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Webinar Moderator

Mark White

Vice President, Senior Environmental Engineer

CDM Smith

Water industry leader Mark White has over two decades of experience in the planning, design, construction, operations, and maintenance of water treatment facilities. Mark has helped create improvements to over 40 water treatment plants around the world, totaling more than one billion-gallons-per-day of capacity. He has expertise in membrane technology, having served as project manager or membrane design lead for over 340 million-gallons-per-day of capacity, publishing widely on the subject, and providing industry leadership through the membrane committees of the American Water Works Association.

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Panel of Experts

Mark Wetzel
Superintendent of Public Works
Town of Ayer, Massachusetts

Ji Im
Environmental Engineer
CDM Smith

William Dowbiggin
Senior Vice President, Senior Environmental Engineer
CDM Smith

Barton Reed
Associate and Environmental Engineer
CDM Smith

Brian Chaplin
Associate Professor
The University of Illinois at Chicago

Kent Sorenson
Senior Vice President
CDM Smith

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Agenda

I. **Granular Activated Carbon and Ion Exchange- Common Technologies for PFAS Treatment, The Ayer Experience**
Mark Wetzel, Town of Ayer, MA, Ji Im, CDM Smith

II. **Reverse Osmosis Technology Advantages And Challenges For PFAS Treatment**
William Dowbiggin, CDM Smith, *Barton Reed*, CDM Smith

III. **Destructive Electrochemical Oxidation of PFAS using a Novel Reactive Electrochemical Membrane Technology**
Brian Chaplin, The University of Illinois at Chicago

IV. **Emerging Technologies for PFAS Treatment, Foam Fractionation & Electrochemical Oxidation**
Kent Sorenson, CDM Smith

Time Permitting – Q&A

Enter your **question** into the **question pane** at the lower right-hand side of the screen.

Please specify to whom you are addressing the question.

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Mark Wetzel, P.E.
Superintendent
Town of Ayer, MA

Ji Im, P.E.
Environmental Engineer
CDM Smith

GRANULAR ACTIVATED CARBON AND ION EXCHANGE - COMMON TECHNOLOGIES FOR PFAS TREATMENT, THE AYER EXPERIENCE

AWWA Webinar
"Current and Emerging Technologies for PFAS Treatment and Lessons Learned Webinar"
June 24, 2020

CDM Smith

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WHAT WILL YOU LEARN?

- Ayer's experience navigating a continuously-changing regulatory environment.

- Site-specific investigations examples

- Understanding the uncertainty of the common media technologies.

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AGENDA

1. Background
2. PFAS Discovery and Response Timeline
3. Grove Pond WTP
4. Spectacle Pond WTP
5. Point-Of-Use Filter Testing
6. Summary

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COMMUNITY BACKGROUND

- Located in central Massachusetts
- 9.5 square miles
- Population 7,600
- Dept. of Public Works – water, wastewater, stormwater, roads & bridges, solid waste, snow plowing, street lights

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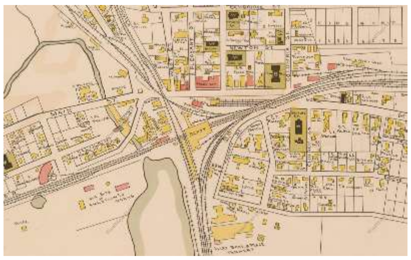
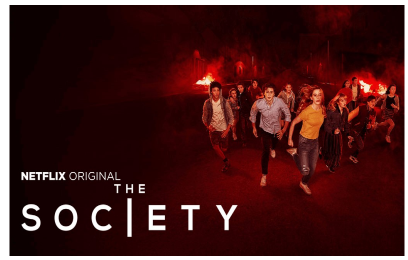
TOWN OF AYER, MASSACHUSETTS



Railroad Town

Army Town



Movie Town?

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AYER'S WATER SUPPLY

- 5 wells – 3 at Grove Pond WTP & 2 at Spectacle Pond WTP
- Two distribution storage tanks
- Demand: 1.4 MGD (average) & 2.7 MGD (maximum)
- 60% of water use is commercial / industrial
- Total supply yield – 3.7 MGD

Grove Pond WTP

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AYER'S WATER SUPPLY CHALLENGES

- Very high iron (2.5 to 3.4 ppm)
  - *Secondary MCL 0.3 ppm*
- Very high manganese (0.85 to 5.66 ppm)
  - *Secondary MCL – 0.05 ppm*
- Arsenic – 0.007 to 0.069 ppm
  - *MCL – 0.01 ppm*
- Lead and Copper Rule
- Total Coliform Rule
- Aging infrastructure

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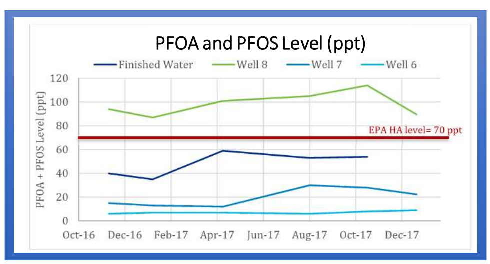
PFAS DISCOVERY & RESPONSE TIMELINE I

Due to proximity to Fort Devens, MassDEP required testing at the Grove Pond wells

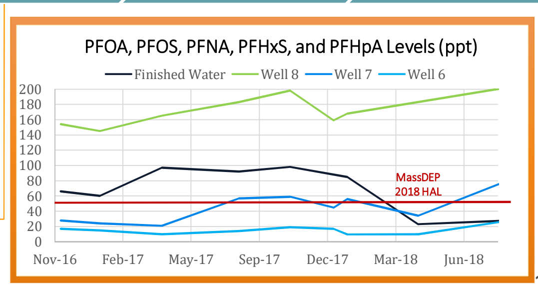


2016 | 2017 | 2018 | 2019 | 2020

Grove Pond desktop treatability study

Grove Pond Well 8 taken offline (most contaminated)

MassDEP Issues HA of 70 ppt for five (5) PFAS



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PFAS DISCOVERY & RESPONSE TIMELINE II

Grove Pond Well 8 *temporary* treatment

2016 | 2017 | 2018 | 2019 | 2020

Grove Pond testing for *permanent* treatment

Grove Pond design begins

Grove Pond construction begins

Grove Pond other challenges:
- Reactivated an old well with very high Fe/Mn
- SCADA update so Well 8 never runs alone
- Dirty water complaints
- Positive Total Coliform in August
- Well 6 "plugging" requiring redevelopment
- Interconnection with Devens who later detected PFAS
- Obtained funding from U.S. Army

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PFAS DISCOVERY & RESPONSE TIMELINE III

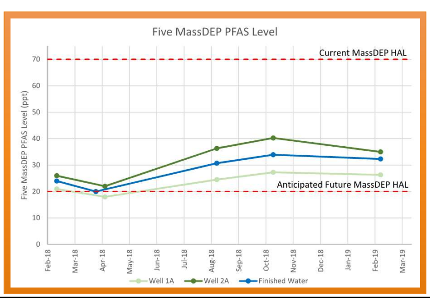
Spectacle Pond detects PFAS (20-30 ppt) & started sampling distribution system

MassDEP updates HA of <u>20 ppt</u> for <u>six (6)</u> PFAS

Spectacle Pond alternative analysis (permanent/temporary treatment, interconnections & use of emergency wells)

Spectacle Pond testing & design for permanent treatment

2016 | 2017 | 2018 | 2019 | 2020



~~MassDEP Issues HA of 70 ppt for five (5) PFAS~~

Spectacle Pond cleaned, redeveloped & replaced existing wells

Worked with MassDEP throughout the entire duration.

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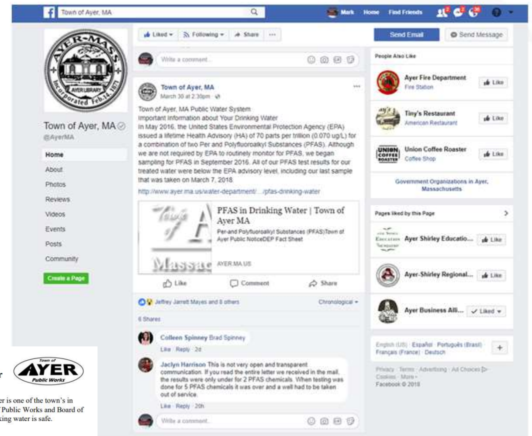
AYER'S PUBLIC OUTREACH

- Public Notifications in 2018, 2019 & 2020
- Updates at Selectmen's meetings and to public on Town website and Facebook
- Town PFAS Forum in 2019
- Info in Water Quality Reports
- Coordination with PACE (People of Ayer Concerned about the Environment)



Important Information about Ayer's Drinking Water
-- Translate it or speak with someone who understands it --

The Boston Globe recently published an article that reported that Ayer's drinking water is one of the town's in Massachusetts that is contaminated with the PFAS chemical. The Ayer Department of Public Works and Board of Selectmen have been very proactive in addressing this issue and making sure our drinking water is safe.

What happened?
In May 2016, the United States Environmental Protection Agency (EPA) issued a lifetime Health Advisory (HA) of 70 parts per trillion (0.070 ug/L) for a combination of two Per and Polyfluoroalkyl Substances (PFAS). In 2018, MassDEP adopted a more conservative advisory addressing a total of five of the PFAS chemicals, and strongly recommended that water suppliers take steps expeditiously to lower levels of the five PFAS, individually or in combination, to below 70 parts per trillion.

Although Ayer is not required by EPA to routinely monitor for PFAS, we began sampling for PFAS in September 2016. The Grove Pond Water Treatment Plant (WTP) is one of two treatment plants that supplies drinking water to our system and treats water from three of the Town's five water supply wells. One of the wells has PFAS levels for the five compounds combined that are over the 70 ppt advisory and the well was taken offline in February 2018 and a notification was mailed out to all water customers. The Ayer DPW continues to monitor all of our water supply wells on a quarterly basis to make sure the PFAS levels in Ayer's water is below the 70 ppt advisory.

What is our water system doing?
We have taken the following pro-active measures:
- Grove Pond Well 8 has been taken out of service.

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RISK COMMUNICATION LESSONS LEARNED

- **Let customers know that it is important for you to provide safe drinking water**
- Build public trust with ALL of your water operations (e.g. lead & copper, capital improvements)
- Get the town boards and other groups involved.
- Use social media – but beware!
- Talk to your State and Federal Reps
- Provide regular updates to BOS, public, and regulators

DEPARTMENT OF PUBLIC WORKS

Mark L. Wetzel, P.E., Superintendent
Dan Van Schalkwyk, P.E. Town Engineer
Pamela J. Martin, Business Manager

25 BROOK STREET
AYER, MASSACHUSETTS 01432
T: (978) 772-8240
F: (978) 772-8244

Ayer Drinking Water PFAS Update
October 17, 2019

The Ayer Department of Public Works will be providing weekly updates regarding the various actions and issues related to the PFAS contamination in Ayer's drinking water. The update will be itemized and in no particular order or priority. If you need additional information or clarification on any of these items, contact Mark Wetzel 978-772-8240 mwetzel@ayer.ma.us.

Water Quality Sampling –The results of the September sampling at the two water storage tanks for the 5 MassDEP ORSG PFAS compounds at Ayer wells, are shown as follows.

	PFOA + PFOS	MassDEP ORSG 5 Compounds
Washington Street Tank	16.24 ppt	28.84 ppt
Pingry Hill Tank	17.81 ppt	35.65 ppt

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MASSDEP HAL & PROPOSED MCL

- Massachusetts Department of Environmental Protection (MassDEP) updated health advisory level (HAL) in June 2018
- 20 ppt in drinking water for: PFOA, PFOS, PFHxS, PFNA, PFDA and PFHpA, individually or combined – *TO BE ADOPTED AS AN MCL*

PFAAs	C4	C5	C6	C7	C8	C9	C10	C11	C12
Carboxylates	PFBA	PFPeA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA
Sulfonates	PFBS	PFPeS	PFHxS	PFHpS	PFOS	PFNS	PFDS	PFUnS	PFDoS

Short-Chain PFAS

Long-Chain PFAS

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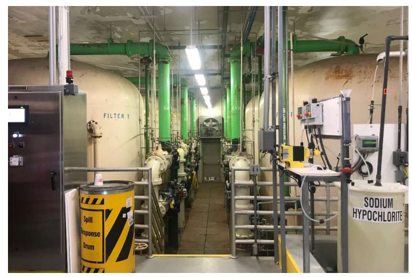
GROVE POND & SPECTACLE POND PLANTS

- Both greensand filtration facilities
  - 2 mgd capacity
  - Removing Fe, Mn & As
  - chemical treatment (e.g. pre-oxidation, disinfection, pH adjustment)

Grove Pond WTP



Spectacle Pond WTP

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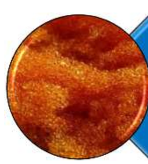
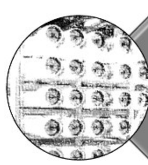
PFAS TREATMENT OPTIONS

- ✓ Water quality (e.g., low organic)
- ✓ Town's familiarity with pressure vessels
- ✓ No liquid waste stream of concern
- ✓ Comparatively lower cost (vs. membrane)

Granular Activated Carbon (GAC)



Anion Exchange (AIX)



Membrane

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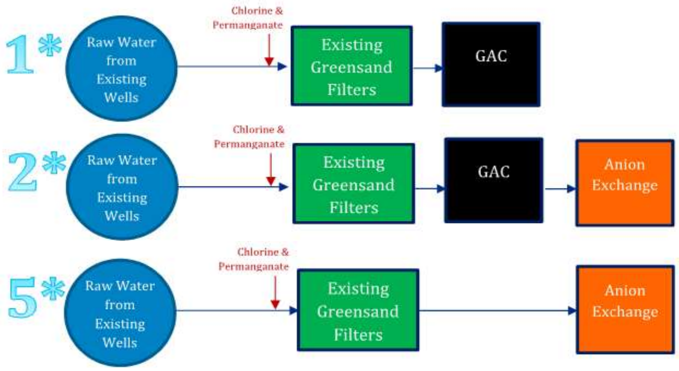
PFAS TREATMENT PLACEMENT AT GROVE POND WTP

- PFAS treatment process to be placed downstream of the existing greensand filters (post iron & manganese removal)
- Rapid small-scale column testing (RSSCTs) performed to evaluate the three options



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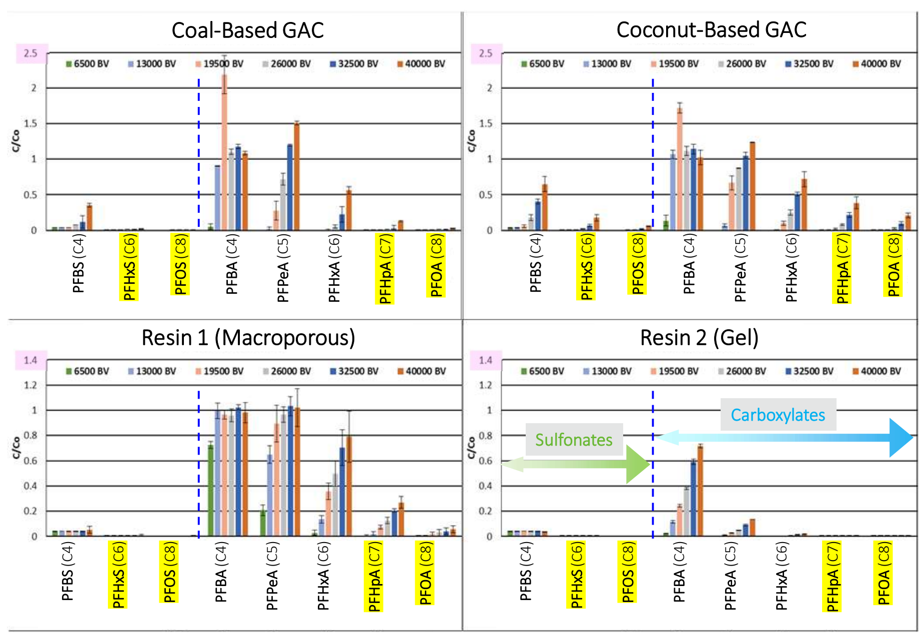
GAC VS. AIX

- Both AIX & GAC treated the target PFAS effectively, but differences in performance among the media products were observed.
- AIX chosen as the treatment technology for removing a wider range of PFAS, including shorter chain compounds



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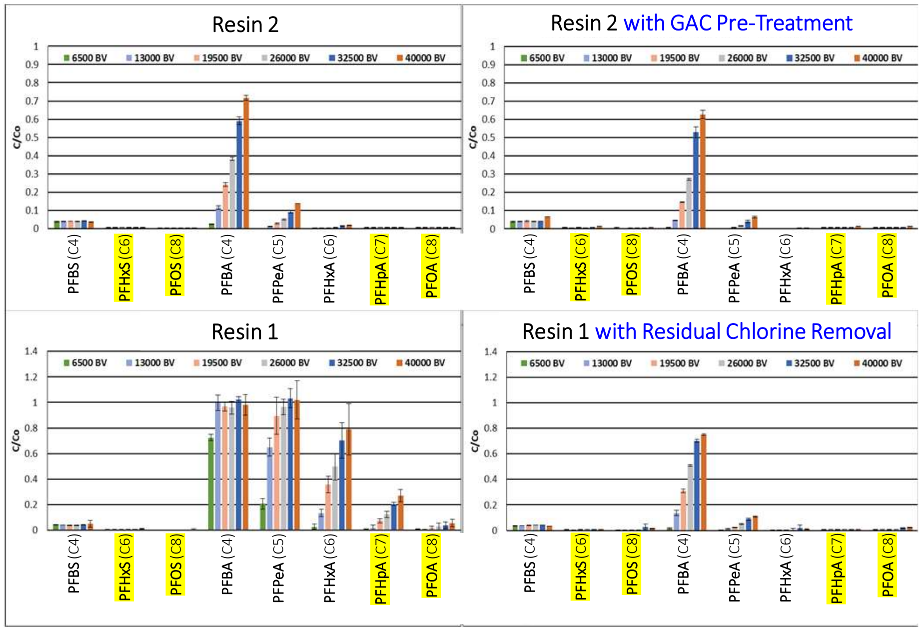
PRE-GAC TREATMENT & CHLORINE REMOVAL ON AIX TREATMENT

- Marginal improvement in AIX effectiveness by GAC pre-treatment upstream. *(TOC=~0.5 mg/L)*
- Removal of free chlorine residual *(0.2-0.5 mg/L)* with calcium thiosulfate resulted in enhanced PFAS treatment.



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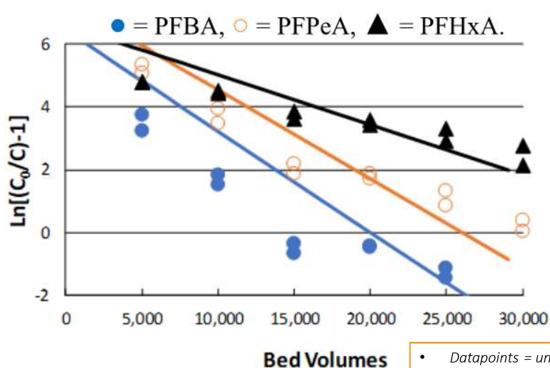
VALIDATING USE OF RSSCTS FOR PFAS ON AIX



- *Datapoints = unground resin testing*
- *Line = scaled from ground resin data*

I&EC research
Industrial & Engineering Chemistry Research

Research Note

Cite This: Ind. Eng. Chem. Res. XXXX, XXX, XXX−XXX

pubs.acs.org/IECR

Assessing Rapid Small-Scale Column Tests for Treatment of Perfluoroalkyl Acids by Anion Exchange Resin

Charles E. Schaefer,[*,†] Dung Nguyen,[‡] Paul Ho,[‡] Jihyon Im,[§] and Alan LeBlanc[§]

Rapid Small-Scale Column Testing (RSSCT)

$$\frac{EBCT_G}{EBCT_U} = \left(\frac{d_G}{d_U}\right)^2$$

constant diffusivity for scaling

Transport Eqn. (Thomas Model):

$$ln\left[\frac{C_0}{C} - 1\right] = \left(\frac{kmq_0}{Q}\right) - [EBCT]kC_0BV$$

where q_0 scales to account for surface sorption

- RSSCT, assuming constant diffusivity and coupled with the Thomas model, were effective for scaling PFAS removal with ground AIX resin in low TOC water

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CHLORIDE TO SULFATE MASS RATIO (CSMR)

- Increased CSMR is associated with galvanic corrosion of lead solder connected to copper pipes
  - Raw water
    - Average sulfate = **16.6 mg/L**
  - After 1,000 BVs:
    - Resin 1: sulfate = **6.4 mg/L**
    - Resin 2: sulfate = **16.6 mg/L**
  - After ~30,000 BVs:
    - Both Resin 1 and Resin 2 at the raw water sulfate level

$$CSMR = \frac{Chloride}{Sulfate}$$

Scenario	CSMR
Current	7.7
After 1000 BVs – Resin 1	20
After 1000 BVs – Resin 2	7.7

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GROVE POND PFAS TREATMENT FACILITIES

- AIX for PFAS Removal with Resin 2
- Calcium thiosulfate for dechlorination & bag filters prior to IX
- Zinc orthophosphate for improved corrosion control

The $3.1M AIX facility to start up in fall of 2020!

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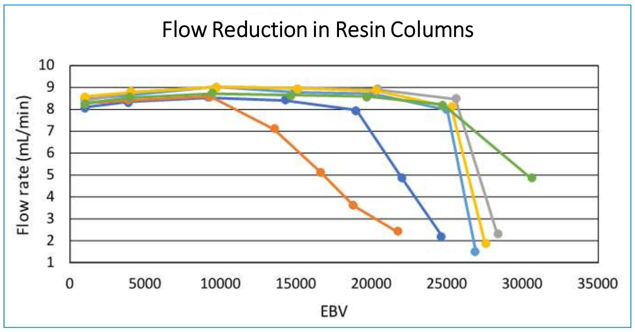
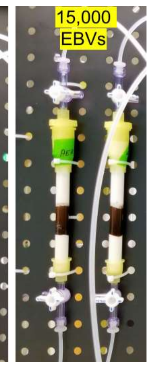
NOW FOR SPECTACLE POND WTP…

- Careful water quality evaluation was conducted, including comparison to Grove Pond WTP, and did not suggest concerns with AIX treatment.
  - Higher hardness in Spectacle Pond's water (115 mg/L vs. 190 mg/L)
- RSSCT to evaluate 3 resins & 1 GAC out of caution.





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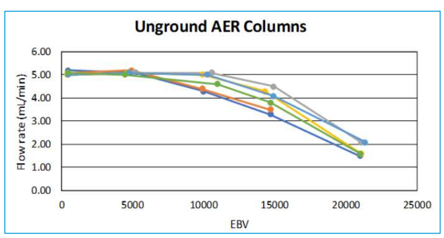
WHY DIDN'T AIX WORK AT SPECTACLE POND WTP?

- AIX resin clogging predicted at full-scale.
- Several investigations confirmed this is not an artifact of the laboratory work, but they could not provide an explanation.
- Emphasizes the importance of testing with the actual water to be treated.

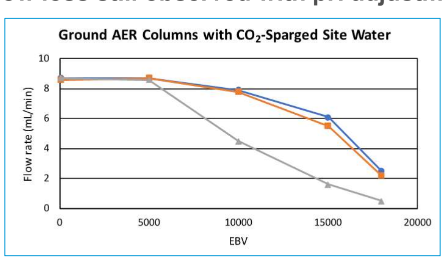
Investigation 1: resin grinding

Flow loss still observed with unground resin



Investigation 2: CO_2 loss during water shipment

Flow loss still observed with pH adjustment



Investigation 3: Electron microprobe analysis:

No significant differences observed between clogged and virgin resins

Investigation 4: Metals analysis:

Did not provide meaningful insights into the clogging mechanisms

Analyte	Unimpacted			Impacted			Unit
	1A	2A	3A	1A	2A	3A	
Calcium	39	49	40	29	22	32	mg/kg
Copper	11	27	1.9	35	18	26	mg/kg
Iron	4.7	17	3.9	29	12	100	mg/kg
Potassium	190	200	200	20	19	19	mg/kg
Sodium	150	160	160	16	15	15	mg/kg

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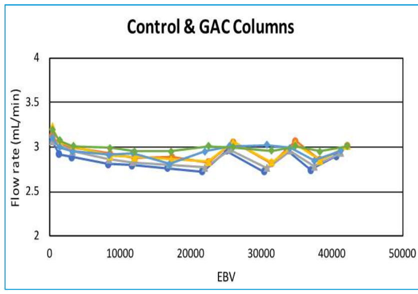
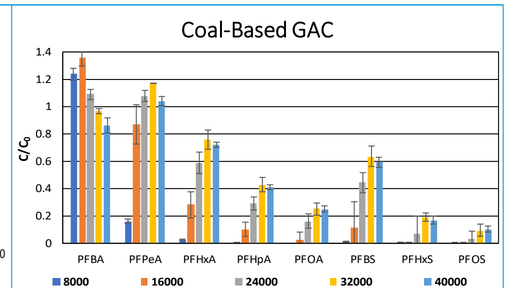
GAC AT SPECTACLE POND WTP

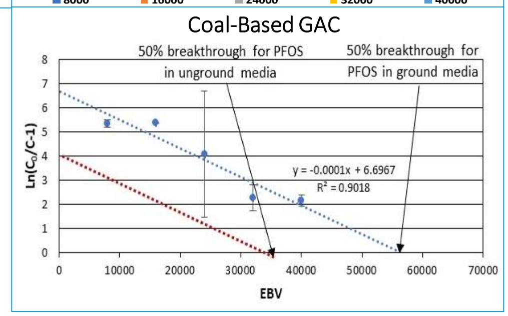
- No loss of flow observed.
- Bituminous coal-based GAC performed slightly better than enhanced coconut-based GAC.
- GAC changeouts predicted after 35,000 EBVs.
- No arsenic release by coal-based GAC observed.
- No impact on CSMR anticipated.





MassDEP PFAS	Coal-Based GAC	Coconut-Based GAC
PFOA	20%	50-70%
PFOS	10%	25-50%
PFHxS	20%	40-60%
PFHxA	80%	90-95%

Treatment facility addition with GAC currently being designed!



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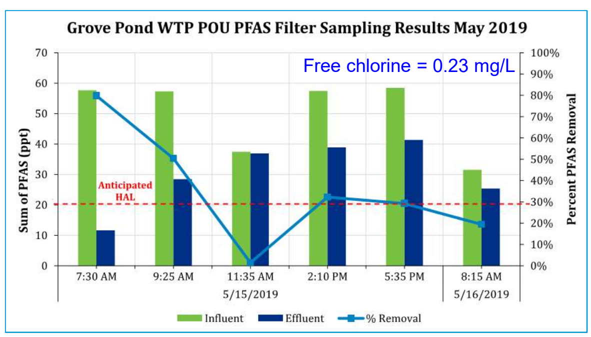
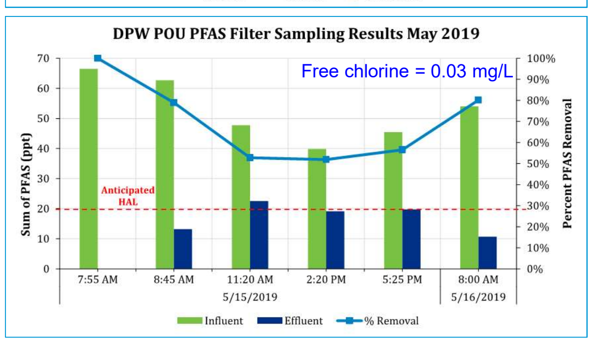
POINT-OF-USE (POU) FILTER TESTING

- POU home faucet filter system testing at WTP vs. in distribution system.
- Monitoring flow & various water quality parameters.
- Cold water testing results showed significant impact on capacity with chlorine residual.
- Determined not beneficial for Ayer's use.





- pH, iron, manganese, temperature & influent PFAS were comparable.
- Influent PFAS = PFOA, PFOS, PFHpA & PHHxS *(PFNA & PFDA = ND)*

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TAKEAWAYS & SUMMARY

Proactive actions, holistic treatment approach, and collaborative working relationships were critical part of the success in addressing the moving regulatory target in Ayer.

Careful site-specific investigations are important for determining treatment selection and compatibility with the existing treatment while avoiding unintended consequences.

GAC and AIX are established technologies for PFAS removal, but there is still more to be learned. Their effectiveness should be not be assumed without pre-design study and testing.

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CDM Smith
listen. think. deliver.

MassDEP
Commonwealth of Massachusetts
Department of Environmental Protection

ACKNOWLEDGEMENT

- Town of Ayer DPW
  - Dan Van Schalkwyk, P.E.
- MassDEP Central Region
- CDM Smith team
  - Lisa Gove, P.E., BCEE
  - Alan LeBlanc, P.E., BCEE
  - Charles Schaefer, Ph.D.

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CONTACT US!

Water Partnership with CDM Smith

Learn more about the water partnership at cdmsmith.com/water and @CDMSmith

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American Water Works Association

Dedicated to the World's Most Important Resource®

Reverse Osmosis Technology Advantages And Challenges For PFAS Treatment

The Brunswick County, NC Experience

CDM Smith

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Reed Barton, PE
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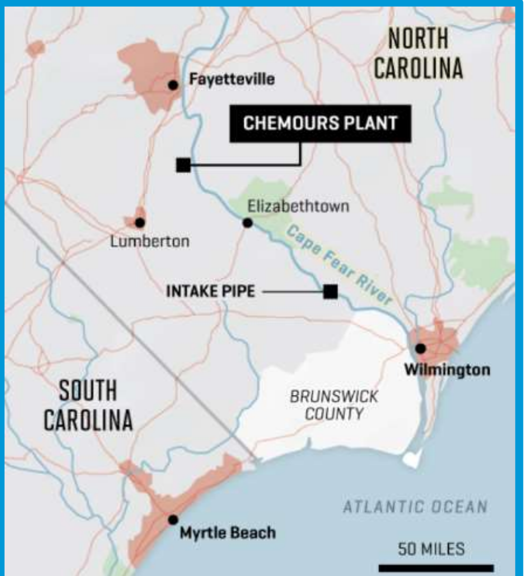

PRESENTATION AGENDA

1 Background
2 Treatment and Case Studies
3 Conclusions

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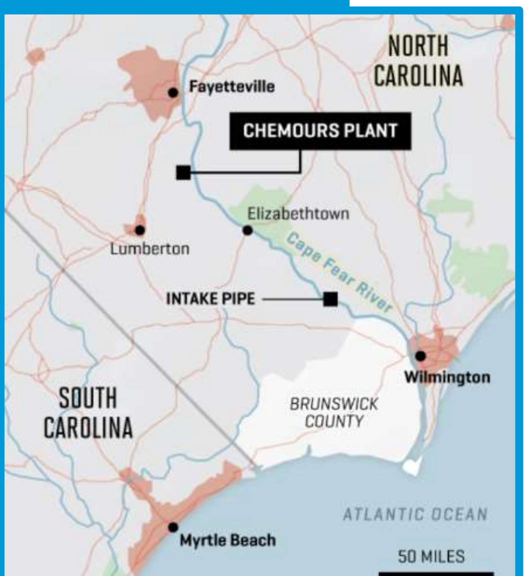

PRESENTATION AGENDA

1 Background
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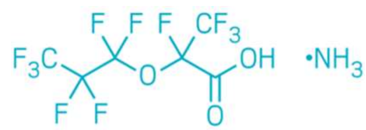
PFAS AND GENX

PFAS

- Pervasive and persistent in the environment
- Some PFAS species have been linked to health problems

GenX

- Multi-chain chemical structure
- GenX developed as a replacement for PFOA in 2009 as a fluoropolymer processing aid (non-stick coatings,etc)
- Linked to multiple health issues



GenX

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BACKGROUND

- Cape Fear River Basin
  - ~20% of NC within Cape Fear River Watershed
  - Numerous upstream discharges (Industrial and Municipal)
  - Primary drinking water source for over 1M+ people
- Brunswick County
  - End of the line: last water supply intake on river
  - Northwest Water Treatment Plant serves ~200,000 peak season population

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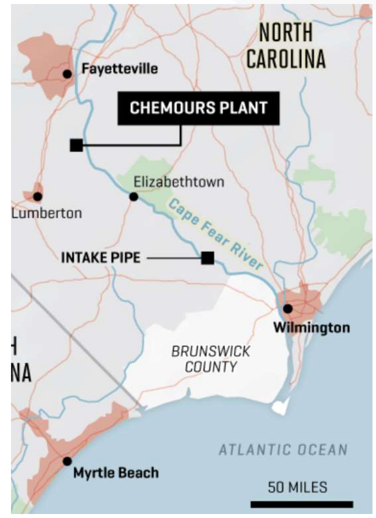
A PFAS STORY UNFOLDS IN BRUNSWICK COUNTY

- 2016 NCSU research study identifies PFAS in river
- 2017 Media coverage explodes
- NC Legislature responds by setting NC health advisory level for GenX and funding studies
- 2018 CDM Smith & Brunswick Co. began a treatment evaluation and pilot study

Originally broadcast June 26, 2017



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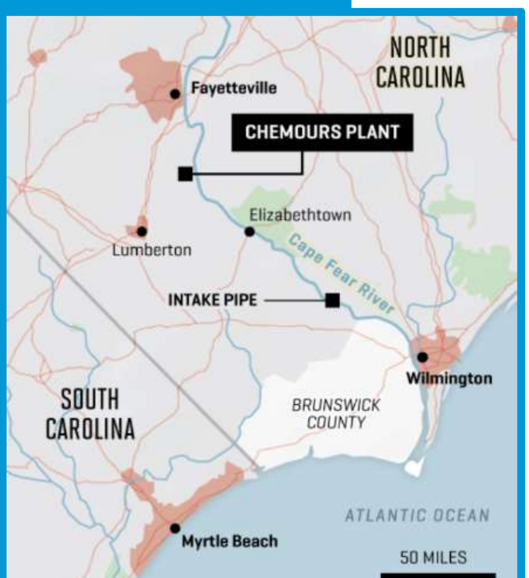

PRESENTATION AGENDA

1 Background
2 Treatment and Case Studies
3 Conclusions

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TREATMENT EVALUATION APPROACH FOR BRUNSWICK COUNTY

- **Determine what contaminants are present**
- **Set treatment goals** for removal of target contaminants
- **Evaluate treatment alternatives** for effective removal of target contaminants (bench or pilot testing as required)
- **Develop recommendations** for the most appropriate treatment technology
- **Prepare a plan for implementation** – Northwest WTP conventional expansion from 24 to 48 mgd and 41 mgd of advanced treatment to remove PFAS

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DETERMINING THE TARGET CONTAMINANTS

Primary Target Contaminants

Per- and Poly-fluoroalkyl Substances (PFAS)

- GenX and other PFAS
  - PFMOAA, PFMOPrA, PFMOBA, PFPrOPrA (GenX), PFO2HxA, etc.
- Additional PFAS compounds not yet identified

Secondary Target Contaminants

- 1,4-Dioxane
- Pharmaceuticals and Personal Care Products (PPCPs)
- Endocrine Disrupting Compounds (EDCs)
- Pesticides and Herbicides
- NDMA, Brominated DBPs
- Additional compounds not yet identified

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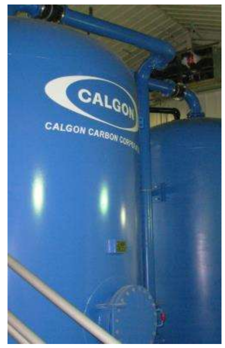
ADVANCED TREATMENT OPTIONS

Ion Exchange (IX)

Low Pressure Reverse Osmosis (LPRO)



Granular Activated Carbon (GAC)

UV-Advanced Oxidation Process (UV-AOP)

Ozone-Biofiltration

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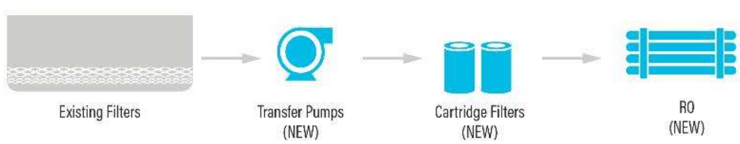
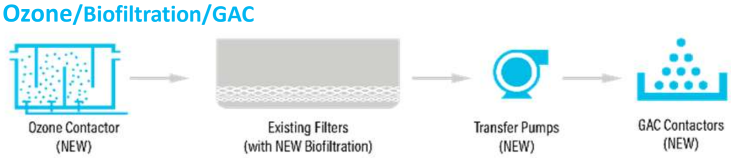
COMBINATIONS OF TECHNOLOGIES COMPARED FOR NWTP

Low Pressure Reverse Osmosis



Ozone/Biofiltration/GAC



GAC/IX/UV-AOP

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CAPE FEAR RIVER BASIN PILOT TESTS

- 4 RO Vendors Tested, 14.1 GFD Permeate Flux
- 3 IX and 4 GAC tested

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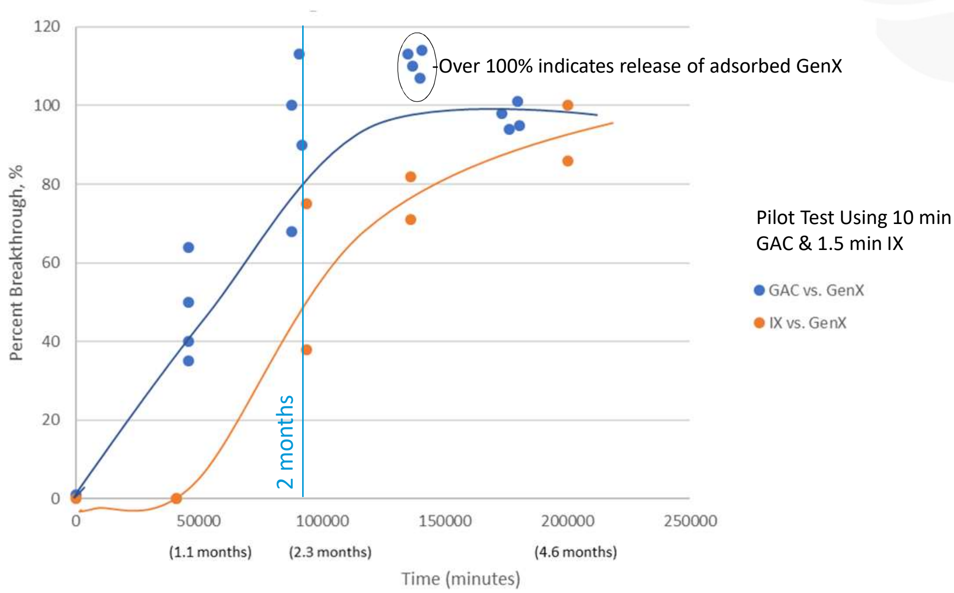
GENX BREAKTHROUGH CURVES: FROM HB 56 DATA



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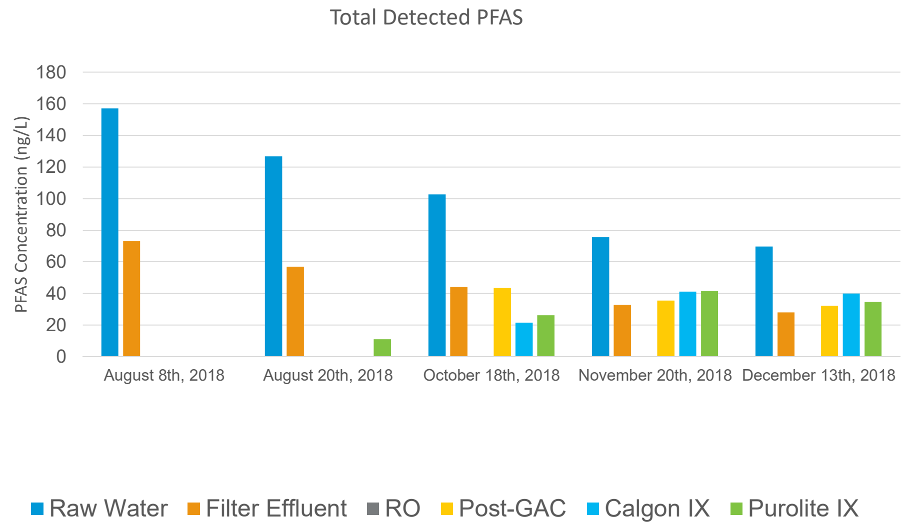
PILOT TEST RESULTS – GAC, IX, AND RO FOR JORDAN LAKE (UPSTREAM ON CAPE FEAR RIVER)



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CAPE FEAR RIVER TESTING PERCENT REMOVALS OF TARGET CONTAMINANTS BY POTENTIAL TREATMENT OPTIONS*

	Lower Cape Fear PFAS Compounds				
Alternative	**Gen X**	**PFMOAA, PFO2HxA**	**Most Other PFAS**	**1,4 Dioxane**	**PPCPs**
LPRO	>95%	>90%	>95%	70-95% ±	>90%
O3/BAF/GAC	90% ±	<90%	>90%	50-70%	>90%
GAC/IX/UV-AOP	>90%	<90%	>90%	>85%	>90%

* GAC and IX performance depends on change-out frequency

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SUMMARY OF TECHNOLOGIES FOR BRUNSWICK COUNTY NWTP

Low Pressure Reverse Osmosis (LPRO)
- Effective for removal of PFAS, PPCPs, & DBP precursors (>90%)
- 70-95% removal for 1,4 Dioxane (temperature)
- Physical barrier more reliable against spikes/spills
- Greatest protection from future unidentified PFAS and emerging contaminants
- Requires new NPDES discharge permit or other disposal option for concentrate

Granular Activated Carbon (GAC)
- Effective for removal of many PFAS, PPCPs, & DBP precursors
- Better media life for removal of long-chain PFAS
- Shorter media life for short- chain PFAS (e.g. GenX, PFMOAA, PFO2HxA)
- Good for PPCPs & DBP precursors
- Not effective for 1,4-dioxane; requires AOP

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SUMMARY OF TECHNOLOGIES (CONTINUED)

Ion Exchange (IX)
- Effective for removal of most PFAS
- Better media life for removal of long-chain PFAS
- Shorter media life for short- chain PFAS (e.g. PFMOAA, PFO2HxA)
- Good for DBP precursors
- Not effective for 1,4-dioxane; requires AOP
- Not effective for PPCPs; requires GAC

Ozone-Biofiltration
- Partial removal of 1,4 Dioxane
- Good removal of DBP precursors and PPCPs
- Not effective for most PFAS

Ultraviolet-Advanced Oxidation Process (UV-AOP)
- Can oxidize 1,4 Dioxane
- Good removal for DBP precursors and PPCPs
- Not effective for most PFAS

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DATA FROM BRUNSWICK COUNTY PILOT SHOWING RO PROVIDES THE BEST REMOVAL OF PFAS COMPOUNDS

Parameter	Filtered Water Concentration	RO Treated Water	Calculated Removal %
Gen X	7 – 12 ng/L	ND	--
Nafion Byproduct 1 & 2	ND	ND	--
PFMOAA	320 – 750 ng/L	ND – 11 ng/L	98%+
PFO2HxA	12 – 26 ng/L	ND	--
PFHxA	19 – 20 ng/L	ND	--
PFPeA	16 - 17 ng/L	ND	
PFOS + PFOA	26 ng/L	ND	--
Sum (45) of PFAS Tested	423 – 892 ng/L	ND – 11 ng/L	--

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LPRO PILOT – EXAMPLE TEST RESULTS

Parameter	Filtered Water Concentration	RO Treated Water	Calculated Removal %
1,4-Dioxane (industrial chemical)	3.2 µg/L	0.2 µg/L	94%
Carbamazepine (seizure medicine)	13 ng/L	ND	--
Atrazine (herbicide)	58 ng/L	ND	--
Cotinine (metabolite of nicotine)	15 ng/L	ND	--
DEET (insect repellant)	44 ng/L	ND	--
Simazine (herbicide)	57 ng/L	ND	--
Tris (1,3 dichloro-2-propyl)phosphate (pesticide, flame retardant)	120 ng/L	ND	--

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ECONOMIC COMPARISON OF ADVANCED TREATMENT OPTIONS FOR NORTHWEST WTP

	Low Pressure Reverse Osmosis (LPRO)	Ozone/O3 BAF – GAC	GAC/IX/UV-AOP
Total Capital Costs	$ 99 M	$ 99 M	$ 84 M
25-yr Present Worth of Annual Costs	$ 59 M	$ 95 M	$ 93 M
Total 25-yr NPW (Capital + Annual O&M)	$ 158 M	$ 194 M	$ 177 M

Capital and O&M costs based on removal of >90% of each target contaminant

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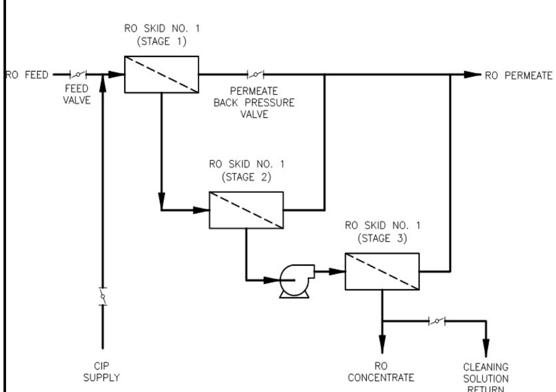
BRUNSWICK COUNTY 41-MGD LPRO 3 STAGE FOR 90% RECOVERY AT 14.1 GFD



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BRUNSWICK COUNTY 41-MGD LPRO FACILITY TO REMOVE PFAS – NOW UNDER CONSTRUCTION

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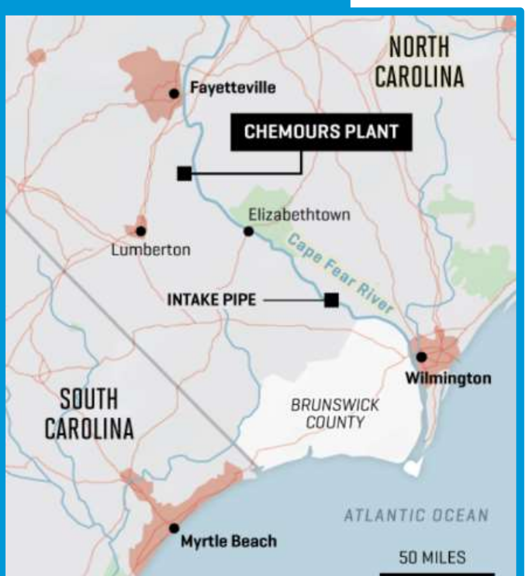

PRESENTATION AGENDA

1 Background

2 Treatment and Case Studies

3 Conclusions

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CONCLUSIONS

- Site-specific pilot testing showed that GAC and IX were spent relatively quickly when removing GenX and some other short-chain PFAS compounds.
- RO has the lowest life-cycle cost for Brunswick County's NWTP and provides the most protection against PFAS and secondary target compounds.
- RO was selected for NWTP, has been designed, bid and is now under construction for 41 mgd
- The estimated construction cost was approximately $72 million for 41 mgd of RO

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DESTRUCTIVE ELECTROCHEMICAL OXIDATION OF PFAS USING A NOVEL REACTIVE ELECTROCHEMICAL MEMBRANE TECHNOLOGY

UIC

Brian P. Chaplin, Ph.D.
Associate Professor
University of Illinois at Chicago

Co-founder, Zyvant Research and Innovations

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AGENDA

- Problem statement
- Technology description: Reactive Electrochemical Membrane (REM)
- Technical objectives
- Electrochemical oxidation results
- Conclusions
- Benefits to Water Community

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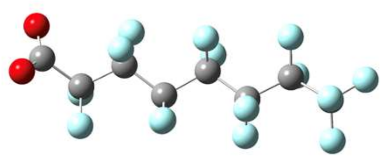
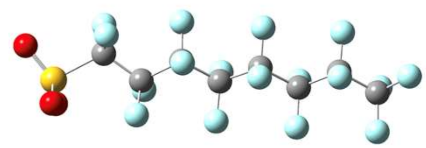
PROBLEM STATEMENT

- Per- and polyfluoroalkyl substances (PFAS) are toxic at low levels
  - EPA has set health advisory levels (< 70 ng/L)
  - States have set lower limits
- PFAS are ubiquitous in the environment
  - Contamination from aqueous film forming foams (AFFF)
  - Contained in various consumer products
- Resistant to traditional treatment processes

Perfluorooctanoic acid (PFOA)



Perfluorooctanesulfonic acid (PFOS)



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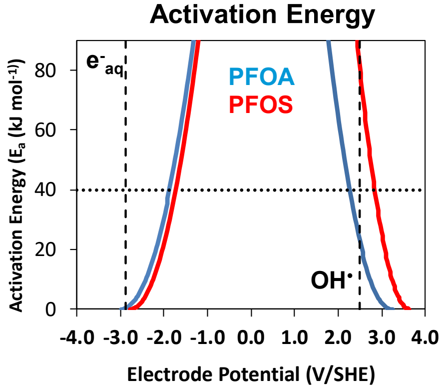
TECHNOLOGY DESCRIPTION

Direct Oxidation/Reduction of PFAS (Estimated by DFT Calculations)

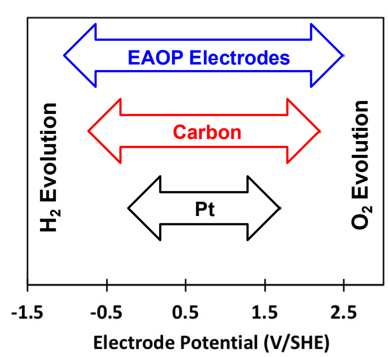
$PFOS + e^- \rightarrow PFOS^-$ $E^o = 3.25$
$PFOS^- + e^- \rightarrow PFOS^{2-}$ $E^o = -2.13$

$PFOA + e^- \rightarrow PFOA^-$ $E^o = 2.65$
$PFOA^- + e^- \rightarrow PFOA^{2-}$ $E^o = -2.25$

Activation Energy



Potential Window



***Notes**: DFT = density functional theory; V/SHE = volts vs. standard hydrogen electrode*

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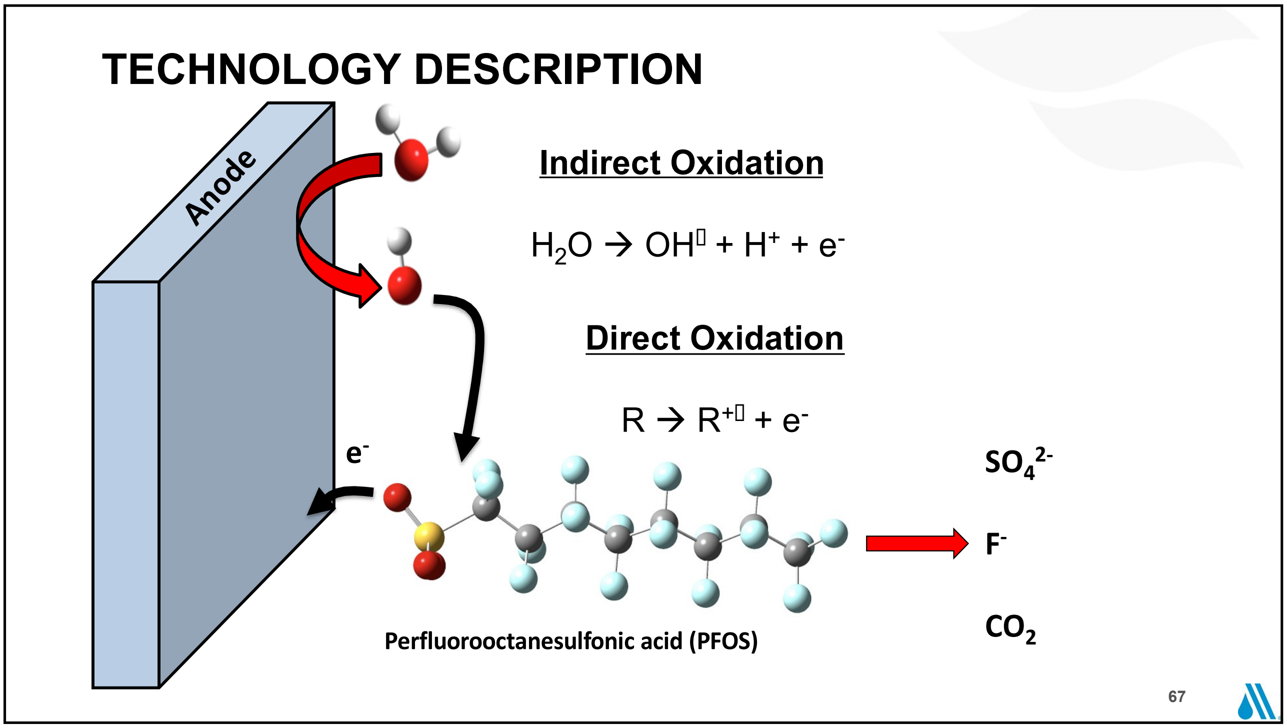
TECHNOLOGY DESCRIPTION
Anode
Indirect Oxidation
$H_2O \rightarrow OH^{\bullet} + H^+ + e^-$
Direct Oxidation
$R \rightarrow R^{+\bullet} + e^-$
e^-
SO_4^{2-}
F^-
CO_2
Perfluorooctanesulfonic acid (PFOS)
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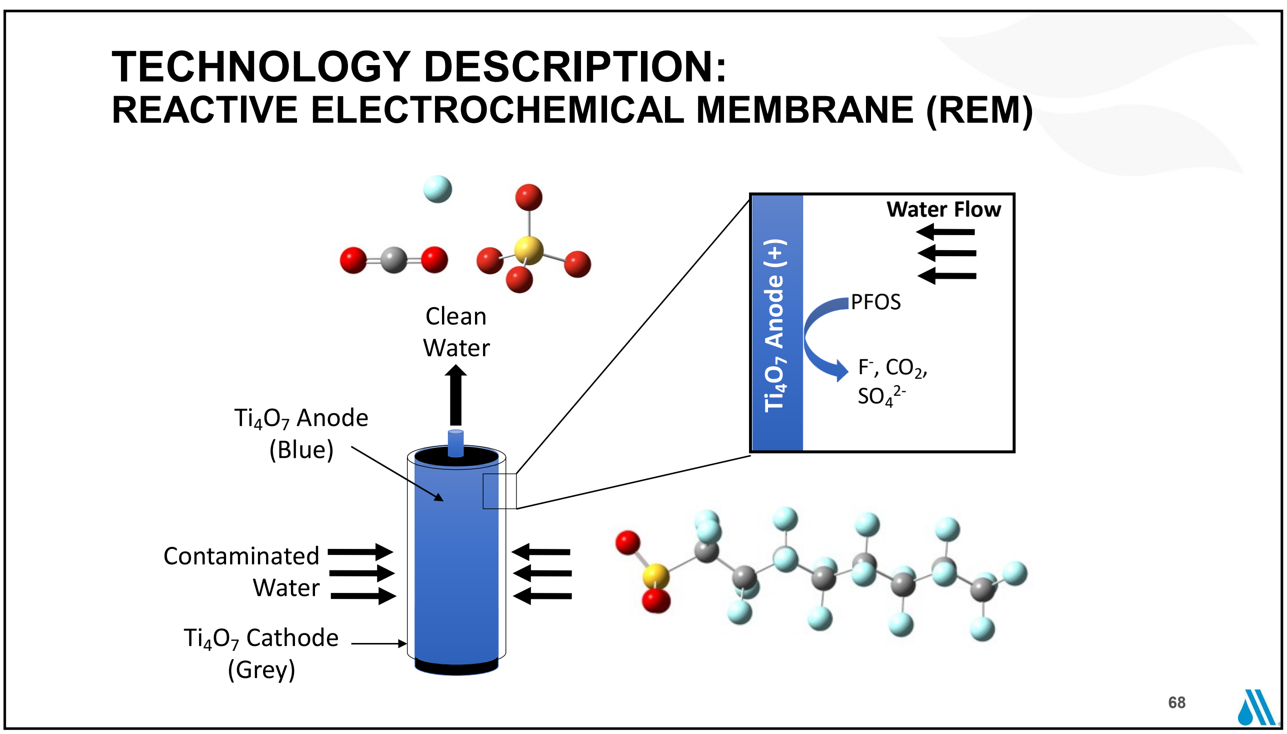
TECHNOLOGY DESCRIPTION:
REACTIVE ELECTROCHEMICAL MEMBRANE (REM)
Clean Water
Ti_4O_7 Anode (Blue)
Contaminated Water
Ti_4O_7 Cathode (Grey)
Ti_4O_7 Anode (+)
Water Flow
PFOS
F^-, CO_2, SO_4^{2-}
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TECHNICAL OBJECTIVES

- Specific technical objectives:
  - Development of REMs for destructive PFAS removal to < 70 ng/L
  - Determination of the optimal operational mode
  - Calculation of energy requirements for the REM-based system

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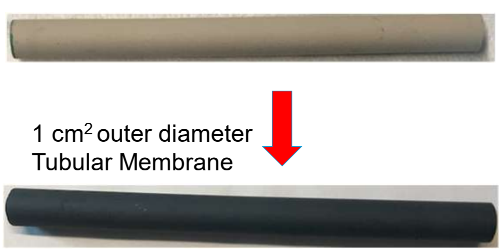
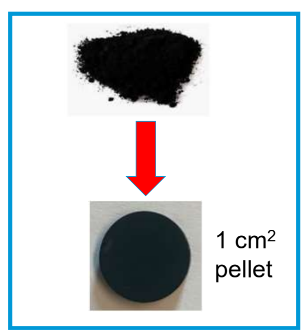
RESULTS: REM SYNTHESIS

- Reduction of non-conductive TiO_2 to conductive Ti_4O_7
- Fabrication of tubular and disk REMs





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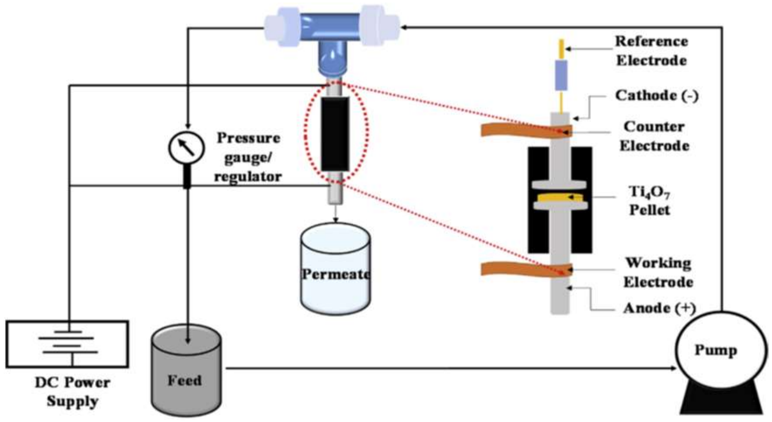
RESULTS:
REM REACTOR *SCHEMATIC OF THE FLOW-THROUGH REACTOR*



Variables to test
- Potential
- Flow rate
- Operational mode (single-pass vs. recycle)

S. Nayak, B.P. Chaplin / Electrochimica Acta 263 (2018) 299–310

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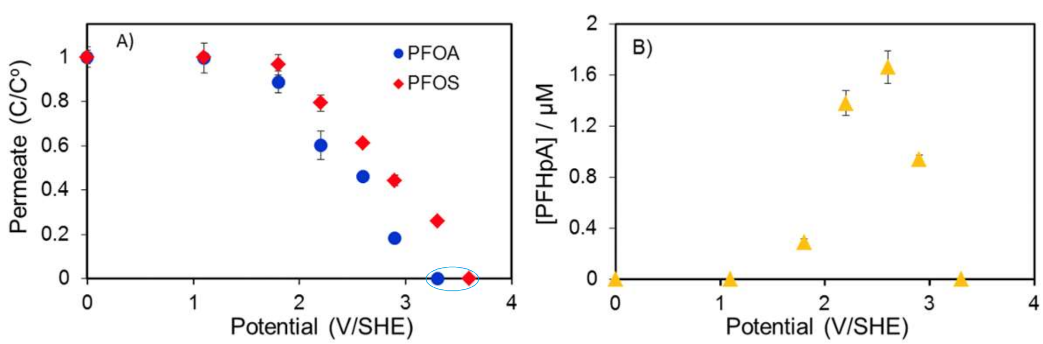
RESULTS: EFFECT OF POTENTIAL

PFOA/PFOS in Synthetic Solutions
(10 μM PFAS, 100 mM K_2HPO_4, pH ~ 7, flux = 240 LMH [(liters/m^2/hour)])



PFOA < 86 ng/L @ 3.3 V/SHE

PFOS < 35 ng/L @ 3.6 V/SHE

PFHpA primary detected product of PFOA oxidation

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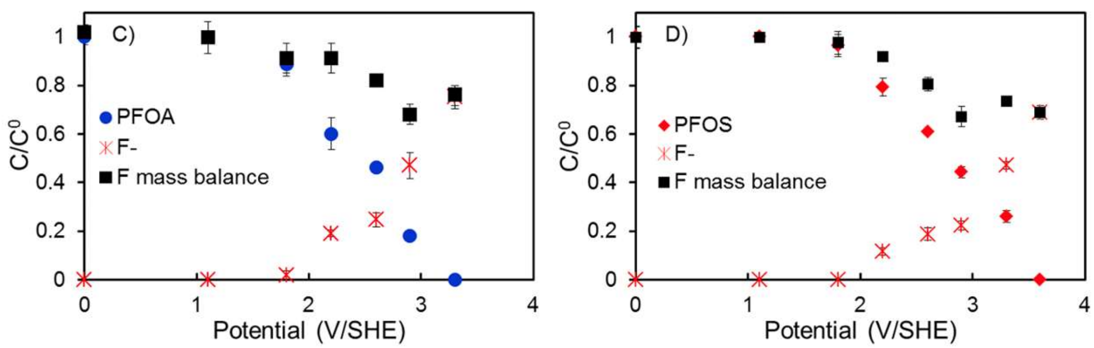
RESULTS: EFFECT OF POTENTIAL

PFOA/PFOS in Synthetic Solutions
(10 μM PFAS, 100 mM K_2HPO_4, pH ~ 7, flux = 240 LMH [(liters/m²/hour)])



F-mass balances: (67-98%)

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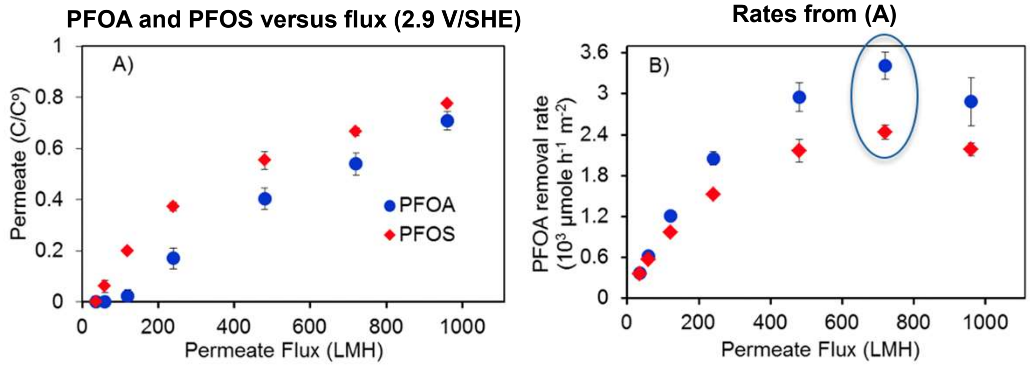
RESULTS: EFFECT OF FLUX

PFOA/PFOS in Synthetic Solutions
(10 μM PFAS, 100 mM K_2HPO_4, pH ~ 7)

PFOA and PFOS versus flux (2.9 V/SHE) **Rates from (A)**



- PFOA and PFOS < detection limits at 36 LMH (86 and 35 ng/L)
- ~ 5-log removal with residence time (t_r = 75 s)
- Maximum rate observed at 720 LMH (t_r = 3.8 s)
- Rate constants (k = 210 and 607 h^{-1})

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RESULTS: GROUNDWATER SAMPLES

General water quality analyses for groundwater samples

Constituent	GW1 mg/L	GW2 mg/L
F^-	1.06	15.7
Cl^-	51.5	27.1
NO_3^-	8.18	< 0.1
SO_4^{2-}	10.8	< 0.1
HPO_4^{2-}	7.78	< 0.1
HCO_3^-	228	87.7
Na^+	72.6	25.3
K^+	13.7	30.1
Ca^{2+}	25.7	34.5
Mg^{2+}	21.4	8.75
pH	6.8	6.5
Conductivity (µS/cm)	788	337
COD (mg/L)	**43.3**	4.35
Alkalinity (mg/L $CaCO_3$)	373	144

- Groundwater 1 (GW1)
  - Geosyntec client in Jacksonville, FL
  - Generally PFAS free
  - Spiked with 1.0-2.5 µM of PFAS: (PFNA, PFOS, PFOA, PFHxS, PFHpA, PFBS)
- Groundwater 2 (GW2)
  - Willow Grove Naval Base in collaboration with Jason Speicher
  - µg/L levels of PFAS: (PFNA, PFOS, PFOA, PFHxS, PFBS)

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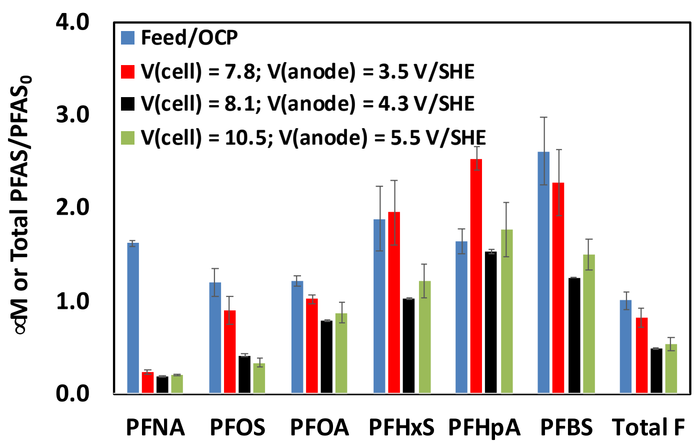
RESULTS: GW1 OXIDATION

Low flux: J = 60 LMH; t_r = 45 s



- Shorter chain PFAS formed
- ~50% total PFAS removal
- Moderately high energy consumption: E_{EO} = 13.2 - 23.8 kWh/m^3
- **High COD content: 43 mg/L (competition)**

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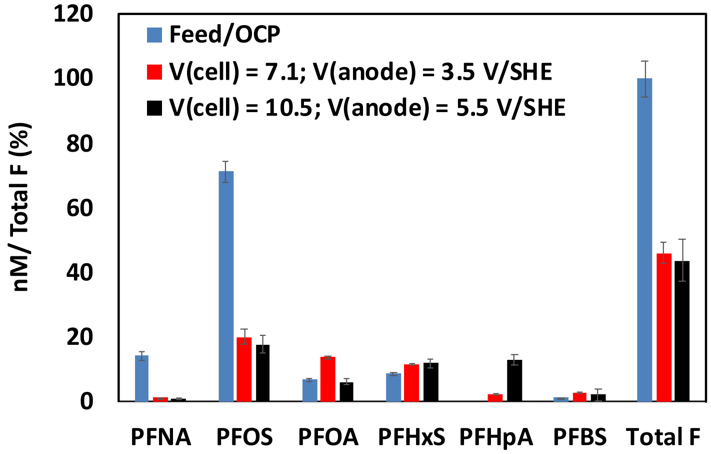
RESULTS: GW2 OXIDATION

Low flux: J = 60 LMH; t_r = 45 s



- Shorter chain PFAS formed
- ~50% total PFAS removal
- Lower energy consumption: E_{EO} (per log removal) = 11 - 15 kWh/m^3
- **Low COD content: 4.4 mg/L** (less competitive reactions than GW1)

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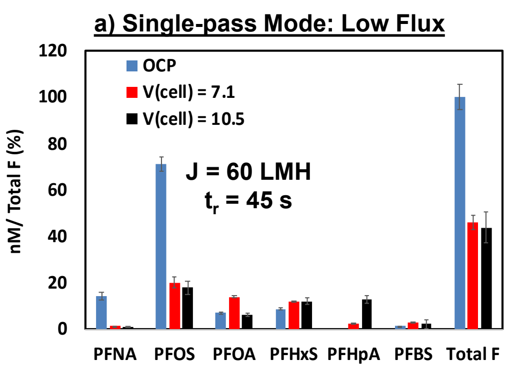
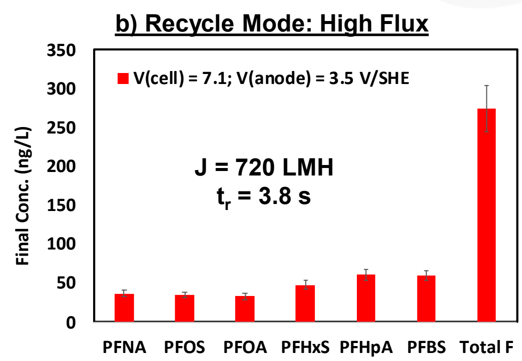
RESULTS: OPERATIONAL MODE
SINGLE PASS VS. RECYCLE MODE (GW2)



- Total PFAS destruction ~ 50%
- Final individual [PFAS] at nM (μg/L) levels
- E_{EO} (per log removal) = 11-15 kWh/m^3



- Total PFAS destruction > 99%
- Individual [PFAS] < 61 ng/L
- E_{EO} (per log removal) = 2.9 kWh/m^3

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RESULTS: ENERGY CALCULATIONS

Energy consumption (E, kWh m⁻³) per log removal: $E_{EO} = 10^{-3} \times \frac{V_{cell} I}{Q \log\left[\frac{C_f}{C_p}\right]}$

Solution	V (Cell)	E_{EO} (kWh m^{-3})	Operational Mode
PFOA	6.0	5.1	Single pass
PFOS	6.1	6.7	Single pass
GW1	7.8-10.5	13-24	Single pass
GW2	7.1-10.5	11-15	Single pass
GW2	**7.1**	**2.9**	**Recycle**

- Low E_{EO} values for electrochemical oxidation
- Order of magnitude lower than most other destructive technologies

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CONCLUSIONS

- PFOA/PFOS oxidized from mg/L to ng/L levels in single-pass mode
- Organic composition of GW samples made single-pass mode less efficient
- Recycle mode (high flux) removed PFAS by 99% and final individual concentrations were < 61 ng/L
- Energy consumption for groundwater treatment
  - E_{EO} = 2.9 kWh m^{-3}
- Rate constants
  - k = 210 and 607 h^{-1}

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BENEFITS TO WATER COMMUNITY

- Understanding of the capabilities of using electrochemical technologies for water treatment
- Low energy, destructive technology for PFAS remediation
- Next step
  - Field-scale prototype REM for remediation of PFAS-contaminated waste streams (e.g., groundwater, domestic/industrial wastewaters)

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ACKNOWLEDGEMENTS

- Amish Shah and Holly Haflich (Purdue University)
- Huong Le (now at Faraday Technologies)
- Funding from SERDP (ER18-1491)

Speaker Contact Information

chaplin@uic.edu; 312-996-0288

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EMERGING TECHNOLOGIES FOR PFAS TREATMENT: FOAM FRACTIONATION & ELECTROCHEMICAL OXIDATION

AWWA Webinar
"Current and Emerging Technologies for PFAS Treatment and Lessons Learned Webinar"
June 24, 2020

Kent S. Sorenson, Jr., PhD, PE
Sr. Vice President
CDM Smith

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WHAT WILL YOU LEARN?

Opportunities for improved separation and concentration technologies

Principles of surface active foam fractionation for water treatment

Potential for complete on-site treatment and destruction of PFAS

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AGENDA

- Addressing limitations of conventional PFAS treatment
- Overview of foam fractionation
- Potential for "closed loop" process

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CONVENTIONAL PFAS TREATMENT CONSIDERATIONS/ LIMITATIONS

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KEY CONSIDERATIONS FOR PFAS WATER TREATMENT

General Considerations

- Influent composition and concentrations
- Co-contaminants and competitive species
- Pre-treatment needs
- Discharge criteria
- Media change-out criteria

Specific Considerations for PFAS

- Potential precursor transformation
- Generation, monitoring and management of PFAS containing waste streams (e.g., sludge, PFAS concentrates, PFAS-laden spent media, biosolids)
- In-situ remediation processes that can change PFAS transport and transformation

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LIMITATIONS OF "CONVENTIONAL" TREATMENT FOR PFAS

- High volume of spent media or waste stream requiring waste management
- Significant pretreatment often required to remove competing solutes
- High concentrations of PFAS can lead to inefficient removal of target compounds
- Overall high costs for removing small mass of contamination (down to trace ppt levels)

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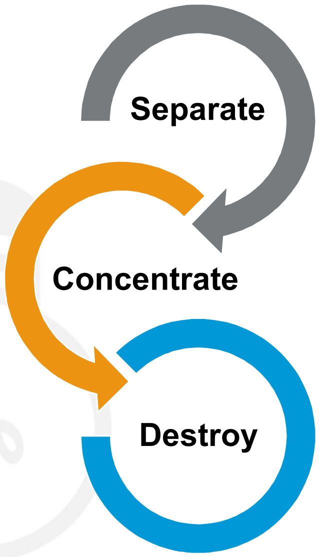
COMPREHENSIVE PFAS TREATMENT SOLUTION



Treatment Goals	Example Treatments
• Protect human health and the environment • Meet safe drinking water and discharge requirements	• GAC, AIX, RO (demonstrated) • NF • Surfactant or coagulant separation • Foam Fractionation
• Reduce waste stream volume	• Regenerable media → regenerant waste • Surfactant or coagulant separation → PFAS laden flocs • Foam fractionation → foam concentrate
• Zero PFAS waste discharge	• High temp thermal, electrochemical, plasma, sonolysis

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SURFACE ACTIVE FOAM FRACTIONATION

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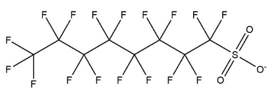
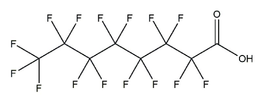
HOW FOAM FRACTIONATION WORKS

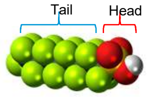
- Molecular structure creates affinity for air-water interfaces
- PFAS separated from water as bubbles
- Foam captured for further concentration

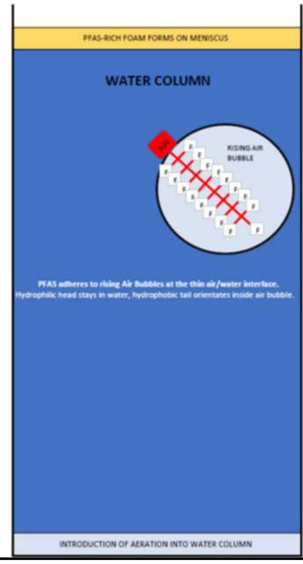


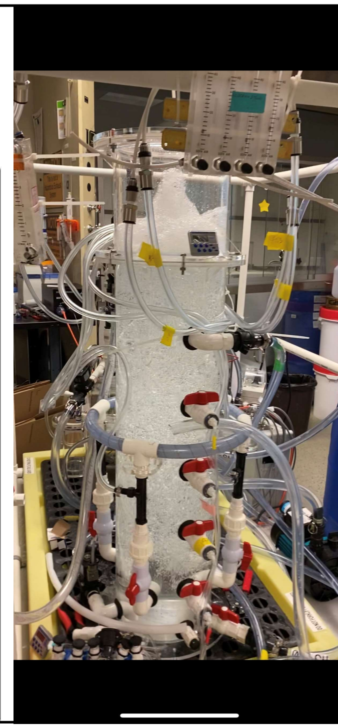
Perfluorooctane sulfonate (PFOS)



Perfluorooctanoic acid (PFOA)







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Oakey Results

SAFF™ + AIX
Commissioned 19th May 2019

- 20 ML Treated
- 500L PFAS Waste Concentrate
- CF 42,000x, (CF 442,000x tested)
- New CF 1-10Mx in-development

SAFF™ + AIX

- Contract <0.07µg/l
- Aust. DoD website reporting <0.01µg/l

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Performance Data: Rates of Removal

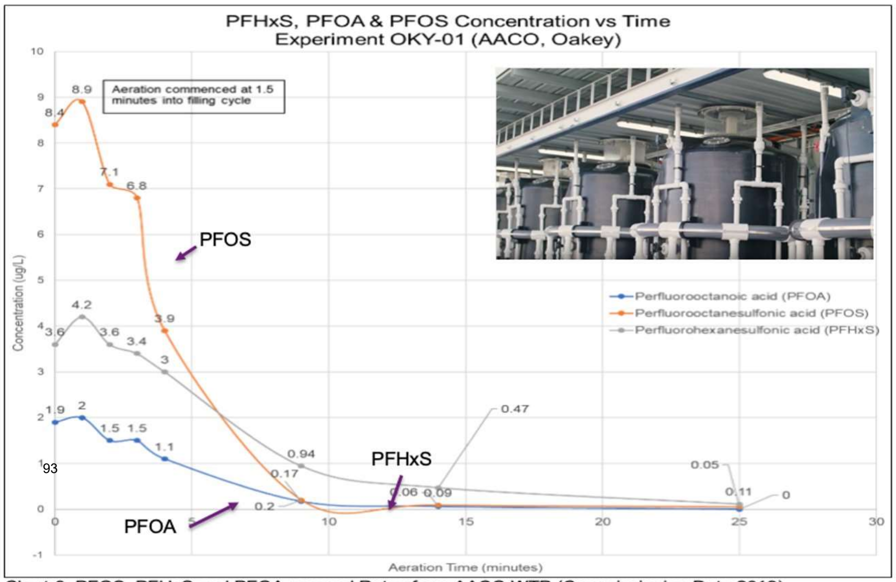

Chart-3: PFOS, PFHxS and PFOA removal Rates from AACO WTP (Commissioning Data 2019).

KEY POINTS

(1) Robust, Proven & Rapid
(2) PFOS: 3-4 mins
(3) PFOA: 3-4 mins
(4) PFHxS: 10-12

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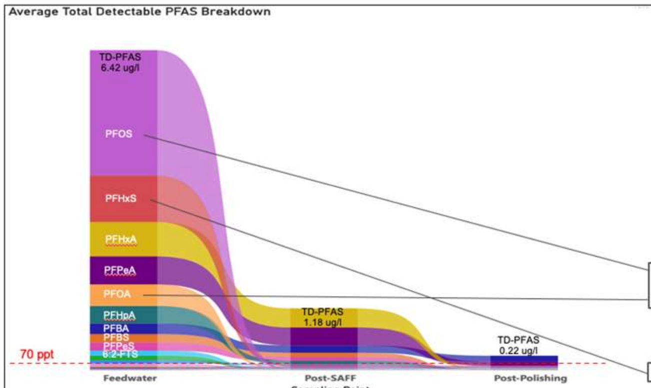
Monitoring 30+ PFAS Compounds

PFAS Ribbon Graph: AACO's 3M Lightwater Signature

Average Total Detectable PFAS Breakdown



SAFF Removes 81.7% of Bulk PFAS from GW's Impacted with 3M Lightwater AFFF prior to AIX Polishing

Reportable	Feedwater	Post-SAFF	Post-Polishing
PFTeDA (µg/L)	< 0.001	< 0.001	< 0.001
PFTrDA (µg/L)	< 0.001	< 0.001	< 0.001
PFDoDA (µg/L)	< 0.001	< 0.001	< 0.001
EtFOSE (µg/L)	< 0.005	< 0.005	< 0.005
EtFOSAA (µg/L)	< 0.005	< 0.005	< 0.005
10:2 FTS (µg/L)	< 0.010	< 0.010	< 0.010
PFUnDA (µg/L)	< 0.001	< 0.001	< 0.001
MeFOSAA (µg/L)	< 0.005	< 0.005	< 0.005
PFDS (µg/L)	< 0.001	< 0.001	< 0.001
PFDA (µg/L)	0.003	< 0.001	< 0.001
EtFOSA (µg/L)	< 0.005	< 0.005	< 0.005
8:2 FTS (µg/L)	0.022	< 0.010	< 0.010
PFNS (µg/L)	0.014	< 0.001	< 0.001
PFNA (µg/L)	0.044	< 0.001	< 0.001
MeFOSA (µg/L)	< 0.005	< 0.005	< 0.005
PFOS (µg/L)	2.539	0.002	0.002
PFOA (µg/L)	0.435	0.003	0.002
FOSA (µg/L)	< 0.005	< 0.005	< 0.005
6:2 FTS (µg/L)	0.100	< 0.005	< 0.005
PFHpS (µg/L)	0.097	0.002	0.002
PFHpA (µg/L)	0.355	0.071	0.002
PFHxS (µg/L)	0.939	0.020	0.002
PFHxA (µg/L)	0.697	0.386	0.004
4:2 FTS (µg/L)	< 0.010	< 0.010	< 0.010
PFPeS (µg/L)	0.162	0.074	0.002
PFPeA (µg/L)	0.565	0.363	0.077
PFBS (µg/L)	0.173	0.087	0.002
PFBA (µg/L)	0.215	0.147	0.124
PFPrS (µg/L)	0.060	0.021	< 0.001

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Key Points:
- SAFF removes PFOS/PFOA completely
- Very effective for C6 and greater
- Less effective for shorter chains (polish might be required)
- Very low operating cost

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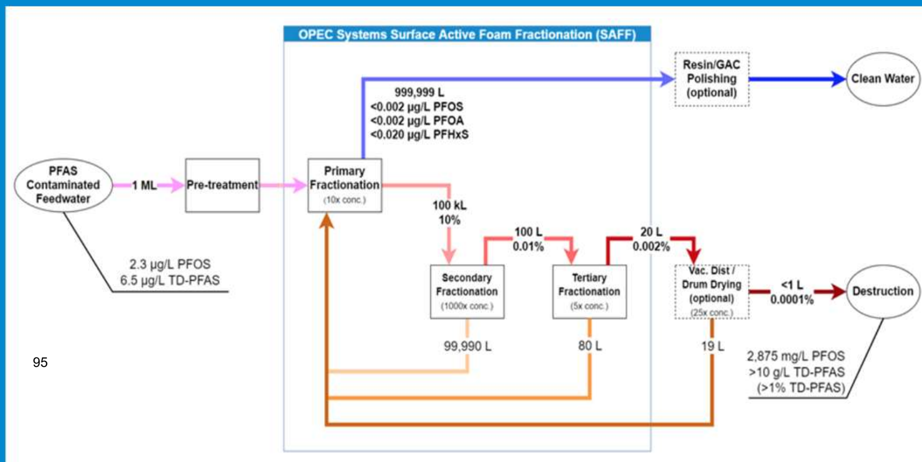
CONCENTRATION FACTORS

Triple SAFF™ Process



KEY POINTS

(1) Primary stage achieves discharge criteria.

(2) Secondary & Tertiary stages minimize waste volumes

(3) PFAS Waste 0.001% (+1% Concentrate)

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CLOSED LOOP TREATMENT?

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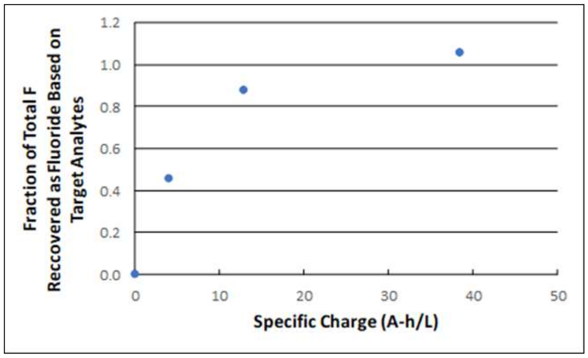
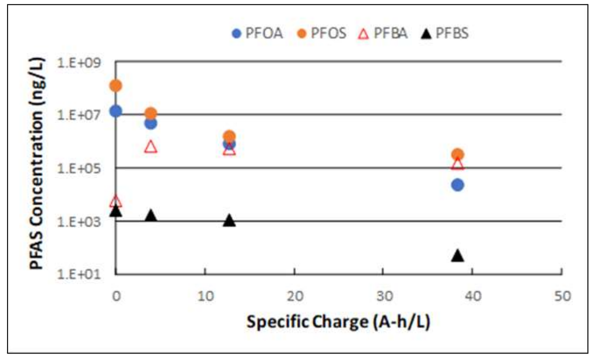
ELECTROCHEMICAL TREATMENT OF SAFF HYPER-CONCENTRATE





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Current density of 40 mA/cm2 for 24 hr reaction time

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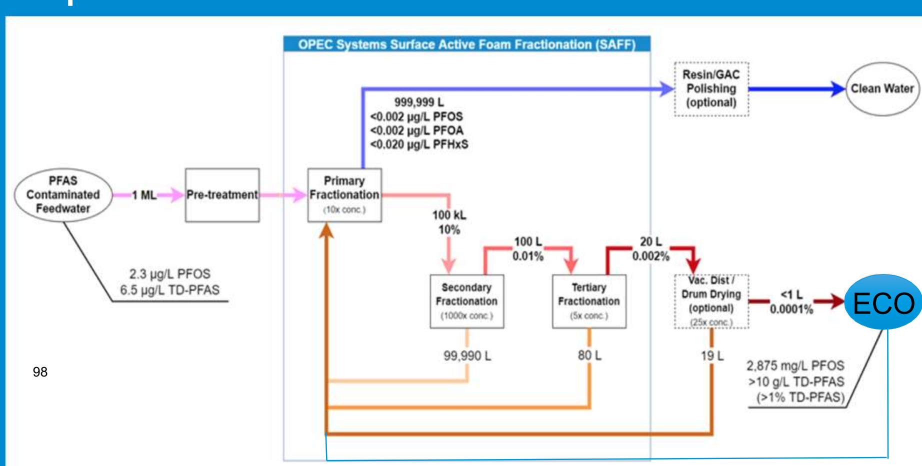
THE BREAKTHROUGH – POTENTIAL FOR CLOSED LOOP TREATMENT

Triple SAFF™ Process + ECO



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KEY POINTS

(1) Primary stage achieves discharge criteria.

(2) Secondary & Tertiary stages minimize waste volumes

(3) PFAS Waste 0.001% (+1% Concentrate)

(4) ECO destroys 99 – 99.9% of PFAS, recycles remainder to Primary stage

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SUMMARY

- SAFF is not DAF
- How SAFF & ECO works:
  - Separation via primary fractionation
  - Concentration via 2^{nd} and 3^{rd} fractionation
  - On-site destruction (ECO)
- Benefits:
  - No chemical addition
  - Low CAPEX & OPEX
  - Little to no waste
  - Lowest $/g PFAS removed

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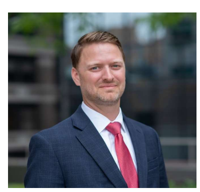
Ask the Experts

Mark Wetzel
Town of Ayer, Massachusetts

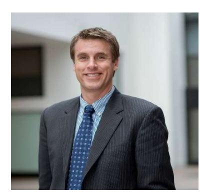
Ji Im
CDM Smith

William Dowbiggin
CDM Smith



Barton Reed
CDM Smith

Brian Chaplin
The University of Illinois at Chicago



Kent Sorenson
CDM Smith

Enter your **question** into the **question pane** at the lower right-hand side of the screen.

Please specify to whom you are addressing the question.

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- **June 30**
- **FREE Webinar from Hach: Log Reduction For Drinking Water Production: What's In It For You?**
- **11:00 AM - 12:00 PM (Mountain)**

- **July 22**
- **PFAS: Messaging, Managing Risk, and Testing for Unregulated Compounds**
- **11:00 AM - 12:30 PM (Mountain)**

- **July 23**
- **Succession Planning: Lessons Learned from a Global Pandemic**
- **11:00 AM - 12:30 PM (Mountain)**

View the full 2020 schedule at awwa.org/webinars

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Thank you for Joining Today's Webinar

- As part of your registration, you are entitled to an additional 30-day archive access of today's program.

- Until next time, keep the water safe and secure.

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Presenter Biography Information

- Mark Wetzel is the Superintendent of Public Works for the Town of Ayer, Massachusetts, responsible for water, wastewater, stormwater, road maintenance, snow plowing, and solid waste. Prior to Ayer, Mark was a consulting engineer specializing in municipal water supply and treatment, working on projects throughout New England. Mark has a BSCE from the University of Vermont and is a registered Professional Engineer, Certified Professional in Storm Water Quality, Certified Drinking Water Operator, Certified Wastewater Treatment Operator and member of MWWA, NEWWA, NEWEA and APWA. He is chairman of the New England Water Works Association Information Technology Committee and has presented multiple papers on water supply and treatment, including, most recently, PFAS contamination and treatment.
- Ms. Ji Im is an environmental engineer who specializes in drinking water treatment projects for municipal clients at CDM Smith and has worked on a number of PFAS treatment studies, design and construction projects throughout the northeast. Her work is in the design of new water treatment facilities, existing plant upgrades, and studies for master planning, treatment evaluations, regulatory review, and water quality analyses. She is an active volunteer for AWWA, presently serving as the Vice Chair of the AWWA's National Young Professionals Committee and as a member of AWWA's Technical and Education Council and the New England section's Program Committee.
- Drinking water expert Bill Dowbiggin has designed more than 60 major water treatment plants, including 12 completely new greenfield plants. As a well-known leader of the water industry, he can often be found making presentations at major conferences, teaching designers and operators, and carrying out bench and pilot-scale research studies. Bill has been awarded multiple honors from the American Water Works Association (AWWA) and the American Council of Engineering Companies (ACEC), ranging from winning the Best Masters Thesis from AWWA in 1987 to his work on numerous Excellence Award winners from ACEC in recent years to a 2013 George Warren Fuller Award from AWWA for distinguished service to the water supply field.
- Reed Barton is an Associate and environmental engineer with CDM Smith. He has 15 years of experience focused on the planning, design, and construction of water treatment and conveyance infrastructure. Reed obtained a BS in Integrated Science from James Madison University and a MS in Environmental Engineering from Virginia Tech and is a licensed professional engineer in multiple states. Reed's expertise includes addressing emerging contaminants in public drinking water systems, and in recent years he has assisted a number of public water systems with addressing PFAS contamination in their drinking water. This work has included pilot studies to evaluate the performance of GAC, Ion Exchange, Membranes, Ultraviolet Advanced Oxidation, and Foam Fractionation for the removal of PFAS. He served on the leadership team for the planning and design of the 48-mgd expansion of the Northwest Water Treatment Plant in Brunswick County, North Carolina; which includes a new 41-MGD Reverse Osmosis (RO) treatment facility to remove high levels of PFAS compounds. When construction is completed, the Northwest WTP membrane facility will be the largest membrane application for advanced PFAS removal and the third largest RO membrane facility in the U.S.
- Dr. Brian Chaplin, associate professor at the University of Illinois at Chicago and co-founder of Zyvant Research & Innovations, has done researches on advanced oxidation and breaking PFAS compounds. He has co-authored tens of influential publications on developing sustainable technologies for water treatment, catalytic and electrochemical treatment for water reuse, electrochemical disinfection, which have been cited more than a thousand times by other researchers in the field.
- Dr. Kent Sorenson, senior vice president and nationally recognized groundwater remediation expert, oversees the development and demonstration of innovative site characterization and remediation technologies in the U.S., Europe, and Asia. As a senior technical reviewer for more than 100 government, private and international sites, Kent oversees design and construction operations and works to implement cutting-edge, cost-effective solutions for the client's most challenging problems. Kent currently holds six U.S. patents and has co-authored over 40 scientific publications related to remediation of soil and groundwater.

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