning of the new NF treatment facility, the existing treatment could be demolished or remain on site:

- Lime softener Units A, B, C, and D.
- Lime storage and feed equipment.
- Sludge pond and lime residual drying bed.
- Filters 1,2,3, and 4.
- Filter backwash basin.
- Regenerable FIX pressure vessels.
- Brine tanks.

Detailed site layout is shown in Figure 5.10.

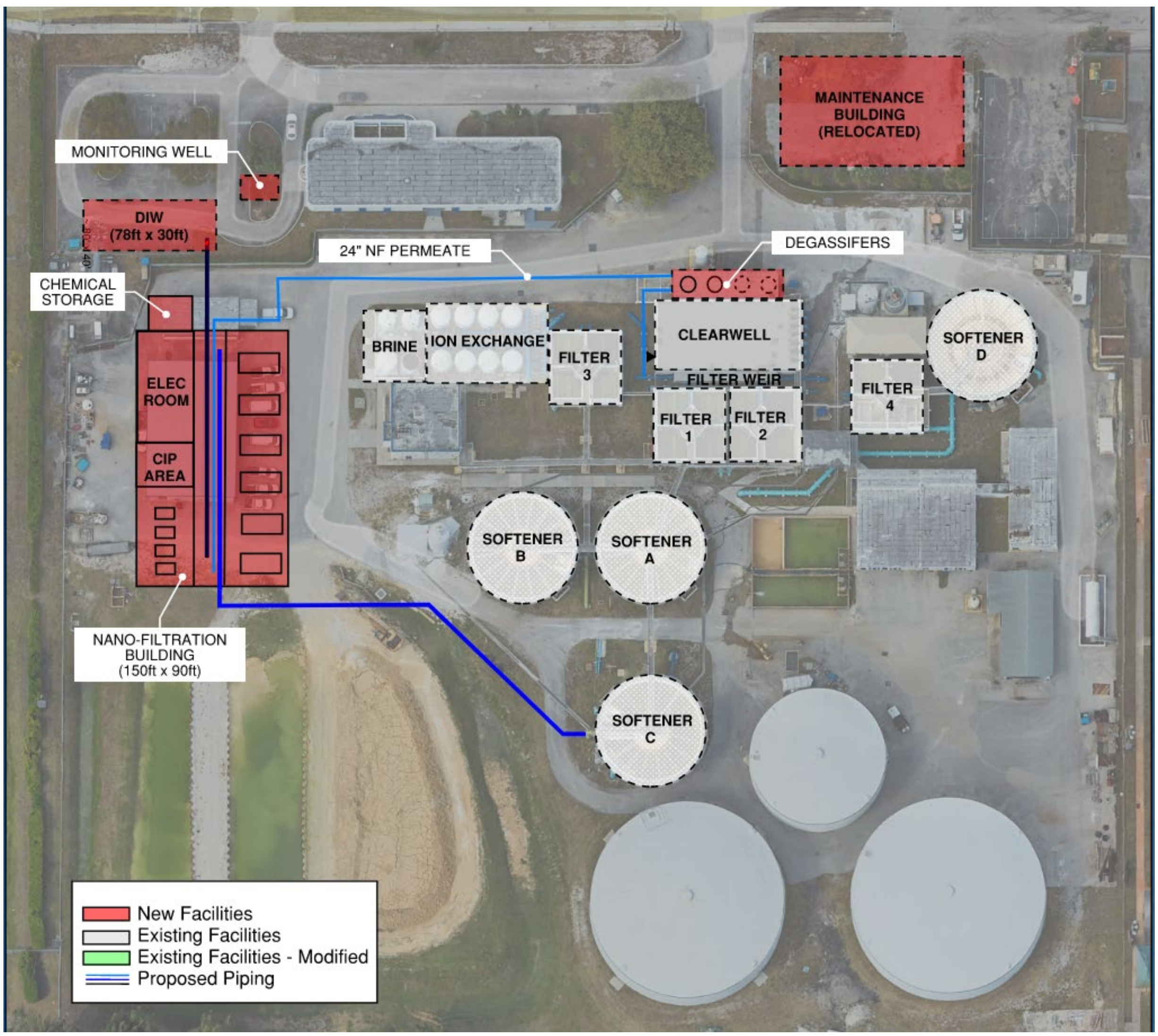


Figure 5.10 Potential Site Layout for Treatment Alternative 4 - Conversion From Lime Softening and Regenerable FIX to High-Pressure Membrane

SECTION 6 COST ESTIMATES

6.1 Capital, Operations and Maintenance, and Life-Cycle Costs

6.1.1 Capital Cost Estimation

Estimates for probable construction costs were developed in accordance with requirements from the AACE. The applicable cost level classification for this evaluation was selected as a Class 4 Estimate, which reflects an order of magnitude estimate and is customarily used for screening and preliminary budget allocations before a detailed design is developed. The project definition at this stage is typically a conceptual design level up to about 15 percent, and the expected accuracy range is between -30 percent and +50 percent. If budgeting is required early-on, it is recommended that the upper range is utilized until additional cost information and project risks and uncertainties are defined. The capital costs estimate for each of the alternatives reflects the following key assumptions:

- Alternative 1 - Expand regenerable FIX and add GAC adsorbers for PFAS treatment:
  - » Existing FIX will be expanded to 18 mgd treatment capacity to ensure low TOC feed for the downstream GAC treatment facility.
  - » Upgrades to the existing FIX include new intermediate transfer pumps.
  - » New brine system constructed so existing brine tanks can be relocated to allow for FIX expansion.
  - » New blending tank to provide flow equalization and bypass flexibility during construction and operations.
  - » New GAC treatment facility, including 16 lead-lag trains of 12-foot diameter pressure vessels (i.e., 32 vessels) with intermediate pumping.
  - » GAC backwash tank and pumping system.
  - » Existing lime-softening and filter system rehabilitation.
- Alternative 2 - Expand regenerable FIX and add IX adsorbers for PFAS treatment:
  - » Existing FIX will be expanded to 18 mgd treatment capacity to ensure low TOC feed for the downstream IX treatment facility.
  - » Upgrades to existing FIX include new intermediate transfer pumps.
  - » New brine system constructed so existing brine tanks can be relocated to allow for FIX expansion.
  - » New blending tank to provide flow equalization and bypass flexibility during construction and operations.
  - » New IX treatment facility, including 10 lead-lag trains of 12-foot diameter pressure vessels (i.e., 20 vessels) with intermediate pumping.
  - » Existing lime-softening and filter system rehabilitation.
- Alternative 3 - Expand regenerable FIX and add FS200 adsorbers for PFAS treatment:
  - » Existing FIX will be expanded to 18 mgd treatment capacity to ensure low TOC feed for the downstream IX treatment facility.
  - » Upgrades to existing FIX include new intermediate transfer pumps.
  - » New brine system constructed so existing brine tanks can be relocated to allow for FIX expansion.

- » New blending tank to provide flow equalization and bypass flexibility during construction and operations.
- » New FS200 treatment facility, including 12 lead-lag trains of 12-foot diameter pressure vessels (i.e., 24 vessels) with intermediate pumping.
- » Existing lime-softening and filter system rehabilitation.

- Alternative 4 - Conversion from lime softening and regenerable FIX to high-pressure membrane (NF/RO):
  - » New NF facility, including NF building, NF treatment skids, pretreatment, and chemical systems.
  - » New DIW for concentrate disposal.
  - » New blending tank and degassifiers.
  - » Provisions for alternative water supply for projected raw water shortfall were not included in the cost estimation.

6.1.2 Operations and Maintenance and Life-Cycle Cost Estimation

Annual O&M and life-cycle costs in terms of 20-year net present value (NPV) for each treatment alternative were also estimated. Table 6.1 presents a summary of estimated costs for the four shortlisted treatment alternatives. Details of the cost estimates and the associated assumptions are referred to in Appendix B.

Table 6.1 Summary of Estimated Capital, Annual O&M, and 20-Year Life-Cycle Costs for Four Short-Listed Treatment Alternatives

Alternatives	1	2	3	4
Description	Expand FIX + GAC	Expand FIX + IX	Expand FIX + FS200	NF/RO
Capital Cost (1)	$72.8M *($51.0 - $109.3M)*	$54.5M *($38.1 - $81.7M)*	$60.0M *($42.0 - $90.0M)*	$140.8M *($98.5 - $211.1M)*
Annual O&M Costs (PFAS Treatment Only)	$7.1M	$6.3M	$6.3M	$9.8M
20-Year NPV (2)	$218M	$179M	$187M	$343M

Note:
(1) Values in parentheses represent AACE Class 4 estimate accuracy range (-30% to+50%).
(2) NPV estimate reflects the upper contingency range for Class 4 capital cost.

Figure 6.1 through Figure 6.3 present bar charts for capital, O&M, and life-cycle cost estimates. All estimated costs are in 2024 dollars. See Appendix B for detailed breakdowns and assumptions made for this cost estimation.

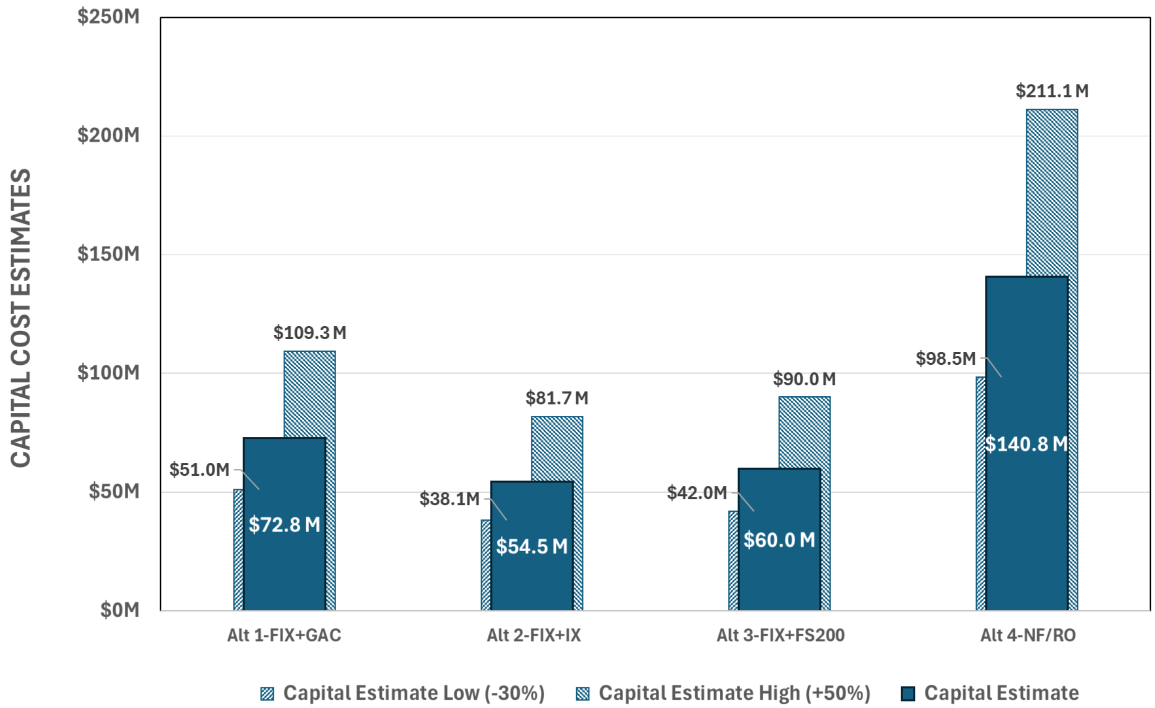


Figure 6.1 Summary of PFAS Treatment Capital Cost Estimates (AACE Class 4)

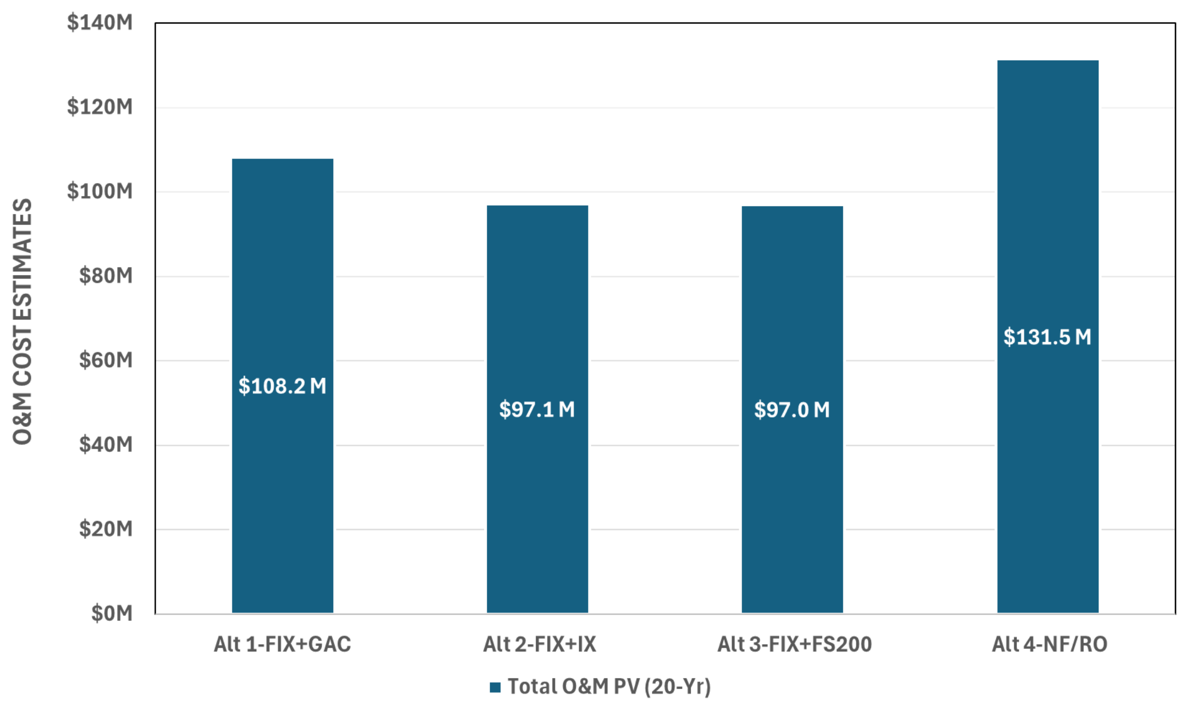


Figure 6.2 Summary of PFAS Treatment O&M Cost Estimates (20-Year)

The estimated capital and O&M costs were further utilized to estimate the 20-year NPV. The NPV is the present value of capital and O&M costs of a project over a specified period of time. The NPV approach is a common evaluation criterion for comparing the long-term cost of treatment alternatives. The 20-year analysis period is commonly used because the 20-years mark is when major renewal and replacement of treatment components are required. It should be noted that this 20-year period does not indicate the duration required for PFAS removal. It is anticipated that the need for PFAS treatment will continue to evolve, including that f more PFAS are to be regulated with respective MCLs or regulated as a mixture using the HI approach.

The following general assumptions were used in the economic evaluation:

- Present Worth Geometric Gradient - this allows for capturing increasing O&M costs over the life of the evaluation period.
- Escalation/Inflation - 3.5 percent.
- Discount Rate - 7.5 percent.
- Evaluation Period - 20 years.

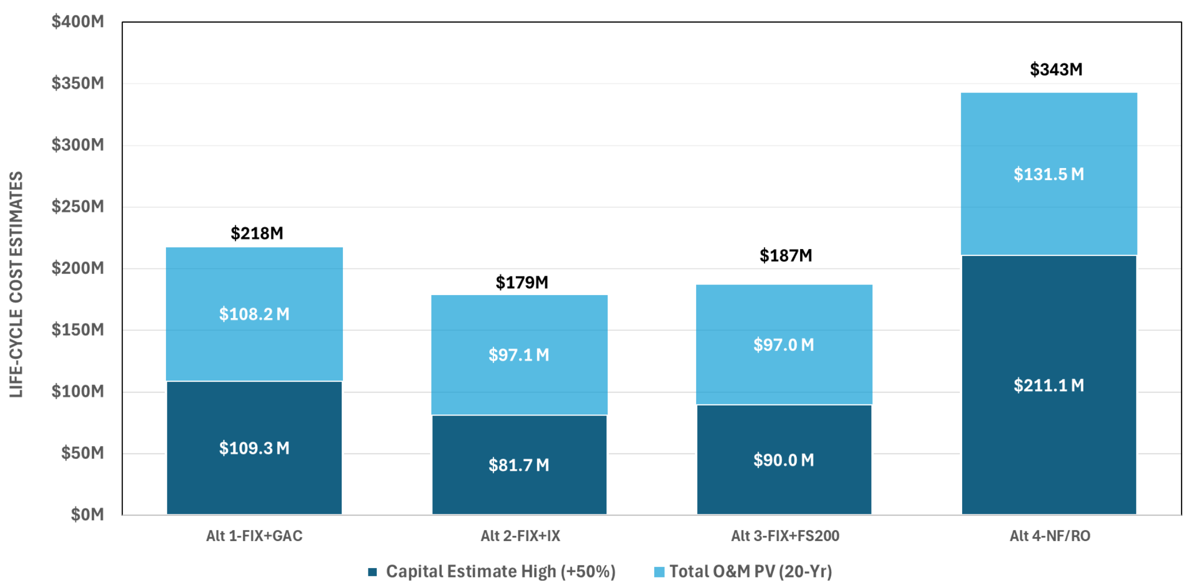


Figure 6.3 Summary of PFAS Treatment Life-Cycle Cost Estimates

SECTION 7 RECOMMENDATIONS AND NEXT STEPS

Carollo recommends that the City proceed with a PFAS treatment facility design at the City's WTP to comply with the upcoming NPDWRs for PFAS. Based on treatment performance, site constraints, cost considerations, and non-cost considerations, the recommended treatment alternative is to employ a PFAS adsorption process using IX resin, along with an expansion to the existing regenerable FIX system to maintain the TOC concentrations in the feed water to or below 1 mg/L going to the PFAS treatment system. This level of TOC pretreatment is critical in minimizing long-term O&M costs associated with media changeout for PFAS treatment. IX resin is the recommended PFAS treatment technology for the City's WTP because of the lowest capital, annual O&M, and life-cycle costs. In addition, the non-cost factors are listed in Section 3 and should be considered when making the final decision on PFAS treatment technology selection.

The recommended next steps for the implementation of a PFAS treatment facility are depicted in Figure 7.1. As previously noted, the compliance schedule established by USEPA is April 26, 2029. However, there are several critical milestones that precede the regulatory enforcement date. Specifically, compliance monitoring will start on April 26, 2027. Following this date, public waters utilities will have to report PFAS levels in the annual Consumer Confidence Reports and are required to provide public notices for monitoring violations. In addition, because the MCL compliance is based on RAA concentrations, the first quarterly sample towards RAA calculation will start in April 2028. This effectively makes April 2028 the operational deadline for PFAS treatment facility.

With these constraints, the critical path for implementation currently proceeds through design, construction, and start-up and commissioning. The schedule is very compressed and only allows approximately 15 months for design (including procurement) and 24 months for construction (excluding bidding and award). It is recommended that City proceed promptly to design phase and actively identify schedule risks and manage potential delays in order to meet the compliance schedule.

Table 7.1 Implementation Schedule Duration and Milestones

Task	Duration	Milestones (1)
PFAS Study	-	February 2025
Procurement- Engineering Services	6 months	August 2025
Design Phase	12 months	August 2026
Permitting	3 months	November 2026
Procurement - Construction	4 months	March 2027
Construction Phase	24 months	March 2029
Initial PFAS Monitoring Ends	-	April 26, 2027
Compliance Monitoring Starts	-	April 26, 2027
Quarterly PFAS Sampling for RAA Calculation Starts	-	April 26, 2028
MCL Compliance Starts	-	April 26, 2029

Notes:
(1) Assume procurement starts on March 1, 2025.

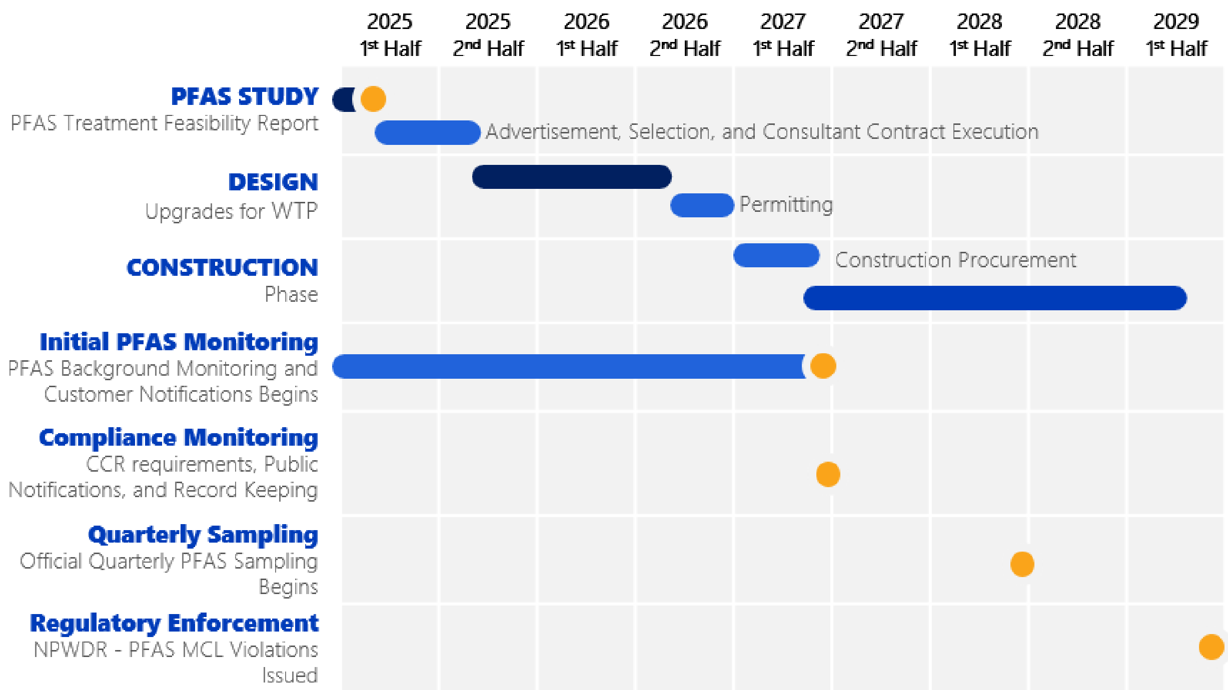


Figure 7.1 Proposed Implementation Schedule

APPENDIX A SUMMARY OF KEY RSSCT FINDINGS

City of Pembroke Pines

PFAS Treatment Feasibility Evaluation

Progress Meeting

Work in Progress Updates

December 5, 2024

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01

Project Overview

Conclusions from Water Quality Data Review (Recap from May 2024)

- Moderate PFOA and PFOS concentrations in the finished water.
  - » ~70% PFOA removal to meet MCL
  - » ~90% PFOS removal to meet MCL
- Need full-flow PFAS treatment without bypass.
- The presence of TOC/color determines PFAS treatment feasibility and economics.
- Need to evaluate the necessity of expanding the existing regenerable FIX for TOC/color removal to make downstream PFAS treatment more cost-effective.

Compound	Units	Final MCL	Mar 2023 UCMR5	Sep 2023 UCMR5
PFOA	ng/L	4.0	14.4	10.2
PFOS	ng/L	4.0	34.7	23.3
PFHxS	ng/L	10	9.1	6.1
PFNA	ng/L	10	ND	ND
HFPO-DA (GenX)	ng/L	10	ND	ND
PFBS	ng/L	--	9.8	7.1
Hazard Index (HI)	--	1.0	0.9	0.6

Project Objectives

Systematically evaluate the feasibility of PFAS treatment by GAC, IX, and FS with and without pretreatment for TOC removal.

- How much TOC makes PFAS treatment infeasible and cost-prohibitive?

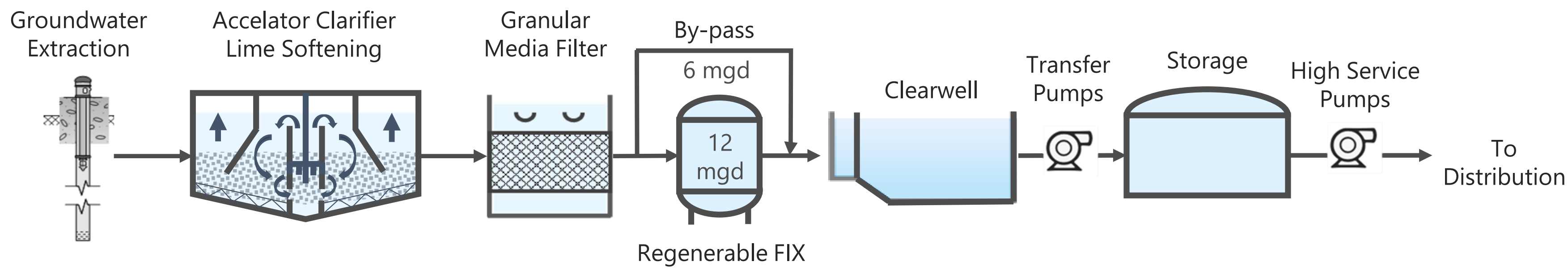
Evaluate the impact of TOC on different media types and different PFAS species.

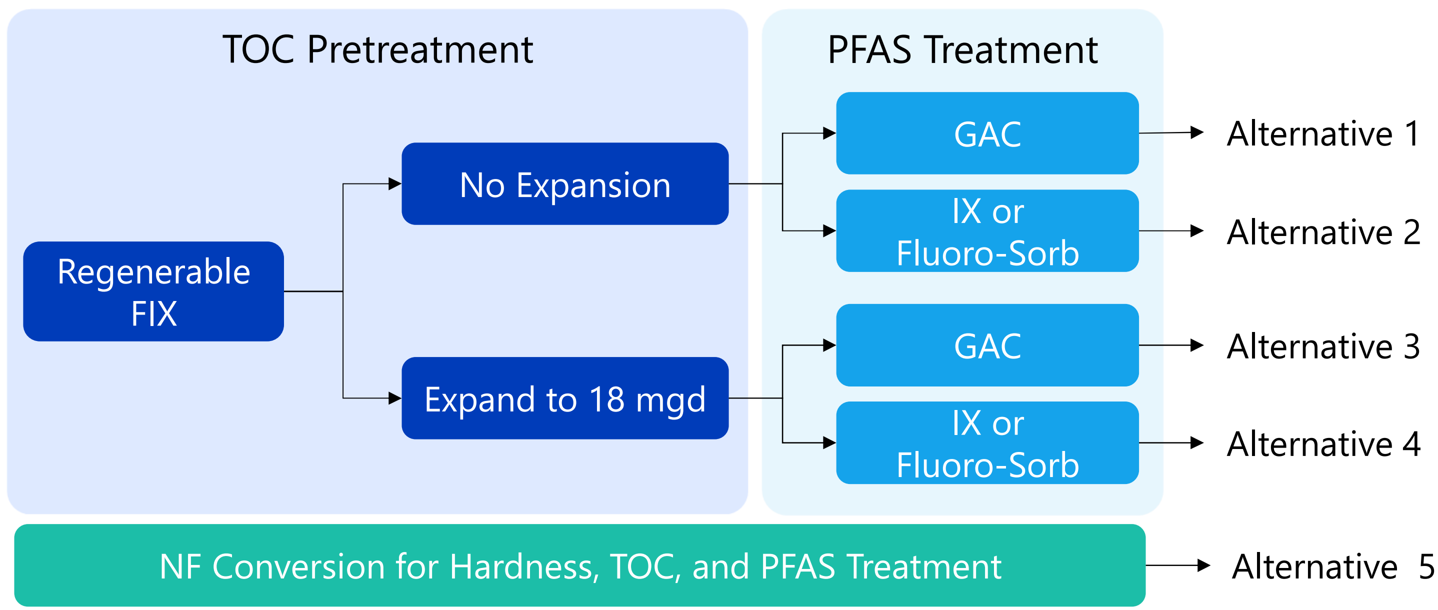
- Which media is more resistant to organics fouling?
- How does TOC impact different PFAS: who's driving media changeout?

Identify the breakeven point between pretreatment costs for TOC removal and O&M savings for PFAS treatment.

- Is it necessary to expand the existing regenerable FIX for more TOC removal?

Treatment Alternatives Drivers – TOC & PFAS

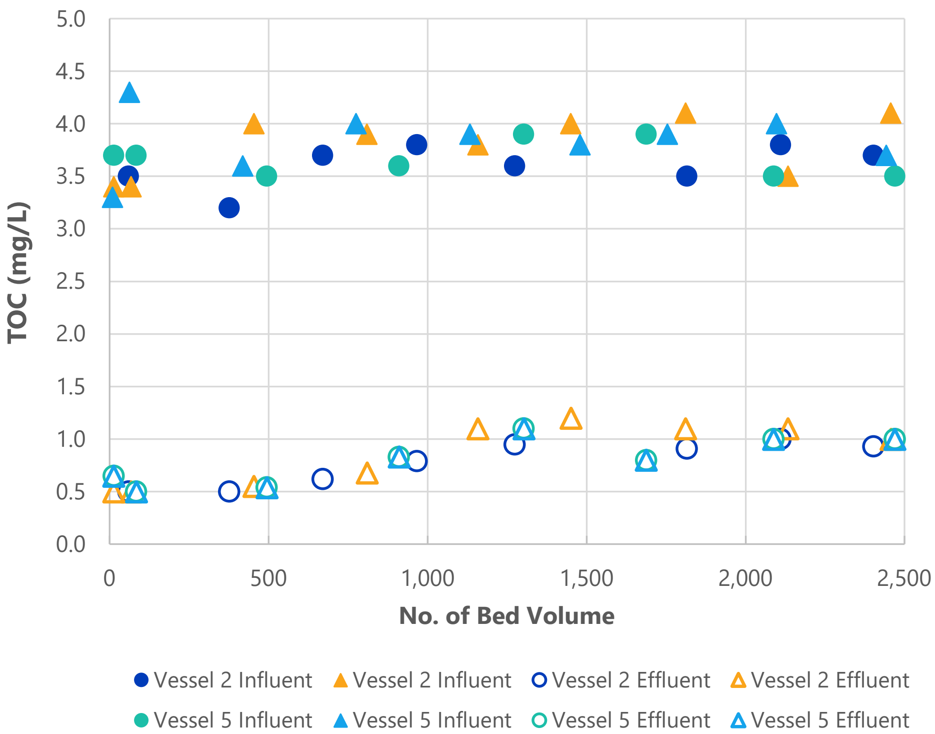


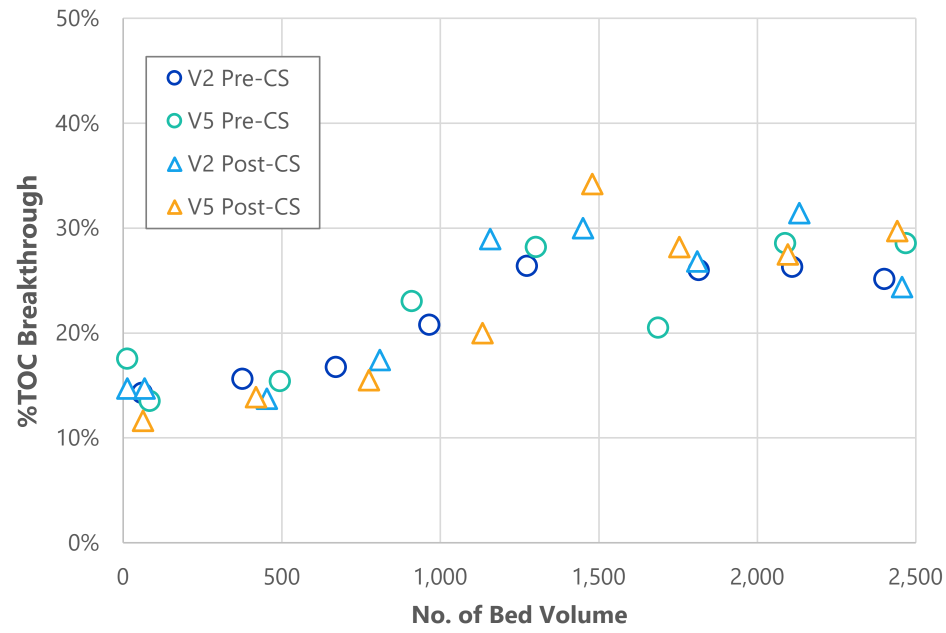


02

Full-scale Regenerable FIX Sampling Results

TOC Sampling Suggested Regenerable IX is Highly Effective in TOC Removal and Caustic Squeeze Does not Impact Performance





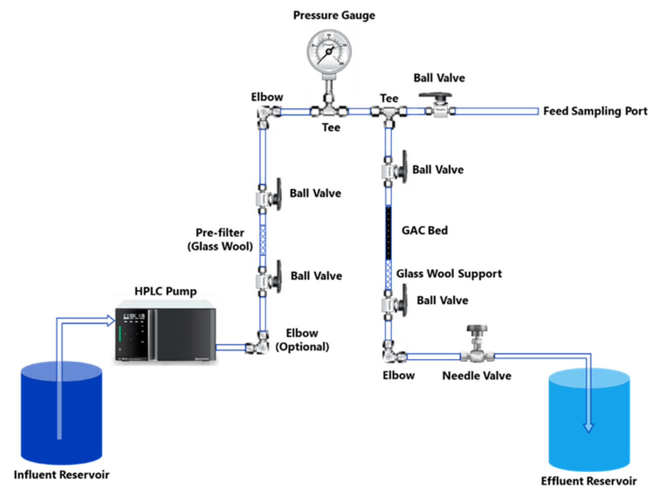
03

Rapid Small-Scale Column Test (RSSCT) Results

RSSCT Design

	Parameter	Units	Column	Column	Column
			GAC	IX	FS
Full-Scale Adsorber	Source		High and Low TOC Feed		
	Supplier	--	Calgon	Purolite	CETCO
	Product	--	F400	PFA694E	FS 200
	Type	--	12×40	20×35	20×40
Bench-Scale RSSCT Column	RSSCT Method	--	Hybrid	CD	CD
	Diffusivity Factor, X	--	0.25	0	0
	Empty Bed Contact Time	min	**12.5**	**2.0**	**3.0**
	Hydraulic Loading Rate	gpm/ft^2	**6.3**	**12.6**	**12.6**
	Scaling Factor	--	8.5	6.1	5.7
	Empty Bed Contact Time	min	0.297	0.059	0.094
	Duration	BV	**65,000**	**350,000**	**280,000**
		days	564	535	583
		years	1.5	1.5	1.5

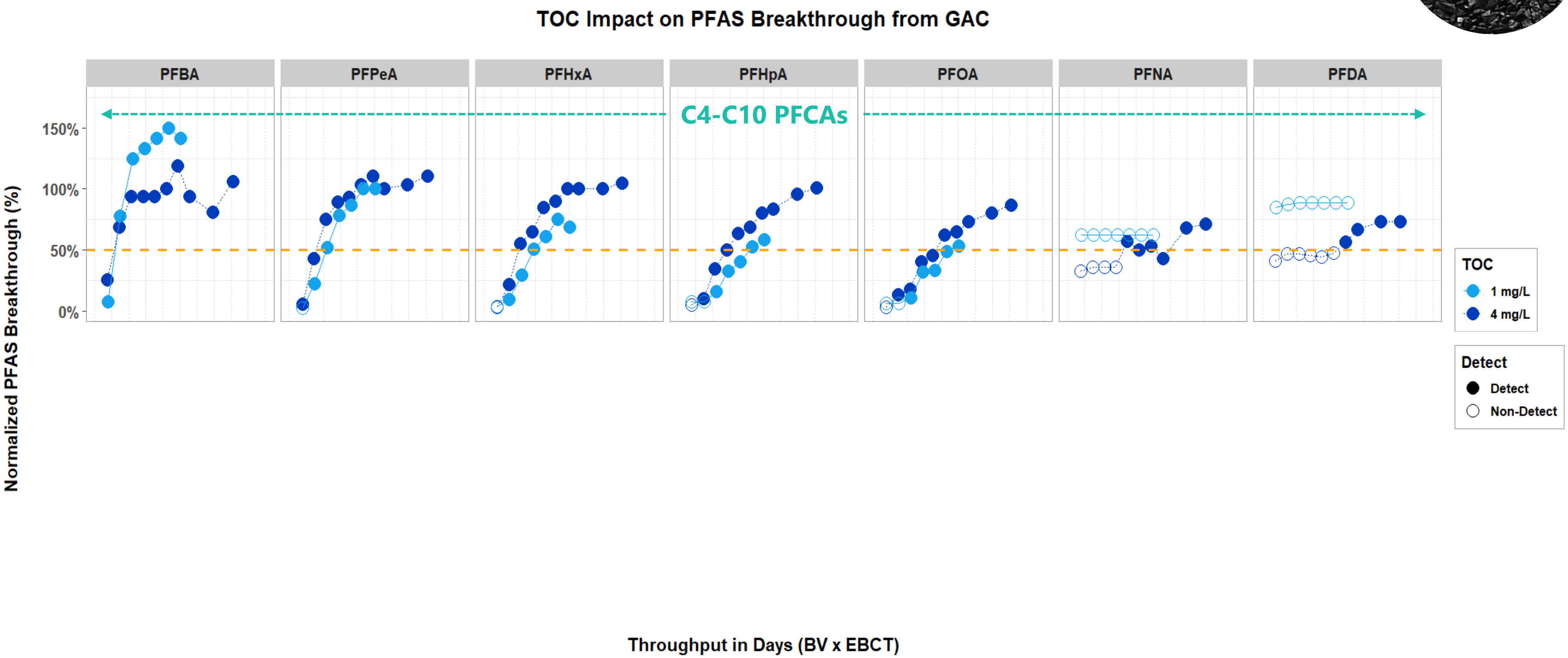
RSSCTs were performed on regenerable FIX combined feed and combined effluent.
2 feed waters × 3 media types = 6 RSSCTs



Feed Water Characterization—Regenerable IX Was Found to Remove PFOS

	Parameter	Units	IX Influent	IX Effluent	UCMR5 Mar 2023	UCMR5 Sep 2023	MCL
General Water Quality	pH	S.U	8.5	8.3	NA	NA	
	UV254	cm^{-1}	0.125	0.022	NA	NA	
	TOC	**mg/L**	**4.1**	**1.0**	NA	NA	
PFCAs	PFBA (C4)	ng/L	18	17	12.2	9.2	
	PFPeA (C5)	ng/L	28	25	23.9	17.7	
	PFHxA (C6)	ng/L	21	16	18.4	13.4	
	PFHpA (C7)	ng/L	9.8	8.2	10.0	6.7	
	PFOA (C8)	**ng/L**	**14**	**11**	14.4	10.2	4.0
	PFNA (C9)	ng/L	2.5	1.9 J	ND	ND	10
	PFDA (C10)	ng/L	1.4 J	1.3 J	ND	ND	
PFSAs	PFBS (C4)	ng/L	10	6.7	9.8	7.1	
	PFPeS (C5)	ng/L	1.1 J	0.9 J	ND	ND	
	PFHxS (C6)	ng/L	8.5	6.0	9.1	6.1	10
	PFHpS (C7)	ng/L	1.2 J	0.7 J	ND	ND	
	PFOS (C8)	**ng/L**	**53**	**18**	34.7	23.3	4.0
FTS	**6:2 FTS**	**ng/L**	**44**	**35**	39.1	28.0	
	8:2 FTS	ng/L	3.1	2.3	ND	ND	

Higher TOC, Earlier PFAS Breakthrough and the Impact of TOC Was Consistent Across the Board of Different PFAS - GAC



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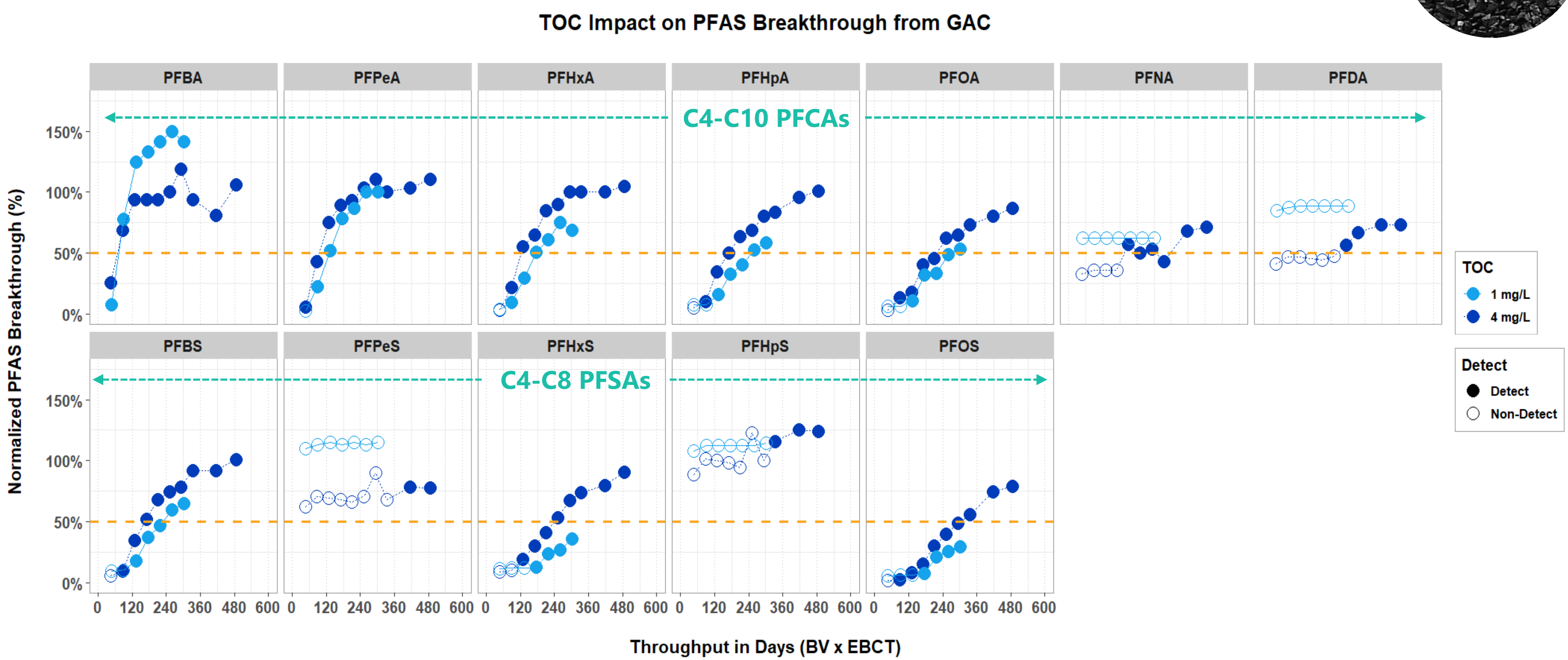
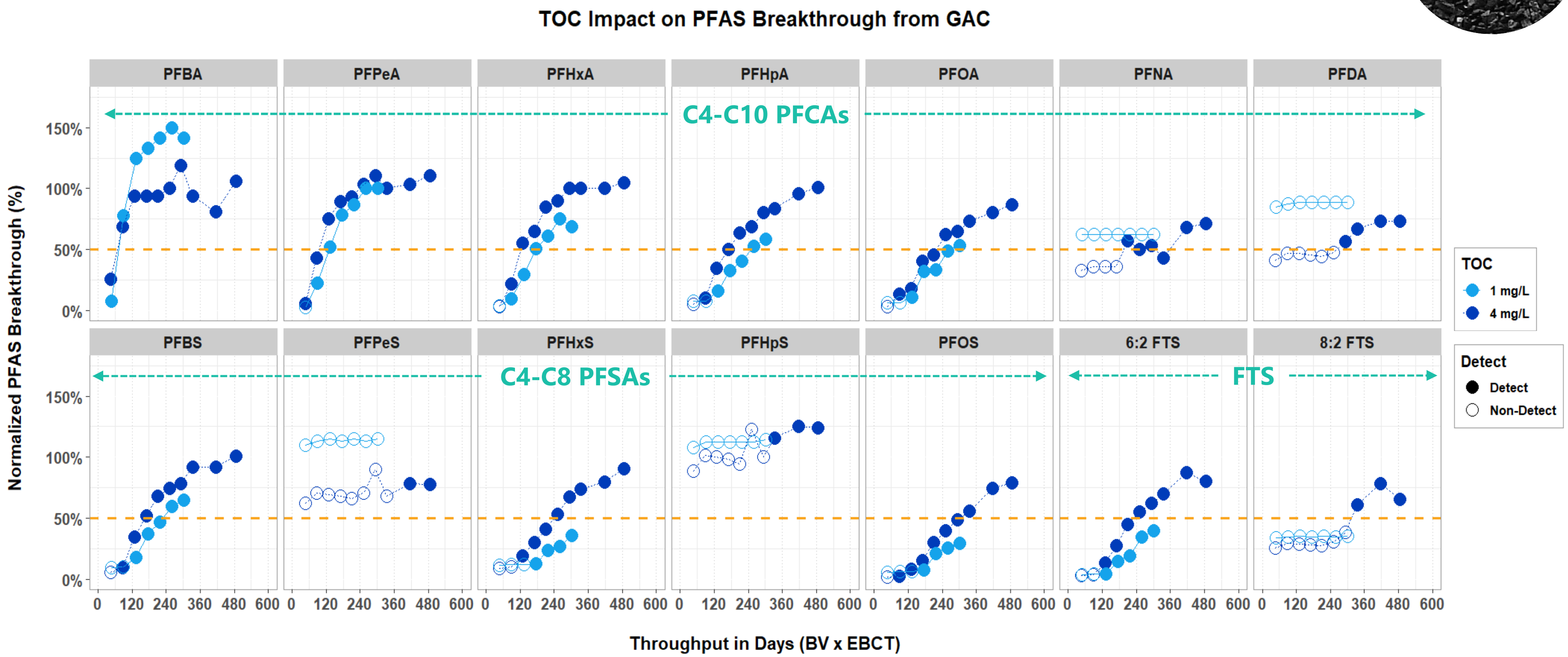


Higher TOC, Earlier PFAS Breakthrough and the Impact of TOC Was Consistent Across the Board of Different PFAS - GAC



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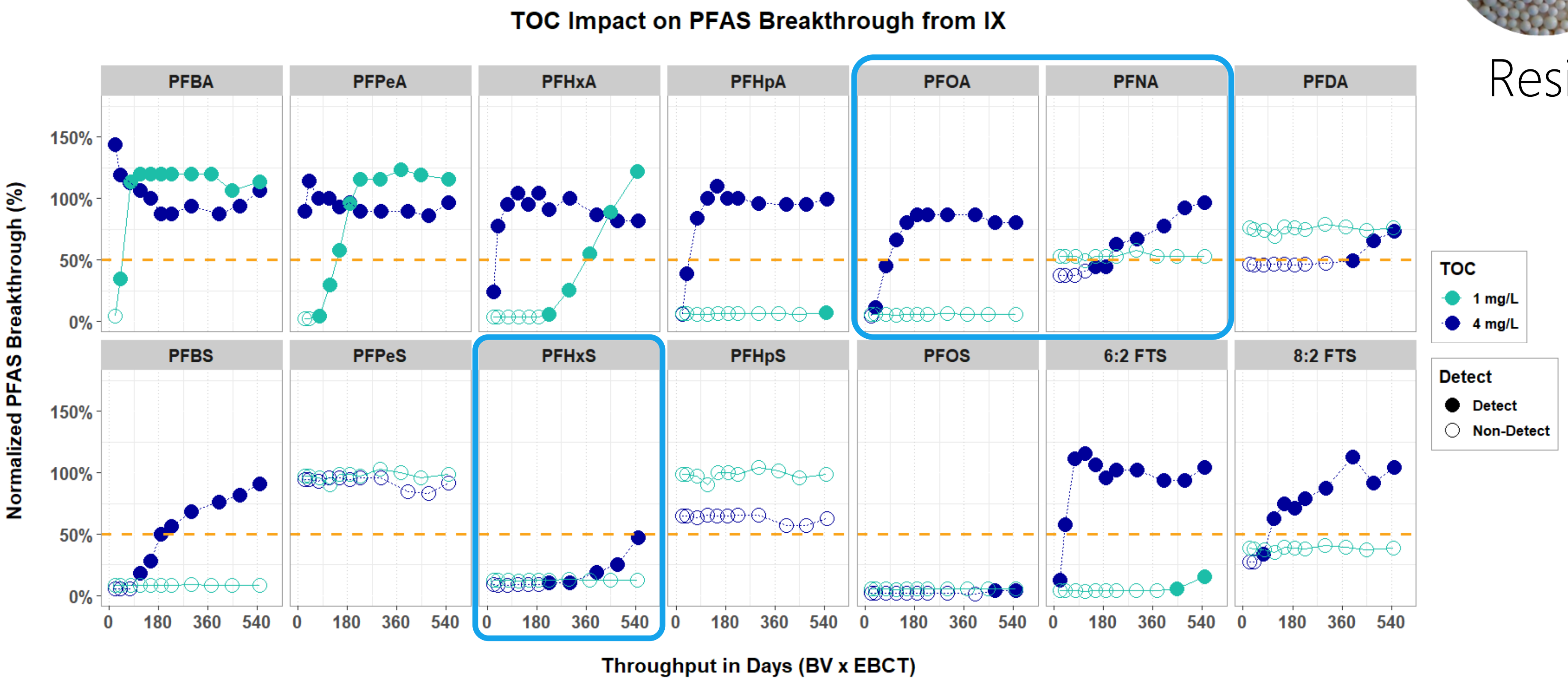
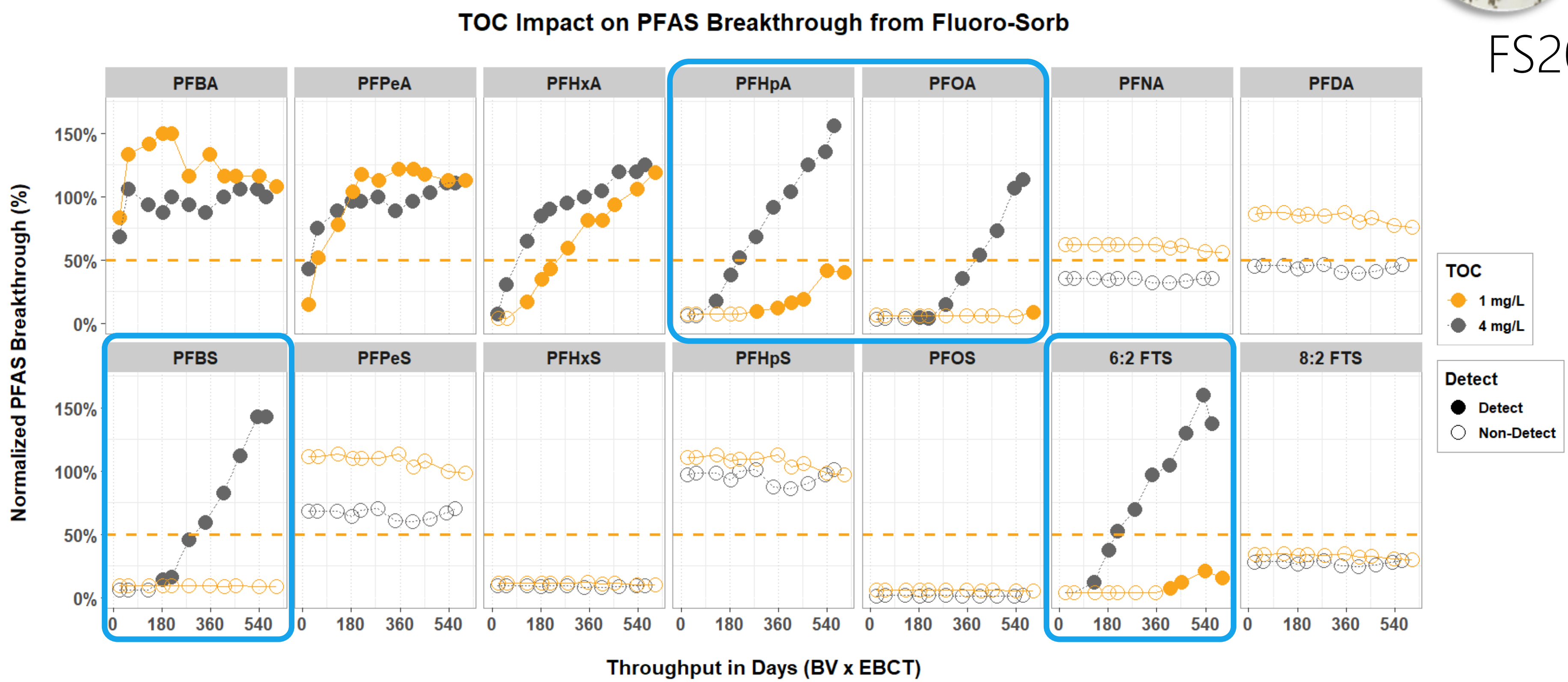
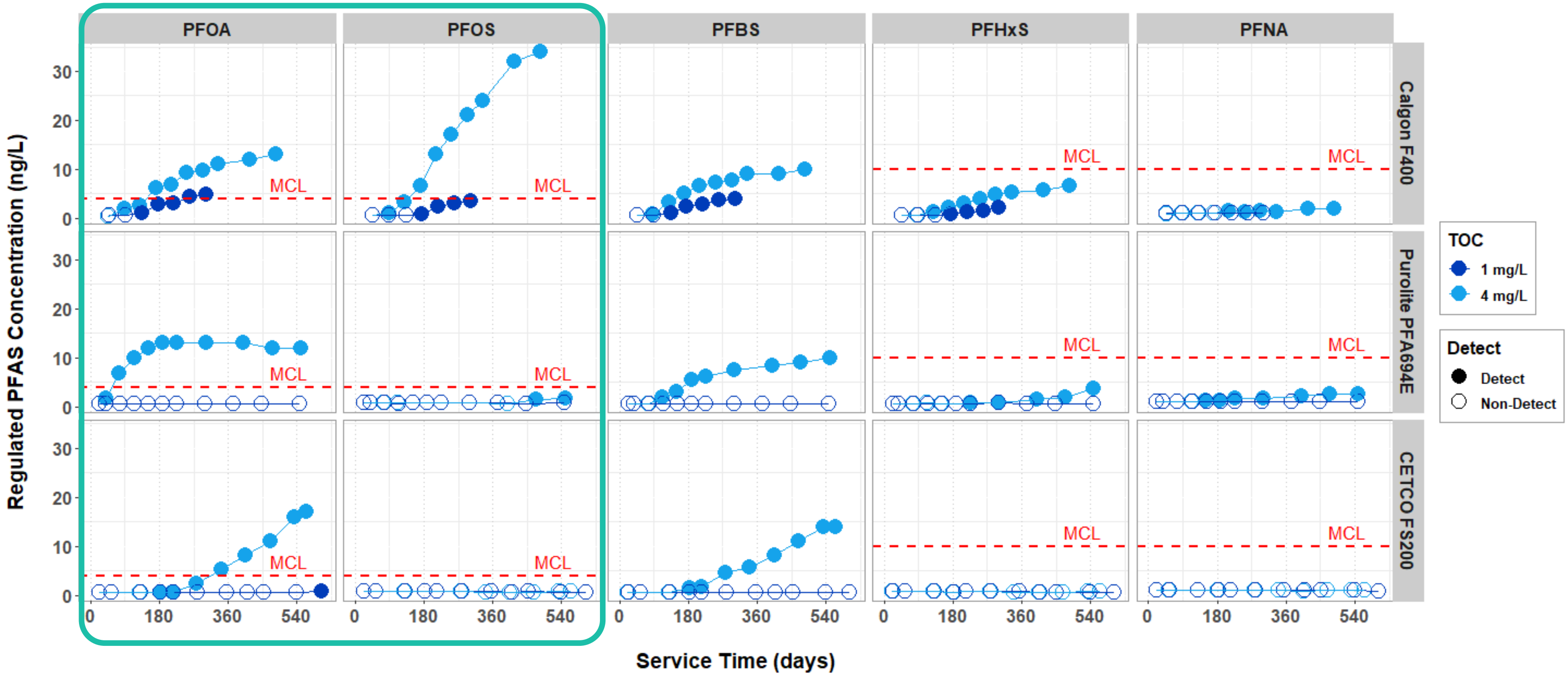
More Apparent Deterioration in IX Performance at Higher TOC



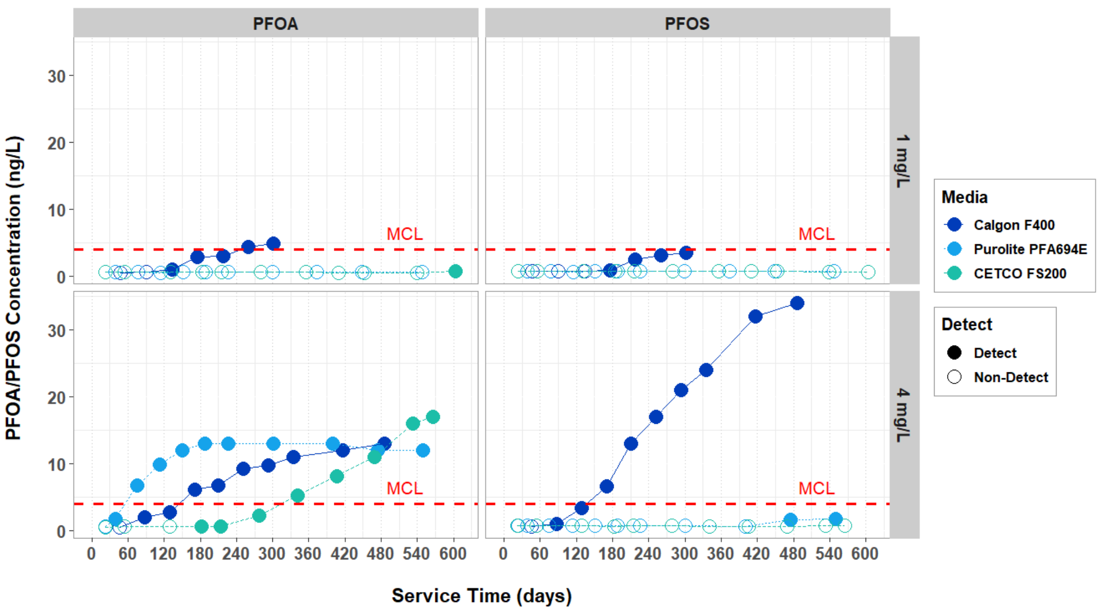
TOC Only Impacts PFHxA, PFHpA, PFOA, PFBS, and 6:2 FTS Breakthrough from FS200



Among the 6 Regulated PFAS, PFOA and PFOS Drive Media Selection and Changeout Frequency



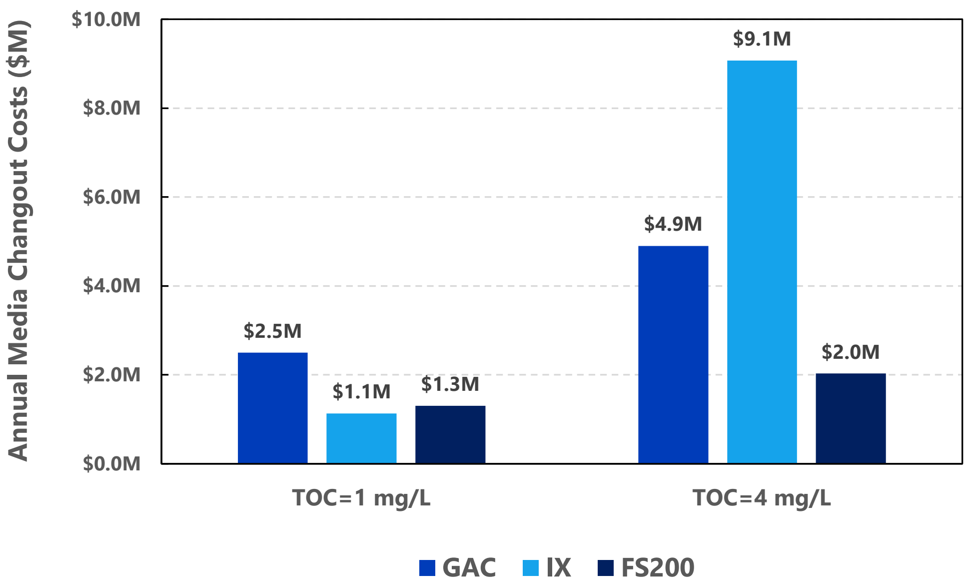
IX and FS200 Outperformed GAC in Treating Low-TOC Feed. GAC and IX are Not Economically Feasible for PFAS Treatment under High-TOC



Feed TOC	Media		PFOA		PFOS	
			Days	Months	Days	Months
1 mg/L	GAC	✗	240	**8**	300	**10**
	IX	✓	540	**18**	540	**18**
	FS200	✓	600	**20**	600	**20**
4 mg/L	GAC	✗	150	**5**	120	**4**
	IX	✗	60	**2**	570	**19**
	FS200	✓	300	**10**	570	**19**

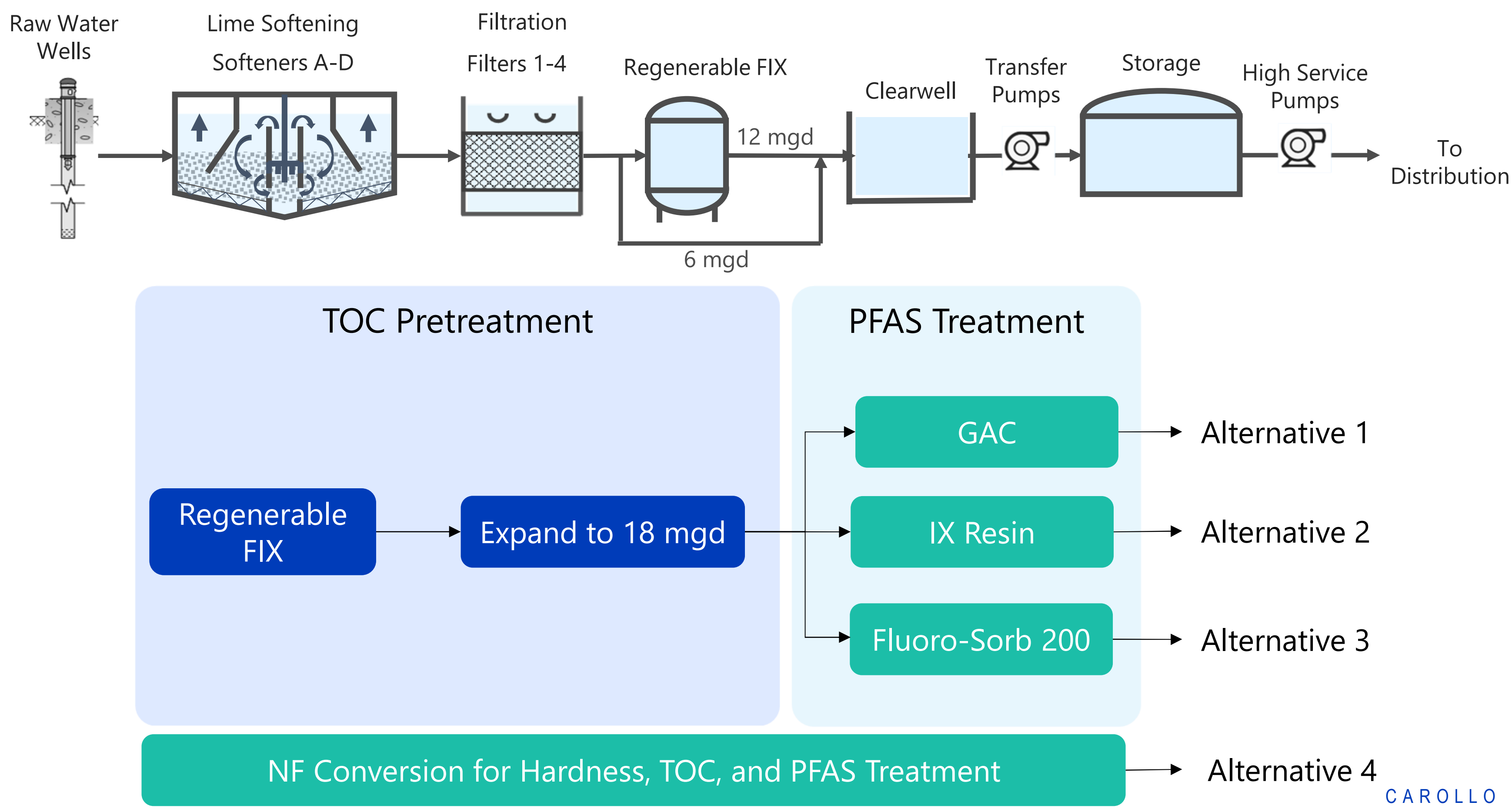
$2.5M/Year Cost Savings for GAC and $8.0M/Year for IX by Reducing Feed Water TOC from 4 mg/L to 1 mg/L

- Design Capacity: 18 mgd
- Media Changeout Costs:
  - GAC: $2.5/lb.
  - IX Resin: $450/ft³
  - FS200: $350/ft³



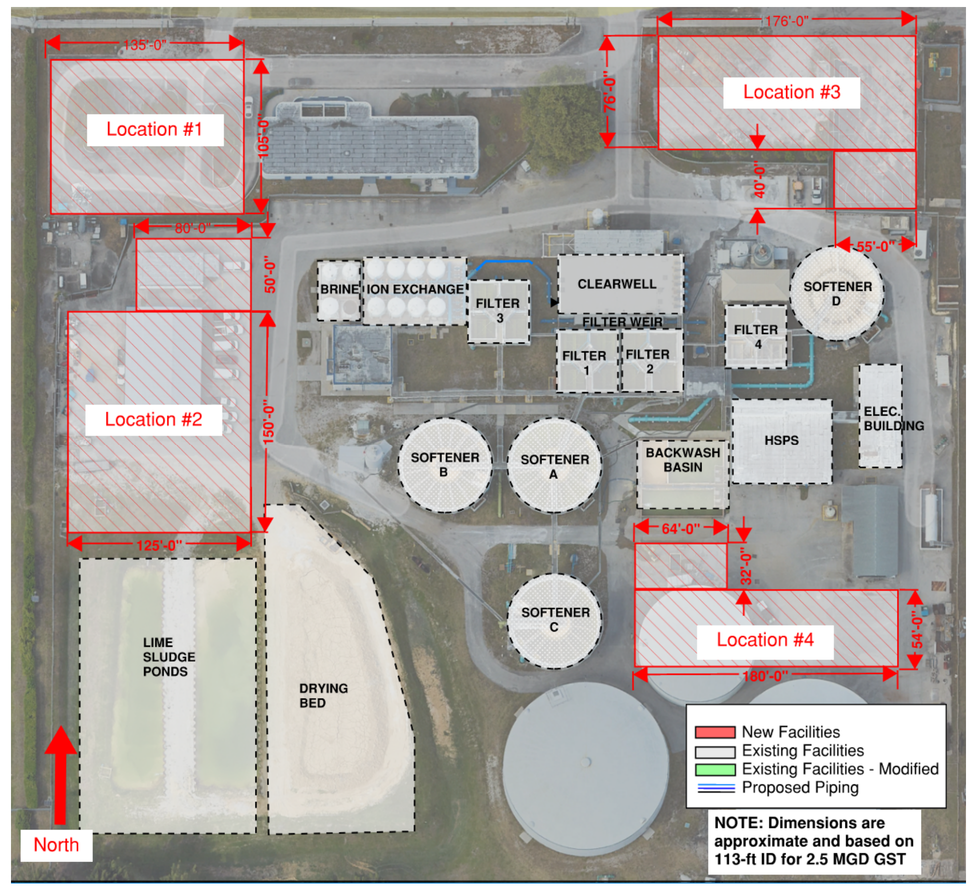
Parameter	Unit	Value
Design Capacity	mgd	18
Treatment Trains (N)	**No.**	**12**
No. of Vessels per Train	No.	1
Flow per Train (N)	gpm	1,042
Vessel Diameter	**ft**	**12**
Hydraulic Loading Rate (N)	gpm/ft²	9.2
Resin Volume per Vessel	ft³	420
EBCT per Vessel (N)	min	3.0
Throughput	MG	8.0
	BV	2,546
	days	5.3
Vessel with Resin	$/vessel	355,000
Total Construction	**$M**	**$11.8M**
4 Additional FIX	**$M**	**$4.0M**
Salt Use per Regeneration	lb	4800
Salt Cost	$/lb.	0.1
Annual Salt Cost	**$M/yr**	**$0.4M/yr**

Shortlisted Treatment Alternatives



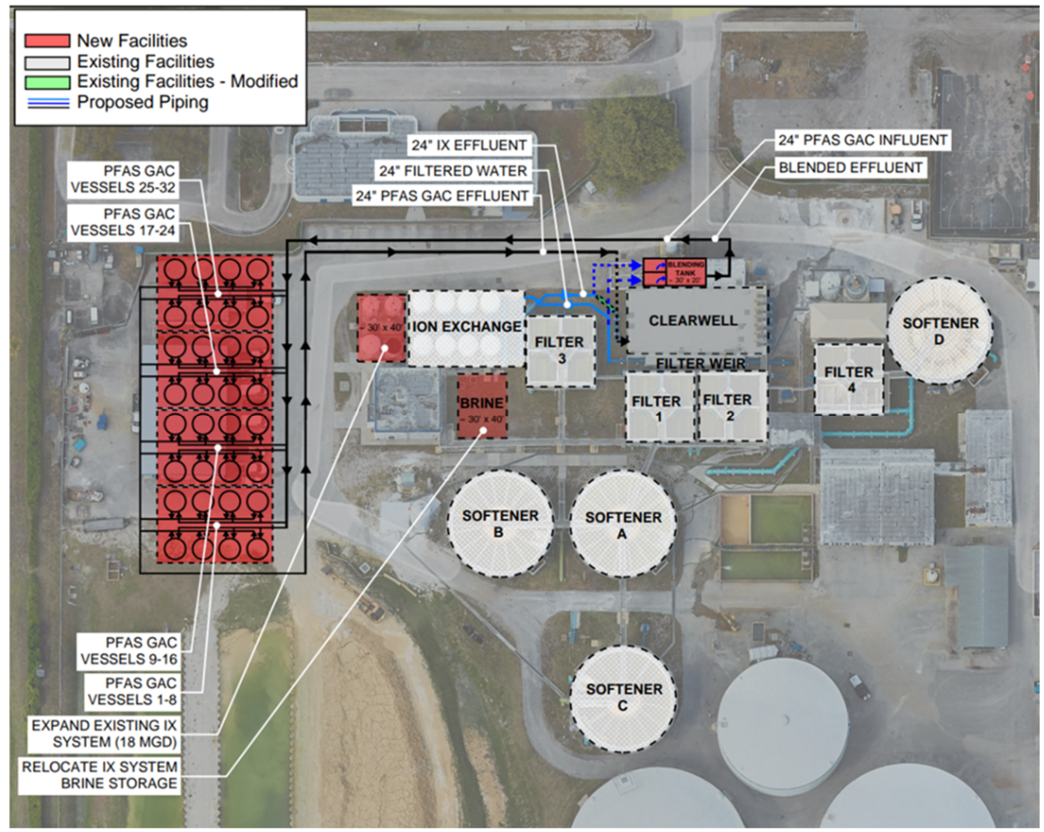
Site Utilization Options

- Location 1- Existing Parking Lot
- Location 2- Maintenance Building
- Location 3- Front Entrance
- Location 4 – Existing GST



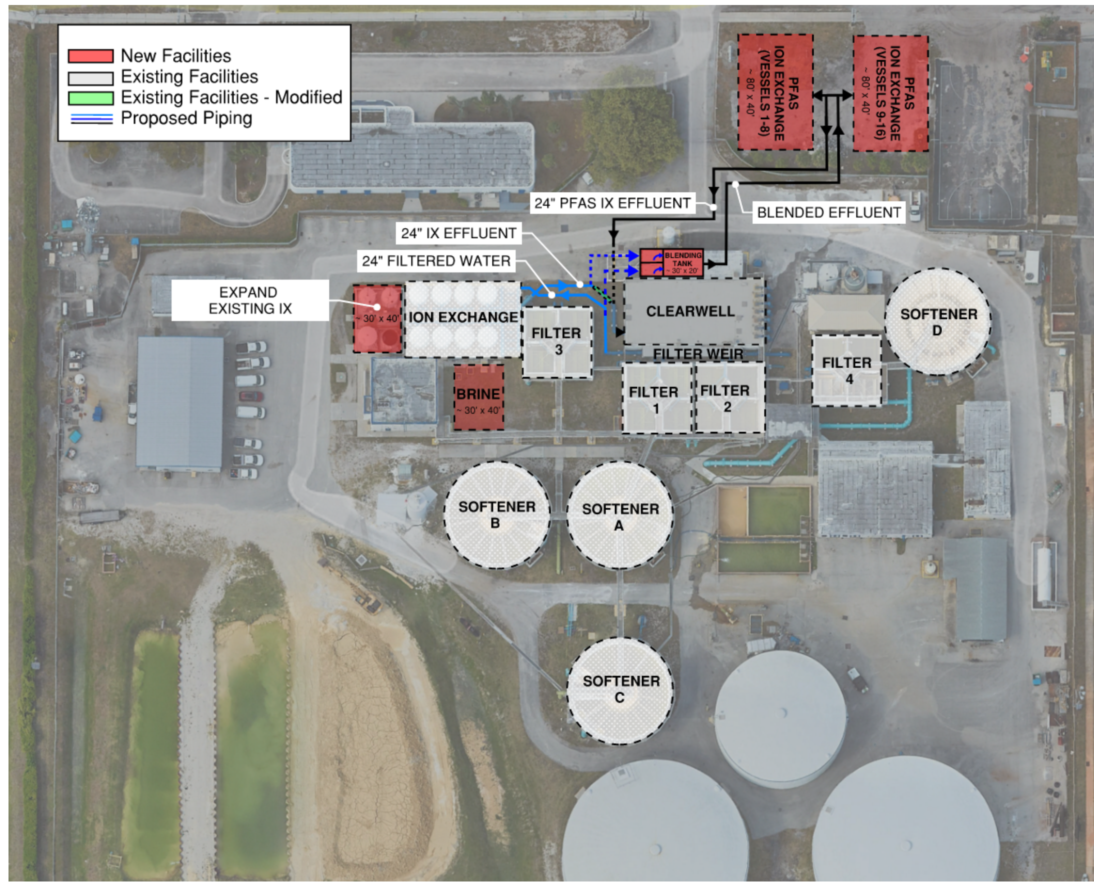
Conceptual GAC Layout

- Options for FIX expansion dependent of O&M cost and operational flexibility
- Relocate brine system for FIX expansion
- New GAC facility located at the current maintenance building and parking lot
- New blending tank for flow EQ and bypass



Conceptual IX Layout

- Options for FIX expansion dependent of O&M cost and operational flexibility
- Relocate brine system for FIX expansion
- New IX facility located at the front entrance
- New blending tank flow EQ and bypass

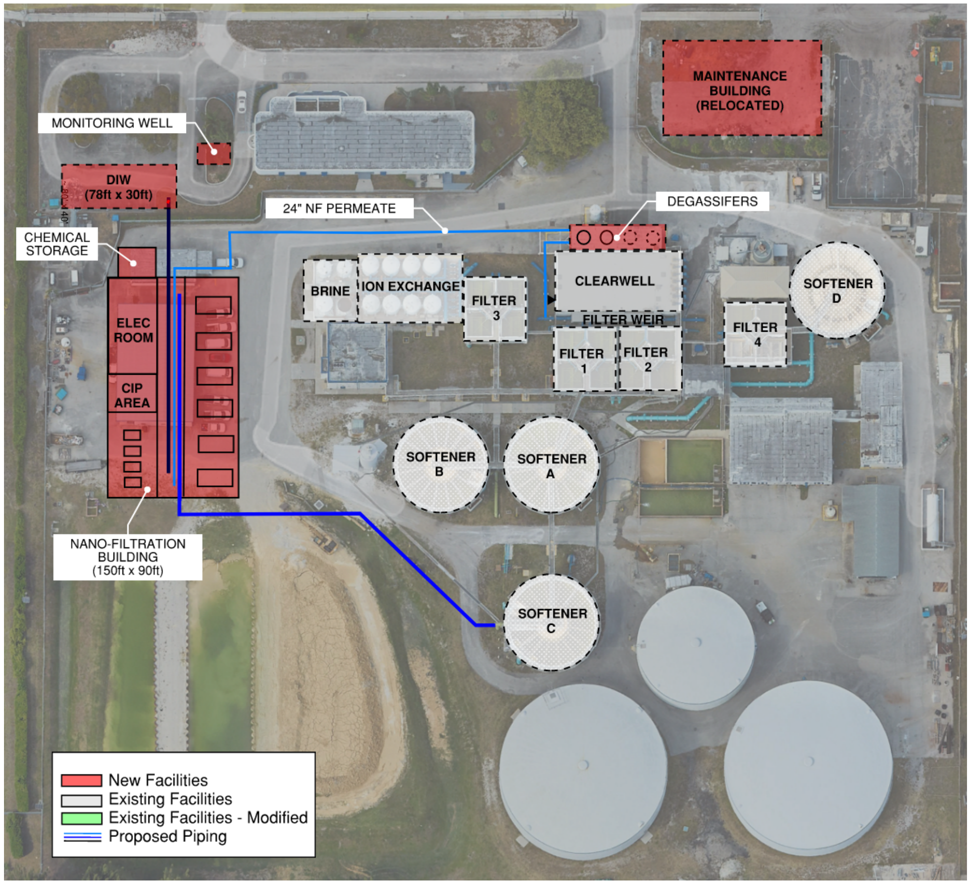


Conceptual FS200 Layout

- Options for FIX expansion dependent of O&M cost and operational flexibility
- Relocate brine system for FIX expansion
- New IX facility located at the front entrance
- New blending tank flow EQ and bypass

Conceptual NF Layout

- New NF Building 150ft x 90ft
- New DIW and monitoring well
- Yard Piping
- Degassifier and blending tank



04

Recommendations and Next Steps

Recommendations and Next Steps

- Complete PFAS facility conceptual design and layout
  - Existing IX- with and without expansion
  - PFAS treatment with IX and Fluoro-sorb
  - Membrane filtration
- Complete life cycle cost analysis for each treatment alternative
- Fluoro-Sorb has demonstrated effectiveness for removing PFAS; longer operating life under higher TOC loading
  - If selected as the treatment technology, a pilot study is recommended.
  - Operation-related evaluation:
    - Particulate fouling?
    - Biofouling?
    - Impact of residual chloramine on FS200?

Data Request

- Existing Drawings (AutoCAD) for Phase 1 and 2 Expansion
- Lime costs – annual budget or bid pricing
- Sludge hauling costs – contract or budget
- Electrical Bill – Need current rates

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APPENDIX B DETAILED BREAKDOWN AND ASSUMPTIONS FOR COST ANALYSIS

Expand Exisitng IX & GAC Vessals for PFAS

GAC CAPITAL COST ESTIMATE

Classification	Quantity	Units	Unit Cost	Subtotal	Installation Factor	Installation Subtotal	Total Cost
Direct Cost							
Water Treatment System							
Expand Existing IX (TOC)	4	EA	$ 275,000	$ 1,100,000	50%	$ 550,000.00	$ 1,650,000
New IX-TOC Pumps	6	EA	$ 50,000	$ 300,000	50%	$ 150,000.00	$ 450,000
New Brine System	1	LS	$ 500,000	$ 500,000	30%	$ 150,000.00	$ 650,000
Demo Existing Brine System	1	EA	$ 50,000	$ 50,000	25%	$ 12,500.00	$ 62,500
New Blend Tank	1	LS	$ 450,000	$ 450,000	50%	$ 225,000.00	$ 675,000
New GAC System	16	LS	$ 750,000	$ 12,000,000	50%	$ 6,000,000	$ 18,000,000
GAC Vessel Feed Pumps	8	EA	$ 50,000	$ 400,000	50%	$ 200,000	$ 600,000
GAC Backwash Storage Tank	1	EA	$ 75,000	$ 75,000	25%	$ 18,750	$ 93,750
GAC Backwash Pumps	3		$ 50,002	$ 150,006	50%	$ 75,003	$ 225,009
Blend Tank to GAC Vessel Piping (24")	550	LF	$ 350	$ 192,500	50%	$ 96,250.00	$ 288,750
GAC Vessel to Clearwell Piping (24")	750	LF	$ 350	$ 262,500	50%	$ 131,250.00	$ 393,750
Subtotal Facility and Equipment							**$ 23,088,759**
Other							
Future (Redudant IX-TOC) Expansion	4	LS	$ 500,000	$ 2,000,000	30%	$ 600,000	$ 2,600,000
LS Rehabilitation including FIX Media	1	LS	$ 5,000,000	$ 5,000,000	0%	$ -	$ 5,000,000
Filter Rehabilitation and Upgrades	1	LS	$ 5,000,000	$ 5,000,000	0%	$ -	$ 5,000,000
I&C (estimate as % of Facility)		%	20%	$ 4,617,752	0%	$ -	$ 4,617,752
Piping, Valves, and Flow Meters (estimate as % of Facility)		%	20%	$ 4,617,752	0%	$ -	$ 4,617,752
Electrical (estimate as % of Facility)		%	20%	$ 4,617,752	0%	$ -	$ 4,617,752
Subtotal Other Cost							**$ 26,453,000**
Design Contingency		%	30%			$ -	$ 6,926,628
Total Direct Costs							**$ 56,468,387**
Indirect Cost							
General Conditions			5%				$ 2,823,000
Bonds and Insurance			2%				$ 1,129,368
Overhead, Profit, and Risk			15%				$ 8,470,000
Taxes (on total direct construction costs unless exempted or pre-purchase)			7%				$ 3,953,000
Total Indirect Cost							**$ 16,375,368**
Total Construction Cost							**$ 72,844,000**
Engineering, Administration, and Legal			25%				**$ 18,211,000**
Total Capital Cost and Engineering Costs							**$ 91,055,000**

Estimate of Probable Construction Cost:

AACE Class 4 Estimate Low	-30%	**$ 50,990,800**
AACE Class 4 Estimate High	50%	**$ 109,266,000**

GAC ANNUAL OPERATION & MAINTENANCE COSTS

Classification	Quantity	Units	Unit Costs	Extended Cost
GAC Change-out Cost/Vessal	40,000	lb	$ 2.50	$ 100,000
Qty of Vessel Change-outs per year	25.0	No./yr		$ 2,500,000
Brine Regeneration	1.0	LS	$ 400,000	$ 400,000
Power	2,500,000	kWh/yr	$ 0.15	$ 375,000
Chemicals Cost (Process Specific) - Lime	1	LS	$ 1,500,000	$ 1,500,000
pH Adjustment (post LS CO2)	1	LS	$ 400,000	$ 400,000
Sludge Hauling Cost	1	LS	$ 800,000.00	$ 800,000
Subtotal of Annual O&M				**$ 5,975,000**
Maintenance Contingencey (% of Major Capital Equipment)			5%	$ 1,154,438
Total Annual O&M				**$ 7,129,000**

Assumptions:

(1) Costs in 2024 dollars and not escalated to mid-point of construction

(2) Buy American provisions for federally-funded infrastructure not considered

(3) Federal regulations related to dispostal of PFAS waste streams not considered

Expand Exisitng IX & IX-Resin for PFAS

IX CAPITAL COST ESTIMATE

Classification	Quantity	Units	Unit Cost	Subtotal	Installation Factor	Installation Subtotal	Total Cost
			Direct Cost				
Water Treatment System							
Expand Existing IX (TOC)	4	EA	$ 300,000	$ 1,200,000	50%	$ 600,000.00	$ 1,800,000
New IX-TOC Pumps	6	EA	$ 50,000	$ 300,000	50%	$ 150,000.00	$ 450,000
New Brine System	1	LS	$ 500,000	$ 500,000	30%	$ 150,000.00	$ 650,000
Demo Existing Brine System	1	EA	$ 50,000	$ 50,000	25%	$ 12,500.00	$ 62,500
New Blend Tank	1	LS	$ 450,000	$ 450,000	50%	$ 225,000.00	$ 675,000
New IX-PFAS System	10	LS	$ 750,000	$ 7,500,000	$ 1	$ 3,750,000	$ 11,250,000
IX-PFAS Feed Pumps	6	EA	$ 50,000	$ 300,000	$ 1	$ 150,000	$ 450,000
Blend Tank to IX-PFAS Piping (24")	200	LF	$ 350	$ 70,000	50%	$ 35,000.00	$ 105,000
IX-PFAS to Clearwell Piping (24")	275	LF	$ 350	$ 96,250	50%	$ 48,125.00	$ 144,375
Subtotal Facility and Equipment							**$ 15,586,875**
Other							
Future (Redudant IX-TOC) Expansion/Redundancy	4	LS	$ 500,000	$ 2,000,000	30%	$ 600,000	$ 2,600,000
LS Rehabilitation	1	LS	$ 5,000,000	$ 5,000,000	0%	$ -	$ 5,000,000
Filter Rehabilitation and Upgrades	1	LS	$ 5,000,000	$ 5,000,000	0%	$ -	$ 5,000,000
I&C (estimate as % of Facility)		%	20%	$ 3,117,375	0%	$ -	$ 3,117,375
Piping, Valves, and Flow Meters (estimate as % of Facility)		%	20%	$ 3,117,375	0%	$ -	$ 3,117,375
Electrical (estimate as % of Facility)		%	20%	$ 3,117,375	0%	$ -	$ 3,117,375
Subtotal Other Cost							**$ 21,952,000**
Design Contingnency		%	30%		0%	$ -	$ 4,676,063
Total Direct Costs							**$ 42,214,938**
			Indirect Cost				
General Conditions			5%				$ 2,111,000
Bonds and Insurance			2%				$ 844,299
Overhead, Profit, and Risk			15%				$ 6,332,000
Taxes (on total direct construction costs unless exempted or pre-purchase; FL Rules)			7%				$ 2,955,000
Total Indirect Cost							**$ 12,242,299**
Total Construction Cost							**$ 54,457,000**
Engineering, Administration, and Legal			25%				**$ 13,614,250**
Total Capital Cost and Engineering Costs							**$ 68,071,250**

Estimate of Probable Construction Cost:

AACE Class 4 Estimate Low	-30%	**$ 38,119,900**
AACE Class 4 Estimate High	50%	**$ 81,685,500**

IX ANNUAL OPERATION & MAINTENANCE COSTS

Classification	Quantity	Units	Unit Costs	Extended Cost
IX Resin Change-out Cost/Vessal	420	ft3	$ 450	$ 189,000
Qty of Vessel Change-outs per year	10.0	No./yr		$ 1,890,000
Brine Regeneration	1.0	LS	$ 400,000	$ 400,000
Power	3,500,000	kWh/yr	$ 0.15	$ 525,000
Chemicals Cost (Process Specific) - Lime	1	LS	$ 1,500,000	$ 1,500,000
pH Adjustment (post LS CO2)	1	LS	$ 400,000	$ 400,000
Sludge Hauling Cost	1	LS	$ 800,000.0	$ 800,000
Subtotal of Annual O&M				**$ 5,515,000**
Maintenance Contingencey (% of Major Capital Equipment)			5%	$ 779,344
Total Annual O&M				**$ 6,294,000**

Assumptions:

(1) Costs in 2024 dollars and not escalated to mid-point of construction

(2) Buy American provisions for federally-funded infrastructure not considered

(3) Federal regulations related to dispostal of PFAS waste streams not considered

Expand Exisitng IX & Fluorosorb for PFAS

FS200 CAPITAL COST ESTIMATE

Classification	Quantity	Units	Unit Cost	Subtotal	Installation Factor	Installation Subtotal	Total Cost
Direct Cost							
Water Treatment System							
Expand Existing IX (TOC)	4	EA	$ 300,000	$ 1,200,000	50%	$ 600,000.00	$ 1,800,000
New IX-TOC Pumps	6	EA	$ 50,000	$ 300,000	50%	$ 150,000.00	$ 450,000
New Brine System	1	LS	$ 500,000	$ 500,000	30%	$ 150,000.00	$ 650,000
Demo Existing Brine System	1	EA	$ 50,000	$ 50,000	25%	$ 12,500.00	$ 62,500
New Blend Tank	1	LS	$ 450,000	$ 450,000	50%	$ 225,000.00	$ 675,000
New IX-PFAS System	12	LS	$ 750,000	$ 9,000,000	$ 1	$ 4,500,000	$ 13,500,000
IX-PFAS Feed Pumps	6	EA	$ 50,000	$ 300,000	$ 1	$ 150,000	$ 450,000
Blend Tank to IX-PFAS Piping (24")	200	LF	$ 350	$ 70,000	50%	$ 35,000.00	$ 105,000
IX-PFAS to Clearwell Piping (24")	275	LF	$ 350	$ 96,250	50%	$ 48,125.00	$ 144,375
Subtotal Facility and Equipment							**$ 17,836,875**
Other							
Future (Redudant IX-TOC) Expansion/Redundancy	4	LS	$ 500,000	$ 2,000,000	30%	$ 600,000	$ 2,600,000
LS Rehabilitation	1	LS	$ 5,000,000	$ 5,000,000	0%	$ -	$ 5,000,000
Filter Rehabilitation and Upgrades	1	LS	$ 5,000,000	$ 5,000,000	0%	$ -	$ 5,000,000
I&C (estimate as % of Facility)		%	20%	$ 3,567,375	0%	$ -	$ 3,567,375
Piping, Valves, and Flow Meters (estimate as % of Facility)		%	20%	$ 3,567,375	0%	$ -	$ 3,567,375
Electrical (estimate as % of Facility)		%	20%	$ 3,567,375	0%	$ -	$ 3,567,375
Subtotal Other Cost							**$ 23,302,000**
Design Contingnency		%	30%		0%	$ -	$ 5,351,063
Total Direct Costs							**$ 46,489,938**
Indirect Cost							
General Conditions			5%				$ 2,324,000
Bonds and Insurance			2%				$ 929,799
Overhead, Profit, and Risk			15%				$ 6,973,000
Taxes (on total direct construction costs unless exempted or pre-purchase; FL Rules)			7%				$ 3,254,000
Total Indirect Cost							**$ 13,480,799**
Total Construction Cost							**$ 59,971,000**
Engineering, Administration, and Legal			25%				**$ 14,992,750**
Total Capital Cost and Engineering Costs							**$ 74,963,750**

Estimate of Probable Construction Cost:

AACE Class 4 Estimate Low	-30%	**$ 41,979,700**
AACE Class 4 Estimate High	50%	**$ 89,956,500**

FS200 ANNUAL OPERATION & MAINTENANCE COSTS

Classification	Quantity	Units	Unit Costs	Extended Cost
FS Change-out Cost/Vessal	420	ft3	$ 350.00	$ 147,000
Qty of Vessel Change-outs per year	12.0	No./yr		$ 1,764,000
Brine Regeneration	1.0	LS	$ 400,000	$ 400,000
Power	3,500,000	kWh/yr	$ 0.15	$ 525,000
Chemicals Cost (Process Specific) - Lime	1	LS	$ 1,500,000	$ 1,500,000
pH Adjustment (post LS CO2)	1	LS	$ 400,000	$ 400,000
Sludge Hauling Cost	1	LS	$ 800,000	$ 800,000
Subtotal of Annual O&M				**$ 5,389,000**
Maintenance Contingencey (% of Major Capital Equipment)			5%	$ 891,844
Total Annual O&M				**$ 6,281,000**

Assumptions:

(1) Costs in 2024 dollars and not escalated to mid-point of construction

(2) Buy American provisisions for federally-funded infrastructure not considered

(3) Federal regulations related to dispostal of PFAS waste streams not considered

Nanofiltration Membranes Treatment for PFAS

NF CAPITAL COST ESTIMATE

Classification	Quantity	Units	Unit Cost	Subtotal	Installation Factor	Installation Subtotal	Total Cost
Direct Cost							
Water Treatment System							
NF Building (Foundation and Shell Only)	13,500	SF	$ 550	$ 7,425,000	50%	$ 3,712,500	$ 11,137,500
Catridge Filters	4	EA	$ 125,000	$ 500,000	50%	$ 250,000	$ 750,000
CIP System	1	LS	$ 150,000	$ 150,000	50%	$ 75,000	$ 225,000
Feed Pumps and Local Panel	6	EA	$ 50,000	$ 300,000	50%	$ 150,000	$ 450,000
NF Skids	6	LS	$ 3,000,000	$ 18,000,000	25%	$ 4,500,000	$ 22,500,000
DIW	1	LS	$ 20,000,000	$ 20,000,000	0%	$ -	$ 20,000,000
Chemical System	1	LS	$ 500,000	$ 500,000	50%	$ 250,000	$ 750,000
Blending Tank	1	LS	$ 250,000	$ 250,000	50%	$ 125,000	$ 375,000
Desgassifier (FRP Vessel, Blower, Motor)	3	LS	$ 75,000.00	$ 225,000	30%	$ 67,500	$ 292,500
Raw Water Piping (24")	450	LF	$ 350.00	$ 157,500	0%	$ -	$ 157,500
Permeate Piping (24")	550	LF	$ 350.00	$ 192,500	0%	$ -	$ 192,500
Centrate Piping (16")	200	LF	$ 350.00	$ 70,000	0%	$ -	$ 70,000
Subtotal Facility and Equipment							**$ 56,900,000**
Other							
Relocate Existing Maintenance Building	1	LS	$ 500,000	$ 500,000	0%	$ -	$ 500,000
Site Demolition	1	LS	$ 500,000	$ 500,000	0%	$ -	$ 500,000
Electrical (estimated as % of Facility)		%	20%	$ 11,380,000	0%	$ -	$ 11,380,000
I&C (estimate as % of Facility)		%	20%	$ 11,380,000	0%	$ -	$ 11,380,000
Piping, Valves, and Flow Meters (estimate as % of Facility)		%	20%	$ 11,380,000	0%	$ -	$ 11,380,000
Alternative Water Supply (C51; Floridan Wells, RO)	1	LS		$ -	0%	$ -	$ -
Subtotal Other Cost							**$ 35,140,000**
Design Contingency		%	30%			$ -	$ 17,070,000
Total Direct Costs							**$ 109,110,000**
Indirect Cost							
General Conditions			5%				$ 5,456,000
Bonds and Insurance			2%				$ 2,182,200
Overhead, Profit, and Risk			15%				$ 16,367,000
Taxes (on total direct construction costs unless exempted or pre-purchase; FL Rules)			7%				$ 7,638,000
Total Indirect Cost							**$ 31,643,200**
Total Construction Cost							**$ 140,753,000**
Engineering, Administration, and Legal			25%				**$ 35,188,250**
Total Capital Cost and Engineering Costs							**$ 175,941,250**

Estimate of Probable Construction Cost:

AACE Class 4 Estimate Low	-30%	**$ 98,527,100**
AACE Class 4 Estimate High	50%	**$ 211,129,500**

NF ANNUAL OPERATION & MAINTENANCE COSTS

Classification	Quantity	Units	Unit Costs	Extended Cost
Chemicals Cost (Process Specific)	1	LS	$ 3,600,000	$ 3,600,000
Consumables	1	LS	$ 636,000	$ 636,000
Power for NF	13,500,000	kWh/yr	$ 0.15	$ 2,025,000
Power for DIW	4,500,000	kWh/yr	$ 0.15	$ 675,000
Subtotal of Annual O&M				**$ 6,936,000**
Maintenance Contingencey (% of Major Capital Equipment)			5%	$ 2,845,000
Total Annual O&M				**$ 9,781,000**

Assumptions:

(1) Costs in 2024 dollars and not escalated to mid-point of construction

(2) Buy American provisions for federally-funded infrastructure not considered

(3) Federal regulations related to dispostal of PFAS waste streams not considered