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**Sorbent Selection and Lab Studies Guide**  
**NESDI Project #578**  
**Task 2**

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**ADMINISTRATIVE INFORMATION**

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## CONTENTS

|                            |   |
|----------------------------|---|
| 1. INTRODUCTION.....       | 6 |
| 2. SORBENT SELECTION ..... | 6 |

## TABLES

|  |   |
|--|---|
| Table 1. Typical PFAS sorbents. ....                       | 7 |
| Table 2: Typical studies to measure sorbent efficacy. .... | 9 |

## 1. INTRODUCTION

Per- and polyfluorinated alkylated substances (PFAS) are a diverse group of chemicals that are widespread in groundwater systems including at US Navy and US Marine Corps sites and may present human and ecological health risks. PFAS are currently removed from groundwater by pumping the water out of the ground through various wells, passing the water through large containers of sorbent material (i.e., granulated activated carbon (GAC)), and then pumping the treated water back into the ground (Figure 1). There is some evidence that different types of sorbent material (for example, anion exchange resin (AIX)) may be differentially effective at treating PFAS-impacted groundwater, and that different background water quality conditions (i.e., salts, organic carbon) may also impact the efficacy of these sorbent-based treatments. Further, novel sorbents are being developed through research programs, such as the Strategic Environmental Research and Development Program and other Department of Defense (DoD), and non-DoD, programs. There is a present need to evaluate how well these sorbents will work to treat PFAS-impacted groundwater, with a variety of background water quality parameters that will vary from site to site.

The objective of this document is to provide the end-user community a roadmap to select and evaluate potential sorbents for use at their remediation sites. This document will begin with a discussion on sorbent selection and then briefly discuss different evaluation studies to select optimal sorbents for pump and treatment systems or in situ.

## 2. SORBENT SELECTION

There are many possible sorbents that can be used for preconcentration of PFAS in groundwater, porewater, surface water, and other sources. Table 1 provides some high-level benefits and drawbacks of various sorbent technologies that were considered as part of this project. This table is not exhaustive but captures common sorbent technologies currently being employed that were considered in this Navy Environmental Sustainability Development to Integration (NESDI) project. Note that there are many sorbents that are currently being developed through Strategic Environmental Research Development Program (SERDP)/ Environmental Security Technology Certification Program (ESTCP) and other research programs; this project focused on sorbents that are at or near commercialization.

Table 1. Typical PFAS sorbents.

| Sorbent  | Benefits   | Drawbacks   |
|--|--|---|
| Activated Carbon (powdered, granulated, colloidal) | <ul style="list-style-type: none"> <li>• Low cost</li> <li>• Useful for many contaminants</li> </ul>   | <ul style="list-style-type: none"> <li>• Low capacity for PFAS compared to other sorbents.</li> <li>• As it sorbs many different contaminants, co-contamination and organic carbon content can reduce effectiveness.</li> <li>• Typically, single use</li> <li>• Slow kinetics – requires long contact times</li> </ul> |
| Anion exchange resins                              | <ul style="list-style-type: none"> <li>• High capacity for PFAS</li> <li>• Typically, more PFAS-specific</li> <li>• Fast kinetics</li> <li>• Can be regenerated</li> </ul> | <ul style="list-style-type: none"> <li>• High cost</li> <li>• Reduced efficacy in high conductivity water, especially for PFCAs</li> </ul>  |
| Biochars   | <ul style="list-style-type: none"> <li>• Low cost</li> <li>• Reuses biomaterial</li> </ul>   | <ul style="list-style-type: none"> <li>• Low capacity for PFAS (comparable to GAC)</li> <li>• Less consistent in formulation than GAC, and thus performance can be more variable</li> </ul>   |
| RemBind™   | <ul style="list-style-type: none"> <li>• Low cost</li> <li>• Fast kinetics</li> <li>• High capacity</li> </ul>   | <ul style="list-style-type: none"> <li>• A powdered sorbent. For water applications it has to be bound to another material (e.g. AquaGate™) or must be filtered out of water after treatment</li> </ul>   |
| Novel Sorbents (e.g. Organo-silica, cyclodextrin)  | <ul style="list-style-type: none"> <li>• High capacity for PFAS</li> <li>• Fast kinetics</li> </ul>  | <ul style="list-style-type: none"> <li>• Not as mature of technologies, still in early stages of commercialization.</li> <li>• High cost</li> </ul>   |

To consider if a site is likely to be a good candidate for sorbent technology to remediate PFAS, and to select appropriate sorbents, consider the following questions about the impacted site:

1. **What type (e.g. carboxylic acids, PFCAs or sulfonic acids, PFSAs) of PFAS are of concern at the site?** Currently, this document is focused on the perfluoroalkyl acids, rather than precursor compounds, as these are of the most pressing concern. Sorbents in general are more effective for sulfonic acids. If carboxylic acids are the primary concern at a site, anion exchange resins or novel sorbents may be more effective than activated carbon or biochar sorbents.

**2. What concentrations of PFAS are present at the site?**

Higher concentrations of PFAS will require more frequent sorbent material changes. Sorbents that can be regenerated or have higher capacity may reduce overall costs.

**3. What co-contaminants are present at the site?**

Co-contaminants can compete with PFAS for binding sites and can reduce efficacy of the sorbent treatment.

**4. What is the typical hardness/ionic strength/salinity of the site?**

High conductivity >5 mS/cm typically reduces the efficacy of sorbent materials, especially for sorbents that rely on electrostatic interactions (such as, anion exchange resins). This reduction in efficacy is typically more apparent with PFCAs compared to PFSAAs. In cases where sites are high in PFCAs and high in conductivity, granulated activated carbon may be as effective as anion exchange resins in removing PFAS (Hayman et al. 2023).

**5. What is the typical organic carbon content of the water?**

For sites with very high dissolved organic carbon content, a dual treatment may be required, such as treating water with activated carbon, which will sorb much of the organic carbon and some of the PFAS, followed by treatment with anion exchange resin to remove the remaining PFAS.

**6. What is your disposal strategy?**

Spent sorbents will need to be disposed when they are replaced with fresh sorbent. Current destruction technologies, such as hydrothermal alkaline treatment (HALT) or supercritical water oxidation (SCWO) are showing promise, but are still being demonstrated for full scale usage. Another option with some anion exchange resins and novel sorbents is the regenerate resin through chemical processes, although these methods are also still being assessed for large scale applicability.

After considering which sorbents are applicable to a site, various studies can be used to determine which will be optimal. Table 2 provides an overview of typical sorbent efficacy studies and what information can be obtained from them. Note, this list is not meant to be exhaustive, but provide an overview of common testing strategies to understand sorbent efficacy for PFAS removal. Following the summary table, several references are listed for further reading.

Table 2: Typical studies to measure sorbent efficacy.

| Test Type  | Test Variable  | Information obtained   | How does this help?   |
|--|--|--|---|
| <p>Isotherm Lab Study</p> <p>(testing sorption using different initial PFAS concentrations for the same exposure time)</p> | <p>Amount of PFAS removed vs. Initial concentration of PFAS</p>                | <p>Isotherms showing a relationship between capacity of sorbent and concentration of PFAS in treated water</p> | <p>Based on the concentration of PFAS at a given site, some sorbents may be more helpful than others. Some sorbents perform better at lower/higher initial PFAS concentrations, compared to others.</p>   |
| <p>Kinetic Lab Study</p> <p>(testing sorption using the same initial PFAS concentrations over different timescales)</p>    | <p>Concentration of PFAS removed vs. time</p>                                  | <p>Rate of uptake of PFAS onto sorbents</p> <p>Experimental capacity of sorbent</p>                            | <p>Faster uptake of PFAS for a given sorbent material means that impacted water needs to be in contact with the sorbent for less time. Depending on site characteristics (e.g. groundwater flow rate), sorbents with very fast kinetics may be able useful to treat larger volumes of water more quickly.</p>   |
| <p>Column Study (Full scale or RSSCT)</p>  | <p>Concentration of PFAS removed vs. bedvolumes (amount) of water treated.</p> | <p>Breakthrough curves</p> <p>Experimental capacity of sorbents</p>  | <p>These are likely to most important studies for selecting an optimal sorbent for remediation at an impacted site. These studies show how long a sorbent will treat impacted water until breakthrough occurs (i.e. when the sorbent has reached capacity for that compound). Typically done in a lab, although use of the Sorbent Onsite Testing Apparatus (SOTA) developed under this project allows for on-site studies using site water in real time.</p> |

## Examples of each study type in the literature

### *Sorbents in general for PFAS removal*

Hayman N., Carilli, J., George R., Hsu L., Sanders M., Liu Y., Shields B., Morrison B. (2021) *Literature Review of Adsorbents for PFAS Removal from Groundwater*. NESDI Project #578 Task 1. Naval Information Warfare Center Pacific Technical Document 3410.

### *Isotherm lab studies*

Deng, S., Y. Nie, Z. Du, Q. Huang, P. Meng, B. Wang, J. Huang, and G. Yu. 2015. Enhanced adsorption of perfluorooctane sulfonate and perfluorooctanoate by bamboo-derived granular activated carbon. *Journal of Hazardous Materials* 282.

Ochoa-Herrera, V., and R. Sierra-Alvarez. 2008. Removal of perfluorinated surfactants by sorption onto granular activated carbon, zeolite and sludge. *Chemosphere* 72:1588–1593.

Yu, Q., R. Zhang, S. Deng, J. Huang, and G. Yu. 2009. Sorption of perfluorooctane sulfonate and perfluorooctanoate on activated carbons and resin: Kinetic and isotherm study. *Water Research* 43:1150–1158.

### *Kinetic lab studies*

Hayman, N.T., Carilli, J.E., Liu, Y., Shields, M.R., Hsu, L., George, R. (2023) Water quality impacts on sorbent efficacy for per- and polyfluoroalkyl substances treatment of groundwater. *Remediation Journal* <https://doi.org/10.1002/rem.21747>

Yu, Q., R. Zhang, S. Deng, J. Huang, and G. Yu. 2009. Sorption of perfluorooctane sulfonate and perfluorooctanoate on activated carbons and resin: Kinetic and isotherm study. *Water Research* 43:1150–1158.

### *Column studies*

Crittenden, J.C., Berrigan, J.K., Hand, D.W. (1986) Design of rapid small-scale adsorption tests for a constant diffusivity. *Journal Water Pollution Control Federation*, 58(4): 312-319.

Hayman, N.T., Carilli, J.E., Liu, Y., Shields, M.R., Hsu, L., George, R. (2023) Water quality impacts on sorbent efficacy for per- and polyfluoroalkyl substances treatment of groundwater. *Remediation Journal* <https://doi.org/10.1002/rem.21747>

McCleaf, P., S. Englund, A. Östlund, K. Lindegren, K. Wiberg, and L. Ahrens. 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.

Schaefer, C. E., Nguyen, D., Ho, P., Im, J., LeBlanc, A. (2019) Assessing rapid small-scale column tests for treatment of perfluoroalkyl acids by anion exchange resin. *Industrial & Engineering Chemistry Research*, 58(22), 9701–9706. <https://doi.org/10.1021/acs.iecr.9b00858>

Schaefer, C. E., Nguyen, D., Culina, V. M., Guelfo, J., Kumar, N. (2020) Application of rapid small-scale column tests for treatment of perfluoroalkyl acids using anion-exchange resins and granular activated carbon in groundwater with elevated organic carbon. *Industrial & Engineering Chemistry Research*, 59(38), 16832–16837. <https://doi.org/10.1021/acs.iecr.0c02290>

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