ADEQ
Arizona Department of Environmental Quality

DECISION TREES FOR

PFAS

MITIGATION SELECTION IN DRINKING WATER

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Purpose

This document is intended to assist the engineers of public water utilities in making informed decisions in determining the most suitable non-treatment and treatment alternatives for mitigating per- and polyfluoroalkyl substances (PFAS). It provides step-by-step guidance on what information to collect, what screening tests to perform, and how to select the most appropriate mitigation alternative through the use of a series of decision trees. ADEQ recommends using this document very early in the planning stages, after PFAS exceedances are detected and as a utility is starting to consider compliance options and conceptual design, to set the foundation for the future steps of evaluation of the selected alternative, cost analysis, detailed design, and eventually permitting. The purpose is not to require one specific approach, but to support utilities in determining the most appropriate path forward. The intended users of this document are professional engineers with previous experience in water treatment design who will ultimately assist utilities' decision-makers.

Decision trees are one of the simplest tools to narrow down available alternatives to ones that are the most technically viable for a specific situation. They are designed to consider utility-specific conditions and mitigation goals. The decision tree approach has already been utilized for similar water treatment purposes, specifically, EPA's 2003 Arsenic Treatment Technology Evaluation Handbook for Small Systems, which was used as the primary basis for this document.

The selection of available strategies should be prioritized so that a utility first considers non-treatment alternatives, such as connecting to a neighboring public water system (PWS) that meets the PFAS Maximum Contaminant Levels (MCLs) at the intertie. These alternatives are preferred because they usually involve lower capital investments and reduced operations, maintenance and labor costs. If non-treatment alternatives are determined to be unsuitable for a specific application, a utility should then refer to best available technologies (BATs) as the most reliable alternatives that have already demonstrated full scale efficacy in the field.

Introduction

Multiple considerations are required when navigating PFAS mitigation alternatives. Even though all the alternatives addressed here have been in use for many years and their basic working mechanisms apply to PFAS mitigation, the optimal choice between them is a balance of many site-specific factors that can be analyzed through these decision trees. While the analyzed scenarios apply for the majority of systems, there are some specific cases that are not covered. In certain instances, selection of a mitigation alternative may be driven by a utility's capacity or constraints such as limitations in operating labor or cost. In such cases, the decision tree approach may not be suitable for making decisions and planning further steps, but rather, the circumstances would require the water utility to further assess their preferences in terms of costs and labor commitments, along with the utility's technical, managerial and financial capacity. These decision trees also may not be suitable for situations when a utility has existing Granular Activated Carbon (GAC), Ion Exchange (IX) or Reverse Osmosis/Nanofiltration (RO/NF) treatment equipment which is targeting other contaminants. While this treatment may also be effective for incidental removal of PFAS, and as such economically preferable over new installation, the process, at the very least, will need to be optimized or upgraded and sometimes even multiplied. For example, a utility may have an existing GAC system for removal of disinfection byproduct precursors, but an additional downstream (i.e., "post-filter") GAC system may be necessary to specifically target PFAS, since GAC types, operations, and changeout frequencies will differ between the two applications.

To best navigate this document and understand the requirements of corresponding alternatives, users should read the following sections in this order:

1. Overview of alternatives: This section provides background information on the various mitigation strategies and discusses the corresponding waste disposal concerns and the need to comply simultaneously with other applicable drinking water regulations.
2. Selection criteria and Water Quality Parameters built into decision trees: This section specifies considerations used to select the type of mitigation and lists information that needs to be gathered in order to use the decision trees.
3. Navigating decision trees: This section describes the recommended process for using the decision trees as well as the recommended subsequent actions that are not addressed by this document.
4. Six decision trees for non-treatment and treatment alternatives: Using the selection variables based upon questions, this section leads the utility through the mitigation decision process.

1.0 Overview of Alternatives

1.1 Non-treatment Strategies

Similar to any other regulated contaminant, PFAS in drinking water can be mitigated by several non-treatment alternatives. The decision trees include the following non-treatment alternatives:

- **New Source - Connection to Neighboring System:** The total abandonment of the problematic source(s) and the subsequent switch to another source. This involves connecting to a nearby PWS that does not contain PFAS in the finished water.
- **New Source - New Well:** Drilling and developing a new well. Additional hydrogeologic studies should be performed prior to drilling a new well(s) to help identify if this is a valid solution, along with identification and isolation of the source of contamination.
- **Rehabilitate or Modify Source:** Rehabilitating, sectional screening of casing or deepening an existing well to avoid a zone of contaminated water. The modified likely source alternative requires intensive zonal sampling and is similar to drilling a new well. It is not a recommended alternative unless hydrogeologic studies are performed prior to well rehabilitation to help identify if this is a valid solution for water systems. These hydrogeologic studies should include the identification and isolation of the source of contamination.
- **Seasonal Use:** Switching the problematic source(s) from full-time use to seasonal or peaking use which must include subsequent blending with other full-time source(s). This strategy is consistent with alternatives for other chronic contaminants and their running annual average compliance criteria.
- **Blending:** The combination of multiple water sources to produce a combined source with a PFAS concentration below the maximum contaminant level. Although theoretically feasible, this alternative is not always easily achievable due to challenges and limitations with the parts per trillion (ppt) MCL and high detection limits of analytical methods.

1.2 Treatment Strategies

At time of publication of this document, four BATs have been identified for PFAS treatment: adsorption and/or exchange by GAC or IX, and membrane separation by RO and NF. If a system is moving toward implementing GAC, it has been shown that in most cases bituminous GAC is the optimal choice, since the diffusion rate into the GAC pore structure appears to govern performance. Also, if a utility is moving toward implementing IX resin, it is recommended that the system use a single use PFAS-selective gel or macroporous anion exchange resin that has demonstrated good performance for PFAS removal to avoid the difficulty in regenerating PFAS-laden IX media.

1.2.1 Mechanism

Both GAC and IX technologies adsorb/exchange PFAS as long as adsorption/exchange sites are available. The difference is that GAC adsorbs the hydrophobic part of the PFAS compound (tail) via van der Waals forces, while IX, in addition to the adsorption mechanism, primarily acts through exchanges of negatively-charged anions like chloride with the hydrophilic head of PFAS, creating stronger chemical interactions. As a result, IX has a more selective PFAS removal mechanism and is less susceptible to desorption of bonded PFAS than GAC. Both GAC and IX are more successful at removal of PFOS than PFOA. However, the efficiency of both technologies declines as the length of PFAS molecules get smaller.

RO/NF is a high pressure-driven membrane separation process capable of removing PFAS from water by means of size exclusion, adsorption, and electrostatic interactions. Because size exclusion is the primary mechanism of PFAS removal, membranes are characterized by their molecular weight cut-off (MWCO) which refers to the lowest molecular weight of a solute that will be 90 percent rejected. For example, a membrane with a MWCO of 200 Daltons will remove at least 90 percent of all PFAS constituents with a molecular weight greater than or equal to 200 Daltons, such as PFBS (300 Daltons), PFOA (414 Daltons), and PFOS (500 Daltons). It should be noted that loose NF membranes are limited to removal of PFAS greater than or equal to 300 Daltons.

1.2.2 Operation (contact time, pre-treatment, backwashing, configuration)

PFAS treatment empty bed contact time (EBCT) is different for GAC (10 to 20 minutes) than it is for IX (2 to 3 minutes) due to the diverse pore structures and removal mechanisms. As a result, about four to five times less media volume is needed for IX than GAC, and, therefore, the footprint of the site may govern treatment decisions. All granular media may become fouled (e.g., by precipitation of inorganics like iron or by retention of sediment), which will have a negative impact on performance (due to the adsorption sites being located mainly in media pores). Backwashing of fouled media should be avoided with both types of media to prevent disturbance of the mass transfer zone, which can have a negative impact on useful bed life, given that the regulatory standards for PFAS concentrations are in the parts per trillion range. The evaluation for, and implementation of pre-treatment is highly recommended before GAC or IX media vessels designed for PFAS removal to remove suspended solids, precipitated solids (e.g. iron and manganese), and to prevent biological growth. In the absence of water quality parameters (WQPs) triggering specific pre-treatment, at the very minimum, 5 µm nominal-rated bag filters and 10 µm bag filters shall be used as particulate pre-filters for IX and GAC respectively. Cartridge filters can substitute for bag filters for smaller installations because they are easier to swap out and replace and can save space. For situations where: (1) a well produces sand, a de-sander addition is recommended; or (2) high levels of suspended solids that can quickly clog the 5 µm or 10 µm filter are expected, the utility should consider installing a series of larger filters ahead of the recommended one based on particle size distribution analysis (for example, 25 µm followed by 10 µm followed by 5 µm for IX). If absolutely necessary, instead of backwashing, a minimal operational backwash that slightly lifts the media may be done with GAC, but not with IX. The wide spread in GAC particle sizes can result in media settling

similar to before backwashing; hence the adsorbed PFAS may be roughly in the same location of the column after backwashing. A minimal operational backwash lifts the media and re-stratifies the GAC particles. This is more difficult for IX due to the typically uniform size of the beads and their low density, which means that fluidization occurs at low hydraulic loading rates (e.g., <0.5 gallons per minute per foot squared (gpm/ft2)). Because of the ease of fluidization, backwashing of an IX media bed may inadvertently allow the denser, precipitated inorganics to penetrate deeper into the bed.

In terms of configuration, it is recommended to use lead/lag series vessels for both GAC and IX. There are two major reasons for this: (1) more efficient usage of media; and (2) additional protection. Efficient usage of media includes both lower long term cost to operate due to longer media life, as well as reduced amount of media needed. The additional protection provided by a lag bed buffers the risk of catastrophic failure of a lead bed. Additionally, it can provide protection from the delay of receiving analytical results. This additional protection also helps to manage potential chromatographic peaking where PFAS or other contaminants may be pushed out from GAC or IX by other more strongly adsorbed contaminants present in water at orders of magnitude higher concentrations (e.g., TOC and nitrate). Chromatographic peaking is different from desorption, and it can be indicated by concentrations of PFAS in effluent that exceed (typically a few times) concentrations in influent. Eventually, the overshoot will subside and the column will reach equilibrium with the PFAS in question and the effluent will match the influent concentration. Specific applications may need GAC and IX used in series to optimize removal capacity and minimize O&M costs. Usually, a GAC vessel is placed ahead of IX to: (1) remove non-PFAS organics (for example, TOC or VOCs); or (2) remove PFAS and allow IX to be solely used in regeneration mode for non-PFAS anion treatment (for example, nitrate and PFAS treatment without PFAS in waste regenerant stream). The lead GAC vessel can also serve to protect the IX bed from a pre-oxidant, microbial fouling, and/or precipitated inorganics. For applications where treatment needs to include hardness removal and other cation treatment, the recommendation is to remove cations prior to PFAS.

Typical operating pressures required for NF treatment are between 70 and 150 pounds per square (psi), while for RO pressures greater than 200 psi are required due to the tighter membrane structure. Additional plant modifications may be needed to pump at an adequate membrane pressure. Both RO and NF must be protected from fouling and scaling by a series of pre-treatment units that commonly include: filtration for suspended solids, addition of chlorine, subsequent dechlorination, addition of anti-scalant, softening, carbon filter, and 5 µm filter cartridge. Although partial stream treatment and blending with raw water is common for RO and NF applications for cost savings and corrosion control, it is usually not feasible or recommended for PFAS due to the PFAS ppt treatment goals and high detection limits of analytical methods.

1.2.3 Removal of Co-contaminants

For adsorption/exchange technologies, removal of co-contaminants along with PFAS might be difficult because the adsorption sites are limited and competition for same sites with co-contaminants shortens

the one-time use media lifetime for PFAS. The deviations from this rule of thumb are still not well explored for PFAS, and several sites treating for both PFAS and VOCs with GAC showed no apparent shortening of PFAS bed life. A major competitor for GAC adsorption sites is TOC, while for IX, those competitors are TOC and anions (sulfate, nitrate, etc.). It is important to note that the impact of competition is very significant for PFAS because competing constituents are commonly present in much higher concentrations than PFAS, and as such, benefit from a larger driving force for diffusion into the media particle.

Although membranes are likely not necessary for the sole purpose of treating PFAS, RO and NF membranes are the most viable treatment alternatives when: (1) PFAS concentrations are high enough to make GAC or IX adsorbent replacement too frequent and cost-prohibitive; (2) PFAS treatment goals are too low to be met by adsorption/exchange technologies; or (3) treatment goals include removal of non-PFAS anions (arsenic, nitrate, uranium, fluoride), cations (hardness and radium), total dissolved solids, or TOC to below detection levels to minimize disinfection by-products (DBP) formation. In contrast to adsorption/exchange technologies that have limited adsorption sites, the membrane removal mechanism allows multiple-contaminant treatment with no significant tradeoffs in terms of media lifetime, the need for additional vessels, or the quality of the produced water.

1.2.4 Impact of Oxidants

In the case of microbial or biological activity at the source, oxidation processes may be necessary before the PFAS treatment units. This configuration, however, usually requires additional treatment adjustments. Specifically, because GAC removes oxidants and eliminates their residual benefits in the distribution system, post-disinfection is required. On the other hand, IX polymer media in contact with oxidants becomes degraded and produces a nitrosamine byproduct, and therefore, removal of trace oxidants is necessary before IX treatment.

Most membranes are polymer based, and, as such, are prone to degradation in contact with oxidants. This applies particularly to polyamide membranes. To prevent degradation, similar to IX, feed water should be dechlorinated.

1.2.5 Residual Management

Waste disposal is an important consideration in the treatment selection process, especially in the case of PFAS where residuals have the potential for being classified as hazardous and can pose disposal problems. Ideally, both GAC and IX technologies should operate as zero liquid discharge because no backwashing should be implemented. In terms of solid waste, a higher quantity of spent media will be generated with GAC (due to larger beds), which may be compensated by the possibility of reactivation of GAC (which is not possible for IX).

While high-pressure membranes are a highly effective treatment technique that can meet very strict treatment goals without being drastically impacted by the water matrix, management of the membrane concentrate poses a significant concern for cost and operation feasibility due to the stringent regulations

on how PFAS contaminated waste can be handled and disposed of. The rejection rate for RO is typically 20 to 40 percent, and ranges from 5 to 20 percent for NF, which makes NF much more suitable for Arizona applications where concentrate discharge is a limiting factor. Two strategies exist to minimize the amount of concentrate to be disposed of: cycling the concentrate through RO/NF membrane(s) multiple times to reduce concentrate waste volume or concentrating the residual via adsorption. Either way, the concentrate must be treated with GAC or ultimately be disposed of at a hazardous waste facility that accepts PFAS waste.

1.2.6 Simultaneous Compliance

Simultaneous compliance refers to the need for careful planning and proper implementation of new processes to comply with a particular drinking water regulation, so that treatment performance or compliance with other Safe Drinking Water Act regulations is not compromised. Specifically, when selecting a mitigation strategy to conform with the PFAS MCL, it is important to revisit compliance with the Revised Total Coliform Rule (RTCR) and the Lead and Copper Rule (LCR). Both GAC and IX beds may support microbiological growth, and fines from GAC transported to finished water can act as a substrate for bacteria which is why post disinfection is needed. Corrosion control, required by the LCR, is highly dependent on the type of PFAS media selected. While GAC is considered beneficial for corrosion control because it removes organics, IX simultaneously removes alkalinity, sulfate and other anions in exchange for chloride potentially causing an initial (short-term) pH drop and change in chloride to sulfate mass ratio (CSMR). There are three options to solve this, (1) modeling can be done to predict what volume of water is to be disposed before it goes to distribution network; (2) buffered resin may be used or a buffering step can be added during start up, and/or (3) when multiple columns are used, staggered starts can allow for adequate blending. The short-term compliance impacts are typically associated with start-up and are mainly addressed by meeting the NSF/ANSI 61 requirements to rinse the media to ensure removal of natural and synthetic residuals. The impacts for GAC are arsenic and high pH, and for IX, nitrosamines and increased chloride and decreased sulfates. Acid-washed GAC can be purchased or a pre-rinse can be performed prior to the final rinse required by NSF/ANSI 61. It is important to consider the supply availability of pre-treated media (acid-washed GAC or buffered IX), as well as possible infrastructure limitations for wastewater disposal (from pre-rinse with chemical supplements and final rinse as guided by NSF/ANSI 61).

Similar to adsorption media in fixed beds (GAC and IX), the membrane surface can act as a substrate for microbiological growth. Although in some cases membrane cleaning can restore treatment performance, this process is difficult and costly. Other areas of concern include the corrosive nature of the finished water due to demineralization that includes removal of alkalinity from water, which in turn could affect corrosion control within the distribution system. From a corrosion and biological standpoint, RO/NF post-treatment includes chlorination and remineralization.

1.2.7 Cost difference

The cost difference between adsorption media is significant with GAC being about four to five times less expensive than IX by volume, but GAC also requires 4 to 5 times more media to accommodate the longer contact time, which may result in a similar cost for media replacement. Therefore, special attention must be taken when a cost-benefit analysis is performed, so that an accurate media lifetime normalized per production rate of water is calculated to avoid misleading results based on a traditional bed volume comparison. A more detailed cost comparison should also take into account that media reactivation is only a benefit for GAC systems. Although this allows cost saving through multiple reuses of media, it should be noted that: (1) reactivation is not suitable for all GAC users, as it depends on the location of reactivation facility, media quantity limitations, and spent GAC quality; and (2) the reactivation process may be impacted by new PFAS-specific waste regulations in the future which will have an effect on current cost benefit analyses.

The capital cost of membranes is highly dependent on the water production rate and the membrane rejection rate. For a small system producing approximately 20 gallons per minute with about a 20 percent rejection rate, the cost of an RO system is comparable to adsorption processes. The O&M cost is, however, significantly different. Membrane modules are replaced every 3 to 10 years, however, daily costs are based on energy usage and reject stream management, where the last two favor NF in comparison to RO membranes.

2.0 Selection Criteria and Water Quality Parameters

2.1 Selection Criteria Built into Decision Trees

The selected process (or coupling of multiple processes for enhanced performance) is one that has the highest chance of achieving the simplest solution for the particular water source, given the variables used in the decision-making process. The following variables should be established prior to navigating the decision trees for such selection:

- PFAS Treatment Goals
- Non-PFAS Treatment Goals
- Water Demand
- Water Sources and Supply
- Existing Treatment Processes for Non-PFAS Contaminants
- Land Availability
- Labor Commitment
- Acceptable Percent Water Loss
- Corrosion Potential
- Residual Management

2.2 Water Quality Parameters Built into Decision Trees

The quality of the source water drives treatment goals and influences the efficacy of PFAS removal processes. This affects treatment train design, process performance, O&M needs, and the disposal of residuals, that all together determine the viability of a specific treatment approach. Therefore, it is critical for all mitigation strategies to be based on a known quality of water matrix and its variations. The water quality parameters should be monitored multiple times over the course of the year to capture variability in concentrations and temporal or seasonal changes in source water quality. In addition to PFAS monitoring, background water quality parameters should be analyzed. It is recommended to include both PFAS and background water quality parameters during the same sampling events (paired samples). Although sampling focused on EPDS locations serves as indicator of a potential PFAS issue, mitigation strategies should expand the sampling locations to include raw water sources and significant points within the existing treatment trains. Only comprehensive sampling allows accurate use of the decision trees, preparation for evaluation of technology performance through pilot testing, optimization of treatment trains, operational parameters, and cost analysis.

The background water quality parameters that influence PFAS treatment selection and drive the need for pre-treatment or technology combination are as follows:

- **Cations:** Calcium, Magnesium, Sodium, Potassium, Iron, Manganese, Total Hardness, Ammonium
- **Anions:** Sulfate, Nitrate, Arsenic, Fluoride, Perchlorate, Bicarbonate, Uranium, Chloride
- **Other:** TSS, TOC, DOC, TDS, pH, Temperature, Silica, Alkalinity, Oil and Grease, Chlorine and Other Oxidants Residual, Total Coliform, Heterotrophic Plate Count (HPC), Langelier Saturation Index (LSI), silt density index (SDI) for membrane application, and turbidity.

3.0 Navigating Decision Trees

This document provides six decision trees for PFAS mitigation purposes which are intended to be used iteratively.

- **Tree 1:** Non-Treatment Selection
- **Tree 2:** General Treatment Selection
- **Tree 3:** GAC Treatment
- **Tree 4:** IX Treatment
- **Tree 5:** RO/NF Treatment
- **Tree 6:** Simultaneous Compliance for Non-Treatment and Treatment Alternatives

The user should start with Tree 1 to first assess the suitability of non-treatment alternatives, which are often preferred to treatment. If non-treatment is not an option for meeting the utility's goals, the user should proceed to Tree 2 for general selection of the most suitable BATs. Each treatment alternative is

further analyzed individually in Trees 3-5 (GAC, IX and RO). Finally, Tree 6 should be used to evaluate simultaneous compliance and, as such, applies to both non-treatment and all three treatment options.

Colors and shapes within the decision trees help the user navigate them. Teal boxes are initial questions and black boxes are switches. Olive green boxes instruct the user to evaluate various factors. Blue boxes pose follow up questions to the user. Orange boxes with rounded corners indicate the user should refer to another tree.

The decision tree process is based upon information or utility preferences and typically relies upon yes or no responses, but at times includes multiple choice responses. Following the most likely flow path will lead to other questions, including information and recommendations to implement for these given scenarios. From this, the utility will reach an action box where the next step will be contingent upon the utility's willingness and ability to impose a particular change in their operating scheme. This will either point the user to another decision tree or make a final recommendation for a PFAS mitigation selection. It should not be forgotten that all final process recommendations lead to Tree 6 to check if additional actions for simultaneous compliance are needed. Ultimately, the decision trees are intended for use as an iterative tool which may not always lead to a single solution but will enable quick exclusion of certain options that are impractical for a particular application.

Additional steps that are recommended to be followed in this order but are outside the scope of this document and decision trees are summarized below:

1. **Estimate planning-level costs**. This involves capital and O&M costs for the mitigation strategy using cost modeling tools | View Tool > To satisfy input requirements for treatment cost estimates, the utility should work with manufacturers to get WQPs-based initial media life estimates. The cost estimates should differentiate between capital and O&M costs which, at the very minimum, will include sediment pre-treatment, lead-lag configurations, post-treatment disinfection and PFAS-specific waste handling. If this planning level cost is not within a range that is financially possible, the user should consider using different alternatives in the decision tree process.
2. **Evaluate treatment mitigation strategies.** Evaluation (preferably long-term (>6 months) pilot testing) is necessary in optimizing treatment variables and avoiding implementing a strategy that will not work for unforeseen reasons. This evaluation is indicated in Trees 3 and 4. Pilot testing protocols are not provided by this document but will be added in the future.
3. **Develop a detailed construction-level and O&M cost estimates.** Refer to AACE International, Cost Estimate Classification System, 2005 | View Document >
4. **Develop the final design and submit for permitting.**

Tree 1: Non-Treatment Selection

Are there one or more active or inactive sources available with PFAS levels below the MCLs?

No → Go to Tree #6 Simultaneous Compliance (See note #2)

Yes → Can the source(s) be operated in lieu of the high PFAS source(s) to meet total system demand?

Yes → Evaluate shutting-off or switching high PFAS source to back-up/seasonal use only. → Next Step → Go to Tree #6 Simultaneous Compliance (See note #2)

No → Can the source(s) be operated in conjunction with the high PFAS source(s)?

No → Can a new source or modification be considered instead of PFAS treatment?

Yes, select one of three options.

- Rehabilitate/ Modify Source → Evaluate modifying the well by:
  - Identifying the likely source of contamination
  - Performing a hydrogeologic study
  - Conducting zonal sampling
  - (See note #4)
- New Source: New Well → Evaluate location for drilling a new well, by:
  - Identifying the likely source of contamination
  - Performing a hydrogeologic study
  - Conducting initial sampling/exploratory boring
  - (See note #4)
- New Source: Connection to Neighboring System → Evaluate connection feasibility and arrangements/ connection options by checking:
  - Distance for connection (dictates pipe length)
  - Flow requirements (dictates pipe diameter)
  - Available vs required pressure (dictates need for booster pumps)
  - Applicability of the Public Water System definition/Safe Drinking Water Act exemption (dictates compliance requirements for systems that become a sole source customer of another PWS)
  - Cost of water and metering arrangements
  - Risk and resiliency

→ Next Step → Go to Tree #6 Simultaneous Compliance (See note #2)

Yes → Can the source(s) be blended so that the PFAS MCLs are met at all entry points to the system?

No → Can a new source or modification be considered instead of PFAS treatment?

Yes → Are there any constraints to blending? (See note #3)

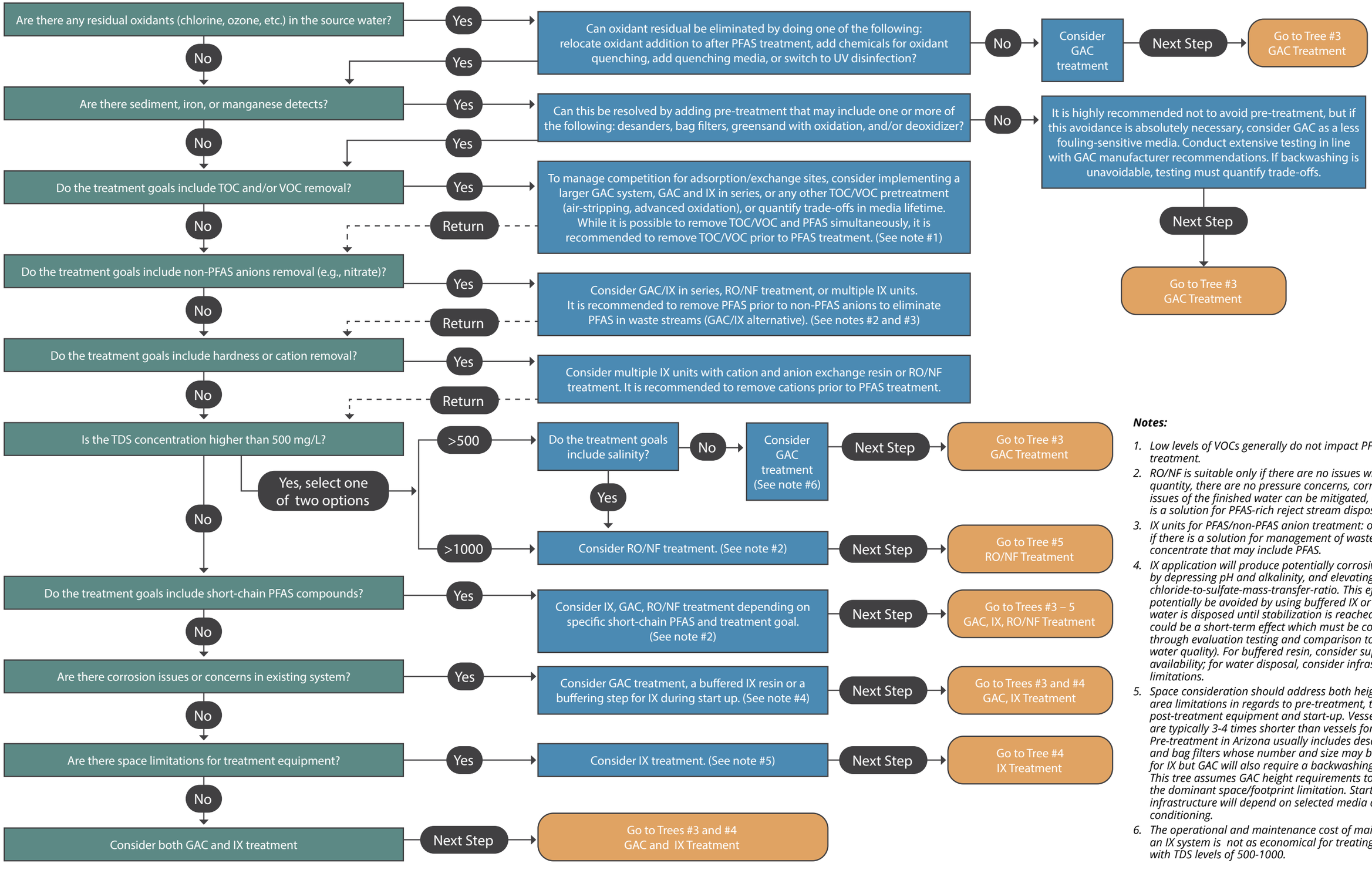
Yes → Go to Tree #2 General Treatment Selection

No → Evaluate using blending to meet MCLs. (See note #1) → Next Step → Go to Tree #6 Simultaneous Compliance (See note #2)

Notes:

1. *Blending is highly challenging for PFAS compliance due to proximity of the MCLs and detection limits of analytical methods.*
2. *Corrosion evaluation is required for non-treatment options including new source, blending with existing or new sources, and connection to another system.*
3. *Constraints to blending could include distance between sources, water quality impacts or water quantity impacts.*
4. *Narrowed to groundwater alone due to local limited avilability of surface water, prevalence of small systems with limited capacity for treatment that is inevitable with this type of source.*

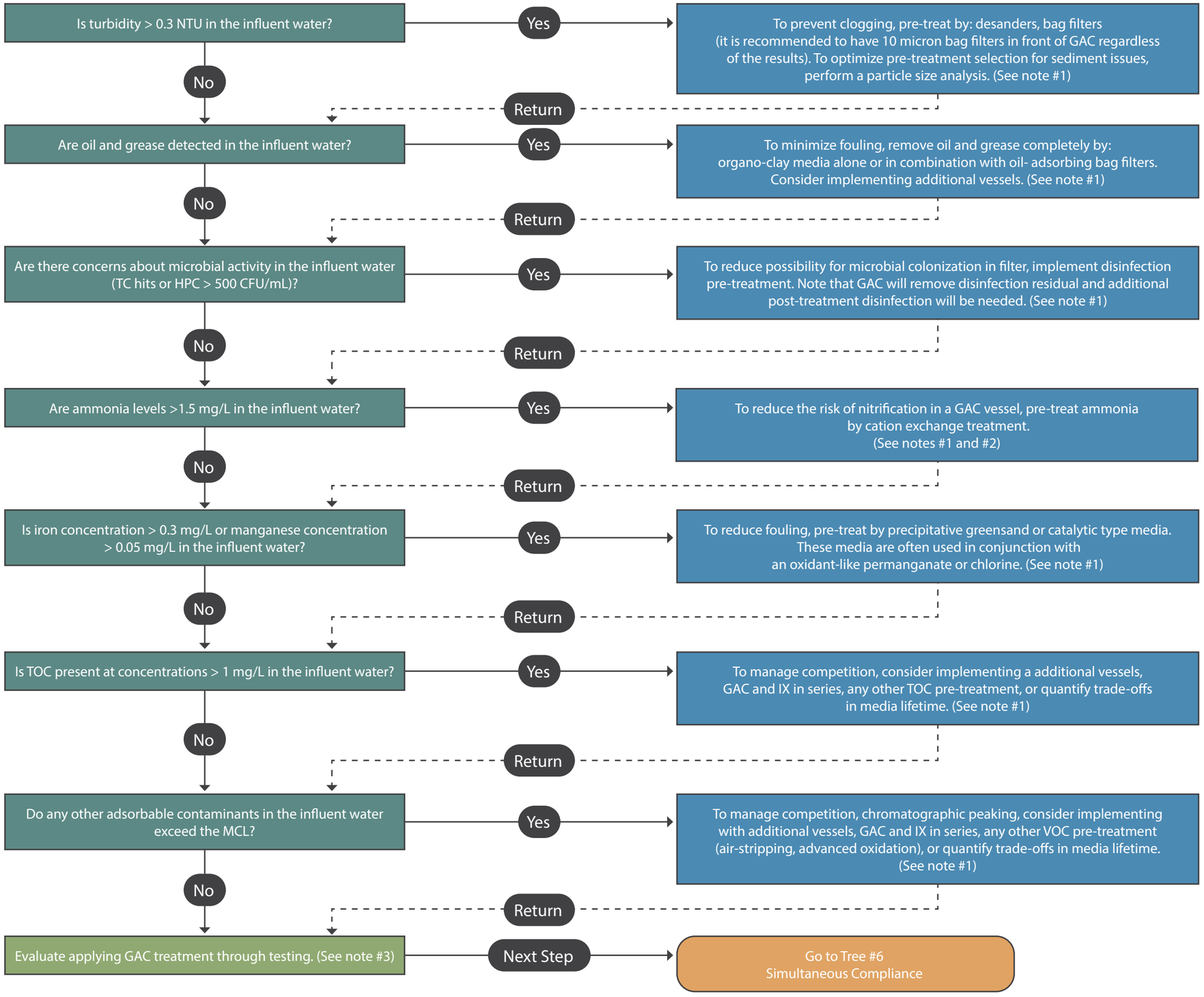
Tree 2: General Treatment Selection



Notes:

1. *Low levels of VOCs generally do not impact PFAS treatment.*
2. *RO/NF is suitable only if there are no issues with water quantity, there are no pressure concerns, corrosion issues of the finished water can be mitigated, and there is a solution for PFAS-rich reject stream disposal.*
3. *IX units for PFAS/non-PFAS anion treatment: only if there is a solution for management of waste concentrate that may include PFAS.*
4. *IX application will produce potentially corrosive water by depressing pH and alkalinity, and elevating the chloride-to-sulfate-mass-transfer-ratio. This effect may potentially be avoided by using buffered IX or if treated water is disposed until stabilization is reached (this could be a short-term effect which must be confirmed through evaluation testing and comparison to previous water quality). For buffered resin, consider supply availability; for water disposal, consider infrastructure limitations.*
5. *Space consideration should address both height and area limitations in regards to pre-treatment, treatment, post-treatment equipment and start-up. Vessels for IX are typically 3-4 times shorter than vessels for GAC. Pre-treatment in Arizona usually includes desanders and bag filters whose number and size may be larger for IX but GAC will also require a backwashing tank. This tree assumes GAC height requirements to be the dominant space/footprint limitation. Start-up infrastructure will depend on selected media and its conditioning.*
6. *The operational and maintenance cost of maintaining an IX system is not as economical for treating streams with TDS levels of 500-1000.*

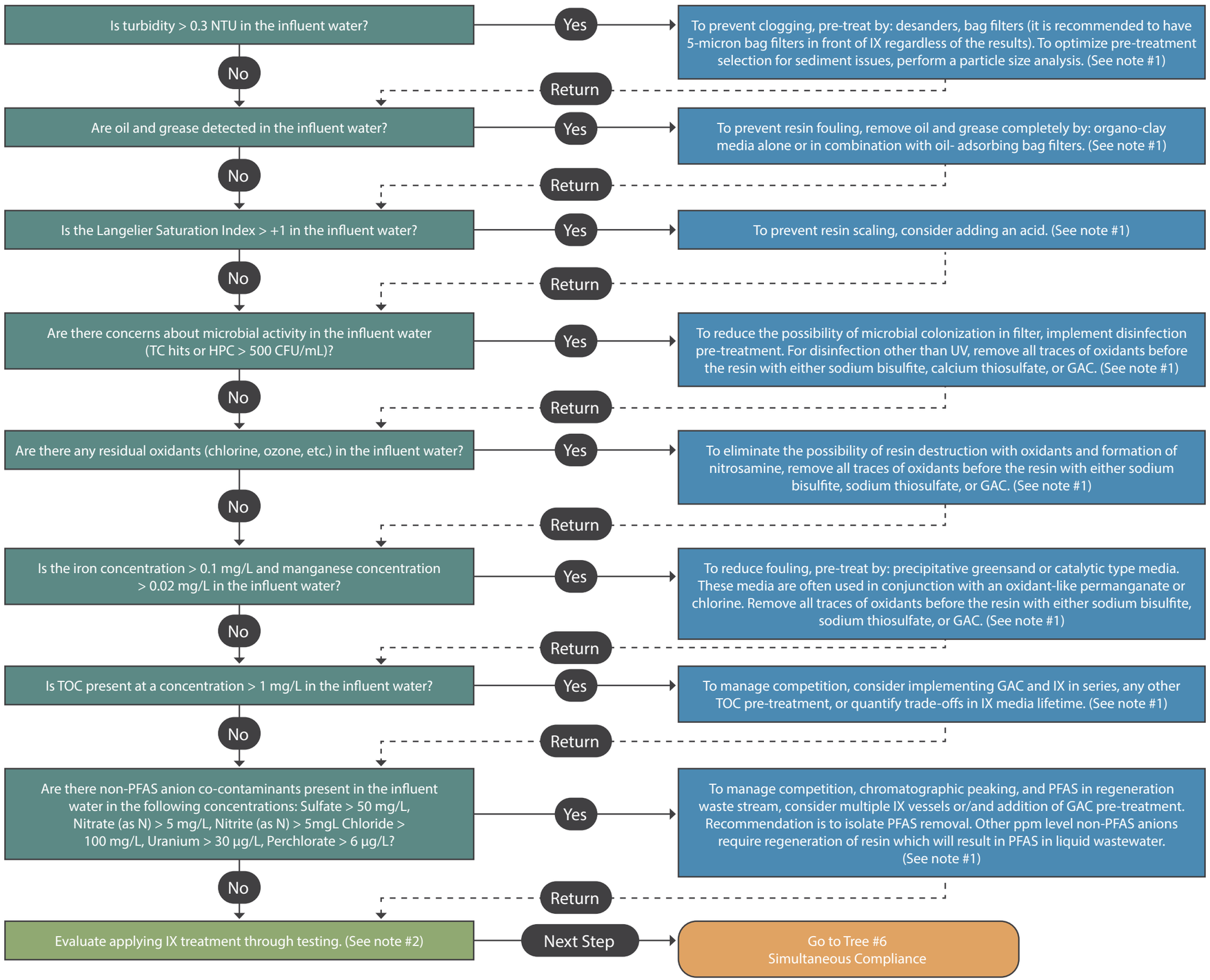
Tree 3: GAC Treatment



Notes:

1. *It is highly recommended not to avoid pre-treatment, but if this avoidance is absolutely necessary, conduct extensive testing in line with manufacturer recommendations to quantify trade-offs resulting from not adding pre-treatment or choosing alternative GAC design.*
2. *Addition of chlorine to convert ammonia to chloramine may not be suitable because GAC will just strip the chlorine off of the chloramine in the first few minutes of the bed and ammonia/ nitrification potential will still remain in the rest of the bed.*
3. *Evaluation through testing should mimic full scale as closely as possible and should include all needed pre-treatment steps identified through decision tree process.*

Tree 4: IX Treatment



Notes:

1. *It is highly recommended not to avoid pre-treatment, but if this avoidance is absolutely necessary, conduct extensive testing in line with manufacturer recommendations to quantify trade-offs resulting from not adding pre-treatment or choosing alternative IX design.*
2. *Evaluation through testing should mimic full scale as closely as possible and should include all needed pre-treatment steps identified through decision tree process.*

Tree 5: RO/NF Treatment

Are there particulates (turbidity > 1 NTU and/or silt density index > 5) in the influent water?

Yes → Ensure that the membrane configuration includes multiple pre-treatment elements, such as granular sediment filter > oxidation > greensand > softening > anti-scalant injection > carbon filter > 5 micron cartridge filter.

Note that LSI, TC, and HPC should be measured in both influent water and membrane concentrate. Although these parameters may be acceptable in the influent, they may change significantly (particularly towards the exit of the membrane module) for RO/NF systems that are designed for high recovery.

Avoiding pre-treatment is not an option for RO/NF design because in addition to poor treatment performance, it could lead to premature equipment failure.

No → Return

Are oil and grease present in the influent water?

Yes → (same box)

No → Return

Is the Langelier Saturation Index > +1 in the influent or concentrate?

Yes → (same box)

No → Return

Are there concerns about microbial activity in the influent or concentrate (TC hits or HPC > 500 CFU/mL)?

Yes → (same box)

No → Return

Are there any residual oxidants (chlorine, ozone, etc.) in the influent water?

Yes → (same box)

No → Return

Does the influent water have organics and potential to cause biological fouling?

Yes → (same box)

No → Return

Does the influent water include contaminants < 300 Daltons (PFOS = 500, PFOA = 414, PFBS = 300, PFNA = 464, PFHxS = 400, GenX = 347 Daltons)?

Yes → Evaluate applying RO treatment through testing

- RO will produce more concentrate than NF
- Consider cycling the concentrate through RO membrane(s) multiple times to reduce concentrate waste volume. Evaluate feasibility during predesign
- Consider treatment of concentrate residual via adsorption
- Coordinate disposal at a hazardous waste facility that accepts PFAS waste

Next Step → Go to Tree #6 Simultaneous Compliance

No → Is the objective to minimize waste (concentrate reject) stream?

No → (same RO box)

Yes → Is avoiding recirculation for the reduction of waste preferable?

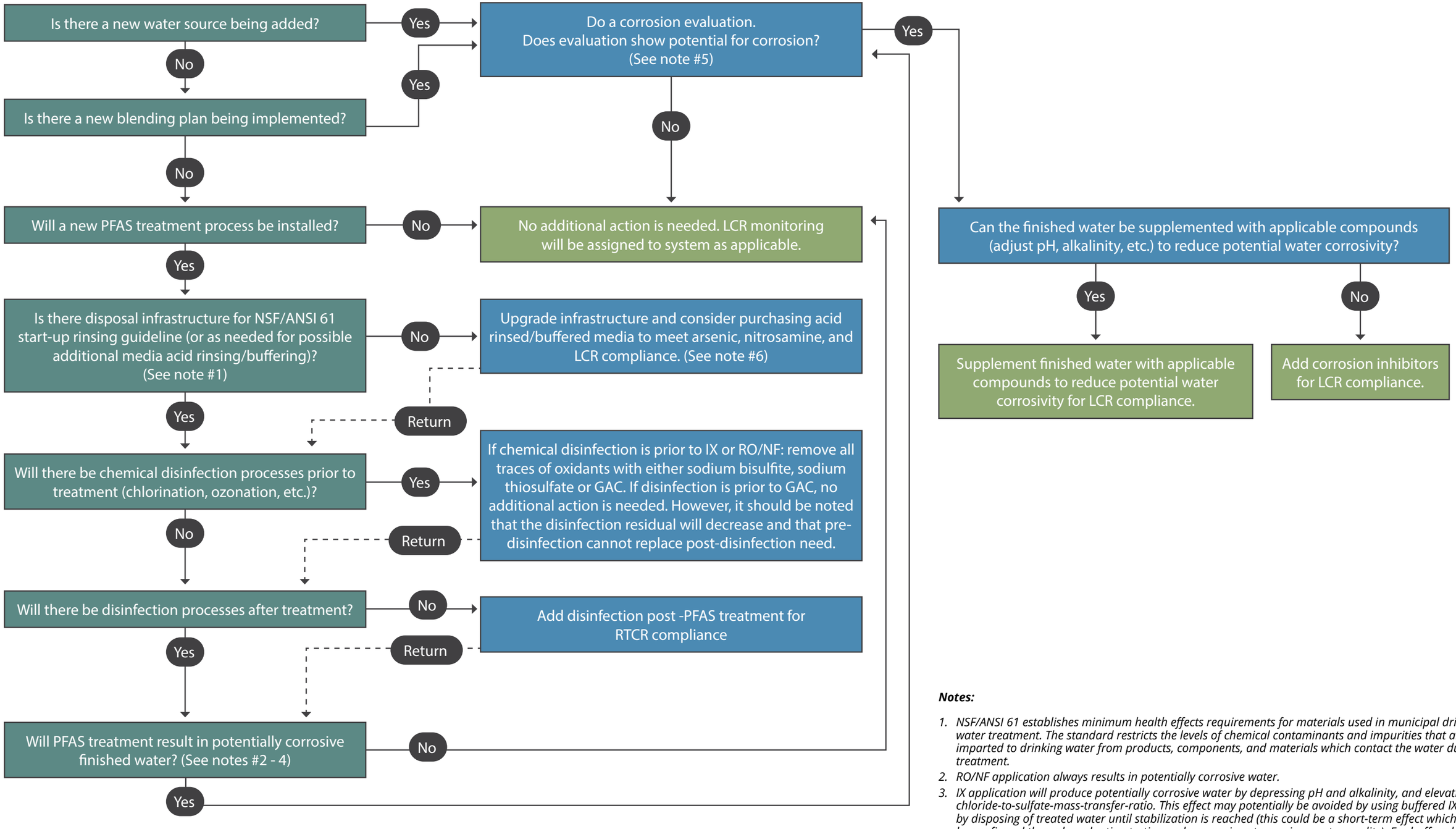
No → (same RO box)

Yes → Evaluate applying NF treatment through testing

- Removal efficiency of compounds < 300 Daltons by NF can be impacted by influent water and membrane chemistry (e.g. pH, membrane charge, feed concentration)
- Consider treatment of concentrate residual via adsorption
- Coordinate concentrate disposal with a PFAS accepting hazardous waste facility

Next Step → Go to Tree #6 Simultaneous Compliance

Tree 6: Simultaneous Compliance for Non-Treatment and Treatment Alternatives



Notes:

1. *NSF/ANSI 61 establishes minimum health effects requirements for materials used in municipal drinking water treatment. The standard restricts the levels of chemical contaminants and impurities that are imparted to drinking water from products, components, and materials which contact the water during treatment.*
2. *RO/NF application always results in potentially corrosive water.*
3. *IX application will produce potentially corrosive water by depressing pH and alkalinity, and elevating the chloride-to-sulfate-mass-transfer-ratio. This effect may potentially be avoided by using buffered IX or by disposing of treated water until stabilization is reached (this could be a short-term effect which must be confirmed through evaluation testing and comparison to previous water quality). For buffered resin, consider supply availability; for water disposal consider infrastructure limitations.*
4. *GAC application does not result in potentially corrosive water.*
5. *Corrosion evaluation starts with analysis of water quality of all sources, estimated impact of treatment, system layout, operation and material inventory. Need for study is determined from evaluation results.*

Acronyms

ADEQ	Arizona Department of Environmental Quality
BAT	Best Available Technology
CFU	Colony Forming Units
CSMR	Chloride to Sulfate Mass Ratio
DOC	Dissolved Organic Carbon
EBCT	Empty Bed Contact Time
EPA	U.S. Environmental Protection Agency
EPDS	Entry Point to the Distribution System
GAC	Granular Activated Carbon
HPC	Heterotrophic Plate Count
IX	Ion Exchange
LCR	Lead and Copper Rule
LSI	Langelier Saturation index
MCL	Maximum Contaminant Level
µm	Micron or Micrometer
MWCO	Molecular Weight Cut-off
NF	Nanofiltration
NTU	Nephelometric Turbidity Units
O&M	Operations and Maintenance
PFAS	Per- and Polyfluoroalkyl Substances
PFBA	Perfluorobutanoic Acid
PFBS	Perfluorobutane Sulfonate
PFHxS	Perfluorohexane Sulfonate
PFNA	Perfluorononanoic Acid
PFOA	Perfluorooctanoic Acid
PFOS	Perfluorooctane Sulfonic AAcid
ppt	Parts Per Trillion
psi	Pounds Per Square Inch
PWS	Public Water System
RO	Reverse Osmosis
RTCR	Revised Total Coliform Rule
SDI	Silt Density Index
TC	Total Coliform
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TSS	Total Suspended Solids
VOC	Volatile Organic Compound
WQP	Water Quality Parameter

References

1. EPA Office of Water, 2003, (4606M) 816-R-03-014, Arsenic Treatment Technology Evaluation Handbook for Small Systems | View Source >
2. AWWA, Drinking Water Treatment for PFAS Selection Guide | View Source >
3. Purolite Design and Operational Guidelines: PFAS-Selective Single Use Ion Exchange Resin for Drinking Water Systems | View Source >
4. EPA, 2020, Simultaneous Compliance Workbook: Key Questions to Consider When Adding or Changing Treatment — A Simplified Approach | View Source >
5. 5. Drinking Water Treatment Technology Unit Cost Models | View Source >
6. 6. AACE International, Cost Estimate Classification System, 2005 | View Source >

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