WRF Research on PFAS in Water, Wastewater and Biosolids

ICPRB – A Conversation on PFAS

Alice Fulmer, Regional Liaison

9/22/22

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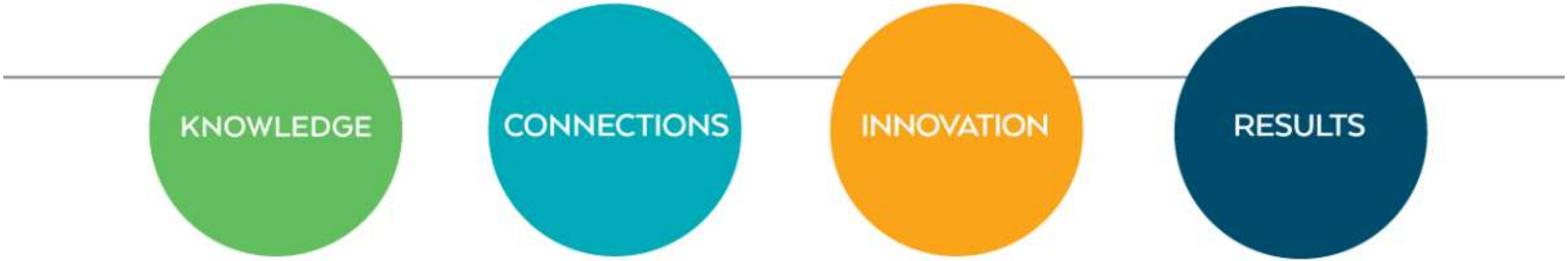
Identify, prioritize and fund research for the water sector.

Accelerate the adoption of new technologies in the water sector.



Convene experts and sector representatives to identify and collaborate on priority water research.

Educate decision-makers on the science of water.

advancing the science of water

THE Water Research FOUNDATION®

BY THE NUMBERS

AS OF 3/31/22

SUBSCRIBERS

1,014 UTILITIES

74 CONSULTANTS

42 MANUFACTURERS

FUNDED RESEARCH

$67 MILLION

52 STAFF

$30 MILLION COST SHARE

$37 MILLION CASH
Contractually Funded Research

RESEARCH PORTFOLIO

216 ACTIVE PROJECTS

61 CO-FUNDED PROJECTS
***146** CO-FUNDERS*

9 FEDERAL/STATE GRANTS

2 FEDERAL CONTRACTS

3 PRIVATE GRANTS

$.82 OF EVERY DOLLAR SUPPORTS PROGRAM SERVICES

RESEARCH PRIORITY | TAILORED COLLABORATION | EMERGING OPPORTUNITIES | GRANTS/AWARDS | PAUL L. BUSCH AWARD | FACILITATED & UNSOLICITED RESEARCH

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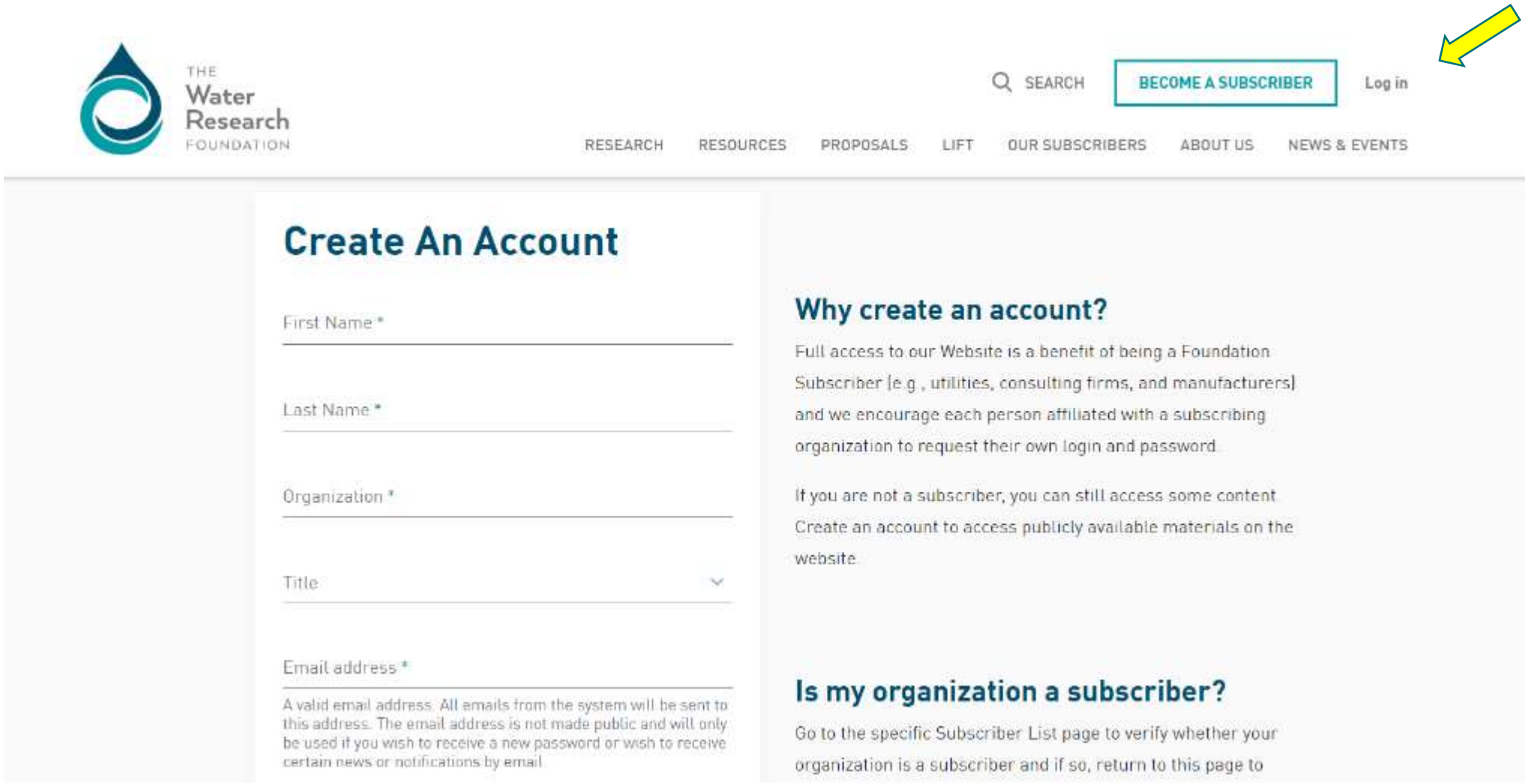

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Per- and Polyfluoroalkyl Substances (PFAS)

Per- and polyfluoroalkyl substances (PFAS), also commonly re
are a group of anthropogenic chemicals with past and current
products. In 2006, the U.S. Environmental Protection Agency cl
carcinogens.

PFAS are used in firefighting foams, coating for food packaging
products. PFAS are highly resistant to chemical decomposition
industrial releases, wastewater treatment plant discharges, st
and land application of contaminated biosolids.

TOPIC OVERVIEW (PDF)

In this topic

8 Projects | 1 Webcast

Talking to Customers and Communities About PFAS

This article, authored by current and former WRF staff, offers risk communication guidance, grounded in WRF research, that utilities can use when communicating about PFAS. The article was published in the May 2020 issue of *Journal AWWA*.

READ THE ARTICLE

Per- and Polyfluoroalkyl Substances: Background Technical Information

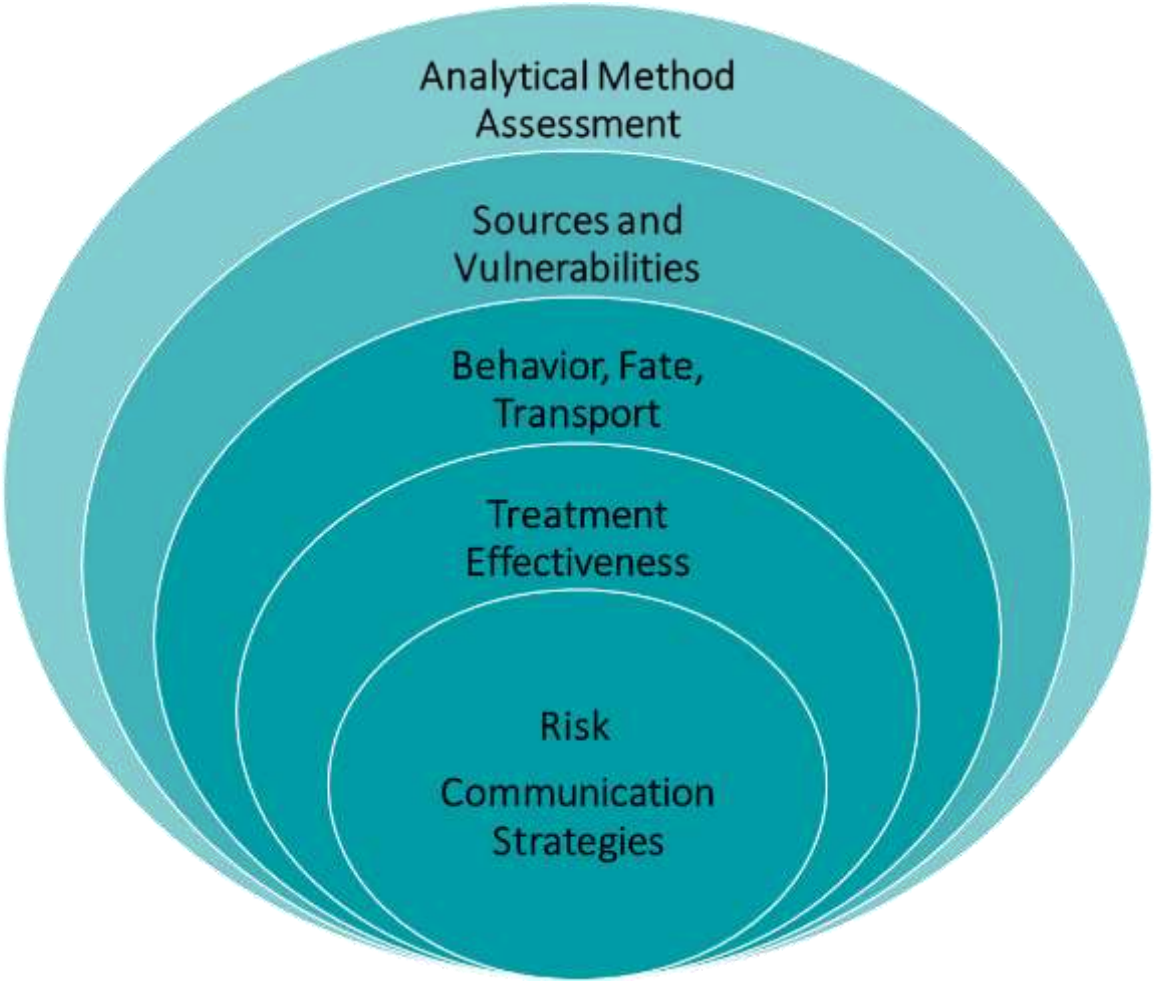
This state of the science document provides an overview of per- and polyfluoroalkyl substances, including sources, health effects, regulations, occurrence and detection methods, and treatment. It also discusses WRF's published, ongoing, and future PFAS research.

DOWNLOAD

"Thinking About PFAS in Drinking Water" Core Message Sheet

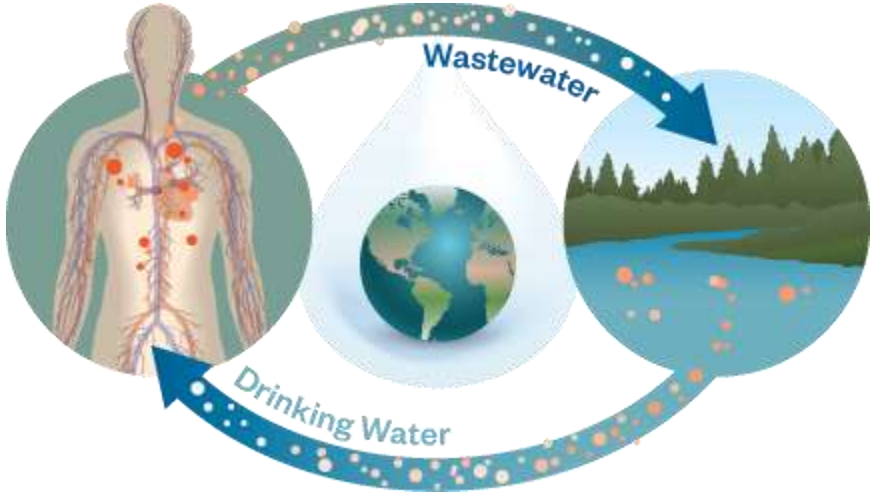
This concise handout can be used by utilities and other agencies to communicate core messages about PFAS: what they are, where they come from, why they are a concern, and what solutions exist to deal with them.

DOWNLOAD



WRF PFAS Research Objectives

Management, analysis, removal, fate and transport of per- and polyfluoroalkyl substances (PFAS) in water



Web Links for WRF PFAS Projects and Resources

Updated 8/23/2022

PFAS Web Page: Topic Overview, Technical Background, and Other Resources

1693: Formation of Nitrosamines and Perfluoroalkyl Acids During Ozonation in Water Reuse Applications (Reuse 11-08)

4322: Treatment Mitigation Strategies of Poly & Perfluorinated Chemicals, Final Report plus webcast

4344: Removal of Perfluoroalkyl Substances by PAC Adsorption and Ion Exchange

4877: Concept Development of Chemical Treatment Strategy for PFOS-Contaminated Water

4913: Investigation of Treatment Alternatives for Short-Chain Per-Polyfluoroalkyl Substances

5002 Webcast: "Relating PFAS Leaching from Sewage Sludge and Biosolids to Water and Sludge Quality" (WEF, February 2020)

5002: Determining the Role of Organic Matter Quality on PFAS Leaching from Sewage Sludge and Biosolids (NSF grant)

5011: Evaluation and Life Cycle Comparison of Ex-Situ Treatment Technologies for Per-and Polyfluoroalkyl Substances (PFASs) in Groundwater (DOD grant)

5031: Occurrence of PFAS Compounds in US Wastewater Treatment Plants

5042: Assessing Poly- and Perfluoroalkyl Substance Release from Finished Biosolids

5082: Investigation of Alternative Management Strategies to Prevent PFAS from Entering Drinking Water Supplies and Wastewater

5102: Application of Novel Method to Estimate Total PFAS Content in Water

5103: Microwave Regeneration of PFAS-Exhausted Granular Activated Carbons

5107: Understanding Pyrolysis for PFAS Removal

5111: Studying the Fate of PFAS through Sewage Sludge Incinerators

5124: PFAS One Water Risk Communication Messaging for Water Sector Professionals

5153: Evaluation of Bench-Scale Methods to Predict Drinking Water PFAS Removal Performance of Ion Exchange and Novel Adsorbents at Pilot- and Full-Scale

5170: State of the Science and Regulatory Acceptability for PFAS Residual Management Options (pre-RFP)

5172: Cost-effective PFAS Mitigation Strategies for Communities (pre-RFP)

Project #5102

UP

Application of Novel Method to Estimate Total PFAS Content in Water

Date Started
JAN 1, 2021

Principal Investigator
GRAHAM PEASLEE

Research Manager
MS. MARY SMITH
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Contractor
UNIVERSITY OF NOTRE DAME

Objectives:
Explore the use of particle-induced gamma ray emission (PIGE) spectrometry as a rapid and practical screening method for PFAS in surface water, recycled water, and groundwater.

Research Investment
$252,943

Completion Year
2022

IN PROGRESS

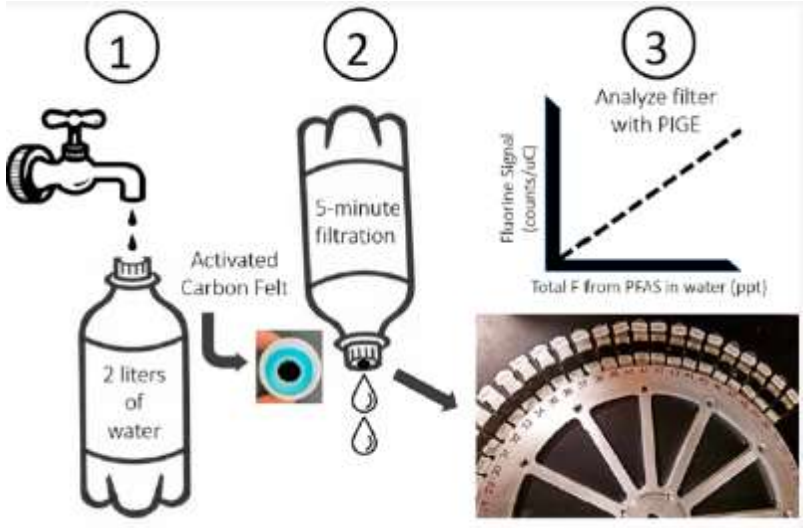
Related Topics
WATER QUALITY
PER- AND POLYFLUOROALKYL SUBSTANCES (PFAS)
MONITORING

Screening for Per- and Polyfluoroalkyl Substances in Water with Particle Induced Gamma-Ray Emission Spectroscopy

Meghanne Tighe, Yukun Jin, Heather D. Whitehead, Kathleen Hayes, Marya Lieberman, Meeta Pannu, Megan H. Plumlee, and Graham F. Peaslee. *ACS ES&T Water* **2021** *1* (12), 2477-2484. DOI: 10.1021/acsestwater.1c00215

Project Approach and Results

- Orange County Water District (OCWD)
- Surface waters, recycled waters, groundwaters, one point-source location, and treated water
- Split samples analyzed by LC-MS/MS at OCWD and University of Notre Dame
- All sample collection and gravity filtration done at OCWD, demonstrating utility feasibility
- Linear PIGE response was observed over a range of six spiked water samples as part of a formal assessment of accuracy and precision of the screening method
- Data analysis included method validation and direct comparison of total extractable fluorine concentration obtained by PIGE compared to the sum (and individual components) of specific PFAS analytes detected by traditional mass spectrometry methods



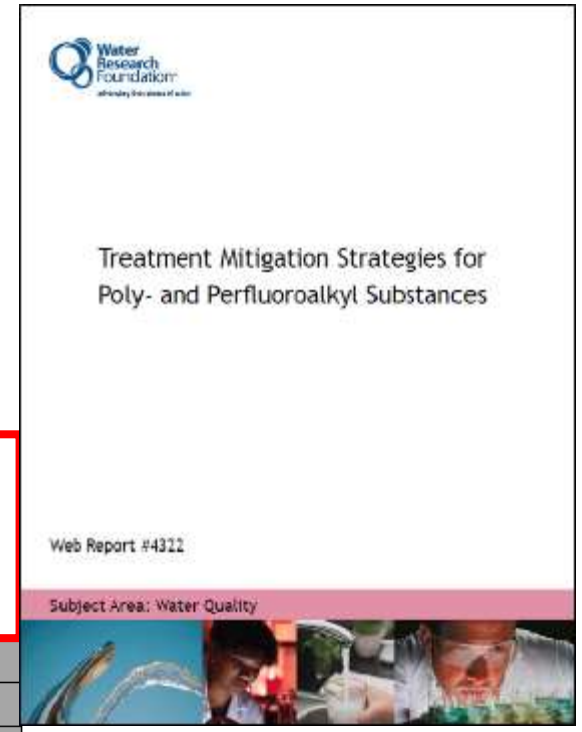
Preliminary Findings

- PIGE can be used as preliminary screening tool to identify samples that have elevated total organic fluorine as a complement to targeted PFAS methods
- Pre-treatment of samples using Fenton's reagent and adjustment to low pH to avoid fluoride were found to be useful to improve the performance of the method in real-world water samples
- For a two-liter sample volume of groundwater, the limit of detection was 38 ppt for total organic fluorine with a precision <20%
- A linear PIGE response was observed over a wide range of PFAS concentrations
- Total Organic Fluorine measured in different water matrices (groundwater, surface water, recycled water) by the PIGE-based method was manyfold greater than the sum of individual PFAS measured by the targeted EPA 537.1 method, which indicates that this TOF method is capturing additional organic fluorine (PFAS), which measures up to 18 analytes

WRF PFAS Research: Treatment

- Concept Development of Chemical Treatment Strategy for PFOS-Contaminated Water (4877, completed)
- Investigation of Treatment Alternatives for Short-Chain Per- Polyfluoroalkyl Substances (4913, in progress)
- Evaluation and Life Cycle Comparison of Ex-Situ Treatment Technologies for Per-and Polyfluoroalkyl Substances (PFASs) in Groundwater (Funding from Dept. of Defense) (5011 in progress)
- Microwave Regeneration of PFAS-Exhausted Granular Activated Carbons (5103, in progress)
- Understanding Pyrolysis for PFAS Removal (5107, in progress)
- Evaluation of Bench-Scale Methods to Predict Drinking Water PFAS Removal Performance of Ion Exchange and Novel Adsorbents at Pilot- and Full-Scale (5153, in progress)

PFAS Removal Summary



Removal <10% | Removal 10-90% | Removal > 90%

Compound	M.W. (g/mol)	AER	COAG/DAF	COAG/ FLOC/SED/ G- or M-FIL	AIX	GAC	NF	RO	MnO_4, O_3 ClO_2, Cl_2, CLM, UV, UV-AOP
PFBA	214	assumed	assumed						
PFPeA	264								
PFHxA	314								
PFHpA	364								
PFOA	414								
PFNA	464		unknown		assumed	assumed			
PFDA	514		unknown		assumed	assumed			
PFBS	300								
PFHxS	400								
PFOS	500								
FOSA	499	unknown	unknown		unknown	assumed	unknown	assumed	unknown
N-MeFOSAA	571	assumed	unknown		assumed	assumed	assumed		unknown
N-EtFOSAA	585		unknown		assumed	assumed	assumed		unknown[a]

Source – WRF Project 4322 Final Report, full-scale removal testing at WTPs

Two Projects

Funded around same time, complementary

- Project 4913 - Investigation of Treatment Alternatives for Short-Chain PFAS
  - PI – Detlef Knappe (NCSU)
  - Co-PIs – Chris Bellona (CSM), Eric Dickenson (SNWA), Erik Rosenfeldt (Hazen and Sawyer), Charles Schaefer (CDM Smith), Brian Steglitz (City of Ann Arbor), and Lauren Weinrich (American Water)
- DOD Grant - Evaluation & Life Cycle Comparison of Ex-Situ Treatment Technologies for PFASs in Groundwater
  - $990K
  - PI – Kenan Ozekin (outreach & project management)
  - Co-PIs - Chris Bellona (CSM), Detlef Knappe (NCSU), Sherri Cook (CU-Boulder), Charles Schaefer (CDM Smith), and Christopher Higgins (CSM)

Project #4913

RPP

Investigation of Treatment Alternatives for Short-Chain PFASs

Objectives:

- Investigate short-chain PFAS removal in a wide range of background water matrices (groundwater, surface water, treated wastewater) at multiple scales (bench, pilot, full) by existing and emerging treatment processes
- Develop guidance manual and decision support tool to select treatment processes and bench-scale testing of media for short-chain PFAS removal

Research Investment
$767,250

Completion Year
2023

IN PROGRESS

Date Started
MAR 1, 2019

Principal Investigator
DETLEF KNAPPE

Research Manager
DR. KENAN OZEKIN
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Contractor
NORTH CAROLINA STATE UNIVERSITY

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GAC - high level interim results

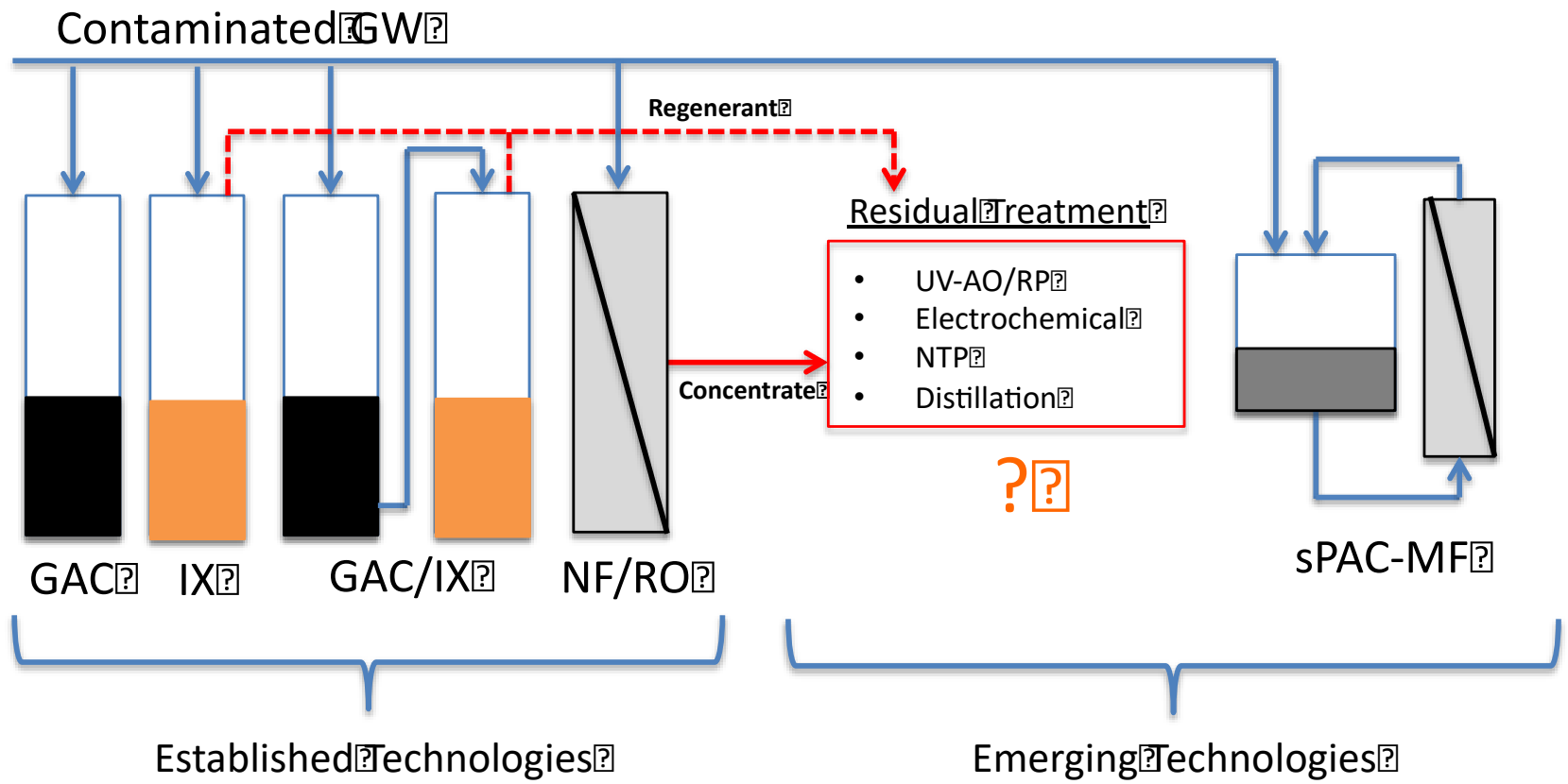
- Data collected from full-scale plants (both drinking water and reuse) to evaluate short-chain PFAS removal (39 plants from 16 states)
- Generated breakthrough curves in the lab
- Validating the promising treatment approaches at the pilot-scale
  - PFAS removal depends on PFAS chain-length
  - EBCT have little to no effect for short-chain PFAS removal
  - Short chain PFAS desorbs due to substitution by long-chain PFAS
  - GAC service life for PFAS removal strongly depends on TOC
  - Removing TOC prior to GAC will lower GAC use rate

Ion Exchange – high level interim results

- Generated breakthrough curves in the lab
- Short chain PFAS are more challenging to remove than long chain PFAS
- Ion Exchange ineffective for many short-chain PFAS
- Removal effectiveness of IX resins for PFAS increases exponentially as the PFAS chain length increases
- Perfluoroalkyl sulfonic acids (PFSAs) are more readily removed by IX than perfluoroalkyl carboxylic acids (PFCAs)

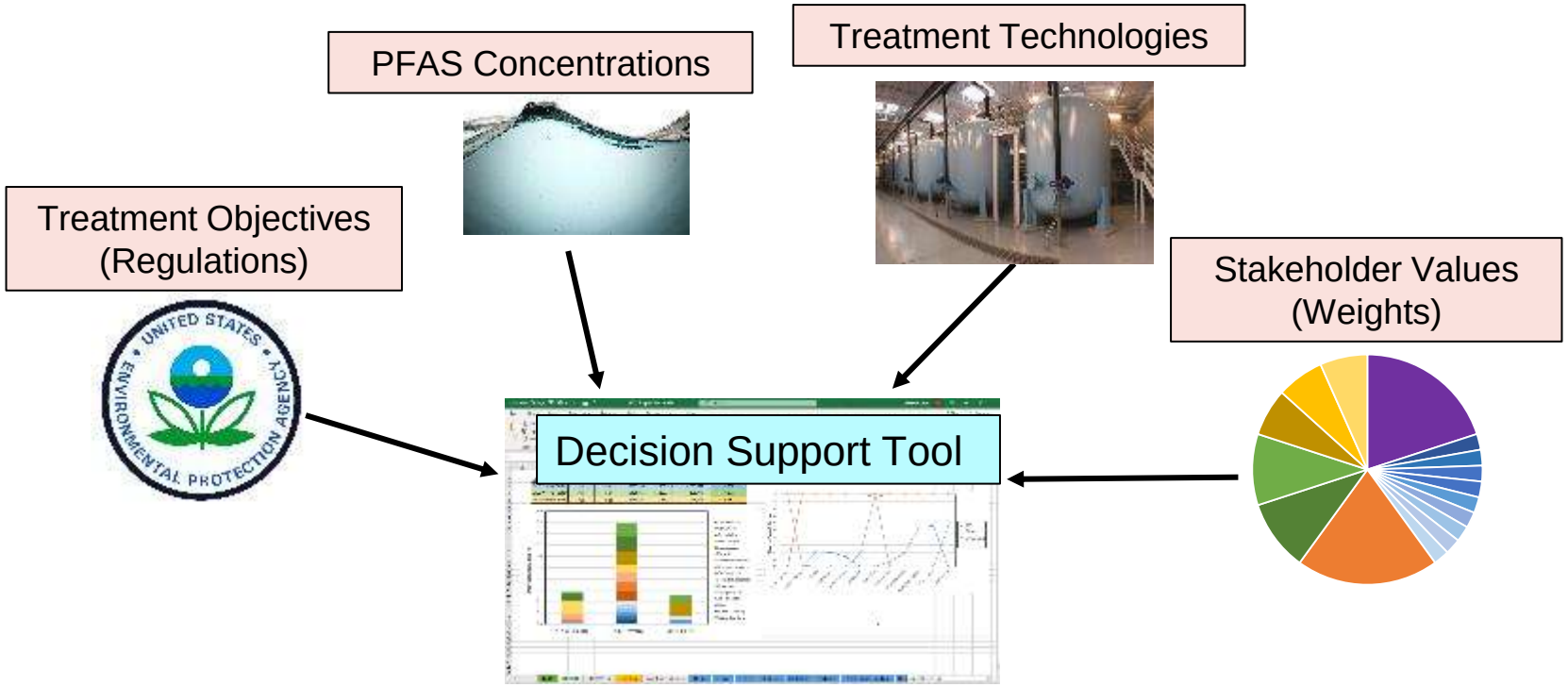
GR

Project 5011: Evaluation and Life Cycle Comparison of Ex-Situ Treatment Technologies for PFASs in Groundwater



Status: On-going, DOD project

Decision Support Tool



WRF PFAS Research: Behavior, Fate, Transport

- Formation of Nitrosamines and Perfluoroalkyl Acids During Ozonation in Water Reuse Applications (1693, completed)
- Determining the Role of Organic Matter Quality on PFAS Leaching from Sewage Sludge and Biosolids (NSF Project) (5002, in progress)
- Occurrence of PFAS Compounds in US Wastewater Treatment Plants (5031, in progress)
- Assessing Poly- and Perfluoroalkyl Substance Release from Finished Biosolids (5042, completed)
- Studying the Fate of PFAS through Sewage Sludge Incinerators (5111, in progress)

Project #5031

RPP

Occurrence of PFAS Compounds in US Wastewater Treatment Plants

Objectives:

- Provide a comprehensive, methodologically consistent dataset regarding PFAS occurrence, fate, and mass distribution in WRRFs.
- Provide the scientific justification to develop appropriate guidance for site managers that benchmarks typical PFAS mass flows from WRRFs, sampling procedures and analytical methods, as well as potential mitigation strategies specific to WRRF unit processes.

Research Investment
$899,693

Completion Year
2023

IN PROGRESS

Date Started
MAR 1, 2020

Principal Investigator
CHARLES SCHAEFER

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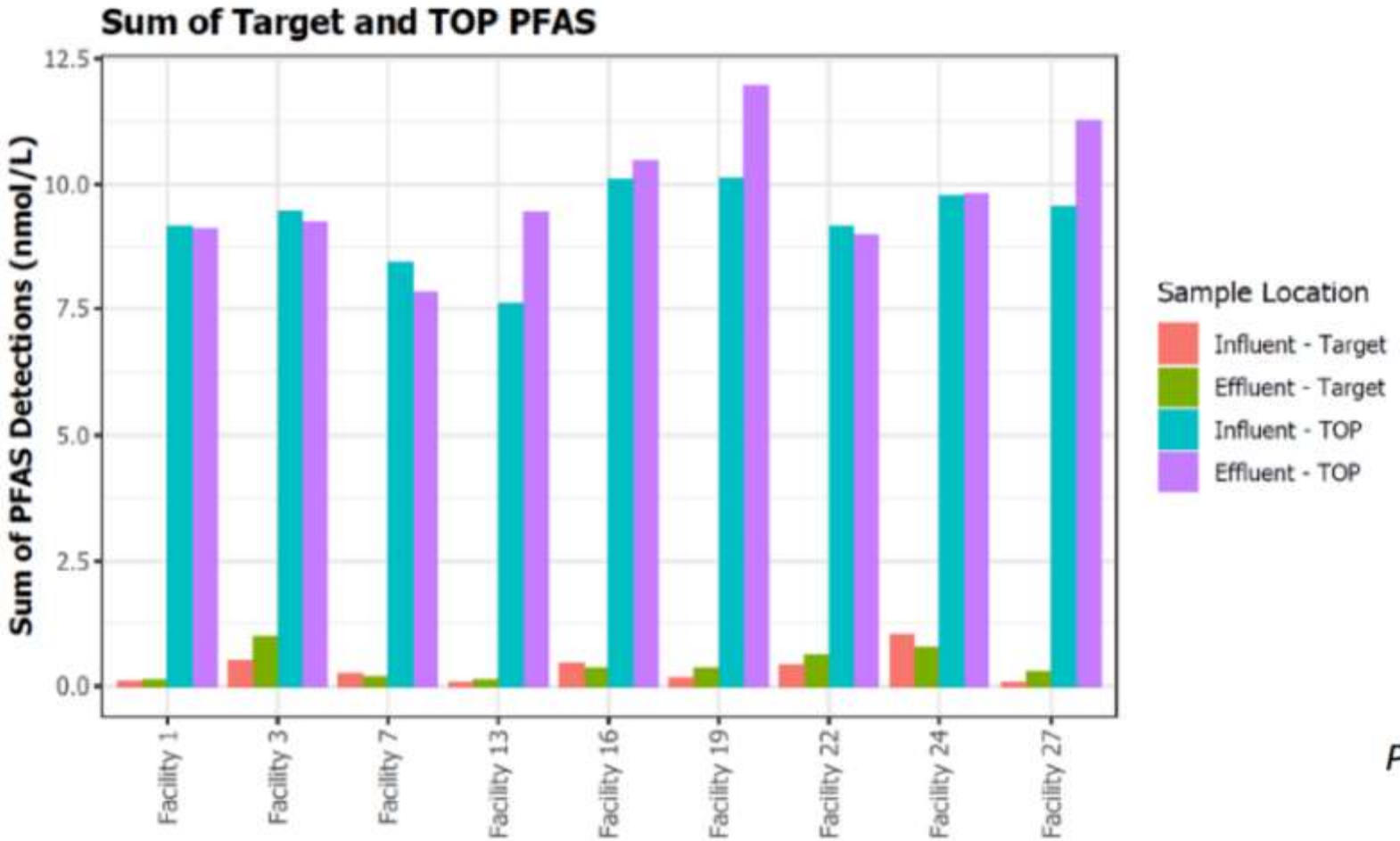
Contractor
CDM SMITH INC.

Related Topics
WATER QUALITY
PER- AND POLYFLUOROALKYL SUBSTANCES (PFAS)
COMPOUNDS OF EMERGING CONCERN (CECS)

WRF 5031: Oxidizable Precursors in Influent and Effluent Streams



Preliminary data

Project #5042

UP

Assessing Poly- and Perfluoroalkyl Substance Release from Finished Biosolids

Objectives:

- Assess PFAS release from finished biosolids using bench-scale leaching tests of biosolids collected from WRRFs with differing post-digestion treatment processes
- Examine release as a function PFAS loading in the finished biosolids, the post-digestion processing of the biosolids, and the age of the biosolids.

Research Investment
$151,000

Completion Year
2022

IN PROGRESS

Date Started
OCT 15, 2019

Principal Investigator
CHARLES SCHAEFER

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Contractor
CDM SMITH INC.

Related Topics
PER- AND POLYFLUOROALKYL SUBSTANCES (PFAS)
COMPOUNDS OF EMERGING CONCERN (CECS)
MONITORING
BIOSOLIDS

PFAS in Biosolids

- Recent webcast 10/14/21, highlighting multiple projects
- PFAS levels similar among all biosolids studied
- Majority of organic fluorine associated with precursors not currently quantified in commercial laboratories
- Precursor transformation to perfluorinated carboxylates likely occurs during land application of biosolids
- **The extent to which release of PFAS (100s of ng/L) poses a risk needs further assessment**

Project #5107

Understanding Pyrolysis for PFAS Removal

TC

Date Started
MAY 1, 2021

Principal Investigator
DERYA DURSUN

Research Manager
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Contractor
HAZEN AND SAWYER

Related Topics
PER- AND POLYFLUOROALKYL SUBSTANCES (PFAS)
COMPOUNDS OF EMERGING CONCERN (CECS)
ADVANCED TREATMENT
BIOSOLIDS TREATMENT

Objectives:

Study performance and feasibility of a full-scale thermal drying and pyrolysis facility to process municipal sludge as the feedstock, focusing on the ability to remove/destroy PFAS.

- Determine fate of selected PFAS compounds through unit processes
- Perform mass balances on metals and organics around various unit processes
- Develop energy balances around system and unit processes
- Determine produced synthetic gas quantity and quality
- Compare process LCA to conventional sludge treatment/disposal technologies.

Project #5111

TC

Studying the Fate of PFAS through Sewage Sludge Incinerators

Objectives:

- Elucidate fate of PFAS through SSIs
- Characterize PFAS content of each input/output stream including solid, liquid, and gas phases
- Provide decision makers with an indication of the extent SSIs can reduce PFAS discharges to the environment

Research Investment
$478,881

Completion Year
2024

IN PROGRESS

Date Started
APR 15, 2021

Principal Investigator
LLOYD WINCHELL

Research Manager
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Contractor
BROWN AND CALDWELL

Is incineration our chance at PFAS destruction?

Project #5082

RPP

Investigation of Alternative Management Strategies to Prevent PFAS from Entering Drinking Water Supplies and Wastewater

Objectives:

- Summarize methodologies to identify potential point and nonpoint sources
- Investigate categories of nonpoint sources in commercial, institutional, and other sectors
- Summarize appropriate pre-treatment and mitigation measures, such as BMPs, permitting at point sources, and potential upstream regulatory and legislative measures for nonpoint sources
- Summarize impacts of wastewater effluent PFAS on drinking water utilities
- Develop roadmap of multiple strategies to mitigate PFAS prior to entry into water facilities.

Research Investment
$793,734

Completion Year
2023

IN PROGRESS

Date Started
MAY 1, 2021

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Contractor
CAROLLO ENGINEERS

Related Topics
WATER QUALITY
PER- AND POLYFLUOROALKYL SUBSTANCES (PFAS)
MONITORING

Project #5124

RPP

PFAS One Water Risk Communication Messaging for Water Sector Professionals

Objectives:
Develop informational products and tools to
- promote effective communications between utilities and their customers
- provide educational materials for the public regarding the risks of PFAS in water sources, tap water, biosolids applications, and treatment process residual
- address customer concerns through a drinking water-specific UCMR5 toolkit and a comprehensive One Water toolkit

Research Investment
$260,080

Completion Year
2022

IN PROGRESS

Date Started
AUG 31, 2021

Principal Investigator
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Contractor
AMERICAN WATER

Related Topics
WATER QUALITY
PER- AND POLYFLUOROALKYL SUBSTANCES (PFAS)
CONSTITUENTS OF EMERGING CONCERN (CECS)
CUSTOMER RELATIONS & STAKEHOLDER ENGAGEMENT
RISK ASSESSMENT

THE Water Research FOUNDATION

American Water Works Association

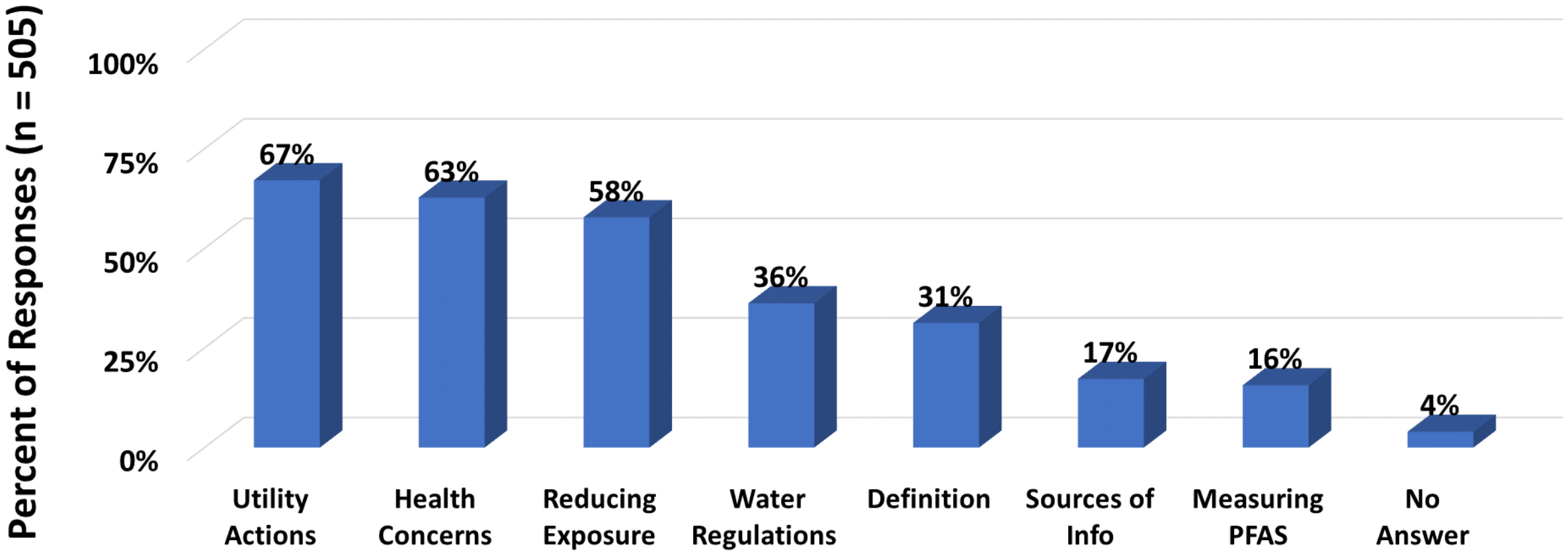
CDM Smith

Hazen

AMERICAN WATER

Topics of Greatest Interest from the Customer's Perspective

We use these insights to inform our customers through the materials we developed.



AMERICAN WATER

PFAS Risk Communication Project Deliverables

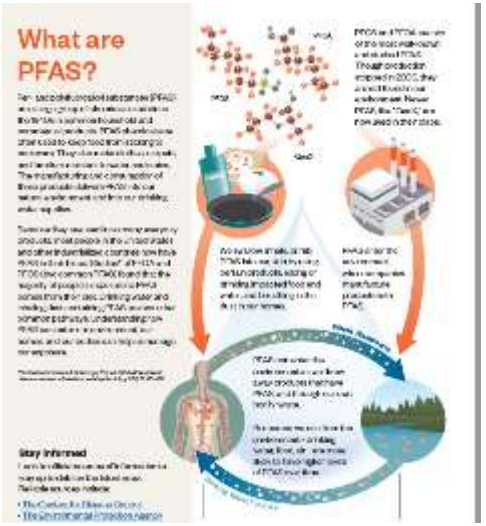
We use these insights to develop the communication materials for informing our customers. These will be available to all drinking water and wastewater utilities in the industry.

UCMR 5 Toolkit

- How-To Guidance
- PFAS Unit graphics
- FAQs, fact sheets
- Bill onserts, etc
- Press releases, etc

One Water Toolkit

- Sample copy for bill inserts and social media
- Brochure and One-pager
- Website copy and images
- Civic action



AMERICAN WATER

THE Water Research FOUNDATION

Thank You!

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WaterResearch

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