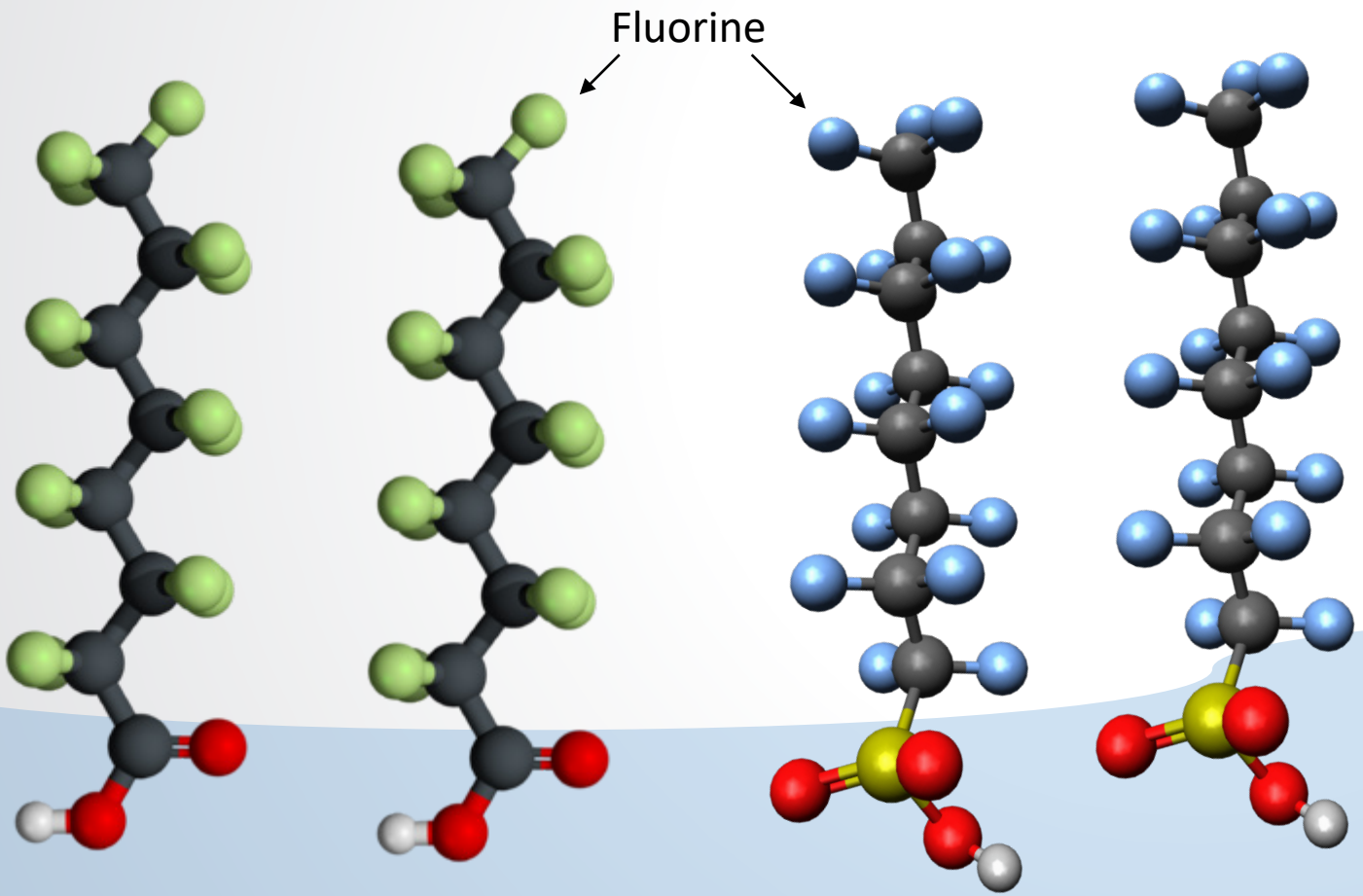
USEPA's Efforts on Evaluating PFAS Treatment Performance and Cost

Teleconference Presentation to ECOS

June 20, 2018

U.S. Environmental Protection Agency

Per- and Polyfluoroalkyl Substances (PFAS)



Perfluorooctanoic acid (PFOA)

Perfluorooctanesulfonic acid (PFOS)

- **A class of man-made chemicals**
  - Chains of carbon (C) atoms surrounded by fluorine (F) atoms
    - Water-repellent (hydrophobic)
    - Stable C-F bond
  - Some PFAS include oxygen, hydrogen, sulfur and/or nitrogen atoms, creating a polar end

Thousands of Chemicals: More Than Just PFOA and PFOS

PFAS

- **Non-polymers**
  - **Perfluoroalkyl acids (PFAAs)**
    $C_nF_{2n+1}R$
    - Perfluoroalkyl carboxylic acids (PFCAs)
    - Perfluoroalkane sulfonic acids (PFSAs)
    - Perfluoroalkyl phosphonic acids (PFPAs)
    - Perfluoroalkyl phosphinic acids (PFPIAs)
  - **Perfluoroalkane sulfonyl fluoride (PASF)** → **PASF-based derivatives**
    $C_nF_{2n+1}SO_2F$
    $C_nF_{2n+1}SO_2$-R, R = NH, $NHCH_2CH_2OH$, etc.
  - **Perfluoroalkyl iodides (PFAIs)** → **Fluorotelomer iodides (FTIs)** → **FT-based derivatives**
    $C_nF_{2n+1}I$
    $C_nF_{2n+1}CH_2CH_2I$
    $C_nF_{2n+1}CH_2CH_2$-R,
    R = NH, $NHCH_2CH_2OH$, etc.
  - **Per- and polyfluoroalkyl ethers (PFPEs)-based derivatives**
    - Polyfluoroalkyl ether carboxylic acids
- **Polymers**
  - **Fluoropolymers**
    - Polytetrafluoroethylene (PTFE)
    - Polyvinylidene fluoride (PVDF)
    - Fluorinated ethylene propylene (FEP)
    - Perfluoroalkoxyl polymer (PFA)
    - Others
  - **Side-chain fluorinated polymers**
    - Fluorinated (meth)acrylate polymers
    - Fluorinated urethane polymers
    - Fluorinated oxetane polymers
  - **Perfluoropolyethers**

Research: Analytical Methods

- **Problem**: Lack of standardized/validated analytical methods for many PFAS analytes (especially short chain), and in media other than drinking water
- **Action**: Perform multi-laboratory validations for analytical methods for (1) non-drinking water samples and solids (SW-846 Methods for facility or site investigation and remediation), (2) additional PFAS analytes for drinking water samples, and (3) methods for sampling air stack emissions
- **Results**:
  - Draft SW-846 Direct Injection analytical method external validation study underway
  - Draft SW-846 Isotope Dilution method in review
  - Method development for short-chained PFECAs (GenX, ADONA) in drinking water, for PFAS in estuarine waters, and for PFAS precursors in aqueous and solid matrices underway
  - Pilot test of air emission sampling and analysis methods underway in NH and NC
- **Impact**: Enable consistent analysis of priority PFAS analytes in different environmental media
- **Tools**: **EPA Method 537** (drinking water) and **SW-846 Compendium** (non drinking water and solids)

Research: Drinking Water Treatment Performance

- **Problem**: Utilities lack drinking water treatment technology performance data for PFAS removal
- **Action**:
  - Review PFAS performance data from available sources (industry, DoD, academia, international)
  - Test commercially available granular activated carbons (GACs) and ion exchange (IE) resins for effectiveness over a range of PFAS under different water quality conditions
  - Evaluate a range of system sizes – large full-scale utility options to home treatment systems
- **Results**:
  - Update EPA's **Drinking Water Treatability Database**, a public database for treatment performance data for regulated and unregulated contaminants
  - Use state-of-the-science models to extrapolate existing treatment studies to other conditions
- **Impact**: Enable utilities to identify effective treatment strategies for removing PFAS from drinking water
- **Tool**: **EPA Drinking Water Treatability Database**

Research: Treatment

Publically Available Drinking-Water Treatability Database

- Interactive literature review database that contains over 65 regulated and unregulated contaminants and covers 34 treatment processes commonly employed or known to be effective (thousands of sources assembled on one site)
- **PFOA, & PFOS:** Pages currently available (29 sources)

Treatability Database

http://oaspub.epa.gov/tdb/pages/general/home.do

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Drinking Water Treatability Database

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You are here: EPA Home » Drinking Water Treatability Database » Welcome to the Drinking Water Treatability Database

- Home
- About the TDB
- Find a Contaminant
- Find a Treatment Process
- Help

Welcome to the Drinking Water Treatability Database

The Drinking Water Treatability Database (TDB) presents referenced information on the control of contaminants in drinking water. It allows drinking water utilities, first responders to spills or emergencies, treatment process designers, research organizations, academicians, regulators and others to access referenced information gathered from thousands of literature sources and assembled on one site. Over time, the TDB will expand to include over 200 regulated and unregulated contaminants and their contaminant properties. It includes more than 25 treatment processes used by drinking water utilities. The literature includes bench-, pilot-, and full-scale studies of surface waters, ground waters and laboratory waters. The literature includes peer-reviewed journals and conferences, other conferences and symposia, research reports, theses, and dissertations. By adding new contaminants and by upgrading references on existing contaminants, the TDB will always be a current source of information on drinking water contaminant control. Visit the About the TDB page for more information.

The TDB offers many features leading to the Data tab which is the heart of the TDB. After selecting a contaminant (Find a Contaminant), you will find a Treatment Processes tab that will present the list of treatment processes for which literature on the control of the contaminant was located. Selecting a treatment process, you will find a Data tab, like that shown below, that presents reference information, log or percent removal, water quality conditions and treatment process operational parameters. The Help page will aid you in navigating the TDB.

Getting Started

Find a Contaminant - Click here to find a contaminant within the TDB.

Find a Treatment Process - Click here to find a treatment process within the TDB.

Data Tab Example: Arsenic/Ion Exchange (Click on the image to view this Data tab)

Quick Links

- EPA Drinking Water Standards
- EPA Water Contaminant Information Tool (WCIT)
- EPA Contaminant Candidate List
- EPA Analytical Methods
- EPA Integrated Risk Information System (IRIS) (Risk Documents)

Future Upgrades to the Drinking Water Treatability Database

Each year, as resources allow, the number of contaminants in the TDB will increase to include other regulated and unregulated drinking water contaminants. It will also upgrade information on contaminants already in the TDB to keep it current. The bottom of each page indicates when additions and upgrades were last incorporated into the TDB. Each contaminant Overview page indicates the most recent literature search date for the contaminant. View a List of Future Contaminants anticipated for the next upgrade and the anticipated upgrade date.

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Treatability Database

https://oaspub.epa.gov/tdb/pages/contaminant/treatmentSummary.do

Water Treatability Database...

Convert Select

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Drinking Water Treatability Database

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Perfluorooctanoic Acid

Overview | Treatment Processes | Properties | Fate and Transport | References

The following processes were found to be effective for the removal of perfluorooctanoic acid: GAC (up to 99 percent removal), membrane separation (up to > 98 percent), powdered activated carbon (88 percent), and ion exchange (73 to 95 percent). UV irradiation at wavelengths in the 185-220 nm range and/or at long irradiation times (up to 72 hours) could potentially be effective (62 to 90 percent). Membrane filtration varied in effectiveness (22 to 56 percent).

Based on the available literature, the following are not considered effective for the removal of perfluorooctanoic acid: conventional treatment (no removal) and UV at wavelengths outside of the 185-220 nm range (4 percent to 10 percent removal). UV/hydrogen peroxide treatment (35 percent removal) was less effective in comparison to UV alone (45 percent) after 24 hours of irradiation.

Studies were identified evaluating the following treatment technologies for the removal of perfluorooctanoic acid:

Conventional Treatment - Multiple full-scale studies reported insignificant removal of PFOA by conventional treatment. PFOA levels after conventional drinking water treatment were found to correlate to the PFOA levels detected in their surface waters sourc...

GAC Isotherm - Adsorption was observed for PFOA detected in a contaminated groundwater. It was found to be nonlinear.

Granular Activated Carbon - Removal of PFOA by GAC can be effective. Bench scale tests, including rapid small scale column tests, showed removals from less than zero to 95 percent, depending on carbon type and background TOC concentrations [1700, 2423, 2441]. At one full sca...

Ion Exchange - Removal of PFOA using anion exchange resins was found to be effective (73 to 95 percent removal) in a bench study [2427], and in a full scale application [2424; 2441] that used a resin designed for arsenic removal. A full scale application using

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PFOS Treatment

Ineffective Treatments

Conventional Treatment
Low Pressure Membranes
Biological Treatment (inclucing slow sand filtration)
Disinfection
Oxidation
Advanced oxidation

Effective Treatments

	Percent Removal
Anion Exchange Resin #	90 to 99
High Pressure Membranes	93 to 99
Powdered Activated Carbon (PAC)	10 to 97
Granular Activated Carbon (GAC) #	
Extended Run Time	0 to 26
Frequent GAC Replacement	> 89 to > 98

PAC Dose to Achieve

50% Removal	16 mg/l
90% Removal	>50 mg/L

Dudley et al., 2015

Research: Treatment

Publically Available Drinking-Water Treatability Database

- Interactive literature review database that contains over 65 regulated and unregulated contaminants and covers 34 treatment processes commonly employed or known to be effective (thousands of sources assembled on one site)
- **PFOA, & PFOS:** Pages currently available (29 sources)
- **PFNA, PFHxA, PFHxS, PFBS, Gen-X:** Pages to be added (End of June, 2018) from 50 additional literature sources for activated carbon, ion exchange, and membrane
- Other PFAS and technologies to follow
- Journal papers on literature review on PFAS treatment in review

http://iaspub.epa.gov/tdb/pages/general/home.do

Search: EPA TDB

USEPA Drinking Water Treatment Performance

- In-house research to develop fundamental parameters and design information applicable for water systems of all sizes and water qualities nationwide.
- Suite of nine PFAS covering sulfonates and carboxylic acids from C4 to C10 including GenX at drinking water concentrations
- **Phase 1 – Batch Studies** - Develop feasibility and equilibrium data that can be widely used for modeling and to screen treatments for various PFAS.
  - AEX isotherms
  - GAC isotherms
- **Phase 2 – Bench Scale Column Studies –** Predict kinetic performance of full-scale with many conditions in less time.
  - AEX small columns
  - GAC RSSCTs
  - Investigations of Dual GAC/AEX Column Configurations

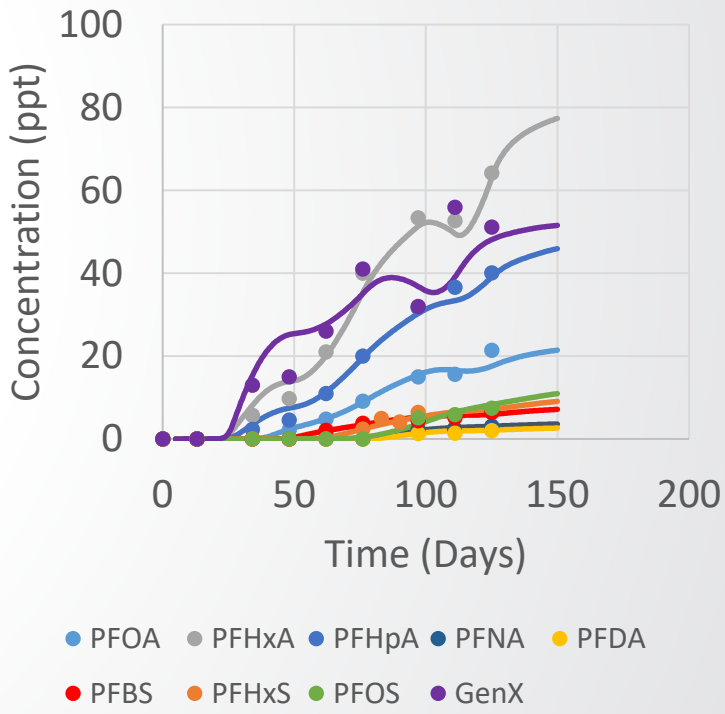
➢ **Phase 3 - Pilot Scale, Full Scale, and Collaboration with Water Utilities – Confirm results of bench-scale research and provide technical support to water utilities nationwide.**

Treatment Issues

Granular Activated Carbon (GAC)	Poor removal of short-chained PFAS Disposal/reactivation of carbon Regeneration/removal frequency
Anion Exchange Resin (selective)	Poor removal of select PFAS Disposal/incineration of resin – potential liability Unclear secondary benefits
High Pressure Membranes	Capital and operations costs Corrosion control Lack of options for concentrate stream treatment or disposal Membrane fouling
Other Novel Technologies	Permitting Ease of operation, Robustness, Reliability Potential unintended consequences Costs Residual streams

Research: Drinking Water Treatment Costs

- **Problem**: Utilities lack treatment technology cost data for PFAS removal
- **Action**:
  - Gather performance and cost data from available sources (DOD, utilities, suppliers, industry, etc.)
  - Compare costs and cost models across different entities
  - Update EPA's **Unit Cost Models** to address PFAS
  - Connect EPA's **Drinking Water Treatability Database** to EPA's cost models for ease of operation
  - Model performance and extrapolate to other scenarios (influent concentrations, number of PFAS, regeneration frequency, etc.)
  - Evaluate tradeoffs between cost and removal of a range of PFASs and mixtures of PFASs at various concentrations and scenarios
- **Results**: Tools and data to support selection of optimal treatment choice
- **Impact**: Enable utilities to make informed decisions about cost-effective treatment strategies for removing PFAS from drinking water
- **Tools**: **EPA Drinking Water Treatment Technology Unit Cost Models**



USEPA Treatment Cost Models

Design treatment process using inputs and assumptions and estimate costs

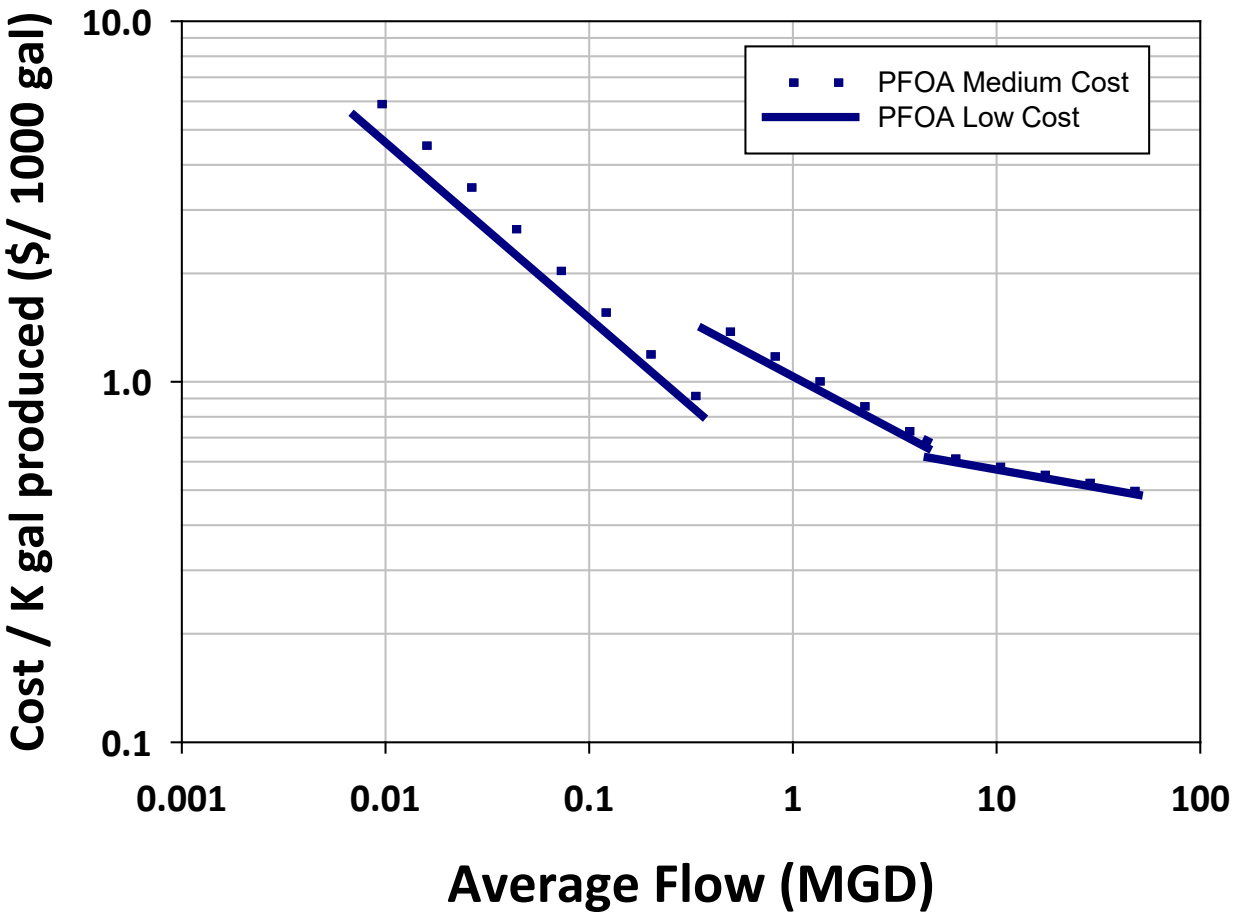
- Capital costs (e.g., equipment size / quantity)
- Operating costs

Flexible inputs and assumptions allow designs to adapt

- Different contaminants (now PFAS)
- Different baseline / compliance conditions

Treatment Cost: PFOA

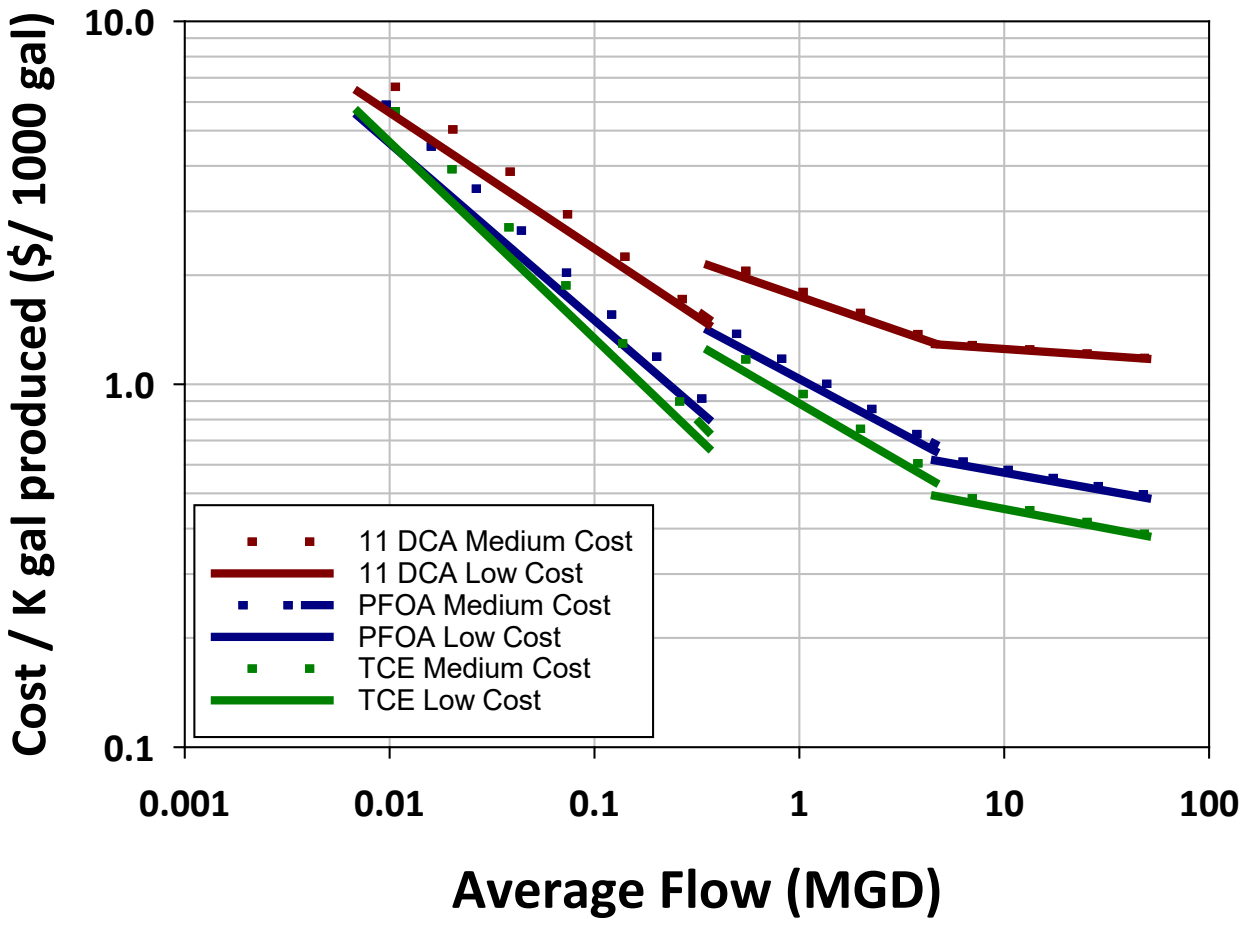
PFOA will break through before PFOS



- Full Scale
- 26 min EBCT
- Lead-Lag configuration
- F600 Calgon carbon
- 1.5 m^3/min flow
- Full automation
- POTW residual discharge
- Off site regeneration
- 70K bed volumes to breakthrough for PFOA

Treatment Cost: PFOA, TCE, 11 DCA

PFOA will break through before PFOS



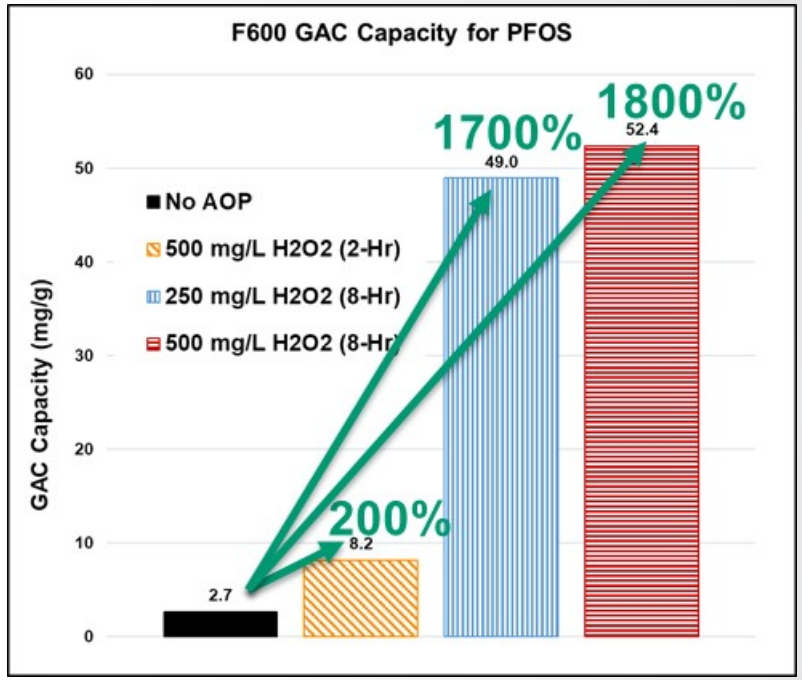
- Full Scale
- 26 min EBCT
- Lead-Lag configuration
- F600 Calgon carbon
- 1.5 m^3/min flow
- Full automation
- POTW residual discharge
- Off site regeneration
- 135K, 70K, and 11K bed volumes to breakthrough for TCE, PFOA, and 11DCA, respectively.

Research: Contaminated Site Remediation

- **Problem**: PFAS-contaminated sites require remediation and cleanup to protect human health and the environment
- **Action**:
  - Characterize sources of PFAS such as fire training and emergency response sites, manufacturing facilities, production facilities, disposal sites.
  - Evaluate treatment technologies for remediating PFAS-impacted soils, waters, and sediments.
  - Develop treatment trains to address complex matrices with co-mingled wastes that may occur with PFAS contamination.
  - Generate performance and cost data with collaborators (DOD, WRF, industry, etc.) to develop models and provide tools to determine optimal treatment choices
- **Results**: Tools, data and guidance regarding cost, efficacy, and implementation for remedy selection and performance monitoring
- **Impact**: Enable responsible officials to reduce risk of PFAS exposure and effects at contaminated sites, and to repurpose sites for beneficial use

Research: Treatment trains for dominant co-contaminants during PFAS Treatment

- **Problem**: Co-contaminants (at parts-per-million) can overwhelm technologies aimed at PFAS treatment
- **Action**:
  - Develop treatment trains for specific water types (surface, ground, waste, leachate-, fire fighting-, etc.)
  - Evaluate performance of widely applicable co-contaminant treatment technologies in conjunction with PFAS treatment approaches
  - Engineer and evaluate mobile platforms, for applicable deployment scenarios
- **Results**: Provide data and tools for site and facility managers
- **Impact**: Enable cost effective, site-specific, and mobile management of PFAS during water treatment



Example improvement in carbon treatment capacity via AOP treatment train in firefighting water containing legacy AFFF

Research: Wastewater Treatment

- **Problem**: Consumer and industrial use of PFAS-containing products often results in disposal to wastewater, becoming a source of PFAS in the environment.
- **Action**:
  - Characterize various waste streams (e.g. municipal, industrial, manufacturing, landfill leachate) contributing to wastewater as sources of PFAS.
  - Evaluate efficacy of current and innovative wastewater treatment technologies (e.g. conventional, advanced, centralized, decentralized, pretreatment, water reuse, biosolids) to manage PFAS contamination.
  - Evaluate performance and cost data with other entities (WRF, industry, consultants, etc.)
- **Results**: Provide data, tools and guidance to operators on management of PFAS in wastewater, biosolids, wastewater reuse, and pretreatment
- **Impact**: Enable effective management of PFAS in wastewater

Research: Land Application of WWT Residuals

- **Problem**: Consumer, commercial, and industrial use of PFAS-containing products often results in disposal to wastewater. Land application of wastewater treatment residuals is a common agricultural practice and may introduce PFAS in the environment.
- **Action**:
  - Characterize persistence and transformation of PFAS in land applied residuals
  - Characterize PFAS uptake into plants in settings of land applied residuals
  - Characterize transport of PFAS from land applied residuals into ground water and surface water
  - Provide technical support to state and local governments, and treatment operators
- **Results**: Provide data, tools and guidance to operators on management of PFAS in residuals and biosolids
- **Impact**: Enable effective management of PFAS in wastewater

Research: Materials Management

- **Problem**: Lack of knowledge regarding end-of-life management (e.g. landfills, incineration) of PFAS-containing consumer and industrial products
- **Action:**
  - Characterize various end-of-life disposal streams (e.g. municipal, industrial, manufacturing, landfills, incinerators, recycled waste streams) contributing PFAS to the environment.
  - Evaluate efficacy of current and advanced waste management technologies (e.g. landfilling, thermal treatment, composting, stabilization) to manage PFAS at end-of-life disposal
  - Evaluate performance and cost data with other entities (DOD, industry, academia, etc.) to manage these materials and manage PFAS releases to the environment
- **Results**: Provide technologies, data and tools to manage these end of use streams
- **Impact**: Enable effective management of end-of-life disposal of PFAS-containing products

Technical Assistance for States, Tribes, and Communities

- **Problem**: State, Tribes, and Communities sometimes lack full capabilities for managing PFAS risk
- **Action:**
  - Make ORD technical staff available to consult on PFAS issues
  - Utilize applied research at impacted sites to develop new research solutions while also providing technical support to site managers
  - Summarize reoccurring or common support requests to share lessons learned from technical support activities in ORD
  - Collaborate with ECOS and ASTHO to develop case studies for effective risk communication
- **Results**: Many examples of past and ongoing technical assistance
  - Cape Fear River NC - Significant reductions in PFAS in source and finished drinking water
  - Wyoming, OH – rapid analysis of PFAS cross contamination in water distribution system
  - Manchester NH – collaboration on air and water sampling
- **Impact**: Enable States, Tribes, and Communities to 'take action on PFAS'

Summary: Ready-to-Use Tools

https://www.epa.gov/pfas/epa-pfas-data-and-tools

EPA PFAS Data and Tools

Secure | https://www.epa.gov/pfas/epa-pfas-data-and-tools

Apps | National Locator | ORD PFAS Wiki | 1601 valley creek, 27 | Imported From IE | Remote Access Solu | U.S EPA Web Server | Sign-In Notification | LastPass

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PFOA, PFOS and Other PFASs

- PFAS Home
- Basic Information on PFAS
- EPA Actions
- PFAS Infographic
- Data and Tools
- State Information

EPA PFAS Data and Tools

Below are links to data and tools that include information on PFAS and are currently available on the agency's website.

Chemistry

- Chemistry Dashboard
- ChemView

Drinking Water

- Drinking Water Treatability Database
  - PFOA
  - PFOS
- Drinking Water Laboratory Methods
- Data from EPA's Third Unregulated Contaminant Monitoring Rule (UCMR)

Toxicity

- GenX Chemicals Studies
- Health & Environmental Research Online (HERO)
- Toxics Release Inventory

Waste

- Sampling and Laboratory Methods (SW-486 Compendium)

Contact Us to ask a question, provide feedback, or report a problem.

Treatment Conclusions

Overall

Much is needed to be known about the treatment of PFAS, but what we do know is that removing a wide range of PFAS from a given water will be extremely expensive and often impossible, also residual stream handling will be an issue to address.

Solution

A great deal of work is needed on treatment performance, cost, analytics, occurrence, and health effects to determine the most flexible treatment option which will need to include

- What PFAS are critical to remove and to what concentrations?
- What other ancillary treatment benefits are gained / lost? Other PFAS? Other contaminants? DBP precursors? Lead or copper corrosion?
- What residual streams are acceptable and how are they handled?

For More Information:

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