# Optimizing the PFAS Puzzle: Piecing Together a Holistic PFAS Restoration Strategy

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**Background/Objectives** Per- and polyfluoroalkyl substances (PFAS) comprise a diverse class of contaminants, which include a range of perfluoroalkyl acids (PFAAs) with varying perfluoroalkyl chain lengths; most notably PFOA (perfluorooctanoic acid) and PFOS (perfluorooctane sulfonate). PFOA and PFOS have gained significant attention in the U.S. because of the USEPA finalizing a combined lifetime Health Advisory Level (HAL) for drinking water of 70 nanograms per liter (ng/L) in 2016. The PFAAs (including PFOA and PFOS) are the "dead-end" daughter products resulting from biotransformation of thousands of polyfluorinated precursor compounds, which are present in many commercial products such as Class B firefighting foams.

The transformation of precursors to PFAAs further complicate the remediation challenges as precursors are not quantified using standard analytical laboratory methods (USEPA Method 537); resulting in underestimation of the PFAS mass when using standard analysis. Further, the aerobic biotransformation of precursors to PFAAs creates an ongoing source of PFAAs. As some precursors are cationic (or cation dominated zwitterions), they are less mobile in fine-grained aquifer systems with primarily negatively charged surfaces, and have the potential to remain in the source area. However, these precursors will eventually biotransform over time forming PFAAs as dead-end daughter products, which seem likely to remain in the ecosystem for thousands of years.

**Approach/Activities** The current state of the practice of available PFAS remediation technologies will be discussed. Innovative and emerging remediation solutions for PFAS include many types of technologies to address highly concentrated source zones, mitigate mass flux of impacts to aquifers, or address PFAS in extracted water. These emerging solutions will be compared against the "de facto" interim remedial action of granular activated carbon (GAC). GAC is currently being used to effectively remove a portion of PFAS from water sources; however, the questionable precursor removal, the less effective removal of short chain PFAAs, and perpetual operation and maintenance (O&M) cost concerns demand alternative solutions and optimization measures. More comprehensive PFAS treatment of impacted water sources typically requires the use of technologies such as reverse osmosis or nano-filtration, but new sorbent media are being developed to remove both long and short chain PFAS. There are new precipitation technologies, sonolytic reactors, foam fractionation technologies, and ion exchange media being developed and optimized for water treatment.

**Results/Lessons Learned** The principles underlying the mechanisms by which multiple technologies act will be summarized with comment on where they could be applied or combined to effectively manage PFAS impacted aquifers and drinking water sources. Additionally, optimization strategies to reduce O&M costs associated with GAC will be discussed as the practicality of more innovative remedial technologies are vetted through academic research. For water, 1) data will be presented on easily reactivated engineered sorbent media showing initial promise at removing both long and short chain PFAS, including PFBA (perfluorobutanoic acid), which is characterized by low adsorption potential; 2) initial field-scale data on PFAS removal using ozofractionation and destruction with sonolysis will be reviewed; 3) the viability and potential limitations of electrochemical treatment will be discussed. The state of the practice currently requires treatment train implementation, with opportunities to offset one technology's weakness with another technology's strength.