



REVIEW STUDY ON COMPARISON OF THE BEHAVIOR OF PERFLUOROOCANOIC ACID (PFAS) AND TRICHLOROETHENE RETARDATION FACTORS IN GROUNDWATER TRANSPORT IN COMPARABLE AQUIFERS.

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Abstract- In this review study, the behaviour of retardation factors for trichloroethene (TCE) and perfluorooctanoic acid (PFAS) in groundwater transport within similar aquifer systems is thoroughly analysed. Understanding the differences between each type of contamination and the function that retardation variables play in controlling their movement and fate in groundwater is critical to the efficient management of the environment. This study looks at the mechanisms determining the retardation of PFAS and TCE through a comprehensive analysis of the literature. These mechanisms include things like adsorption, solubility, and hydrogeological qualities. Additionally, a critical assessment is conducted on the parallels and divergences between the behaviour of TCE and PFAS in comparable aquifer environments. The review's conclusions shed insight on the difficulties in controlling the pollution caused by TCE and PFAS and advance our knowledge of the dynamics of contaminant movement in groundwater. The significance of customized approaches for repair and monitoring strategies in comparable aquifer situations is shown by this comparative analysis.

Index terms- Per-fluorinated carboxylic acids (PFCAs), Per-fluorooctanoic acid (PFOA), Perfluorooctane sulfonic acid (PFOS), Toxicology, Trichloroethene (TCE), Environment

INTRODUCTION

One of the primary sources of fresh water in the globe, groundwater, is used for industrial, agricultural, and residential applications. Groundwater supplies drinking water to about one-third of the global population. Groundwater is an extremely important resource in arid and semi-arid regions with little surface water and precipitation. Ensuring a steady and replenish able supply of drinking water from the ground is one of the most significant variables affecting a nation's sustainable growth.[1] Nonetheless, industrialization, urbanization, agriculture, and climate change pose serious threats to the quality of groundwater. Hydrocarbons, pesticides, toxic metals, trace organic contaminants, nanoparticles, micro plastics, and other recently identified contaminants are among the substances that pose a threat to human health, ecological services, and sustainable socioeconomic development.

Over the past thirty years, groundwater research has focused a lot of attention on the topic of chemical pollution. While groundwater contamination is a major concern for human populations, it also provides a valuable opportunity for scholars and policymakers to gain insights into the formation of our subterranean aquifers and methods for preserving their amount and quality. [2]

The fresh water aquifers comprise the most important parts of the Critical Zone (CZ), which extends from the top of the vegetation canopy to the bottom of the aquifer. The addition of undesirable materials to groundwater as a result of human activity is known as groundwater contamination, according to the Government of Canada (2017). This can be caused by chemicals, fertilizers, fuel, bacteria, viruses, road salt, and prescription drugs. [3] However, groundwater pollution is difficult to recover resources from given current technological capabilities and is invisible in contrast to surface water contamination. The majority of pollutants discovered in groundwater are odourless and colourless. In addition, the negative consequences of contaminated groundwater on human health are persistent and very hard to pinpoint. [4]Groundwater is located in layers of underlying geology that have long residence times, making cleaning of contaminated groundwater challenging and costly. The natural cleansing processes for contaminated groundwater may take decades or even hundreds of years, even after the pollution source is eliminated. [5]

When man-made materials like chemicals, oil, road salt, and gasoline seep into the groundwater, they contaminate it and make it dangerous for human use.

Materials on the surface have the capacity to seep into the groundwater through the soil. For example, pesticides and fertilizers may eventually seep into groundwater supplies. Road salt, toxic waste from mining sites, and spent motor oil can all seep into groundwater. Moreover, toxic materials from leaking landfills, untreated septic tank waste, and subterranean storage tanks can contaminate groundwater. There can be major health consequences from drinking tainted groundwater. Septic tank waste pollution can lead to diseases including dysentery and hepatitis. Toxins that have seeped into well water supplies may be the cause of poisoning. Contaminated groundwater can also be harmful to wildlife. Exposure to contaminated water may potentially have other long-term impacts, such as some forms of cancer.

The voids seen in rocks and in loose sediments are where groundwater is kept. Since they are not as compressed as those that are much deeper, rocks and sediments that are closer to the surface typically have more available space. The majority of groundwater that is accessible to individual users is found in the first 100 meters of the surface due to this and the high cost of drilling deep wells. Although there is a limit to how deep we can go, some groundwater users—municipal, agricultural, and industrial—originate from deeper depths. However, deeper groundwater is typically of worse quality than shallow groundwater. The percentage of free space in unconsolidated rock or silt is known as porosity. The voids found in sediments and sedimentary rocks are indicative of primary porosity. Porosity that has evolved after the formation of the rock is known as secondary porosity. It can include the amount of space within any rock's fractures, or fracture porosity. Certain types of porosity associated with vesicles are present in some volcanic rocks, while higher porosity associated with cavities seen in fossils is present in some limestones.

The volume of open space in a rock divided by the total volume of the rock yields the percentage that represents porosity. Since most unconsolidated sediments have not been heavily compacted and lack cement, they often have more porosity than consolidated sediments. More porosity—up to 70 percent—is typically found in finer-grained materials (like silt and clay) than in coarser-grained ones (like gravel). When compared to poorly sorted sediments, which have a variety of smaller particles to fill the gaps left by the bigger particles, well-sorted sediments typically, have higher primary porosity. The porosity of glacial till is very low, despite its wide range of grain sizes and usual formation process beneath glacial ice by compression. [6]

1.1 Aquifers:

A deposit of groundwater-saturated porous rock or sediment is known as an aquifer. Aquifers are filled with groundwater that seeps through the earth due to precipitation. It can go through the aquifer and emerge again via wells and springs. Aquifers can be classified as either contained or unconfined. Unconfined aquifers are found beneath a permeable layer of soil, whereas confined aquifers are covered in an impenetrable layer of rock or clay. Unconfined aquifers are usually unbounded above but not below by a non-porous layer. Confined aquifers are those that are encased in two strata of rock.

An aquifer's porosity indicates how much water is contained inside it. Aquifers can be formed by a wide variety of sediments and rocks, such as cracked limestone, sandstone, gravel, and conglomerates. There are instances where aquifers are classified based on the kind of rock or sediments that make them up. An uncommon situation that might occasionally be discovered within an unconfined aquifer is the perched aquifer. [7] A perched aquifer is a type of aquifer that is found to support a body of saturated material inside the zone of saturation under an impervious deposit that is beneath a pervious deposit. The top surface of the water contained in the perched aquifer is known as the perched water table.

Conservative water conservation is personified by the saturated aquifer, which symbolizes abundance and steady output. The pore spaces in this type of aquifer are completely saturated with water, creating an underground reservoir that abundantly supports springs and wells. An essential measure of water availability, the water table reflects the balance of nature's resources.[8] Accepting the fundamental conservative ideas of equilibrium and natural replenishment, the unsaturated aquifer illustrates the complex interactions that occur between rock, soil, and water. The vadose zone, a type of aquifer, contains pore spaces that support a delicate balance between water and air, with the natural forces determining the exact ratio. With every drop of rain, every vapour released, and every hug from plants, the unsaturated aquifer protects the fragile balance between surface and groundwater.

1.2 Fluorinated carboxylic acids (PFCAs)

One of a variety of Per fluorinated carboxylic acids (PFCAs), perfluorooctanoic acid (PFOA) is a near-symmetric, highly prolate molecule with a fluorocarbon tail and a carboxylic ($-\text{COOH}$) terminal group. The combination of carboxylic groups and the fluorocarbon tail gives it valuable features like oil repellence and heat and water resistance, which make it a perfect product for a variety of industrial applications. The most well-known industrial uses are cleaning supplies, food packaging, paints, textiles for clothes, and firefighting foam. But PFOA has raised issues with the environment, especially with regard to local air and groundwater contamination.[9]

The chemical PFOA is classified as a Group 2 carcinogen by the International Agency for Research on Cancer (IARC). After looking into PFOA, the US Environmental Protection Agency (EPA) found links between exposure to the chemical and testicular and kidney malignancies. PFOA in environmental matrices can be detected by highly selective analytical techniques, which would be ideal to better understand the destiny of PFOA in the environment and its impact. This has been accomplished through the use of conventional analytical techniques like GC/MS and LC-MS/MS. But in order for these methods to be successful, any non-volatile matrix residue that might have a detrimental effect on column life must be carefully removed using extraction and clean-up procedures, as well as other measures.[10]

The two PFAS compounds that have been examined the most are PFOS and PFOA. Both PFOS and PFOA are resistant to normal environmental degradation processes and remain persistent in the environment. Because of this, they are widely dispersed throughout all trophic levels and can be found in groundwater, soil, and the air in various locations around the United States.

Because of their toxicity, mobility, and bioaccumulation potential, PFOS and PFOA may have negative consequences on human health as well as the environment. The stable compounds PFOS and PFOA are made up of eight-carbon chains. Due to their special capacity to ward off water and oil, these chemicals have been used in: carpet and clothing treatments; coatings for paper, cardboard packaging, and leather products; industrial surfactants, emulsifiers, wetting agents, additives, and coatings; manufacturing aids for fluoropolymer production, such as non-stick cookware coatings; waterproof and breathable clothing membranes; electrical wire casing; fire and chemical resistant tubing; and plumbing thread seal tape.[11]

Since the 1920s, trichloroethylene, a chlorinated solvent, has been produced on an industrial scale. Prior to its more modern applications, trichloroethylene was employed as an anaesthetic, a stain remover in dry cleaning, a component in paints, adhesives, and cleaners, as well as a metal part cleaner and feedstock for the synthesis of chlorinated chemicals. Because trichloroethylene has so many applications, occupational exposure was formerly commonplace, but since the 1940s, exposure levels and the number of exposed workers in Europe and North America have decreased by at least a factor of ten. The industries that have experienced some of the highest exposures include screw-cutting and the production and maintenance of automobiles and aircraft. Air, water, soil, food, and animal tissues have all been reported to contain trichloroethylene, and exposure to environmental sources (such as contaminated water and hazardous waste sites) is widespread in the United States and other countries.[12]

The enormous family of anthropogenic compounds known as perfluoroalkyl and polyfluoroalkyl substances (PFAS) has a broad range of industrial applications. Owing to its unique characteristics, PFAS are also frequently utilized as constituents in Class B firefighting foam compositions, which are intended to put out flammable liquid fires. When testing firefighting equipment or conducting training exercises, PFAS can and have been released into the environment.[13] Owing to their toxicity, bioaccumulation potential, and persistence, multiple members of the PFAS family are considered environmental pollutants of concern. A number of new rules have been put into place to limit the production and application of per- and polyfluoroalkyl substances (PFAS), especially those that include more than six completely fluorinated carbon atoms. Because of their mobility, endurance, and wide range of applications, PFAS are pervasive environmental pollutants. Because of their previous use, they have also been discovered in soils and groundwater at oil refinery sites. As a result, there is a desire to get rid of PFAS from groundwater in contaminated areas, water runoff, and fire-fighting (also known as fire extinguishing).[14] PFAS is a ubiquitous environmental toxin due to its persistence, mobility, and variety of applications. They have also been found in soils and groundwater at oil refinery sites due to their prior use. Consequently, there is a need to remove PFAS from water runoff, fire-fighting (sometimes called fire extinguishing), and groundwater in affected locations.[15]

It is difficult to eliminate PFAS from water due to their distinct physical and chemical characteristics as well as the range of their chemical structures. The removal of PFAS from water is not possible using conventional drinking water treatment methods such as coagulation/flocculation, air stripping, or fast sand filtration. [16] As a result, a new market with cutting-edge technology that specifically handle PFAS removal has emerged. There is little performance information available about these innovative devices' PFAS removal efficiency. Perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA), two of the most prevalent, extensively researched, and regulated PFAS, are also widely detected in a variety of biological and environmental matrices.

Generally, the only information available relates to their elimination. But during the last ten years, short-chain PFAS and precursor compounds have become more significant, and the active components in Class B foams have altered. [17] Large amounts of water need to be treated; however PFAS concentrations in contaminated groundwater are usually in the $\mu\text{g/L}$ range. Significantly greater PFAS concentrations, up to mg/L , are seen in firefighting water, while the water volume is normally restricted to a few hundred or thousands of cubic meters.

1.3 Trichloroethene (TCE)

Environmental pollutants such as Trichloroethene (TCE) and poly- and perfluoroalkyl substances (PFASs) have been linked to harmful health consequences in humans following exposure through contaminated water systems. TCE was shown to be present in groundwater as early as the 1960s, and it is now known that these areas have been widely contaminated by the chemical due to past spills and underground releases. Where AFFF was employed to put out flames using chlorinated solvents, there is a sizable chance that TCE and PFASs will get co-contaminated. When AFFF fuels and wastewater were allowed to seep into unlined training pits during firefighter training exercises on US military installations, TCE and PFASs were released into the groundwater and soil, causing extensive contamination. Recent years have seen increased monitoring of PFASs in environmental samples, leading to the identification of PFAS contamination at locations with distinct plumes of chlorinated solvents. At these sites, remediation efforts have mostly concentrated on getting rid of hydrocarbons and chlorinated solvents, with less attention paid to how AFFF components affect performance outcomes. Moreover, little is understood about how PFAS biotransformation occurs in these environments and how its byproducts impact TCE cleaning. Understanding the impact of per- and polyfluoroalkyl substances (PFASs) on dechlorinating microbial communities is vital for the effective remediation of TCE; nevertheless, understanding the pathways of PFAS biotransformation and the expected creation of their products is crucial for the successful remediation of PFASs.[18]

2. Technologies under consideration for treating PFAS

PFAS are often concentrated in a solid or liquid phase by sorption, flocculation, and liquid-liquid separation; this requires additional processing of the PFAS-enriched residue, such as loaded adsorbent material, sludge, or concentrate. Because

destruction-based solutions do not produce residual levels of PFAS, they are able to achieve PFAS degradation and may, thus, offer a more sustainable solution.

Various sorbent materials, such as activated carbon, MatCare, RemBind, Ion Exchange resins, CustoMem, and cyclodextrin-based adsorbents, are included in sorption technologies. A flow-through fixed-bed filter vessel is the most widely used application, and these systems' technical complexity is minimal when compared to alternative treatment choices. Material usage and used material disposal (reactivation or incineration) prices are the primary cost drivers. For water matrices including iron or manganese, pre-treatment is necessary. Effective PFAS removal from water is theoretically possible up until the target compounds pass through the filter bed. The operation time or the corresponding loading capacity of the adsorbent is therefore the crucial factor, particularly when used for groundwater treatment, until the wasted material needs to be replenished. Both ion exchange resins and activated carbon are tried-and-true technologies that have been validated in the field through full-scale and pilot treatments of actual water matrices that yield consistent performance data. Long operation times are necessary for these technologies, particularly for long-chain PFAS. Suppliers of cutting-edge adsorbents assert improved efficacy for water containing potentially conflicting elements and increased efficacy for the removal of short-chain PFAS. Nevertheless, there are currently no trustworthy statistics on feasible operating times for treating groundwater with pertinent water matrix components.[13]

PerfluorAd and InSite are two examples of flocculation methods that necessitate frequent flocculent dose, stirring tanks, and separation of the flocs containing PFAS (either by sedimentation or filtration). Compared to adsorption filtration, the technical execution is more complicated. In most cases, a polishing process is necessary to reduce the content of PFAS. The expenses for chemical additives and sludge disposal primarily control operating costs. Pre-treatment is necessary for manganese-containing waters and if co-contaminants that do not co-precipitate during the flocculation stage are likely to occur during the polishing phase. The flocculent dosage and the corresponding PFAS elimination are important factors, with the flocculent dosage having a significant impact on the removal efficiency. Pilot and large-scale applications of perfluorAd have produced remarkable removal efficiency at moderate doses. High PFAS removal is recommended, at least for a high flocculent dosage, as InSite has been proven at the pilot scale. But, as the vendor was the only source of the performance information for this InSite experiment, caution should be exercised.[19]

Technologies for liquid-liquid separation concentrate PFAS into a reduced volume of water. This report examines vacuum distillation, ozone or air-based foam fractionation, reverse osmosis, and Nano filtration. Additionally, as adsorptive methods are categorized as liquid-liquid separations, they are taken into consideration. Technically speaking, adsorption filtration with regeneration is less complicated than Nano filtration, reverse osmosis, foam fractionation, and distillation. It is anticipated that the energy need of the membrane filtering, foam fractionation, and vacuum distillation processes will be the primary cost factor. Iron and manganese removal are the primary pre-treatment requirements; however, additional processes to eliminate turbidity are required for technologies like reverse osmosis. The energy consumption and the quantity of PFAS-enriched water that still needs to be treated are the main factors influencing expenses. Technically complex and dependable, reverse osmosis eliminates all PFAS from water. However, the procedure leaves behind a sizable amount of concentrate that, like vacuum distillation, needs to be treated further. Foam fractionation pilot-scale results show effective PFAS removal and minor amounts of PFAS-enriched concentrate; however, the performance data were mostly supplied by the vendor and were not subjected to independent verification. Adsorptive technologies used in conjunction with regeneration typically yield a high separation factor with minimal energy input. However, these technologies still need to be developed further given their current state and intended uses.[20]

Technologies used for destruction include water incineration, electrochemical degradation, oxidation processes, UV radiation, sonochemistry, plasma therapy, and nanoscale zero-valent iron. The complete breakdown of the PFAS into fluorine and CO₂ should be accomplished by the destruction-based treatment. The very important critical characteristic for these methods is the amount of energy needed to accomplish full mineralization. Sonochemistry, oxidation, electrochemical deterioration, and UV radiation all have comparatively little technological complexity. On the other hand, more complicated processes include plasma treatment, nanoscale zerovalent iron, and water incineration with flue gas cleaning. PFAS can be entirely eliminated using a widely accessible commercial process called high temperature cremation of hazardous liquids. For now, the performance data of the other technologies is based on lab-scale experience, with the exception of sono-chemistry and plasma therapy, which are accessible in pilot-scale installations. The majority of methods have shown promise in fully degrading per- and polyfluoroalkyl substances (PFAS); however, data about energy consumption and prices in pilot and practical applications is missing. Moreover, co-contaminants may raise energy consumption even more and perhaps result in the production of hazardous by-products.[21]

3. Retardation factor

The slow apparent velocity of some dissolved elements, or solutes, relative to the water's own velocity during movement, is referred to as "retardation" when discussing groundwater. Conditions unique to each site have a significant impact on the efficacy of the various technologies used for cleanup. Increased bulk density corresponds to an increased retardation factor. The retardation factor increases with the adsorption coefficient. Higher is the retardation factor, lower is the water content. In the case of the air-water system, the retardation factor for PFOS movement in the sand was 7, as opposed to 1.8 under saturated conditions. In unsaturated (air-water) vs. saturated conditions, the PFOS retardation factors for soil transport were 7.3 and 3.6, respectively. In these two systems, air-water interfacial adsorption accounts for more than 80% of the total PFOS retention for the sand and 32% for the soil. Adsorption at the decane-water interface contributed more than 70% to the overall retention for PFOS transit in the studies carried out with decane residual inserted within the sand. Techniques for figuring out or estimating important distribution variables are offered in order to parameterize the model. The conceptual model adequately represented the pertinent

retention processes, and the parameter estimate techniques yielded respectable values, as evidenced by the predicted retardation factors' similarity to the measured values.[22]

The concentrations of Perfluoroalkyl Substances (PFAS), water volume and quality, and the desired concentrations of PFAS significantly impact the choice of technology or a combination of multiple technologies. In the end, a treatment train consisting of multiple technologies in succession may be the preferred method of treatment in order to get both high remediation efficiency and economy. Retardation factors (R) characterize the partitioning between the aqueous phase and the solid (soil) phase and show how many pollutants in groundwater sorb onto the aquifer solids. Furthermore, the retardation factor explains how a growing pollutant plume is delayed in comparison to a dissolved chemical that does not absorb. When the retardation factor is 1, it means that the plume is expanding at the average rate of the groundwater seepage velocity. When it is 2, it means that the plume travels at half the rate, three times the rate, and so on. Comparisons with PFAS sites are predicated on the utility of the linear hydrophobic sorption model. PFAS-specific elements including the way surfactants partition and how charges affect cationic and anionic. The hydrophobic sorption metric can become less accurate and relevant due to PFAS and other factors including hysteresis during desorption, which also impacts numerous non-PFAS pollutants.

Retardation factors for certain PFAS compounds may be higher than those of many known pollutants. Still, the lower PFAS plume footprint due to retardation may outweigh the extra challenge of eliminating the greater sorbed bulk. Higher retardation factors, on the other hand, would be a more advantageous method for applying MNA at PFAS sites when long-term risk to receptors is decreased by PFAS retention in the subsurface.

Compared to the present groundwater remediation process for conventional groundwater contaminants, the PFAS groundwater remediation project will be smaller in scope. According to the hydrophobic sorption metric, a smaller PFAS plume footprint and higher retardation factors may offset the increased complexity of remediation based on higher sorbed mass.

In a compartment model, the ramifications of this surfactant behaviour are demonstrated by the retardation factor of 7 for PFOS through unsaturated sand, which is lower than the retardation factor of 1.8 for fully saturated circumstances. Additional research has demonstrated that this build-up at air-water interfaces can keep a sizable portion of the PFAS (well over half the total mass in coarse soils) in the unsaturated zone. Larger PFAS sites may not be able to remove all of the source mass, therefore overall the existence of long-term sustained PFAS source processes raises the necessity for some sort of active remediation (e.g., removal or containment of source materials). [16]

4. Health effects of Perfluorooctanoic acid (PFOA)

PFAS pollution of soil and groundwater is a global problem brought on by the pervasive usage of PFAS in many different applications. Historical industrial discharges, firefighting events, wastewater treatment plant effluent, landfills, and firefighting training grounds are the primary point sources. PFOS continues to be the main pollutant in numerous instances. The combination of PFAS detected in the environment varies greatly according on the particular site, as firefighting foam formulas have varied over time. Specifically, short-chain PFAS have long been present in these mixes. However, other pollution events, such as the unlawful disposal of waste from the production of paper, may also result in the presence of short-chain PFAS in groundwater.[23] The majority of the information regarding the health effects of perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS) is derived from studies conducted on humans and animals exposed to these substances. Although PFOA and PFOS are no longer produced in the United States, they can still be found in human blood. Human blood has also been found to contain more recent PFAS that are still being produced. The following health consequences could arise from consuming water contaminated with high concentrations of PFAS:

- Elevated levels of cholesterol
- Alterations in liver enzyme levels
- Thyroid illness risk is elevated due to hormone imbalance.
- Reduced likelihood of women getting pregnant
- Pre-eclampsia or elevated blood pressure during pregnancy
- Slight drops in baby birth weights
- Children's reduced responsiveness to vaccinations
- Elevated risk of testicular or kidney cancer

CONCLUSION:

Certain PFAS chemicals may have retardation factors that are greater than those of numerous other recognized contaminants. However, the additional difficulty of removing the larger sorbed bulk may be outweighed by the reduced PFAS plume footprint brought about by retardation. Conversely, while PFAS retention in the subsurface reduces long-term risk to receptors, using MNA at PFAS sites would be more beneficial with higher retardation factors. Shorter-chain PFAS are typically less hazardous than longer-chained PFAS. But in soil contamination situations, they spread more quickly because they are more mobile in groundwater than long-chain PFAS. Remediating groundwater contaminated by PFAS will need lengthy treatment times for huge amounts of water. In theory, groundwater treatment can be carried out ex-situ by utilizing an on-site treatment technology and pump-and-treat procedures, or in-situ by applying a remediation strategy inside the contaminated soil. Since there are currently no commercially viable in-situ techniques for PFAS, the current practice is ex situ. Compared to long-chain PFCA, short-chain PFCA are removed by activated carbon less effectively. There are, however, superior ion exchangers that function better when it

comes to eliminating this kind of PFAS. Additionally, novel adsorption technologies that are said to have a higher affinity for short-chain PFAS are being developed. Large amounts of water need to be treated; however PFAS concentrations in contaminated groundwater are usually in the $\mu\text{g/L}$ range. Significantly greater PFAS concentrations, up to mg/L , are seen in firefighting water, while the water volume is normally restricted to a few hundred or thousands of cubic meters. In situations when there is a larger concentration of PFAS in the groundwater, it may be more advantageous to use multiple adsorbent filters operating in series. Iron and manganese removal (to drinking water standards, for example) is regarded as a prerequisite for treatment. This is due to the fact that these components have the potential to severely foul the filter system, which would limit the amount of sorbent that can be loaded and restrict flow. Moreover, PFAS may build up in the iron and manganese sludge, necessitating extra care such back-washing and, in certain situations, costly specialized waste disposal. The unique characteristics of the site have a significant impact on the remediation efficiency of the various technologies. The concentrations of Perfluoroalkyl Substances (PFAS), water volume and quality, and the desired concentrations of PFAS significantly impact the choice of technology or a combination of multiple technologies. Ultimately, the best course of action for achieving high remediation efficiency and economy may be to use a treatment train that combines many technologies in succession.

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