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*FINAL*

# Emerging Contaminants Compliance Preliminary Engineering Report

Lake Murray Water Treatment Plant

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September 25, 2025

# Table of Contents

## List of Tables

## List of Figures

# Executive Summary

## Introduction and Background

On April 10, 2024, the United States Environmental Protection Agency (USEPA) announced the final National Primary Drinking Water Regulation, which includes regulatory requirements for five individual PFAS compounds (PFOA, PFOS, PFNA, PFHxS, and HFPO-DA (GenX chemicals)) as well as a Hazard Index for a mixture of two or more of four compounds (PFNA, PFHxS, HFPO-DA, and PFBS). Compliance must be achieved by 2029, although monitoring results that must be included in Consumer Confidence Reports must begin in 2027 and monitoring for compliance must begin in 2028.

Subsequently, in May 2025, USEPA announced their intentions to modify the rule, with the maximum contaminant levels (MCLs) for PFOA and PFOS remaining the same, but the regulatory determinations for PFHxS, PFNA, HFPO-DA (GenX chemicals) and the Hazard Index rescinded and reconsidered. USEPA also announced their intent to extend the compliance deadlines for PFOA and PFOS by two years to 2031. The modified rule is anticipated to be finalized in Spring 2026. This report reflects considerations for the current rule while acknowledging the anticipated rule modifications announced by USEPA.

Based on historical data from NCWSA and surrounding utilities that utilize Lake Murray as a water source, PFOA and PFOS levels in the raw and finished water are often above the regulatory limit of 4.0 ng/L and treatment modifications will be required to comply with the new regulation. In addition, HFPO-DA (GenX) levels in the raw and finished water have occasionally approached or exceeded the regulatory limit of 10 ng/L and is also present in high concentrations in upstream water quality sampling completed by the South Carolina Department of Environmental Services (SCDES), so removal of GenX could be a consideration for NCWSA as well.

NCWSA has several other water quality challenges such as control of taste and odor causing compounds and removal of TOC and reduction of disinfection byproducts that NCWSA would like to address if a treatment technology is added for PFAS removal.

## Technology Evaluation

Several treatment alternatives are available for PFAS removal, including adsorptive technologies (PAC, GAC, and AIX) and high-pressure membranes (RO and NF). There are also emerging technologies, such as novel clay-based adsorbents like FLUORO-SORB®, foam fractionation, and non-thermal plasma; however, these technologies are relatively new to the water treatment industry and less proven. To meet the PFAS Rule requirements and also provide additional capabilities for taste and odor and TOC/DBP control, PAC and GAC were chosen as the preferred alternatives for potential addition at the NCWSA Lake Murray WTP. Although high-pressure membranes can effectively remove PFAS and also meet the multi-barrier approach criteria, the cost and added complexity of managing disposal of the concentrated waste stream make it a less desirable solution for NCWSA.

## Powdered Activated Carbon (PAC) Bench-Scale Testing

PAC bench-scale testing of three different PAC products (Ingevity AquaNuchar, Carbpure TRA, and Jacobi CB1-MW) resulted in the following findings:

- PAC was effective for PFOA and PFOS removal to meet regulatory requirements, with greater effectiveness for PFOS than PFOA. PAC was much less effective for GenX removal.
- The most effective product for reduction of PFOA and PFOS was the Ingevity AquaNuchar product followed by the Carbpure TRA product. These products were also effective for MIB and geosmin removal and TOC reduction, with greater removal of geosmin as compared to MIB.
- Testing simulated the addition of a PAC contact tank (30-minute detention time) and use of the raw water line for PAC contacting (4.5-minute contact time). Greater PFOA, PFOS, MIB, geosmin, and TOC reduction was achieved at 30-minute PAC contact time versus 4.5-minute PAC contact time.
- Estimated dosages for PFAS removal ranged from 13 to 45 mg/L at 4.5-minute PAC contact time and 11 to 32 mg/L at 30-minute PAC contact time to achieve finished water PFOA and PFOS levels ranging from 1 to 3 ng/L. For comparison purposes with GAC, a design dose of 13 mg/L was chosen, which is the dose needed to achieve a finished water PFAS goal of 3 ng/L based on historical average PFOA and PFOS levels and 4.5-minute contact time. These dosages are based on the use of either the Ingevity AquaNuchar or Carbpure TRA products.
- A PAC dosage greater than 13 mg/L would be required to achieve MIB and geosmin goals when raw water MIB and geosmin levels are elevated.

## Granular Activated Carbon (GAC) Evaluation and Rapid Small Scale Column Testing

Desktop and bench-scale testing of GAC resulted in the following findings:

- A desktop analysis of GAC was performed to provide an initial estimate of the required EBCT and replacement frequency of GAC. The initial estimate was based on a lead-lag configuration with an EBCT of 10 minutes per vessel and replacement frequency of one year.
- Rapid small scale column testing (RSSCT) was conducted on two GAC products that have performed well at other locations: Calgon F400 and Carbpure GAC1240.
- For PFOA and PFOS removal, the Carbpure GAC1240 performed best, while the Calgon F400 performed best for GenX removal. GenX release by the media during

testing was also seen, with effluent GenX concentrations up to 1.4x influent concentrations observed in the RSSCT columns as the run progressed.

- Based on historical average PFOA and PFOS concentrations, the estimated time to breakthrough is greater than 630 days for the Carbpure GAC1240 and approximately 330 days for the Calgon F400. The time to breakthrough for GenX was slightly less than 200 days for the Carbpure GAC1240 and approximately 340 days for the Calgon F400.

## Additional Impacts of PAC and GAC

The additional impacts of PAC or GAC treatment at the NCWSA Lake Murray WTP include the following:

- From a water quality standpoint, other impacts of PAC and GAC should be positive in the areas of taste and odor control, TOC/DBP reduction, distribution system water quality, and maintenance of distribution system disinfectant residuals.

- PAC addition will increase the solids that must be processed at the plant and disposed. Based on current operation, it is estimated that the use of PAC for PFAS removal (typical dose of 13 mg/L each day) will increase the solids production at the plant by approximately 50 percent. This creates the need for additional residuals lagoons and increased cost for removal and disposal of solids. In addition, PFAS-laden PAC solids may be more difficult and costly to dispose of in the future based on potential changes in CERCLA and RCRA requirements. Operationally, PAC can also be difficult to handle, and equipment can be difficult to maintain.

- GAC treatment should have minimal impact on operations. Media changeout is often conducted by the media supplier and should have limited impact on WTP staff. Post-filtration chemical feed will need to be moved downstream of GAC treatment and prior to the Finished Water Storage Tank. The pre-filter chlorine dose will need to be controlled to minimize chlorine residual in the GAC contactor influent, with desired levels typically 0.5 mg/L or less.

## Conceptual Design

Five alternatives were developed for conceptual design and costing:

- PAC Silo with One New Lagoon

- PAC Silo with Two New Lagoons

- PAC Bulk Bag Systems with One New Lagoon

- GAC Pressure Vessels in Building
- GAC Pressure Vessels with Pad and Roof (Canopy)

The conceptual design of each system includes the following components:

- PAC Silo Options:
    - PAC silo on a concrete pad sized to receive a truckload of PAC (3,500 cu ft capacity), which equates to 50,000 pounds of PAC at 15 lb/cu ft density. This silo is adequate at the plant capacity of 6 mgd.
    - Water line, waste drain, and PAC feed lines.
    - Either one or two additional residuals lagoons.
    - Associated sitework, electrical, and instrumentation.
- PAC Bulk Bag Option:
    - PAC bulk bag feeders (redundant feeders) with bag storage in a building. Size storage space for ultimate capacity of 6 mgd (approximately 19 bags).
    - Water line, waste drain, and PAC feed lines.
    - One additional residuals lagoon.
    - Associated sitework, electrical, and instrumentation.
- GAC Options:
    - Two sets of lead-lag GAC pressure vessels with approximately 10-minute EBCT in each vessel. Space available for five sets of lead-lag pressure vessels for the ultimate plant flow rate of 6 mgd.
    - Construction of a building to house pressure vessels or construction of a canopy only.
    - Construction of a new transfer pump station to transfer filtered water to the GAC contactors prior to flowing to the onsite clearwells. Construction for the pump station is assumed to be similar to the finished water pumping station that is currently under construction.
    - Pressure vessel inlet and outlet piping; associated water supply and drain piping.
    - Associated sitework, electrical, and instrumentation.

Capital and operations and maintenance (O&M) cost estimates were developed for each of the alternatives:

- The lowest capital cost was the bulk bag system (with redundancy) with one residual lagoon ($7.1M), followed by the PAC silo option with one residual lagoon and the GAC option without a building (both approximately $7.8-7.9M).
- O&M costs were similar between all the options. The O&M costs were based on the use of either of the top two performing PAC products or GAC products; O&M costs may be reduced if the top performing products are utilized.
- The 20-year net present value for the alternatives was developed and the bulk bag system had the lowest net present value ($9.8M), followed by the PAC silo option with one residual lagoon ($10.4M) and the GAC option without a building ($10.7M).

## Recommendations

Based on the findings of the evaluation and discussions with NCWSA staff, the following recommendations were developed:

- Based on the efficacy of GAC treatment for PFOA and PFOS removal and the ability to remove GenX more effectively than PAC, utilize GAC treatment for PFAS removal at the NCWSA Lake Murray WTP. This eliminates the need for immediate improvements and handling of additional PAC solids and protects against the uncertainty of disposal of PFAS-laden PAC solids in the future.
- Design GAC system to be installed beneath a canopy, with the ability to enclose the canopy as a bid alternate or in a future project.
- As part of the design, conduct a product selection pilot to further evaluate the effectiveness of the selected GAC and alternate products during varying water quality and also for the removal of GenX.
- Consideration should be given to repairing the existing 50-pound bag feed system such that it is operable. If repaired, the existing PAC feed system could be available in the interim while the GAC system is being constructed and also could be beneficial as a supplement to GAC if raw water MIB levels ever spike up to historical maximum levels seen at other utilities on Lake Murray.

# 1. Introduction

## 1.1 Purpose

In April 2024, the United States Environmental Protection Agency (USEPA) released the final National Primary Drinking Water Regulation (NPDWR) for six poly- and per-fluoroalkyl substances (PFAS). As indicated in **Table 1-1**, the final regulations include regulatory requirements for five individual PFAS compounds (PFOA, PFOS, PFNA, PFHxS, and HFPO-DA (GenX chemicals)) as well as a Hazard Index for a mixture of two or more of four compounds (PFNA, PFHxS, HFPO-DA, and PFBS).

Just over one year after finalizing the regulation, in May 2025, USEPA announced their intentions to maintain the maximum contaminant levels for PFOA and PFOS, extend compliance deadlines for PFOA and PFOS to 2031, establish a federal exemption framework, and rescind the regulations and reconsider the regulatory determinations for PFHxS, PFNA, HFPO-DA (GenX Chemicals), and the Hazard Index mixture of these three plus PFBS to ensure that the determinations and any resulting drinking water regulation follow the legal process laid out in the Safe Drinking Water Act.

Although USEPA has announced their intentions to modify the rule in these ways, the regulatory process will take time and USEPA plans to develop rulemaking to reflect these changes, issue a proposed rule in Fall 2025, and finalize the rule in Spring 2026. **Table 1-1** summarizes the rulemaking to date, along with these intended modifications by denoting the affected compounds and deadlines as Note 5. The text in this report reflects considerations for the current rule while acknowledging the anticipated rule modifications announced by USEPA.

**Table 1-1: USEPA PFAS National Primary Drinking Water Regulation (Notes 1,2)**

| Chemical | Maximum Contaminant Level Goal (MCLG) (Note 3) | Maximum Contaminant Level (MCL) |
|---|---|---|
| **PFOA** | 0 | 4.0 parts per trillion (ppt) |
| **PFOS** | 0 | 4.0 ppt |
| **PFNA (Note 5)** | 10 ppt | 10 ppt |
| **PFHxS (Note 5)** | 10 ppt | 10 ppt |
| **HFPO-DA (GenX Chemicals) (Note 5)** | 10 ppt | 10 ppt |
| **Mixture of two or more: PFNA, PFHxS, HFPO-DA, and PFBS (Note 5)** | Hazard Index (HI) of 1 (Note 4) | Hazard Index (HI) of 1 (Note 4) |

**Notes:**

1. **https://www.epa.gov/system/files/documents/2024-04/pfas-npdwr_fact-sheet_general_4.9.24v1.pdf**
2. **https://www.epa.gov/system/files/documents/2024-04/pfas-npdwr_fact-sheet_general_4.9.24v1.pdf**
3. **MCLG is the level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals.**
4. **HI = $[\text{HFPO-DA}_{ppt}]/[10\ \text{ppt}] + [\text{PFBS}_{ppt}]/[2000\ \text{ppt}] + [\text{PFNA}_{ppt}]/[10\ \text{ppt}] + [\text{PFHxS}_{ppt}]/[10\ \text{ppt}]$**
5. **https://www.epa.gov/newsreleases/epa-announces-it-will-keep-maximum-contaminant-levels-pfoa-pfos**

PFAS monitoring conducted by the Newberry County Water and Sewer Authority (NCWSA), neighboring utilities, and the South Carolina Department of Environmental Services (SCDES) indicate that the PFOA and PFOS levels in the raw and finished water are often above the regulatory limit of 4.0 ng/L. GenX has approached the regulatory limit of 10 ng/L with one sample from a neighboring utility exceeding 10 ng/L in one sampling event. The levels of the other regulated compounds (PFHxS, PFNA, and PFBS) have historically been less than the regulatory limit. As mentioned previously, EPA has indicated their intent to reconsider the GenX regulation, so this may not be an issue for NCWSA. Because PFOA and PFOS are above the maximum contaminant level (MCL) in the source and finished water at the NCWSA Lake Murray Water Treatment Plant (WTP), treatment modifications will be required to comply with the new regulation.

NCWSA contracted with Hargette LLC (Hargette), with assistance from Hazen, to evaluate treatment alternatives to remove PFAS at the NCWSA Lake Murray WTP to meet the new regulation. The purpose of this report is to summarize the evaluations performed to select the most appropriate treatment option for removal of PFAS at the NCWSA Lake Murray WTP.

## 1.2 Scope

The principal elements of this study include the following:

- Compile and summarize existing available water quality data for the NCWSA Lake Murray WTP and neighboring utilities, including general water quality data, taste and odor data, and PFAS data.
- Perform bench-scale testing of powdered activated carbon (PAC) products to determine the efficacy of PAC for removal of PFAS compounds as well as taste and odor compounds and total organic carbon (TOC).
- Perform a desktop technology evaluation of adsorption technologies for PFAS removal as well as removal of other contaminants of concern, including granular activated carbon (GAC), anion exchange resins (AIX), and Fluorosorb®. Use the results of the desktop evaluation to screen alternatives for rapid small scale column testing.
- Conduct bench-scale rapid small scale column testing (RSSCT) of two alternative adsorbent media to determine treatment effectiveness on filter effluent water from the NCWSA Lake Murray WTP.
- Perform a high-level evaluation of the impacts of the different treatment alternatives (PAC and post-filtration GAC, AIX, or Fluorosorb®) on solids quantities, solids handling requirements, corrosion control, and lead and copper compliance.
- Develop a conceptual design and life cycle costs for one PAC alternative and one GAC/AIX/Fluorosorb® alternative, including general sizing of the new facilities for the current plant capacity of 2 million gallons per day (mgd) and an ultimate future capacity of 6 MGD.
- Summarize the results of the evaluation in a technical report.

## 1.3 List of Abbreviations

| Abbreviation | Definition |
|---|---|
| ac | acre |
| AIX | Anion exchange |
| avg | average |
| BV | bed volumes |
| CECs | contaminants of emerging concern |
| CFE | combined filter effluent |

| Abbreviation | Definition |
|---|---|
| cu ft | cubic foot |
| DBPs | disinfection byproducts |
| EBCT | empty bed contact time |
| GAC | granular activated carbon |
| HAA5 | haloacetic acids |
| hr | hour |
| lb | pound |
| LRAA | locational running annual average |
| MCL | maximum contaminant level |
| MG | million gallons |
| mgd | million gallons per day |
| mg/L | milligrams per liter |
| MIB | Methyl-Isoborneol |
| min | minimum, minute |
| MOR | monthly operating report |
| ng/L | nanograms per liter |
| NCWSA | Newberry County Water and Sewer Authority |
| NF | nanofiltration |
| NPDWR | National Primary Drinking Water Regulation |
| OH&P | overhead and profit |
| PAC | powdered activated carbon |
| PER | Preliminary Engineering Report |
| PFAS | per- and polyfluoroalkyl substances |
| PFOA | perfluorooctanoic acid |
| PFOS | perfluorooctanesulfonic acid |
| PS | pumping station |
| RO | reverse osmosis |
| RSSCT | rapid small scale column test |

| Abbreviation | Definition |
|---|---|
| SCDES | South Carolina Department of Environmental Services |
| sf | square feet |
| TTHM | total trihalomethanes |
| USEPA | United States Environmental Protection Agency |
| WTP | Water Treatment Plant |
| yr | year |

# 2. Background and Historical Data Review

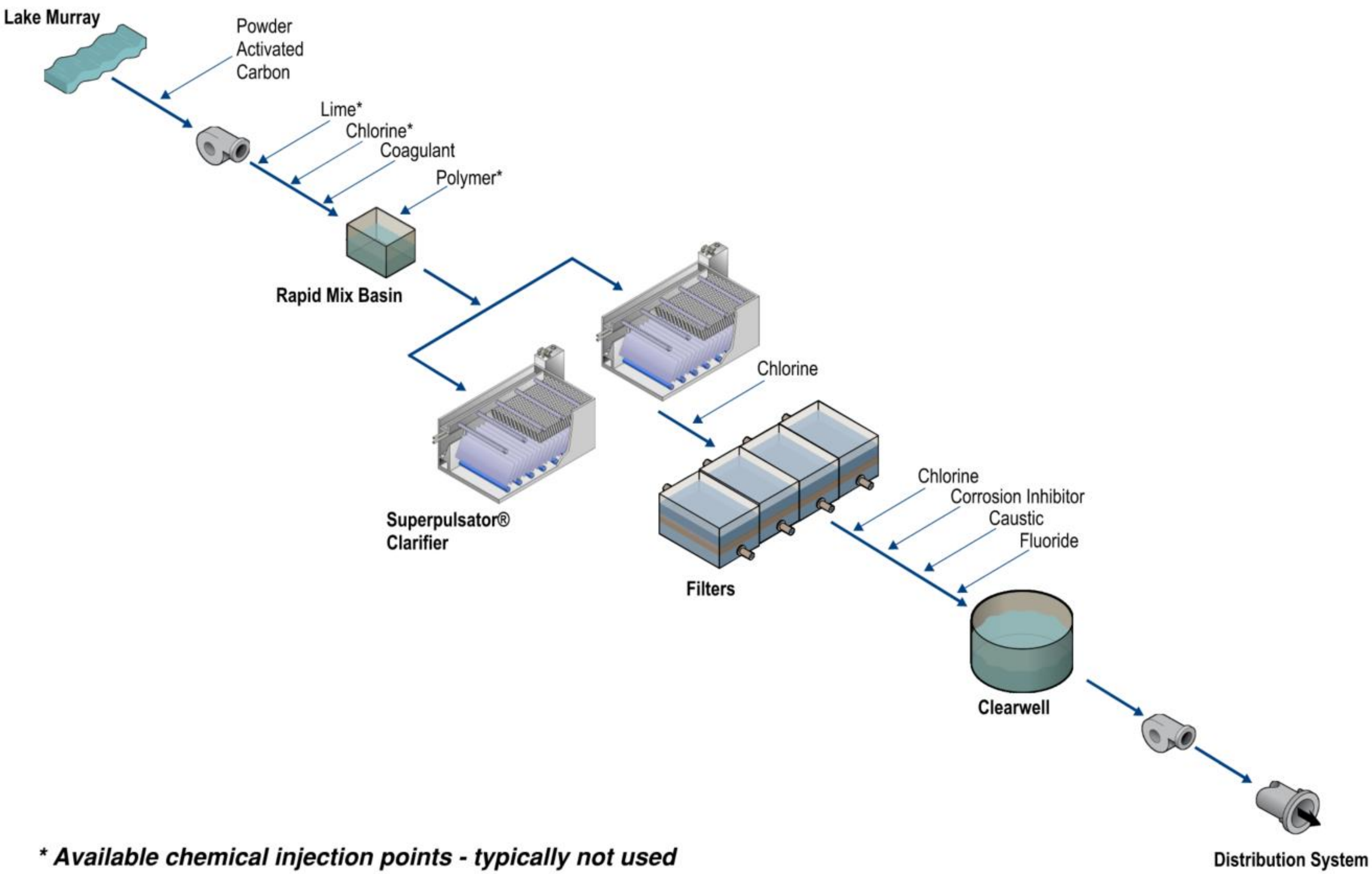
## 2.1 Background

The Newberry County Water and Sewer Authority (NCWSA) serves approximately 9,900 drinking water customers in Newberry County, South Carolina. Water is supplied to these customers largely through the Lake Murray WTP, which NCWSA owns and operates. NCWSA also buys a small percentage of water from the City of Newberry, which is treated at the City of Newberry's water treatment plant located on the Saluda River at the headwaters of Lake Murray.

The NCWSA Lake Murray WTP treats water from Lake Murray and has a rated capacity of 2 million gallons per day (mgd). A submerged intake screen is installed in Lake Murray and is connected to the raw water pumping station through a 24-inch pipeline. The raw water pumping station has three pumps that pump raw water through a 16-inch pipeline to the WTP approximately 0.25 miles from the raw water pumping station.

The main treatment chemicals and processes used at the NCWSA Lake Murray WTP are shown in **Figure 2-1** on the following page and include the following:

- Powdered activated carbon (PAC) addition in the wetwell of the raw water pumping station.
- Raw water chemical addition in the raw water flow metering vault on the plant site, including lime for pH adjustment (when needed to optimize coagulation pH), chlorine (not typically used), and coagulant (polyaluminum chloride).
- Rapid mixing with polymer addition (not typically used).
- Two Veolia Pulsator® clarification basins.
- Pre-filter chlorination.
- Dual media filtration.
- Post filter chemical addition, including chlorine for disinfection, phosphate for corrosion control, caustic for pH adjustment, and fluoride for dental health.
- One 250,000 gallon clearwell.
- Finished water pumping station with two pumps. Construction of a new pumping station to replace the existing pumping station is expected to start in the near future.



*** Available chemical injection points - typically not used***

**Figure 2-1: NCWSA Lake Murray WTP Process Flow Diagram**

## 2.2 Historical PFAS Data

Available historical PFAS data for NCWSA and neighboring utilities that utiize Lake Murray as their water source are contained in **Table 2-1** and **Figure 2-2** and **Figure 2-3**. The levels of PFOA are generally near or slightly above the MCL of 4.0 ng/L, while the levels of PFOS consistently exceed the MCL of 4.0 ng/L, indicating that additional treatment processes will be needed to meet the PFAS MCLs.

**Table 2-1: Historical PFAS Data for NCWSA and Neighboring Utilities**

| | PFOA (ng/L) | PFOS (ng/L) | HFPO-DA (GenX) (ng/L) | PFBS (ng/L) |
|---|---|---|---|---|
| **NCWSA (Note 1)** | | | | |
| **Average** | 4.4 | 7.0 | 7.8 | 2.5 |
| **95th Percentile** | 4.7 | 8.0 | 9.2 | --- |
| **Maximum** | 4.8 | 8.1 | 9.7 | 2.5 |
| **Neighboring Utilities (Note 2)** | | | | |
| **Average** | 4.9 | 7.4 | 7.8 | 3.9 |
| **95th Percentile** | 6.2 | 11 | 10.1 | 4.8 |
| **Maximum** | 6.3 | 11.3 | 10.2 | 5.0 |

**Notes:**

1. **Includes data collected by SCDES, UCMR5 data, and data collected from full-scale plant during PAC bench-scale testing.**
2. **Includes UCMR5 data for Saluda County Water and Sewer Authority, City of Newberry, Amicks Ferry Water System, City of Columbia, Joint Municipal Water and Sewer Commission, and West Columbia available on EPA website as of August 15, 2025. (https://www.epa.gov/dwucmr/fifth-unregulated-contaminant-monitoring-rule-data-finder)**

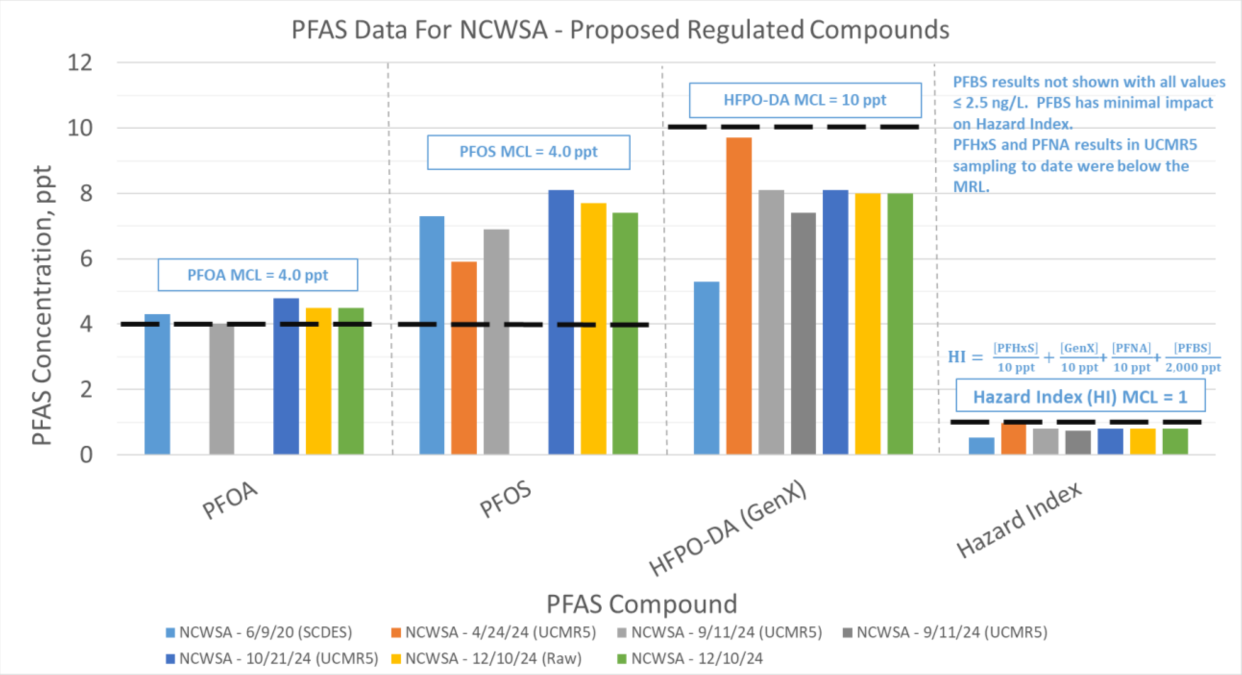


**Figure 2-2: Historical PFAS Data for NCWSA**

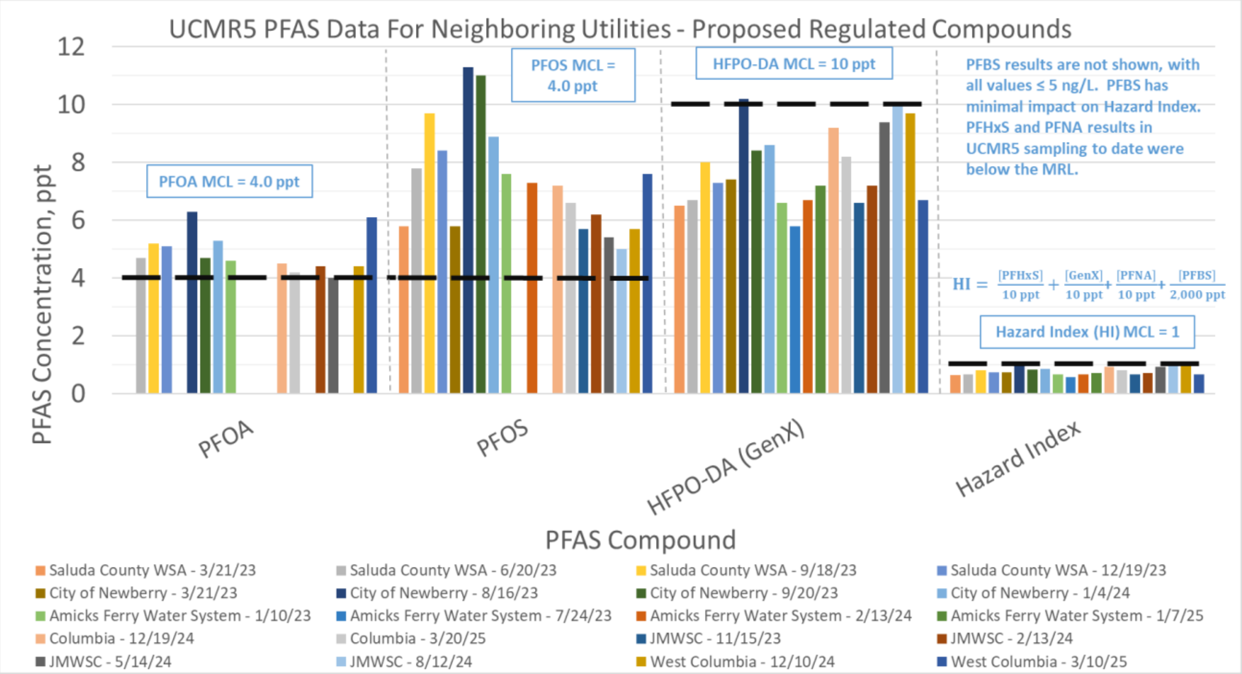


**Figure 2-3: Historical PFAS Data for Neighboring Utilities**

Of the other regulated compounds, HFPO-DA (GenX) levels have averaged approximately 8.0 ng/L in the testing to date, slightly below the regulatory requirement of 10 ng/L. Ambient water quality sampling performed by the SCDES as part of their Ambient Surface Water PFAS Project and Long-Term Monitoring PFAS Project have indicated widely varying levels of GenX in the raw water upstream of Lake Murray, particularly at the intersection of the Saluda River and Cooley Bridge Road (SCDES Sample Site S-1014). GenX concentrations at this location have varied from less than the method reporting limit to 206 ng/L and are contained in **Figure 2-4**. Furthermore, Sample Site S-131 where Highway 72 W crosses Lake Greenwood has measured GenX levels up to 23 ng/L within the last year, and Sample Site S-311 in Boyd Mill Pond on the Reedy River captured an elevated GenX reading of 44.1 ng/L on May 15, 2023. While GenX concentrations do not currently exceed the MCL in NCWSA sampling and USEPA has announced their intent to rescind and reconsider the GenX regulation, the ability to remove GenX either now or in the future will be a consideration in the technology selection process.

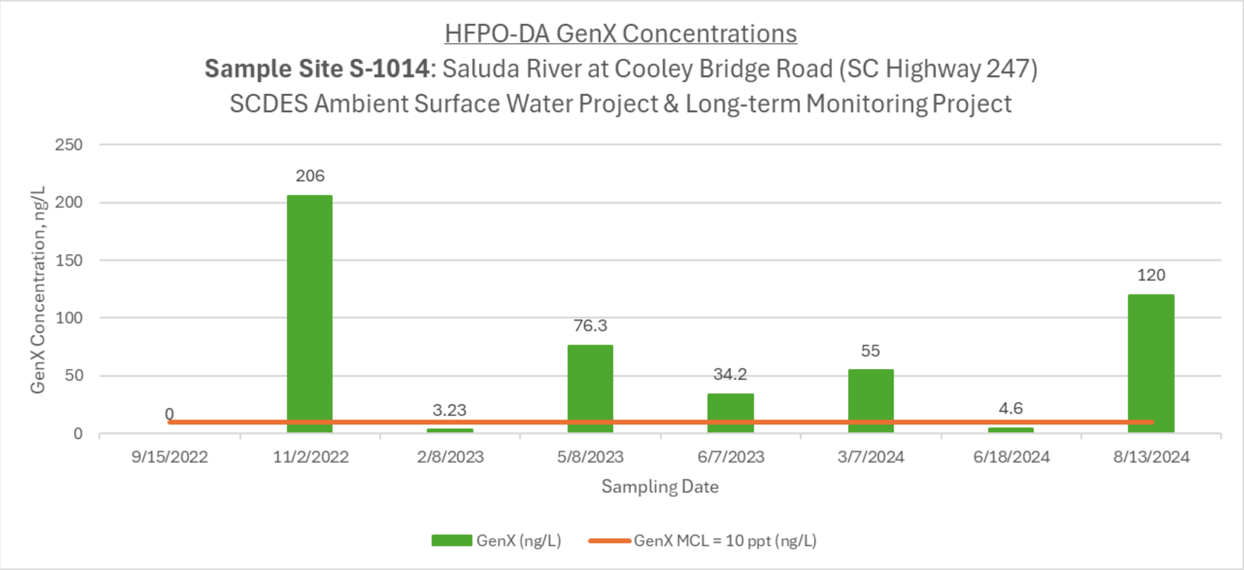


**Figure 2-4: GenX Concentrations at the Saluda River at Cooley Bridge Road**

(Source: https://gis.dhec.sc.gov/gisportal/apps/webappviewer/index.html?id=162b8d1e7fdf459db7ff6b251671651f)

The other regulated compounds, PFNA and PFHxS, have not been present in sampling at NCWSA and neighboring utilities to date. PFBS, which is part of the Hazard Index calculation, has been present, but at low levels, much less than the health reference concentration of 2,000 ng/L. These regulatory requirements, including the Hazard Index calculation, are anticipated to be rescinded and reconsidered.

## 2.3 Additional Water Quality Considerations

NCWSA prefers a PFAS treatment strategy that can also provide benefits for controlling other periodic source water quality challenges, including removal of taste and odor (T&O) causing compounds (e.g. methyl-isoborneol [MIB] and geosmin) and reduction of total organic carbon/disinfection byproducts. MIB and geosmin data at the Lake Murray intake are not available, but taste and odor issues (earthy-musty) related to MIB and geosmin have been an issue in recent years at NCWSA and neighboring utilities. One neighboring utility that utilizes Lake Murray as its water source is in the process of constructing an ozone treatment system for taste and odor control, while several other utilities feed powdered activated carbon at dosages periodically up to approximately 40 mg/L for taste and odor treatment.

Disinfection byproduct levels in the NCWSA distribution system have consistently met the MCL requirements for the last few years, but in the 2015-2016 time frame, locational running annual average (LRAA) levels of total trihalomethanes (TTHMs) and haloacetic acids (HAA5) exceeded the MCLs of 0.08 mg/L and 0.06 mg/L, respectively. In addition, in 2022 and 2023, LRAA concentrations were closer to the MCL than desired at some sites. Data from 2013 through 2024 in the distribution system are contained in **Figure 2-5** and **Figure 2-6** for TTHMs and **Figure 2-7** and **Figure 2-8** for HAA5, respectively. Even though NCWSA has been consistently in compliance in recent testing, a PFAS treatment tool that improves TOC removal and consequently reduces DBP formation is desired. Total organic carbon levels in the raw and treated water are contained in **Figure 2-9.**

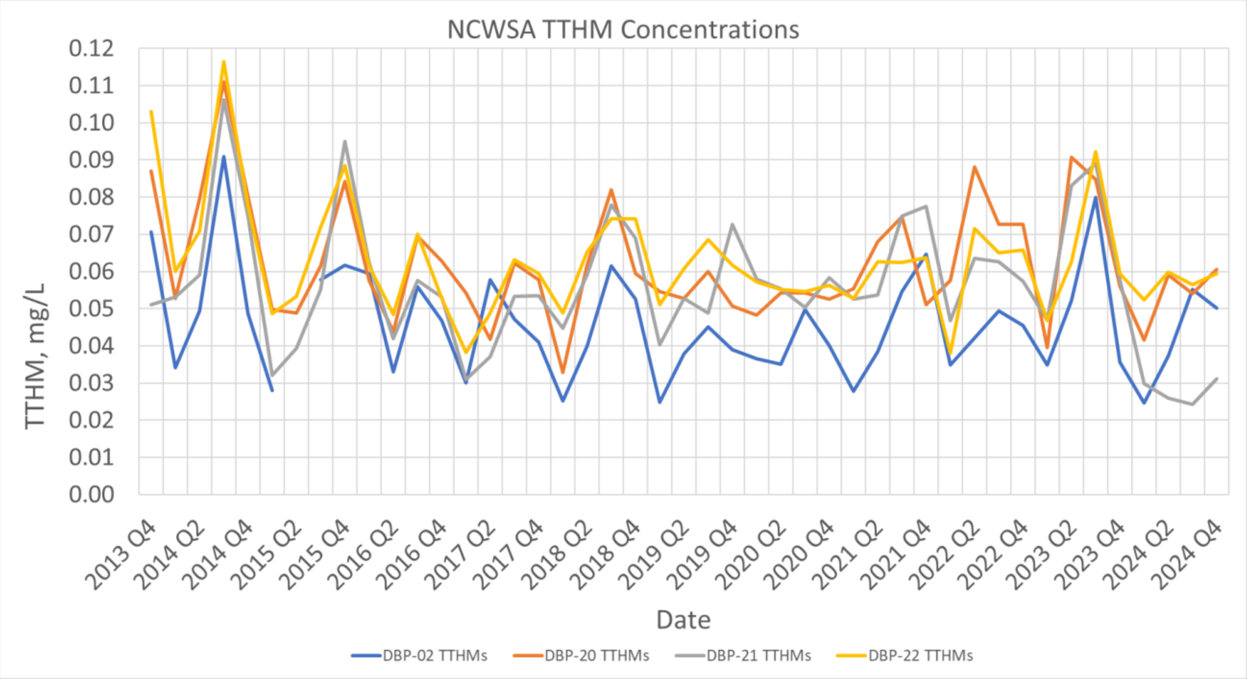


**Figure 2-5: TTHM Data**

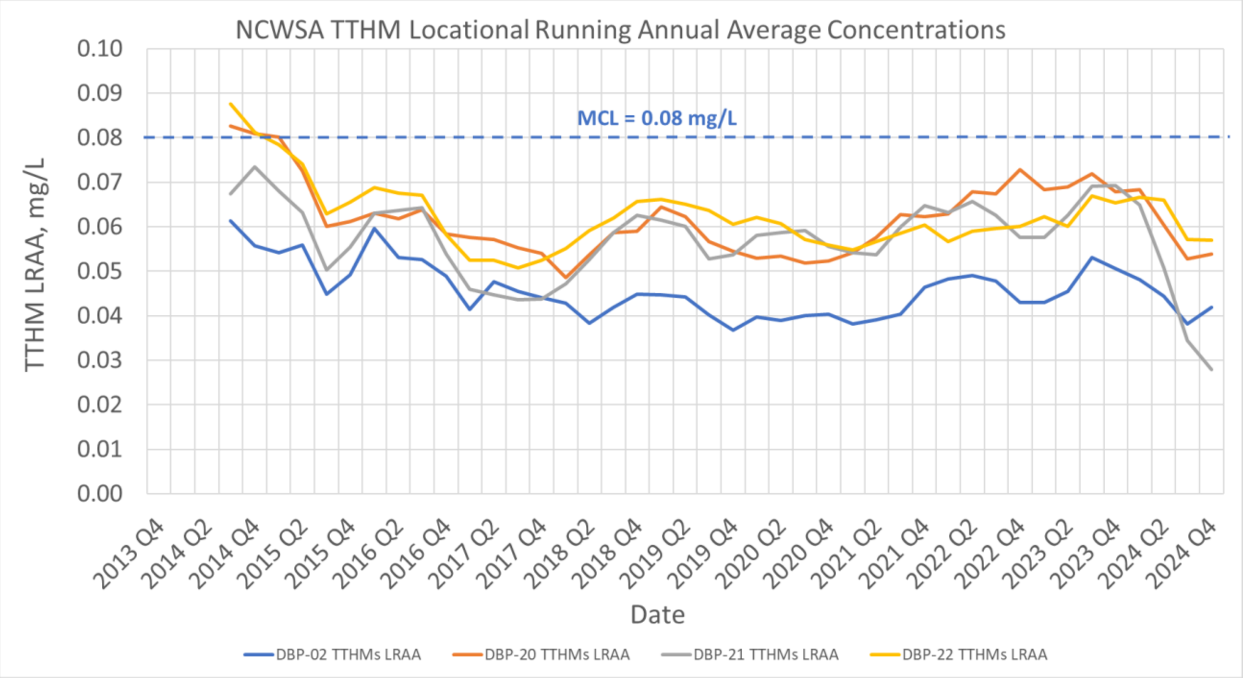


**Figure 2-6: Locational Running Annual Average TTHM Data**

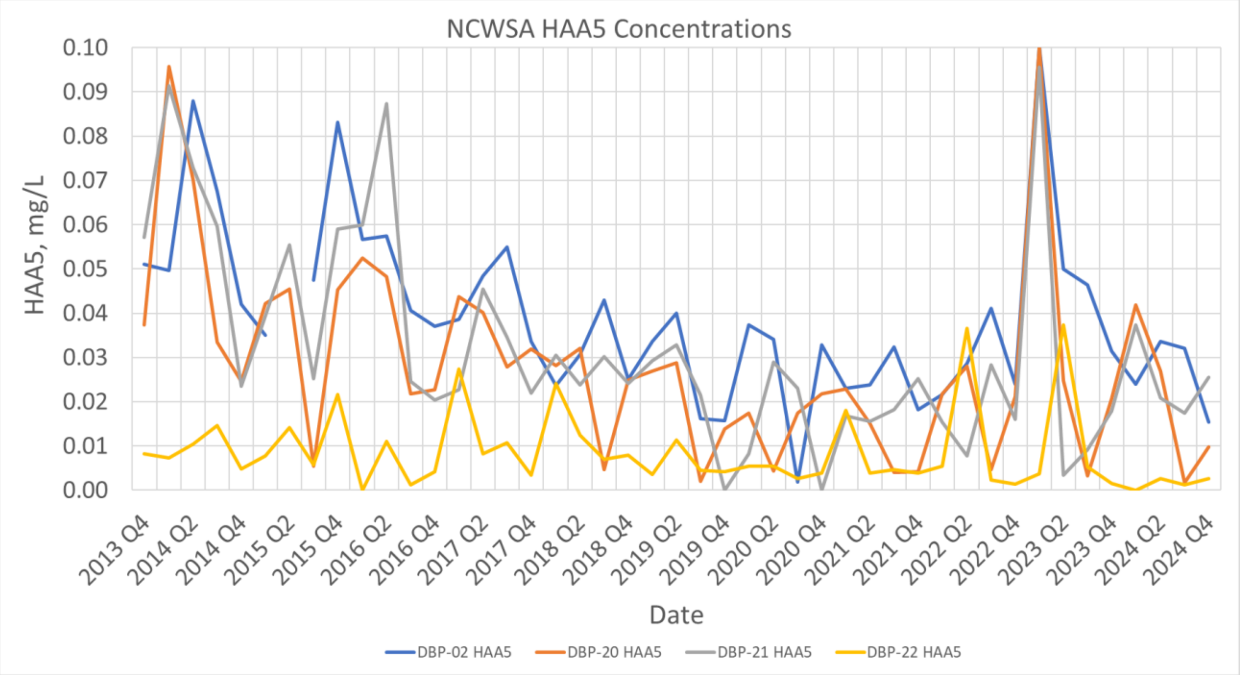


**Figure 2-7: HAA5 Data**

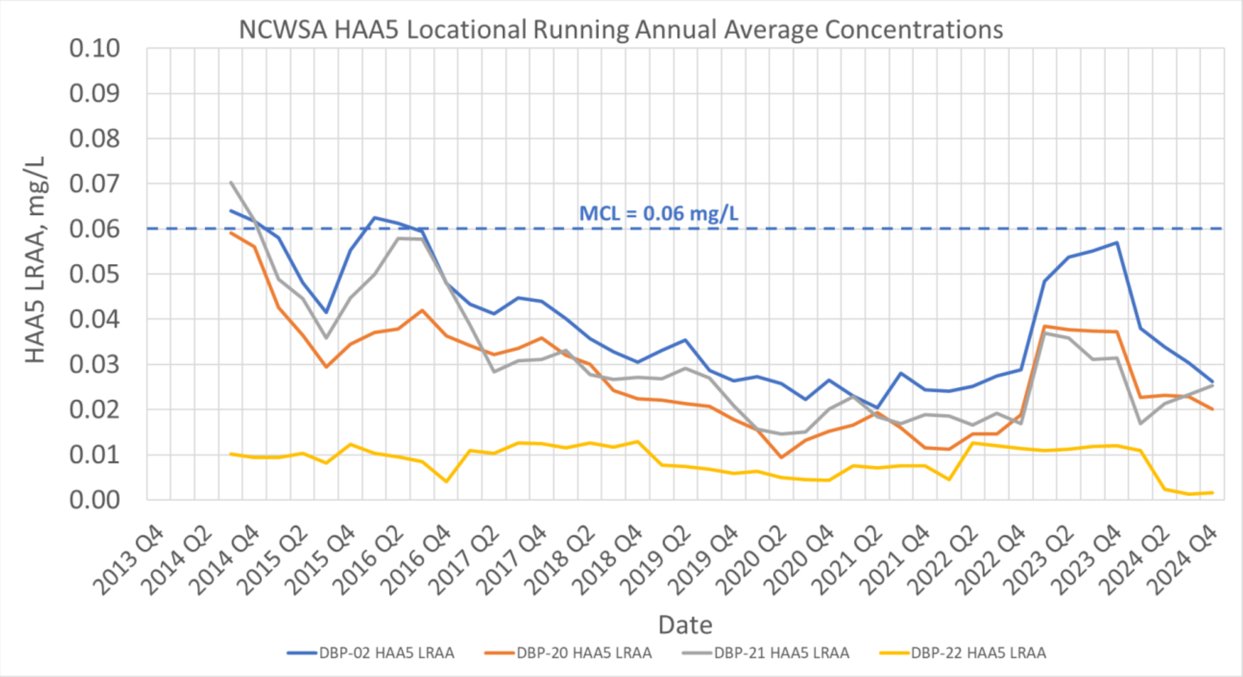


**Figure 2-8: Locational Running Annual Average HAA5 Data**

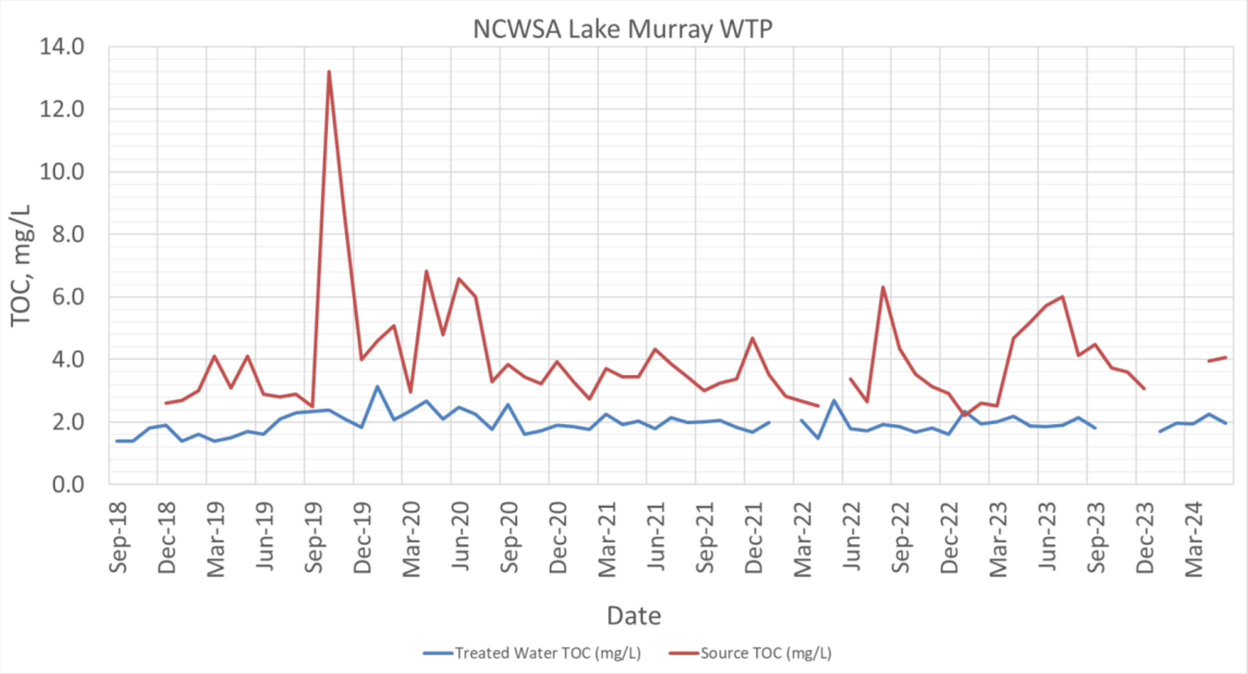


**Figure 2-9: Raw and Treated TOC**

Other general water quality data for raw, treated, and finished water at the NCWSA Lake Murray WTP are contained in **Table 2-2.**

**Table 2-2: Additional NCWSA Water Quality Data (8/1/2019 to 6/30/2024)**

| | Min | 5th Percentile | Average | 95th Percentile | Maximum |
|---|---|---|---|---|---|
| **Raw Water** | | | | | |
| **pH** | 6.0 | 6.6 | 6.9 | 7.2 | 7.5 |
| **Temperature, deg C** | 6.0 | 13 | 20 | 27 | 29 |
| **Alkalinity, mg/L as $CaCO_3$** | 8.0 | 16 | 22 | 28 | 31 |
| **Hardness, mg/L as $CaCO_3$** | 5.0 | 13 | 18 | 22 | 38 |
| **Turbidity, NTU** | 0.7 | 1.2 | 5.7 | 21 | 152 |
| **TOC, mg/L** | 2.2 | 2.5 | 4.0 | 6.5 | 13 |
| **Coagulated /Settled Water** | | | | | |
| **Coagulated pH** | 5.4 | 6.4 | 6.7 | 7.1 | 7.3 |
| **Settled Turbidity, NTU** | 0.1 | 0.1 | 0.3 | 0.8 | 2.7 |
| **Filtered Water** | | | | | |
| **Turbidity, NTU** | 0.02 | 0.03 | 0.05 | 0.10 | 0.99 |
| **TOC, mg/L** | 1.4 | 1.4 | 2.0 | 2.5 | 3.1 |
| **Finished Water** | | | | | |
| **pH** | 6.6 | 7.0 | 7.3 | 7.5 | 8.5 |
| **Alkalinity, mg/L as $CaCO_3$** | 8.0 | 16 | 22 | 27 | 30 |
| **Hardness, mg/L as $CaCO_3$** | 9.0 | 14 | 18 | 22 | 30 |
| **Chlorine Residual, mg/L** | 0.7 | 1.2 | 1.5 | 1.8 | 3.7 |
| **Orthophosphate, mg/L** | 0.4 | 0.6 | 0.8 | 1.0 | 1.5 |

# 3. Technology Evaluation

A variety of treatment technologies are available to effectively remove PFAS, including adsorptive technologies, high-pressure membranes, and other emerging technologies. The adsorptive technologies include powdered activated carbon (PAC), granular activated carbon (GAC), and anion ion exchange (AIX) resins. High-pressure membranes include reverse osmosis (RO) and nanofiltration (NF). Of these, GAC, IX, RO, and NF have been identified by USEPA as Best Available Technology (BAT) for PFAS removal.

Other emerging technologies, such as novel clay-based adsorbents like FLUORO-SORB®, foam fractionation, and non-thermal plasma offer alternative options for PFAS removal; however, these technologies are still relatively new to the water treatment industry and less proven in full-scale installations than the adsorbents and high-pressure membranes and do not have a BAT classification.

This section provides an overview of potential technologies for removal of PFAS, a summary of the effectiveness of those technologies related to other water quality treatment challenges that NCWSA experiences, results from previous testing performed by others on PAC, GAC, and ion exchange (IX), and the approach used to select technologies for further evaluation.

## 3.1 Technology Overview

### 3.1.1 Powdered Activated Carbon

Activated carbon is an effective adsorbent as it provides a large, hydrophobic surface area for adsorption and separation of contaminants from water. This material can be derived from several different sources including bituminous and lignite coals, wood, and coconut shell, and is produced in a variety of sizes that range from very fine powdered material to granular sized material. PAC has a smaller size than GAC that is suitable for injection into liquid streams. PAC is defined by the American Water Works Association Standard B600-05 to not have less than 90% by mass (60% for wood-based carbons) passing through a 44-µm sieve. PAC can be applied as a slurry or, in some cases, as a dry product. This treatment technology has been shown to be effective for removing many PFAS compounds, with a higher affinity for long-chain PFAS chemicals and specifically those with a sulfonic acid functional group, such as PFOS and PFHxS.

PAC may require high doses to effectively adsorb PFAS, depending on influent concentrations as well as other water quality parameters, and it is typically less effective and efficient than GAC. When comparing PAC and GAC usage on an annualized basis, the carbon usage rate is higher for PAC than GAC since several factors reduce PAC efficiency to adsorb PFAS, including tendency to settle prior to exhaustion of adsorption sites as well as interference from coagulants and other chemicals.

PFAS removal with PAC is dependent on operating conditions of the system, including flow rate, contact time, influent PFAS concentration, and background water quality. Similar to GAC, organics and other non-target contaminants have been reported to compete with PFAS for adsorption sites. The use of a PAC strategy for PFAS removal will require consideration for other downstream processes, especially residuals production and handling. In the future, disposal regulations regarding PFAS-containing residuals may affect the O&M costs and require special considerations for handling, hauling, and disposal.

PAC generally effectively removes PFOA and PFOS to below the MCL in source waters with lower concentrations at or below approximately 10 ng/L, although higher PAC doses can effectively remove higher concentrations of PFOA and PFOS to below the MCL in certain cases. PAC is less effective for shorter-chain compounds like GenX. Although PAC is less effective than GAC, it is commonly used to reduce taste and odor compounds and a few additional CECs. Compared to other evaluated technologies, PAC requires the least additional equipment, footprint and capital cost. Other in-plant modifications may be required to handle the increased amount of solids that will be created by using PAC.

The historical raw water PFAS sample results shown in **Table 2-1**, **Figure 2-2**, and **Figure 2-3** indicate that PFOA and PFOS levels are typically below 10 ng/L, suggesting that PAC could be effective for NCWSA.

### 3.1.2 Granular Activated Carbon

Like PAC, GAC may be derived from bituminous and lignite coals, wood, or coconut shell. GAC has an average particle size ranging from 0.30 millimeters (50 mesh size) to 2.36 millimeters (8 mesh size). GAC is the most studied treatment method for PFAS removal (Environmental Protection Agency 2016) and has been shown to be effective for removing many PFAS compounds, with a particularly high affinity for long-chain PFAS chemicals and those with a sulfonic acid functional group. The media is typically applied in a fixed-bed, flow-through “filter” configuration.

PFAS removal with GAC media is dependent on operating conditions of the system that include flow rate, GAC media volume and type, influent PFAS concentration, background water quality, and other filter operational parameters such as empty bed contact time (EBCT), and hydraulic loading rate. A typical EBCT for PFAS control via GAC ranges from 10 to 20 minutes. Influent water quality is also important when evaluating GAC as natural organic matter and other non-target contaminants have been reported to compete with PFAS for adsorption sites (AWWA 2019).

The process is particularly affected by high levels of dissolved organic carbon (DOC) concentrations (greater than 2-3 mg/L) that inhibit PFAS adsorption effectiveness via pore blockages or direct site competition (Appleman et al., 2013; McCleaf et al., 2017; Rahman et al., 2014). Additional water quality factors that affect PFAS removal efficiency include pH, water temperature, properties of the selected carbon, concentration of inorganic substances in the water, and the presence or absence of chlorine (New Jersey Drinking Water Quality Institute 2015).

Effectiveness of GAC for PFAS removal is also dependent upon the speciation of PFAS in the source water. Studies have shown GAC to provide greater removal of long-chain PFAS including PFOA and PFOS than short-chain PFAS such as PFBA, PFBS, and PFPA (Rahman, Peldszus and Anderson 2013). This effect is attributed to the hydrophobic interactions between the GAC and the more-hydrophobic long-chain PFAS.

Removal of short-chain PFAS has been shown to be affected by elevated concentrations of DOC and longer-chain PFAS, an outcome that is attributed to competition and ultimate displacement of shorter-chain PFAS from adsorption sites over time (Franke, et al. 2019). Even so, GAC demonstrates better removal than PAC of shorter-chain PFAS such as GenX. Based on historical PFAS sample results shown in **Table 2-1**, **Figure 2-2**, and **Figure** 2-3, NCWSA Lake Murray WTP and neighboring utilities have long-chain PFAS concentrations (PFOA and PFOS) that exceed the MCL of 4.0 ppt and GenX concentrations that approach the current MCL of 10 ppt, suggesting that GAC would be an effective treatment alternative.

GAC is typically implemented either in lead/lag or parallel configuration when using pressure vessels (applicable to smaller water systems). In lead/lag configuration, the media in the lead vessel is replaced when breakthrough of PFAS occurs and the lag vessel is rotated into the lead. In parallel operation, media in the vessel is replaced upon exhaustion, with vessels at multiple levels of exhaustion operating in parallel and the final effluent blended to ensure PFAS compliance. Gravity contactors are applicable to larger water systems (typically >25 mgd) and are typically designed with flow through contactors in a parallel configuration. Gravity contactors are placed in service in phases to allow for staggered media replacements to prevent all contactors from requiring media replacement at the same time.

The use of GAC for PFAS removal will require replacement of the media over time as adsorption sites are exhausted. Important considerations are disposal, potential for regeneration, and replacement of spent media. Regeneration of spent GAC media is available as an alternative to disposal and at a reduced cost when compared to replacement with virgin GAC media. Both means of media replacement are handled by the media supply vendors and subcontractors although some larger plants such as Greater Cincinnati’s Richard Miller Treatment Plant have on-site regeneration facilities.

Regeneration is especially favored in PFAS treatment applications since PFAS can be thermally destroyed at temperatures >1500 $^0$F. Regeneration allows approximately 90% of the spent GAC volume to be reused, and the remaining 10% is replaced with virgin media to restore the required GAC volume.

Disposal of spent GAC media is also a common practice. Current regulations do not classify the spent media as hazardous waste, which allows for disposal at non-hazardous facilities such as landfills and incineration. Uncertainty in future regulations regarding the potential classification of spent PFAS-laden media as hazardous material could impact O&M costs including removal procedures, hauling, and disposal. Because of this, disposal of spent GAC in a landfill may carry additional liability, and a reactivation approach is preferred over disposal in a landfill.

In addition to removing PFAS, GAC has consistently proven effective as a treatment barrier for many other contaminants, including those of concern for NCWSA such as TOC (and resulting DBPs), taste and odor compounds (MIB and geosmin), and other CECs. The same adsorption mechanism removes these contaminants, leading to competition for GAC adsorption sites. Consequently, the inlet concentration of TOC and other competing contaminants may dictate the timing of GAC media changeouts. Although this competition may shorten media life, it would provide NCWSA with an additional treatment barrier during taste and odor episodes, reduce organics that contribute to the formation of DBPs, and remove CECs that may be regulated in the future.

### 3.1.3 Anion Exchange

AIX is a treatment process used in PFAS applications that utilizes a resin material to remove negatively charged species (anions) from a solution via electrostatic interactions. The mobile counter ion is chloride or hydroxide ions. These ions, when exchanged into the treated water, can impact the pH by adding the hydroxide ion or altering the chloride to sulfate mass ratio when releasing the chloride ion. Both ion releases will impact key corrosion control water quality parameters.

Resin types are available from multiple distributors, including Purolite, Evoqua, and Calgon. There are several factors that must be evaluated when determining which resin to use for PFAS removal (e.g., resin matrix, pore structure, and functional group). PFAS-selective AIX resins are designed to be more selective in their contaminant removal and limit adsorption of co-contaminants; thus, these AIX resins will typically have a longer time in service before replacement than GAC media, which is less selective. In PFAS applications, quaternary ammonium or dimethyl ethanol ammonium polyacrylic gel resins have generally been the most effective (Rahman, Peldszus and Anderson 2013).

For PFAS applications, treatment occurs with flow through a fixed-bed vessel with EBCTs ranging from 1.5 to 5 minutes (Murray, et al. 2021). PFAS removal through AIX is significantly influenced by background water quality, including TOC and DOC, and the presence of inorganic ions. PFAS adsorption in drinking water can also be impacted by pH, affecting the charged nature of specific resins and thereby influencing the strength of interaction with PFAS.

The presence of inorganic ions coexisting in the same treated water can also affect the removal of PFAS. Divalent cations can form a bridge between negatively charged PFAS resulting in co-removal or reduced PFAS uptake (Du, et al., 2014). Other anions, such as sulfate, chloride, and chromate, have been shown to decrease PFAS adsorption in AIX applications (Du, et al. 2014). Additionally, natural organic matter (NOM) is typically negatively charged and may impact PFAS removal, usually by competition for charged sites on the AIX resin.

Other important considerations are disposal, potential for regeneration, and replacement of spent AIX media. The use of an AIX strategy will require replacement of the resin over time as exchange sites are exhausted. AIX is implemented in pressure vessels in a lead/lag configuration to ensure media replacement occurs prior to breakthrough of PFAS. In other uses for AIX resin besides PFAS removal, resin may be regenerated on site; however, currently, conventional methods of AIX regeneration are inefficient for PFAS removal. This is due to the disposal requirements of regenerant solutions and limited effectiveness after successive regeneration cycles.

Research evaluating alternative regeneration methods is being conducted, often incorporating combinations of organic solvent and brine solutions (Boyer, et al. 2021), but has not yet led to viable regeneration methods in practice. The current method for spent AIX resin is incineration, contracted through the resin supplier, due to the high concentration of PFAS loaded onto the media. Incineration of resin also destroys the PFAS contaminant. Like GAC and PAC, O&M costs may be impacted by changes in future regulations if the spent resin containing PFAS is classified as hazardous material.

### 3.1.4 High-Pressure Membranes

Membrane processes, including reverse osmosis (RO) and nanofiltration (NF), have also been designated by USEPA as Best Available Technologies for PFAS removal. These are pressure-driven processes that are commonly used for treatment of brackish and saline water supplies, softening, potable reuse, bottled water purification, and industrial applications. Both RO and NF have been shown to be effective in the removal of PFAS. Removal efficiency can vary by PFAS compound and is a function of the membrane element selection.

RO and NF systems may require additional pretreatment since they are highly susceptible to scaling and fouling, which can reduce the production capacity. Ultrafiltration may be needed to assure that solids from the conventional process do not clog the RO or NF membranes. Biological fouling (biofouling) is a common concern with the treatment of surface waters. Chloramination of the membrane influent is a common approach to address biofouling.

Whereas recovery rates with membrane filtration of brackish supplies are typically 75-85%, RO and NF in freshwater applications such as surface water drinking facilities can achieve recovery rates greater than 90%. Reject water (or membrane concentrate) has high concentrations of PFAS, TOC, and other constituents and should be managed properly (perhaps requiring treatment) prior to discharge to surface waters, which could result in additional permitting challenges. In addition, it would be expected that WTP capacity would be derated 5-15% due to the loss of membrane concentrate, unless the reject waste stream can be further treated.

Membrane filtration provides the ability to remove multiple contaminants; however, as noted previously, there are some considerations that should be evaluated, including membrane selection, pretreatment to control membrane fouling, potential for scaling, life of membranes before replacement, and treatment and disposal of a large membrane concentrate stream. Membrane filtration typically is the highest capital cost alternative for controlling PFAS.

### 3.1.5 Emerging Technologies (Novel Sorbents)

Of the emerging technologies with capability to remove PFAS, FLUORO-SORB®, a novel adsorbent, is advancing in development rapidly. FLUORO-SORB® is a novel proprietary amine functionalized bentonite clay adsorbent. Unlike GAC and PAC, FLUORO-SORB has the ability to selectively remove PFAS with limited effect from typical adsorbate competitors, such as DOC. Further, FLUORO-SORB® is likely efficient for a wide spectrum of long-chain as well as short-chain PFAS compounds. Typically, FLUORO-SORB® is deployed in fixed bed pressure vessels with an EBCT of approximately 3 minutes and can have longer times in service prior to changeout than GAC.

While this technology offers a shorter EBCT and a higher projected capacity for PFAS before replacement, as a novel product, there are many associated uncertainties. A few of these include rate of headloss accumulation, backwashing frequency, and future availability and replacement costs for proprietary media.

## 3.2 Additional Treatment Goals

The primary driver of this project is to select a technology for PFAS removal to meet the current PFAS regulation. In addition, selecting a technology that can provide additional treatment benefits or offer a multi-barrier approach to an existing contaminant would be desirable if it is cost effective. **Figure 3-1** provides a general comparison of the effectiveness of various technologies on NCWSA's other raw water quality challenges noted above.

| Challenge | PAC | GAC | IX | RO/NF | Emerging Technologies |
|---|---|---|---|---|---|
| Algal related T&O | ✓ | ✓ | 🚫 | ✓ | ? |
| DBPs | ? | ✓ | 🚫 | ✓ | ? |
| Dist. Syst. Discoloration / WQ | ? | ✓ | ? | ? | ? |
| Future (short-chain) regulated PFAS | 🚫 | ? | ? | ✓ | ? |
| Additional CECs | ? | ✓ | 🚫 | ✓ | ? |

**Figure 3-1: Additional Considerations for PFAS Treatment Technology**

## 3.3 Technology Evaluation

### 3.3.1 Benchtop GAC Performance Modeling

As part of the evaluation of treatment options, Hazen performed modeling to understand PFAS removal performance utilizing post-filter GAC. Hazen has developed a machine learning based model to predict GAC breakthrough of PFAS compounds, as a function of design and water quality parameters. The model is based on more than 600 datasets from bench, pilot, and full-scale testing, and predicts GAC performance as a function of key design parameters such as empty bed contact time (EBCT), carbon product, and background water quality (Koyama et. al. 2024).

Critical water quality parameters for the modeling effort, provided by NCWSA, are shown in **Table 3-1**.

**Table 3-1: NCWSA Key Water Quality Parameters for GAC Performance Modeling**

|  | Raw Water (Note 1) | Finished Water (Note 1) |
|---|---|---|
| **Flow, mgd** | 1.0 | 0.9 |
| **pH** | 6.9 | 7.3 |
| **Total Organic Carbon (TOC), mg/L** | 4.0 | 2.0 |

**Notes:**

1. **Water Quality Based on averages of MOR Data (8/1/19 to 6/30/2024)**

Assumptions of the primary input parameters for modeling include TOC, pH, carbon type, EBCT, and concentration of PFAS and are summarized in **Table 3-2**.

**Table 3-2: Modeling Input Parameters**

| | Input Parameters |
|---|---|
| **pH** | 7.3 |
| **Total Organic Carbon (TOC), mg/L** | 2.0 |
| **Carbon** | Calgon F400 |
| **EBCT, min** | 10 & 15 |
| **PFOA, ng/L(Note1)** | 4.81 |
| **PFOS, ng/L(Note 1)** | 8.25 |
| **Gen-X, ng/L(Note 1)** | 7.52 |
| **PFBS, ng/L(Note 1)** | 3.98 |
| **PFHxA, ng/L** | 4.57 |
| **PFPeA, ng/L** | 5.3 |
| **PFBA, ng/L** | 6.5 |

**Notes:**

1. **Compounds that have Maximum Contaminant Levels (MCL) and/or are subject to Hazard Index (HI).**

## 3.3.2 Modeling Results

Among the detected PFAS compounds listed in **Table 3-2**, PFOA and PFOS exceed the MCL level of 4 ng/L. The two additional regulated PFAS compounds detected, Gen-X and PFBS, do not exceed the MCL or HI levels. Therefore, PFOA and PFOS are the primary factors for changing the GAC media. The target concentration for PFOA and PFOS is set to 2 ng/L to comply with regulatory requirements with an adequate compliance buffer. Assuming average observed PFOA and PFOS concentrations of 4.81 ppt and 8.25 ppt, respectively, breakthrough to the target concentration of 2 ppt corresponds to 41% (PFOA) and 24% (PFOS) breakthrough, respectively.

**Figure 3-2** shows the GAC breakthrough curves for PFOA and PFOS to achieve target concentration, with an EBCT of 10 minutes, The modeling results indicate that, for an average flow rate of 1-MGD, the breakthrough occurs approximately 367 days after GAC runs for PFOA, and 323 days for PFOS.

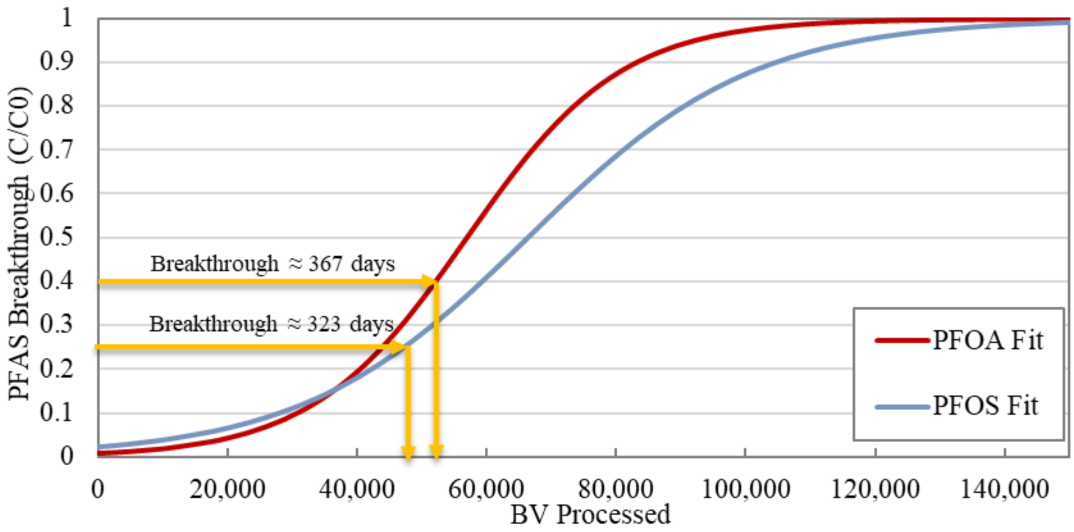


**Figure 3-2: GAC Breakthrough Curves for PFOA and PFOS with EBCT = 10 min**

**Figure 3-3** shows the GAC breakthrough curves for PFOA and PFOS with an EBCT of 15 minutes. The modeling results indicate that the breakthrough occurs approximately 506 days after GAC runs for PFOA, and 447 days for PFOS, also for an average flow of 1-mgd.

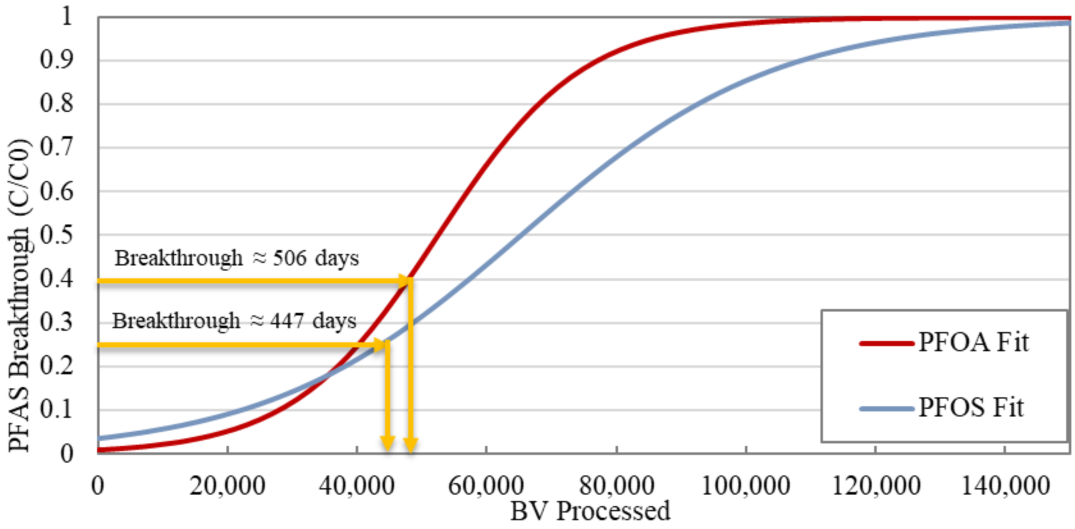


**Figure 3-3: GAC Breakthrough Curves for PFOA and PFOS with EBCT = 15 min**

The results show that the expected performance of GAC is reasonable, with an estimate of nearly a year of service for a 10-minute EBCT design at average flows (~1-mgd). Practically, this means that the lead vessel in a 20-minute designed lead-lag system (10-minutes in each vessel) would need to be replaced approximately annually.

Extending the EBCT to 15-minutes per vessel does increase the lifespan of the GAC media by approximately 4-months. However, achieving this longer EBCT requires expanding GAC bed volume, either through more trains or larger vessels, both of which have significant cost implications.

### 3.3.3 Conclusions and Recommendations

Hazen's Machine Learning based GAC breakthrough prediction tool suggests that GAC is capable of extended performance at reasonable design EBCTs. Utilizing average water quality and PFAS levels, a 10-minute EBCT contactor utilized to treat PFOA and PFOS down to 2 ppt would require changeout on an approximate annual basis. It is most likely that the treatment train would include 2 GAC vessels, each sized for a 10-minute EBCT, in a lead-lag formation. In this way, the finished water levels of PFOA and PFOS will most often be at or near non-detect, as long as the lead-vessel is changed on an approximately annual cycle.

While the GAC model provides reasonably accurate breakthrough predictions for many water quality and PFAS scenarios, it is recommended that additional testing be performed, either on the bench- or pilot-scale, to verify design parameters and expected performance of GAC for PFAS removal. In addition, testing of multiple products and operational scenarios can help NCWSA optimize GAC treatment in the long-term, consider impacts on ancillary water quality (i.e. taste and odor, DBPs), and determine the most effective GAC products for long-term operation at the facility.

## 3.4 Selected Alternatives for Further Consideration

While each of the technologies can remove PFAS from drinking water, a technology that addresses a broader range of water quality concerns is recommended and desired by NCWSA. As such, AIX and novel sorbents were not considered further, as they do not provide the additional water quality benefits. Other emerging technologies are not a USEPA BAT for PFAS removal and would pose additional risk to NCWSA, if implemented; therefore, these were not considered further. Although high-pressure membranes can effectively remove PFAS and meet the multi-barrier approach criteria, cost and the added complexity of managing disposal of the concentrated waste stream make it a less desirable solution for NCWSA.

# 4. PAC Bench-Scale Testing

## 4.1 Testing Plan

To determine effectiveness of PAC for PFAS removal, three PAC products were evaluated in bench-scale testing at the NCWSA Lake Murray WTP in December 2024. The products were selected based on their effectiveness for PFAS removal at other locations. The products used in the testing and their general characteristics are included in **Table 4-1**.

**Table 4-1: Characteristics of Powdered Activated Carbon Alternatives Evaluated in PAC Bench-Scale Testing**

| | Base Material | Particle Size Distribution | Iodine Number, mg/g | Density, lb/cu ft |
|---|---|---|---|---|
| **Ingevity AquaNuchar** | Wood | 99% (min) – 100 mesh<br>95% (min) – 200 mesh<br>90% (min) – 325 mesh | 900 | 13 – 24<br>(15 typ) |
| **Arq Carbpure TRA** | Coal | 99% (min) – 100 mesh<br>95% (min) – 200 mesh<br>90% (min) – 325 mesh | 800 | 12 – 38<br>(20 typ) |
| **Jacobi AquaSorb CB1-MW** | Coconut | 99% (min) – 100 mesh<br>95% (min) – 200 mesh<br>90% (min) – 325 mesh | 950 | 12 – 47<br>(25 typ) |

Due to difficulty distinguishing adsorption performance at low (below 10 ng/L) contaminant concentrations, as observed in Lake Murray, a spike solution was utilized to increase the concentrations of PFAS and MIB/geosmin prior to testing. Spiking the water with PFAS does not affect adsorption performance with PAC if the following criteria are met: target contaminant is below 1,000 ng/L, organic matter is present, and the PAC dose is greater than 10 mg/L (Knappe, et. al., 1998; Corwin, et. al., 2011). These criteria are applicable to the Lake Murray source water; therefore, PFAS compounds and MIB and geosmin were spiked into the raw water with a target of approximately 50 ng/L for the six regulated PFAS compounds and 100 ng/L for MIB/geosmin. The actual levels in the spiked samples were approximately 40-60 ng/L for the six regulated PFAS compounds, 55-60 ng/L for MIB, and 130-140 ng/L for geosmin.

For each of the three PAC products tested, four doses were selected: 5, 15, 25, and 40 mg/L. These dosages were selected based on the range of doses shown to be sufficient for PFAS removal in similar waters.

Two PAC contact times were used for testing. The contact times were 4.5 minutes to simulate the approximate contact time in the 16” raw water pipeline within the boundary of the WTP site at a flow rate of 3 mgd and 30 minutes to simulate the construction of a new PAC contactor with 30 minutes contact time at the WTP.

The general procedure for the PAC jar testing was as follows:

- Collect raw water from the lab sample sink. The raw water had been dosed with copper sulfate.
- Analyze the raw water for general water quality characteristics. Collect raw water samples for PFAS and MIB/geosmin on the first day of testing. Collect raw water samples for TOC on each day of testing. Ship samples to contract laboratory.
- Prepare stock solutions for chemicals to be used in the jar testing and for the spiking standards for MIB/geosmin and PFAS.
- Collect approximately 9L of raw water in a 5-gallon bucket and spike with desired amount of MIB, geosmin, and PFAS. Stir raw water to ensure adequate mixing.
- Transfer 2-L of spiked raw water into each of the four square jar test beakers.
- Dose the raw water in each jar with the desired dose of PAC and mix for the desired contact time.
- Dose the raw water with coagulant (polyaluminum chloride) to match the dosage of the plant on the day of sample collection and run a standard jar test including rapid mixing, flocculation, and settling.
- Collect settled water samples from each jar for PFAS, MIB/geosmin, and TOC and ship to contract laboratory.
- Repeat the same procedure for the other PAC products and contact times.
- Throughout the testing, procedures were followed and equipment/supplies were utilized that would not affect the PFAS results.

A summary of the jar test conditions at Lake Murray is shown in **Table 4-2**. The detailed PAC Bench-Scale Testing Plan is included in **Appendix A** for reference.

**Table 4-2: Jar Test Conditions for PAC Testing**

| Jar Test Conditions NCWSA Lake Murray WTP | | |
|---|---|---|
| **PAC Contact Time** | | |
| Speed, rpm | Initial 150 rpm for 30 seconds to mix PAC followed by 25 rpm to keep solids in suspension | |
| Total Duration, minutes | 4.5 (Contact Time 1)<br>30 (Contact Time 2) | |
| **Rapid Mix** | | |
| Speed, rpm | 100 | |
| Duration, seconds | 30 | |
| **Flocculation** | | |
| Stage | Speed (rpm) | Duration (minutes) |
| 1 | 35 | 10 |
| 2 | 25 | 10 |
| 3 | 12 | 10 |
| **Settling, min** | 5 | |

## 4.2 Results

The testing was conducted at the NCWSA Lake Murray WTP on December 10 and December 11, 2024. The raw water used for the testing was collected from the sample tap in the Operations Lab prior to each jar test. The raw water contained copper sulfate (1.5 mg/L dose) that is fed into the raw water pumping station wetwell. A summary of the raw water characteristics during the testing period is contained in **Table 4-3**. Raw water without copper sulfate (collected from the surface of Lake Murray near the raw water pumping station) and finished water were also analyzed for PFAS, MIB/geosmin, and TOC and that data is also included in **Table 4-3**. Settled water characteristics from the operator's process control log sheet are also contained in **Table 4-3**. Raw water full-scale chemical dosages on the days of testing are contained in **Table 4-4**. A graph comparing MIB, geosmin, PFAS compounds, and TOC between the raw water, raw water after copper sulfate dosing, and finished water is contained in **Figure 4-1**. The PFAS results between the three samples are essentially the same, indicating no PFAS removal within the plant. Geosmin and TOC were slightly higher in the raw water sample collected from the lake surface as compared to the raw water sample with copper sulfate taken from the raw water pumping station.

### Table 4-3: Raw and Settled Water Characteristics – December 10, 2024

| Parameter | Value | | |
|---|---|---|---|
| | Raw Water | | |
| Temperature, deg C | 17 | | |
| pH | 7.17 | | |
| Turbidity, NTU | 2.21 | | |
| Alkalinity, mg/L as CaCO3 | 22 | | |
| Hardness, mg/L as CaCO3 | 18 | | |
| | Raw Water w/o Copper Sulfate $^{\text{(Note 1)}}$ | Raw Water w/ Copper Sulfate $^{\text{(Note 2)}}$ | Finished Water $^{\text{(Note 3)}}$ |
| Total Organic Carbon, mg/L | 5.1 | 3.8 | 2.2 |
| Geosmin, ng/L | 3.6 | < 2.0 | < 2.0 |
| MIB, ng/L | < 2.0 | < 2.0 | < 2.0 |
| PFOS, ng/L | 7.7 | 7.1 | 7.4 |
| PFOA, ng/L | 4.5 | 4.3 | 4.5 |
| PFHxS, ng/L | < 2.0 | < 1.9 | < 2.0 |
| PFNA, ng/L | < 2.0 | < 1.9 | < 2.0 |
| HFPO-DA (GenX), ng/L | 8 | 7.8 | 8 |
| PFBS, ng/L | 2.5 | 2.5 | 2.5 |
| PFHpA, ng/L | 2 | 2 | < 2.0 |
| PFHxA, ng/L | 3.7 | 3.7 | 3.6 |
| PFPeA, ng/L | 3.9 | 33.9 | 3.8 |
| PFBA, ng/L | 3.5 | 3.5 | 2.6 |
| | Settled Water | | |
| pH | 6.87 | | |
| Turbidity, NTU | 0.16 | | |
| TOC, mg/L | 2.3 | | |

**Notes:**

1. Collected from surface of Lake Murray near raw water pumping station.
2. Collected from raw water sample tap in Operations Laboratory.
3. Collected from finished water sample tap in Operations Laboratory.

### Table 4-4: Raw Water Chemical Dosages – December 10, 2024

| Chemical | Dose (mg/L) |
|---|---|
| Copper sulfate | 1.5 |
| PAC | 0 |
| PACl | 35 |

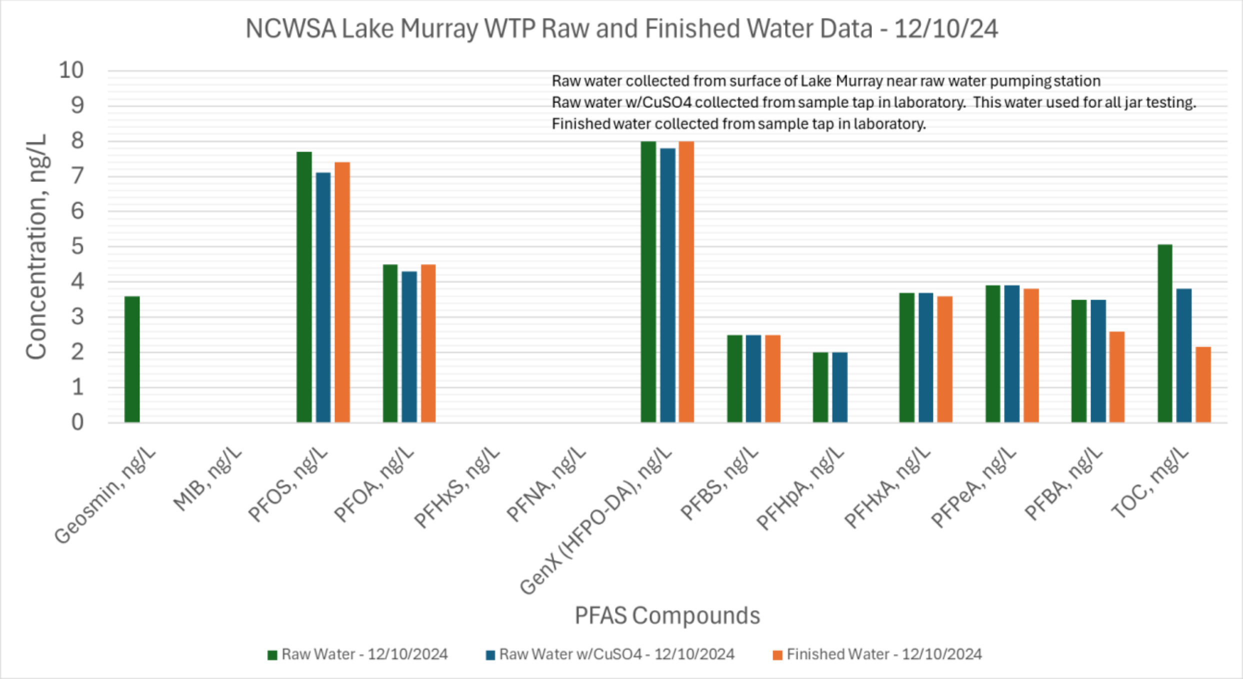


**Figure 4-1: Raw and Finished Water MIB, Geosmin, PFAS, and TOC – December 10, 2024**

### 4.2.1 PFAS

The results of the testing for the three PAC products for PFOA, PFOS, and HFPO-DA (GenX) removal are contained in

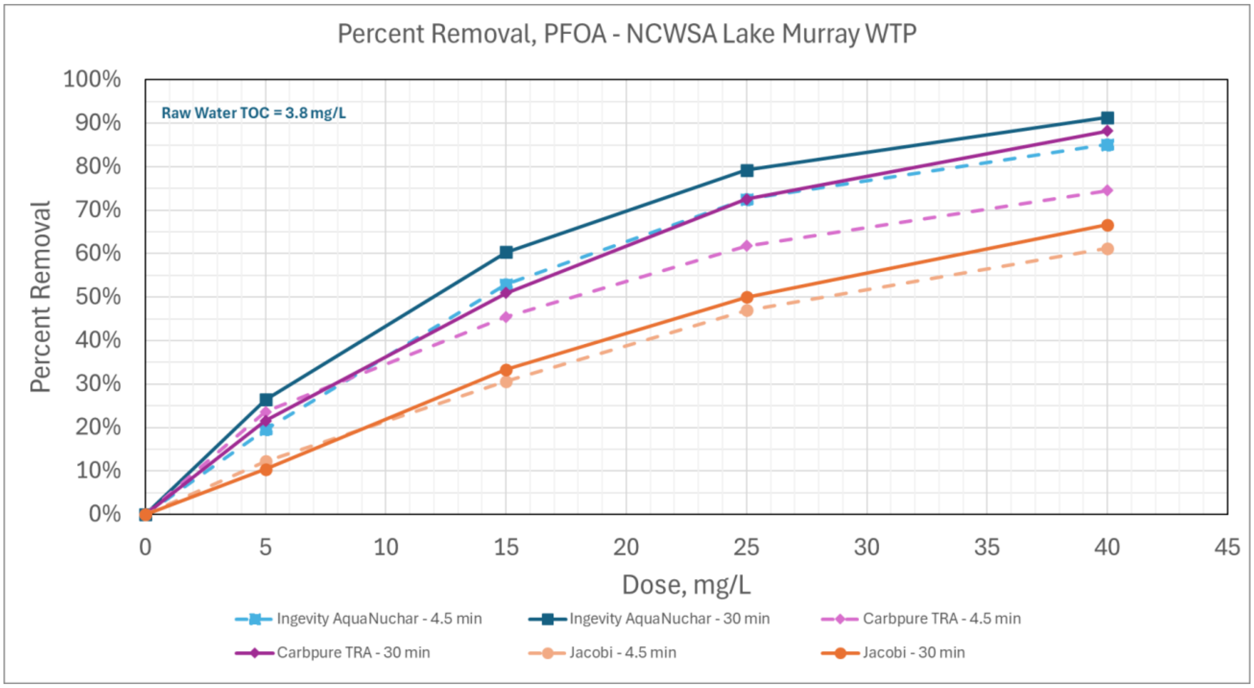


**Figure** 4-2, **Figure 4-3**, and **Figure 4-4**. Several observations can be made from these figures:

- The products were more effective for PFOS removal than PFOA removal at equivalent dosages. The products were least effective for GenX removal.
- Percentage removals increased with increasing PAC dosage.
- The Ingevity AquaNuchar product was the most effective product for PFOA and PFOS removal, followed by the Carbpure TRA product and then the Jacobi AquaSorb CB1-MW product.
- For GenX, the Jacobi product was most effective, followed by the Carbpure product and then the Ingevity product.
- Greater PFOA and PFOS removal was achieved at the contact time of 30 minutes versus the contact time of 4.5 minutes, with a typical increase in removal of approximately 7-9% at the longer contact time at comparable doses for the top two performing products.

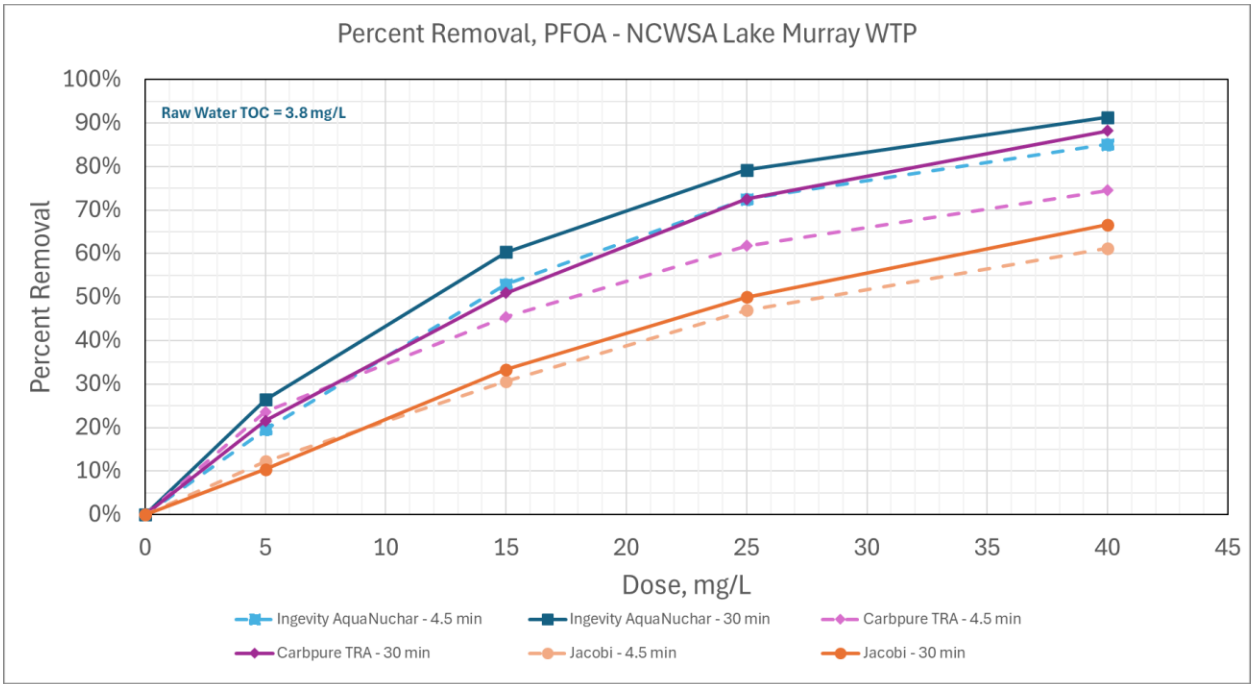


**Figure 4-2: PFOA Removal with PAC (4.5-minute and 30-minute contact times)**

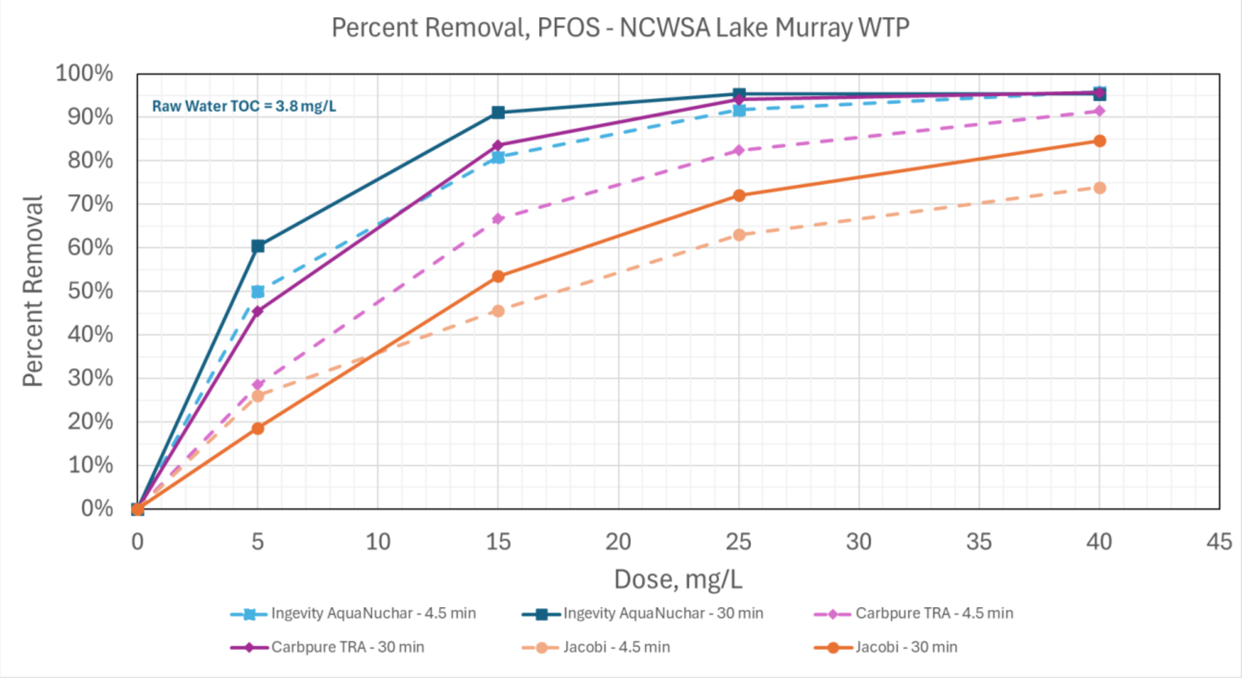


**Figure 4-3: PFOS Removal with PAC (4.5-minute and 30-minute contact times)**

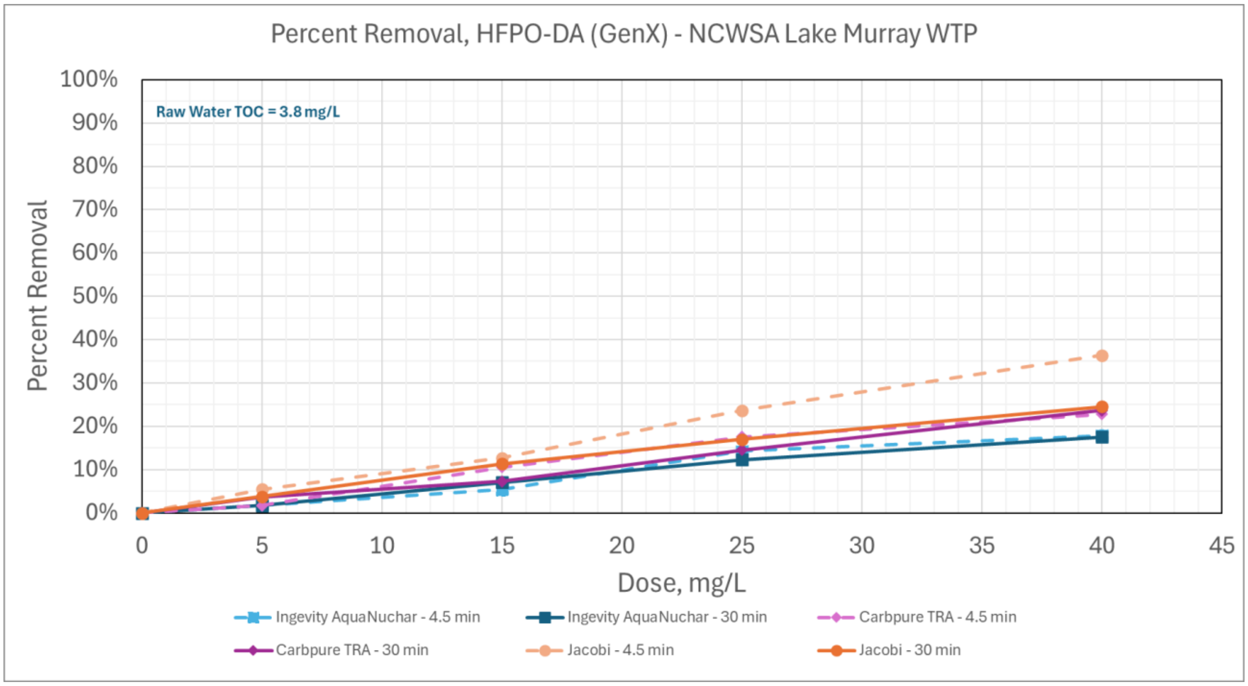


**Figure 4-4: HFPO-DA (GenX) Removal with PAC (4.5-minute and 30-minute contact times)**

As indicated in Chapter 2, the historical average PFOA and PFOS concentrations in the raw and finished water for NCWSA and surrounding utilities have been approximately 4.4-4.9 ng/L for PFOA and 7.0-7.4 ng/L for PFOS. Assuming raw water concentrations of 5.0 ng/L for PFOA and 8.0 ng/L for PFOS, the following approximate percentage removals are needed to meet treated water goals of 3 ng/L, 2 ng/L, and 1 ng/L:

- PFOA:
    - 75% of the MCL (3 ng/L): 40% removal required
    - 50% of the MCL (2 ng/L): 60% removal required
    - Non-detect (defined as 1 ng/L): 80% removal required.
- PFOS:
    - 75% of the MCL (3 ng/L): 60% removal required
    - 50% of the MCL (2 ng/L): 75% removal required
    - Non-detect (defined as 1 ng/L): 90% removal required.

**Figure 4-5** and **Figure 4-6** indicate the approximate range of PAC dosages needed for the top two PAC products (Ingevity and Carbpure) to meet the removal goals listed for PFOA and PFOS, respectively, at both the 4.5-minute contact time (no PAC contactor on site) and the 30-minute contact time (with PAC contactor on site). The Jacobi data is not shown on the graph since it was not as effective as the other two carbons for PFOA and PFOS removal. The percentage removals for the different goals are summarized in **Table 4-5**.

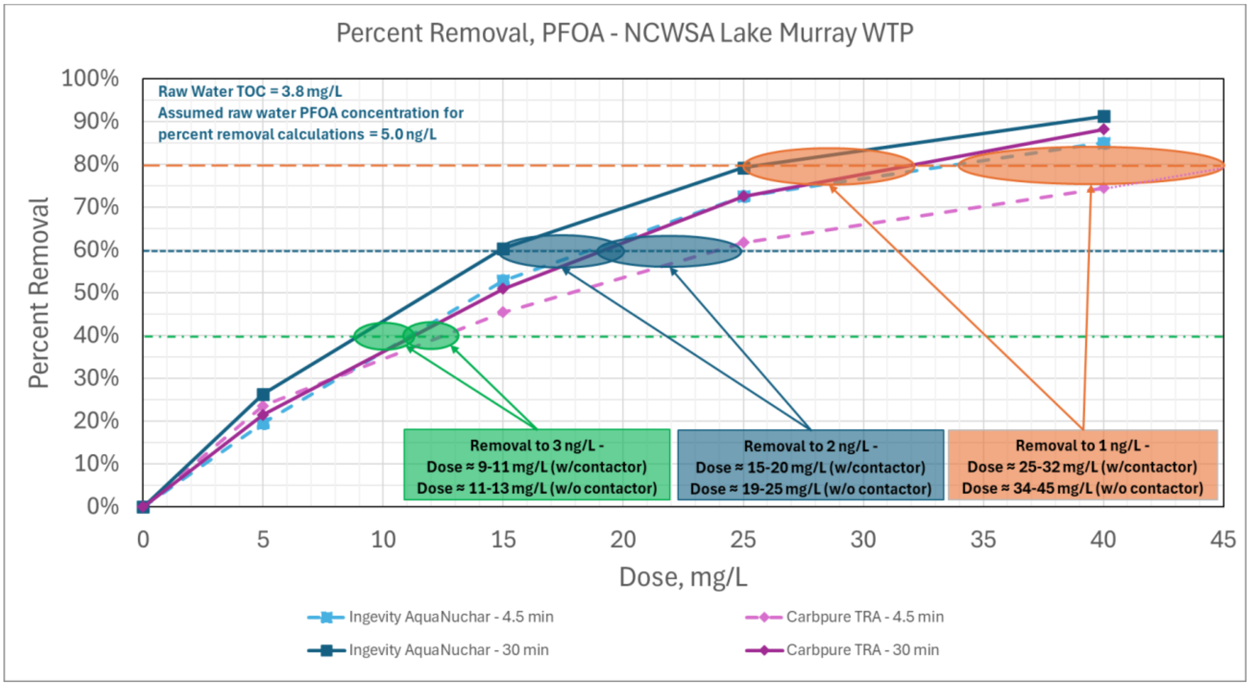


**Figure 4-5: PAC Dosages Needed to Meet PFOA Removal Goals**

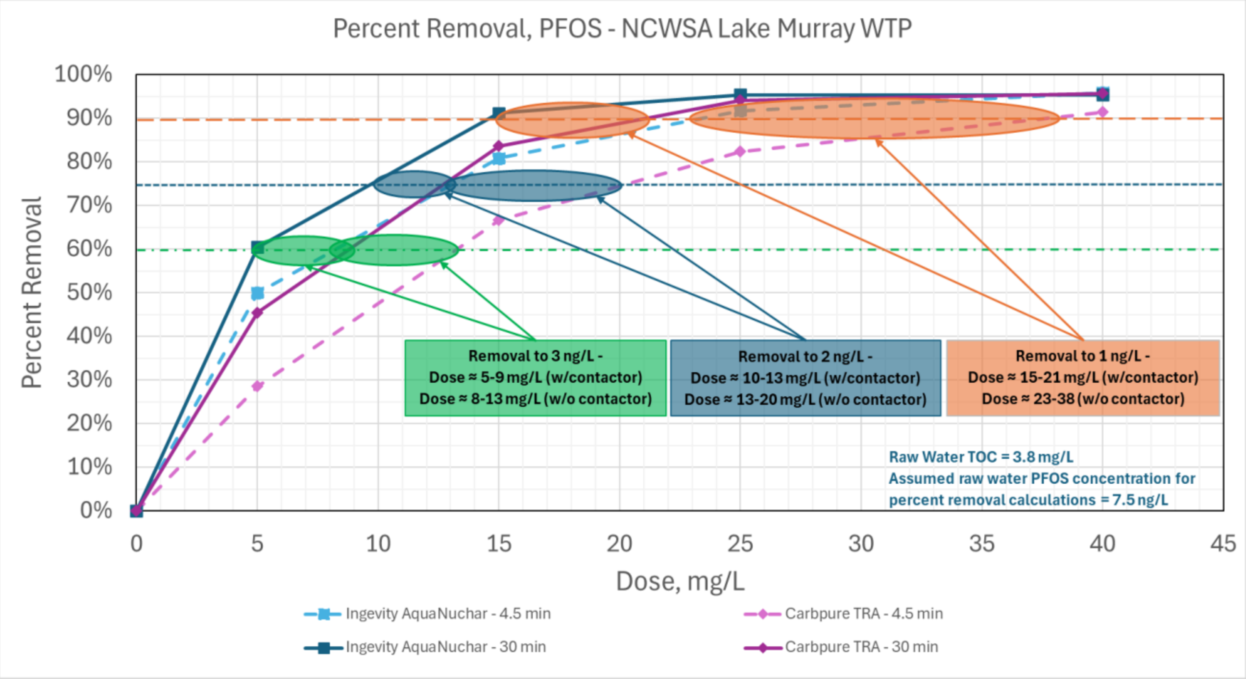


**Figure 4-6: PAC Dosages Needed to Meet PFOS Removal Goals**

**Table 4-5: Estimated PAC Dosages to Meet PFOA and PFOS Goals**

| Goal | Required PAC Dosage Range, mg/L | | Estimated Design Dose, mg/L |
|---|---|---|---|
| | PFOA | PFOS | |
| | w/o 30-minute PAC Contactor | | |
| **3 ng/L (75% of MCL)** | 11-13 | 8-13 | 13 |
| **2 ng/L (50% of MCL)** | 19-25 | 13-20 | 25 |
| **1 ng/L (Non-Detect)** | 34-45 | 23-38 | 45 |
| | w/30-minute PAC Contactor | | |
| **3 ng/L (75% of MCL)** | 9-11 | 5-9 | 11 |
| **2 ng/L (50% of MCL)** | 15-20 | 10-13 | 20 |
| **1 ng/L (Non-Detect)** | 25-32 | 15-21 | 32 |

At the estimated design dosages shown in **Table 4-5**, the percent removal of GenX is shown in **Figure 4-7**. The percent removals of GenX shown are based on the results of the top two performing PAC products for PFOA and PFOS removal – the Ingevity AquaNuchar product and the Carbpure TRA product. The Jacobi product provided greater removal of GenX on the day of testing but was not as effective for PFOA and PFOS removal as the other two products.

At the lowest design dosages of 11-13 mg/L, percentage GenX removals were 5-10%; assuming a starting concentration of 8.0 ng/L, these dosages would reduce the GenX concentrations in the finished water to approximately 7.2-7.6 ng/L. At the highest design dosages of 32-45 mg/L, percentage GenX removals were 15-25%; assuming a starting concentration of 8.0 ng/L, these dosages would reduce the GenX concentrations in the finished water to approximately 6.0-6.8 ng/L.

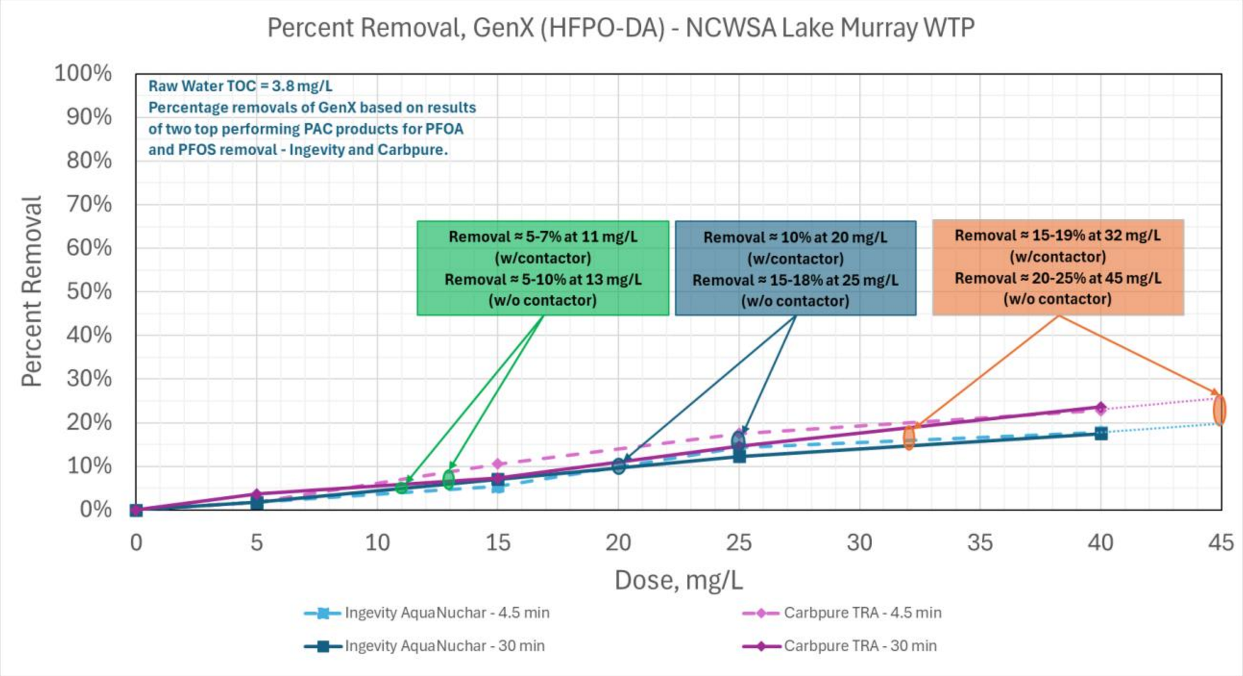


**Figure 4-7: GenX Removal at Estimated PAC Dosages to Meet PFOA/PFOS Goals**

### 4.2.2 MIB/Geosmin

The results for MIB and geosmin reduction are contained in **Figure 4-8** and **Figure 4-9**, respectively for Ingevity AquaNuchar and Carbpure TRA; results for Jacobi CB1-MW are not included in the graphs because of its lower effectiveness for removing PFAS compounds. The figures also show the approximate MIB and geosmin removal at the estimated design dosages (from **Table 4-5**) that are needed for PFOA and PFOS removal for the goals both with and without a PAC contact basin. Observations drawn from these data include:

- The PAC products were more effective for geosmin removal than MIB removal at equivalent dosages.
- Percentage removals increased with increasing PAC dosage.
- The percentage removal of MIB and geosmin was greater at the 30-minute contact time versus the 4.5-minute contact time, generally providing approximately 7-9% greater removal at the 30-minute contact time versus the 4.5-minute contact time.
- For MIB, the Ingevity AquaNuchar product was more effective than the Carbpure TRA product. The Jacobi CB1-MW product (data not shown) was typically approximately 4 % more effective than the Ingevity product at the 30-minute contact time; however, the limited effectiveness of Jacobi CB1-MW for the PFAS compounds make it less desirable for this project. The Jacobi product had similar effectiveness to the Carbpure product at the 4.5-minute contact time.

- For geosmin, the Ingevity product was the most effective product followed by the Carbpure product (and the Jacobi product).

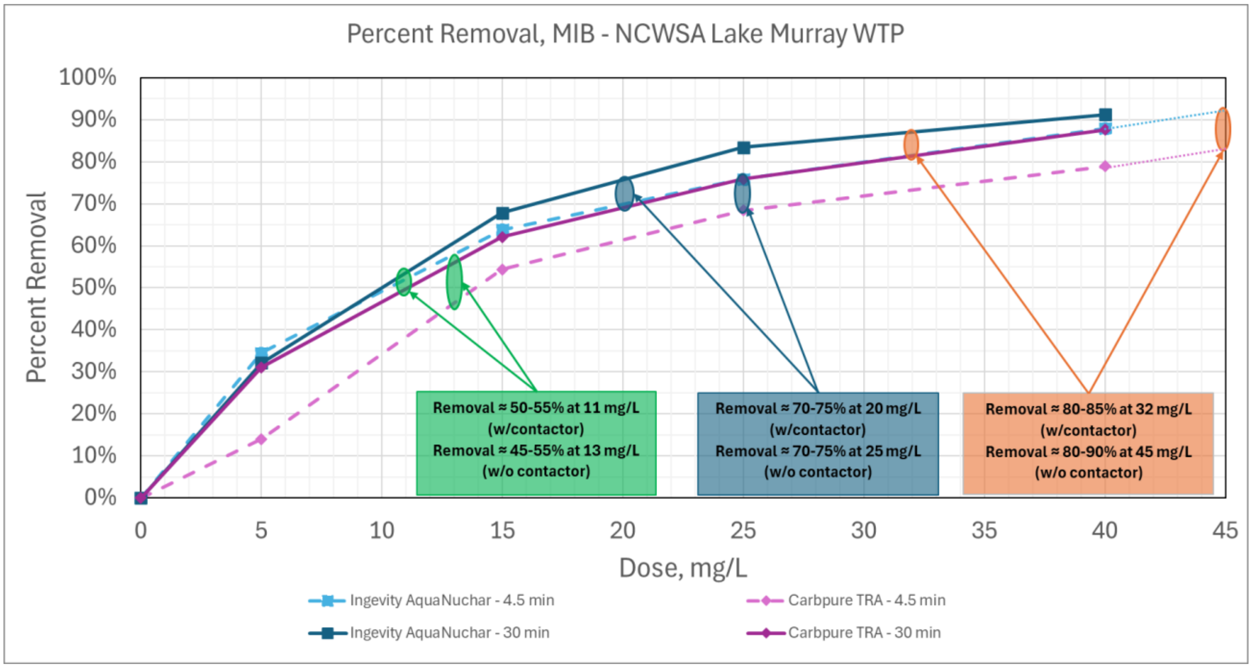


**Figure 4-8: MIB Removal at Estimated PAC Dosages to Meet PFOA/PFOS Goals**

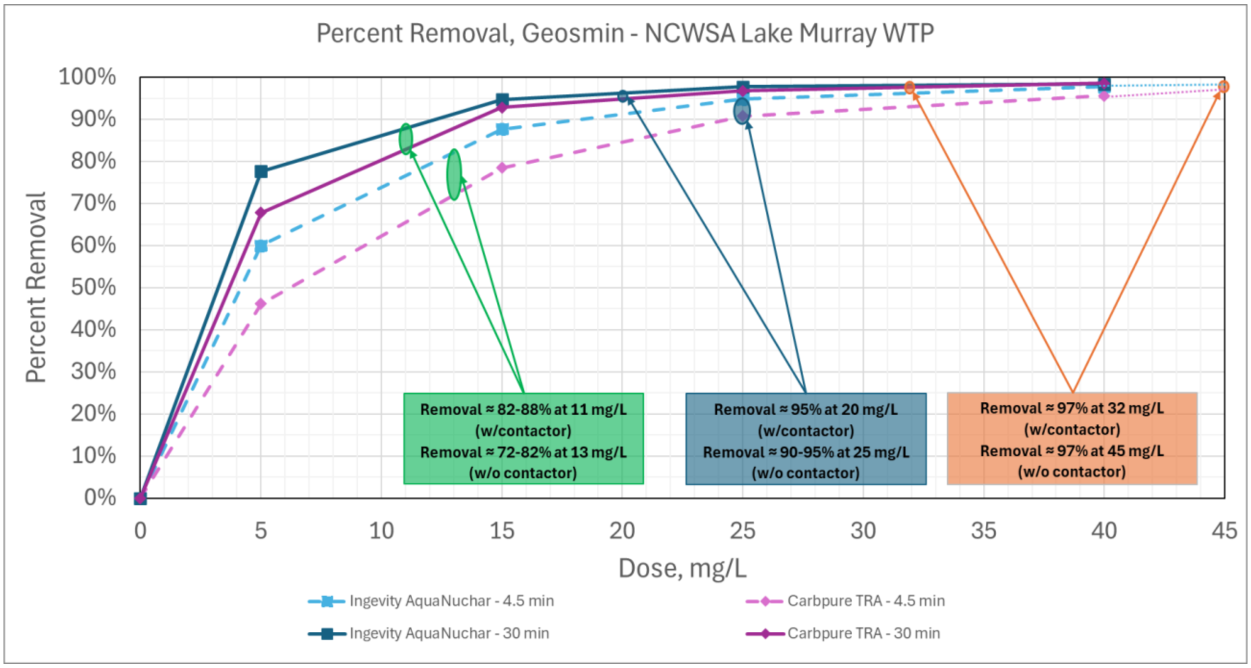


**Figure 4-9: Geosmin Removal at Estimated PAC Dosages to Meet PFOA/PFOS Goals**

NCWSA does not have any raw water MIB/geosmin data available, but data from the City of Columbia were reviewed. From 2019-2023, the maximum MIB concentration in the raw water at the City of Columbia's Lake Murray WTP was approximately 500 ng/L, with a 95th percentile value of approximately 50 ng/L. During that same time period, the maximum geosmin concentration in the raw water at the City of Columbia's Lake Murray WTP was 32 ng/L, with a 95th percentile value of 12 ng/L. Based on these data, it was assumed that the raw water at the NCWSA Lake Murray WTP has similar values, with a raw water MIB concentration of 50 ng/L and raw water geosmin concentration of 30 ng/L. Using these assumptions, and based on the estimated design dosages to meet the various PFOA/PFOS removal goals (see **Table 4-5**), finished water MIB and geosmin concentrations were estimated based on the results of the bench-scale testing and are contained in **Table 4-6**. These calculations are based on the two best PAC products for PFOA and PFOS (Ingevity and Carbpure).

At the estimated design dosages for PFOA/PFOS removal, MIB concentrations less than the recommended 5-10 ng/L may be difficult to achieve except at the highest dosages of 45 mg/L (w/out a contactor) and 32 mg/L (w/ a contactor). If lower dosages are used to meet different PFOA/PFOS goals, these higher PAC dosages may be required seasonally when MIB and geosmin levels in the raw water are elevated. Geosmin concentrations less than 5-10 ng/L can be achieved at any of the dosages chosen for the different PFAS goals. If levels in the raw water approach the maximum MIB concentrations of 500 ng/L seen in the City of Columbia's raw water, PAC would not be able to achieve levels of 5-10 ng/L at reasonable dosages.

**Table 4-6: Estimated Percent Removals and Finished Water Concentrations of MIB and Geosmin at the Estimated Design Dosages for PFOA/PFOS Removal**

| PAC Dose, mg/L | MIB Removal, % | Projected FW MIB Conc, ng/L(Note 1) | Geosmin Removal, % | Projected FW Geos Conc, ng/L(Note 1) |
|---|---|---|---|---|
| **w/o 30-minute PAC Contactor** | | | | |
| **13 mg/L (PFOS/PFOA goal of 3 ng/L)** | 45-55 | 23-28 | 72-82 | 5-8 |
| **25 mg/L (PFOS/PFOA goal of 2 ng/L)** | 70-75 | 13-15 | 90-95 | 2-3 |
| **45 mg/L (PFOS/PFOA goal of 1 ng/L)** | 80-90 | 5-10 | 97 | 1 |
| **w/30-minute PAC Contactor** | | | | |
| **11 mg/L (PFOS/PFOA goal of 3 ng/L)** | 50-55 | 28 | 82-88 | 4-5 |
| **20 mg/L (PFOS/PFOA goal of 2 ng/L)** | 70-75 | 13-15 | 95 | 2 |
| **32 mg/L (PFOS/PFOA goal of 1 ng/L)** | 80-85 | 8-10 | 97 | 1 |

**Notes:**

1. **Based on 50 ng/L raw water MIB and 30 ng/L raw water Geosmin.**

### 4.2.3 TOC

The results for TOC reduction for Ingevity AquaNuchar and Carbpure TRA are contained in **Figure 4-10.**Observations drawn from these data include:

- The PAC products provided additional TOC removal at both contact times as compared to the TOC removal in the full-scale plant without PAC addition.
- Percentage TOC removals increased with increasing PAC dosage.
- The percent removal of TOC was generally slightly greater at the 30-minute contact time versus the 4.5-minute contact time.
- The Ingevity AquaNuchar product was the more effective of the two for TOC reduction. For reference, the Jacobi product provided similar TOC removal to the Ingevity product; however, as previously stated, the limited effectiveness of Jacobi CB1-MW for the PFAS compounds make it less desirable for this project.

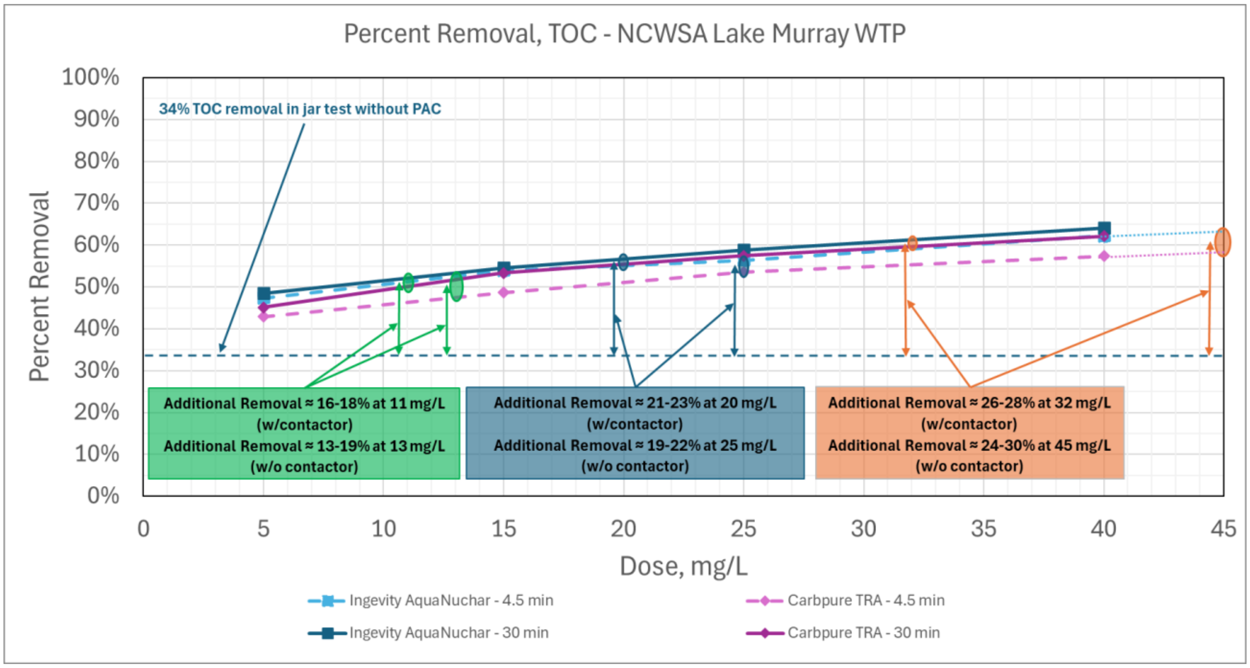


**Figure 4-10: TOC Removal at Estimated PAC Dosages to Meet PFOA/PFOS Goals**

Based on the estimated design dosages to meet the various PFAS goals both with and without a PAC contactor, the estimated additional TOC removal from the PAC addition is contained in **Table 4-7**.

**Table 4-7 Estimated Additional Percent TOC Removal at the Estimated Design Dosages for PFOA/PFOS Removal**

| PAC Dose, mg/L | TOC Removal, %(Note 1) |
|---|---|
| **w/o 30-minute PAC Contactor** | |
| **13 mg/L**<br>**(PFOS/PFOA goal of 3 ng/L)** | 13-19 |
| **25 mg/L**<br>**(PFOS/PFOA goal of 2 ng/L)** | 19-22 |
| **45 mg/L**<br>**(PFOS/PFOA goal of 1 ng/L)** | 24-30 |
| **w/30-minute PAC Contactor** | |
| **9 mg/L**<br>**(PFOS/PFOA goal of 3 ng/L)** | 16-18 |
| **20 mg/L**<br>**(PFOS/PFOA goal of 2 ng/L)** | 21-23 |
| **32 mg/L**<br>**(PFOS/PFOA goal of 1 ng/L)** | 26-28 |

**Notes:**
1. **Additional TOC removal above that achieved in the full-scale plant with no PAC addition.**

## 4.3 Summary – PAC Bench-Scale Testing

Powdered activated carbon was effective for removal of PFOA, PFOS, MIB, geosmin, and total organic carbon on the days of testing. PAC had limited effectiveness on GenX removal. A summary of the results is as follows:

- The most effective product for reduction of PFOA and PFOS present in the raw water was the Ingevity AquaNuchar product followed by the Carbpure TRA product. The Jacobi AquaSorb CB1-MW was much less effective than the other two and was eliminated from comparisons for other treatment goals.

- The Ingevity product was the more effective product for MIB and geosmin reduction than the Carbpure product.

- The Ingevity product provided better TOC removal than the Carbpure product.

- The PAC products were more effective for PFOS removal than PFOA removal, and for geosmin removal as compared to MIB removal.

- Greater PFOA, PFOS, MIB, geosmin, and TOC reduction was achieved at 30-minute PAC contact time versus 4.5-minute PAC contact time.

- A summary of the estimated design dosages to achieve the desired PFAS goals at each contact time is presented in **Table 4-8** along with the estimated MIB, geosmin, and TOC removal at each of the dosages. This data is based on the results of the top two products (Ingevity AquaNuchar and Carbpure TRA) for PFOA and PFOS removal.

**Table 4-8: Design Dosages to Achieve PFOA/PFOS Goals and Corresponding Estimated Removal Percentages of MIB, Geosmin, and TOC**

| Design Dose, mg/L | Estimated MIB Removal, % | Estimated Geosmin Removal, % | Estimated TOC Removal, %(Note 1) |
|---|---|---|---|
| **w/o 30-minute PAC Contactor** | | | |
| **13 mg/L (60% PFOS removal to meet goal of 3 ng/L)** | 45-55 | 80-93 | 13-19 |
| **25 mg/L (60% PFOA removal to meet goal of 2 ng/L)** | 70-75 | 90-95 | 19-22 |
| **45 mg/L (80% PFOA removal to meet goal of 1 ng/L)** | 80-85 | 97 | 24-30 |
| **w/30-minute PAC Contactor** | | | |
| **11 mg/L (60% PFOS removal to meet goal of 3 ng/L)** | 45 | 75-85 | 16-18 |
| **20 mg/L (60% PFOA removal to meet goal of 2 ng/L)** | 70-75 | 90-95 | 21-23 |
| **32 mg/L (80% PFOA removal to meet goal of 1 ng/L)** | 80-85 | 95 | 26-28 |

**Notes:**

1. **Additional TOC removal above that achieved in the full-scale plant with no PAC addition.**

# 5. Rapid Small Scale Column Testing

## 5.1 Testing Plan

Two GAC products were evaluated in RSSCT conducted by One Water Engineering in Raleigh NC. The GAC products were selected based on their effectiveness for PFAS removal at other locations. The GAC products used in the testing and their general characteristics are included in the **Table 5-1**. A detailed writeup of the RSSCT Testing Protocol is included in **Appendix B** and a detailed writeup of the RSSCT results is contained in **Appendix C**.

**Table 5-1: Characteristics of GAC Alternatives Evaluated in RSSCT**

| GAC | Base Material | Effective Size mm | Iodine Number mg/g | Density lb/cu ft |
|---|---|---|---|---|
| **Calgon F400** | Coal | 0.55 - 0.75 | 1,000 | 33.7 |
| **Arq Carbpure GAC1240** | Coal | 0.5 - 1.0 | 1,000 | 29.9 |

Lake Murray WTP Staff collected two 55-gallon drums of filtered water prior to chlorination, and shipped the drums to One Water Engineering. Upon receiving the raw water samples, they were spiked with 30 ng/L of PFAS. The PFAS spiking solution included PFBA, PFBS, PFPeA, PFHxA, GenX, PFHpA, PFOA, PFHxS, 6:2 FTS and PFOS. The purpose of spiking with PFAS was to increase the influent concentration and thereby improve resolution when detecting breakthrough. The samples were then analyzed for bulk water quality parameters that impact sorbent capacity for PFAS, as well as PFAS concentrations. Results from duplicate samples were averaged and are reported in

**Table 5-2**. Temperature, pH, and chlorine residual were analyzed in the laboratory the day of RSSCT startup.

## 5.2 Results

PFAS breakthrough curves were plotted and grouped based on chain length. Breakthrough fraction plots are presented in **Figure 5-1, Figure 5-2, and Figure 5-3**. PFAS plots were divided into four groups based on chain length:

- Group 1: PFBA, PFBS, PFPeA
- Group 2: GenX, PFHxA, PFHxS, PFHpA, 6:2 FTS
- Group 3: PFOA, PFOS

Each plot has two horizontal axes: bed volumes and operating time. Operating time assumed that each contactor would be operated at the design EBCT.

### Table 5-2: Source Water Quality Parameters

| Parameter | Unit | Newberry County WTP Filter Effluent (PFAS Spiked) |
|---|---|---|
| **Bulk Water Quality Parameters** | | |
| **Temperature** | deg C | 23.2 |
| **pH** | - | 7.4 |
| **Chlorine Res.** | mg/L | <0.05 |
| **TOC** | mg/L | 2.9 |
| **Nitrate as N** | mg/L | 0.1 |
| **Sulfate** | mg/L | 2.9 |
| **PFAS** | | |
| **PFBA** | ng/L | 24.5 |
| **PFBS** | ng/L | 25.0 |
| **PFPeA** | ng/L | 25.0 |
| **PFHxA** | ng/L | 26.5 |
| **11Cl-PF3OUdS** | ng/L | 0.0 |
| **9Cl-PF3ONS** | ng/L | 0.0 |
| **ADONA** | ng/L | 0.0 |
| **HFPO-DA** | ng/L | 26.0 |
| **8:2FTS** | ng/L | 0.0 |
| **PFDA** | ng/L | 2.4 |
| **PFDoA** | ng/L | 0.0 |
| **PFEESA** | ng/L | 0.0 |
| **PFHpS** | ng/L | 0.0 |
| **4:2FTS** | ng/L | 0.0 |
| **PFHxS** | ng/L | 26.5 |
| **PFMPA** | ng/L | 0.0 |
| **PFMBA** | ng/L | 0.0 |
| **6:2FTS** | ng/L | 23.0 |
| **PFPeS** | ng/L | 0.0 |
| **PFUnA** | ng/L | 0.0 |
| **NFDHA** | ng/L | 0.0 |
| **PFHpA** | ng/L | 23.0 |
| **PFOA** | ng/L | 9.8 |
| **PFOS** | ng/L | 28.0 |
| **PFNA** | ng/L | 2.6 |

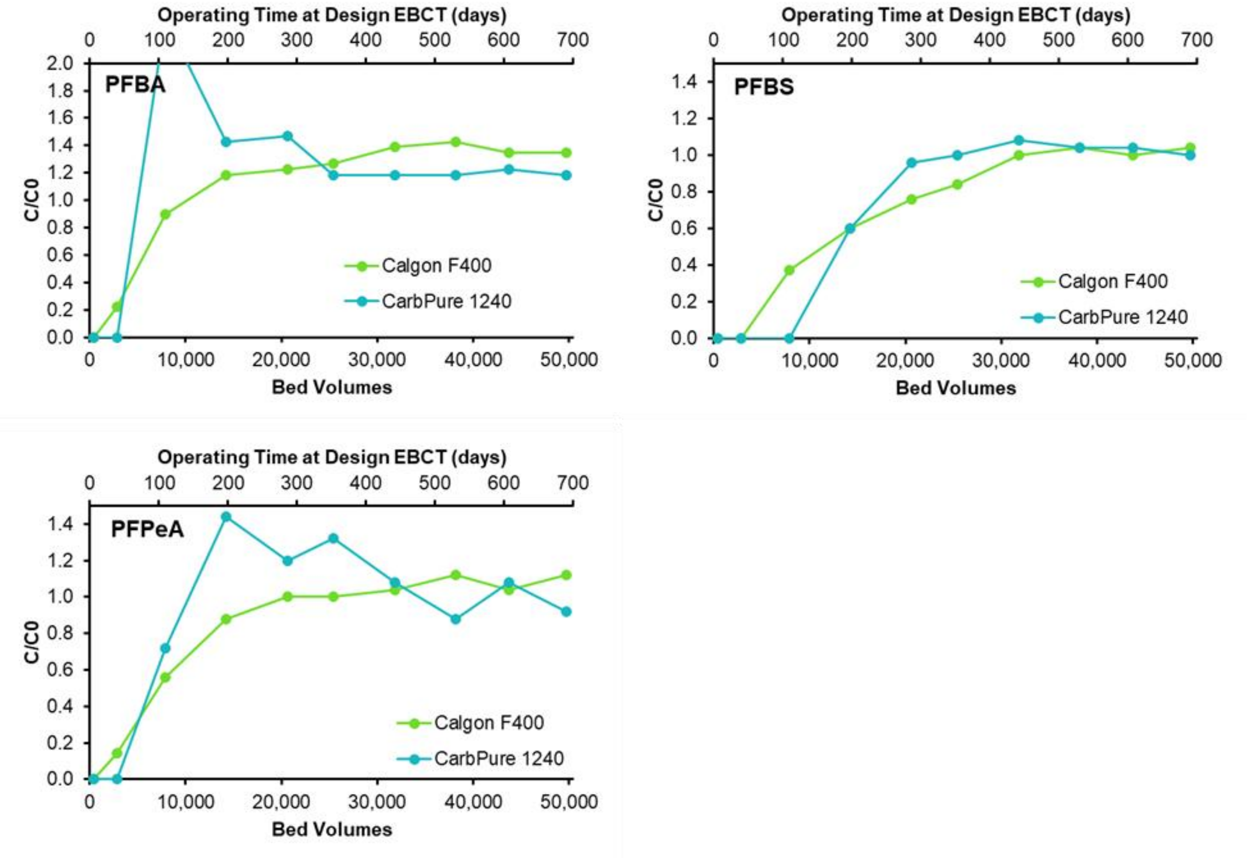


Figure 5-1: Breakthrough Fraction for PFBA, PFBS, and PFPeA

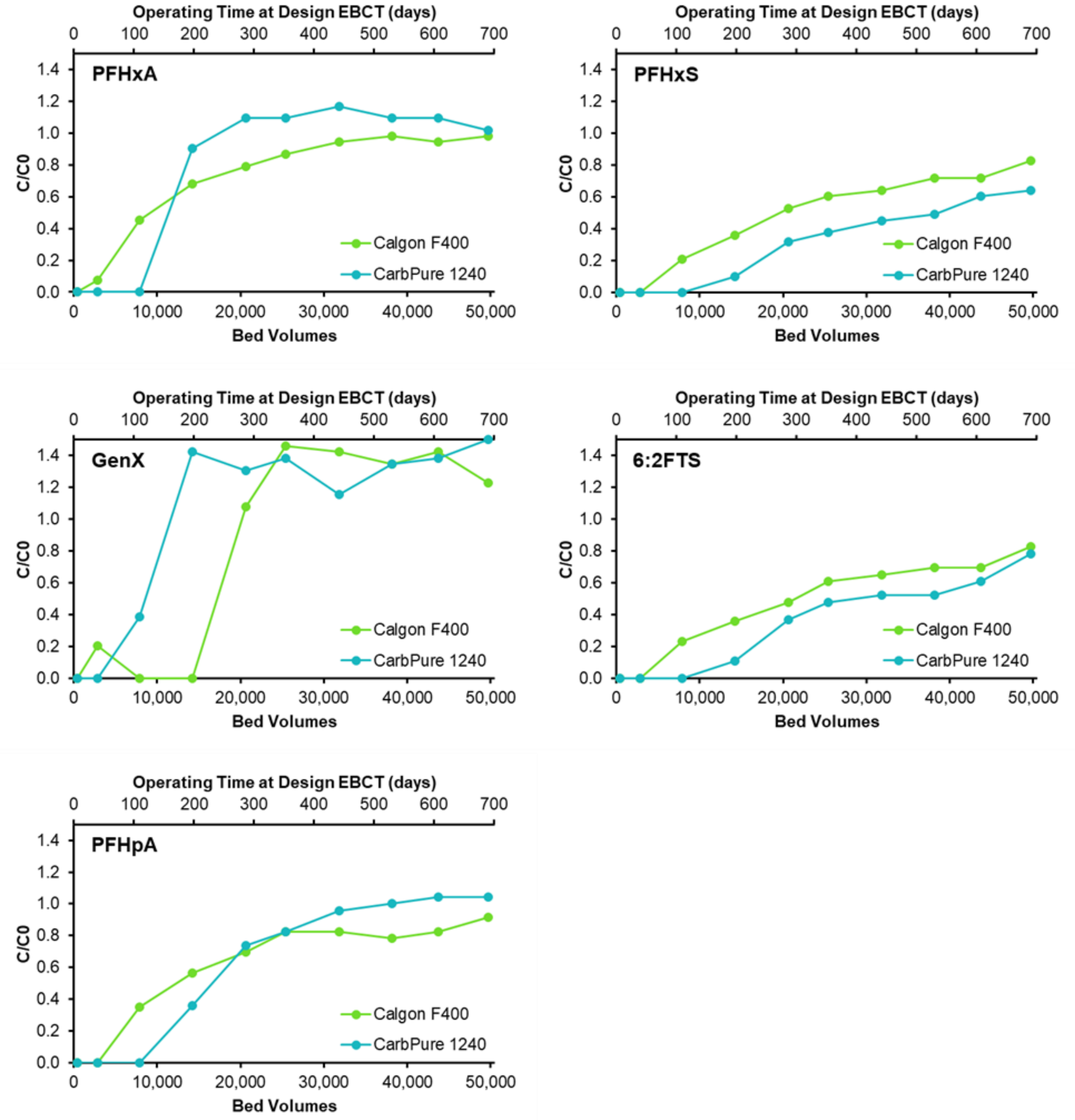
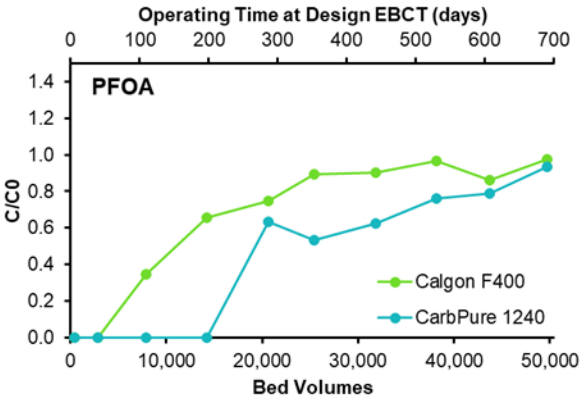


Figure 5-2: Breakthrough Fraction for GenX, PFHxA, PFHxS, PFHpA, 6:2 FTS



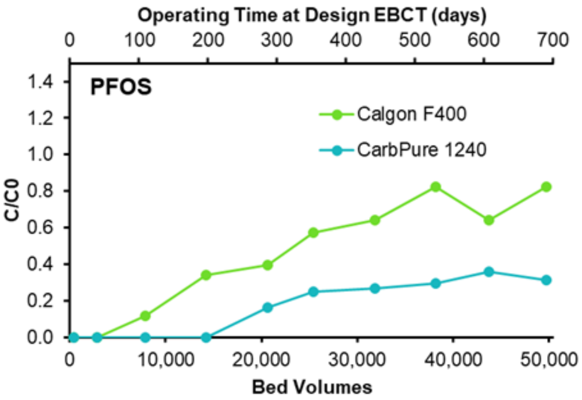


**Figure 5-3:** Breakthrough Fraction for PFOA and PFOS

To compare the efficacy of different media, determination of an acceptable changeout threshold is needed. In practice, this will be some fraction of the PFAS MCL (e.g., 50%, 75%, or 100%). Because regulated PFAS were spiked to the source drums, the comparison should not be performed on the basis of raw concentration units. Therefore, historical PFAS occurrence data was used to estimate a breakthrough fraction (C/C0) that would be used for changeout and then interpolate RSSCT data to estimate the number of bed volumes to reach that breakthrough fraction.

At the time of the GAC evaluation, Newberry County had limited PFAS occurrence data, so UCMR 5 concentrations from neighboring utilities were utilized. The average, 95th percentile, and maximum concentrations of these data at that time are summarized in **Table 5-3**. Changeout frequency in this memorandum was estimated based on both 95th percentile and average PFAS concentrations. As seen in **Table 2-1**, more recent sampling at Newberry County indicates average and 95th percentile values that are similar to the data in **Table 5-3**.

**Table 5-3: Summary of UCMR 5 Detects from Neighboring Utilities (source: UCMR5 Data as of 09/24/2024)**

| | Average | 95th Percentile | Maximum |
|---|---|---|---|
| **PFOA** | 4.8 | 5.9 | 6.3 |
| **PFOS** | 8.0 | 11.2 | 11.3 |
| **HFPO-DA (GenX)** | 7.4 | 9.3 | 10.2 |
| **Hazard Index** | 0.7 | 0.9 | 1.0 |

Because a GAC treatment system is being designed with lead-lag vessels, changeout threshold in the lead vessel was assumed to be equal to the MCL for PFOA, PFOS, and HFPO-DA (GenX). This allows full utilization of the media in the lead bed because the lag is available to prevent PFAS breakthrough into the finished water. It is important to note that RSSCT results and estimates of time to breakthrough are representative of the initial fill of the lead vessels only. When the lag vessel becomes the lead vessel, time to breakthrough will be shorter due to the prior loading of the media before it is placed in the lead position. Another important caveat is that days to changeout were estimated based on design flow and EBCT. At lower flows representative of typical operation, media changeout would be expected less frequently.

The breakthrough thresholds were compared to the RSSCT breakthrough curves presented previously to estimate bed volumes and operating time to changeout for each material. The results of that analysis assuming average flow are presented in **Table 5-4**. For Calgon F400, PFOA or PFOS were estimated to drive changeout at around 220 days of operation assuming 95th percentile influent concentrations, and approximately 325 days assuming average influent concentrations. For CarbPure 1240, PFOA and PFOS were estimated to drive changeout at around 500 days assuming 95th percentile influent concentrations, and 630 days assuming average influent concentrations. These represent significant improvements over the Calgon product and indicate that NCWSA can likely expect more than a year of GAC capacity prior to replacement of lead vessels. Although USEPA has currently indicated the desire to remove the GenX regulation, it must be noted that breakthrough of GenX greatly impacted lifetime of GAC media, particularly impacting the CarbPure media. Because of observed rapid breakthrough and even desorption behavior, consideration of GenX as a breakthrough trigger would significantly shorten the expected time to replacement, particularly impacting performance of the CarbPure product.

**Table 5-4: Estimated Bed Volumes and Time to Changeout (at Average Flow) for Each Sorbent**

| Estimated BV and Days to Changeout | | | | | | |
|---|---|---|---|---|---|---|
| | PFOA | | PFOS | | GenX | |
| 95th Percentile Concentration - Neighboring Utilities | | | | | | |
| **Influent Conc. (ng/L)** | 5.9 | | 11.2 | | 11.2 | |
| **Threshold** | 4 ng/L | | 4 ng/L | | 10 ng/L | |
| | 68% | | 36% | | 89% | |
| **Media** | BV | Days | BV | Days | BV | Days |
| **Calgon F400** | 15,700 | 218 | 16,400 | 228 | 19,500 | 271 |
| **CarbPure 1240** | 35,600 | 494 | 43,700 | 607 | 11,000 | 153 |
| Average Concentration - Neighboring Utilities | | | | | | |
| **Influent Conc. (ng/L)** | 4.8 | | 8.0 | | 7.4 | |
| **Threshold** | 4 ng/L | | 4 ng/L | | 10 ng/L | |
| | 83% | | 50% | | 135% | |
| **Media** | BV | Days | BV | Days | BV (Note 1) | Days (Note 1) |
| **Calgon F400** | 23,500 | 326 | 23,500 | 326 | 24,100 | 335 |
| **CarbPure 1240** | 45,500 | 632 | >49,600 | >689 | 13,800 | 192 |
| **Notes:**<br>**1. CarbPure 1240 GenX interpolated omitting ND at 25,400 BV.** | | | | | | |

# 6. Additional Impacts of PAC and GAC

## 6.1 Residuals Impacts

One of the biggest factors in considering PAC addition for PFAS removal is the additional amount of treatment residuals that will be generated from the addition of PAC. For each pound of PAC added, an additional pound of residuals is created that must be processed and disposed.

In order to estimate historical residuals production that could be compared to the additional solids from PAC addition for PFAS removal and also be applied to future flows, a modified version of a published empirical equation (AWWA Research Foundation, 1987) was used. This formula incorporates daily raw water flow and turbidity values along with coagulant dosages and solids from additional chemicals. This formula was slightly modified because the published equation is based on alum addition, while the NCWSA plant utilizes polyaluminum chloride. The modified formula is as follows:

$$S = 8.34\,(Q)\,(0.51\,Al + bT + A) \qquad \textbf{Equation 1}$$

Where:

S = residuals production (lb/day)
Q = plant flow (MGD)
Al = coagulant dose (mg/L as product)
b = factor to equate turbidity to suspended solids
T = raw water turbidity (NTU)
A = net solids from additional chemicals added such as polymer, PAC, or lime (mg/L)

The factor of 0.51 used in the formula differs from the factor of 0.44 that is typically used when alum is the coagulant. This is based on the fact that alum ($Al_2(SO_4)_3$*14.3H2O) is approximately 9% $Al^{3+}$, while the polyaluminum chloride being used at the plant (DelPAC 2950) is estimated to be approximately 10.5% $Al^{3+}$ (10.5/9 * 0.44 = 0.51).

The “b” value represents the correlation between raw water turbidity and suspended solids. For surface waters, the “b” value typically varies between 0.5 and 2.0. For this evaluation, “b” was assumed to be equal to 1.0. Using this factor, the solids production from September 2022 through August 2024 (2 years of solids) was calculated to be approximately 471 wet tons, which is within 10 percent of the 508 wet tons that were cleaned out in August 2022 after two years in service.

Using Equation 1, the daily residuals production from August 2019 through June 2024 was calculated and was normalized to the daily flow. The average residuals production for this time period was approximately 206 lb/day using an average raw water flow during that time period of 0.98 mgd, which equates to a normalized average day residuals production of 212 lb/MG.

Based on the PAC bench-scale testing discussed previously, the estimated design dosages for PFAS removal ranged from approximately 11 mg/L to 45 mg/L, depending on the finished water PFAS goal and whether a PAC contactor is constructed. For purposes of evaluating the additional solids generated from PFAS treatment, a PAC design dose of 13 mg/L was used which corresponds to a PFAS goal of 3 ng/L without the construction of a PAC contactor on site. At an average plant flow of 0.98 mgd, the additional PAC dosage of 13 mg/L adds approximately 106 lb/day of solids, which equates to 108 lb/MG. Note that the plant already feeds PAC periodically, so some PAC solids are already generated at the plant; it was assumed that the additional PAC dosage needed for PFAS was above what was already being fed. This helps to account for the fact that higher PAC dosages than those required for PFAS removal may be required at times to address taste and odor issues. The additional PAC required for PFAS increases the solids production at the WTP by approximately 50% over current operation, with an estimated total solids production if PAC is added for PFAS reduction of approximately 312 lb/day at current flows, or normalized average day residuals production of 320 lb/MG. A summary of calculated overall solids production at varying flow rates is contained in **Table 6-1**.

**Table 6-1: Solids Production at Varying Plant Flow Rates**

| Design Plant Flow, mgd | Average Plant Flow, mgd | Average Solids Generation, lb/MG | Average Solids Generation, lb/day | Annual Solids Production, dry tons/yr | Wet Tons to Dispose (Note 1), wet tons/yr |
|---|---|---|---|---|---|
| **---** | 0.98(Note 2) | 212(Note 3) | 207 | 38 | 252 |
| **---** | 0.98(Note 2) | 320(Note 4) | 313 | 57 | 381 |
| **2** | 1.42(Note 5) | 320(Note 4) | 454 | 83 | 552 |
| **3** | 2.13(Note 5) | 320(Note 4) | 681 | 124 | 828 |
| **6** | 4.25(Note 5) | 320(Note 4) | 1361 | 248 | 1656 |

**Notes:**

1. **Based on dewatering the solids in the residuals lagoons to 15% solids prior to disposal.**
2. **Current average flow.**
3. **Based on current chemical dosing rates.**
4. **Based on current chemical dosing rates plus the addition of 13 mg/L PAC.**
5. **Estimated average flow at design flow based on a historical (September 2019 to June 2024) maximum day to average day ratio of 1.41.**

## 6.2 Other Impacts

From a water quality standpoint, other impacts of PAC and GAC on the treatment process at NCWSA should be positive including providing a more robust barrier for taste and odor removal, improving TOC removal with the potential for reduced DBP formation, greater stability in the disinfectant residual in the distribution system, and the potential for reduced disinfectant dosages.

Operationally, both PAC and GAC will have some impact on the plant. PAC can be difficult to feed and will require maintenance to keep the system running. Disposal of PAC solids and the potential for classification of the solids as a hazardous waste is a long-term consideration for the PAC option. GAC will impact operations because of the need for pressure vessel downtime, significant backwashes, and increased truck traffic when media is replaced. Much of the work of removing and replacing media will likely be conducted by the media supplier and should have limited impact on staff.

Treatment of PFAS at water treatment facilities may produce PFAS-laden adsorbent media that will need to be managed, whether it's through landfill, incineration, reactivation, or another residuals management strategy. In January 2022, the EPA submitted a proposed rule to designate PFOA and PFOS as hazardous substances under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The proposed rule was then released for public comment and the period closed August 11th, 2023, with a final rule released in April 2024. The listing of PFOA and PFOS as hazardous substances under CERCLA may increase the potential costs associated with the historical management of residuals.

With this finalized rule, entities will be required to report releases of PFOA and PFOS that meet or exceed the reportable quantity of one pound in a 24-hour period. Based on current levels in the raw water (approximately 13 ng/L of PFOA and PFOS combined), NCWSA would remove 0.0001 lb/day/MGD, much lower than one pound per 24-hours at flow rates up to 6 mgd. In documentation associated with the final rule, the EPA concluded that the designation of PFOA and PFOS as CERCLA hazardous substances does not require disposal or treatment of water treatment residuals as hazardous wastes.

In parallel to CERCLA hazardous substance designation for PFAS, the EPA proposed listing several PFAS as hazardous constituents under the Resource Conservation and Recovery Act (RCRA) which may dictate residuals handling strategies moving forward.

# 7. Conceptual Design

Conceptual designs were developed for powdered activated carbon and granular activated carbon and are summarized below.

## 7.1 Powdered Activated Carbon (PAC)

### 7.1.1 PAC Feed

Based on the bench-scale testing discussed in Chapter 4, PAC design dosages for PFAS removal were determined for PAC contact time that would occur in the raw water pipeline on site and for a PAC contactor with 30 minutes of contact time, respectively. These data indicate that the reduction in dose from use of a contactor would be relatively small when compared to PAC application to the pipeline, particularly for the finished water goals of 3 ng/L (11 mg/L PAC dose with a contactor versus 13 mg/L PAC dose without a contactor) and 2 ng/L (20 mg/L PAC dose with a contactor and 25 mg/L PAC dose without a contactor), indicating that the benefit of a contactor would be limited for PFAS removal. Therefore, the design concept for PAC is developed based on addition of PAC to the onsite pipeline.

An average design dose of 13 mg/L was chosen for the conceptual design based on test results shown in **Table 4-5**. This dose is based on achieving a finished water PFOA/PFOS goal of 3 ng/L without the construction of a PAC contactor onsite. Contact with PAC in the raw water will be achieved in the raw water pipeline and PAC will be fed into the pipeline just as the pipeline enters the WTP site. Contact time in the existing 16” pipeline on the plant site at 3 mgd is approximately 4.5 minutes. At flows above 3 mgd up to the ultimate plant capacity of 6 mgd, detention time will be reduced to between 2.25 and 4.5 minutes; at those flow rates, if it is determined that treatment can be accomplished with shorter PAC contact times than 4.5 minutes, then modifications to the raw water piping may not be required; alternately, if a detention time of at least 4.5 minutes is needed, a second parallel pipeline could be installed or a PAC contactor with longer contact time could be installed.

PAC feeder capacity will be designed to feed an average dose of 13 mg/L but also have the capability to feed more than 13 mg/L in cases where MIB/geosmin are elevated. Based on 95th percentile MIB/geosmin values seen at other utilities on Lake Murray and the results of the bench-scale testing, a maximum dose of up to 45 mg/L may be required, but only on a seasonal basis (see **Table 4-6**).

Regardless of the chosen technology (PAC or GAC), it may be beneficial to repair the existing 50-pound bag feed system such that it is operable. If PAC is chosen as the long-term technology, it could be available in the interim, largely for taste and odor control, while the onsite PAC system is being constructed. If GAC is chosen as the long-term technology, the existing PAC feed system could be available in the interim while the GAC system is being constructed, and also could be beneficial long-term if MIB levels spike up to historical maximum levels seen at the City of Columbia's Lake Murray WTP (500 ng/L MIB), as a combination of PAC and GAC would provide some additional capability to address extreme high levels of MIB. Even with both PAC and GAC, reducing raw water MIB concentrations of 500 ng/L down to 5-10 ng/L will be difficult.

A summary of PAC feed requirements at current and future plant flow rates is contained in **Table 7-1**.

**Table 7-1: PAC Feed Requirements (lb/day)**

| Flow, mgd | Dose | |
|---|---|---|
| | 13 mg/L (Average) | 45 mg/L (Maximum) |
| **0.4 (Current min)** | 43 | 150 |
| **0.98 (Current avg)** | 106 | 368 |
| **2 (Current max)** | 217 | 751 |
| **3** | 325 | 1,126 |
| **4** | 434 | 1,501 |
| **5** | 542 | 1,877 |
| **6** | 651 | 2,252 |

### 7.1.2 PAC Storage

Several PAC storage options are available, including storage as a slurry in a concrete tank, dry silo storage, and bulk bag storage. Storage of at least 30 days (typically calculated at average dose and average flow) is required by SCDES regulations; ability to store a full truckload of PAC is also a consideration. **Table 7-2** contains the PAC storage requirements for NCWSA at current and future flow rates. The storage in pounds is equivalent to the storage needed in gallons in a slurry tank based on a 1 lb/gal slurry. The storage in cubic feet (cu ft) would determine the storage needed in a PAC silo and is based on a PAC density of 15 lb/cu ft, which is the density of the best performing PAC for PFAS removal (Ingevity AquaNuchar). The other PAC product that performed well was the Carbpure TRA product and it has a density of 20 lb/cu ft, which would require a smaller silo than the Ingevity product. The number of bulk bags is based on the capacity of a bulk bag with the Ingevity AquaNuchar product, which is 750 pounds. Most bulk bags are in the 750-900 pound range.

A full truckload of PAC is typically 30,000-40,000 pounds. For concrete tank systems, the tank volume is often around 60,000 gallons, which equates to a storage of 60,000 pounds of PAC at a 1 lb/gal slurry. This allows the tank to be somewhere between 33 and 50 percent full and receive a full truckload of PAC. For a silo system, a silo of approximately 50,000 pounds (approximately 3,500 cu ft at 15 lb/cu ft) would allow the silo to be between 20 and 40 percent full and receive a full truckload.

In a previous desktop analysis conducted by Hargette LLC, conceptual layouts and opinions of probable construction cost were developed for each of these storage alternatives including partial and full truckload concrete tank and silo options and a bulk bag option. The costs of a concrete tank versus silo system were relatively similar, with the cost of a bulk bag system the lowest if only one bulk bag system (no redundancy) is installed. The cost of a bulk bag system with redundancy was similar to the concrete tank and silo costs sized for a partial truckload. The costs of a system (concrete tank or silo) sized for partial truckloads versus full truckloads were within 20% of each other and partial truckloads have higher per unit PAC product costs.

For planning purposes, the ability to receive a full truckload is desired. For comparison with GAC, a silo system sized for a full truckload or redundant bulk bag system [two bulk bag systems (one duty/one standby) in a building] were assumed. These assumptions could be revisited during detailed design if PAC is chosen as the preferred alternative. Note that even if the silo is sized to receive a full truckload, the plant may not want to typically receive a full truckload due to the long storage times in the silo during normal operation.

**Table 7-2: PAC Storage Requirements**

| Average Flow/Plant Capacity, mgd | Storage (lbs)(Note 1) | Storage (cu ft)(Notes 1,2) | Storage (Number of bulk bags)(Notes 1,3) |
|---|---|---|---|
| **0.98(Note 4)/2** | 3,200 | 210 | 5 |
| **1.42(Note 5)/2** | 4,600 | 310 | 7 |
| **2.13(Note 5)/3** | 6,900 | 460 | 10 |
| **2.84(Note 5)/4** | 9,200 | 620 | 13 |
| **3.55(Note 5)/5** | 11,500 | 770 | 16 |
| **4.25(Note 5)/6** | 13,900 | 920 | 19 |

**Notes:**

1. **Storage calculations are based on 30 days storage at average flow and average dose (13 mg/L) conditions.**
2. **Based on 15 lb/cu ft density for PAC (Ingevity AquaNuchar).**
3. **Based on 750 lb bags (Ingevity AquaNuchar).**
4. **Current average flow.**
5. **Estimated average flow at design flow based on a historical (September 2019 to June 2024) maximum day to average day ratio of 1.41.**

### 7.1.3 Residuals Improvements

An increase in size of the residuals lagoons is needed to handle the additional solids that will be generated from PAC addition for PFAS removal. To determine the area needed, a published empirical formula of 8 lb/sf was used (Kawamura 2000), where the pounds of solids are based on a dry weight basis. This formula was compared to actual historical production at the NCWSA Lake Murray WTP. Over the most recent 2-year period from September 2022 to August 2024, the plant removed approximately 508 wet tons of solids from the two existing lagoons. NCWSA staff indicated that the lagoons were essentially full when they were cleaned out (at 5’ water depth, one lagoon had 5’ of solids in it and one lagoon had 4’ of solids in it). At the current average solids production of 207 lb/day (see Table 6-1) the calculated area needed per year is 9,460 sf or 18,920 sf for two years of storage. Each existing lagoon has a surface area of approximately 9,200 sf, with 18,400 sf for the two lagoons. This matches well with the calculated area using the formula.

The additional lagoon area needed to store solids assuming the addition of PAC for PFAS removal (13 mg/L) was calculated for current and future plant capacities and is contained in **Table 7-3**. Solids depth of 5 ft in the lagoons was assumed to match the existing lagoons. A total lagoon area of two years of solids storage was assumed for all conditions. This allows for the lagoons to be cleaned out every two years as is currently done or for one lagoon to be taken offline and cleaned out each year while the second lagoon is in service.

**Table 7-3: Lagoon Area Needed at Varying Plant Flow Rates**

| Average Flow/Plant Capacity, mgd | Total Area Needed, sf (Note 1) | Existing Lagoon Area, sf | Additional Lagoon Area Needed, sf | Additional Number of Lagoons | Area Per New Lagoon at Mid-Depth, sf |
|---|---|---|---|---|---|
| **0.98(Note 2)/2** | 28,600 | 18,400 | 10,200 | 1 | 10,200 |
| **1.42(Note 3)/2** | 41,400 | 18,400 | 23,000 | 1 | 23,000 |
| **2.13(Note 3)/3** | 62,100 | 18,400 | 43,700 | 2 | 21,900 |
| **2.84(Note 3)/4** | 82,800 | 18,400 | 64,400 | 3 | 21,500 |
| **3.55(Note 3)/5** | 103,500 | 18,400 | 85,100 | 4 | 21,300 |
| **4.25(Note 3)/6** | 124,200 | 18,400 | 105,800 | 4 | 26,500 |

**Notes:**

1. **Based on current chemical dosing rates plus the addition of 13 mg/L PAC for PFAS removal.**
2. **Current average flow rate.**
3. **Estimated average flow at design flow based on a historical (September 2019 to June 2024) maximum day to average day ratio of 1.41.**

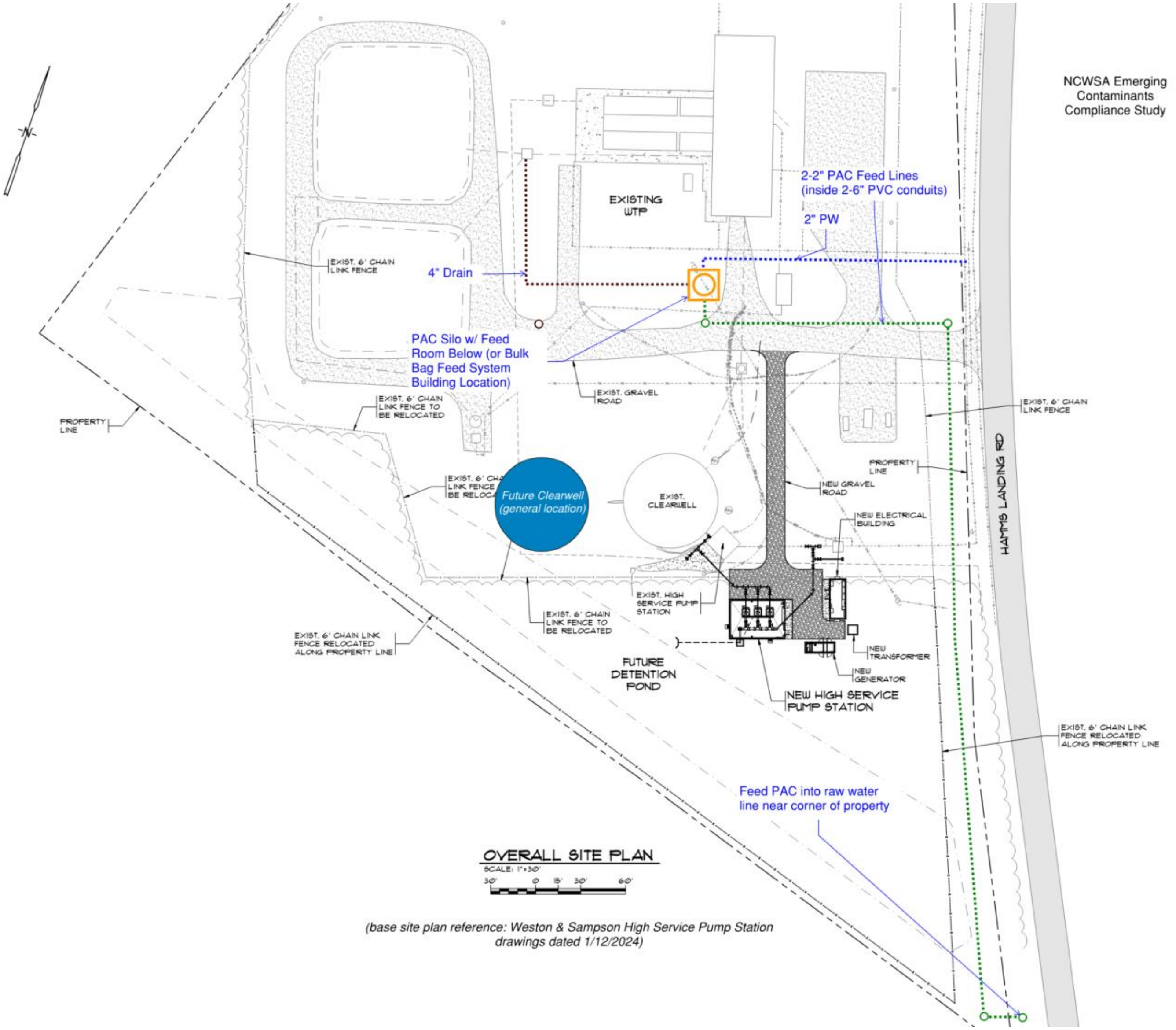
In order to best position NCWSA for the ultimate plant flow rate of 6 mgd, it is recommended that each additional lagoon has an area of approximately 26,500 sf at mid-depth and approximately 30,600 sf at the top of slope. An initial addition of one lagoon would provide lagoon capacity of slightly greater than 2 mgd, while the addition of two lagoons of that size would provide greater than 3 mgd of lagoon capacity. Additional lagoons can be added as needed to get to the ultimate plant capacity of 6 mgd (four total new lagoons needed). For each set of two additional lagoons, the area needed is approximately 2.0 acres when accounting for roadways around the lagoons. The available land area for lagoons onsite is estimated to be approximately 1.5 acres, meaning that the addition of lagoons for capacities of approximately 3 mgd and beyond would require the purchase of additional land. Lagoons are assumed to be clay-lined with sidewater depth, piped withdrawals, and overflows like the existing lagoons. A new decant pumping station will be required to pump the overflow from the lagoons to the wastewater treatment plant.

### 7.1.4 Design Criteria

A summary of the design criteria for the PAC feed alternative is contained in **Table 7-4**. A preliminary site plan for the PAC alternatives is contained in **Figure 7-1**.

**Table 7-4: PAC Alternative Design Criteria**

| **PAC Design Criteria** | |
|---|---|
| **Design Conditions** | |
| **Initial Conditions:** | Min Flow/Avg Dose: 0.4 MGD, 13 mg/L<br>Avg Flow/Avg Dose: 0.98 MGD, 13 mg/L<br>Max Flow/Max Dose: 2 MGD, 45 mg/L |
| **Ultimate Conditions:** | Avg Flow/Avg Dose: 4.25 MGD, 13 mg/L<br>Max Flow/Max Dose: 6 MGD, 45 mg/L |
| **PAC Feed** | |
| **Initial Capacity, lb/day:** | Min Flow/Avg Dose: 43<br>Avg Flow/Avg Dose: 106<br>Max Flow/Max Dose: 751 |
| **Ultimate Capacity, lb/day:** | Avg Flow/Avg Dose: 461<br>Max Flow/Max Dose: 2,252 |
| **Number of Feeders (silo option):**<br>**Number of Systems (bulk bag option):** | 2 min – 1 duty/1 standby<br>2 – 1 duty/1 standby |
| **PAC Storage** | |
| **PAC Silo Option:** | |
| **Number of silos:** | 1 |
| **Storage required, cu ft:** | Initial: 310 cu ft; Ultimate: 920 cu ft |
| **Storage provided, cu ft:** | 3,500 cu ft (to receive full truckload) |
| **Storage provided, days:** | Initial: 340 days; Ultimate: 115 days |
| **Diameter, ft:** | 14 |
| **Height, ft:** | 50 |
| **Bulk Bag Option:** | |
| **Bag storage required, number of bags:** | Initial: 7; Ultimate: 19 |
| **Storage provided (20 bags), days:** | Initial: 97 days; Ultimate: 32 days |
| **Residuals Lagoons** | |
| **Additional lagoons required:** | Initial: 1<br>3 mgd capacity: 2<br>Ultimate: 4 |
| **Surface area per lagoon, sf (ac):** | 26,500 sf (0.6 ac) at mid-depth (30,600 sf at top of slope) |
| **Side water depth, ft:** | 5 |
| **Freeboard, ft:** | 2 |
| **Sidewall slope:** | 2:1 |
| **Liner:** | Clay |
| **Decant Pumps:** | |
| **Number:** | 2 |
| **Capacity, gpm:** | TBD |



*(base site plan reference: Weston & Sampson High Service Pump Station drawings dated 1/12/2024)*

**Figure 7-1: Conceptual Site Plan for PAC PFAS Treatment System**

## 7.2 Granular Activated Carbon

### 7.2.1 Design Criteria

A GAC PFAS treatment system will be designed to initially treat up to a maximum daily flow of 2.0 mgd. This will be accomplished utilizing two (2) lead-lag pairs of GAC Pressure vessels. A lead/lag configuration is recommended for improved ease of operations and to provide the NCWSA with reduced risks of non-compliance with the PFAS MCLs. Each lead-lag pair will be designed to treat up to 1.0 mgd. Each pressure vessel will provide an EBCT of 12.8 minutes for a total EBCT through each lead-lag pair of 25.6 minutes. At ultimate plant capacity of 6.0 mgd, each lead-lag pair would treat up to 1.2 mgd, with an EBCT of 10.7 minutes for a total EBCT through each lead-lag pair of 21.3 minutes. A summary of the number of vessels and footprint required at current and future flow rates is contained in **Table 7-5**. A general process flow diagram for GAC treatment is presented in **Figure 7-2** and a conceptual site plan is contained in **Figure 7-3**.

Information from a GAC vendor, Calgon Carbon Corporation, was used to assess equipment sizing. Based on the information supplied, the design basis uses two pairs of Model 12-40 pressure vessels with the media selection of Calgon F 400. This GAC media provided the second longest time to breakthrough for PFOA, PFOS and the longest time to breakthrough for GenX (breakthrough of all of these compounds was approximately 325-335 days based on average influent conditions). If the GenX regulation is rescinded and reconsidered as anticipated, the Carbpure 1240 product may provide much longer times to breakthrough based on the RSSCT testing that was done as part of this report, with changeout times of 630 days based on average influent PFOA and PFOS concentrations. To further identify the best GAC product over varying water quality conditions, a product selection pilot is recommended to be conducted in parallel with design if the GAC alternative is selected. Further clarity on modifications to the PFAS rule should also be available during the product selection pilot and GAC design.

The preliminary sizing of the pressure vessels will be 12-ft diameter and approximately 27-ft tall. Each pressure vessel will contain 40,000 lbs of GAC media. The design hydraulic loading rate for each lead-lag pair will be 6.1 gpm/ft$^2$ at 1.0 mgd. The target HLR range was designed to balance head loss accumulation at higher flow rates with the footprint of the pressure vessels.

A new filtered water transfer pump station will be required to transfer filtered water to the GAC pressure vessels. The transfer pump station will include space for four vertical turbine pumps in steel cans. The initial design will include one duty and one standby pump, and the pumps will be located in a pre-engineered metal building. Each pump will be rated for 1,389 gpm (2 mgd) @ 55 ft of TDH. The pumps will be powered using variable frequency drives. At ultimate capacity, three duty pumps and one standby pump will be installed. After the GAC pressure vessels, post-treatment chemicals will be added (relocated from their current feed location just downstream of the filters) and water will flow to the onsite clearwell and finished water pumping station.

**Table 7-5: GAC Pressure Vessel Design**

| | 2 Train GAC | 3 Train GAC | 5 Train GAC |
|---|---|---|---|
| **Design Flow Rate (mgd)** | 2 | 4 | 6 |
| **Vessel Diameter (ft)** | 12 | 12 | 12 |
| **Number of Trains** | 2 | 3 | 5 |
| **Media per Vessel (lb GAC)** | 40,000 | 40,000 | 40,000 |
| **Treatment Footprint required (square ft)** | 50' x 50' | 50' x 68' | 50' x 105' |
| **Pump Station Footprint required (square ft)** | 37' x 27' | 37' x 27' | 37' x 27' |

### 7.2.2 Backwashing

Backwashing uses upward flow through the media bed to fluidize the media to reduce accumulated headloss when put back in service. Backwashing occurs very infrequently, at a projected one event per month per pressure vessel. This low frequency is due to the low particulate and low turbidity in the filtered water. It is not uncommon for this backwash frequency to vary depending on the amount of biological activity occurring in the pressure vessels. GAC pressure vessels form an ideal environment for biological growth which may remove biodegradable organics and provide water quality benefits related to enhancing biological stability in the distribution system, reducing chlorine demand, and minimizing aesthetic concerns such as taste and odor. However, biofilm development must be managed as excessive biofilms create additional headloss accumulation resulting in shorter contactor runtimes and increased backwashing frequency. Although sodium hypochlorite can be added prior to the GAC contactors, any remaining chlorine residual will be rapidly consumed which may allow for potential biological growth. It is recommended that free chorine concentrations in the GAC influent be maintained at or below 0.5 mg/L or less as high levels of chlorine in the GAC pressure vessels can accelerate the breakdown of the GAC media. Headloss will also increase with the development of media fines as the GAC media ages and breaks down. Backwash waste should be directed to one of the onsite lagoons for disposal. Fine GAC material will be discharged during the backwash process which may contain PFAS adsorbed onto the media. A standard backwash waste stream for a contactor in service will contain minimal solids as this backwash is not meant to remove solids, and only to “fluff” the bed from downward compaction during service cycles. In contrast, virgin media backwashing and backwashes performed after media regeneration can contain between 1-3% solids; however, it will not contain significant PFAS.

### 7.2.3 Backwash Supply

Water required for backwashing will be supplied from the Macedonia Tank. A flow control/pressure reducing valve and flow meter will be supplied to control the backwash rate for the GAC pressure vessels. Having this large volume of water available will allow for extended backwash requirements when loading virgin GAC during commissioning and during media replacement events.

### 7.2.4 GAC Changeout

Calgon has a Custom Municipal Reactivation service where they will reactivate a customer's spent carbon and return it for continued use. When a customer sets a recurring scheduled time for GAC reactivation Calgon can remove and replace the carbon in two vessels in one day. In GAC changeout events, GAC can be loaded directly from the GAC truck and is typically accomplished by the media supplier. Utilizing reactivated carbon is generally less expensive than purchasing virgin carbon for replacement. If a customer is not on a recurring replacement schedule it will typically take 3 to 4 weeks to remove, reactivate and replace spent carbon.

A water line with quick-connect fitting is necessary to provide water to fluidize the fresh GAC in the tanker truck and/or for eduction of GAC into the treatment units. Tanker trucks transfer the fluidized GAC to the fill line by applying pressure (by water and compressed air) to the tanker. GAC slurry is conveyed to the pressure vessels via piping in the GAC treatment train. For removing GAC from a treatment unit, GAC is transferred as a slurry via eductor from the pressure vessel to a bulk tanker truck. After delivery of spent GAC to the delivery truck, the transfer water can be drained out of the truck through the waste line and into the backwash waste line. Before a GAC pressure vessel is returned to service after a changeout, it is recommended practice to filter-to-waste for a period of time to stabilize effluent water quality and remove media fines from the unit during media placement or reactivation. During the short time for changeout of media in a vessel, flow will only be going through one train which may cause the plant to reduce flow through the vessels to maintain the design empty bed contact time or, if flow is not reduced, shorten empty bed contact time below design levels.

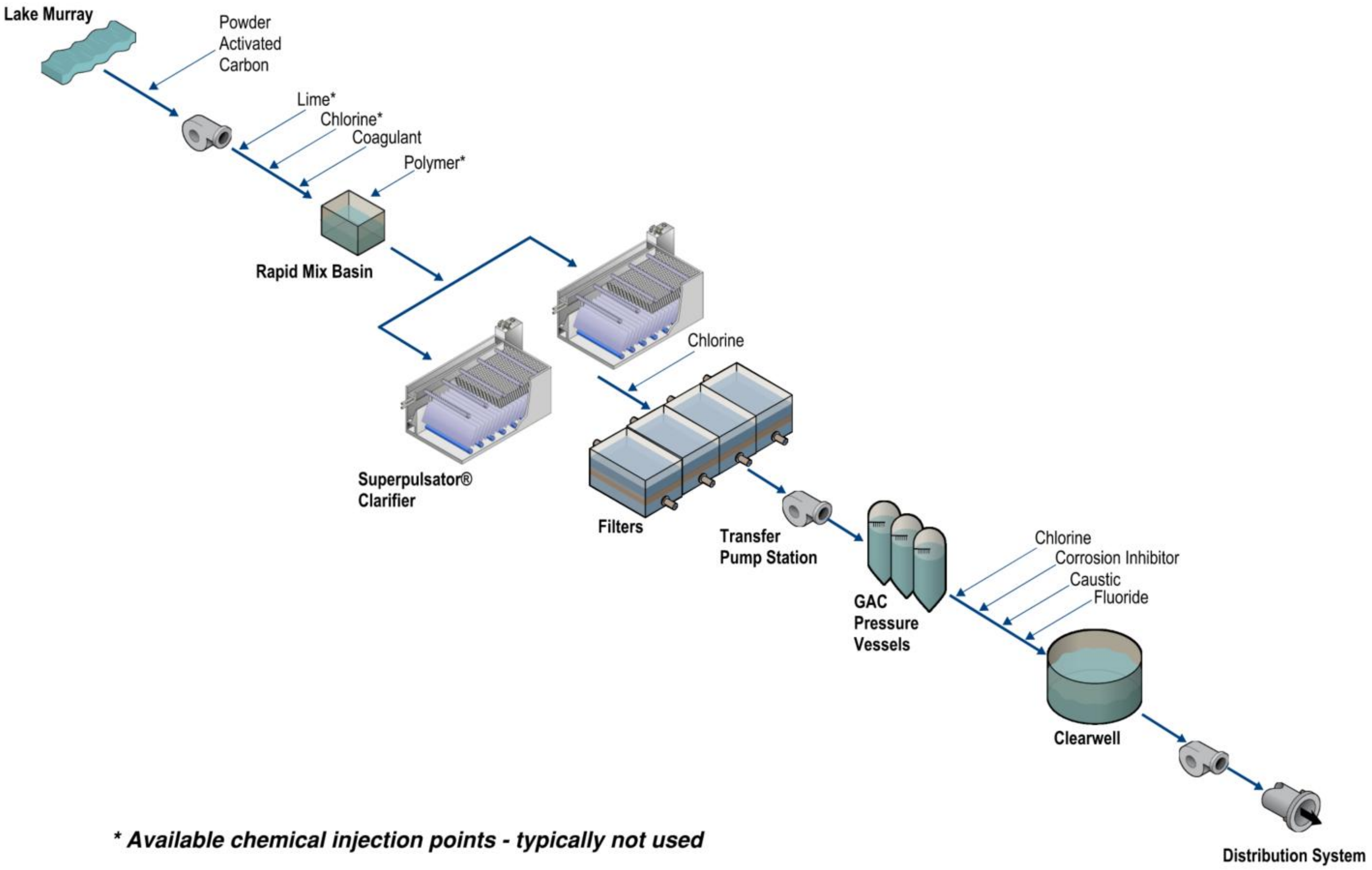
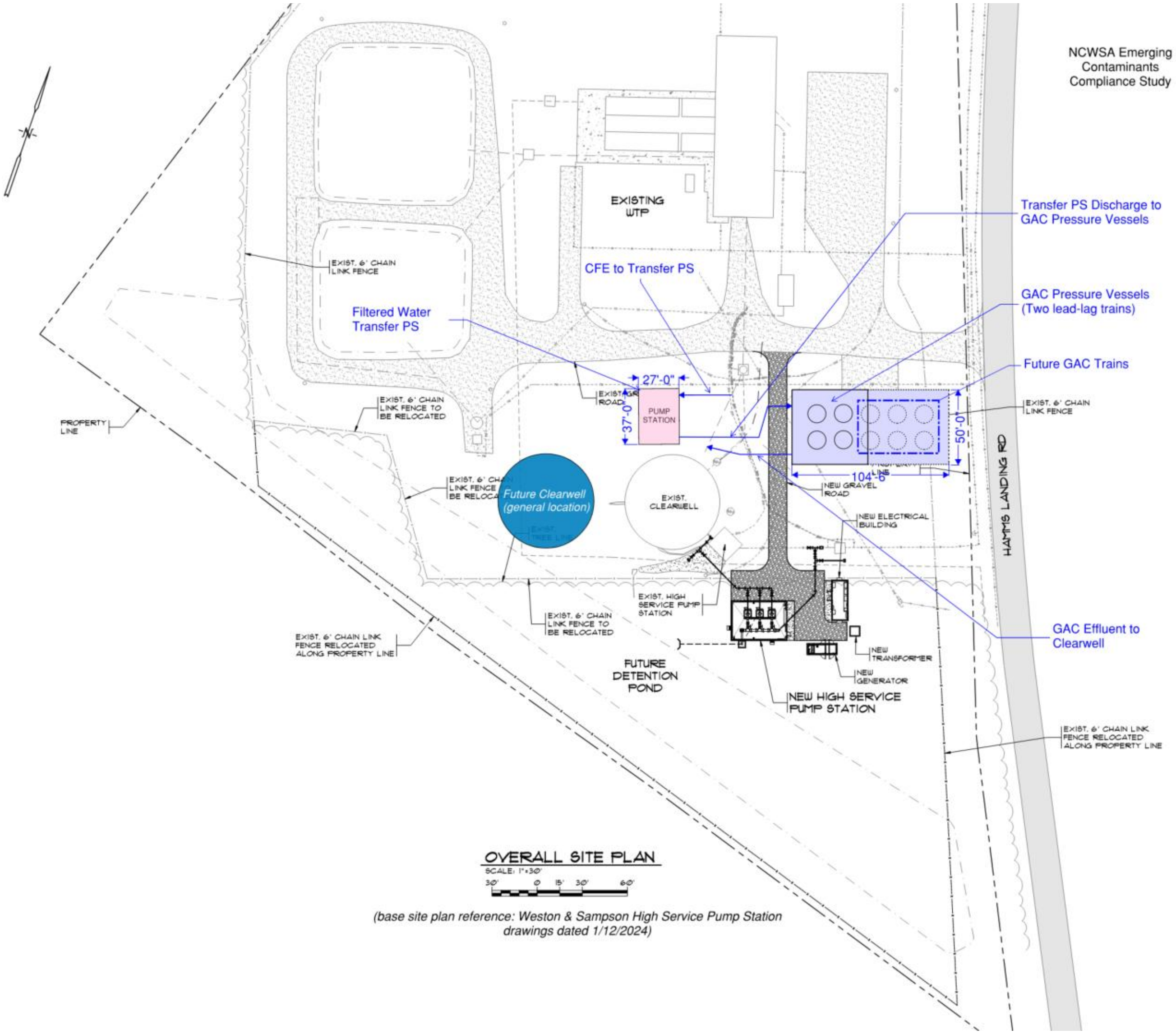


**Figure 7-2: General Process Flow Diagram for GAC PFAS Treatment System**



*(base site plan reference: Weston & Sampson High Service Pump Station drawings dated 1/12/2024)*

**Figure 7-3: Conceptual Site Plan for GAC PFAS Treatment System**

## 7.3 Estimated Construction and Life Cycle Costs

Construction costs were developed for both the PAC and GAC options. For PAC, costs were developed for three options:

- PAC Silo with One New Lagoon
- PAC Silo with Two New Lagoons
- PAC Bulk Bag System (Two Systems – One Duty/One Standby) with One New Lagoon

For GAC, costs were developed for two options:

- GAC in Building
- GAC with Pad and Roof (Canopy)

### 7.3.1 Construction Costs

A summary of estimated construction costs for the different alternatives is contained in **Table 7-6**. The following assumptions were made in developing the opinions of probable construction costs:

- Initial plant capacity of 2 mgd, with ultimate plant capacity of 6 mgd.
- No major utility relocations are required.
- All new structures will utilize shallow foundations; a deep pile system is not required.
- No rock excavation is required.
- A placeholder cost of $1,000,000 is assumed for a new decant pumping station for pumping of lagoon decant to the wastewater treatment plant.
- Contractor General Requirements of 15 percent.
- Contractor Overhead and Profit of 12 percent.
- Contingency of 25 percent.
- Market Volatility of 5 percent.
- Engineering, Legal, and Administrative of 15%.
- Land cost of $25,000 per acre.

**Table 7-6: Opinion of Probable Construction Costs for PFAS Treatment Alternatives**

| | PAC Silo w/1 lagoon | PAC Silo w/2 lagoons | PAC Bulk Bag w/1 lagoon | GAC w/Building | GAC w/Pad and Roof |
|---|---|---|---|---|---|
| **Mech/Civ/Struct** | $3,368,000 | $4,017,000 | $3,089,000 | $5,048,000 | $3,967,000 |
| **Sitework** | $256,000 | $321,000 | $258,000 | $40,000 | $40,000 |
| **Electrical/I&C** | $433,000 | $433,000 | $320,000 | $459,000 | $459,000 |
| **Contractor General Req's** | $604,000 | $711,000 | $550,000 | $254,000 | $234,000 |
| **Contractor OH&P** | $566,000 | $654,000 | $506,000 | $697,000 | $564,000 |
| ***Subtotal – No Contingency*** | *$5,217,000* | *$6,136,000* | *$4,723,000* | *$6,498,000* | *$5,264,000* |
| **Contingency and Market Volatility** | $1,555,000 | $1,831,000 | $1,245,000 | $1,950,000 | $1,580,000 |
| ***Subtotal - Construction*** | ***$6,772,000*** | ***$7,967,000*** | ***$6,140,000*** | ***$8,448,000*** | ***$6,844,000*** |
| **ELA** | $1,011,000 | $1,190,000 | $921,000 | $1,268,000 | $1,027,000 |
| **Land** | $50,000 | $75,000 | $50,000 | | |
| **Total Project Cost** | **$7,833,000** | **$9,232,000** | **$7,111,000** | **$9,716,000** | **$7,871,000** |

The lowest construction cost is the PAC bulk bag option and the addition of one lagoon ($7.1M), while the highest construction cost is the GAC option contained in a building ($9.7M). The PAC silo alternative with the addition of two lagoons and the GAC alternative with a canopy over the contactors both have similar construction costs at approximately $7.8-$7.9M.

### 7.3.2 O&M Costs

Operation and maintenance cost estimates were developed for the PAC and GAC alternatives. The assumptions for the PAC and GAC alternatives are contained in **Table 7-7** and **Table 7-8**. In addition, the following assumptions were made:

- Flow increase of 1.0% per year.
- Annual inflation rate of 4.8% based on a 5% escalation on equipment and materials and 4.5% escalation on labor.
- Annual interest rate of 4.5%.

A summary of O&M costs in the first year (2028) are contained in **Table 7-9**. The O&M costs between the alternatives are relatively similar between the different alternatives when accounting for the cost to process the additional solids from PAC addition.

### Table 7-7: PAC O&M Cost Estimate Assumptions

| Category | Description | Value |
|---|---|---|
| **Media Costs** | PAC Unit Cost (Tanker) | $1.60/lb |
| | PAC Unit Cost (Bulk Bag) | $1.75/lb |
| **Residuals Costs** | Dredging, Dewatering and Hauling Cost | $1,310/dry ton |
| | Tipping Fee | $590/dry ton |
| **Additional FTEs** | Number of Additional FTEs | 0 |
| | Assumed Full-Time Employee Pay Rate | $30/hour |
| **Sampling Costs** | Monthly Samples | 2 samples (Influent and Finished Water) |
| | Sampling Cost | $400/sample |

### Table 7-8: GAC O&M Cost Estimate Assumptions

| Category | Description | Value |
|---|---|---|
| **Media Costs** | Virgin GAC Unit Cost | $2.50/lb |
| | Reactivated GAC Unit Cost | $2.00/lb |
| | Assumed Virgin GAC Replacement Percent | 10% |
| **Pumping Costs** | Power Cost | $0.10/kWh |
| **Additional FTEs** | Number of Additional FTEs | 0 |
| | Assumed Full-Time Employee Pay Rate | $30/hour |
| **Sampling Costs** | Monthly Contactor Effluent Samples | 2 samples |
| | Monthly Influent Samples | 2 samples |
| | Sampling Cost | $400/sample |

**Table 7-9: O&M Costs Year 1 (2028)**

| Category | PAC (Bulk Tanker Delivery) | PAC (Bulk Bag Delivery) | GAC |
|---|---|---|---|
| **Media Changeouts per Year** | N/A | N/A | 1.1 |
| **Media Cost** | $72,000 | $79,000 | $104,000 |
| **Pumping Cost** | N/A | N/A | $7,000 |
| **Residuals Cost**(Note 1) | $0<br>(Year 1)<br>$90,000<br>(Year 2) | $0<br>(Year 1)<br>$90,000<br>(Year 2) | N/A |
| **Additional FTEs** | $0 | $0 | $0 |
| **Sampling Cost** | $11,000 | $11,000 | $22,000 |

**Notes:**

1. **Assumes lagoons are cleaned out every two years to match current operation.**

## 7.3.3 Net Present Value

The construction and O&M costs were utilized to develop net present value costs for each alternative and are contained in **Table 7-10**. The net present value of the O&M costs for each of the alternatives is relatively similar, ranging from approximately $2.6-$2.8M per year. The overall 20-year net present value including capital and O&M costs follows the same trend as the capital costs, with the bulk bag system and one lagoon being the least expensive options, followed by either the PAC silo option with one lagoon or the GAC option without a building.

**Table 7-10: Net Present Value Costs for GAC and PAC Alternatives**

| Category | PAC (Silo w/1 lagoon) | PAC (Silo w/2 lagoons) | PAC (Bulk Bag w/ 1 lagoon) | GAC (w/Building) | GAC (no Building) |
|---|---|---|---|---|---|
| **Capital Costs** | $7.8 M | $9.2 M | $7.1 M | $9.7 M | $7.9 M |
| **NPV O&M Costs** | $2.6 M | $2.6 M | $2.7 M | $2.8 M | $2.8 M |
| **20-year NPV** | $10.4 M | $11.8 M | $9.8 M | $12.5 M | $10.7 M |

## 7.4 Project Schedule

The preliminary schedule for both PAC and GAC options is summarized below in **Table 7-11**.

**Table 7-11: Preliminary Schedule of PFAS Treatment Alternatives**

| Task | PAC | GAC |
|---|---|---|
| **Begin Design** | January 2026 | January 2026 |
| **PER and 30% Design Complete** | March 2026 | April 2026 |
| **60% Design Complete** | June 2026 | August 2026 |
| **90% Design Complete** | August 2026 | November 2026 |
| **100% Design Complete** | October 2026 | January 2027 |
| **Advertisement for Bids** | November 2026 | February 2027 |
| **Receive Bids** | January 2027 | April 2027 |
| **Construction Notice to Proceed** | March 2027 | June 2027 |
| **Construction Completion** | March 2028 | December 2028 |

# 8. Recommendations

## 8.1 Summary of Findings

A general summary of findings is included below:

- Based on historical data from NCWSA and surrounding utilities that utilize Lake Murray as a water source, PFOA and PFOS levels in the raw and finished water are often above the regulatory limit of 4.0 ng/L contained in the recently enacted USEPA National Primary Drinking Water Regulation for PFAS, and treatment modifications will be required to comply with the new regulation. In addition, HFPO-DA (GenX) levels in the raw and finished water have approached the regulatory limit of 10 ng/L and is also present in high concentrations in upstream water quality sampling completed by the SCDES; therefore, removal of GenX could be a consideration for NCWSA as well.

- NCWSA has several other water quality challenges such as control of taste and odor causing compounds, removal of TOC, and reduction of disinfection byproducts that they would like to address if a treatment technology is added for PFAS removal.

- To meet the PFAS Rule requirements and also provide additional capabilities for taste and odor and TOC/DBP control, PAC and GAC were chosen as the preferred alternatives for potential addition at the NCWSA Lake Murray WTP.

- In bench-scale testing, PAC was shown to be effective for PFOA and PFOS removal at concentrations presently encountered, MIB and geosmin removal, and TOC reduction. PAC was much less effective for GenX removal as compared to PFOA and PFOS removal. The most effective product tested for PFOA and PFOS removal was the Ingevity AquaNuchar product followed by the Carbure TRA product.

- For comparison purposes with GAC, an estimated PAC design dose of 13 mg/L was chosen for PFAS removal. This is the dose needed to achieve a finished water PFAS goal of 3 ng/L based on historical average PFOA and PFOS levels and 4.5-minute contact time in the raw water pipeline. Higher dosages may be needed to meet MIB and geosmin goals when raw water MIB and geosmin levels are elevated. Construction of a PAC contact tank with 30-minute detention time could be considered to reduce the seasonal PAC dosage required for taste and odor removal; however, the reduction in PAC dose for PFAS removal with the added detention time was minimal.

- Based on desktop analysis and bench-scale (RSSCT) testing of two products (Calgon F400 and Carbpure GAC1240), GAC was shown to be effective for PFOA and PFOS removal. For PFOA and PFOS removal, the Carbpure GAC1240 performed best, while the Calgon F400 performed best for GenX removal. GenX release by the media during testing was also seen, with effluent GenX concentrations up to 1.4x influent concentrations seen in the RSSCT columns.

- Based on historical average PFOA and PFOS concentrations, the estimated time to breakthrough at 10-minute EBCT is greater than 630 days for the Carbpure GAC1240 and approximately 330 days for the Calgon F400. The time to breakthrough for GenX was slightly less than 200 days for the Carbpure GAC1240 and approximately 340 days for the Calgon F400. To allow flexibility in product selection, Calgon F 400 was chosen as the design basis for media changeout. If GenX is removed from the PFAS regulation as anticipated, the Carbpure GAC1240 may provide significantly longer times before breakthrough based on testing to date. A product selection pilot concurrent with design can provide additional information on the best GAC product for this application.

- The additional impacts of PAC or GAC treatment at the NCWSA Lake Murray WTP are positive from a water quality standpoint in the areas of taste and odor control, TOC/DBP reduction, and distribution system water quality.

- The main challenge with PAC for PFAS treatment is the additional solids that must be processed at the plant and disposed. Based on current operation, it is estimated that the use of PAC for PFAS removal (typical dose of 13 mg/L each day) will increase the solids production at the plant by approximately 50 percent. This creates the need for additional residuals lagoons and increased cost for removal and disposal of solids. In addition, PFAS-laden PAC solids may be more difficult and costly to dispose of in the future based on potential changes in RCRA requirements. Operationally, PAC can also be difficult to handle and equipment can be difficult to maintain.

- GAC treatment should have minimal impact on operations. Media changeout is often conducted by the media supplier and should have limited impact on WTP staff. Post-filtration chemical feed will need to be moved downstream of GAC treatment and prior to the Finished Water Storage Tank. The pre-filter chlorine dose will need to be controlled to minimize chlorine residual in the GAC contactor influent, with desired levels typically 0.5 mg/L or less.

- Five alternatives were developed for conceptual design and costing:
    - PAC Silo with One New Lagoon (3,500 cu ft capacity silo)
    - PAC Silo with Two New Lagoons (3,500 cu ft capacity silo)
    - PAC Bulk Bag Systems (Redundant Systems) in Building with One New Lagoon

  - GAC Pressure Vessels in Building (two sets of lead-lag vessels; a new filtered water transfer pumping station is also required)
  - GAC Pressure Vessels with Pad and Canopy Roof (two sets of lead-lag vessels; a new filtered water transfer pumping station is also required)
- Capital and O&M cost estimates were developed for each of the alternatives:
  - The lowest capital cost was the bulk bag system (two systems) with one residual lagoon ($7.1M), followed by the PAC silo option with one residual lagoon and the GAC option without a building ($7.8-7.9M).
  - O&M costs were similar between all of the options.
  - The 20-year net present value for the alternatives was developed and the bulk bag system had the lowest net present value ($8.8M), followed by the PAC silo option with one residual lagoon ($10.4M) and the GAC option without a building ($10.7M).

## 8.2 Recommendations

Based on the findings of the evaluation, the following recommendations were developed:

- Based on the efficacy of GAC treatment for PFOA and PFOS removal and the ability to remove GenX more effectively than PAC, GAC treatment is recommended for PFAS removal at the NCWSA Lake Murray WTP. This eliminates the need for handling of additional PAC solids and protects against the uncertainty of disposal of PFAS-laden PAC solids in the future. Also, while PAC can be applied for lower PFOA and PFOS levels that are just above the MCL, as is the present condition, it may not be suitable if higher raw water levels are encountered.
- Design a GAC system to be installed beneath a canopy, with the ability to enclose the canopy as a bid alternate or in a future project.
- As part of the design, conduct a product selection pilot to further evaluate the effectiveness of the selected GAC and alternate products during varying water quality and also for the removal of GenX.
- Consideration should be given to repairing the existing 50-pound bag feed system such that it is operable. The existing PAC feed system could be available in the interim while the GAC system is being constructed and also could be beneficial as a supplement to GAC if raw water MIB levels ever spike to historical maximum levels seen at other utilities on Lake Murray.

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# Appendix A: NCWSA PAC Bench-Scale Testing Protocol

Newberry County Water and Sewer Authority
Emerging Contaminants Compliance Study
**PAC Bench-Scale Testing Protocol**

Project 7001
October 28, 2024
*Revised: December 9, 2024*

To: Distribution

From: Paul Hargette and Andrea Hargette, Hargette LLC

## Introduction

Newberry County Water and Sewer Authority (NCWSA) owns and operates the 2 million gallon per day (mgd) Lake Murray Water Treatment Plant (LMWTP). The plant utilizes the Suez Superpulsator® process for treatment followed by filtration and disinfection. The LMWTP receives raw water from Lake Murray via a submerged intake screen and raw water pumping station. Raw water is pumped approximately 1900 feet through a single 16” pipeline to the raw water flow meter vault and then to the rapid mix basin.

Recently, the United States Environmental Protection Agency (USEPA) finalized regulations on per- and poly-fluoroalkyl substances (PFAS) in drinking water. As indicated in Table 1, the final regulations include regulatory requirements for five individual PFAS compounds (PFOA, PFOS, PFNA, PFHxS, and HFPO-DA (GenX chemicals)) as well as a Hazard Index for a mixture of two or more of four compounds (PFNA, PFHxS, HFPO-DA, and PFBS).

**Table 1**
**USEPA PFAS National Primary Drinking Water Regulation** (Notes 1,2)

| Chemical | Maximum Contaminant Level Goal (MCLG)(Note 3) | Maximum Contaminant Level (MCL) |
|---|---|---|
| PFOA | 0 | 4.0 parts per trillion (ppt) |
| PFOS | 0 | 4.0 ppt |
| PFNA | 10 ppt | 10 ppt |
| PFHxS | 10 ppt | 10 ppt |
| HFPO-DA (GenX Chemicals) | 10 ppt | 10 ppt |
| Mixture of two or more: PFNA, PFHxS, HFPO-DA, and PFBS | Hazard Index (HI) of 1(Note 4) | Hazard Index (HI) of 1(Note 4) |

Notes:
1. pfas-npdwr_fact-sheet_general_4.9.24v1.pdf (epa.gov)
2. pfas-npdwr_fact-sheet_hazard-index_4.8.24.pdf (epa.gov)
3. MCLG is the level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals.
4. HI = $[\text{HFPO-DA}_{ppt}]/[10\text{ ppt}] + [\text{PFBS}_{ppt}]/[2000\text{ ppt}] + [\text{PFNA}_{ppt}]/[10\text{ ppt}] + [\text{PFHxS}_{ppt}]/[10\text{ ppt}]$

South Carolina Department of Environmental Services (SCDES, formerly SCDHEC) conducted monitoring of PFAS compounds in Lake Murray raw water in June 2020. Results from this sampling are shown in Figure 1. In addition, Unregulated Contaminant Monitoring Rule 5 (UCMR5) is being collected by NCWSA and neighboring utilities. These data are contained in Figure 2.

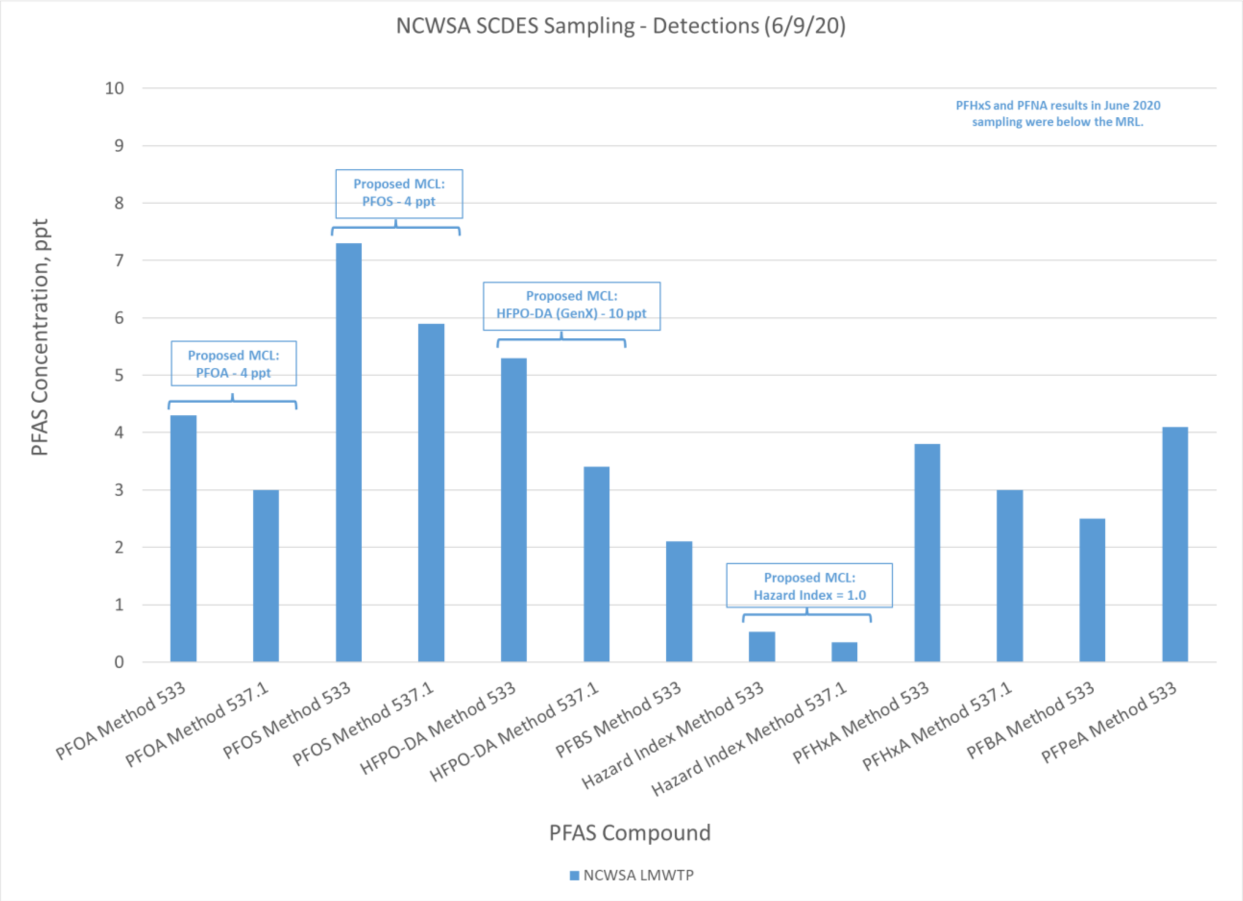


**Figure 1. Newberry County WSA – PFAS Detections from SCDES Sampling (June 2020)**

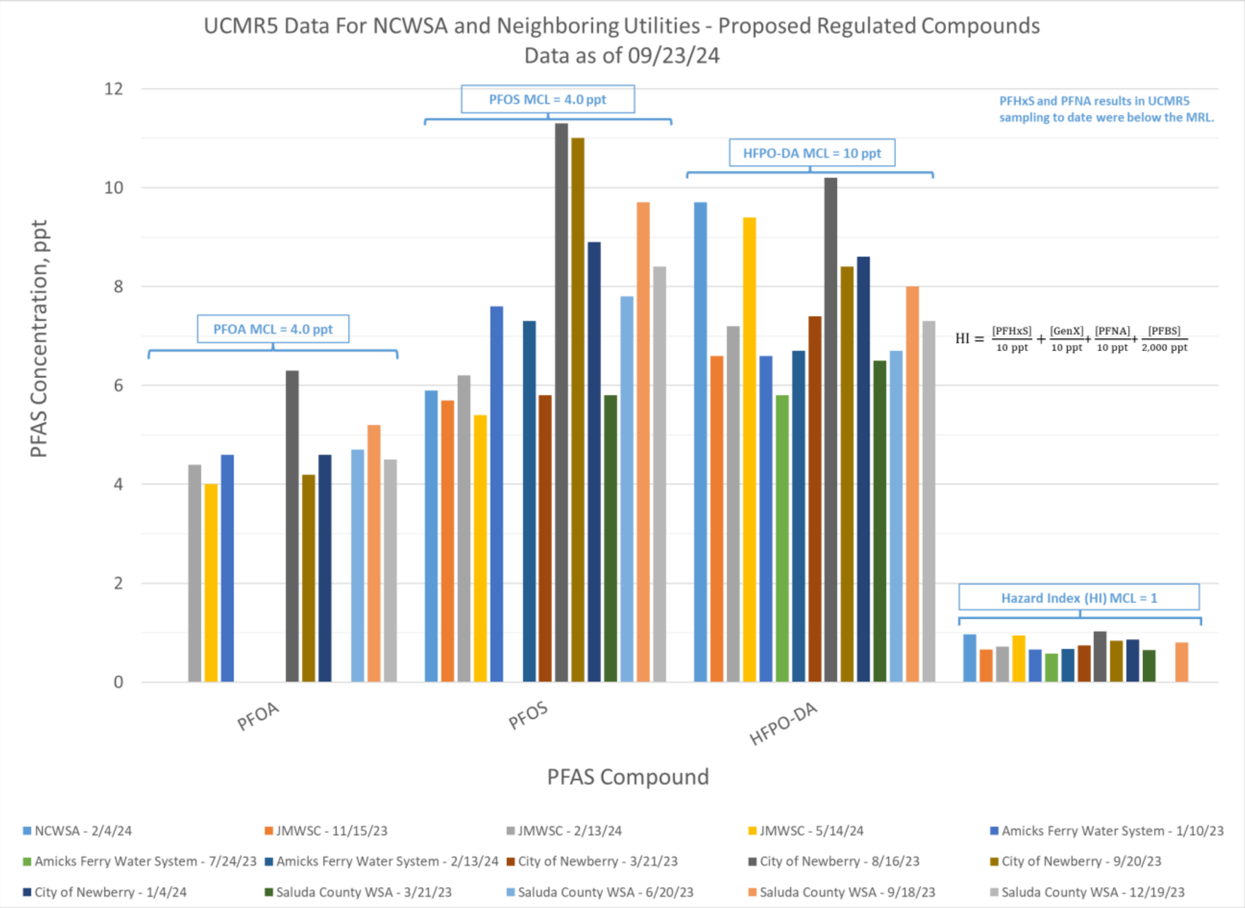


**Figure 2. UCMR5 Data for NCWSA and Neighboring Utilities (Data as of 9/23/24)**

As indicated in Figures 1 and 2, levels of PFOA, PFOS, and HFPO-DA (GenX) have exceeded the recently finalized MCLs for NCWSA and/or for neighboring utilities. This project is intended to evaluate options for removal of PFAS at the NCWSA LMWTP and includes bench-scale testing of the following alternatives:

- Bench-scale testing (jar testing) to evaluate powdered activated carbon (PAC) alternatives.
- Bench-scale testing (rapid small scale column testing (RSSCT)) to evaluate granular activated carbon alternatives.

This document contains the protocol for the jar testing of PAC. The protocol for the RSSC testing has been submitted under separate cover.

## Jar Testing Protocol

### PAC Products

The following products will be used in the jar testing:

- Ingevity AquaNuchar*
- Carbpure Technologies Carbpure TRA*
- Jacobi AquaSorb CB1-MW*

* These products were selected based on PAC testing experience at other utilities.

### Jar Testing Conditions

The jar testing will consist of a contact time for the PAC followed by coagulation flocculation, and clarification. The clarified water at the end of the jar test will be collected for analytical testing of the desired parameters.

Two PAC contact times will be used for the testing as follows:

- 4.5 minutes: This is the approximate contact time in the 16” raw water pipeline from the edge of the property closest to the raw water pump station to the raw water flow meter vault at a plant flow rate of 3 mgd.

- 30 minutes: This is the approximate contact time assuming a new PAC contactor with 30 minutes contact time is constructed at the plant.

A summary of jar test conditions is contained in Table 2.

**Table 2**
**Jar Test Conditions NCWSA Lake Murray WTP**

| | | |
|---|---|---|
| PAC Contact Time | | |
| Speed, rpm | Initial 150 rpm for 30 seconds to mix PAC followed by 25 rpm to keep solids in suspension | |
| Total Duration, minutes | 4.5 (Contact Time 1)<br>30 (Contact Time 2) | |
| Rapid Mix | | |
| Speed, rpm | 100 | |
| Duration, seconds | 30 | |
| Flocculation | | |
| Stage | Speed (rpm) | Duration (minutes) |
| 1 | 35 | 10 |
| 2 | 25 | 10 |
| 3 | 12 | 10 |
| Settling, min | 5 | |

## Water Quality Analyses

The following parameters will be measured and/or recorded during the bench-scale testing:

- pH (raw water and all jar tests)
- Turbidity (raw water and all jar tests)
- Alkalinity (raw water)
- Hardness (raw water)
- UV254 (raw water and all jar tests)
- TOC (raw water and all jar tests)*
- MIB/Geosmin (raw water and all jar tests)*
- PFAS Method 533 (raw water and all jar tests)*

* Samples to be sent to an independent laboratory for analysis

## Sample Collection

1. For each jar test, collect raw water that has not been dosed with any chemicals at the raw water pump station or in the sample tap in the plant laboratory (if PAC is not being fed in the full-scale plant).

2. Record the following from the operator log sheets at the time of sample collection:

    a. Raw Water: Temperature, pH, turbidity, alkalinity, and hardness
    b. Chemical Dosing: PAC dose, coagulant dose, and pre-caustic dose
    c. Settled Water: pH and turbidity

3. On the first day, collect raw water samples for TOC, MIB/Geosmin, and PFAS in bottles provided by the contract laboratory. On subsequent days, collect samples for only TOC in bottles provided by the contract laboratory.

## Jar Testing Procedure

1. Prepare stock solutions for PAC, coagulant, and caustic (pH adjusting chemical).

    a. PAC: 20 g/L solution (1 mL = 10 mg/L in a 2-L jar). Make by adding 10 g to 0.5 L of DI water.

    b. Coagulant: Determine from plant staff the method of calculating coagulant dose and prepare solutions accordingly or dose product neat.

    c. Caustic: 4 g/L solution (1 mL = 2 mg/L as dry caustic in a 2-L jar). Make by adding 0.5 mL of 50% caustic to 99.5 mL of DI water.

2. Determine the desired coagulant dosage and pH for each jar based on the chemical dosages used at the plants on the day of sample collection.

3. Transfer 9 L of raw water into a 5-gallon bucket (enough for four 2-L jars with some extra). Spike the raw water with MIB/geosmin and PFAS compounds as indicated in Table 3.

| Table 3. Spiking of MIB, Geosmin, and PFAS | | |
|---|---|---|
| | **MIB/Geosmin** | **PFAS Compounds** |
| Approximate stock concentration, mg/L | 1.0 | 1.0 |
| Sample volume, L | 9 | 9 |
| Vol of stock solution to add, mL | 0.9 | 0.45 |
| Concentration, ng/L | 100 | 50 |

Note: One MIB/Geosmin stock solution and two PFAS stock solutions will be utilized. One PFAS stock solution will include five of the six regulated compounds: PFOA, PFOS, GenX, PFNA, and PFBS, and the second PFAS stock solution will include the sixth regulated compound: PFHxS.

4. Transfer 2-liters of spiked raw water into each of the four square jar test beakers.

5. Collect spiked raw water samples for:

   - TOC
   - MIB/geosmin
   - PFAS

6. Measure out the desired amount of PAC to feed in each jar. The dosages for the jars will be as indicated in Table 4.

| Table 4. Dosing of PAC | | | | |
|---|---|---|---|---|
| | **Jar 1** | **Jar 2** | **Jar 3** | **Jar 4** |
| PAC Dose, mg/L | 5 | 15 | 25 | 40 |
| Stock PAC solution concentration, g/L | 20 | 20 | 20 | 20 |
| Volume of stock solution to add, mL | 0.5 | 1.5 | 2.5 | 4.0 |

7. Increase the bench stirrer to 150 rpm and add PAC solution to each jar. After 30 seconds, reduce the bench stirrer to 25 rpm for the remainder of the desired PAC contact time.

8. After desired PAC contact time, transition to the coagulation jar test and add caustic (if being fed in the full-scale plant) and coagulant at the start of the rapid mix phase of the jar testing.

9. Complete the jar test using the conditions and times described previously.

10. At the end of the settling period collect samples and run pH and turbidity on the samples.

11. Collect settled water samples from each jar for:

    - TOC
    - MIB/geosmin
    - PFAS

12. Ship raw water and settled water samples to the contract laboratory for analysis.

13. Repeat the same procedure for the different PAC products and different contact times. Triple rinse labware with DI water between tests.

14. Also perform a control jar test with one jar with only mixing (no chemicals added), two jars with coagulant and caustic added, but no PAC added, and one jar with 15 mg/L of one of the PAC products. The water used for this jar test will be spiked raw water.

# Appendix B: NCWSA RSSCT Testing Plan

One Water
ENGINEERING

October 28, 2024

To: Erik Rosenfeldt, PhD, PE

From: Alex Gorzalski, PhD, PE, PO

# NEWBERRY COUNTY RSSCT TESTING PLAN

REVISED

## 1. PROJECT BACKGROUND

Hazen retained One Water to perform rapid small-scale column tests (RSSCTs) to test different adsorbents for the removal of per- and polyfluoroalkyl substances (PFAS). PFAS removal will be tested in waters collected from the Newberry County Water and Sewer Authority (Newberry County). Media to be tested include granular activated carbon (GAC). Water will be spiked with PFAS to enable higher-resolution observation of early column breakthrough.

## 2. RSSCTS

### 2.1. Experimental Apparatus

A flow schematic of the anticipated experimental apparatus is shown in **Figure 1**. Water delivered to One Water's laboratory will be filtered through a high-purity 0.45 µm filter and transferred to the column feed drum. The high-purity 0.45 µm filter is proposed because One Water has observed that 1 µm filtration can be insufficient to remove particulates that lead to high headloss, particularly in challenging waters (e.g., wastewater or surface water during/after an algae bloom).

From the column feed drum, an HPLC pump will provide pressure to drive water through the RSSCT column in upflow mode. Column effluent will either be sampled or directed to an effluent drum. The effluent drum will be translucent with volumetric gradations. This totalized volume can be helpful in the event that flow through the column ceases or decreases between operational checks (e.g., the HPLC pump losses prime or pressure relief valve is partially opened).

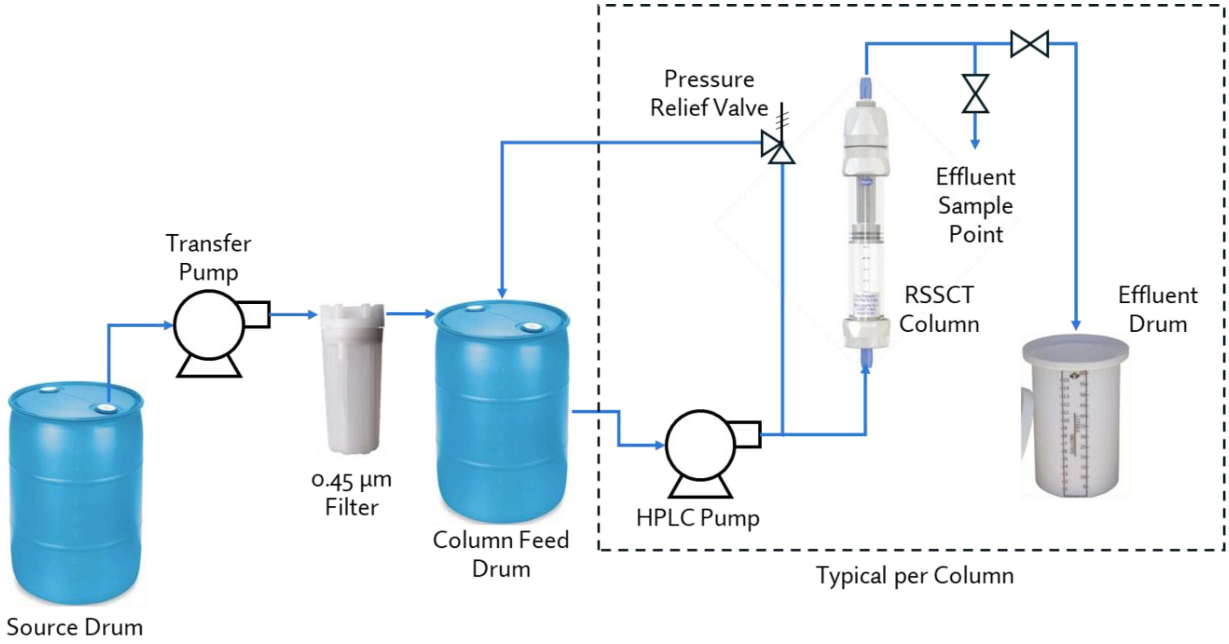


**Figure 1. Anticipated Experimental Apparatus Schematic**

## 2.2. Summary of RSSCTs

A total of two RSSCTs will be conducted as part of this work. A summary of the conditions requested by Hazen is provided in **Table 1**.

**Table 1. Summary of RSSCTs to be Conducted (provided by Hazen)**

| RSSCT No. | Plant | Adsorbent/Resin | EBCT (min) |
|---|---|---|---|
| 1 | Newberry County WTP | Calgon F400 (GAC) | 10 |
| 2 | Newberry County WTP | CarbPure 1240 (GAC) | 10 |

## 2.3. RSSCT Design

The equation for scaling empty bed contact time (EBCT) in RSSCTs was developed by Crittenden et al. (1986[1]) and is described by

$$\frac{EBCT_{SC}}{EBCT_{LC}} = \left[\frac{d_{p,LC}}{d_{p,SC}}\right]^{x-2} = (SF)^{x-2}$$

where $d_p$ is the particle diameter, SF is the scaling factor, and SC and LC indicate small column and large column, respectively. For constant diffusivity, x = 0, while for proportional diffusivity x = 1. It was recently shown that RSSCT results for PFAS removal by GAC more accurately matched pilot observations when a value of x = 0.25 was used (Hopkins and Knappe 2024[2]). GAC column design conducted here will use a value of x = 0.25.

---

[1] Crittenden, J.C., Berrigan, J.K. Hand, D.W. 1986. Design of rapid small-scale adsorption tests for a constant diffusivity. *Journal Water Pollution Control Federation*, 312-319.

[2] Hopkins, Z. R., & Knappe, D. R. 2024. Predicting per-and polyfluoroalkyl substances removal in pilot-scale granular activated carbon adsorbers from rapid small-scale column tests. *AWWA Water Science*, 6(2), e1369.

Scaling assumptions, column depth, and other RSSCT design information is provided in **Table 2**. For the large column average particle diameter, a geometric mean was taken of the sieve mesh or range of sizes provided by the manufacturer.

All columns will be 0.66 cm in diameter. GAC columns will be filled to a depth of 3.5 cm. All ground media will be wet sieved using Type 2 ultrapure water. GAC will be sieved between No. 120 (0.149 mm) and No. 200 (0.074 mm) sieves.

The number of bed volumes (BV) assumed in **Table 2** provides an estimate of the minimum water requirements to complete the planned testing. Section 2.4 provides the total estimated volume to be collected, including conservative factors. The BV at which column effluents will be sampled for PFAS is described in Section 2.7.

**Table 2. RSSCT Column Design (yellow cells are inputs, green in cells are key calculated parameters)**

| | Parameter | Unit | Col #1 | Col #2 |
|---|---|---|---|---|
| | **Water** | | **Newberry County** | |
| | **Media** | | **Calgon F400** | **CarbPure 1240** |
| Large Column | EBCT | min | 10 | 10 |
| | HLR | gpm/ft2 | Not Scaled | Not Scaled |
| | Mesh or Diam. Upper Bound | # | No. 12 | No. 12 |
| | Mesh or Diam. Lower Bound | # | No. 40 | No. 40 |
| | Geom. Mean Part. Diameter | mm | 0.840 | 0.840 |
| Small Column Inputs | Column Inner Diameter | cm | 0.66 | 0.66 |
| | Mesh Upper Bound | # | No. 120 | No. 120 |
| | Mesh Lower Bound | # | No. 200 | No. 200 |
| | Geom. Mean Part. Diameter | mm | 0.096 | 0.096 |
| | Non-Constant Diffusivity Mod | - | 0.25 | 0.25 |
| | Column Depth | cm | 3.5 | 3.5 |
| | BV Assump. for Samp. Vol. | BV | 50,000 | 50,000 |
| | Full-Scale Run Time | Days | 347 | 347 |
| | Temperature | C | 20 | 20 |
| Small Column Calculated Parameters | Col Diam : Part. Diam | - | 68.6 | 68.6 |
| | Scaling Factor | - | 8.7 | 8.7 |
| | $EBCT_{SC}$ / $EBCT_{LC}$ | - | 44.4 | 44.4 |
| | Dynamic Viscosity, μ | g/s-cm | 0.0100 | 0.0100 |
| | Density of Water, ρ | g/cm3 | 1 | 1 |
| | PFAS Diffusivity | cm2/s | 5.00E-06 | 5.00E-06 |
| | Sc = μ/(ρ * D) | - | 2,003 | 2,003 |
| | Re | - | 0.25 | 0.25 |
| | Re*Sc | - | 498 | 498 |
| | EBCT | sec | 13.5 | 13.5 |
| | HLR | cm/s | 0.26 | 0.26 |
| | | gpm/ft2 | 3.8 | 3.8 |
| | Bed Volume | mL | 1.20 | 1.20 |
| | Flow Rate | mL/min | 5.3 | 5.3 |
| | Water Volume Required | L | 59.9 | 59.9 |
| | | gal | 15.8 | 15.8 |
| | Testing Duration | days | 7.8 | 7.8 |

## 2.4. Source Water Collection, Filtration, and Disinfection

Newberry County WSA with assistance as needed from Hargette LLC and Hazen will collect the source water and ship it to One Water. **Table 3** provides information on water sample collection. Samples will be collected from the combined filter effluent location prior to post-filtration chemical addition. No field filtration is required as all drums will be filtered in the laboratory prior to testing (field filtration is primarily a concern for high-solids settling points, such as raw or settled water, or wastewater). No additional field chlorination should be performed.

The volume required for each source is based on the column design and assumed BV in **Table 2**, plus conservative factors. It is estimated that two (2) 55-gallon drums of combined filter effluent will be required. Drums should only be filled ~90% full, do not top off drums. If drums can be loaded on top of pallets, that would simplify offloading at One Water's laboratory.

Hazen will coordinate with One Water on the day of water delivery. Water should be delivered to the address shown below. Forklift assistance is available for offloading between 9:30am and 4:30pm M-F.

Attn: Alex Gorzalski
One Water Engineering
517 Pylon Dr
Raleigh, NC 27606

**Table 3. Source Water Collection Information**

| | Newberry County WTP |
|---|---|
| Sample Point | Combined Filter Effluent |
| Field Filtration? | None Required |
| Field Chlorination? | Background Cl2 Residual |
| Volume Required (gal) | 50.0 |
| Safety Factor (gal) | 50 |
| No. 55-gal Drums | 2 |

## 2.5. PFAS Spiking

Source samples will be spiked with PFAS to increase the influent concentration, and thereby improve resolution when detecting breakthrough. Hazen will prepare stock PFAS stock solutions and ship them to One Water. The spiking of an additional 60 ng/L of different PFAS to each water was assumed. PFAS to be spiked include PFBA, PFHxA, PFPeA, **Gen-X**, **PFBS**, 6:2 FTS, PFDA, PFHpA, **PFHxS**, **PFNA**, **PFOS**, and **PFOA**. Stock solutions are assumed to be prepared in ultrapure water and provided in 50 mL centrifuge tubes. The estimated mass per centrifuge tube and number of centrifuge tubes is provided in **Table 4**. This assumes that each centrifuge tube will contain the amount of PFAS to spike one 55-gallon drum that is ~90% full.

PFAS stock solutions should be delivered to One Water at least one week prior to water delivery.

**Table 4. PFAS Stock Solutions for Spiking (to be provided by Hazen)**

| Parameter | Unit | Value |
|---|---|---:|
| Drum Volume | gal | 50 |
| | L | 189.3 |
| Target PFAS Conc. in Drum | ng/L | 60 |
| Mass per Tube (each PFAS) | µg | 5.7 |
| Min No. of Tubes | # | 4 |
| Requested No. of Tubes | # | 6 |

## 2.6. RSSCT Checks Operations Data Collection

RSSCT apparatuses will be checked at least once per day. The following operations data will be collected no less than once per day:

- Manual confirmation of flow rate at or near the set point
- Column bed depth
- Column back pressure
- Column effluent UV-254

## 2.7. Proposed Sampling BV and Dates/Times

The proposed sampling times and bed volumes for PFAS sample collection is shown for each media in **Table 5**. The associated days of operation at design EBCT is also shown. Additionally, TOC will be collected at the times indicated in the table.

**Table 5. Column Sampling Times with BV and Operating Days (at Design EBCT) for PFAS Analysis**

| | Newberry County | | | | |
|---|---|---|---|---|---|
| | Calgon F400 | | CarbPure 1240 | | |
| Date Time | BV | Days | BV | Days | TOC |
| Mon 11/4 10:00 AM | | | | | |
| Mon 11/4 11:30 AM | 399 | 3 | 399 | 3 | X |
| Mon 11/4 4:00 PM | | | | | |
| Mon 11/4 8:30 PM | 2,795 | 19 | 2,795 | 19 | |
| Tue 11/5 9:00 AM | | | | | |
| Tue 11/5 3:30 PM | 7,854 | 55 | 7,854 | 55 | X |
| Wed 11/6 9:00 AM | | | | | |
| Wed 11/6 3:30 PM | 14,244 | 99 | 14,244 | 99 | X |
| Wed 11/6 8:30 PM | | | | | |
| Thu 11/7 9:00 AM | | | | | |
| Thu 11/7 3:30 PM | 20,633 | 143 | 20,633 | 143 | X |
| Thu 11/7 8:30 PM | | | | | |
| Fri 11/8 9:30 AM | 25,425 | 177 | 25,425 | 177 | |
| Fri 11/8 3:30 PM | | | | | |
| Sat 11/9 2:30 PM | 33,146 | 230 | 33,146 | 230 | X |
| Sun 11/10 2:30 PM | 39,536 | 275 | 39,536 | 275 | |
| Mon 11/11 10:00 AM | 44,728 | 311 | 44,728 | 311 | X |
| Mon 11/11 4:15 PM | | | | | |
| Tue 11/12 9:15 AM | 50,918 | 354 | 50,918 | 354 | |
| Tue 11/12 12:00 PM | | | | | |
| | | | | | |
| **# Samples** | **10** | | **10** | | **6** |

## 3. ANALYTICAL BOTTLE REQUIREMENTS

Parameters including PFAS, TOC, and major anions will be analyzed by an external analytical laboratory. The total number of sample bottles for each parameter are included in **Table 6**. This includes the number of bottles necessary to complete the work proposed in this test plan, plus spare bottles in the event of bottle breakage and to account for potential changes to the experiment during collection (e.g., collecting additional PFAS samples).

Analytical bottles should be delivered to One Water at least one week prior to water delivery. All samples will be shipped at the conclusion of the experiments. Given the low flow rates through RSSCT columns and the large number of bed volumes in each 250 mL sample, collection of multiple 250 mL bottles per sample will not be performed. One Water assumes that collection of PFAS samples at each time point will not exceed 250 mL.

**Table 6. Number of Bottles to Request from Analytical Laboratory**

| | PFAS | TOC | Major Anions |
|---|---|---|---|
| Example Method | EPA 533 | SM 5310 | EPA 300.0 |
| **RSSCTs** | | | |
| Number of Columns / Conditions | 2 | 2 | 0 |
| Number of Time Points | 10 | 6 | 0 |
| Source / Controls | 4 | 2 | 2 |
| **RSSCT Subtotal** | **24** | **14** | **2** |
| **Spare and Total Bottles** | | | |
| Spare Bottles | 6 | 4 | 2 |
| **Total Bottles Requested** | **30** | **18** | **4** |

## 4. SCHEDULE

The proposed schedule for this work is as shown below. This schedule may need to be modified during the experiment in the event of delays water shipment, sample bottle delivery, or column feed disruption.

- Thursday October 17th: Hazen ships PFAS stock solutions to One Water (from a previous project).
- Wednesday October 30th to Thursday October 31st: One Water grinds and sieves media, assembles columns, tests equipment.
- Friday November 1st: Full-scale filtered water is received at One Water's laboratory.
- Friday November 1st: One Water Loads the RSSCT columns.
- Monday November 4th to Monday November 11th: One Water operates RSSCT columns.
- Monday November 11th: One Water ships analytical samples to the third-party analytical laboratory.
- Late November to early December: Analytical laboratory analyzes samples and sends results. One Water will prepare a summary memo with the results of the experiment within two weeks of receiving all data from the analytical laboratory.

# Appendix C: NCWSA RSSCT Testing Results

February 14, 2025

To: Erik Rosenfeldt, PhD, PE
Joseph Greenburg, PE

From: Alex Gorzalski, PhD, PE, PO

# NEWBERRY COUNTY RSSCT RESULTS MEMO

## FINAL

## 1. PROJECT BACKGROUND

Hazen retained One Water to perform rapid small-scale column tests (RSSCTs) to test different adsorbents for the removal of per- and polyfluoroalkyl substances (PFAS). PFAS removal was tested in waters collected from the Newberry County Water and Sewer Authority (Newberry County). Media tested included granular activated carbon (GAC). Water was spiked with PFAS to enable higher-resolution observation of early column breakthrough.

## 2. RSSCTS

### 2.1. Experimental Apparatus

A flow schematic of the experimental apparatus is shown in **Figure 1**. Water delivered to One Water's laboratory was filtered through a high-purity 0.45 µm filter and transferred to the column feed drum. The high-purity 0.45 µm filter was used because One Water has observed that 1 µm filtration can be insufficient to remove particulates that lead to high headloss, particularly in challenging waters (e.g., wastewater or surface water during/after an algae bloom).

From the column feed drum, an HPLC pump provided pressure to drive water through the RSSCT column in upflow mode. Column effluent was either sampled or directed to an effluent drum. The effluent drum was translucent with volumetric gradations. This totalized volume can be helpful in the event that flow through the column ceased or decreased between operational checks (e.g., the HPLC pump losses prime or pressure relief valve is partially opened).

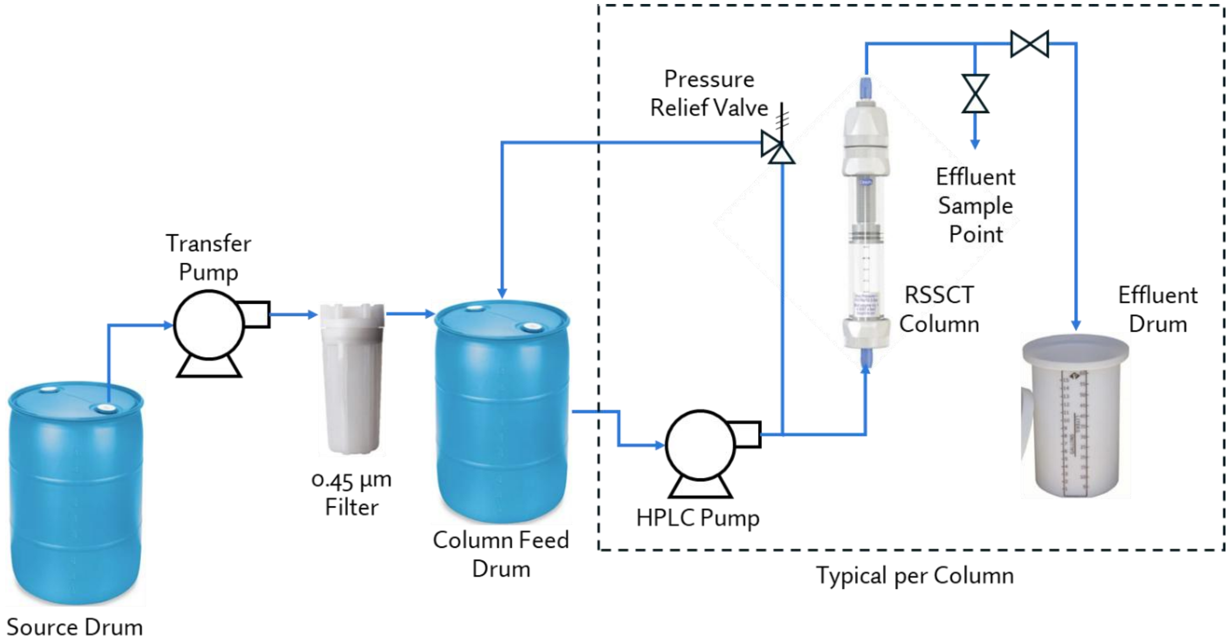


**Figure 1. Anticipated Experimental Apparatus Schematic**

## 2.2. Summary of RSSCTs

A total of two RSSCTs were conducted as part of this work. A summary of the conditions requested by Hazen is provided in **Table 1**.

**Table 1. Summary of RSSCTs to be Conducted (provided by Hazen)**

| RSSCT No. | Plant | Adsorbent/Resin | EBCT (min) |
|---|---|---|---|
| 1 | Newberry County WTP | Calgon F400 (GAC) | 10 |
| 2 | Newberry County WTP | CarbPure 1240 (GAC) | 10 |

## 2.3. RSSCT Design

The equation for scaling empty bed contact time (EBCT) in RSSCTs was developed by Crittenden et al. (1986[1]) and is described by

$$\frac{EBCT_{SC}}{EBCT_{LC}} = \left[\frac{d_{p,LC}}{d_{p,SC}}\right]^{x-2} = (SF)^{x-2}$$

where $d_p$ is the particle diameter, SF is the scaling factor, and SC and LC indicate small column and large column, respectively. For constant diffusivity, x = 0, while for proportional diffusivity x = 1. It was recently shown that RSSCT results for PFAS removal by GAC more accurately matched pilot observations when a value of x = 0.25 was used (Hopkins and Knappe 2024[2]). GAC column design conducted here will use a value of x = 0.25.

---

[1] Crittenden, J.C., Berrigan, J.K. Hand, D.W. 1986. Design of rapid small-scale adsorption tests for a constant diffusivity. *Journal Water Pollution Control Federation*, 312-319.

[2] Hopkins, Z. R., & Knappe, D. R. 2024. Predicting per-and polyfluoroalkyl substances removal in pilot-scale granular activated carbon adsorbers from rapid small-scale column tests. *AWWA Water Science*, 6(2), e1369.

Scaling assumptions, column depth, and other RSSCT design information is provided in **Table 2**. For the large column average particle diameter, a geometric mean was taken of the sieve mesh or range of sizes provided by the manufacturer.

All columns were 0.66 cm in diameter. GAC columns were filled to a depth of 3.5 cm. All ground media were wet sieved using Type 2 ultrapure water. GAC was sieved between No. 120 (0.149 mm) and No. 200 (0.074 mm) sieves.

**Table 2. RSSCT Column Design (yellow cells are inputs, green in cells are key calculated parameters)**

| | Parameter | Unit | Col #1 | Col #2 |
|---|---|---|---|---|
| | **Water** | | **Newberry County** | |
| | **Media** | | **Calgon F400** | **CarbPure 1240** |
| Large Column | EBCT | min | 10 | 10 |
| | HLR | gpm/ft2 | Not Scaled | Not Scaled |
| | Mesh or Diam. Upper Bound | # | No. 12 | No. 12 |
| | Mesh or Diam. Lower Bound | # | No. 40 | No. 40 |
| | Geom. Mean Part. Diameter | mm | 0.840 | 0.840 |
| Small Column Inputs | Column Inner Diameter | cm | 0.66 | 0.66 |
| | Mesh Upper Bound | # | No. 120 | No. 120 |
| | Mesh Lower Bound | # | No. 200 | No. 200 |
| | Geom. Mean Part. Diameter | mm | 0.096 | 0.096 |
| | Non-Constant Diffusivity Mod | - | 0.25 | 0.25 |
| | Column Depth | cm | 3.5 | 3.5 |
| | BV Assump. for Samp. Vol. | BV | 50,000 | 50,000 |
| | Full-Scale Run Time | Days | 347 | 347 |
| | Temperature | C | 20 | 20 |
| Small Column Calculated Parameters | Col Diam : Part. Diam | - | 68.6 | 68.6 |
| | Scaling Factor | - | 8.7 | 8.7 |
| | $EBCT_{SC}$ / $EBCT_{LC}$ | - | 44.4 | 44.4 |
| | Dynamic Viscosity, µ | g/s-cm | 0.0100 | 0.0100 |
| | Density of Water, ρ | g/cm3 | 1 | 1 |
| | PFAS Diffusivity | cm2/s | 5.00E-06 | 5.00E-06 |
| | Sc = µ/(ρ * D) | - | 2,003 | 2,003 |
| | Re | - | 0.25 | 0.25 |
| | Re*Sc | - | 498 | 498 |
| | EBCT | sec | 13.5 | 13.5 |
| | HLR | cm/s | 0.26 | 0.26 |
| | | gpm/ft2 | 3.8 | 3.8 |
| | Bed Volume | mL | 1.20 | 1.20 |
| | Flow Rate | mL/min | 5.3 | 5.3 |
| | Water Volume Required | L | 59.9 | 59.9 |
| | | gal | 15.8 | 15.8 |
| | Testing Duration | days | 7.8 | 7.8 |

## 2.4. Source Water Collection, Filtration, and Disinfection

Newberry County WASA collected the source water and shipped it to One Water. **Table 3** provides information on water sample collection. Samples were collected from the combined filter effluent location prior to post-filtration chemical addition. No field filtration was performed as all drums were filtered in the laboratory prior to testing. No additional field chlorination was performed.

The volume required for each source was based on the column design and assumed BV in **Table 2**, plus conservative factors. It was estimated that two (2) 55-gallon drums of combined filter effluent were required.

Table 3. Source Water Collection Information

| | Newberry County WTP |
|---|---|
| Sample Point | Combined Filter Effluent |
| Field Filtration? | None Required |
| Field Chlorination? | Background Cl2 Residual |
| Volume Required (gal) | 31.6 |
| Safety Factor (gal) | 30 |
| No. 55-gal Drums | 2 |

## 2.5. PFAS Spiking

Source samples were spiked with PFAS to increase the influent concentration, and thereby improve resolution when detecting breakthrough. Hazen prepared stock PFAS stock solutions and shipped them to One Water. The spiking of an additional 30 ng/L of different PFAS to each water was targeted (and verified with sampling). PFAS spiked included PFBA, PFBS, PFPeA, PFHxA, GenX, PFHpA, PFOA, PFHxS, 6:2 FTS, and PFOS. Stock solutions were prepared in ultrapure water and provided in 50 mL centrifuge tubes. The estimated mass per centrifuge tube and number of centrifuge tubes is provided in **Table 4**. This assumed that each centrifuge tube will contain the amount of PFAS to spike one 55-gallon drum that is ~90% full.

Table 4. PFAS Stock Solutions for Spiking (to be provided by Hazen)

| Parameter | Unit | Value |
|---|---|---|
| Drum Volume | gal | 50 |
| | L | 189.3 |
| Target PFAS Conc. in Drum | ng/L | 30 |
| Mass per Tube (each PFAS) | µg | 5.7 |
| Min No. of Tubes | # | 2 |
| Requested No. of Tubes | # | 4 |

## 2.6. RSSCT Checks Operations Data Collection

RSSCT apparatuses were checked at least once per day. The following operations data were collected no less than once per day:

- Manual confirmation of flow rate at or near the set point
- Column bed depth
- Column back pressure
- Column effluent UV-254

# 3. RESULTS

## 3.1. Sieved Media Microscopy

Sieved media were imaged under a microscope to confirm particle size and adequacy of sieving. **Figure** 2 includes microscope images of sieved media. Based on these images, we can observe the relatively narrow size distribution, including removal of fines.

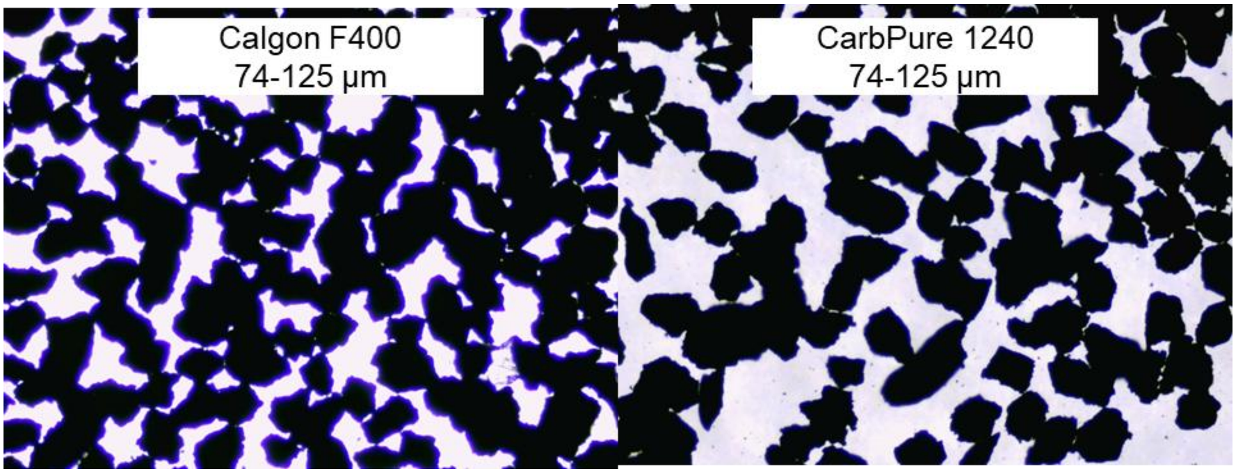


**Figure 2. Microscope Images of Sieved Media**

## 3.2. Source Water Characterization

Samples were collected from the column feed drum on November 4th and November 10th and analyzed for bulk water quality parameters that impact sorbent capacity for PFAS, as well as PFAS concentrations. Results from the duplicate samples were averaged and are reported in **Table 5**. Temperature, pH, and chlorine residual were analyzed in the laboratory the day of RSSCT startup.

Organic carbon, measured as TOC, is expected to be the primary competing constituent. TOC concentration in the source was measured to be 2.9 mg/L. PFAS concentrations were highest for those PFAS that were spiked to the drums (i.e., PFBA, PFPeA, PFHxA, GenX, PFHpA, PFOA, PFBS, 6,2:FTS, PFHxS, and PFOS). The concentration of PFOA (9.8 ng/L) was much lower than expected based on target dose concentration.

It should be noted that PFAS, even after spiking, are present in trace concentrations relative to TOC. For example, TOC was measured to be 2.9 mg/L and the most concentrated PFAS (i.e., PFOS) at 28 ng/L. The mass ratio of TOC : PFOS was > 100,000 : 1. Because natural organic matter (NOM) is more than 5 orders of magnitude more concentrated than PFAS, the concentration of PFAS is not anticipated to affect its time to breakthrough. Spiking of RSSCT source waters does improve detection and resolution in breakthrough curves, and is thus a common practice[3,4].

---

[3] Cheng, L., & Knappe, D. R. (2024). Removal of Per-and Polyfluoroalkyl substances by anion exchange resins: Scale-up of rapid small-scale column test data. *Water Research*, 249, 120956.

[4] Hopkins, Z. R., & Knappe, D. R. (2024). Predicting per-and polyfluoroalkyl substances removal in pilot-scale granular activated carbon adsorbers from rapid small-scale column tests. *AWWA Water Science*, 6(2), e1369.

### Table 5. Source Water Quality Parameters

| Parameter | Unit | Newberry County WTP Filter Effluent (PFAS Spiked) |
|---|---|---|
| Bulk Water Quality Parameters | | |
| Temperature | deg C | 23.2 |
| pH | - | 7.4 |
| Chlorine Res. | mg/L | <0.05 |
| TOC | mg/L | 2.9 |
| Nitrate as N | mg/L | 0.1 |
| Sulfate | mg/L | 2.9 |
| PFAS | | |
| PFBA | ng/L | 24.5 |
| PFBS | ng/L | 25.0 |
| PFPeA | ng/L | 25.0 |
| PFHxA | ng/L | 26.5 |
| 11Cl-PF3OUdS | ng/L | 0.0 |
| 9Cl-PF3ONS | ng/L | 0.0 |
| ADONA | ng/L | 0.0 |
| HFPO-DA | ng/L | 26.0 |
| 8:2FTS | ng/L | 0.0 |
| PFDA | ng/L | 2.4 |
| PFDoA | ng/L | 0.0 |
| PFEESA | ng/L | 0.0 |
| PFHpS | ng/L | 0.0 |
| 4:2FTS | ng/L | 0.0 |
| PFHxS | ng/L | 26.5 |
| PFMPA | ng/L | 0.0 |
| PFMBA | ng/L | 0.0 |
| 6:2FTS | ng/L | 23.0 |
| PFPeS | ng/L | 0.0 |
| PFUnA | ng/L | 0.0 |
| NFDHA | ng/L | 0.0 |
| PFHpA | ng/L | 23.0 |
| PFOA | ng/L | 9.8 |
| PFOS | ng/L | 28.0 |
| PFNA | ng/L | 2.6 |

## 3.3. RSSCT Results

### 3.3.1. Flow Rate and Differential Pressure

Column flow rate versus bed volume as a percent of target flow rate is shown in **Figure 3**, with differential pressure shown in **Figure 4**. Manual flow measurements obtained by graduated cylinder were within 99-101% of the target flow rate. Differential pressures were low and stable for the first 20,000 bed volumes. Around 32,000 bed volumes, differential pressure in the Calgon F400 column began to increase exponentially. Replacement of the upper frit resolved headloss issues in the column. Both columns were able to reach ~50,000 bed volumes without encountering further headloss issues.

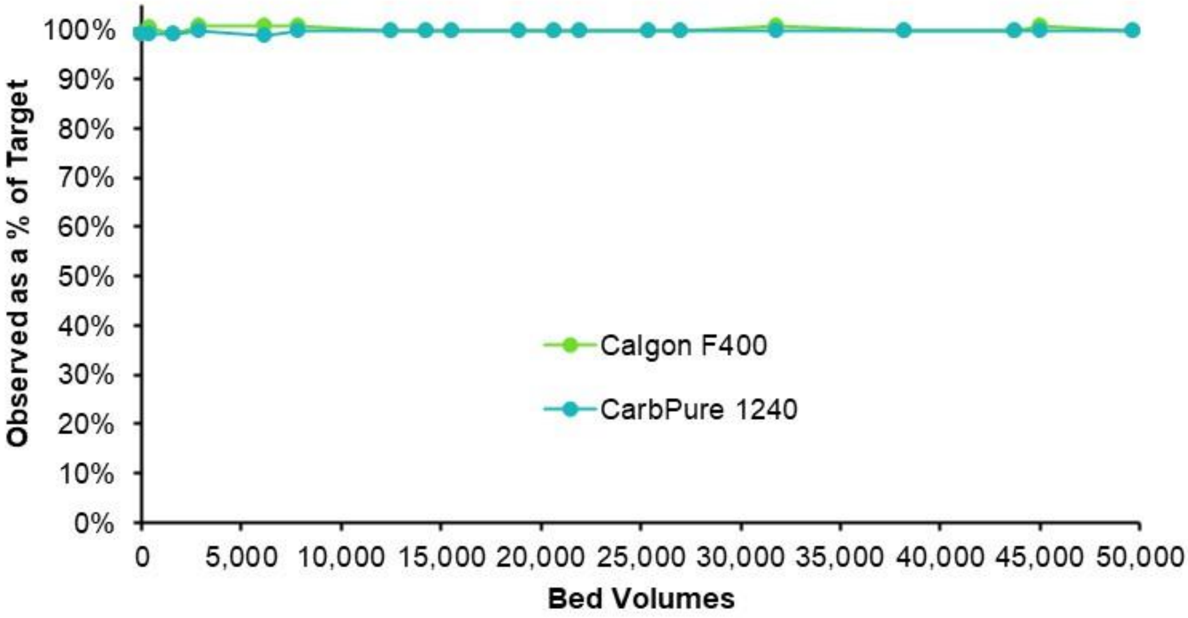


Figure 3. Flow Rate vs. Bed Volume

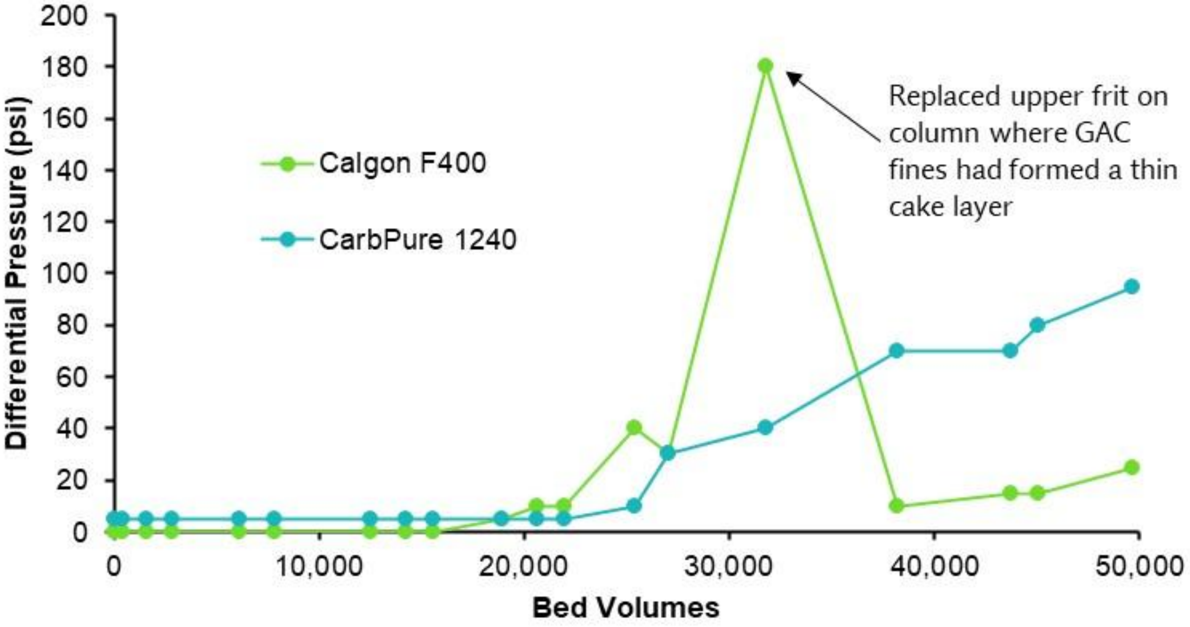


Figure 4. Differential Pressure vs. Bed Volume

### 3.3.2. PFAS Breakthrough Curves

PFAS breakthrough curves were plotted and grouped based on chain length. Plots of concentration units are shown in Section 3.3.2.1 and breakthrough fraction plots in Section 3.3.2.2. PFAS plots were divided into four groups based on chain length:

- Group 1: PFBA, PFBS, PFPeA
- Group 2: GenX, PFHxA, PFHxS, PFHpA, 6:2 FTS
- Group 3: PFOA, PFOS

Each plot has two horizontal axes: bed volumes and operating time. Operating time assumed that each contactor would be operated at the design EBCT, but only operated 50% of the time (i.e., total run time twice that if the system was operated at design EBCT 24 hours per day, 365 days per year). Hazen described this mode of operation as assuming the average flow rate (i.e., 1 MGD), with two contactors alternating in operation.

Based on the results in in Section 3.3.2.1 and 3.3.2.2, the general observations below were made. Estimates of bed volumes and operating time to media changeout are discussed in Section 3.3.3.

- Short-chain PFAS broke through faster than long-chain PFAS for all media tested, and for a given chain length, PFAS with carboxylic acid head groups (ending in "A") broke through faster than PFAS with sulfonic acid head groups (ending in "S"). These results are consistent with typical pilot and RSSCT results obtained in other waters.
- Competitive adsorption of PFAS and NOM can cause desorption of PFAS from media, resulting in effluent concentrations that exceed the influent. This was particularly noticeable for PFBA, PFPeA, and GenX. Desorption of GenX has regulatory significance given that source concentrations may be below the MCL, but effluent could exceed the MCL due to desorption (see Section 3.3.3).
- For PFOA and PFOS, CarbPure 1240 broke through later than Calgon F400. However, PFOA reached near 100% breakthrough at similar times for both media; this is similarity is particularly important if source concentrations and changeout thresholds lead to GAC replacement around this level of breakthrough (see Section 3.3.3).
- CarbPure 1240 had longer bed life for long-chain PFAS (e.g., PFOA, PFOS) than Calgon F400, but exhibited more competitive desorption of short chain PFAS than Calgon F400, including for GenX.

### 3.3.2.1. Concentration Units

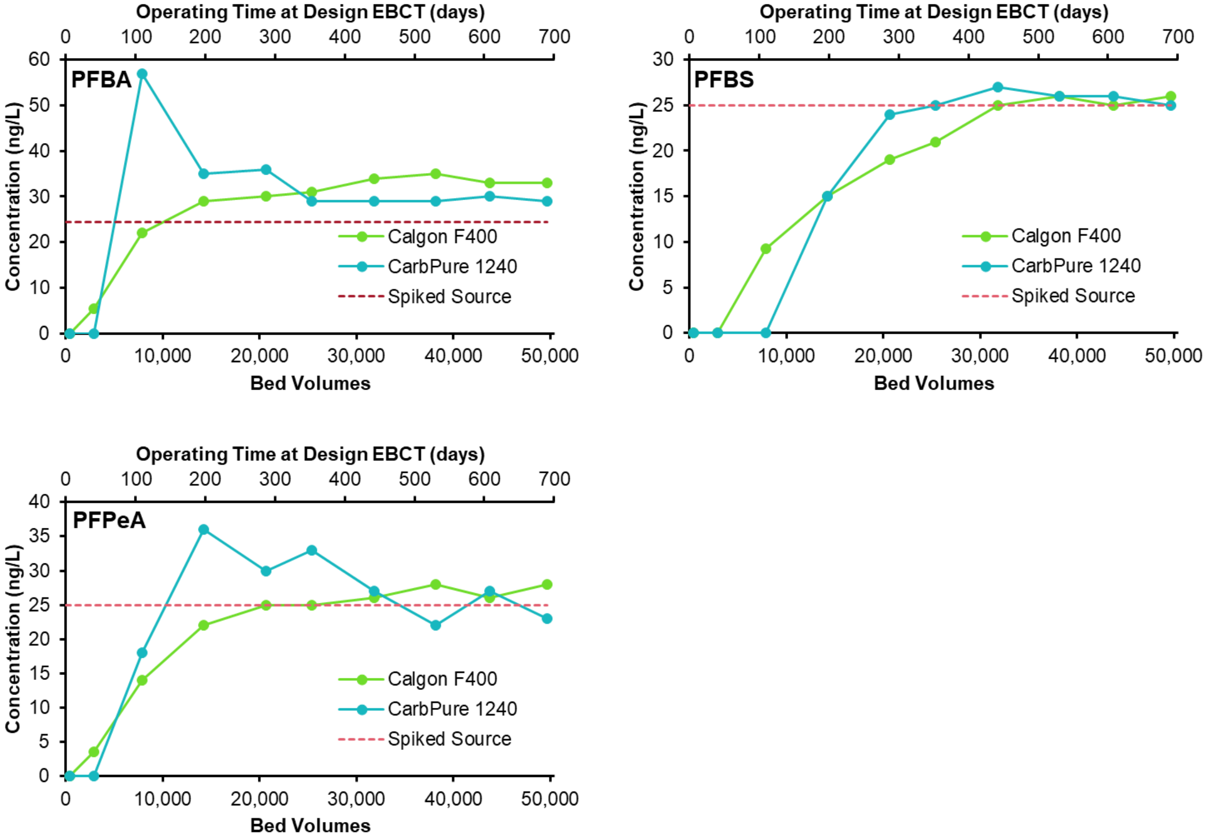


Figure 5. Column Effluent Concentrations for PFBA, PFBS, and PFPeA

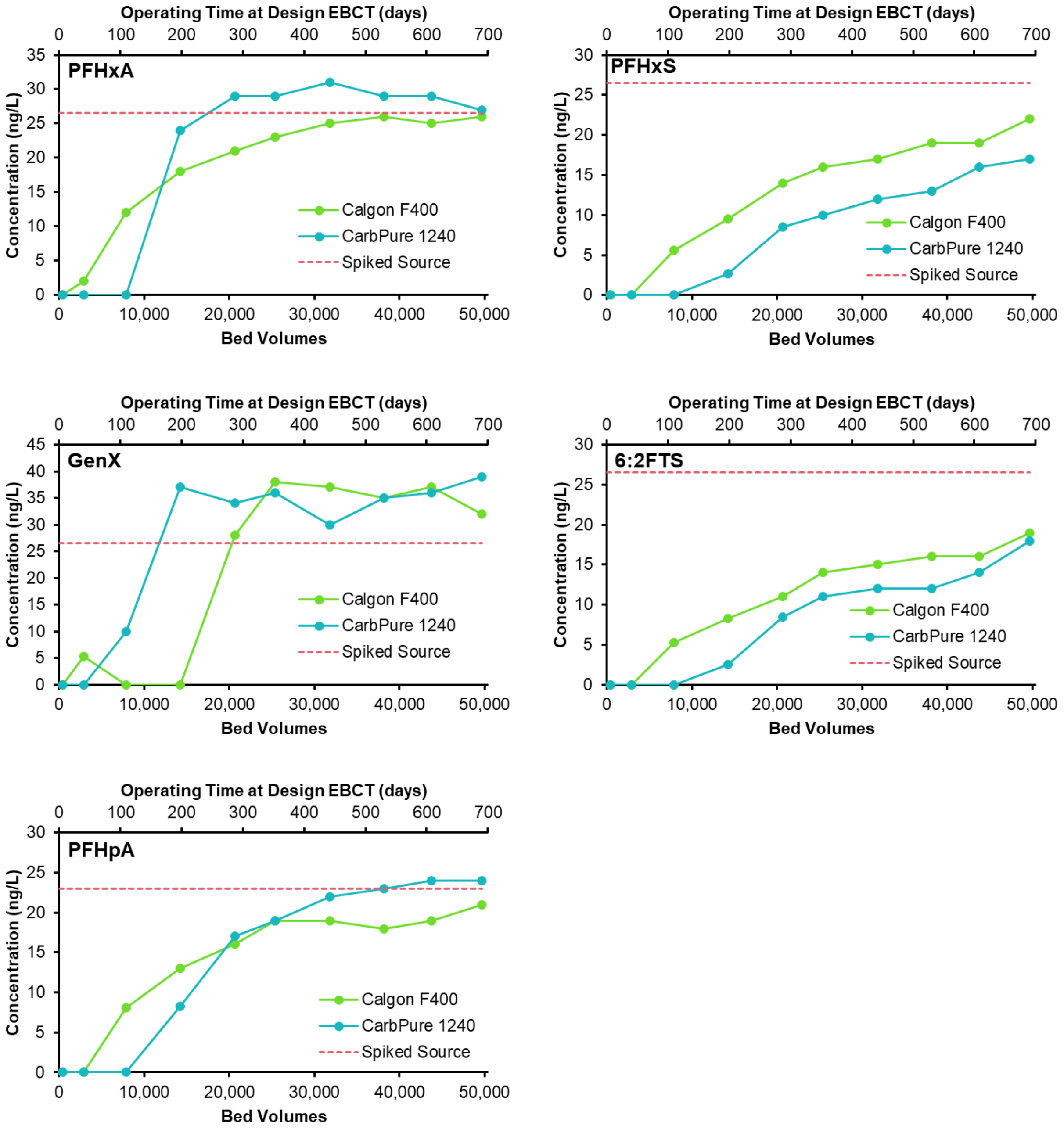


**Figure 6. Column Effluent Concentrations for GenX, PFHxA, PFHxS, PFHpA, 6:2 FTS**

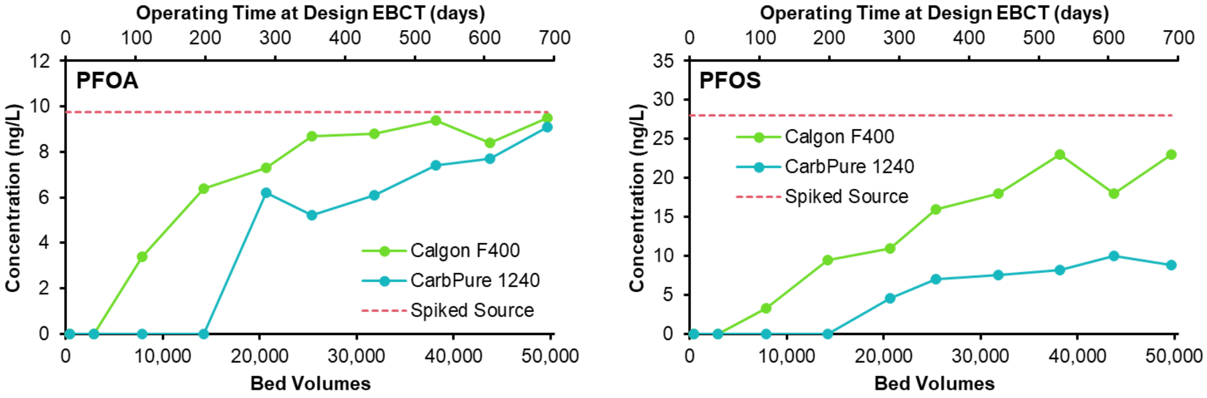


Figure 7. Column Effluent Concentrations for PFOA and PFOS

### 3.3.2.2. Breakthrough Fraction

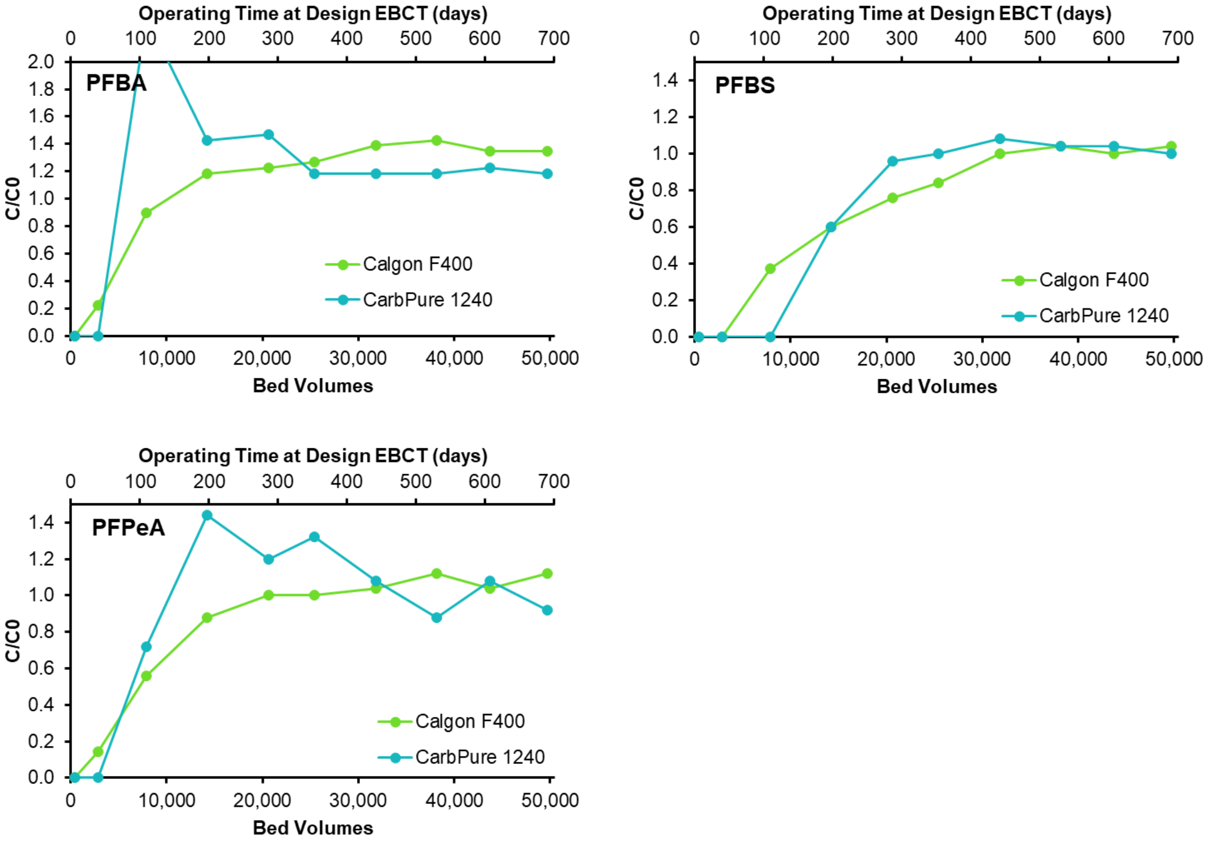


Figure 8. Breakthrough Fraction for PFBA, PFBS, and PFPeA

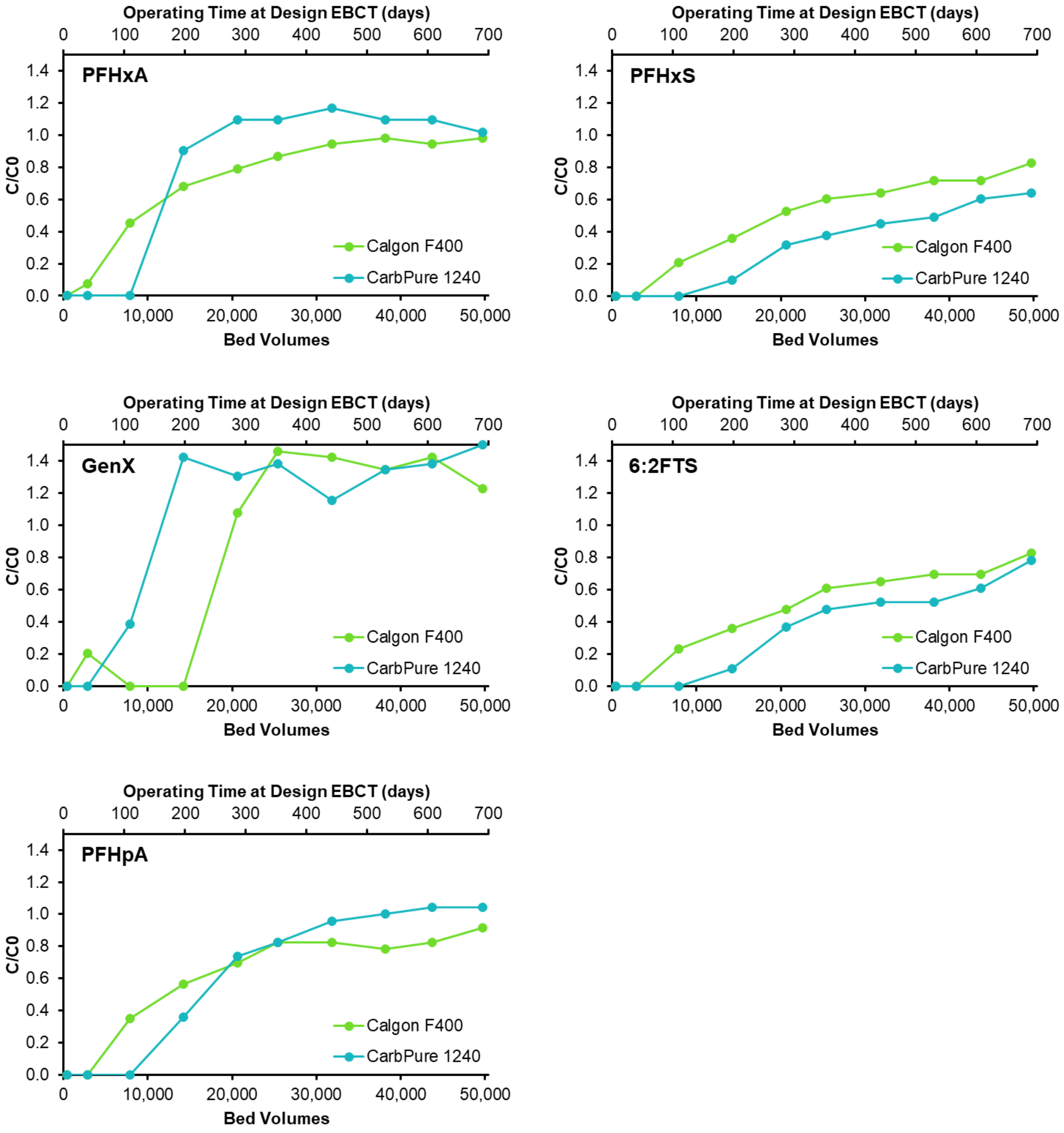


Figure 9. Breakthrough Fraction for GenX, PFHxA, PFHxS, PFHpA, 6:2 FTS

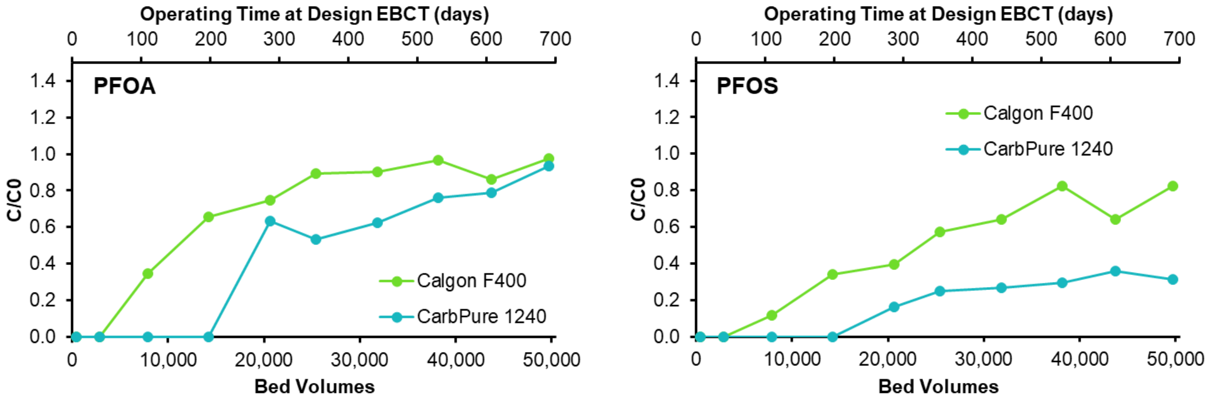


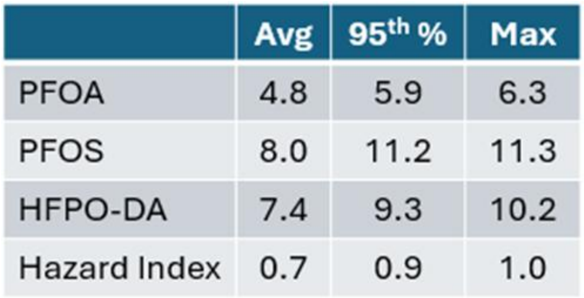
**Figure 10.Breakthrough Fraction for PFOA and PFOS**

### 3.3.3. Estimates of Bed Volumes and Time to Breakthrough

To compare the efficacy of different media, a changeout threshold is needed. In practice, this will be some fraction of the MCL (e.g., 50%, 75%, or 100%). Because regulated PFAS were spiked to the source drums, the comparison should not be performed on the basis of raw concentration units. Therefore, historical PFAS occurrence data was used to estimate a breakthrough fraction ($C/C_0$) that would be used for changeout, and then interpolating RSSCT data to estimate the number of bed volumes to reach that breakthrough fraction.

Newberry County currently has limited PFAS occurrence data, so Hazen reviewed UCMR 5 concentrations from neighboring utilities and summarized the average, 95th percentile, and maximum concentrations (see **Table 6**). Changeout frequency in this memorandum was estimated based on both 95th percentile and average PFAS concentrations.

**Table 6. Summary of UCMR 5 Detects from Neighboring Utilities (source: Hazen)**



| | Avg | 95th % | Max |
|---|---|---|---|
| PFOA | 4.8 | 5.9 | 6.3 |
| PFOS | 8.0 | 11.2 | 11.3 |
| HFPO-DA | 7.4 | 9.3 | 10.2 |
| Hazard Index | 0.7 | 0.9 | 1.0 |

Because a GAC treatment system is being designed with lead-lag vessels, changeout threshold in the lead vessel was assumed to be equal to the MCL for PFOA, PFOS, and HFPO-DA (GenX). This allows full utilization of the media in the lead bed because the lag is available to prevent PFAS breakthrough into the finished water. It is important to note that RSSCT results and estimates of time to breakthrough are representative of the initial fill of the lead vessels only. When the lag vessel becomes the lead vessel, time to breakthrough will be shorter due to the prior loading of the media before it is placed in the lead position. Another important caveat is that days to changeout were estimated based on design flow and EBCT. At lower flows representative of typical operation, media changeout would be expected less frequently.

The breakthrough thresholds were compared to the RSSCT breakthrough curves presented previously to estimate bed volumes and operating time to changeout for each material. The results of that analysis assuming average flow are presented in **Table 7**. For Calgon F400, PFOA or PFOS were estimated to drive changeout at around 220 days of operation assuming 95th percentile influent concentrations, and approximately 325 days assuming average influent concentrations. For CarbPure 1240, GenX was estimated to drive changeout at approximately 150 days assuming 95th percentile influent concentrations, and approximately 190 days assuming average influent concentrations. These findings are consistent with observations from the previous section where CarbPure 1240 had longer bed life for long-chain PFAS (i.e., PFOA and PFOS) relative to Calgon F400, but faster breakthrough and greater desorption for short-chain PFAS like GenX.

**Table 7. Estimated Ved Volumes and Time to Changeout (at Average Flow) for Each Sorbent**

| **Estimated BV and Days to Changeout** | | | | | | |
|---|---|---|---|---|---|---|
| | **PFOA** | | **PFOS** | | **GenX** | |
| **95th Percentile Concentration - Neighboring Utilities** | | | | | | |
| Influent Conc. (ng/L) | 5.9 | | 11.2 | | 11.2 | |
| Threshold | 4 ng/L | | 4 ng/L | | 10 ng/L | |
| | 68% | | 36% | | 89% | |
| Media | BV | Days | BV | Days | BV | Days |
| Calgon F400 | 15,700 | 218 | 16,400 | 228 | 19,500 | 271 |
| CarbPure 1240 | 35,600 | 494 | 43,700 | 607 | 11,000 | 153 |
| **Average Concentration - Neighboring Utilities** | | | | | | |
| Influent Conc. (ng/L) | 4.8 | | 8.0 | | 7.4 | |
| Threshold | 4 ng/L | | 4 ng/L | | 10 ng/L | |
| | 83% | | 50% | | 135% | |
| Media | BV | Days | BV | Days | BV [1] | Days [1] |
| Calgon F400 | 23,500 | 326 | 23,500 | 326 | 24,100 | 335 |
| CarbPure 1240 | 45,500 | 632 | >49,600 | >689 | 13,800 | 192 |

[1] CarbPure 1240 GenX interpolated omitting ND at 25,400 BV

### 3.3.4. UV-254 Breakthrough

UV-254 can be used as a surrogate for NOM and can be measured in real time. UV-254 was collected during RSSCTs to estimate NOM breakthrough from each sorbent. Caution should be used in interpretation of the results because only a fraction of TOC absorbs UV at 254 nm, and that fraction is not likely removed in the same ratios as TOC as a whole. Also, the use of constant diffusivity RSSCT design is likely to underpredict removal of NOM at full-scale, particularly for GAC.

NOM is made up of large, complex molecules, unlike smaller micropollutants such as PFAS. For GAC, NOM removal follows proportional diffusivity assumptions[5]. Thus, the modified constant diffusivity assumptions used for GAC result in shorter RSSCT EBCTs, and thus likely underpredict organics

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[5] Crittenden, J. C., Reddy, P. S., Arora, H., Trynoski, J., Hand, D. W., Perram, D. L., & Summers, R. S. (1991). Predicting GAC performance with rapid small-scale column tests. *Journal AWWA*, 83 (1): 77-87.

removal. Nonetheless, it is worth reporting the relative trends of different materials as UV-254 can be used as an indicator of DBP precursor reduction, as well as the level of organic fouling or competition.

**Figure 11** shows UV-254 breakthrough versus bed volumes and operating time at average flow (i.e., 50% of design flow). CarbPure 1240 removed more NOM than Calgon F400, which was consistent with long-chain PFAS removal capacity presented previously.

At the estimated BV to changeout based on PFAS breakthrough, UV-254 removals were estimated to be 25-30% by Calgon F400 and 50-65% by CarbPure 1240. These findings suggest that most of the NOM removal capacity for Calgon F400 would be exhausted at the time of changeout due to PFAS breakthrough. However, if filter changeouts are staggered, there would likely be more significant removal in blended effluent. CarbPure 1240 would likely have greater removal of NOM given that it has greater capacity and would be changed out more frequently (i.e., earlier on the breakthrough curve).

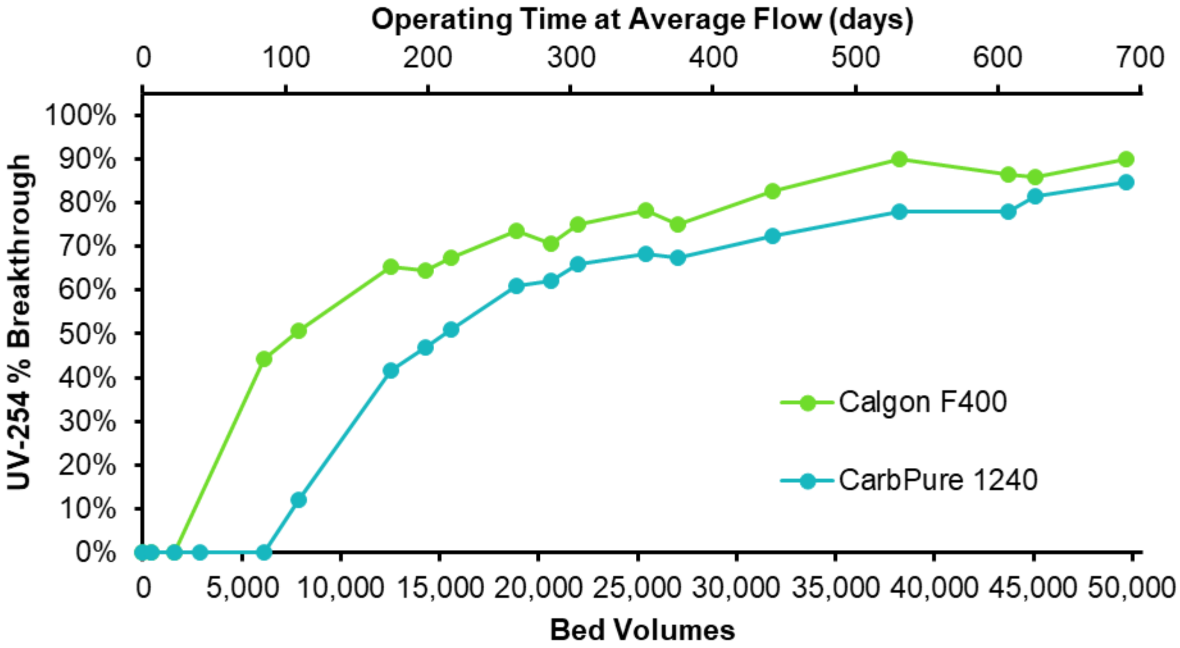

**Figure 11. UV-254 Breakthrough vs. Bed Volumes**