Vermont Agency of Natural Resources,
Department of Environmental Conservation

PFAS Treatment Engineering Document

August 2024

Contact Information

Contact:

Nadine Demers, Environmental Analyst
Agency of Natural Resources, Department of Environmental Conservation
nadine.demers@vermont.gov, 802-261-5872

Nathan Callas, P.E. – Division Engineer
Agency of Natural Resources, Department of Environmental Conservation
nathan.callas@vermont.gov, 802-461-8565

Sille Larsen - Engineering and Water Resources Program Manager
Agency of Natural Resources, Department of Environmental Conservation
sille.larsen@vermont.gov, 802-522-8709

Table of Contents

1 Introduction

On April 10, 2024, the U.S. Environmental Protection Agency (EPA) finalized drinking water standards for six per- and polyfluoroalkyl substances (PFAS). The federal Maximum Contaminant Levels (MCLs) are lower than Vermont's current regulatory standards. Under these new federal MCLs, many water systems will be required to either install treatment or find an alternative water supply source without PFAS. If treatment is selected to address PFAS contamination, the implementation requires thoughtful consideration to ensure optimized operation and treatment performance. The selection of PFAS treatment technologies is dependent on target PFAS to be removed, raw water quality, treatment facility space, operational changes, and capital and lifecycle costs (American Water Works Association (AWWA), 2020). This document presents important considerations in design and implementation, standard startup procedures, and expectations from permitting to final construction completion and subsequent maintenance. It is intended for use by engineers, water systems, and operators that will be designing, implementing and operating PFAS treatment at Vermont Public Water Systems.

2 PFAS Treatment Systems in Vermont

In March 2023, the EPA proposed the National Primary Drinking Water Regulation of six PFAS: perfluorooctanoic acid (PFOA), perfluorooctane sulfonic acid (PFOS), perfluorohexane sulfonic acid (PFHxS), perfluorononanoic acid (PFNA), hexafluoropropylene oxide dimer acid (commonly known as GenX Chemicals; HFPO-DA), and perfluorobutane sulfonic acid (PFBS). On April 10, 2024, EPA finalized the regulation with some differences from what was proposed. The federal MCLs are different than Vermont's current regulatory approach and include levels lower than the current Vermont standard and utilizes a new hazard index to assess a mixture of certain PFAS chemicals. The final federal maximum contaminant levels (MCLs) and maximum contaminant level goals (MCLGs) are summarized below:

Regulatory Levels: Summary

Chemical	Maximum Contaminant Level Goal (MCLG)	Maximum Contaminant Level (MCL)
PFOA	0	4.0 ppt
PFOS	0	4.0 ppt
PFHxS	10 ppt	10 ppt
HFPO-DA (GenX chemicals)	10 ppt	10 ppt
PFNA	10 ppt	10 ppt
Mixture of two or more: PFHxS, PFNA, HFPO-DA, and PFBS	Hazard Index of 1	Hazard Index of 1

Notes:

Compliance is determined by running annual averages at the sampling point

ppt – parts per trillion

More information on the final rule is available at https://www.epa.gov/sdwa/and-polyfluoroalkyl-substances-pfas. The final rule requires Community (C) and Non-Transient Non-Community (NTNC) water systems to provide notification of an MCL violation as soon as practicable but no later than 30 days after the system learns of the violation. The Drinking Water and Groundwater Protection Division (the Division) is working to develop a State specific approach to public notification in the event of an MCL exceedance.

As of May 2024, 35 public water systems have concentrations of PFOA or PFOS over 4 parts per trillion (ppt). Additionally, 73 public water systems currently have PFAS detections that are below the federal MCLs of 4.0 ppt for PFOA and PFOS. As a result of the new federal MCLs, more water systems will be required to install treatment or find an alternative water supply source.

2.1 PFAS Treatment Systems

PFAS treatment systems using granular activated carbon (GAC) were installed prior to the passing of Act 21 in 2019 at Pownal FD2 (VT0020734), the Rutland Airport Business Park (VT0020639), Warren Elementary School (VT0006664), and Grafton Elementary School (VT0006076) as part of the early PFAS investigations. These treatment systems do not meet the technical design requirements as stated in the 2020 Vermont Water Supply Rule (Rule) update. Since the passing of Act 21 in 2019 to 2023, seventeen (17) water systems have exceeded the Vermont MCL and have been working with the Division to install treatment, evaluate a new source of water that is not contaminated with PFAS, or evaluate well repairs. The table below summarizes the water systems and their status in addressing PFAS as of June 1, 2024 and the proposed solutions.

Water System PFAS Mitigation Method and Status as of June 1, 2024

WSID	Water System Name	Water System Type	PFAS Mitigation Method and Status	Treatment Type
VT0020734	POWNAL FD2	C	Temporary treatment installation complete; actively constructing permanent treatment.	GAC
VT0020639	RUTLAND AIRPORT BUSINESS PARK	NTNC	Treatment installation complete	GAC
VT0006664	WARREN ELEMENTARY SCHOOL	NTNC	Treatment installation complete	GAC
VT0006076	GRAFTON ELEMENTARY SCHOOL	NTNC	Treatment installation complete	GAC
VT0006764	THETFORD ACADEMY	NTNC	Treatment installation complete	GAC
VT0002396	KILLINGTON MOUNTAIN SCHOOL	NTNC	Treatment installation complete	GAC
VT0002603	BUTTERNUT PROPERTIES	NTNC	Treatment installation complete	GAC
VT0001436	SUMMIT LODGE AT KILLINGTON	TNC	Treatment installation complete	GAC
VT0000402	CHALET KILLINGTON	TNC	Treatment installation complete	GAC
VT0000918	FOUNDRY	TNC	Treatment installation complete	GAC
VT0000756	KVI 2500	TNC	Treatment installation complete	GAC
VT0003263	KILLINGTON MOUNTAIN LODGE	TNC	Treatment installation complete	GAC
VT0006098	LEICESTER CENTRAL SCHOOL	NTNC	Well repair complete	NA
VT0005504	FIDDLEHEAD CONDOMINIUMS	C	New well – complete	NA
VT0006075	MOUNT HOLLY SCHOOL	NTNC	New well and treatment installation- in progress	proposed - GAC
VT0020361	KIDS IN THE COUNTRY	NTNC	New well - in progress	NA
VT0006690	E TAYLOR HATTON	NTNC	New well - In progress	NA
VT0005194	CRAFTSBURY FIRE DISTRICT 2	C	New well - in progress	NA

VT0006669	WOODBURY ELEMENTARY SCHOOL	NTNC	TBD - In progress	NA
VT0005304	NORTHSHORE MHP	NTNC	TBD - In progress	NA
VT0005165	MOUNTAIN SIDE RESORT	C	TBD	NA

Notes:

NTNC – Non-Transient Non-Community Water System

TNC – Transient Non-Community Water System

C – Community Water System

NA – Not Applicable

TBD - To be determined

2.2 PFAS Treatment Efficacy Study

The Division is conducting a PFAS Treatment Efficacy Study (Study) to further the State's understanding of treatment requirements and evaluate how to optimally design treatment for PFAS. The Division will evaluate the effectiveness of GAC filtration, considering pretreatment, water quality, filter configuration, and operational requirements. The Study is being conducted on four (4) Public Water Systems with existing PFAS treatment installed in a lead/lag filter configuration that meet the required total Empty Bed Contact Time (EBCT) of 20 minutes, and Public Water Systems that also operate at a reduced EBCT (less than 20 minutes). Initial water quality samples were collected of raw water, after pretreatment (where applicable), between the lead and lag filters (midpoint) of the GAC treatment, and entry point to distribution from each of the water systems at the start of the Study and annually at the beginning of the year. PFAS samples are collected at the GAC filter midpoint sample location according to the existing compliance monitoring schedule. Additional water quality samples are collected at the GAC filter midpoint quarterly or on an as-needed basis.

The data from the Study will be used to understand GAC treatment efficacy, media lifespan and operational considerations. This information will allow the Division to better assist impacted water systems on media type, life span, media changeout, etc., and inform changes to the Rule on treatment design. The study is expected to run from January 2024, for 2-5 years.

3 Planning for New PFAS Treatment Systems in Vermont

The implementation of PFAS treatment requires thoughtful consideration to ensure optimized operation and treatment performance. The selection of appropriate PFAS treatment technologies is dependent on several factors such as target PFAS to be removed, treatment objectives, raw water quality, size and location of the treatment facility space, operational changes, and capital and lifecycle costs (AWWA, 2020). The following sections describe important considerations in designing and implementing PFAS treatment, standard startup procedures, and overall expectations from permitting to final construction completion.

The expectation for PFAS treatment is to meet the MCLG of 0 ppt for regulated PFAS. This document is meant to provide supporting guidance and considerations when designing treatment that align with design standards and regulatory requirements outlined in the Rule where applicable.

3.1 Best Available Technology

Three technologies have been identified as best available technologies by the EPA. GAC, anion exchange (AIX) and reverse osmosis (RO)/nanofiltration (NF) have demonstrated the ability to effectively remove PFAS from drinking water in full-scale applications (EPA, 2024a). Their application in drinking water PFAS removal has grown in recent years and have been documented in practice and in peer-reviewed literature.

Although RO/NF is effective at removing both short and long chain PFAS types, there are limitations that make it an impractical choice in a public drinking water treatment application. Approximately 20% of feedwater ends up as the concentrate stream with PFAS as part of the process. The Vermont Underground Injection Control (UIC) Program does not offer drinking water treatment exemption for PFAS, making indirect discharge of RO concentrate impermissible. For these reasons, this document only focuses on the application of GAC and AIX for PFAS treatment.

For additional resources on alternative treatment technologies, the Interstate Technology Regulatory Council (ITRC) has developed a PFAS Technical and Regulatory Guidance Document which includes a summary of current treatment methods, in addition to novel technologies. These novel technologies show promise for removing PFAS but have not yet adequately demonstrated PFAS removal from drinking water. As this is a very active area of research, the ITRC updates this section and the table periodically as additional treatment approaches and technologies continue to be developed and evaluated in the future (https://pfas-1.itrcweb.org/12-treatment-technologies/). Using a novel technology would need to be reviewed and assessed on a system-by-system basis.

3.2 Treatment Space Evaluation

An assessment of the proposed treatment space shall be conducted evaluating any potential impacts (i.e., exposure to weather elements, located within a flood plain, etc.) and ensuring that the treatment components will be located within a building with appropriate environmental controls suitable for Vermont’s climate (i.e., heating, ventilation, lighting, not in a confined space). The treatment components shall be housed in enclosures that provide adequate room for all routine operation, monitoring, and maintenance tasks, and include easy accessibility for filter media changeout. It is important to evaluate if existing buildings are sufficient to meet the needs of the PFAS treatment or if a bigger footprint is required. Different types of treatment should be evaluated if the footprint is restricted (i.e., AIX has a smaller footprint than GAC).

As part of the treatment space evaluation, consider existing infrastructure such as existing wells, pump stations, treatment components, and storage that may affect proposed treatment design. If applicable, existing disinfection treatment infrastructure shall be evaluated and will address any improvements that are necessary to ensure disinfection treatment will meet requirements of Appendix A, Subpart 4.3 of the Rule and 40 CFR Part 141. Any other improvements to the water system infrastructure must be considered (e.g., new storage or pumping facilities, etc.) that may be necessary as part of the proposed treatment design, and make sure to include such additional improvements in the life cycle costs analysis.

If existing or proposed treatment components need backwashing, filtering to waste, or create an effluent waste stream, a plan for disposing of process waste shall be included in the basis of design. Depending on the location and size of the facility and the contaminants in the waste, this may involve discharging to an existing wastewater facility, the construction of a new dry well, or another method that meets all applicable regulations (e.g., chlorinated water is not discharged to waters of the state). The area surrounding the treatment facility should be evaluated for feasible solutions.

3.3 Water Quality Evaluation for Selection of Treatment Technology

A water quality evaluation shall include characterization of water quality with an emphasis on contaminants and co-contaminants and the removal rate of the contaminants by the proposed treatment facility. Water quality characterization shall be developed based on laboratory data obtained from representative samples of the water to be treated in the water system within the past two years unless the Division has given prior approval to use older water quality data (Appendix A, Subpart 4.11.1(a)). Samples must be collected and analyzed in accordance with the requirements of Subchapter 21-6 of the Rule.

Water quality results for raw and finished water (if there is existing treatment) should include all relevant co-contaminants necessary to adequately characterize the water quality and determine the use of treatment technology. At a minimum, water quality parameters such as turbidity, nitrate, iron, manganese, pH, alkalinity, hardness, and total organic carbon (TOC) are needed to evaluate GAC and AIX treatment technologies. Additional parameters such as nitrite, phosphate, sulfate, bicarbonate, and chloride have been identified through studies from other states and literature as part of the sampling regime. Consultants are encouraged to decide which water quality parameters are needed for a thorough evaluation to better assess constituents that may interfere with treatment efficacy and evaluate if pretreatment is necessary. Details on water quality evaluations of competing contaminants for GAC and AIX are described in Sections 4.1.1 and 4.2.1, respectively.

3.4 Granular Activated Carbon (GAC) and Anion Exchange (AIX) Comparison

3.4.1 GAC

GAC successfully removes PFAS through adsorption processes where the entire PFAS molecule binds to the surface of the GAC media. The process of activating carbon increases the pore size and the internal surface area on which compounds can adsorb. GAC media can originate from different carbonaceous materials such as bituminous coal, wood, lignite coal, and coconut shells. The performance of these different GAC products can vary widely in adsorption capacity depending on several factors such as target organic contaminant, EBCT, hydraulic loading rate, influent water quality, and flow rate of water flowing through the bed (Rahman et al., 2014). Most originating carbonaceous materials have proven to be effective in PFAS adsorption; however, bituminous GAC has been utilized for the majority of PFAS treatment applications in Vermont. Recent studies have shown that bituminous GAC media exhibit higher PFAS adsorption and removal than non- and sub-bituminous GACs such as coconut-based media (McNamara et al., 2018, Medina et al., 2022, Pannu et al., 2023). Bituminous GACs have a higher capacity to adsorb PFAS due to the presence of larger transport pores allowing the PFAS compounds to access the adsorption sites whereas non-bituminous GACs contain a narrower pore structure which can restrict access to more PFAS adsorption sites (Liu et al., 2019). Media performance can vary even among the bituminous GACs based on recent studies by Medina et al., 2022 and Pannu et al., 2023. For instance, Medina et al., 2022 showed that Calgon Carbon F400 had higher adsorption for longer chained PFAS, such as PFOA and PFOS whereas Calgon Carbon F600 had higher adsorption capacity for shorter chained PFAS, such as PFBS and perfluorohexanoic acid (PFHxA). Additionally, PFAS type present in raw water may also influence the choice of media. This highlights the need to understand the contaminant characteristics and concentrations being removed and evaluating how that can influence the selected choice of media.

3.4.2 AIX

There are commercially available PFAS-selective AIX resins that have high affinity for PFAS compounds and can remove PFAS in drinking water. AIX resins are made of synthetic polymer plastic beads or gel material. The surface of the AIX resins is chemically activated with a solution leaving negatively charged ions, (typically chloride, Cl^{-}) combined with a positively charged functional group on the resin. PFAS compounds typically have a negatively charged anionic “head” which are exchanged with the negatively charged ions on the resin. Thus, the PFAS compounds remain attached to the positively charged exchange sites on the resin surface. PFAS-selective resins implement a dual removal process of ion exchange and adsorption which increases PFAS removal capacity when compared to treatment technologies using only adsorption (Woodard et al., 2017). This exchange process continues until the resin material no longer has sufficient exchange sites to remove the PFAS compounds. Capacity depends on the concentrations of competing anions, such as sulfate and nitrate, and on the specific PFAS breakpoint chosen for resin changeout. A study by GSI Environmental Inc. to conduct pilot testing to evaluate the performance and life cycle costs for ion exchange (IX) and GAC to treat groundwater impacted by PFAS, found that the IX resin PSR2 Plus performed the best when evaluated against PFOA breakthrough. However, the results are based on extrapolation of data due to lack of breakthrough during the pilot (GSI Environmental Inc., 2021).

In traditional AIX contaminant removal (e.g. nitrate removal), the resin can be regenerated by rinsing the resin with a concentrated chloride solution. However, commercially available resins used for PFAS removal in drinking water applications are single use (EPA, 2024b).

3.4.3 GAC vs. AIX

Each technology comes with its own limitations and important considerations that need to be evaluated prior to the installation of full-scale treatment. The removal of PFAS using GAC relies on the adsorptive properties of activated carbon media, where PFAS contaminants are adsorbed into the surface of pores within the media. GAC may be preferential to other treatment technologies depending on the presence and concentrations of raw water co-contaminants, PFAS type, and available treatment space. GAC is commonly used to treat organic compounds. Therefore, there may be an added benefit of co-contaminant removal in addition to PFAS removal, however, this may reduce media lifespan due to the adsorption of non-target compounds. However, PFAS-selective AIX resins use two forms of contaminant removal: adsorption and ion exchange, resulting in the need for less media and a smaller footprint than GAC filters and a shorter EBCT resulting in longer media lifespan and reduced long term operation and maintenance (O&M) costs. PFAS type and the presence of co-contaminants may also influence treatment selection (i.e. high levels of TOC may impact media lifespan of GAC to a greater degree than lifespan of AIX resin; the presence of raw water anions may impact media lifespan of AIX). Both GAC and AIX removal efficiency can be affected by the PFAS chain length, functional group, and isomer structure (branched or linear) (McCleaf et al., 2017). Additionally, PFAS with sulfonate functional groups show greater removal efficiency than those with carboxylate groups (McCleaf et a., 2017). A study conducted by Pannu et al., 2023 showed that short chain PFAS and carboxylic functional groups breakthrough faster than longer chain PFAS and a sulfonic functional group. This is due to short chain PFAS and a carboxylic functional group being less adsorbable to GAC media. GAC is more efficient at removing longer chain PFAS than shorter chain PFAS (Murry et al., 2021). GAC media life can be negatively impacted by the presence of TOC as it competes for adsorption sites with PFAS compounds (Pannu et al., 2023). Given these considerations, treatment selection and design must be justified in detail (media lifespan, pretreatment selection, etc.) to determine the most cost-effective PFAS mitigation alternative.

To compare media lifespan, EPA has developed bed life equations for GAC and AIX (https://www.epa.gov/system/files/documents/2024-04/2024-pfas-tech-cost_final-508.pdf). Bed life refers to the amount of time a technology remains effective and can maintain a target removal efficiency. Bed life is the time until a media becomes saturated with adsorbed compounds and can no longer effectively remove the target constituents. It can be expressed as days or months or bed volumes treated. For the GAC bed life equations, the EPA compiled data from six peer-reviewed publications with existing bed life data, multiple PFAS compounds, measured TOC or dissolved organic matter (DOC), and with an EBCT of 10 minutes per vessel. For the AIX bed life equations, the EPA used rapid small scale column tests (RSSCT) data from Zeng et al., 2020 since full-scale bed life data were not available for AIX using PFAS resins. Using this data, the EPA developed models using multiple linear regression resulting in PFAS compound specific bed life equations for GAC and AIX. These bed life equations may be used as a rough assessment of potential media lifespan, however, they have their limitations and should not be assumed to replace site-specific engineering analyses or pilot studies. Several assumptions have been made and the equations do not account for factors like media fouling, the presence of other competing contaminants, variations in peak demand through the filter, or average day demand (used in media lifespan estimates, and differences in EBCT). Therefore, the bed life equations may result in a high estimate of bed life. However, despite the limitations, bed life calculations may be useful to compare GAC and AIX based on site-specific water chemistry as part of the alternatives analysis in lieu of a pilot or other methods.

Additionally, Drinking Water Treatment Technology Unit Cost Models are available to estimate treatment costs for GAC and AIX (https://www.epa.gov/sdwa/drinking-water-treatment-technology-unit-cost-models). The EPA developed these models with the purpose of estimating national regulatory compliance costs. However, these models may be used for other applications when sufficient care is considered. They could be used in developing preliminary site-specific treatment cost estimates for a water system when adjusted with relevant cost data, site-specific design configurations, and operational conditions. Although there are assumptions made and default values programmed into the model, it can be used for the relative comparisons between GAC and AIX treatment costs based on water system conditions, design assumptions, and other water system specific factors.

These bed life equations and cost models may be submitted in a planning document as a part of the document's alternatives analysis or as part of a construction permit application to satisfy Appendix A, Subpart 1.2.3 of the Rule. Water systems proposing to treat PFAS using GAC shall include an alternatives analysis in their construction permit application that satisfies the requirements of Appendix A, Subpart 4.11.1 of the Rule. The Division may require additional justification such as a pilot, RSSCT, or other types of site-specific technical justification if the cost models, non-monetary factors, and other submitted materials do not provide adequate justification for the selected alternative.

3.5 Piloting

Treatment efficacy can be influenced by the water being treated, PFAS type, media type, EBCT, peak flow through the treatment, and consistency of flow through the treatment. Conducting lab and/or pilot testing can help assess the efficacy of different treatment technologies or media types with site specific water quality and operational conditions and determine if pretreatment is necessary. Additionally, these tests can identify potential unknown impacts to the design prior to making the investment of full-scale treatment installation. Testing can provide a better understanding of media replacement frequency and actual life cycle costs and O&M estimates.

Pilot studies may be required by the Secretary for proposed applications of GAC treatment when other compounds in the water may interfere with effective GAC treatment (Appendix A Part 4 of the Rule). If the technical design standards for treatment as stated in the Rule cannot be met, other options may need to be explored to ensure the appropriate selection of treatment. Pilot studies may range from a review of pilot studies on similar systems with similar raw water quality to full scale pilot system construction and evaluation.

Currently in Vermont, GAC has been the only treatment technology used for PFAS removal. The Division may require a full-scale pilot test at a water system choosing to implement AIX or other novel technology.

3.6 Cost Evaluation

During the planning phase, a cost estimate evaluating treatment installation and life-cycle costs shall be completed. Cost estimates for each feasible alternative must be evaluated, including a breakdown of the following costs associated with the project: construction, non-construction, and annual O&M costs. A construction contingency should be included as a non-construction cost. Cost estimates shall be included with the descriptions of each technically feasible alternative. O&M costs should include a rough breakdown by O&M category and not just a value for each alternative. The O&M cost estimate should include:

- Personnel (i.e., Salary, Benefits, Payroll Tax, Insurance, Training) if treatment would require a Water System to obtain an operator of a higher class than their current operator
- Energy cost (Fuel and/or Electrical)
- Process chemicals
- Monitoring and testing
- Short lived asset maintenance/replacement
- Professional services
- Residuals disposal, and
- Miscellaneous

Information from other sources, such as the recipient's accountant or other known technical service providers, can be incorporated to assist in the development of this evaluation.

A life cycle present worth cost analysis (an engineering economics technique to evaluate present and future costs for comparison of alternatives) shall be completed to compare the technically feasible alternatives. All feasible alternatives that were considered in planning a solution shall be included in the life cycle cost analysis. Do not leave out alternatives because of anticipated costs; let the life cycle cost analysis show whether an alternative may have an acceptable cost. This analysis shall meet the following requirements and shall be repeated for each technically feasible alternative.

1. The analysis should convert all costs to present day dollars;
2. The planning period to be used is recommended to be 20 years;
3. The discount rate to be used should be the "real" discount rate taken from Appendix C of OMB circular A-94 and found at (www.whitehouse.gov/omb/circulars/a094/a94_appx-c.html);
4. The total capital cost (construction plus non-construction costs) shall be included;
5. Annual O&M costs shall be converted to present day dollars using a uniform series present worth (USPW) calculation;
6. The net present value (NPV) is calculated for each technically feasible alternative as the sum of the capital cost (C) plus the present worth of the uniform series of annual O&M (USPW (O&M)) costs minus the single payment present worth of the salvage value (SPPW(S)): NPV = C + USPW (O&M) – SPPW (S)
7. A table showing the capital cost, annual O&M cost, present worth of each of these values, and the NPV shall be developed. All factors (major and minor components), discount rates, and planning periods used shall be shown within the table;
8. Short lived asset costs (See Appendix A of the United States Department of Agriculture (USDA) Rural Utilities Service Bulletin 1780-2 for examples) shall also be included in the life cycle cost analysis if determined appropriate by the consulting engineer or the Division. Life cycles of short lived assets should be

tailored to the facilities being constructed and be based on generally accepted design life. Different features in the system may have varied life cycles.

3.6.1 O&M costs

When considering treatment, federal funding may be available for the installation; however, the continued O&M costs will be the responsibility of the water system. The evaluation of O&M costs is thus important to make sure the water system is aware of the ongoing costs associated with the selected alternative. For example, GAC may have cheaper capital costs but could result in higher long-term O&M costs due to more frequent media replacement. Alternatively, AIX may have higher capital costs, but a lower long-term O&M cost due to less frequent changeout of resin.

Breakthrough curves of target PFAS compounds derived from tested or piloted data inform the life cycle costs of treatment by considering actual treated water quality, performance of selected media, unit media cost, and anticipated changeout frequency. In Murray et al., 2021, they conducted bench scale column tests comparing the adsorption capacity of GAC and AIX treatment technologies and evaluated levelized media costs accounting for PFAS breakthrough and anticipated changeout frequency. AIX was the more cost-effective adsorbent despite having a more expensive average unit media cost than GAC due to the higher adsorption capacity of AIX and less frequent media changeout. In the study conducted by Medina et al., 2022, the predicted unit water cost based on piloted data for different treatment technologies was the lowest for an alternative adsorbent, followed by AIX, and then GAC. Despite these evaluations, treatment costs assessments should be handled on an individual water system basis accounting for site-specific water quality and infrastructure needs.

The EPA bed life equation and cost model can help assess the GAC vs. AIX O&M costs by taking site-specific conditions into consideration, however, it's important to recognize that the ultimate lifecycle costs will vary based on actual observed media life, evolving media disposal costs and logistics, etc.

It is important to understand the ongoing O&M costs of treatment (e.g., media replacement strategies and residuals disposal) to determine if it is feasible for a system to operate and maintain the treatment. The management and cost of spent PFAS containing treatment residuals (i.e., spent GAC media or single-use AIX resins, etc.) must be considered in the cost evaluation as it can influence a water system's selected alternative. The cost of disposing PFAS residuals may vary widely based on the type of materials, the concentration of contaminants on the media, or the distance to a facility (i.e., transportation costs to distant disposal facilities may be higher for rural areas) as described in more detail in Section 3.7. The cost of PFAS residual disposal may change over time based on demand and the evolution of available options. Therefore, recent accurate cost estimates directly from potentially applicable disposal facilities should be provided. Furthermore, the Preliminary Engineering Report (PER) requires a cost evaluation describing the selected alternative and must include an accurate description of the treatment residuals disposal approach. This information is needed for design approval.

3.7 GAC Media and AIX Resin Disposal

Inevitably, GAC media and AIX resins will become exhausted, and the spent materials will need to be destroyed or disposed of. Under the 2022 Vermont Listed Hazardous Wastes (https://dec.vermont.gov/sites/dec/files/wmp/HazWaste/Documents/VHWMR%20Effective%20Feb%2001%2C%202022%20Complete%20Document.pdf), liquid wastes containing PFOA and PFOS in concentrations equal to or greater than 20 ppt are considered hazardous waste. However, per July of 2024, it does not apply to spent treatment residuals used in removing PFAS. Furthermore, the destruction and disposal of these spent PFAS containing materials is not currently federally regulated. There is regulatory uncertainty on how these PFAS treatment residuals will be handled in the future. EPA recommends selecting a destruction or disposal approach which minimizes environmental exposure with a lower potential for release and a higher potential to control PFAS releases into the environment (EPA, 2024c). Commercially available destruction and disposal technologies are landfills, thermal treatment, and underground injection.

Although there are different approaches to managing PFAS treatment residuals, these options differ based on spent material type. Destruction/disposal options for spent GAC are disposal in landfills, reactivation, or incineration. For disposal in landfills, the EPA recommends Resource Conservation and Recovery Act (RCRA) Subtitle C landfills when PFAS levels of the waste are relatively high. Subtitle C landfills have the most stringent environmental controls in place for minimizing environmental releases and migration of some PFAS from disposed waste (EPA, 2024c). The only landfill currently operating in Vermont, the NEWSVT landfill (Casella), has restrictions and protocols when dealing with PFAS containing materials likely making it more expensive for disposal. Thus, landfill options would likely be to ship PFAS containing waste materials to out of state facilities. Reactivation, only applicable to GAC, is a well-established technology that utilizes high temperatures for the thermal destruction of adsorbed PFAS chemicals, after which reactivated carbon can then be used for non-drinking water use. In Vermont, GAC media is required to meet AWWA Standard B604 which applies to virgin GAC. Incineration, a type of thermal treatment, uses high-temperature combustion and incineration to destroy and control organic materials and pollutants. However, more data is needed on incineration in PFAS destruction applications, such as evaluating destruction performance and formation of byproducts from this technology (EPA, 2024c).

AIX resins used for PFAS removal in drinking water applications are single-use (non-regenerable). Thus, options available for spent resin management would be landfill disposal or incineration. EPA recommendations for AIX resin disposal is similar to GAC.

Incineration unknowns are also applicable to AIX resins. However, EPA states that AIX disposal of single-use AIX resins may be less expensive than incineration. More information is available on the destruction and disposal of PFAS substances and materials containing PFAS (https://www.epa.gov/system/files/documents/2024-04/2024-interim-guidance-on-pfas-destruction-and-disposal.pdf).

To date, there have been different approaches to spent treatment residual management. Note, GAC treatment is the only technology used to remove PFAS from drinking water in Vermont thus far (no systems are currently using AIX resins), therefore, only GAC media is referenced in the following discussion. There are currently only two contractors assisting Vermont public drinking water systems dispose of spent media, Clear Water Filtration and Culligan.

Clear Water Filtration uses the services of US Ecology and Absolute for landfill disposal of spent media. The disposal companies handle and transport the spent media to a facility out of state. When media is spent, it is vacuumed out of the vessels and transferred to 55-gallon drums. Once removed, the spent media must be analyzed for PFAS using EPA Method 1633 to determine the media PFAS concentration. Disposal cost may increase substantially at concentrations greater than the 20 ppt. It is likely PFAS concentrations on spent media will exceed this 20 ppt threshold, however, estimates on how much disposal costs will increase is currently unknown. Final disposal cost is dependent on the volume of media and PFAS concentrations which creates a level of uncertainty in evaluating costs

Culligan has a contract directly with Calgon Carbon Corporation for their GAC reactivation services of spent media. In setting up the contract for Calgon Carbon's reactivation services, Culligan provides a characterization of the water and the contaminants that are potentially loaded on the spent media. Culligan stockpiles the spent media in super sacks (approximately 40-50 cubic feet (cu ft)). When they have 3 to 4 full super sacks, they ship it back to Calgon Carbon via freight delivery for media reactivation. Reactivated carbon is then used for non-drinking water industrial processes and new GAC media is used for drinking water treatment. By using the reactivation approach for spent media handling, this avoids sending PFAS containing media to landfills reducing the potential for environmental release.

A thorough evaluation of appropriate disposal strategies and actual costs must be conducted as part of the planning document. Some things to consider when evaluating residuals disposal strategies are the selected media type (e.g., GAC vs. AIX), volume of media, replacing the vessels or vacuuming out spent media, and media changeout approach (i.e., replacing media in both vessels or conducting a lead/lag switch). AIX is known to have a higher capacity for PFAS than GAC resulting in less volume of resin needed to meet similar treatment goals but potentially higher concentrations of PFAS in the spent media. Additionally, a changeout frequency of different media types and selected approach would also have to be considered. For example, if treatment is designed in a lead/lag configuration, the media in the lead vessel would be removed and replaced with new media. The lag vessel would be switched operating now as the lead. As only media from one vessel would be replaced, this essentially cuts media replacement costs in half. However, since the lag vessel would now be in the lead position and if breakthrough at entry point to the distribution system (entry point) was already occurring, capacity would be reduced relative to having new media in both vessels. Given these differences in disposal approach, the planning document shall include a disposal cost evaluation that represents the chosen design and operation of the system.

4 Treatment Design Requirements and Considerations

To streamline and expedite the design and Permit to Construct process for PFAS treatment, the Division has developed a GAC treatment checklist and an AIX treatment checklist (Attachments A and B, respectively) to review and address as part of the planning and final design phases. The following information is meant to act as documentation and support when addressing the checklist items.

4.1 Granular Activated Carbon (GAC)

If GAC treatment for the removal of PFAS is proposed at a Public Community or NTNC Water System, the construction permit application shall include an Engineer's Report that meets the requirements of Appendix A, Part 1 of the Rule. Transient Non-Community (TNC) Water Systems shall include a report that meets the requirements of Appendix A, Part 11 of the Rule. A Basis of Design shall include the GAC system design parameters and technical information listed in Part 4.11.1. The design shall follow the Technical Standards for GAC filters in Part 4.11.2. A checklist (Attachment A) is available for use which outlines some required documentation and important considerations in designing and implementing effective PFAS treatment that aligns with design standards and regulatory requirements outlined in the Rule. Any proposed variances to the Rule shall be accompanied by supporting documentation and a separate Variance Request (Section 3.7 of the Rule). Descriptions of additional design details and considerations are summarized in the following sections.

4.1.1 Water Quality Evaluation Before Design

A characterization of water quality must include constituents that may interfere with GAC or AIX treatment (see Section 3.3). For GAC specifically, water quality constituents shall include TOC, iron, manganese and turbidity. Natural organic matter, measured as either DOC or TOC, is known to impact GAC media capacity to adsorb PFAS (Berretta et al., 2021, McNamara et al., 2018) and the interference may be dependent on the type of natural organic matter present in the raw water (Gagliano et al., 2020). TOC can be orders of magnitude higher than the concentrations of PFAS being removed and will compete with PFAS for adsorption sites on the GAC. For water systems with high TOC concentrations present in raw water, this could result in more frequent GAC media replacement (EPA, 2024a) and increased lifecycle costs.

Other parameters that can affect treatment are iron and manganese. Iron and manganese can cause fouling/preloading of the GAC media reducing capacity for contaminant removal and slowing down kinetics (Speth, T., 2022). Turbidity can interfere with the effectiveness of the GAC treatment process by clogging the media with suspended particles.

4.1.2 Proposed Treatment Design Requirements

4.1.2.1 GAC Media and Filter Configuration

GAC media shall meet AWWA B604, Standard for GAC, as stated in Appendix A Part 4.11.2(g). As part of the treatment design, a justification for the choice of selected GAC media shall be provided, including manufacturer cut sheets.

As part of treatment design, filter to waste and backwash provisions should be in place to allow for backwashing during the startup procedures of the GAC media. Startup procedures, along with backwashing, are described in more detail in Section 4.1.5.2.

Per the Rule, Non-Community and Domestic Bottled Water Systems are required to install at least one train of two GAC filters plumbed in series. Community Water Systems are required to install at least two filter trains, each train consisting of two GAC filters plumbed in series. For Community Water Systems where only two filter trains are provided, each train shall be capable of meeting the plant design capacity (the projected maximum daily demand) at the approved filtration rate. Where more than two filter trains are provided, the treatment facility shall be capable of meeting the plant design capacity at the approved filtration rate with one filter train removed from service (Appendix A Part 4.11.2).

The lead/lag configuration will use more of the filter capacity because the lead filter will be fully spent by the time there is breakthrough of the lag filter measured at the entry point to the Water System distribution system. If the lag filter is subsequently moved to the lead filter position, it too will be fully spent when breakthrough occurs at entry point, resulting in 100% use of capacity. A drawback to the lead/lag configuration, is the reduction in capacity of the lag filter due to pre-loading of co-contaminants, such as TOC, reducing the capacity of the filter by up to 30% (WSID 20734 Pownal FD2, estimated by Vermont Department of Environmental Conservation (VT DEC)). The lead/lag configuration also provides a margin of safety if additional midpoint samples are collected to monitor contaminant levels. Midpoint monitoring may also be used to direct media changeout prior to exceedance of contaminant drinking water standards; however, midpoint monitoring results cannot be used for compliance purposes.

The construction permit application Basis of Design should include:

- Number and arrangement of treatment trains;
- Number and size of GAC vessels and typical flow configuration;
- GAC media selection and volume of media in vessels;
- Evaluation of potential competition for GAC adsorption sites by TOC and other contaminants;
- Anticipated lifespan of the GAC;
- EBCT and hydraulic loading rate;
- Pretreatment, if necessary; and
- Disinfection

4.1.2.2 Empty Bed Contact Time (EBCT)

EBCT is the theoretical amount of time water spends in contact with the GAC media which is calculated as the volume of GAC media (gallons) divided by the design flow rate in gallons per minute (gpm). To ensure an accurate calculation of EBCT, calculations must be based on the **actual volume of GAC media in the vessels and not the vessel volume.** Depending on the treatment system configuration and the location of the GAC filters in the overall facility treatment train, the design flow rate will likely equal either the instantaneous peak demand (IPD) or the maximum daily demand (MDD). It is recommended that the Division be contacted for concurrence prior to the submittal of a construction permit application. EBCT for each filter shall be at least 10 minutes and should meet or exceed media manufacturer specifications. Upon initial installation or media changeout, backwashing is conducted to flush out carbon fines that are present and to properly stratify and reset the carbon bed. Media volume and space above the GAC bed should be sufficient to allow the recommended bed expansion without GAC loss during backwashing. The amount of headspace required for backwashing should be accounted for when determining total media volume. If the EBCT of the proposed design is less than 10 minutes per filter after sufficient headspace has been provided, a larger filter will be needed to provide adequate volume to achieve the minimum EBCT. The Secretary must explicitly approve a modified design that includes a proposed EBCT less than a total of 20 minutes through the approval of a variance request.

4.1.2.3 Hydraulic Loading

Appendix A Part 4.11.2 (i) of the Rule states that the hydraulic loading rate for each unit shall not exceed 7 gallons per minute per square foot (gpm/ft^2) of bed area. Hydraulic loading rate is the rate of water applied to the filter divided by the filter’s cross-sectional area. The number of filter trains, vessel diameter, and system flow rate need to be considered in the hydraulic loading calculation. The hydraulic loading rate should be calculated using IPD, peak hourly flow, the proposed operating node of a booster pump or a well pump, or another method depending on the configuration of the treatment train and the size of the Water System. Justification for calculation of the hydraulic loading rate must be provided in the design. It is recommended that the Division be contacted for concurrence prior to submittal of a construction permit application if the flow rate is estimated using a method other than an IPD calculation or well pump node.

4.1.2.4 Disinfection

As stated in Appendix A Part 4.11.2 (n) of the Rule, disinfection treatment that meets the requirements of Appendix A Part 4.3 and 40 CFR Part 141 shall be provided to treat all water treated by GAC. Disinfection treatment shall be provided prior to the entry point to the distribution system and can either be chlorine or non-chlorine based, such as ultraviolet light.

If proposing post-GAC chlorination, chlorine contact time calculations must be provided and ensure storage provides adequate chlorine contact time during peak demand. Peak demand should be based on the Water System's peak hourly flow. If unknown, peak hourly flow should be conservatively estimated. Peak hourly flow rate is dependent on the location of treatment infrastructure within the treatment train. For very small systems, peak hourly flow may equal IPD. It is recommended that the Division be contacted for concurrence prior to submittal of a construction permit application if peak hourly flow is estimated using a method other than an IPD calculation. If IPD is used to determine contact time, the IPD shall be calculated as follows for non-community systems:

(a) determined by the State Plumbing Code; or
(b) for residential units only, the IPD equals 5 gpm multiplied by the number of units.

The calculated peak demand should be no less than the total gpm obtained by using fixture methods outlined in AWWA Manual M22, Sizing Water Service Lines and Meters, or the required fire flows if fire hydrants are provided for the system. If peak demand is calculated using a method other than those outlined in the State Plumbing Code or AWWA Manual M22, it is recommended that the Division be contacted for concurrence prior to submittal of a construction permit application. Chlorination will likely require storage for contact time downstream of the GAC filter trains.

Design and installation of disinfection methods other than chlorine-based systems, such as ultraviolet light, may be permitted, provided such designs conform to the Secretary's written guidelines (VT DEC, 2014).

4.1.2.5 Other Design Considerations

GAC filters shall have necessary piping and valves to facilitate ease of operational adjustments to modify the configuration of primary (lead) and secondary (lag) carbon filters, and to remove one filter or filter train from service while maintaining functionality of treatment process. Additionally, the water system shall demonstrate that all sampling ports and gauges are accessible. This is typically accomplished by including a floor plan that is to scale of the treatment facility in the design drawings.

Pressure gauges shall be located to monitor pressure loss across each filter. Range and precision of the gauges shall be specified, and the gauges shall be appropriately sized to monitor the pressure loss across the filters per gauge manufacturer specification. Anticipated head loss across filter units shall be considered when determining treatment facility peak flow capacity and pump design.

Sample ports shall be provided for the inlet and outlet of each filter and shall be accessible. If individual water meters for new or existing wells need to be installed as part of the project, the meters shall be shown on the Engineering Drawings and cut sheets shall be submitted. If new well pumps are proposed, rationale for well pump selection shall be provided, including well pump cut sheets and operating curves. If more than one source is used, details of well pump operation shall be provided. (For example, do well pumps operate at the same time or are they alternating? What is the flow rate under specific operating conditions for each well?). If new source(s) are proposed, a new source permit is required.

To prevent GAC filters from dewatering, consider installing a vacuum breaker or specialty valve. As part of the GAC system design stage, startup and conditioning of the GAC media such as soaking, backwashing, pH neutralization, arsenic rinsing, and disinfection (described in more detail in Section 4.1.5) shall be considered in the design. Backwash water used in startup and conditioning of new or changed out media shall be finished water or water without PFAS above the MCLs. Backwashing shall be incorporated as part of the initial design of the system. Backwash and forward rinse to waste piping shall have appropriate backflow prevention. Unlike other applications of GAC treatment, regular backwashing of media is not allowed when treating for PFAS. This can adversely affect media lifespan.

All wetted components and materials shall be certified for compliance with American National Standards Institute (ANSI)/National Sanitary Foundation (NSF) Standard 61 for use in drinking water. All treatment chemicals shall be NSF 60 certified.

4.1.3 Pretreatment

Per Appendix A Part 4.11.2 (o) of the Rule, pretreatment shall be provided for the presence of any water quality constituent that will prevent successful performance of the proposed carbon treatment, or to remove contaminants that are not removed by GAC. Pretreatment shall be provided in the proposed design as necessary to ensure that concentrations of co-contaminants such as iron and manganese are consistently and reliably less than the Secondary Maximum Contaminant Levels established in Subchapter 21-6. The presence of iron and manganese in influent water can foul the GAC media, inhibiting effective PFAS removal. Similarly, primary contaminants such as arsenic will need separate treatment to ensure that concentrations are consistently and reliably less than the Primary Maximum Contaminant Levels established in Subchapter 21-6. A pretreatment rationale and the sequence of treatment shall be described in detail.

Treated water below the Vermont PFAS MCL shall be used for the backwashing of any pretreatment processes and backflow prevention on the backwash line shall be provided. The additional demand on booster pumps and well pumps in gpm, total volume of backwash, and the anticipated frequency of backwashing shall be provided. Evaluation of negative impacts or limitations to use/demand during backwash/regeneration must be provided.

4.1.4 Operations and Maintenance

4.1.4.1 Operator Certification

A Public water system with PFAS treatment using GAC is classified as a Treatment Class 3 for groundwater or Class 4 for surface water. It is important to ensure that the water system has the appropriate Operator Classification to run the system. If the water system’s operator on record is not a Class 3 or 4 operator, the system is required to obtain an appropriately certified operator to run the treatment equipment.

4.1.4.2 Pressure Changes

The effectiveness of a GAC filter depends on the time of contact between the carbon and the untreated water. The longer the contact time, the better the adsorption of contaminants onto the GAC filter media. Over time, channels can form within the GAC media, which may allow some untreated water to pass through the media.

Alternatively, if present, iron and manganese or turbidity can foul the GAC media resulting in pressure loss across the filter. In either instance, it is important to monitor the pressure gauges for any changes over time.

4.1.4.3 Piping and Valves

GAC filters shall be provided with piping and valves as necessary to facilitate ease of operational adjustments to modify the configuration of lead and lag filters, and to remove a filter from service while maintaining functionality of the treatment process. A procedure shall be in place to identify the position of each lead/lag filter where multiple filters are used in series. If the position of the vessels in the series are changed (swapped), there shall be the ability to change label positions accordingly.

4.1.4.4 Midpoint Sampling

The lead time to have GAC media replaced can vary dependent on availability of media and contractors and should be considered before exceeding the PFAS MCL. Occasional sampling for PFAS between the lead and lag filters (midpoint), although not a requirement, can enable media changeout decisions before breakthrough of the second filter or a violation of the MCL occurs. A midpoint sample result can be used to infer remaining filter capacity before breakthrough of PFAS from the lag filter. Entry point monitoring must be performed to satisfy compliance requirements regardless of midpoint sampling efforts.

4.1.4.5 Operations and Maintenance (O&M) Manuals/Standard Operating Procedures

As part of the standard conditions listed in the Construction Permit, an O&M Manual or Standard Operating Procedure (SOP) update shall be prepared. For Community water systems and NTNCs, this O&M Manual update shall be prepared to reflect the improvements authorized by the construction permit and shall meet the requirements of Appendix D of the Rule. The O&M Manual update must be available for review and approval when the Construction Completion Certification is submitted. Once this O&M Manual update is approved, the Permittee(s) shall incorporate it into the Water System’s approved O&M Manual per the requirements of Subchapter 21-7 of the Rule.

The O&M Manual or SOP shall include procedures to be followed in response to breakthrough of PFAS from the GAC filter and changing out the GAC media. The O&M Manual or SOP shall state that virgin NSF 61 certified media will be used for all GAC media changeouts. The O&M Manual or SOP shall include information about the changeout procedure, such as swapping of lead/lag filters or complete replacement, and startup procedure including media conditioning. Provisions to condition new GAC media shall be in accordance with manufacturer recommendations.

To demonstrate the treatment is working, performance testing (including PFAS and any other contaminant(s) of concern) shall be conducted and included in the O&M Manual or SOP.

When developing these procedures, consider the following:

a. Consider the size and potential weight of the vessels. With smaller vessels, the lead/lag switch may be conducted by rolling the units into their respective place. However, with larger vessels (e.g., greater than 16” diameter), this may not be possible due to the weight. Discuss provisions to precondition new GAC media in accordance with manufacturer recommendations.
b. Clearly outline the anticipated lead time required for the vendor. Sufficient time must be given for media changeout to accommodate for sample analysis and reporting time, contractor scheduling, completing changeout, and post-changeout sample analysis and reporting (i.e., how many days/weeks lead time are required for them to complete the changeout of the media?).
c. Demonstrate that the GAC units are not being bypassed to ensure untreated water is not going to distribution
d. Describe the approach for media disposal (See Section 3.7).

4.1.5 Startup Procedures

When GAC treatment is installed at a water system or when media is changed out, it is essential that manufacturer-prescribed standard startup procedures and media conditioning are followed. Proper startup and conditioning ensure optimized media performance and maximizes adsorption capacity of the media and reduces the likelihood of any aesthetic concerns or turbid water following filtration. Startup procedures aim to optimize media performance by removing fines that result from the normal handling of media, stratify the bed to ensure optimized performance, and to remove naturally occurring impurities present in the carbon.

All considerations for soaking and backwashing can be product specific thus, exact manufacturer-provided startup procedures should be followed. However, if not provided, general guidelines described in the following sections should be adhered to.

4.1.5.1 Soaking

When new GAC is brought into a system, the media is dry and needs to be properly wetted within the vessel allowing water to diffuse and displace the air entrained within the external and internal pore spaces. Filters must be able to discharge to waste. Operational and performance problems can arise if the carbon is not properly soaked resulting in an increase in pressure drop and little adsorption taking place. Soaking times for different carbon types can vary and are a function of temperature and carbon mesh size. It is recommended to follow manufacturer guidelines.

4.1.5.2 Backwash

The main objectives of backwashing upon initial installation or media changeout is to flush out carbon fines that are present and to properly stratify and reset the carbon bed. Backwashing takes place under a specified flow rate in gpm/ft² that is water temperature dependent and specific to the GAC media being used. The reverse flow fluidizes the bed. Bed expansion of 25%-30% should be targeted for backwashing with a ramp-up period to remove air, a backwash period, and a ramp-down period to stratify the bed. The specifics of backwashing procedures may vary based on the vendor/manufacturer. Backwash the GAC media per the manufacturer’s recommendations.

4.1.5.3 pH Adjustment Period

During the startup of GAC filters, pH levels are often elevated. This is due to protonation (attraction of H+ to the media) that occurs during the activation process resulting in temporarily high pH values in the effluent water of the GAC media. However, pH decreases as a function of runtime as the charge eventually neutralizes with the anions that are present in the water. Filter to waste could reach pH stabilization.

4.1.5.4 Arsenic Content

Arsenic can be found naturally occurring in GAC media. When new GAC media is put online, leachable arsenic present on the surface of the media can migrate into the liquid and in some cases result in arsenic levels exceeding the MCL. Similarly, as with pH, the optimal approach to addressing the elevated arsenic concentrations is adequate forward flushing with effluent water to waste. Flushing procedures must follow vendor recommendations in order to reduce the risk of arsenic contamination upon startup.

4.1.5.5 Bacterial Contamination

During media transport, GAC can become contaminated. After undergoing the initial startup and conditioning of the media, the new media may need to be rinsed at the design flow rate. Bacteria may take up dissolved nutrients in the water and nutrients adsorbed onto the GAC resulting in bacterial growth in high densities (National Research Council (US) Safe Drinking Water Committee, 1980). Bacteria may adsorb to the GAC media and may have the potential to colonize the filter bed. Hence, disinfection treatment must be provided to treat all water treated by GAC (See Section 4.1.2.4).

4.1.6 Performance Testing Upon Initial Start up

Following the construction of treatment components authorized by the Permit to Construct and prior to placing the treatment components into service for potable water use, performance testing shall be conducted. Prior to being placed in operation, the newly constructed portions of the Water System shall be flushed, pressure tested, disinfected (not treatment media), and flushed again. After this procedure, at least two bacteriological samples must be collected from representative sample points while meeting the minimum resampling periods between sample collection specified in the Rule and sent to a Vermont Department of Health certified laboratory for Bacteriological Examination of Public Water Supply. The Permittees shall indicate on the laboratory form that the sample is for “Construction Permit Compliance.” Coliform Absent sample results are required before the system may be placed into operation for potable water use. The pressure/leakage and bacteriological test results shall be submitted to the Division.

The performance testing shall also include analysis of the post treatment sample tap as stated in the Construction Permit for PFAS; specifically, PFBS, HFPO-DA, PFHxS, PFHpA, PFNA, PFOS, and PFOA using EPA Method 537.1 or 533. Water quality samples shall be labeled as ‘special’ samples collected for construction permit compliance; and shall be collected, transported, and analyzed in accordance with Subchapter 21-6 of the Rule. Results of the analyses shall be provided to the Division prior to placing the newly constructed treatment system into operation for potable water use.

4.2 Anion Exchange (AIX)

The design considerations for PFAS treatment using AIX resin outlined in the following sections are based on requirements outlined in the Rule, 10 State Recommended Standards for Water Works, 2022 or most recent version (10 State Standards), and the EPA document; Technologies and Costs for Removing Per- and Polyfluoroalkyl Substances from Drinking Water (EPA, 2024b).

If AIX treatment for the removal of PFAS is proposed at a Public Community or NTNC Water System, the construction permit application shall include an Engineer’s Report that meets the requirements of Appendix A, Part 1 of the Rule. TNC Water Systems shall include a report that meets the requirements of Appendix A, Part 11 of the Rule. A Basis of Design shall include AIX system design parameters and technical information. The design shall follow the Technical Standards as laid out in this document and the Rule.

A checklist (Attachment B) is available for use which outlines some required documentation and important considerations in designing and implementing effective AIX treatment.

4.2.1 Water Quality Evaluation Before Design

A characterization of water quality must include constituents that may interfere with GAC or AIX treatment (see Section 3.3). For AIX specifically, water quality constituents shall include TOC, iron, manganese, nitrate, and turbidity. EPA highlights anions such as nitrate, sulfate, bicarbonate, and chloride as competing anions (EPA, 2024b), whereas other research has shown the most competitive inorganic ions are sulfates followed by phosphates and nitrates (Dixit et al, 2018, Dixit et al., 2020). Although PFAS-selective resins are designed to have higher affinity for PFAS than these other anions, the concentrations of these anions may be orders of magnitude higher than the target PFAS compounds.

PFAS-selective AIX resin is less sensitive to TOC than GAC (Berretta et al., 2021), however, TOC is typically negatively charged and may negatively impact AIX resin. The vendor, Purolite, has stated TOC can foul and negatively impact resin performance (Purolite, 2024), however, to a lesser degree than its impacts on GAC media. The use of GAC or a brine regenerable organic-scavenger resin before the PFAS-selective resin can significantly improve the capacity when TOC exceeds 2 milligrams per liter (mg/L). In a study conducted by Boyer et al., 2021, the presence of natural organic matter (NOM) reduced PFAS removal efficacy. Rahman et al., 2022 found that NOM and sulfate in the microporous anion exchange resin were the dominant competitor in PFAS removal. Iron and manganese can foul the resin and elevated turbidity can clog the resin with suspended particles (Purolite, 2024).

4.2.2 Proposed Treatment Design Recommendations

4.2.2.1 AIX Resin and Filter Configuration

In traditional applications of AIX resins, the resins can be restored through the process of rinsing the spent resin with a concentrated chloride solution. However, in applications where PFAS-selective resins are being used, conventional regeneration processes are not effective at restoring the resin. It is also not recommended to backwash the resin. Therefore, it is recommended to use single-use resins where spent resin would be disposed of and replaced with fresh PFAS-selective resin (EPA, 2024b).

As part of the treatment design, a justification for the choice of selected AIX resin shall be provided, including manufacturer cut sheets. Manufacturers of PFAS selective resins may have different requirements for AIX treatment start up; some manufacturers list initial regeneration, backwashing, and rinse requirements, and others do not. A description of the resin startup and changeout procedure must be provided as required by the manufacturer and must be followed. General startup procedure considerations are described in more detail in Section 4.2.5.

As of this moment, the Rule does not specify Technical Standards for AIX treatment. However, for PFAS removal, it is commonly recommended to operate two vessels in series (lead/lag) (EPA, 2024b).

For comparison, when installing GAC in a lead/lag treatment configuration, Non-Community and Domestic Bottled Water Systems are required to install at least one train of two GAC filters plumbed in series. Community Water Systems are required to install at least two filter trains, each train consisting of two GAC filters plumbed in series. For Community Water Systems where only two filter trains are provided, each train shall be capable of meeting the plant design capacity (the projected MDD) at the approved filtration rate. Where more than two filter trains are provided, the treatment facility shall be capable of meeting the plant design capacity at the approved filtration rate with one filter train removed from service (Appendix A Part 4.11.2). Justifications for a lead/lag configuration are provided in detail in section 4.1.2.1.

The construction permit application Basis of Design should include:

- Number and arrangement of treatment trains;
- Number and size of AIX vessels and typical flow configuration;
- AIX resin selection and **volume of resin in vessels**;
- Evaluation of potential competition for AIX adsorption sites by other anions and other contaminants (e.g. the resin’s preferential list)
- Anticipated lifespan of the AIX;
- EBCT and hydraulic loading rate;
- Post-AIX pH adjustment, if necessary;
- Pretreatment, if necessary; and
- Disinfection, if necessary.

4.2.2.2 Empty Bed Contact Time (EBCT)

The EBCT for each unit shall meet the recommendation by the manufacturer for the selected AIX resin. A common vendor recommendation is to use a total EBCT of 3 to 6 minutes (EPA, 2024b). 10 State Standards requires a minimum EBCT of 2 minutes to ensure adequate PFAS adsorption. A pilot may be required if sufficient justification for the manufacturer recommended EBCT cannot be provided.

To ensure an accurate calculation of EBCT, calculations must be based on the **actual volume of AIX resin in the vessels and not the vessel volume.** Depending on the treatment system configuration and the location of the resin vessels in the overall facility treatment train, the design flow rate will likely equal either the IPD or the MDD. It is recommended that the Division be contacted for concurrence prior to the submittal of a construction permit application.

4.2.2.3 Hydraulic Loading

Hydraulic loading rate is the rate of water applied to a unit, commonly expressed in gallons per minute, divided by the AIX unit’s cross-sectional area, commonly expressed in square feet. The number of treatment trains, vessel diameter, and system flow rate need to be considered in the hydraulic loading calculation. The hydraulic loading rate should be calculated using IPD, peak hourly flow, the proposed operating node of a booster pump or a well pump, or another method depending on the configuration of the treatment train and the size of the Water System. Justification for calculation of the hydraulic loading rate must be provided in the design. It is recommended that the Division be contacted for concurrence prior to submittal of a construction permit application if the flow rate is estimated using a method other than an IPD calculation or well pump node. Follow manufacturer's recommendations on appropriate hydraulic loading rate.

4.2.2.4 Disinfection

AIX treatment does not trigger the need for post-AIX chlorination. Chorine can degrade AIX resin. If the system has the capability to disinfect or is actively chlorinating, chlorine disinfection should be applied after the AIX resin.

4.2.2.5 Other Design Considerations

AIX treatment units shall have necessary piping and valves to facilitate ease of operational adjustments. The piping and valving should allow for the operator to modify the configuration of the lead and lag units, and to remove one unit or train from service while maintaining functionality of treatment process.

Pressure gauges shall be located to monitor pressure loss across each unit. Range and precision of the gauges shall be specified, and the gauges shall be appropriately sized to monitor the pressure loss across the AIX units per gauge manufacturer specification. Anticipated head loss across units shall be considered when determining treatment facility peak flow capacity and pump design.

Sample ports shall be provided for the inlet and outlet of each AIX unit and shall be accessible. This is typically demonstrated by including a to-scale floor plan of the treatment facility in the design drawings. If individual water meters for new or existing wells need to be installed as part of the project, the meters shall be shown on the Engineering Drawings and cut sheets shall be submitted. If new well pumps are proposed, rationale for well pump selection shall be provided, including well pump cut sheets and operating curves. If more than one source is used, details of well pump operation shall be provided (i.e., Do well pumps operate at the same time or are they alternating? What is the flow rate under specific operating conditions for each well?) If new source(s) are proposed, a new source permit is required.

To prevent AIX units from dewatering, consider installing a vacuum breaker or specialty valve. As part of the AIX system design stage, startup and conditioning of the AIX resin (described in more detail in Section 4.2.5) shall be considered in the design. If rinsing and/or backwashing is required in startup and conditioning of new or changed out resin, finished water or water without PFAS above the MCLs shall be used. Backwash and rinse to waste piping shall have appropriate backflow prevention.

Unlike other applications of AIX treatment, regular backwashing of resin is not recommended when treating for PFAS.

All wetted components and materials shall be certified for compliance with ANSI/NSF Standard 61 for use in drinking water. All treatment chemicals shall be NSF 60 certified.

4.2.3 Pretreatment and Post-Treatment

Pretreatment shall be provided in the proposed design as necessary to ensure that iron and manganese concentrations are consistently and reliably less than the Secondary Maximum Contaminant Levels established in 21-6 and within the manufacturer's specified water quality parameters.

Evaluation of total suspended solids should be considered and if necessary, pretreatment should be installed to prevent blockage and subsequent channeling within the resin bed. As an example, Purolite recommends a 5-micron bag or cartridge filter before the resin (Purolite, 2024). If high levels of suspended solids are expected, consider installing a series of larger filters ahead of the 5-micron filter. Other pretreatment considerations include total dissolved solids (TDS) and TOC. As TDS of the influent increases, the AIX resin bed life decreases. The same applies to TOC, however to a lesser degree than GAC (EPA, 2024b).

Treated water below the Vermont PFAS MCL shall be used for the backwashing of any pretreatment processes and backflow prevention on the backwash line shall be provided. The additional demand on booster pumps and well pumps in gpm, total volume of backwash, and the anticipated frequency of backwashing shall be provided. Evaluation of negative impacts or limitations to use/demand during backwash/regeneration must be provided.

4.2.4 Operations and Maintenance

4.2.4.1 Operator Certification

A Public water system with PFAS treatment using AIX is classified as a Treatment Class 3 for groundwater or Class 4 for surface water. It is important to ensure that the water system has the appropriate Operator Classification to run the system. If the water system's operator of record is not a Class 3 or 4 operator, the system is required to obtain an appropriately certified operator to run the treatment equipment.

4.2.4.2 Regeneration

In traditional applications of AIX resins, the resins can be restored through the process of regenerating the spent resin with a concentrated chloride solution. However, in applications where PFAS-selective resins are being used, conventional regeneration processes are not effective at restoring the resin (EPA, 2024b). Therefore, PFAS-selective, single-use AIX resin is required for PFAS treatment.

4.2.4.3 Pressure Changes

Pressure drop across the lead vessel could be an indication of dirt accumulation. If a pressure change is seen to increase excessively, a vessel inspection may be recommended. An increase in pressure and then a sudden reduction could indicate the resin bed has shifted and should be promptly evaluated (Purolite, 2024).

4.2.4.4 Piping and valves

AIX units shall be provided with piping and valves as necessary to facilitate ease of operational adjustments to modify the configuration of lead and lag vessels, and to remove a vessel from service while maintaining functionality of the treatment process. A procedure shall be in place to identify the position of each lead/lag vessel where multiple vessels are used in series. If the position of the vessels in the series are changed (swapped), there shall be the ability to change label positions accordingly.

4.2.4.5 Midpoint Sampling

The lead time to have AIX resin replaced can vary dependent on availability of resin and contractors and should be considered before exceeding the PFAS MCL. Occasional sampling for PFAS between the lead and lag vessels (midpoint), although not a requirement, can enable media changeout decisions before violation of the MCL occurs. A midpoint sample result can be used to infer remaining filter capacity before breakthrough of PFAS from the lag vessel. Entry point monitoring must be performed to satisfy compliance requirements regardless of midpoint sampling efforts.

4.2.4.6 Bacterial Contamination

Bacterial contamination of the resin may occur if the system is sitting idle for a prolonged period. Follow manufacturer’s recommendations on appropriate measures to avoid bacterial growth, such as rinsing or complete draining of vessels until next startup (Purolite, 2024).

4.2.4.7 Operations and Maintenance Manuals/Standard Operating Procedures

As part of the conditions listed in the Construction Permit, an O&M Manual or SOP update shall be prepared. For Community water systems and NTNCs, this O&M Manual update shall be prepared to reflect the improvements authorized by the construction permit and shall meet the requirements of Appendix D of the Rule. The O&M Manual update must be available for review and approval when the Construction Completion Certification is submitted. Once this O&M Manual update is approved, the Permittee(s) shall incorporate it into the Water System's approved O&M Manual per the requirements of Subchapter 21-7 of the Rule.

The O&M Manual or SOP shall include procedures to be followed in response to breakthrough of PFAS from the AIX units and changing out the resin and shall state that NSF 61 certified media will be used for all AIX resin changeouts. They should also include information about the swapping of lead/lag vessels and startup procedures including resin conditioning shall be described in detail in an O&M Manual or SOP.

To demonstrate the treatment is working, performance testing (including PFAS and any other contaminants of concern) shall be conducted and included in the O&M Manual or SOP.

When developing these procedures, consider the following:

a. Consider the size and potential weight of the vessels. With smaller vessels, the lead/lag switch may be conducted by rolling the units into their respective place. However, with larger vessels (e.g., greater than 16" diameter), this may not be possible due to the weight. Discuss provisions to precondition new AIX resin in accordance with manufacturer recommendations.

b. Clearly outline the anticipated lead time required for the vendor. Sufficient time must be given for media changeout to accommodate for sample analysis and reporting time, contractor scheduling, completing changeout, and post-changeout sample analysis and reporting (i.e., how many days/weeks lead time are required for them to complete the changeout of the media).

c. Demonstrate that the AIX units are not being bypassed to ensure untreated water is not going to distribution

d. Describe the approach for resin disposal (See Section 3.7).

4.2.5 Startup Procedures

It is essential that manufacturer-recommended startup procedures and resin conditioning are followed when AIX treatment is installed at a water system or when being changed out.

4.2.5.1 Backwash

Vendors and manufacturers of PFAS-selective AIX resins may have different requirements for resin backwash. Some manufacturers do not recommend backwashing their resin during or after startup. If backwashing is recommended, it typically is done with a specified flow rate that is water temperature dependent and specific to the resin being used. The reverse flow fluidizes the bed. Bed expansion per manufacturer's recommendations should be targeted for backwashing with a ramp-up period to remove air, a backwash period, and a ramp-down period to stratify the bed.

4.2.5.2 pH Adjustment Period

AIX treatment can temporarily increase finished water corrosivity due to removal of alkalinity, sulfate and other anions in exchange for chloride. The effect on pH and chloride to sulfate mass ratio is limited to the initial startup as equilibrium will establish once the resin reaches its capacity to exchange major anions. Once that occurs, alkalinity and pH of the treated water returns to the levels of the influent water (EPA, 2024a). Initial rinsing of the resin per manufacturers recommendations could eliminate this concern. Alternatively, pre-buffered resin can reduce the effects of water chemistry changes at startup.

In cases where increased corrosivity remains a longer-term problem, distribution system effects must be managed by adjusting corrosion control programs, the installation of post-AIX pH adjustment, or operational changes such as dilution of the corrosive water (EPA, 2024b).

4.2.5.3 Volatile Organic Chemicals Leaching

Recent research has shown that new synthetic AIX resins may leach VOCs and is a concern, specifically for nitrosodimethylamine (NDMA), *N*-nitro-sodi-n-butylamine (NDBA), and styrene. A minimum initial rinse to waste of 40 bed volumes was recommended (Najm, 2024). Vendor specific information regarding VOC leaching should be identified.

4.2.6 Performance Testing Upon Initial Startup

Following the construction of treatment components authorized by the Permit to Construct and prior to placing the treatment components into service for potable water use, performance testing shall be conducted. Prior to being placed in operation, the newly constructed portions of the Water System shall be flushed, pressure tested, disinfected (not treatment media), and flushed again. After this procedure, at least two bacteriological samples must be collected from representative sample points while meeting the minimum resampling periods between sample collection specified in the Rule and sent to a Vermont Department of Health certified laboratory for Bacteriological Examination of Public Water Supply. The Permittees shall indicate on the laboratory form that the sample is for “Construction Permit Compliance.” Coliform Absent sample results are required before the system may be placed into operation for potable water use. The pressure/leakage and bacteriological test results shall be submitted to the Division.

The performance testing shall also include analysis of the post treatment sample tap as stated in the Construction Permit for pH and PFAS; specifically, PFBS, HFPO-DA (commonly referred to as GenX Chemicals), PFHxS, PFHpA, PFNA, PFOS, and PFOA for analysis using EPA Method 537.1 or 533. Water quality samples shall be labeled as ‘special’ samples collected for construction permit compliance; and shall be collected, transported, and analyzed in accordance with Subchapter 21-6 of the Rule. Results of the analyses shall be provided to the Division prior to placing the newly constructed treatment system into operation for potable water use.

5 Sampling

5.1 PFAS Rule Sampling

Under the current State Rule, if any sampling results indicate a concentration above 15 ppt of any combination of PFHxS, PFHpA, PFNA, PFOS, and PFOA at a sampling site identified in Section 6.18.4 of the Rule, then sampling shall be increased to quarterly sampling at that sampling site, beginning in the next quarter. Under the federal rule, there is a different sampling framework which is yet to be integrated into Vermont’s regulations but will be in the coming year(s). Under the federal framework, systems need to initially demonstrate their results are reliably and consistently below the respective federal MCLs for PFOA, PFOA, PFHxS, PFNA, HFPO-DA, and the calculated hazard index values (https://www.epa.gov/sdwa/and-polyfluoroalkyl-substances-pfas). Once initial monitoring requirements are satisfied, systems may be eligible for a reduction in monitoring frequency should the regulated PFAS results remain below the trigger level. On-going required sampling frequencies will vary based on previous results, water system source type, and size.

A public water system shall take a minimum of one sample at every entry point to distribution representative of each source after treatment. If a system draws water from more than one source and the sources are combined before distribution, for that sampling site the system shall sample at an entry point to the distribution system where water is representative of all sources supplying the entry point. Composite sampling among multiple entry points to the distribution system shall not be used.

Sample analysis shall be conducted pursuant to EPA Method 537.1 or Method 533. While the State Rule states 537.1, the Secretary recently published an approval letter, authorizing the use of EPA Method 533 for public drinking water systems in Vermont. The federal regulation allows for analysis under either Method 537.1 or Method 533.

5.2 Lead and Copper Rule Sampling

Because of the likelihood that both GAC and AIX treatment will influence the overall water chemistry, upon installation of either form of treatment, the lead and copper sampling schedule will be returned to standard (6 month) monitoring in order to assess any potential adverse impacts the treatment may have on the corrosivity of the water. This is a required step under the federal Lead and Copper Rule upon making long-term treatment changes.

6 Media Changeout Policy

Under the current rule, providing water in exceedance of the MCL would result in a violation leading to the water system being placed on a Do Not Drink, and be required to issue a public notice and take operational measures (e.g., bulk water hauling).

Exposure to PFAS at any level may result in a wide range of negative health outcomes (To learn more visit https://www.epa.gov/pfas/our-current-understanding-human-health-and-environmental-risks-pfas). PFAS treatment should be effective at removing target contaminants and designed to treat to the MCLG which is zero for PFOA and PFOS. Therefore, the Division strongly recommends initiating the media changeout process upon seeing PFAS detected in the treated/finished water sample. While the Division cannot mandate replacement of the media based on concentrations below the MCL at this time, initiating changeout upon detection ensures there is adequate time to line up contractors, obtain the necessary equipment, etc. to changeout the media before the MCL is exceeded. Additionally, if piloting was not completed during treatment design, the rate at which PFAS concentrations will increase and exceed the MCL in the finished water is unknown. At no time can the MCL be exceeded.

The media changeout process is expected to be included in the water system’s permit to operate (PTO). Media changeout should follow the standard operating procedure in the O&M Manual. The water system will be required to collect a PFAS sample from the entry point(s) to distribution once the filter(s) are ready to be placed into use. The entry point is the location at which water enters the distribution system from any applicable source(s), storage tank, pumping facility, treatment plant or other water system facility immediately prior to or at the first location where water can be consumed. This location reflects all applicable source water treatment and disinfection contact time. Please refer to the performance testing requirements in Sections 4.1.6 and 4.2.6 of this document.

6.1 Lead/Lag Changeout Policy

Treatment units designed in a lead/lag configuration provide a margin of safety if PFAS is monitored at midpoint and can be used to direct media changeout prior to exceeding the MCL at entry point to distribution (Sections 4.1.4.4 and 4.2.4.4 for GAC and AIX, respectively). Sampling for PFAS at midpoint is a proactive way to evaluate media performance, however, sampling at midpoint cannot be used for compliance purposes; entry point sample results must be submitted to satisfy routine sampling requirements.

There are two approaches to changeout. The water system could choose to conduct a lead/lag filter switch where the spent media/resin in the primary lead filter is removed and replaced with new media. The secondary lag filter (which still has some capacity to remove PFAS) is then moved to the new lead position and the new filter media/resin in the lag position. For larger filters (e.g. >16” in diameter), it may be difficult to physically move the lag filter into the lead position and the treatment facility may be plumbed accordingly to accommodate the vessel switch. If the lag filter is subsequently moved to the lead filter position, it too will be fully spent when breakthrough occurs at entry point, resulting in 100% use of capacity. Subsequent changeouts will be more frequent than the initial due to the loading on the original lag filter which is moved to the lead position.

Alternatively, the water system may choose to remove and replace media/resin from both vessels at the same time. This can be achieved by either physically removing the two spent vessels and replacing with new vessels or vacuuming out the spent media from both vessels and refilling with fresh media. However, this approach would not take full advantage of the media capacity of the lag filter. This may be an option if the changeout procedure cost outweighs the cost savings of fully saturating the lag filter. The more cost-effective option may depend on the characteristics of the individual water system.

7 Resources

American Water Works Association (AWWA). 2020. Drinking Water Treatment for PFAS Selection Guide, Technical Support on Per- and Polyfluoroalkyl Substances Policy. AWWA. https://www.awwa.org/Portals/0/AWWA/ETS/Resources/Technical%20Reports/Drinking-Water-Treatment-PFAS.pdf?ver=2020-11-10-100726-250

Berretta, C., Mallmann, T., Trewitz, K., and Kempisty, D.M. 2021. Removing PFAS from Water: From Start to Finish. In Kempisty, D.M. and Racz, L. (Eds.), Forever Chemicals: Environmental, Economic, and Social Equity Concerns with PFAS in the Environment (pp. 235-253). CRC Press. https://doi.org/10.1201/9781003024521

Dixit, F., Barbeau, B., Mohseni, M., 2018. Simultaneous uptake of NOM and Microcystin-LR by anion exchange resins: effect of inorganic ions and resin regeneration. Chemosphere 192, 113e121. https://doi.org/10.1016/j.chemosphere.2017.10.135.

Dixit, F., Barbeau, B., Mohseni, M., 2020. Impact of natural organic matter characteristics and inorganic anions on the performance of ion exchange resins in natural waters. Water Supply. https://doi.org/10.2166/ws.2020.197.

Great Lakes – Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers. 2022. Recommended Standards for Water Works. ("10 State Standards"). 2022 Edition.

GSI Environmental Inc., 2021. Pilot Test Results for Ion Exchange Resin and Granular Activated Carbon to Treat Groundwater, La Habra Heights County Water District, Water Supply Well #10, Water Replenishment District of Southern California, GSI Job No. 5302, Issued October 6, 2021.

Liu, C. J., Werner, D., & Bellona, C. 2019. Removal of per- and polyfluoroalkyl (PFASs) from contaminated groundwater using granulated activated carbon: A pilot study with breakthrough modeling. Environmental Science: Water Research & Technology, 5(11), 1844–1853.https://pubs.rsc.org/en/content/articlelanding/2019/ew/c9ew00349e

McCleaf, P., Englund, S., Östlund, A., Lindegren, K., Wiberg, K. & Ahrens, L. 2017. Removal efficiency of multiple poly- and perfluoroalkyl substances (PFASs) in drinking water using granular activated carbon (GAC) and anion exchange (AE) column tests. Water Research. 120, 77–87. https://doi.org/10.1016/j.watres.2017.04.057.

McNamara, J. D., Franco, R.,Mimna, R., & Zappa, L. 2018. Comparison of Activated Carbons for Removal of Perfluorinated Compounds From Drinking Water. Journal AWWA, 110(1), E2–E14. https://awwa.onlinelibrary.wiley.com/doi/abs/10.5942/jawwa.2018.110.0003

Medina, R., Pannu, M. W., Grieco, S. A., Hwang, M., Pham, C., & Plumlee, M. H. 2022. Pilot-scale comparison of granular activated carbons, ion exchange, and alternative adsorbents for per- and polyfluoroalkyl substances removal. AWWA Water Science, 4(5), e1308.https://awwa.onlinelibrary.wiley.com/doi/abs/10.1002/aws2.1308

Murray, C. C., Marshall, R. E., Liu, C. J., Vatankhah, H., & Bellona, C. L. 2021. PFAS treatment with granular activated carbon and ion exchange resin: Comparing chain length, empty bed contact time, and cost. Journal of Water Process Engineering, 44, 102342. https://www.sciencedirect.com/science/article/abs/pii/S2214714421004293

Najm, I., 2024. PFAS Bench Testing and Full-Scale Implementation Webinar. Water Quality and Treatment Solutions (Presentation Date: 7/26/2024)).

National Research Council (US) Safe Drinking Water Committee. 1980. Drinking Water and Health: Volume 2. Washington (DC): National Academies Press (US); 1980. IV, An Evaluation of Activated Carbon for Drinking Water Treatment. Available from: https://www.ncbi.nlm.nih.gov/books/NBK234593/

Pannu, M. W., Chang, J., Medina R., Grieco, S. A., Hwang, M., & Plumlee, M. H. 2023. Comparing PFAS removal across multiple groundwaters for eight GACs and alternative adsorbent. AWWA Water Science, 5 (3), e1345. https://doi.org/10.1002/aws2.1345

Purolite, 2024. PFAS-Selective Single-Use Ion Exchange Resin for Drinking Water Systems. Retrieved from: https://www.purolite.com/dam/jcr:e7dc9abb-abeb-4363-b46a-e44f1ae4ce18/PFAS-Drinking%20Water.pdf

Rahman, M. F., Peldszus, S., & Anderson, W. B. 2014. Behaviour and fate of perfluoroalkyl and polyfluoroalkyl substances (PFASs) in drinking water treatment: A review. Water Research,50, 318–340. https://pubmed.ncbi.nlm.nih.gov/24216232/

Riegel, M., Egner, S., Sacher, F. 2020. Review of Water Treatment Systems for PFAS Removal. Concawe. Report No. 14/20. https://www.concawe.eu/wp-content/uploads/Rpt_20-14.pdf

Speth, T. 2022. Removing PFAS from Drinking Water: Performance, Cost, and Management of Residual Streams. USEPA Presentation. https://cfpub.epa.gov/si/si_public_file_download.cfm?p_download_id=546405&Lab=CESER [accessed 3/11/24].

Stewart MH, Wolfe RL, Means EG. 1990. Assessment of the bacteriological activity associated with granular activated carbon treatment of drinking water. Appl Environ Microbiol. 1990 Dec;56(12):3822-9. doi: 10.1128/aem.56.12.3822-3829.1990. PMID: 2082828; PMCID: PMC185074.

United States Department of Agriculture (USDA). 2013. Rural Utilities Service Bulletin 1780-2, RD-GD-2013-70. https://www.rd.usda.gov/files/UWP_Bulletin_1780-2.pdf

United States Environmental Protection Agency (EPA). 2024a. Best Available Technologies and Small System Compliance Technologies Per and Polyfluoroalkyl Substances (PFAS) in Drinking Water. 815-R-24-011.

https://www.epa.gov/system/files/documents/2024-04/2024-final-pfas-bat-ssct_final-508.pdf

EPA. 2024b. Technologies and Costs for Removing Per- and Polyfluoroalkyl Substances from Drinking Water. 815-R-24-012. https://www.epa.gov/system/files/documents/2024-04/2024-pfas-tech-cost_final-508.pdf

EPA. 2024c. Interim Guidance on the Destruction and Disposal of Perfluoroalkyl and Polyfluoroalkyl Substances and Materials Containing Perfluoroalkyl and Polyfluoroalkyl Substances – Version 2 (2024). https://www.epa.gov/system/files/documents/2024-04/2024-interim-guidance-on-pfas-destruction-and-disposal.pdf

Vermont Department of Environmental Conservation (VT DEC). 2024. Environmental Protection Rules, Chapter 21, Water Supply Rule, Revision Date: February 21, 2024. https://dec.vermont.gov/sites/dec/files/dwgwp/dwrules/WSR%2024%20Feb%202024%20Rev.pdf

VTDEC. 2014. Technical Guidelines for Ultraviolet Disinfection for Non-Community Water systems; Installation, Operation, and Maintenance.

Woodard, S., Berry, J, and Newman, B. 2017. Ion exchange resin for PFAS removal and pilot test comparison to GAC. Remediation Journal 27.3 (2017): 19-27. https://onlinelibrary.wiley.com/doi/abs/10.1002/rem.21515

8 Attachments

Attachment A - PFAS GAC Treatment Design Checklist

Attachment B - PFAS AIX Treatment Design Checklist

Attachment A - PFAS GAC Treatment Design Checklist

Attachment B - PFAS AIX Treatment Design Checklist