NC STATE UNIVERSITY
Subaward Number: 2019-0386-03

[X] New
[ ] Modification No.

Cost Reimbursement Subaward Notice (SN)

SUBRECIPIENT	NC STATE UNIVERSITY
1. **City of Ann Arbor** Public Services Administration Water Treatment Plant 919 Sunset Road Ann Arbor, Michigan 48103-2924 (See Page 2 for Contact Information.)	2. **NC STATE UNIVERSITY** Sponsored Programs & Regulatory Compliance Services Campus Box 7514, Administrative Services III 2701 Sullivan Drive, Suite 240 Raleigh, NC 27695-7514 (See Page 2 for Contact Information.)
3. **Proposal/Project Title:** Investigation of Treatment Alternatives for Short-Chain Poly- and Perfluoroalkyl Substances	4. **Source of Funding**: Prime Sponsor: Water Research Foundation Prime Agreement Number: 4913 CFDA Number: N/A NCSU Project Title: Investigation of Treatment Alternatives for Short-Chain Poly- and Perfluoroalkyl Substances (See Block 16, Appendix C)
5. **Description/Purpose of This Action**: To issue a new subaward with cost share.	
6. **Special Terms and Conditions**:	7. **Funding Information / Period of Performance**:
• Technical Reporting Frequency: Quarterly and as requested by the NC State PI. • Final Report Due: 5/15/2021 so that NC State may meet its reporting deadline of 7/1/2021. • Invoicing Frequency: Monthly • Final Invoice Due: 5/15/2021 so that NC State may meet its invoicing deadline of 7/1/2021.	a. Amount Funded This Action: **$35,000** b. Amount Prior Funding: $0 c. Total Sponsored Funds To Date: **$35,000** d. Cost-sharing Added with This Action: $24,500 e. Total Cost Sharing Required To Date: $24,500 f. Start Date: 3/1/2019
☐ Special T&C Continued in Block 17, page 2	g. End Date: 3/1/2022
Each signatory below certifies that they are authorized to execute legally binding commitments on behalf of their named party.	
For: **SUBRECIPIENT** Signature: _____ Name & Title: Date: _____ **TIN/EIN**: **DUNS**: 004913166	For: **NC STATE UNIVERSITY** Signature: Stefanie D. Saunders Stefanie D. Saunders Associate Director, Operations NCSU Sponsored Programs Name & Title: Date: 4/10/19 **TIN/EIN**: 56-6000756 **DUNS**: 042092122

NC STATE UNIVERSITY [X] **New**
Subaward Number: 2019-0386-03 [ ] **Modification No.**

(Subaward Notice Continued) Contact Information
The parties agree that pen and ink entries to correct or update the information in Blocks 10-15 are not "changes" requiring initials.

SUBRECIPIENT	NC STATE UNIVERSITY
8. **Principal Investigator**: Name: Brian Steglitz Phone: 734-794-6426 ext. 43905 Fax: Email: bsteglitz@a2gov.org	9. **Project Director**: Name: Detlef Knappe Phone: 919-515-8791 Fax: 919-515-7908 Email: knappe@ncsu.edu
10. **Negotiator / Administrator**: Name: Brian Steglitz Phone: 734-794-6426 ext. 43905 Fax: Email: bsteglitz@a2gov.org Address: Same as Block 1	11. **Negotiator / Administrator**: Name: Anne Lesky Phone: 919-515-2444 Fax: 919-515-7721 Email: anne_lesky@ncsu.edu (alt. sps@ncsu.edu) Address: NC State University Sponsored Programs & Regulatory Compliance Services, Admin. Services III, Campus Box 7514, 2701 Sullivan Drive, Suite 240 Raleigh, NC 27695-7514
12. **Reserved.**	13. **Fiscal Officer**: Name: Pat Hayes Phone: 919-515-7009 Fax: 919-515-7951 Email: phayes@ncsu.edu Address: NC State University College of Engineering Campus Box 7901 Raleigh, NC 27695
14. **Reserved.**	15. **Send Invoices To**: Name: Millie Gilmartin Address: NC State University 2501 Stinson Drive Campus Box 7908 Raleigh, NC 27695 Phone: 919-515-0728 Email: magilmar@ncsu.edu
16. **Incorporation**: The documents checked are incorporated into this subaward as noted: ☒ Appendix A: SUBRECIPIENT's Proposal and or Statement of Work including the approved budget. ☒ Appendix B: NC State University Standard CR Subaward Terms and Conditions, 08-16. ☒ Appendix C: Funding Source Prime Agreement. ☐ Other:	
17. Special Terms & Conditions from # 6, may be continued here:	

APPENDIX A

CITY OF ANN ARBOR
PUBLIC SERVICES ADMINISTRATION

June 18, 2018

Detlef Knappe
Professor
Department of Civil, Construction, and Environmental Engineering
North Carolina State University
Campus Box 7908
Raleigh, NC 27695-7908

Re: Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances (RFP #4913)

Dear Professor Knappe,

The City of Ann Arbor is pleased to support your proposal in response to The Water Research Foundation's RFP 4913 entitled " Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances."

The City of Ann Arbor is interested in furthering the research in developing and optimizing treatment technologies for both short and long-chain PFAS. The City has detected low levels of these substances in both its raw and finished water and remains interested in developing solutions that will improve the City's finished water quality as well as help to guide utilities faced with similar water quality concerns. Participation in this project with this outstanding team, under your direction, would be an honor for the City of Ann Arbor. We anticipate that your proposed research on treatment options, such as activated carbon adsorption, anion exchange, and membrane treatment will result in much needed information to effectively design removal processes for PFAS.

In addition to offering access to a staff with decades of applied water treatment knowledge and skills, the City will offer use of both full scale and pilot scale filtration processes during this project. The City operates 26 mixed media filters, several of which could be used to assess different granular activated carbon products. At the pilot scale, the City has six pilot filter columns that can be used to test different operating scenarios as wells as different media, including granular activated carbon, anion exchange resins, and innovative sorbents that show promise in bench-scale experiments. Use of both pilot and full scale filtration infrastructure will allow principles developed at the bench scale to be vetted at a working on-line, water treatment plant. This opportunity will help ensure that recommendations developed through this research can be both applied and scaled to plant production level.

Water Treatment Plant, 919 Sunset Road, Ann Arbor, Michigan 48103-2924
(734) 994-2840 • Fax (734) 994-0151
http://www.a2gov.org

CITY OF ANN ARBOR
PUBLIC SERVICES ADMINISTRATION

We are also supportive of your efforts to develop structure-property relationships that will permit removal predictions of PFASs that are yet to be discovered. Also, we welcome your idea to integrate the data developed in the research effort proposed here into your ongoing efforts to develop life cycle assessment and costing models for PFAS removal technologies.

We estimate the value of support at $25,000 as in-kind contributions in the way of staff time, communication, pilot testing and equipment, and access to reports and data as needed. We also will be participating as a project subcontractor with a budget allocation of $35,000 to cover costs associated with the pilot study. Please contact Brian Steglitz at (734) 794-6426 ext. 43905 or bsteglitz@a2gov.org if you have any questions or comments. We sincerely look forward to working with your team on this important research topic.

Sincerely,

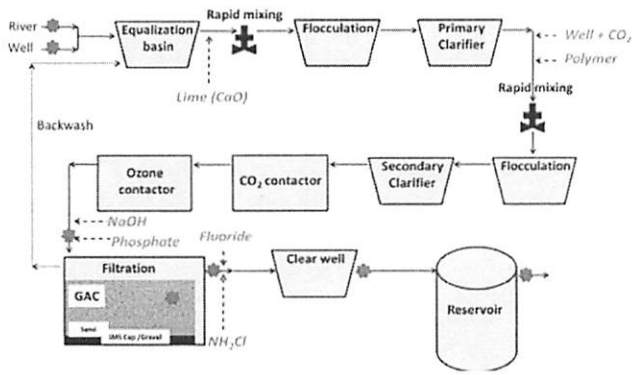
Brian Steglitz, P.E.
Water Treatment Services Unit Manager
City of Ann Arbor
919 Sunset Road
Ann Arbor, MI 48103

Statement of work for the City of Ann Arbor

Ann Arbor Pilot-Scale and Full-Scale Studies

Pilot-scale. In 1999, the City of Ann Arbor Water Treatment Plant commissioned construction of six pilot-scale filters to replicate performance of its full-scale filters. The pilot plant was recommissioned in 2017 and is fully functional. This project will use the 6 pilot filter columns to test promising GAC and IX media as identified in Task 4. While the pilot filters were designed to mimic the operational parameters of the City's full scale filters, they also have the flexibility to operate at greater media depths. The work proposed will take advantage of this feature to evaluate the effects of EBCT (5, 10, and 20 minutes for GAC; 1.5, 3, and 6 minutes for IX) on sorbent use rates. Pilot-scale testing will be conducted in two rounds. In round 1, the pilot columns will receive settled water to mimic GAC performance in filter adsorber mode. In round 2, pilot columns will receive filtered water from a full-scale adsorber containing spent GAC to mimic GAC performance in post-filter adsorber mode. These results will show whether filter adsorber performance for PFAS removal is impacted by higher influent turbidities and a greater backwash frequency. Also, if GAC/IX process trains show promise, the City will evaluate the effectiveness of a GAC/IX treatment train at the pilot scale. Using a pilot-scale ion exchange columns built by NCSU, the City will install the IX column in series after the GAC columns. This scenario will quantify the improved media life of the ion exchange resins resulting from the reduced loading by following GAC.

Full-scale. The City of Ann Arbor, MI operates a 50 MGD lime softening water treatment plant that serves 125,000 people in Ann Arbor and its surroundings. The treatment plant was built in 1938 and modified over the years to its current treatment configuration illustrated in the figure. One key feature of the City's water treatment plant is the blending of two water sources prior to treatment. The primary source of water for the City is the Huron River where the City has detected C4, C5, C6, C7, C8, PFBS, and PFOS at combined concentrations up to approximately 60 ppt. The City also has a series of wells that comprise approximately 15% of the source water requirements to the plant. The City has not detected any PFAS in its groundwater supply.



The City has been experimenting with different filter configurations to address removal of PFAS from its source water. The City has 26 filters, with different combinations of GAC and sand that range from 24 to 28 in. deep, with 18 to 24 in. comprising GAC and the remainder sand. Two of the 26 filters are full bed GAC with no sand. Five of the filters use Calgon F400 GAC and the remainder have Calgon F300. The City typically replaces GAC every 5 years in its filters, but is evaluating the impact on effective life if the media is used for PFAS removal. As part of this proposal, the City intends to dedicate two to five of its filters to explore the impact empty bed contact time (EBCT) and GAC type on PFAS removal. The City normal loads its filters at 1.5 gpm/ft^2, but can operate up to 3.0 gpm/ft^2 to explore the effect of EBCT (5-10 min) at the full scale. These EBCTs are typical for utilities considering GAC filter adsorbers for PFAS removal.

City Of Ann Arbor

	Rates	Year 1	In-Kind
PI Salary		$ -	$ 5,000
Water Quality Manager		$ -	$ 4,800
Lab Supervisor			$ 6,000
Graduate student salary		$ 30,000	
Fringes			$ 2,700
Materials and Supplies		$ 5,000	$ 6,000
Total Costs		**$ 35,000**	**$ 24,500**

The budget for the **City of Ann Arbor** is as follows:

Personnel and fringes:	$30,000
Materials and Supplies:	$ 5,000
Total Subaward:	**$35,000**

The budget justification for the **City of Ann Arbor** is as follows:

Personnel and fringes: $30,000 is requested to support a student at $20/hour for 1,500 hours to operate and maintain the pilot plant.

Materials and Supplies: $5,000 is requested for materials to maintain the pilot plant.

In-kind Contributions: In-kind contributions consist of donated time by co-PI Brian Steglitz ($5,000), Water Quality Manager Sarah Page ($4,800), and the lab supervisor ($6,000) to oversee on-site sample collection and analytical measurements. Fringes for personnel are calculated at 17% of salary ($2,700). Additional cost-share ($6,000) includes materials and supplies as well as travel to present research results at a local conference.

Appendix B
NC State University
Cost Reimbursement Subaward 08-16
Terms and Conditions

1. **General Provisions**.

A. These terms and conditions apply to all Cost Reimbursement Subawards issued by University. They are binding when incorporated by reference into a fully executed University Subaward, using a Subaward Notice (SN). All references to "Block #" are to the SN. The SN identifies the parties, the key persons, the project proposal, establishes funding and cost share obligations, the period of performance, special terms and conditions, and carries the signatures of authorized representatives of each party.

B. The Subaward may also include other documents incorporated by the SN. Such other documents may include a proposal from the Subrecipient, or a Statement of Work with a budget as well as a Prime Award from the sponsor.

C. The Subaward is a binding agreement whereby the Subrecipient shall provide the personnel, materials, required facilities and use its reasonable best efforts to accomplish the work described in the project proposal (incorporated into this Subaward as Appendix A) or required by the associated Statement of Work. University in turn agrees to reimburse Subrecipient for the allowable costs of said project or work effort in accordance with these and other incorporated terms, up to a total funded dollar amount, (Block 7).

D. The Subaward supersedes any prior or contemporaneous agreements or representations, between the parties regarding the proposed project, whether oral or written. Each party remains an independent entity. The Subaward does not establish any employment or agency relationship between the parties.

2. **Changes and Modifications**.

A. These Terms and Conditions may be altered by the Special Terms and Conditions recorded on a given SN or in subsequent written modifications. Any changes to the Subaward after the initial SN has been executed must be recorded in written modifications, using the SN form annotated with a Modification Number. Both parties must sign modifications, except that University may elect to issue the following types of modifications unilaterally:

1. Changes in key personnel when subrecipient submits a written request for change
2. Revisions to the project budget when subrecipient submits a written request
3. Changes to administrative information
4. Funding actions identified in the approved budget
5. Extension of the project end date (no-cost extension)

B. Subrecipient may reject such unilateral modifications by providing written notice of exceptions to the University Negotiator /Administrator (Block #11) within 30 days after receipt of said modification. If the Subrecipient objects to a unilateral modification, the parties will negotiate an acceptable one.

3. **Incorporation of Prime**. The Subaward is also subject to the terms and conditions of the Prime Agreement, identified in Block #4 and incorporated into the Subaward as Appendix C. Prior approval from University is required to extend the period of performance of this Subaward. Any exceptions or additions to the Prime Award will be identified in the Special Terms and Conditions, under Block #6. In the event of conflicts among the various documents and agreements, the following order of precedence will govern:

   1. Subaward Notice including any Special Terms and Conditions and modifications
   2. University Standard Terms and Conditions Cost Reimbursement Subaward, 08-16
   3. Proposal or Statement Of Work, and approved budget incorporated into the Subaward
   4. Terms and conditions of the Prime Award

4. **Invoice and Payment**.

   A. Subrecipient must request reimbursement for allowable costs incurred no more frequently than monthly but at least quarterly from the individual named in Block #15. Invoices must include the Subaward number; the period covered by the invoice and must show the same level of cost detail as the approved proposal budget. Invoices must show expenditures and cost share contributions for the current period and the cumulative amount to date. The invoice must include a certification by an authorized official as to truth and accuracy of the invoice.

   B. Subrecipient must submit an invoice marked "FINAL," not later than sixty (60) days after Subaward end date. Notwithstanding any terms and conditions or other provisions contained in the final invoice or any accompanying correspondence, the final invoice and/or financial statement constitutes Subrecipient's final request for reimbursement and upon its payment by University, a release by which the Subrecipient does remise, release and discharge University, its officers, agents and employees of and from all liabilities, obligations, claims and demands whatsoever under or arising from the Subaward. Both University and Subrecipient understand that all payments are provisional and are subject to adjustment as a result of an adverse audit finding concerning the Subaward. In the event that Subrecipient fails to submit either a FINAL invoice or request for no-cost extension within the time frame established above, University shall consider the last regular invoice to be the FINAL invoice. Any unexpended balance from the Total Sponsored Funds to Date (7.c.) will be automatically deobligated and University will not make any further payments to that Subrecipient.

   C. If a cost-sharing amount appears in Block #7.e., Subrecipient must report such cost-share expenditures to University with each invoice, either on the invoice or separately on the Subrecipient's letterhead. The report must show current period expenditures, cumulative expenditures, and a certification as to the truth and accuracy of the report. The Subrecipient may not use Federal funds to meet cost-share obligations under any other Federal awards.

Appendix B
NC State University
Cost Reimbursement Subaward 08-16
Terms and Conditions

5. **Access to Records**. The Subrecipient will make all access to any and all documents, papers, or other records of the Subrecipient which are pertinent to the subaward, in order to make reviews, audits, examinations, excerpts, transcripts, and inspections available at all reasonable times by the Federal Awarding agency, the Inspectors General, the Comptroller General of the US, University or by their authorized representative(s). This right also includes timely and reasonable access to the Subrecipient's personnel for the purpose of interview and discussion related to such documents. Subrecipient must retain these records for a period of at least three (3) years from the date of submission of the final invoice or from the settlement date of any claims, audits, appeals, or litigation, whichever is later, or as the Prime Agreement prescribes.

6. **Inspection**. Designated representatives of University have the right to inspect and review the progress of the work performed at the Subrecipient's place of business pursuant to this Agreement. Subrecipient must make available all reasonable facilities, including access to relevant data, test results, and computations used or generated under this Agreement if requested by University. University must conduct such inspections in such manner so as not to unduly delay the progress of the work. University must give the Subrecipient reasonable notice prior to conducting any such inspection.

7. **Audit**. Throughout the term of the Subaward, Subrecipient agrees to forward upon request, audit information in accordance with an OMB single audit. This could include certification of audit results, web links to audit reports, the most recent report, corrective action plans or other pertinent information. In the absence of an OMB single audit, Subrecipient must submit a record of its most recent audit by an independent accountant, including a certification as to the accuracy and reliability of the Subrecipient's financial statements and internal control structure. Upon request, Subrecipient must complete a questionnaire (to be provided) regarding its accounting system and internal controls. Audits and/or related documents must be sent to the address in Block 13, Attn: Compliance Manager.

8. **Key Persons, Technical Direction and Reporting**.

   A. The individual named in Block #8 (normally Subrecipient's Principal Investigator) is designated as a Key Person. Subrecipient agrees not to replace that individual nor reduce his/her level of commitment to the project without prior written approval of University.

   B. The University Project Director named in Block #9 is responsible for monitoring Subrecipient's performance, technical reporting and approval of Subrecipient's invoices. All questions about technical and financial matters should be directed to that individual. Technical reporting requirements are stated in Block #6.

9. **Administration**. Matters concerning any changes in the terms, conditions, dates or amounts cited in the SN should be directed to the other party's Negotiator /Administrator identified in Blocks #10 and #11.

Appendix B
NC State University
Cost Reimbursement Subaward 08-16
Terms and Conditions

10. **Publications**. Subrecipient and its investigators are free to publish papers dealing with the results of the research project sponsored under this Subaward. However, Subrecipient must give University's Project Director (Block #9) the opportunity to review such papers or presentations prior to their being released. University agrees to complete such review within sixty (60) days. Subrecipient must include in every publication or presentation appropriate recognition of the support received from University and the Prime Sponsor.

11. **Certifications and Assurances**. Subrecipient, by signing the SN incorporating these Terms and Conditions, certifies its compliance with any applicable regulatory requirements including but not limited to those listed below. Subrecipient agrees to immediately report to University any change in its compliance status. Subrecipient must flow these requirements down to any lower tier subrecipients. See Appendix B of the Federal Demonstration Partnership Operating Procedures. (http://www.nsf.gov/awards/managing/fed_dem_part.jsp.) for a complete description of the following:

1. Nondiscrimination statues on the basis of race, color, national origin, sex, blindness, handicap or age.
2. Common Federal Policy for the Protection of Human Subjects (45 CFR Parts 46 & 690).
3. USDA Rules that implement the Laboratory Animal Welfare Act of 1966 (9 CFR Parts 1-4).
4. Regulations for the Clean Air Act, 42 USC 7606, 40 CFR 6 & 32.
5. Regulations for the Clean Water Act 33 USC 1368, as implemented by E.O. 11738.
6. National Scenic Rivers Act of 1968, 16 USC1271, 40 CFR 6.
7. For NSF & DHHS awards only, internal conflict of interest policy.
8. E.O. 11246, & E.O. 11375 "Equal Employment Opportunity," per 41 CFR part 60.
9. OMB Circular A-129 and 40 CFR 30.73, the parties are not delinquent on any Federal debt.
10. The parties are in compliance with the Drug-Free Workplace Act of 1988, Public Law 100-690, 41 USC 701, 40 CFR 32 or equivalent.
11. HIPAA Patient Privacy Rule, 45 CFR 160 & 164.
12. Coastal Barriers Resource Act, 40 CFR 6.
13. The Anti-Kickback Act of 1986, Pub. L. 99-634, amending 18 U.S.C. 874, 29 C.F.R. Part 3
14. The Safe Drinking Water Act, 42 U.S.C. 300h-3(e)
15. Davis-Bacon Act, 40 U.S.C. 276a to 276a-7, 29 C.F.R. Part 5
16. Contract Work Hours and Safety Standards Act, 40 U.S.C. 327 – 330, 29 C.F.R. Part 5
17. Environmental Protection Agency Regulations, 40 C.F.R. Parts 1 through 49
18. Mandatory Standards & Policies contained in the State Energy Conservation Plan issued in compliance with the Energy Policy and Conservation Act, Pub. L. 94-163, 89 Stat. 871
19. "Debarment and Suspension" Regulations under E.O. 12549 & 12689, 7 CFR 3017, 10 CFR 606 & 40 CFR 32, or equivalent.
20. Prohibitions against lobbying as set forth in 7 CFR 3018, 31 USC 1352 and 18 USC 1913.
21. The Hatch Act (5 U.S.C. s 1501-1508 and 7324-7328)
22. Comply with environmental regulations that may be issued pursuant to:
    a. Institution of environmental quality control measures under NEPA (PL 91-190 & EO11514.
    b. Notification of violating facilities EO 11738
    c. Protection of wetlands EO 11990
    d. Evaluation of flood hazards in floodplains EO 11988
    e. Assure project consistency under Costal Zone Management Act of 1972 16 USC 1451
    f. Endangered Species Act of 1973, as amended PL 93-205

g. National Historic Preservation Act of 1966, 16 USC470, EO11593
h. Lead-Based Paint Poisoning Prevention Act 42 USC 4801
i. Requirements governing the applicable Grant Program

(Abbreviations: CFR = "Code of Federal Regulations," USC = "United States Code," E.O. = "Executive Order," OMB = "Office of Management and Budget")

12. **Termination**.

A. University and Subrecipient have the right to terminate the Subaward in whole or in part, without cause, with 30 days advance written notice to the other party.

B. The Subrecipient must stop work to the extent specified in the Notice of Termination on the date such notice is received from or issued to University. Subrecipient may not place any orders or subcontracts for materials, services, or facilities, except as may be necessary for the completion of such portion of the work that is not terminated. University agrees to reimburse the Subrecipient for all allowable costs of the work that has been performed prior to said notice of termination and all obligations relating to such work that cannot be canceled.

13. **Liability**. Each party is responsible for its negligent acts or omissions and the negligent acts or omissions of its employees, officers, or directors, to the extent allowed by applicable law.

14. **Notices**. Unless otherwise provided in the SN, official notices, from either party to the other, shall be deemed to have been fully given when made in writing, addressed/delivered to the individual shown on the SN, Block #10 for Subrecipient and Block #11 for University. The parties agree that the following methods are acceptable for delivering official notices: Certified mail, return receipt requested, electronic mail with confirmation of receipt, Express courier service (e.g. FedEx or UPS) or fax with confirmation of receipt.

15. **Assignment and Subcontracting**. Subrecipient may not assign the Subaward nor any right, remedy, obligation or liability arising there under or by reason thereof nor may Subrecipient further subcontract any of the work to be performed under the Subaward without prior written approval from University.

16. **Use of Names**. Either party may use the name of the other in a public announcement of the existence of the Subaward. Other than that, neither party to the Agreement may use the names, marks or symbols of the other or of the other party's employees in any manner, including public announcements, advertising, or promotional sales literature without the prior written consent of the other party.

17. **Disputes**. In the event of a dispute or claim regarding any matter under the Subaward that is not disposed of by mutual agreement, the parties agree to pursue those necessary institutional and/or legal remedies as may be appropriate. Legal remedies may include pursuit of the dispute by either party in a court of competent jurisdiction. In this event, each party shall be responsible for all costs they incur as a result of such action. Subrecipient agrees to continue performance on a disputed matter until any such dispute is resolved.

18. **Inventions**.

A. The parties agree to abide by the applicable United States regulations governing patents and inventions issued by the US Department of Commerce at 37 CFR 401, wherein the rights of the Federal Government are established. Any invention or discovery made or conceived in the performance of the research or other work (hereinafter called "Invention"), or any patent to be granted on such Invention shall be jointly or individually owned by Subrecipient and/or University in accordance with the following criteria:

1) Title to any Invention made or conceived jointly by employees of both Subrecipient and University in the performance of the Research (hereinafter called "Joint Invention") shall vest jointly in University and Subrecipient.

2) Title to any Invention made or conceived solely by employees of either Subrecipient or University in the performance of the Research shall vest in the party whose employees or students made or conceived such Invention or discovery.

B. The Subrecipient will, within 2 months after their inventor makes a written disclosure, submit a written report to the University Administrator (Block 11), identifying the Subaward number, date of disclosure by Subrecipient's PI, and a brief (non-disclosing) description, identifying the purpose of the invention. Subrecipient will concurrently make a full disclosure directly to the Prime Sponsor in accordance with the Prime Agreement.

C. The Subrecipient will submit a final invention report to University concurrently with the final invoice. Subrecipient will use the forms prescribed by the Prime Sponsor (e.g. DD Form 882 or NASA Form C-3044). The list will identify all subject inventions, including the disclosure date(s) or stating that there were no inventions (negative report is required).

D. The Subrecipient will, upon request, submit a written report concerning each patent filing, including: the filing date, serial number and title, a copy of the patent application, patent number, and issue date.

19. **Copyright**. The Subrecipient may copyright any work product, software or data that is subject to copyright and was first developed by or on behalf of Subrecipient under the Subaward. For such copyrights or copyrighted material (including any computer software and its documentation and/or databases), subject to its legal ability to do so, Subrecipient

grants to the Federal Government the rights established in the Prime Agreement and grants to University, an irrevocable, royalty-free, non-transferable, non-exclusive right and license to use, reproduce, display, and perform publicly to the extent required to meet University's obligations under its Prime Agreement and for the purposes of its noncommercial research and educational missions.

20. **Data Rights**. For Data and computer software created in the performance of this Subaward Agreement, Subrecipient grants to the Prime Sponsor the rights established in the Prime Agreement and grants to University the right to use data to the extent required to meet University's obligations under its Prime Agreement and for the purposes of its noncommercial research and educational missions.

21. **Confidentiality**.

A. In the performance of the Project, it may be necessary for one party to disclose information that is proprietary and confidential to the disclosing party. All such information must be disclosed in writing and designated as confidential or, if disclosed orally, must be identified as confidential at the time of disclosure and confirmed in writing and designated as confidential within thirty (30) days of such disclosure. Except as otherwise provided herein, for a period of Three (3) years following the date of such disclosure, the receiving party agrees to use the confidential information only for purposes of this Agreement and further agrees that it will not disclose or publish such information except that these restrictions do not apply to:

(i) information that is or becomes publicly known through no fault of the receiving party;

(ii) information learned from a third party entitled to disclose it;

(iii) information already known to or developed by receiving party before receipt from disclosing party, as shown by receiving party's prior written records;

(iv) information for which receiving party obtains the disclosing party's prior written permission to publish;

(v) information required to be disclosed by court order or operation of law, including, but not limited to, the North Carolina Public Records Law; or

(vi) information that is independently developed by the receiving party's personnel who are not privy to the disclosing party's confidential information.

B. The receiving party must use a reasonable degree of care to prevent the inadvertent, accidental, unauthorized or mistaken disclosure or use by its employees of confidential information disclosed hereunder.

22. **Law and Severability**. It is agreed that if either party is an agency of its respective state government, the applicable constitutional provisions or statutes that govern sovereign immunity shall dictate the appropriate forum and law governing substantive issues. Subrecipient agrees to comply with all relevant federal, state, county, and municipal executive orders, rules, regulations, laws and ordinances. In the event that any provision(s) of the Agreement are rendered void or illegal the remainder of its provisions shall remain in effect. Failure on the part of either party to exercise a right or remedy shall not preclude exercising them in the future.

23. **Survivability**. In the event of early termination of this Subaward, the parties agree that Articles 18 through 21 and the obligations inherent in them will survive the termination of this agreement for a minimum of 3 years.

24. **Export Controls**. The parties acknowledge that each is responsible for compliance with US Export Control regulations. In the event that either party becomes aware that the research work that is being or will be conducted, is or is likely to involve a technology that is subject to Export Controls, each party agrees to notify the other within three working days so that the situation can be evaluated and an appropriate course of action taken.

End of NC State University Cost Reimbursement Subaward 08-16 Terms and Conditions

APPENDIX C

RECEIVED
FEB 2 5 2019

THE Water Research FOUNDATION
The Water Research Foundation

6666 W. Quincy Ave.
Denver, CO 80235-3098

1199 N. Fairfax St., Ste. 900
Alexandria, VA 22314-1445

Project Funding Agreement #4913

Titled

"Investigation of Treatment Alternatives for Short-Chain Poly- and Perfluoroalkyl Substances"

This Project Funding Agreement (hereafter "PFA") is entered into on February 25, 2019, (the "Effective Date") by and among The Water Research Foundation ("WRF"), a Colorado non-profit corporation, whose place of business is located at 6666 W. Quincy Ave., Denver, Colorado 80235, and North Carolina State University ("Sub-recipient"), whose principal place of business is located at 2701 Sullivan Drive, Admin Services III Box 7514, Raleigh, NC 27695-7514 in furtherance of their common interest to support research on behalf of the water community.

WRF has selected said Sub-recipient to receive a research and development grant as more specifically detailed in this PFA. The parties mutually agree as follows:

I. **DEFINITIONS.** The following defined terms shall apply in this PFA:

A. "Cost Share" the portion of allowable costs that the Sub-recipient, Subcontractor or third-party participant funds toward completing WRF project. Cost share includes any non-federal cash and non-cash project funding from the Sub-recipient and Subcontractors, and nonfederal cash funding from participants. All Cost Share must comply with Code of Federal Regulations (CFR) requirements in 2 CFR Part 200.306.

B. "Co-Principal Investigator" or "Co-PI" An individual involved with the Principal Investigator in the scientific development or execution of a project. A Co-PI typically devotes a specified percentage of time to the project and is considered "key personnel." The designation of a Co-PI, if applicable, does not affect the Principal Investigator's roles and responsibilities as specified in this agreement.

C. "Educational Purpose" is defined as any non-commercial and non-profit use of Intellectual Property, including, but not limited to, a WRF owned publication or report utilized as a research tool and/or reference, to inform the water community, water utility personnel, or the general public of the outcome of this Project.

D. "Effective Date" for purposes in this agreement, the Effective Date is the date of the last signature received by WRF.

E. "Expenses" Any WRF approved expenses associated with the research and development performed by the Sub-recipient for the Project.

F. "Intellectual Property - IP" is all rights to copyrights, trademarks, service marks, patents, trade secrets, know how, and confidential information, including the right to enforce, divest, license, seek registration, prosecute infringers, and commercially or otherwise exploit such rights.

G. "PAC" is the Project Advisory Committee that consists of independent volunteers selected by WRF and any co-funders of the Project (if applicable) to provide technical review, assistance, and/or expertise related to the Project. The number of volunteers to serve on the PAC will be determined by WRF.

H. "Participating Utility" is a utility that provides data or information for the research effort- not survey respondents or workshop participants.

I. "Party or "Parties" one or more of the participants in this research Project who has an interest in the research outcome.

J. "Principal Investigator" or "PI" is the Sub-recipient employee identified in Exhibit B, who is primarily responsible via his/her employer for ensuring that all terms and conditions of this PFA are met and to whom WRF shall give all notices intended for the Sub-recipient.

K. "Project" is the work to be completed by the Sub-recipient, as described more specifically in the Project Proposal attached hereto as Exhibit A.

L. "Project (Award) Funds" is the aggregate maximum amount of cash award which WRF agrees to provide to Sub-recipient to fund its performance of the Project pursuant to this PFA.

M. "Project Coordinator" WRF staff member who assists the Research Manager with monitoring Project contractual agreements to assure effective delivery of research, fiscal accountability, compliance with contract provisions, and compliance with federal administrative and financial requirements.

N. "Project Proposal" is the final and written description of the Project as described in Exhibit A, to be undertaken by Sub-recipient for which the Project Funds is granted and performance is required and monitored pursuant to this PFA.

O. "Proposal Guidelines" is the WRF's written guidelines, currently maintained at http://waterrf.org/funding/ProposalDocuments/GuidelinesForFocusAreaProgramProposals.pdf in which the procedures, criteria and requirements for eligibility, proposal, performance, administration, reporting, and other matters governing the proposal of and performance of the Project are set forth. The Proposal Guidelines were provided to the Sub-recipient prior to its submission of a Project Proposal, and its terms and requirements are incorporated in this PFA by this reference. The terms "Deliverable", "Periodic Report", "Draft Report", and "Final Report" appearing in this PFA shall have the definitions, and be governed by the requirements applicable thereto, as set forth in the Proposal Guidelines.

P. "Research Manager" is the WRF staff member whose responsibility is to manage the development, research, and technology related to the Project in coordination with the Principal Investigator to ensure the effective delivery of all related research.

Q. "Reports" are the Periodic Reports, Draft Report, and/or Final Report, individually or collectively.

R. "Subcontractor" is any individual or entity identified by Sub-recipient in the Project Proposal as assisting in the performance of the Project under this PFA.

S. "Subject Data" shall mean all non-patented original and raw research data, notes, computer programs, writings, sounds recordings, pictorial reproductions, drawings or other graphical representations and works of any similar nature originated by the Sub-recipient in performance of this PFA and used to validate the research or results, but specifically excluding WRF Intellectual Property or Sub-recipient Intellectual Property as defined within this PFA. Subject Data also excludes financial reports, receipts, costs, analysis, and similar information incidental to contract administration.

T. "Work Product" is copyrightable works of authorship created by or on behalf of the Sub-recipient or its Subcontractors in the course of performing under this PFA or the Project, including, without limitation, the Scope of Workd Periodic Reports, Draft Reports, the Final Report, all interim drafts of the foregoing, and any computer software and related documentation developed under the Project. The Parties expressly acknowledge and agree that Sub-recipient will not be required to assign its invoices, insurance certificate and financial records.

II. GENERAL OBLIGATIONS OF THE PARTIES

A. The Sub-recipient.

1. The Sub-recipient agrees to complete the research, prepare written Reports, deliver the Deliverables to WRF, and perform such other functions, all in accordance with the schedules and other requirements set forth in the Exhibits and this PFA. The Sub-recipient shall itself, and shall require all its Subcontractors to, perform the Project and all other activities related thereto in full compliance with all laws, regulations, ordinances, and other requirements governing them. All Reports shall be sent to the Research Manager and Project Coordinator identified in Exhibit B-WRF Key Contacts.

2. Sub-recipient may not use Project Funds received under this PFA as a match or cost-sharing vehicle to secure U.S. Federal monies or money from any other sources, unless otherwise expressly stated and fully disclosed in the Project Proposal. The Sub-recipient may not use any portion of the Project Funds for any purpose other than as detailed in the Project Proposal, and as is necessary to perform the Project.

3. All disbursements of Project Funds will be paid directly to Sub-recipient. Sub-recipient shall remain solely responsible for payment of its Subcontractors, and for procurement of all equipment, materials, and other resources necessary for performance of the Project hereunder.

B. WRF. WRF will disburse the Project Funds to the Sub-recipient as detailed in this PFA and Exhibit C. WRF's disbursement of the Project Funds may further be subject to WRF's receipt of its own funding from appropriate sources.

III. DISBURSEMENT OF PROJECT FUNDS

A. Advance Payment. All payments of the Project Funds will be disbursed by WRF directly to the Sub-recipient. The amount of Project Funds was determined based on the budget submitted by the Sub-recipient, and set forth in Exhibit C. The Project Funds is a "not to exceed" amount and no payments in excess of such amount are authorized or required. Following the Effective Date, WRF will advance to the Sub-recipient 10% of the Project Award Funds (see III.B.3.a below). All subsequent disbursements of the Project Funds shall be governed by the requirements described in Section III.B below and in Exhibit C.

B. Invoicing and Payments.

1. Beginning three (3) months after the Project Start date as detailed in Exhibit C and every three (3) months thereafter during the term of this PFA, Sub-recipient shall submit to WRF a detailed invoice itemizing the expenses incurred in the three (3) months prior to the invoice date by the Sub-recipient in the performance of the Project as defined in the budget, and identifying all Cost Share and third party in-kind contributions as well as the contributing parties. The invoice shall be sent to the Research Manager and Project Coordinator identified in Exhibit B-WRF Key Contacts.

2. Each invoice should be displayed per the budget line items in Exhibit A. All invoices must be submitted using the form attached in Exhibit D, must be on the Sub-recipient's letterhead, and must be accurate and complete and sent to WRF's Project Coordinator identified on Exhibit B. Only out of pocket costs and expenses incurred by the Sub-recipient may be invoiced under this PFA.

3. WRF will disburse Project Funds within thirty days of receipt of Sub-Recipient invoice and in accordance with the schedule set forth Exhibit B and approved by the Research Manager. Corresponding technical Reports will be submitted under separate cover by the Sub-Recipient Principal Investigator. No portion of the Project Funds will be disbursed by WRF unless and until WRF receives and accepts each corresponding invoice and Report. If the invoices and Reports are accepted, the Sub-recipient will be paid as follows:

   (a) The ten percent (10%) advance payment must be shown on all invoices, including the final invoice, as an advance payment received by Sub-recipient. Subject to the hold back provision below, invoices will be paid to the extent actual costs incurred exceed the advance payment.

   (b) Regardless of the actual amounts invoiced, WRF will at all times during this PFA hold back twenty percent (20%) of the Project Funds and will only disburse same as follows: Ten percent (10%) of the Project Funds will be disbursed to the Sub-recipient when WRF receives and accepts the Draft Report. The remaining held back ten percent (10%) of the

Project Funds will be disbursed to the Sub-recipient after the Sub-recipient has completely and adequately responded to editor queries on the Final Report, has made all revisions reasonably requested by WRF to finalize the Final Report, submitted a final invoice, and Exhibit E – Assignment of Copyright for Work Product (if applicable).

(c) No conditions, notations, acknowledgements, comments, or terms other than the items required to be included and itemized on the Sub-recipient's invoice shall be binding on WRF.

(d) WRF may deduct amounts or withhold payments invoiced by the Sub-recipient if the Sub-recipient fails to comply with any WRF standard terms contained herein and/or Federal Uniform Administrative Requirements of the Sub-recipient's cognitive agency.

IV. COMPLIANCE MONITORING

A. Financial Management System. The Sub-recipient shall maintain an accounting system and accurate and complete accounting records that, at a minimum but without limitation, allow for the identification, tracking, and verification of costs, expenses, cost share, in-kind contributions, invoiced items, and funding received, all in a manner that is segregated and allocable solely to performance of the Project. All costs incurred must be supported by original receipts and, for disputed costs, be made available to WRF upon request.

B. WRF federal compliance. This Project is not federally funded; however, WRF is categorized as a Pass Thru Entity (PTE) because of the federal funding we receive. To stay in procurement compliance, WRF is required to list federal language in all agreements.

C. U.S. Federal Administrative, Cost and Audit Requirements. The Sub-recipient represents that the budget disclosures included in the Project Proposal and presented to WRF were prepared by Sub-recipient in full compliance with The Water Research Foundation Guidelines and all relevant U.S. laws, regulations and agreement terms and conditions related to U.S. Federal Financial Assistance including, but not limited to, 2 CFR 200 [U.S. Code of Federal Regulations Title 2 (Grants and Agreements) Part 200: Uniform Administrative Requirements, Cost Principles and Audit Requirements for Federal Awards (a/k/a/ Uniform Grants Guidance or UGG). Cost Principles specifically applicable for awards to for-profit organizations are set forth in the Federal Acquisition Regulations System (FARS, at 48 CFR 31.2) to determine allowable costs under WRF project funding agreements. Sub-recipient shall throughout the Project, and in the preparation of every invoice, report, and maintenance of its accounting system, remain in compliance with the above regulations. It shall be Sub-recipient's obligation to determine and comply with its governing cost principles, and to ensure all of its Subcontractors' invoices are equally in compliance with these requirements.

D. Indirect Costs and Allocation of Costs. If the Sub-recipient proposes to invoice for indirect costs, substantiation of those charges must be in compliance with WRF's "Focus Area Proposal Guidelines," which include compliance with the applicable cost principles referenced in Section IV.B.

E. Record Retention. Sub-recipient shall retain, at a minimum, electronic copies of all original books and records pertinent to this PFA and the Project for at least three (3) years from the termination of this PFA.

F. Audit and Monitoring.

1. The Sub-recipient's use of the Project Funds under this PFA shall be in compliance with 2 CFR 200, including Subpart F, Audit Requirements, and may be audited by WRF and its designee. Furthermore, WRF shall have the right, itself and through a designee, to visit the Sub-recipient premises to observe, review, and monitor the Sub-recipient's performance of the Project, as well as its application and use of the Project Funds. Accordingly, following a ten (10) business day prior notice from WRF, the Sub-recipient shall reasonably provide WRF and its designee access to its premises, technical staff, supervisors, knowledgeable personnel, computer systems and databases, assistance, original documents, including those required to be maintained under this PFA, and any information related to the Sub-recipient's use of the Project Funds and performance under this PFA, to enable the WRF's audit and monitoring. The WRF's audit rights shall survive termination of this PFA by three (3) years. The cost of audit shall be borne by WRF.

2. WRF will keep the Sub-recipient's Project Proposal submittal containing any proprietary financial, technical and/or scientific information reviewed under this Section in confidence provided that such material is appropriately marked as "Confidential," that was not already generally known to the public, is not required to be disclosed as a result of a legal proceeding, or applicable legal requirement, and was not already known to WRF or others without a confidentiality obligation.

3. Any deficiencies or non-compliance in Sub-recipient's systems, procedures, record keeping, finances, and performance of other obligations under this PFA discovered in the audit, review or monitoring process, or discovered otherwise, may, at WRF's option, require Sub-recipient to take corrective action that has been detailed by the Sub-recipient and approved by WRF for the Sub-recipient to remedy the deficiency or noncompliance, or may result in WRF exercising its termination rights under Section VII below.

4. If WRF approves of the Sub-recipient's proposed corrective action plan, in connection with such approval it may require the Sub-recipient to submit additional periodic written verification that the corrective action plan has been implemented and continues to correct the targeted deficiencies and noncompliance. If the approved corrective action fails to correct the deficiencies within the time set by WRF in its sole discretion, WRF may exercise its termination rights under Section VII.

5. Nothing herein obligates WRF to accept or approve a corrective action or to forbear from exercising its right to terminate this PFA. WRF's right to termination shall be in addition to all other rights and remedies available to it at law or in equity.

V. PROCUREMENT STANDARDS

A. Procurement Standards. It is an express requirement under the Proposal Guidelines and this PFA that the Sub-recipient remain in compliance with the U.S. Federal standards for procurement under 2 CFR 200 Subpart D, Procurement Standards. These standards govern procedures for

procurement of supplies, equipment, and other services, including Subcontractors, for which cost is incurred in whole or in part under this PFA. These standards include but are not limited to the following:

1. Sub-recipient procurement policies must adhere to the Uniform Grants Guidance;

2. Sub-recipient shall maintain and enforce with its officers, employees, and agents (including Subcontractors) a code of conduct designed to enhance goodwill, ethics, and compliance with laws while performing under this PFA; and

3. Sub-recipient shall conduct all procurement transactions in a manner that maximizes open and free competition and in compliance with the restrictions and limitations in this PFA and also in compliance with applicable State procurement policies.

4. Sub-recipient shall ensure that its Subcontractors comply with the requirements and restrictions in this Section and in this PFA generally.

5. Sub-recipient shall notify WRF, within two (2) months of the Project start date pursuant to the schedule detailed in Exhibit B, of all Subcontractor agreements executed between the Sub-recipient and the Subcontractors identified in the Project Proposal.

VI. IP RIGHTS AND PUBLICATION

A. Work Product.

1. Copyrights. WRF shall own all worldwide copyrights in all the Work Product, including the Scope of Work, all Periodic Reports, all Draft Reports, the Final Report, and all drafts of these works and reports. Sub-recipient shall and hereby does assign exclusively to WRF all right, title, and interest in and to the Work Product and the copyrights embodied therein, and subject to provisions of 2 CFR 200 Subpart D, Property Standards, Intangible Property (200.315); and 37 CFR 401 which are made part of this PFA by reference except where superseded by this Section VI or the U.S. Federal Grant Agreement. The Sub-recipient may use without restrictions all data from the Work Product such as, innovations, creations, processes, designs, methods, formulas, plans, technical data, and specifications. The use of this Intellectual Property will not be utilized externally by the Sub-recipient or Co-funder, if applicable, before WRF has published the final Work Product's Final Report (see VI.A.2 regarding permission of use).

2. Distribution Permission. Upon request, WRF will provide the Sub-recipient with five (5) hardcopies of the Final Report and a PDF. If the Final Report is published in a PDF format only, the Sub-recipient will receive the Final Report in PDF format. The Work Product may not be copied, published, adapted, posted on an intranet or website, or disclosed in any manner by the Sub-recipient, any Subcontractor or other third party except with WRF's prior written approval. WRF granting permission will not be unreasonably withheld. The Sub-recipient shall utilize the WRF's *Material Use Permission Request Form* located at http://www.waterrf.org//funding/Pages/project-report-guidelines.aspx for securing the foregoing required permission for WRF.

3. Requests for permission are not unreasonably withheld by WRF, and WRF encourages Project information distribution. The permission request process enables WRF to confirm accuracy of data distribution, and if needed, redact any specific subscriber, utility, academic institution, or other contributing party's information to the project to ensure the parties confidential information.

4. License Granted to Sub-recipient. WRF hereby grants the Sub-recipient a royalty free, perpetual, irrevocable, world-wide, nonexclusive license, without the requirement for any accounting, to utilize WRF's Intellectual Property for internal educational purposes and for securing the foregoing required permission from WRF.

5. WRF PI and Co-PI Intellectual Property Guidelines are available at: http://www.waterrf.org/funding/ProjectReportGuidelines/IntellectualPropertyGuidelinesforPIsandco-PIs.pdf.

6. PI guidelines for Periodic Report Format/Content and Preparation of Research Reports are available at: http://www.waterrf.org/funding/pages/project-report-guidelines.aspx.

B. Inventions and Patents.

1. All proprietary or patentable ideas, devices, methods, formulations, designs, and other inventions developed or conceived by or on behalf of the Sub-recipient during performing under the Project, including, but not limited to, the right to apply for patent protection thereon (collectively, "Inventions"), shall remain the property of the Sub-recipient.

2. If the Sub-recipient decides to abandon its rights to the Inventions, or not to seek patent protection on its Inventions, or to abandon any pending patent application or patent issued on the Inventions, Sub-recipient shall notify WRF of the same and promptly assign all rights in the abandoned Inventions to WRF at its request in the event WRF decides to seek a patent.

3. Sub-recipient shall not withhold any information on or descriptions of Inventions, whether or not patentable, from Work Products or any Report. The Sub-recipient's rights in Inventions shall not limit, delay, restrict, or in any other manner interfere with WRF's right to own, publish, and exercise all other copyrights in the Work Product. If information contained in the Work Product owned by WRF is considered to be and is treated by the Sub-recipient as confidential information and/or trade secrets, the Sub-recipient shall be solely responsible for marking confidential portions of the Work Product as such so that it can be removed prior to publication by WRF. Additionally, Sub-recipient may request that WRF reasonably delay, but in no event by more than three months, publication of a Work Product in order to allow the Sub-recipient to apply for patent protection on Inventions described in the Work Product.

4. All IP rights that were owned and developed by the Sub-recipient or third parties prior to the Project Start Date and outside the scope of the Project as outlined in the Project Proposal (collectively, "Preexisting IP"), and which the Sub-recipient will use in the performance of the Project, or incorporate in whole or in part into any Work Product has been fully disclosed and identified by the Sub-recipient in the Project Proposal. The Sub-recipient represents that all

Preexisting IP outlined in the Project Proposal is used with full authorization to WRF herein. The Sub-recipient shall reasonably assist WRF to exercise its ownership and publication rights in the Work Product, including the Final Report, such right shall not be subject to any payment or other obligation on the part of WRF. Such agreements to procure rights for WRF shall be subject to the WRF's prior approval, in its sole discretion.

5. The Sub-recipient hereby grants WRF a fully paid-up, royalty free, perpetual, irrevocable, world-wide, nonexclusive license, without the requirement for any accounting, to utilize the Inventions and Preexisting IP outlined in the Project Proposal for Educational Purpose or other non-profit purposes.

C. Publication. As the owner of Work Product, all rights to publish, distribute, publicly perform, and publicly present the Reports belong solely to WRF. The Co-funders and Sub-recipient may publish or present the Work Product, in whole or in part, and only with the prior written permission of WRF, which may be withheld or conditioned at WRF's sole discretion. Any such request for permission from WRF must be made to WRF at least three (3) weeks prior to the requesting party's proposed date of publication or presentation of any portion of the Work Product, and the request must be accompanied by copies of the proposed publication or presentation material. All copies of or presentations of the Work Product authorized to be made by WRF shall furthermore conspicuously display the following notice:

Source: Author, Title of The Water Research Foundation Work
Copyright [year of publication],
The Water Research Foundation. Reproduced with permission.

D. Participating Utility Review: The PI shall, with each Participating Utility, (a) grant the Participating Utility the right to review the Project's use and conclusions concerning that organization's data and/or test results, and (b) provide the Participating Utility with the reasonable opportunity to correct, or if correction will take an unreasonably long time, to respond to any problems or difficulties uncovered by the data, information, or test results, all of which must occur prior to the publication or use of such information. This provision shall apply to each water utility participating in any manner with the Project, including, but not limited to, providing services, data, materials for testing, test results, and/or documentation. If the PI has made reasonable efforts but is not able to obtain confirmation from each Participating Utility, the Principal Investigator may submit documentation to this fact and further state that the Participating Utility was provided reasonable opportunity to correct or respond to any problems or difficulties as stated above.

E. Student Thesis. In the event a college or graduate student is a part of Sub-recipient work on the project contemplated by this PFA, and that student completes a thesis, dissertation, or report relating to this Project, solely for Educational Purposes, the student may utilize Subject Data, and/or WRF Intellectual Property. Such thesis may be published prior to the issuance of the Final Report, if reasonably necessary to complete a specific, required course of study once it has been reviewed by WRF prior to submission. Sub-recipient shall provide WRF with a copy of such thesis at least thirty (30) days prior to submission for WRF's review.

F. Acknowledgement. Any public presentation or publication by the Sub-recipient, including a student writing a thesis, dissertation, or report, based on the Inventions or any portion of the Work Product, if permitted by WRF, shall include a statement substantially as follows: *"North Carolina State University gratefully acknowledges that The Water Research Foundation are funders of certain technical information upon which this publication [manuscript] [presentation] is based. North Carolina State University thanks The Water Research Foundation, for their financial, technical, and administrative assistance in funding the project through which this information was discovered. This material does not necessarily reflect the views and policies of the funders, and any mention of trade names or commercial products does not constitute the funders' endorsement or recommendations thereof."*

G. Return of IP. The Sub-recipient shall provide to WRF legible copies of all Work Product, (including source, and object code of any computer software program created under this Project) and all Inventions abandoned by the Sub-recipient and shall furthermore provide to WRF legible copies of all Preexisting IP, all within thirty (30) days of any party's delivery of a notice of termination hereunder, whether or not a cure period is provided. Further, at the same time, Sub-recipient shall provide copies and shall be delivered in whatever medium and format is reasonably designated by the WRF. No further payments will be made unless the Sub-recipient fully complies with the foregoing requirements.

H. Originality. The Sub-recipient represents and covenants that it, and its Subcontractors, are the sole creator(s) and originator(s) of all Work Product, Inventions, and Preexisting IP; none of those rights have been bargained, sold, encumbered, licensed or otherwise transferred to any other party in a manner that would limit or interfere with the requirements and covenants of the Sub-recipient under this PFA. Further, the Sub-recipient shall ensure that no portion of this Project, including any portion completed by Subcontractors, infringes upon the IP rights of any other person or entity or violates the common law or statutory right, title, or interest of any person or entity. The Sub-recipient, shall execute and deliver to WRF, and shall cause its Subcontractors and agents to execute and deliver to WRF, all documents and instruments reasonably requested by WRF, including, without limitation, the Assignment of Copyright attached hereto as Exhibit E, to further evidence or memorialize the assignment of rights to WRF set forth in this PFA.

I. Trade Secrets. In accordance with the Defend Trade Secrets Act of 2016, Trade Secrets have previously been protected by state laws in the U.S. This bill amends the Economic Espionage Act of 1996 to permit a private federal civil action for misappropriation of a trade secret that is "related to a product or service used in, or intended for use in, interstate or foreign commerce." For further information, go to: https://www.congress.gov/bill/114th-congress/senate-bill/1890/text.

VII. TERM AND TERMINATION

A. Term. This PFA is effective as of the Effective Date (date of last signature received), and shall continue for the duration of the Project, ending on the WRF's delivery to the Sub-recipient of the final disbursement of the Project Funds in accordance with Section III.B above, and as further specified in Exhibit C. This PFA may be terminated earlier for the following reasons:

1. WRF may terminate this PFA by thirty days written notice to Sub-recipient at any time in the event of a breach of this PFA or any requirements of or timelines in the Project by the Sub-recipient or its agents, following Sub-recipient's receipt of WRF's notice of breach.

2. WRF may terminate this PFA by thirty days written notice to Sub-recipient in the event WRF after consultation with the PAC reasonably determines that the Project is no longer feasible or its performance desired, or that if Sub-recipient is not likely to complete the requirements of the Project on time.

3. Upon receipt of any thirty days written notice of termination, the Sub-recipient shall cease all work associated with this PFA as of the date of receipt of the notice, but shall continue to prepare whatever reports, accounting statements, and invoices that are necessary to support receipt of any payments and deliver existing Work Product as required under the PFA and due as of the date of termination.

4. If the Sub-recipient, after reasonable consultation with WRF and sufficient exploration of other options and possible mutual agreements to amend this PFA, determines that circumstances beyond its control prevent it from continuing the Project, the Sub-recipient may terminate this PFA at any time by written notice to WRF.

5. Any change in legal requirements or entitlements which materially alter Sub-recipient's performance under this PFA, or any change in the availability of funds to WRF, shall warrant good faith renegotiation of the provisions of this PFA impacted by such change. If the parties cannot agree to an amendment to this PFA, at WRF's option the Sub-recipient's performance of the Project may be suspended, or this PFA may be terminated effective immediately by the WRF's written notice.

6. If termination occurs under this Section, the Sub-recipient shall prepare and submit to WRF a final invoice and accounting of expended and non-cancellable funds as of the date of receipt of the notice of termination. Any portion of the Project Funds that was prepaid to the Sub-recipient but which remains unspent shall be returned to WRF with the final invoice. WRF shall pay any amount owed under the final invoice, if reasonably accepted by WRF. The Sub-recipient shall be entitled to compensation for all authorized work completed as of the termination date, provided that all Work Product corresponding to the invoiced amounts have been delivered to WRF, and further provided that funds are available (i.e., subject to any reduction in granted funds as stated above).

VIII. DISPUTE RESOLUTION

In the event of a dispute between WRF and the Sub-recipient arising under this PFA, such dispute may be resolved by non-binding arbitration conducted in accordance with the then effective rules of expedited commercial arbitration of the American Arbitration Association ("AAA"). There shall be one Arbitrator selected in accordance with such rules. Any determination issued by the Arbitrator shall be in writing within thirty (30) days of the final mediation session. Such written decision may be enforced in any court having proper jurisdiction. Notwithstanding the foregoing, either Party shall be entitled to seek redress in a court of competent jurisdiction without the need to arbitrate in order to seek injunctive relief to enforce its IP rights and protection of its confidential information under this PFA.

IX. STANDARD TERMS AND CONDITIONS

A. Survival. All terms which by their nature and intent are required to be performed after termination of this PFA shall survive to the extent necessary to enable their fulfillment.

B. Quality Assurance. The Sub-recipient shall use its reasonable best efforts to ensure that all data and test results developed during this PFA and included, or relied upon, in the Final Report are accurate to the best of its knowledge, information, and belief. In the event the Sub-recipient obtains any data, test results, information derived from such data or test results, or other information to be included in the Project from water utilities or any Subcontractor, the Sub-recipient will utilize reasonable and customary efforts to ensure the accuracy of the information obtained.

C. Standard of Performance. At all times, all obligations performed by the Sub-recipient or by any Subcontractors pursuant to this PFA shall be performed in a manner consistent with or exceeding the professional standards governing such activities. Each party shall be responsible for its negligent acts or omissions and the negligent acts or omissions of its employees, officers, or agents, to the extent allowed by law and WRF will be responsible for use of the Work Product.

D. Insurance. The Sub-recipient shall be responsible in accordance with the NC Tort Claims Act for claims and all reckless, intentional, knowing, and negligent actions or omissions of any and all of Sub-recipient's officers, directors, employees and agents in the amount of one million dollars ($1,000,000.00). Nothing in this statement shall be construed as enlarging the responsibility or liability of Sub-recipient or its Subcontractors beyond applicable state laws. Proof of the applicability of the NC Tort Claims Act shall be presented to WRF pursuant to the schedule detailed by Exhibit B.

E. Worker's Compensation. The Sub-recipient and all Subcontractors shall maintain Worker's Compensation Insurance or a program of self insurance which complies with the applicable state laws. Proof of such insurance shall be presented to WRF pursuant to the schedule detailed by Exhibit B.

F. Authority. The individuals executing this PFA on behalf of their respective parties hereby represent and warrant that they have the right, power, legal capacity, and appropriate authority to enter this PFA on behalf of the entity for which they sign below.

G. Modifications. No provision, requirement, or term of this PFA may be modified, supplemented or amended, nor may it be waived or discharged, except in writing, signed by all parties. A written waiver of a breach of one provision in this PFA shall not operate as a waiver of a subsequent breach of the same provision.

1. Examples of items requiring WRF's prior written approval include, but are not limited to, the following:

    - Deviations from the Project plan.
    - Change in scope or objective of the Project.
    - Change in a key person specified in the application.

- The absence for more than three months or a 25% reduction in time by the Principal Investigator and/or Co-PI.
- Need for additional funding.
- Inclusion of costs that require prior approvals as outlined in the Uniform Grants Guidance and 48 CFR 31.2, as applicable.
- Any changes in budget line item(s) as described in Exhibit A of greater than ten percent (10%) of the total.

I. No Assignment. The Sub-recipient shall not assign this PFA in whole or in part, including by operation of law, merger, reorganization, or change in ownership or control. Any unauthorized assignments shall be void.

J. Sub-Contracting: The Sub-recipient may only utilize Subcontractors under this PFA that have been disclosed in the Project Plan and are pre-approved by WRF.

1. Sub-recipient shall require any and all Subcontractors to comply with all applicable and material terms of this PFA prior to working on the Project in any manner. All obligations of the Sub-recipient apply equally to the Subcontractor(s). Sub-recipient shall at all times remain primarily responsible to WRF for the performance of the Project.

2. Payment for services of any and all Subcontractors shall be the Sub-recipient's sole obligation and responsibility. The Sub-recipient hereby holds WRF harmless for any liability concerning such payment In furtherance of the foregoing, and to safeguard WRF if Sub-recipient or any Subcontractors is legally prohibited from indemnifying others, Sub-recipient shall in all its Subcontractor agreements specify that WRF and its co-funders shall have no liability or obligation to the Subcontractor, and that the Subcontractor agrees to look solely to the Sub-recipient for payment and enforcement of its rights under its agreement with the Sub-recipient.

3. Subcontractor shall conduct all procurement transactions in a manner that maximizes open and free competition.

4. Sub-recipient shall notify WRF via email, within two (2) months of the project start date pursuant to the schedule detailed in Exhibit B, that all Subcontractor agreements have been executed between the Sub-recipient and any Subcontractors set forth in the Project Proposal or the reason why such Subcontracts are pending. Sub-recipient shall provide WRF a copy of the full Subcontractor agreement upon WRF's request. Email notification should be sent to Christine Conville, WRF Contracts Manager, Email: cconville@WaterRF.org .

K. Integration. This PFA, including all attachments hereto and the documents and requirements referenced herein, contains the entire understanding between the parties relating to this PFA. This PFA supersedes all prior and contemporaneous understandings, representations, negotiations, and agreements between the parties whether written or oral. In the event of a conflict between the terms of an Exhibit or other document referenced herein and this PFA, the terms of this PFA shall control.

L. Severability. The provisions of this PFA shall be severable, and the invalidity, illegality or unenforceability of any provision of this PFA shall not affect the validity or enforceability of any

other provisions. If any provision of this PFA is found to be invalid, illegal, or unenforceable, such provision shall be modified to the extent necessary to render it enforceable, and as modified, this PFA shall remain in full force and effect.

M. WRF Right of Approval. WRF shall have the right, in their sole discretion, to refuse to permit any employee of the Sub-recipient, or employee of an approved agent, assignee, or Subcontractor of the Sub-recipient, to be located at a WRF work location, or to provide services to WRF pursuant to this PFA.

N. Notices. Any notice, request, demand, or communication required or allowed under this PFA shall be sent in writing to the addresses and contact information for the parties set forth in Exhibit B, and shall be deemed sufficiently given upon delivery, if delivered by hand (signed receipt obtained), or three (3) days after posting if properly addressed and sent certified mail return receipt requested, or upon receipt if sent via facsimile or email, if delivery can be confirmed by the sender. Notwithstanding the foregoing, if any Amendments are required in the future for revisions to this PFA or the Exhibits the Sub-recipient will be the only signor required. Notices shall become effective on the date of receipt or the date specified within the notice, whichever comes later.

O. Captions for Convenience. All captions, fonts, underlining, or footers used in this PFA are for convenience only and shall have no meaning in the interpretation or effect of this PFA.

P. Construction. This PFA, and any and all amendments to it, shall not be construed against the drafter.

Q. Force Majeure. None of the parties hereto will be liable for damages for any delay or default in performance during the term hereof if such delay or default is caused by conditions beyond its control, including, but not limited to, acts of God, Government restrictions, continuing domestic or international problems such as wars, threats of terrorism, or insurrections, strikes, fires, floods, work stoppages and embargoes; provided, however, that any party will have the right to terminate this PFA upon thirty (30) days prior written notice if another party's delay or default due to any of the above-mentioned causes continues for a period of two (2) months.

R. Limitation of Liability. IN NO EVENT SHALL EITHER PARTY OR ANY OF ITS OFFICERS, DIRECTORS, EMPLOYEES, AFFILIATES, AGENTS OR REPRESENTATIVES BE LIABLE TO THE OTHER PARTY, OR ANY THIRD PARTY FOR ANY SPECIAL, INDIRECT, INCIDENTAL, EXEMPLARY OR CONSEQUENTIAL DAMAGES OR LOSS OF GOODWILL OR EXPECTED PROFITS OR REVENUES, IN ANY WAY RELATING TO THIS PFA, INCLUDING, WITHOUT LIMITATION, THE FAILURE OF ESSENTIAL PURPOSE, EVEN IF IT HAS BEEN NOTIFIED OF THE POSSIBILITY OR LIKELIHOOD OF SUCH DAMAGES OCCURRING, AND WHETHER SUCH LIABILITY IS BASED ON CONTRACT, TORT, NEGLIGENCE, STRICT LIABILITY, STATUTE, PRODUCTS LIABILITY OR OTHERWISE. IN NO EVENT, SHALL EITHER PARTY'S LIABILITY TO THE OTHER PARTY HEREUNDER EXCEED THEIR RESPECTIVE FUNDING ALREADY MADE UNDER THIS PFA.

S. Applicable Law/Venue. Sub-recipient is a public entity and this PFA shall be construed and interpreted in accordance with its laws.

T. Counterparts. This PFA may be executed and delivered in counterparts, and by facsimile and email, and each shall be valid as if all parties had executed the same document.

U. Relationship. The parties are independent contractors, and no agency, employer-employee, partnership, or joint venture relationship is intended or created by this PFA. No party shall have any right or authority to assume or create any obligation, commitment or responsibility for or on behalf of the others except as the other may expressly authorize in writing. No party shall be eligible to participate in another's benefit program. Sub-recipient shall be solely responsible for the performance and compensation of its employees, for withholding taxes and providing unemployment and other benefits.

V. Additional Representations and Covenants of Sub-recipient. In addition to all other representations, warranties, and covenants of Sub-recipient in this PFA, Sub-recipient further represents, and covenants, on behalf of itself, its Subcontractors, and all of their respective employees, agents, directors, officers, affiliates and other representatives:

1. They will at all times comply with all Federal, state, municipal, and local laws, regulations, ordinances, and other governing requirements regarding their performance of the Project, including, without limitation, compliance with requirements related to anti-discrimination and anti-harassment in hiring and employment practices, provision of workers compensation and benefits, and accommodations for disabilities, compliant accounting, record-keeping, and invoicing for approved costs and expenses, and payment of all fees, taxes, payroll, and other expenses related to performance of the Project;
2. Performance of the Project does not and shall not conflict with any of Sub-recipient's obligations, or violate the rights of any third party;
3. All taxes, licenses, permits, certifications, and other permissions required to perform any aspect of the Project shall be secured and maintained throughout the term of this PFA;
4. There are no, and will not be any, third party encumbrances of liens created as a result of the performance of the Project, whether on WRF's or the co-funders' assets, or on rights, Deliverables, or IP provided under this PFA; and

5. There is sufficient liability insurance coverage to ensure Sub-recipient's full compliance with its obligations, and coverage for Sub-recipient's liability exposure for any breach of this PFA.

W. Order of Precedence. If any provisions stated in this PFA, resulting WRF purchase orders, and/or appendices are in conflict, the order of precedence, beginning with the first to last, shall be (1) this PFA, (2) Exhibits or Appendices and (3) the WRF purchase order. The parties understand and agree that any purchase order or similar document issued by WRF will be for the sole purpose of establishing a mechanism for payment of any sums due and owing hereunder.

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The Water Research Foundation
THE Water Research FOUNDATION

Project 4913

Title: Investigation of Treatment Alternatives for Short-Chain Poly- and Perfluoroalkyl Substances

IN WITNESS, WHEREOF, the parties have caused this PFA to be signed and dated as shown below.

The Water Research Foundation

By: Robert C. Renner, PE, BCEE
Title: Chief Executive Officer
Date: 2/19/2019

North Carolina State University

By: Sherrie Settle
Title: Director of Sponsored Programs
Date: February 21, 2019

Martina Krzywicki
Assistant Director
Sponsored Programs
NC State University

The Water Research Foundation

By: Kenan Ozekin, PhD
Title: Senior Research Manager
Date: 2/19/19

Above signed has read and understands the terms, conditions, and deliverables of this PFA.

North Carolina State University

By: Detlef Knappe, PhD
Title: Principal Investigator
Date: 2/21/19

Above signed has read and understands the terms, conditions, and deliverables of this PFA.

Exhibit A
Project 4913

Title: Investigation of Treatment Alternatives for Short-Chain Poly- and Perfluoroalkyl Substances

Project proposal, & all subsequent correspondence including but not limited to compiled PAC comments, Sub-recipient's responses, and in-kind contribution letters).

Proposal Cover Worksheet

RFP # 4913

Project Title: Investigation of Treatment Alternatives for Short-Chain Poly- and Perfluoroalkyl Substances

Organization: *(Legal name as shown on W9)*

Organization: North Carolina State University

Legal Address *(No P.O. Boxes Please)*: 2701 Sullivan Drive

Admin Services III; Box 7514

Raleigh, NC 27695-7514

Personnel: *(Separately upload CV or brief resume for PI, Co-PIs and other key research team members)*

Principal Investigator: *Individual responsible for the technical completion of the proposed work.*
Name: Detlef Knappe
Title: Professor
Organization: North Carolina State University
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Co-Principal Investigator: *Individual responsible for the completion of major portions of the proposed work.*
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Title: Assistant Professor
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Phone: 303-273-3061
E-mail: cbellona@mines.edu

Co-Principal Investigator: *Individual responsible for the completion of major portions of the proposed work.*
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Co-Principal Investigator: *Individual responsible for the completion of major portions of the proposed work.*
Name: Eric Dickenson
Title: R&D Project Manager
Organization: Southern Nevada Water Authority

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Co-Principal Investigator: *Individual responsible for the completion of major portions of the proposed work.*
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E-mail: schaeferce@cdmsmith.com

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E-mail: bsteglitz@a2gov.org

Authorized Representative:*Individual at your organization authorized to sign legal contracts and commit organization's participation.*
Name: Sherrie Settle
Title: Director of Sponsored Programs
Organization: North Carolina State University
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Accounting Contact: *Individual authorized to accept payments.*
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Administrative Contact: *Individual from Sponsored Programs office to contact concerning administrative matters (i.e., indirect cost rate computation, rebudgeting requests, etc.).*
Name: Sherrie Settle
Title: Director of Sponsored Programs
Organization: North Carolina State University
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Phone: (919) 515-2444 FAX: (919) 515-7721
E-mail: sps@ncsu.edu

Contracting (legal) Contact: *Individual responsible for contract administration including contract negotiation and contract amendments (if applicable)*
Name: Sherrie Settle
Title: Director of Sponsored Programs
Organization: North Carolina State University
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All Other Participating Organizations: *(not listed above)*

Organization	City/State/Country
North Carolina Policy Collaboratory	Chapel Hill, NC, USA
Aurora Water	Aurora, CO, USA
City of Fountain	Fountain, CO, USA
Cape Fear Public Utility Authority	Wilmington, NC, USA
Town of Cary	Cary, NC, USA
Plainfield Township	Grand Rapids, MI, USA
Tucson Water	Tucson, AZ, USA
City of Los Angeles - Bureau of Sanitation	Los Angeles, CA, USA
Hampton Roads Sanitation District	Newport News, VA, USA
Upper Occoquan Service Authority	Centreville, VA, USA
City of Altamonte Springs	Altamonte Springs, FL, USA
Washoe County	Reno, NV, USA

Project Period: October 1, 2018 - September 30, 2019

Project Abstract

Poly- and perfluoroalkyl substances (PFAS) are persistent and bioaccumulative, and there is mounting evidence for the human toxicity of many of these compounds. The US EPA has issued a drinking water health advisory level for two long-chain PFAS, perfluorooctanoic acid (C8) and perfluorooctane sulfonate (PFOS), at a sum concentration of 70 ng/L. In June of 2018, the Agency for Toxic Substances and Disease Control issued minimal risk levels for public comment, and the corresponding drinking water equivalent levels for PFOA and PFOS would be 11 and 7 ng/L, respectively. Due to regulatory focus on long-chain PFAS, manufacturers have switched to the production and use of short-chain PFAS and fluorinated alternatives, such as perfluoroalkyl ether acids (PFEA). Despite growing regulatory, scientific and public attention, there are still critical knowledge gaps about the selection of treatment approaches for short-chain PFAS, PFEA, and other emerging PFAS. Therefore, the **overarching goal** of the proposed research is to develop a **guidance manual** that allows water treatment professionals to select the most **cost-effective and sustainable treatment options for short-chain PFAS removal**. This guidance manual will take into account the effects of background water matrices and the uncertainties regarding scale-up from bench-scale performance data to field-scale design.

This project will systematically investigate short-chain PFAS removal by readily implementable treatment processes—and to a more limited extent, innovative techniques—in a wide range of background water matrices (groundwater, surface water, treated wastewater) at multiple scales (bench, pilot, full). Specific objectives are to advance the state-of-the-art of short-chain PFAS removal by (1) evaluating conventional and innovative sorbents, (2) identifying essential membrane properties, (3) assessing the impact of background water matrix parameters, (4) comparing pre-treatment options to enhance downstream adsorption, (5) developing scale-up protocols to estimate full-scale sorbent use rates, (6) generating data for residuals management (e.g., treatment of spent ion exchange regenerant by electrochemical oxidation), (7) modeling quantitative structure-property relationships to predict removal by adsorption, anion exchange, and membrane processes, and (8) applying this information towards life-cycle cost and environmental impact models. These models are being developed in a separate, recently funded research project (Department of Defense, ESTCP) that will be conducted by co-PIs Knappe and Bellona.

To address these objectives, we have assembled a diverse team of researchers, engineers and utility representatives with a wealth of research and practical experience related to PFAS treatment. We have support from approximately forty PFAS-impacted utilities as well as sizeable additional cash support from the North Carolina Policy Collaboratory and the Hampton Roads Sanitation District. We will use full-scale sampling campaigns, pilot-scale studies, and lab-scale experimentation to develop information for the guidance manual. We envision a decision support tool that will help water professionals select (1) effective treatment options for short-chain PFAS removal in their unique water matrix and (2) appropriate bench-scale tests to compare sorbents, resins, or membranes. Project outcomes will also include recommendations for the quantitative analysis of short-chain PFAS, including emerging PFEA. Project deliverables will include a concise and accessibly written guidance document for the drinking water community as well as a detailed final report. Results will also be disseminated through presentations at national and regional conferences, AWWA/TWRF webinars, and peer-reviewed publications.

Project Description

a. Background and Statement of Need

Poly- and perfluoroalkyl substances (PFAS) serve as processing aids in the production of fluoropolymers such as polytetrafluoro-ethylene (PTFE, aka Teflon) and are active ingredients in stain repellents (e.g. Scotchgard), firefighting foams, and food-contact paper coatings. Perfluoroalkyl substances are aliphatic organic compounds in which all C-H bonds of a non-fluorinated analogue have been replaced by C-F bonds (Buck et al. 2011), while polyfluoroalkyl substances contain at least one perfluorinated carbon atom, but also one or more C-H bonds. Until about 2000, use of long-chain PFAS chemistries, defined as perfluorocarboxylic acids (PFCA) with 7 or more carbon atoms (sometimes the cutoff is at 8, as written in the RFP) and perfluorosulfonic acids (PFSA) with 6 or more carbon atoms (Buck et al. 2011, OECD 2013), was dominant. The most well-studied examples of long-chain PFAS are perfluorooctanoic acid (C8) and perfluorooctane sulfonate (PFOS). Increasing evidence about ecotoxicological and human health effects associated with exposure to long-chain PFAS has led to efforts to eliminate their production and use. In May of 2016, the USEPA issued health advisory levels (HAL) for C8 and PFOS for drinking water at a sum concentration of 70 ng/L. On June 21, 2018, the Agency for Toxic Substances and Disease Registry (ATSDR) released for public comment Minimal Risk Levels for four long-chain PFAS: C8, perfluorononanoic acid (C9), perfluorohexane sulfonate (PFHxS), and PFOS (ATSDR 2018). Drinking water equivalent levels corresponding to the MRLs would be 11 ng/L for C8, 11 ng/L for C9, 74 ng/L for PFHxS, and 7 ng/L for PFOS. For PFOS and C8, the levels are substantially below the current HAL. Adoption of PFAS standards below the current HAL would greatly expand the number of drinking water providers that would need to consider PFAS treatment options (Guelfo and Adamson 2018).

As long-chain PFAS chemistries are being abandoned, industry is moving towards (1) short-chain PFAS chemistries and (2) fluorinated replacements (Wang et al. 2013, Scheringer et al. 2013). For example, the active ingredient of the stain repellent Scotchgard was changed from PFOS, an 8-carbon PFAS, to perfluorobutane sulfonate (PFBS), a 4-carbon PFAS, in 2003 (Renner 2006). The effect of global efforts to eliminate PFOS production/use is reflected in decreasing blood serum levels of PFOS in pregnant and nursing women in Sweden (Glynn et al. 2012). On the other hand, blood serum levels of PFBS and PFHxS have been rising since 2004 (Glynn et al. 2012). Similarly, Sun et al. (2016) showed that the PFAS fingerprint in the Cape Fear River basin of North Carolina shifted from long-chain PFCA dominance in 2006 to short-chain PFCA dominance in 2013.

While the move towards short-chain PFAS chemistries is tractable in a relatively straight-forward manner, the move towards fluorinated replacements represents a much more complex challenge from a standpoint of drinking water safety as well as environmental and human health assessment. As noted in the Helsingør Statement, little information is available about production volumes, uses, properties, and biological effects of fluorinated replacements (Scheringer et al. 2014). For example, DuPont began to phase out the use of C8 to manufacture Teflon around 2009/10 and replaced C8 with GenX. GenX is the ammonium salt of hexafluoropropylene dimer acid (HFPA-DA) as shown in Figure 1. When dissolved in water both GenX and HFPO-DA form the same anion. For the purposes of this proposal, GenX generically refers to the common anion. At the time this switch occurred, almost nothing was known about the molecular structure of GenX, its production volume, environmental releases, and human health effects. Only through non-targeted analysis did Strynar et al. (2015) identify GenX and other poly- and perfluoroalkyl ether acids (PFEA) in the Cape Fear River downstream of a fluorochemical manufacturer. A

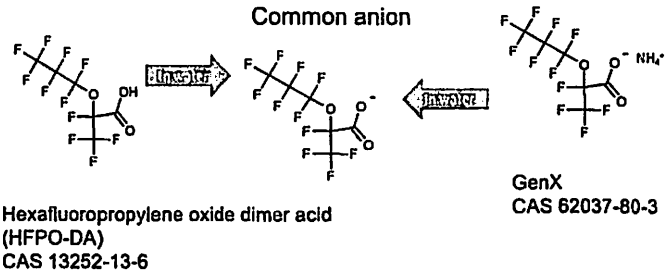


Figure 1. GenX and HFPO-DA

challenge for drinking water providers is that the presence of short-chain PFAS, fluorinated replacements, and fluorinated manufacturing by-products is typically unknown.

As highlighted by the UCMR3, PFAS occur in drinking water derived from both groundwater and surface water. Nationwide, the UCMR3 data highlight that PFAS detection in finished drinking water was more commonly associated with contaminated ***groundwater*** sources - 76% of PFAS-positive UCMR3 samples were derived from groundwater. However, in some states, such as North Carolina, PFAS detection in finished drinking water is principally linked to contaminated ***surface*** water - 79% of PFAS-positive UCMR3 samples from NC were derived from surface water. Sources of PFAS contamination are manifold and include firefighting training activities involving storage and use of aqueous film-forming foams (AFFF) at military and civilian airports (e.g. Hu et al. 2016), industrial and municipal wastewater treatment plants (Sun et al. 2016), landfill leachate (Lang et al. 2017), land applied sewage sludge (Lindstrom et al., 2011; Sepulveda et al. 2011), and air emissions from fluorochemical production facilities (e.g. Davis et al. 2007). The multitude of sources has led to the contamination of drinking water sources with a wide range of background water characteristics (e.g. sources with low/moderate/high total organic carbon (TOC), sources with low/high hardness, sulfate, alkalinity, iron), and these background water constituents strongly impact the performance of treatment processes for PFAS removal. We ***hypothesize*** that selection of the most cost-effective PFAS removal process(es) is strongly dependent on background water matrix composition and targeted PFAS.

Data Gaps

The research proposed herein is principally motivated by knowledge gaps associated with the selection of treatment approaches for the removal of short-chain PFAS, fluorinated replacements, such as GenX, and other perfluoroalkyl ether acids, and emerging PFAS associated with the use of AFFF. The **overarching goal** of the proposed research is to develop a **guidance manual** that allows water treatment professionals to select the most **cost-effective treatment options for short-chain PFAS removal**, recognizing the PFAS removal performance of individual treatment processes is strongly dependent on background water matrix effects.

Objectives

1. Identify conventional and innovative sorbents for effective control of short-chain PFAS
2. Identify membrane properties for effective control of short-chain PFAS
3. Assess the impact of background water matrix parameters on short-chain PFAS removal
4. Identify pre-treatment options that enhance PFAS removal in downstream processes; e.g. enhance TOC removal prior to granular activated carbon (GAC) adsorption
5. Develop scale-up protocol to estimate full-scale sorbent use rates
6. Develop information for residuals management (e.g., treatment of spent ion exchange regenerant by electrochemical oxidation)

7. Develop a quantitative structure-property relationship to predict the removal of structurally diverse PFAS by adsorption, anion exchange, and membrane processes.
8. Develop information for life-cycle cost and environmental impact models. These models are being developed in a separate, recently funded research project (Department of Defense, ESTCP) that will be conducted by co-PIs Knappe and Bellona.

To meet the above objectives, we have assembled a research team that has broad PFAS expertise. We have developed an ambitious research plan that builds on past and ongoing work of each team member as well as past and existing collaborations among team members. The experience of our team and the roles of each team member in this admittedly ambitious effort are described in the Project Management Plan. The effort is also made possible by additional cash contributions the team was able to raise – in particular a >$130,000 cash contribution by the North Carolina Policy Collaborative, which is available without overhead cost to support the laboratory and modeling work at NCSU. As a result, we are able to support substantial additional research efforts by the organizations of each co-PI [Colorado School of Mines (CSM), Hazen and Sawyer (HS), Southern Nevada Water Authority (SNWA), American Water (AW), the City of Ann Arbor (AA), and CDM Smith (CDM)].

Research objectives will be met by completing the following tasks:

1. Literature review and review of existing data (led by NCSU and CSM)
2. Analytical method validation among participating laboratories (NCSU, CSM, SNWA, AW)
3. Evaluation of short-chain PFAS removal in full-scale water treatment plants (led by NCSU, CSM, SNWA, AW with support from HS and CDM)
4. Systematic evaluation of established and innovative treatment approaches for short-chain PFAS removal at the bench-scale (led by NCSU and CSM with significant support from SNWA and CDM)
5. Validation of promising treatment approaches at the pilot scale (led by CSM, AW, and AA)
6. Development of quantitative structure-property relationships to predict PFAS removal by activated carbon and anion exchange treatment processes (led by NCSU with support from CSM)
7. Comparison of treatment approaches using life cycle analysis and cost models (led by CSM with support from NCSU, Hazen, CDM, and SNWA)
8. Development of a decision support tool for treatment process selection (led by HS)

b. Research Approach

Overview. In this study, we propose to investigate short-chain PFAS removal at multiple scales, from bench-scale to full-scale. To maximize the value of our study, we have recruited 39 utilities, who will either share existing data or collect new data during the course of the project, some at multiple scales. Table 1 summarizes the utility participants, the scale(s) at which PFAS removal data have been or will be collected, and the treatment processes that have been or will be investigated. Participating utilities from 16 states, stretching from the Pacific to the Atlantic coasts, are represented (Figure 2). The selection of utility participants was based on the type of source water (groundwater, surface water, treated wastewater for reuse), known presence of

short-chain PFAS, and impact by a variety of PFAS sources (e.g. manufacturing sites, military facilities, airports, etc.). Named participants include utilities in known PFAS hotspots, such as Plainfield Township, MI (impacted by waste disposal from the Wolverine shoe factory), the City of Fountain, CO (impacted by firefighting training activities with AFFF at an Air Force base), and the Cape Fear Public Utility Authority in Wilmington, NC (impacted by GenX and related compounds that originated from a fluorochemical manufacturer).

Table 1. Confirmed utility participants

Utility	State	Source Water	Study Scale			Treatment Trains Evaluated							
			Bench	Pilot	Full-scale	GAC	PAC	IX	O3	BAC	MF/UF	RO	UV-AOP
A	CA	WW			●						●	●	●
B	CA	GW			●	●							
C	CA	GW			●								
D	CA	WW	●	●		●			●	●	●	●	●
E	CO	GW			●			●					
F	CO	GWUDI			●	●				●			●
G	CO	GW		●	●	●		●					
H	FL	WW		●					●	●	●	●	●
I	FL	WW		●		●			●	●			●
J	GA	WW		●	●				●	●	●		
K	IA	SW			●					●			
L	IL	SW			●					●			
M	IL	SW			●					●			
N	IL	SW(+GW)			●					●			
O	IL	SW			●					●			
P	KS	GW			●								
Q	MA	GW	●			●							
R	MA	GW	●			●		●					
S	MI	GW+SW	●	●	●	●		●	●				
T	MI	GWUDI			●	●							
U	NC	SW		●								●	
V	NC	SW		●	●	●	●	●				●	
W	NC	SW+ASR	●	●	●	●		●	●	●			
X	NJ	GW			●	●							
Y	NJ	SW+GW			●	●							
Z	NJ	SW+GW			●	●							●
AA	NJ	SW+GW			●	●							
AB	NJ	SW+GW			●	●							
AC	NJ	SW+GW			●	●							
AD	NJ	GW			●								
AE	NJ	GW			●	●							
AF	NV	SW+WW		●		●			●	●			
AG	NV	WW	●	●		●			●	●			
AH	OH	SW		●		●				●			
AI	PA	GW			●								
AJ	PA	SW(+GW)			●	●							
AK	VA	WW		●	●	●			●	●			
AL	VA	WW		●		●			●	●			
AM	WV	SW			●	●							

GW: groundwater, SW: surface water, WW: wastewater, GWUDI: groundwater under the direct influence of surface water, ASR: aquifer storage and recovery

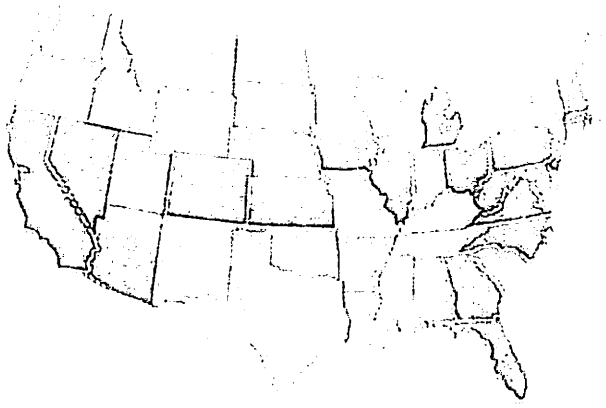


Figure 2. Locations of utility participants

Task 1: Literature Review and Review of Existing Data (NCSU and CSM)

While our team is already at the forefront of many PFAS projects currently underway, it is critical that our study builds upon past and on-going studies in order to fill existing knowledge gaps. To that end, a literature review will be conducted as a continuous process throughout this project. Project personnel, supported by graduate students and postdocs at NCSU, CSM, and SNWA will conduct an initial review of our existing database of documents, search for new literature, and then continue to track ongoing work through participation in conferences such as WQTC, ACS, and the Gordon Research Conference on emerging contaminants (2018). We do not envision a formal literature review as a deliverable to the Foundation and the PAC; rather, the information collected and discussed throughout the project will ultimately become part of the guidance document and will be used to support statements and guidelines developed as part of that document. Should the Foundation and PAC request updates on this task or information on new data/findings from outside sources, our Project Team can provide those on-going updates as part of the Quarterly Reports. We are also aware that US EPA is conducting a thorough review of the PFAS treatment literature and is planning to submit the review for publication in a peer-reviewed journal. Should enough new information be collected, the NCSU team will lead the development of a review article for a journal such as Water Research or JAWWA.

During this task, we will also assemble and analyze existing data that will be shared by named utility participants, participating AW utilities, and clients of Hazen and Sawyer and CDM Smith. As shown in Table 1, full-scale, pilot-scale, and bench-scale data are available for a wide range of treatment processes and water matrices (groundwater, surface water, wastewater). These data will be analyzed together with new data that will be collected in Tasks 2-4.

Task 2: Analytical Method Validation among participating laboratories (NCSU, CSM, SNWA, AW)

The objective of Task 2 is to assess whether each of the four participating laboratories (NCSU, CSM, SNWA, and AW) produces comparable PFAS results in a blinded round-robin analysis. All four participating labs have ongoing PFAS projects and the ability to determine PFAS concentrations in aqueous samples at drinking water-relevant concentrations (method reporting limits are in the <2-5 ng/L range for most targeted compounds). While each lab follows elements of EPA Method 537 for finished drinking water and/or EPA standard operating procedures 113.0 and 114.2 (EPA 2009, EPA 2016) for collection and analysis of environmental waters (i.e. groundwater and surface water), each lab has made modifications that increase the number of targeted PFAS analytes and enhance method performance, especially for short-chain PFAS. The team has analytical methods in place that follow the EPA Method 537 workflow closely (solid-phase extraction, analysis by LC-tandem mass spectrometry, LC/MS-MS), but other methods suitable for bench-scale studies are in place as well (e.g. large-volume direct injection, analysis by LC-quadrupole time of flight, LC/QToF-MS). Details of available analytical methods and

quality control/quality assurance (QA/QC) protocols are presented in the QA/QC document of this proposal.

Target Compounds. The focus of the proposed research is on developing treatment solutions for short-chain PFAS and fluorinated replacements such as GenX, ADONA, and other PFEA. As shown in Table 2, 16 short-chain PFAS will be targeted along with understudied precursor compounds such as fluorotelomer sulfonic acids. In addition, overlooked longer-chain PFAS will be included. In total, >35 PFAS, including 18 perfluoroalkylether acids (PFEA), were selected. The majority of the compounds shown in Table 1 were chosen because they are known to occur in drinking water sources. It should be noted that NCSU is one of very few laboratories that has authentic standards for a number of PFEA that are not commercially available. As a result, we will be able to accurately determine concentrations for a large number of PFEA and conduct controlled PFEA experiments by spiking them into aqueous matrices as described in Task 4.

Table 2 also includes a few PFAS we included because of our interest to develop quantitative structure property relationships describing PFAS removal by adsorption, anion exchange, and membrane treatment processes. Some PFAS shown in Table 2 were chosen because they (1) are members of homologous series with increasing numbers of perfluorinated methylene groups and/or ether groups, (2) exist in branched and linear forms, and (3) are available in pure form at NCSU. The list of target compounds will be finalized based on feedback from the project advisory committee should our proposal be selected for funding.

Round Robin Analysis. To conduct the round-robin analysis, each laboratory will receive three sets of samples in triplicate. These samples will be prepared by Dr. Mark Strynar at the US EPA in Research Triangle Park, NC and will include use of NIST standard reference materials. The number of PFAS analytes and their concentrations in the round-robin samples will not be known to the analysts in each of the four participating laboratories. Results from the round-robin analysis will be submitted directly to Dr. Mark Strynar, who will tabulate the results and distribute them to the research team along with the known concentrations contained in each sample. The research team will review the results and assess whether results of the round robin analysis are acceptable (i.e. within 30% of true values) or whether corrective actions are needed by one or more teams. Corrective action would lead harmonization of procedures among the four participating laboratories. An outcome of Task 2 will be a set of recommendations for the accurate analysis of short-chain PFAS.

Task 3: Evaluation of short-chain PFAS removal in full-scale water treatment plants

Overview. The objectives of this task are to (1) evaluate the behavior of short-chain PFAS (as well as long-chain PFAS) in utilities using diverse water sources (groundwater, surface water, treated wastewater) and treatment processes (PAC, GAC, anion exchange, membranes, (advanced) oxidation processes, biofilters) and (2) to conduct full-scale experiments to support optimization of GAC adsorption processes. Results from this Task will demonstrate the effectiveness of full-scale treatment processes for PFAS removal. In addition, we will explore whether oxidation/ disinfection processes have the potential to increase the concentrations of PFAS we are targeting (Table 2).

Table 2. Proposed List of Target Compounds

PFAS Name (Abbreviation)	MW	PFAS Name (Abbreviation)	MW
Perfluoroalkylcarboxylic acids ($C_nHF_{2n-1}O_2$)			
Perfluoroacetic acid (PFAcA=C2)[+]	114	Pefluoroheptanoic acid (PFHpA=C7)*	364
Perfluoropropanoic acid (PFPrA=C3)[+]	164	Perfluorooctanoic acid (PFOA=C8)*	414
Perfluorobutanoic acid (PFBA=C4)*	214	Perfluorononanoic acid (PFNA=C9)*	464
Perfluoropentanoic acid (PFPeA=C5)*	264	Perfluorodecanoic acid (PFDA=C10)*	514
Perfluorohexanoic acid (PFHxA=C6)*	314		
Perfluoroalkyl carboxylic acids with one ether group ($C_nHF_{2n-1}O_3$)			
Perfluoro-2-methoxyacetic acid (PFMOAA)	180	Perfluoro-2-ethoxypropanoic acid (PFEOPrA branched)	280
Perfluoro-2-methoxypropanoic acid (PFMOPrA branched)	230	Perfluoro-3-methoxybutanoic acid (PFMOBA linear)	280
Perfluoro-3-methoxypropanoic acid (PRMOPrA linear)	230	Perfluoro-2-propoxypropanoic acid (PFPrOPrA) = hexafluoropropylene oxide-dimer acid (HFPO-DA = "GenX")*	330
Per- and polyfluoroalkylcarboxylic acids with one or more ether groups ($C_nHF_{2n-1}O_4$)			
Perfluoro-4-dimethylmethoxybutanoic acid (PFDMMOBA)	380	Perfluoro-4,8-dioxa-3H-perfluorononanoic acid (ADONA parent acid)	378
Perfluoro-3,5-dioxahexanoic acid (PFO2HxA)	246	Perfluoro(3,6,9-trioxatridecanoic) acid (PFO3TDA)	446
Perfluoro-3,5,7-trioxaoctanoic acid (PFO3OA)	312	Perfluoro(3,6-dioxadecanoic) acid (PFO2DA)	412
Perfluoro-3,5,7,9-tetraoxadecanoic acid (PFO4DA)	378	Nafion by-product 4	442
Perfluoroalkylsulfonic acids ($C_nHF_{2n+1}SO_3$)			
Perfluoroethane sulfonic acid (PFEtS)[+]	200	Perfluorohexane sulfonic acid (PFHxS)*	400
Perfluorobutane sulfonic acid (PFBS)*	300	Perfluoroheptane sulfonic acid (PFHpS)	450
Perfluoropentane sulfonic acid (PFPeS)	350	Perfluorooctane sulfonic acid (PFOS)*	500
Per- and polyfluoroalkylsulfonic acids with one or more ether groups			
NVHOS	298	Nafion by-product 1	444
F-53B	533	Nafion by-product 2	464
Precursor compounds			
4:2 fluorotelomer sulfonic acid (4:2 FtS)*	328	6:2 fluorotelomer unsaturated carboxylic acid	358
6:2 fluorotelomer sulfonic acid (6:2 FtS)*	428	8:2 fluorotelomer unsaturated carboxylic acid	458
4:2 fluorotelomer unsaturated carboxylic acid	258		

[+] percent removal measurements, but no quantitation of concentrations

* matched mass-labeled internal standard available

Approach. The occurrence and removal of short-chain PFAS across full-scale water systems treating a wide variety of water sources that are located downstream and/or the vicinity of known sources of PFAS will be evaluated in this task. At the time of this writing, we have received commitments from 39 utility participants (Table 1), and we anticipate that, with input from the PAC and TWRF, additional utilities will be added to this Task. The division of labor for this Task will be as follows: AW will analyze samples from 19 AW participants, and SNWA will analyze the 9 water reuse systems (indicated by WW source in Table 1). Of the remaining plants, CSM will analyze samples from plants located in CO and to the west and NCSU from plants located to the east of CO. For this task, we propose to evaluate removal (or production, Xiao 2018) of PFAS (Table 2) by sampling the raw and finished water from all participants twice,

once ~4 months after the project start date, and once ~6 months thereafter. Collection of finished water samples will take into account the hydraulic residence time (HRT) of the plant. E.g. if a plant has and HRT of 24 hours, the finished water sample will be collected 24 hours after the raw water sample. In addition, more intense monitoring will be conducted at utilities that, based on the first sampling campaign, exhibit elevated short-chain PFAS levels in their raw water, operate processes capable of PFAS removal, and/or exhibit an increase in PFAS levels across the plant. At the latter plants, we will sample the raw and finished water as well as the influent and effluent of individual treatment processes capable of PFAS removal (or production) quarterly during four consecutive quarters. A more comprehensive full-scale testing will also be performed for the Hampton Road Sanitation District's GAC process, i.e., to capture breakthrough behavior for PFAS after fresh GAC has been implemented (reflected in cash contribution to SNWA to support additional analyses). In addition to PFAS analyses, selected water quality parameters (e.g. pH, TOC, turbidity, alkalinity, TDS) will be determined during the course of the study.

Task 4: Systematic evaluation of established and innovative treatment approaches for short-chain PFAS removal at the bench-scale

4.1. GAC Introduction (NCSU leads) – GAC is used extensively for PFAS removal from drinking water sources because it effectively adsorbs certain PFAS, such as long-chain PFAS. However, relatively early breakthrough has been observed for short-chain PFAS . Pilot data collected by a NC utility participant treating coagulated surface water showed that GenX and other short-chain PFAS broke through within 5,000 bed volumes for two GAC products (Hopkins et al. 2018). The performance of GAC for PFAS removal depends on numerous factors including GAC characteristics, source water PFAS species and concentrations, source water chemistry (e.g., presence of background organic matter, co-contaminants) and design/operating parameters (e.g. empty bed contact time, EBCT). GAC pilot data collected by co-PI Bellona on contaminated groundwater illustrated that GAC selection is of critical importance as certain products exhibited much earlier short- (and long-)chain PFAS breakthrough than other products. Currently, there is minimal guidance on GAC selection for short-chain PFAS removal as well as the treatment and life cycle costs associated with GAC compared with competing technologies. The latter is important as exhausted GAC must be disposed of, or shipped to a regeneration facility periodically for energy-intensive thermal regeneration.

The ***goal of the proposed bench-scale testing program*** is to answer the following questions: (1) Is there adsorption competition among co-existing PFAS and, if so, do the competitive effects manifest themselves in terms of earlier breakthrough and/or peaking (GAC effluent concentrations > GAC influent concentrations), (2) Can bench-scale RSSCT data be used reliably for (a) GAC selection and (b) prediction of GAC service life, (3) what GAC properties are associated with effective short-chain (and other) PFAS removal, (4) how does the background water matrix affect PFAS removal (groundwater, coagulated surface water, treated wastewater), and (5) what opportunities exist to enhance GAC service life for short-chain PFAS removal by optimizing pretreatment (e.g. PAC, MIEX)?

Task 4.1.1 - Select most appropriate RSSCT design for scale-up and subtasks 4.1.2-4.1.5. Scale-up of RSSCT data to estimate field-scale GAC service life for micropollutant removal is challenging as RSSCTs overpredict field-scale GAC service life (Summers et al. 2014). The reason for the overprediction is that the smaller GAC particles used in RSSCTs are less impacted by background organic matter fouling than the larger GAC particles used in field-scale adsorbers. Intraparticle diffusivity controls adsorption kinetics. However, studies conflict about

whether intraparticle diffusivity is independent or linearly related to particle size, leading to the design of constant diffusivity RSSCTs (CD-RSSCTs) or proportional diffusivity RSSCTs (PD-RSSCTs), respectively (Crittenden et al. 1991; Summers et al. 2014). Nevertheless, CD-RSSCTs are more commonly used for GAC selection and estimation of GAC service life because CD-RSSCTs can be completed in a shorter time than PD-RSSCTs. Given the many objectives of the project proposed herein, perfecting a scale-up approach that permits estimation of field-scale GAC service life for short-chain PFAS removal from RSSCT data is likely not feasible. What is feasible, however, is to identify the RSSCT design that is most appropriate for GAC selection for short-chain PFAS removal. For this purpose, linking RSSCT data to pilot-scale data in this study is of critical importance. We will also explore whether fouling factors, as proposed by Summers et al. (2014), can be used to scale RSSCT data for estimation of GAC service life.

Approach. In PI Knappe's lab, we have evaluated three types of RSSCT designs: (1) mini-column CD-RSSCTs that permits rapid completion of the experiment (< 1 week) (Knappe et al. 1997), (2) conventional CD-RSSCTs that permit relatively rapid completion of the experiment (< 1 month) and (3) PD-RSSCTs that require a longer time to complete the experiment, ~3 months for long-chain PFAS in groundwater at a simulated EBCT of 20 minutes. In this subtask, we will complete RSSCTs with waters from utilities W (coagulated SW with moderate TOC) and Z (GW with low TOC). Matching pilot data are available (utility W, EBCT = 10 min, bituminous coal-based GAC and enhanced coconut GAC) or will be collected during the project (utility Z, EBCT = 10 min, bituminous coal-based GAC). Utility W is impacted by PFAS discharged by a fluorochemical manufacturer and contains a range of PFEA, including GenX, while utility Z is impacted by AFFF-derived PFAS. If needed, PFAS will be spiked into the RSSCT influents to match concentrations present during the pilot study.

For each water/GAC combination, a set of three RSSCTs will be completed: (1) mini-column CD-RSSCT, (2) conventional CD-RSSCT, and (3) PD-RSSCT. For the SW utility (W), RSSCTs will be conducted with both GACs, for which pilot data exist, to more robustly assess which RSSCT design is most appropriate for GAC selection and estimation of service life for short-chain PFAS removal. Resulting RSSCT breakthrough curves will be compared to pilot data, and we will assess how well RSSCT data describe pilot-scale PFAS adsorption kinetics (shape of the breakthrough curve) and adsorption capacity (position of RSSCT breakthrough curves relative to pilot-scale breakthrough curves). We currently have six RSSCT setups (see methods section), and a total of 9 RSSCTs will be completed in this sub-task. This sub-task is expected to take 3 months to complete.

Task 4.1.2. Effect of co-existing PFAS on onset of PFAS breakthrough and PFAS peaking. A second key knowledge gap is whether there is adsorption competition among PFAS that co-occur in drinking water sources. PFAS generally occur at ng/L levels in drinking water sources, and it is generally assumed that background organic matter constituents are primarily competing with PFAS for adsorption sites while adsorption competition among co-existing PFAS is negligible. However, this assumption has not been validated for GAC adsorption systems. Similarly, the impacts of background organic matter type and concentration on the extent of GAC fouling and the peaking of short-chain PFAS has not been quantified. By peaking, we mean that the concentration of a PFAS in the GAC effluent is higher than in the GAC influent as a result of its displacement by one or more strongly adsorbing constituents. Peaking for short-chain PFAS is expected to occur (based on existing bench-scale and pilot-scale data) when the GAC

replacement or regeneration frequency is based on breakthrough levels of longer-chain PFAS, as illustrated in Figure 3 for C4 and C5 when breakthrough exceeds 100%.

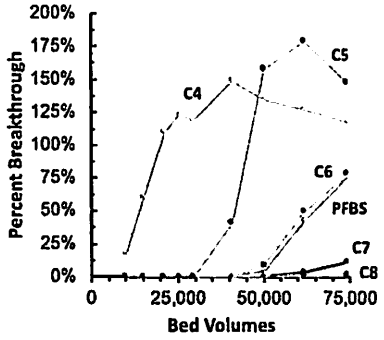


Figure 3. PFAS breakthrough curves obtained with enhanced coconut GAC in GW with low TOC. PD-RSSCT, EBCT = 15 min

Approach: Using the most appropriate RSSCT design selected in Task 4.1.1, we will conduct RSSCT as follows: using "PFAS-free" GW with low TOC (<0.5 mg/L) and coagulated SW with moderate TOC (2-3 mg/L), we will conduct a pseudo-single-solute RSSCT with C6 only, a pseudo-bisolute experiment with two PFAS of similar adsorbability (C6 and PFBS, see Figure 3), and a bi-solute experiment containing a more weakly adsorbing short-chain PFAS (C6) and a more strongly adsorbing long-chain PFAS (C8). All compounds will be spiked into "PFAS-free" water matrices at a level of 100 ng/L. RSSCTs will be conducted with bituminous coal-based GAC and will simulate a field-scale EBCT of 10 min. Results will show whether or not co-existing PFAS affect onset of PFAS breakthrough as well as PFAS peaking in low TOC GW and in coagulated surface water with moderate TOC. A total of 6 RSSCTs will be conducted in this subtask, which will require 2 months to complete.

Task 4.1.3. Linking PFAS removal performance to GAC properties. Using the most appropriate RSSCT design determined in Task 4.1.1, we will evaluate the effect of GAC properties on PFAS removal. We will include at least six well-characterized GACs prepared from different starting materials (2 bituminous coal, 1 coconut/coal blend, 1 enhanced coconut, 1 coconut, 1 lignite) with widely different pore size distributions. Experiments in this sub-task will be conducted with the same waters as in 4.1.1 (low TOC GW, coagulated SW with moderate TOC), but in this sub-task, we will spike all compounds shown in Table 2 into the RSSCT influent at a level of 100 ng/L each. RSSCTs will simulate an EBCT of 10 min. Results of this subtask will show whether GAC selection is influenced by the background water matrix (i.e. is the best GAC for GW different than the best GAC for SW?) and whether GAC selection is influenced by PFAS type (is the best GAC for C4 removal different than the best GAC for GenX removal?). One of the bituminous coal GACs and the enhanced coconut GAC will be the same as in 4.1.1. As a result, RSSCTs results for the two GAC obtained in this subtask can be compared to those in 4.1.1, which will allow us to assess whether the addition of PFAS beyond those present in the pilot study impacted onset of PFAS breakthrough and/or PFAS peaking. Finally, the results obtained in subtask 4.1.3 will serve as a basis for QSPR development (Task 6). Completion of this subtask (12 RSSCTs) is expected to take 3 months.

Task 4.1.4. Effect of background water matrix and EBCT. One important knowledge gap is how the character and concentration of background organic matter in the GAC influent affects GAC service life for PFAS removal. In this subtask, we will conduct RSSCTs with a wide range of water types as follows:

- GW with high TOC (utility G)
- Coagulated SW with low (utility AF) and high (Utility K) TOC
- GW/SW blend (utility S), GWUDI (utility T), ASR (utility W)
- Treated WW (utility AF)

RSSCT influent will be spiked with the PFAS shown in Table 2 (100 ng/L each). RSSCTs in this sub-task will be conducted with a GAC that performed well in subtask 4.1.3 at simulated EBCTs of 10 and 20 minutes. For this purpose, two RSSCT columns will be operated in series with an additional sampling port between the two columns. All RSSCT influents will be characterized in terms of their organic and inorganic composition. Based on prior results (Dudley et al. 2015), we do not expect pH and ionic strength (total dissolved solids) to affect PFAS removal by GAC. In contrast, background organic matter will likely have a strong effect. We will characterize background organic matter by its dissolved organic carbon (DOC) concentration, UV absorbance spectrum, and excitation-emission matrix. Data collected in this subtask will answer how background matrix characteristics impact PFAS removal and whether selection of the "best" GAC depends on the background water matrix. Also, the data will illustrate how carbon use rates are impacted by EBCT. Results of this subtask will be used for model development (Task 6).

Task 4.1.5. Effect of pretreatment. A final important question we plan to explore is whether GAC influent can be pretreated in a manner that extends GAC service life for PFAS removal. Three pretreatment options that will remove or alter background organic matter will be explored: PAC adsorption, MIEX treatment, and ozonation. PAC and MIEX pretreatments will be explored with coagulated surface water with high TOC from utility K. PAC and MIEX treatment conditions will be chosen such that either treatment lowers the RSSCT influent TOC by ~25%. Subsequently, all PFAS shown in Table 2 will be spiked into the pretreated RSSCT influent to match levels in non-treated controls. RSSCT results for utility K will be compared to those obtained in 4.1.4. To assess the effect of ozonation, coagulated surface water from utility W will be evaluated. It should be noted that water from utility W for subtasks 4.1.1 and 4.1.3 will be collected at the plant following raw and settled water ozonation. In this subtask, we will collect raw water from utility W and coagulate it prior to conducting the RSSCT to avoid the full-scale ozonation step. Raw water for this subtask will be collected on the same day as the coagulated, settled, ozonated water for 4.1.1 and 4.1.3 to assure comparability. RSSCT results for utility W in this subtask will be compared to those obtained in 4.1.3. Results from this sub-task will highlight to what extent PAC, MIEX, and ozone pre-treatment change carbon use rates for the control of short-chain (and other) PFAS.

4.2. IX Introduction (NCSU leads) – Although used less extensively than GAC, anion IX has garnered recent attention as an alternative to GAC. Several studies have evaluated the removal of long- and short-chain PFASs by anion-exchange resins (McCleaf et al. 2017, Woodard et al. 2017, Zaggia et al. 2016, Dudley et al. 2015). For example, Woodard et al. (2017) showed that the number of bed volumes to the onset of PFAS breakthrough was larger for anion exchange than for GAC treatment. Differences were more pronounced for longer-chain PFASs compared with shorter-chain PFASs, and more pronounced for sulfonic acids compared with carboxylic acids with the same number of perfluorinated carbons. To evaluate PFEA removal, a pilot study evaluating anion-exchange resins at a utility in the lower Cape Fear River basin is ongoing. Pilot columns (EBCT = 1.5 min) showed that GenX was removed to below the method reporting limit of 5 ng/L for at least 27,400 BV, and GenX removals for the two tested resins were 38 and 75% after treating 62,500 BV (CFPUA, 2017). Also, no detectable breakthrough was observed for Nafion byproduct 2, PFOA, or PFOS after 62,500 BV of water had been treated. The latter data were collected in coagulated surface water with moderate TOC and low total dissolved solids (TDS) concentrations. Results from controlled laboratory studies suggest that background organic matter does not appear to substantially impact IX resin performance for PFAS removal (Dudley et al. 2015). In contrast, we do expect that IX resin performance is adversely impacted

by increasing concentrations of competing anions, especially sulfate and nitrate (Dudley et al. 2015). While these results are encouraging, further evaluation is needed before life cycle costs of anion exchange and GAC treatment options can be compared. Management of spent anion-exchange resin requires careful consideration. Spent resin can be regenerated on site, landfilled, or incinerated. On-site resin regeneration would require the development of a suitable regeneration strategy that may require both brine and an organic solvent (McCleaf et al. 2017, Woodard et al. 2017, Zaggia et al. 2016, Dudley et al. 2015) and management of the spent brine that contains high levels of PFASs. Currently, there are several related projects evaluating IX regenerant treatment including non-thermal plasma (NTP), electrochemical processes, UV-persulfate, UV-bisulfite, and distillation. Methods to address the IX regenerant stream will also be examined in a new SERDP Project (ER18-1063), on which co-PI Schaefer is involved.

Task 4.2.1. Selection of bench-scale approach. To date, there is little experience with scale-up of bench-scale IX data for PFAS removal. Guidance is therefore needed for a suitable bench-scale test that can be used for IX resin selection and for estimating resin service life in different background water matrices. Ongoing work in co-PI Schaefer's lab is evaluating CD-RSSCTs with crushed IX resin for scaleup, and ongoing work in PI Knappe's lab is evaluating a small column test conducted with as-received resin at the same EBCT as a corresponding pilot column, but with a lower hydraulic loading rate. In this subtask, we will build on ongoing work and also explore mini-column CD-RSSCTs for their suitability to more rapidly complete bench-scale evaluations. Since background organic matter does not appear to substantially impact IX resin performance for PFAS removal (Dudley et al. 2015, CFPUA 2017), we do not anticipate that the PD-RSSCT approach needs to be evaluated for IX resins.

Approach. In this subtask, we will complete bench-scale experiments with waters from utilities W (coagulated SW with moderate TOC and low TDS) and Z (GW with low TOC and high TDS). Matching pilot data are available (utility W, EBCT = 1.5 and 3 min, IX resins A and B) or will be collected during the project (utility Z, EBCT = 3 min, IX resin A). Utility W is impacted by PFAS discharged by a fluorochemical manufacturer and contains a range of PFEA, including GenX, while utility Z is impacted by AFFF-derived PFAS. If needed, PFAS will be spiked into the bench-scale column influents to match concentrations present during the pilot study.

For each water/IX resin combination, a set of three bench-scale tests will be completed: (1) mini-column CD-RSSCT, (2) conventional CD-RSSCT, and (3) bench-scale column with as-received IX. For the SW utility (W), bench-scale data will be conducted with two resins, for which pilot data exist, to more robustly assess which bench-scale approach is most appropriate for GAC selection and estimation of service life for short-chain PFAS removal. PFAS breakthrough curves will be compared to pilot data, and we will assess how well RSSCT data describe pilot-scale PFAS adsorption kinetics (shape of the breakthrough curve) and adsorption capacity (position of RSSCT breakthrough curves relative to pilot-scale breakthrough curves). A total of 9 RSSCT/column tests will be completed in this sub-task. This sub-task is expected to take 3 months to complete. This sub-task will be conducted in parallel with 4.1.1 experiments to assure that identical influents will be used for IX and GAC experiments.

Task 4.2.2. Effect of co-existing PFAS on onset of PFAS breakthrough and PFAS peaking. Using the most suitable test identified in 4.2.1, NCSU will conduct bench-scale studies to evaluate the effect of co-existing PFAS on resin performance using the experimental approach described for GAC in 4.2.2. Experiments will be conducted in parallel with 4.1.2.

Task 4.2.3. Linking PFAS removal performance to IX properties. Using the most suitable test identified in 4.2.1, up to five strong base anion exchange resins will be assessed for their PFAS removal effectiveness. Resins that have shown promise in previous studies will be included in the selection process as well as effective resins that are currently being evaluated at our utility participants and at DoD sites. The experimental design will be similar to that proposed for GAC in 4.1.3 (same waters, but different EBCTs) and will include evaluation of all PFAS listed in Table 2. Experiments will be conducted in parallel with 4.1.3

Task 4.2.4. Effect of background water matrix (and EBCT). An important knowledge gap is how the background water matrix affects PFAS removal by IX. In contrast to GAC, we anticipate that PFAS removal by IX will be more strongly impacted by competing inorganic anions (e.g. sulfate, nitrate) than by background organic matter (Dudley et al. 2015). A testing matrix will be developed to assess the impact of water chemistry on IX performance for PFAS removal. Through participating utilities our team has access to different background matrices with a range of sulfate, nitrate, hardness, total dissolved solids, and TOC concentrations, as well as a wide range of water sources (groundwater, surface water, treated wastewater). We will also evaluate the effect of EBCT (1.5 and 3 min at the field scale) in this subtask by operating to IX resin columns in series.

Task 4.3. GAC/IX Introduction (NCSU leads) - Our team has hypothesized that a GAC/IX treatment train may be advantageous as longer-chain PFAS will be preferentially removed by GAC, along with other organic micropollutants and disinfection by-product (DBP) precursors, leaving the adsorption of short-chain PFAS as the treatment objective for the IX resin. Key benefits of a treatment train approach are (1) **Lower GAC replacement frequency by focusing GAC treatment on removal of long-chain PFAS**, while allowing short-chain PFAS to break through the GAC for subsequent removal by IX, and (2) **Effective removal of short-chain PFAS by IX and the possibility for on-site IX resin regeneration**, which is more readily accomplished for short-chain PFAS than for long-chain PFAS (Dudley et al. 2015). While a GAC/IX treatment train approach may facilitate on-site regeneration of IX resins, we expect that utilities with multiple treatment objectives (pharmaceuticals, DBP precursors, etc.) may benefit from the treatment train approach even with single-use IX resins if GAC service life can be substantially prolonged by relying on the IX resin for short-chain PFAS removal.

Approach. Using the most effective bench-scale testing approaches identified in Task 4.2, we will explore possible benefits of operating a GAC/IX resin treatment train for short-chain PFAS removal. Experiments will be conducted with waters from utilities W (coagulated SW with moderate TOC and low TDS) and S (softened GW/SW blend with moderate TOC and high chloride and sulfate). Bench-scale columns will be operated with the most effective GAC and IX resin identified in Task 4.2 and will simulate field-scale EBCTs of 10 min for the GAC and 1.5 min for the IX resin. Results from the GAC/IX treatment train will be compared to results obtained for individual GAC and IX columns obtained in Tasks 4.1 and 4.2 to assess the impact of a treatment train approach on carbon and resin use rates. Data obtained here will also be used in Task 7, where we will explore optimization of GAC and IX treatment operations using models. For example, we will explore whether a GAC/IX treatment train offers benefits relative to a GAC lead/lag design.

Task 4.4 – Powdered Activated Carbon (PAC) and Innovative Sorbents Introduction (SNWA leads, NCSU supports). This task will focus on the evaluation of innovative sorbents and index their PFAS removal performance to that of PAC. Many innovative sorbents have been

proposed for PFAS treatment, but have not yet been systematically evaluated for short-chain PFAS in relevant water matrices. One such class of innovative sorbents contains cyclodextrins. Typical cyclodextrins consist of six to eight glucose monomers in a ring. Contaminants such as PFOA form host-guest inclusion complexes, with the contaminant bound inside the cyclodextrin ring (Karoyo et al., 2011). By selecting different sizes of cyclodextrin rings (Weiss-Errico et al., 2017a), or choosing different monomers to cross-link cyclodextrin polymers (Xiao et al., 2017), cyclodextrin can be "tuned" for specific contaminants. Cyclodextrin polymers with fluorinated cross-linkers appear especially effective (Xiao et al., 2017), possibly due to C-F to C-F fluorophilic interactions (Du et al. 2017). One of these cyclodextrin polymers became recently commercially available as CycloPure CD-PFAS (CycloPure, 2018).

Another promising class of innovative sorbents is organoclays. Synthetic organoclays are "swellable" and so have greater, faster adsorption than natural minerals (Martin et al., 2018). These sorbents can be resilient to competition or pore blockage: organo-functionalized swelling mica achieved 68-78% removal of PFBA in aqueous solution, tap water, surface water, raw wastewater, and treated wastewater with the same sorbent dose (Martin et al., 2018). It is expected that more mesoporous sorbents will perform better for PFAS removal by promoting hemi-micelle self-aggregation (Du et al., 2014) and reducing pore blockage (Newcombe et al., 2002). Preliminary data suggest mesoporous organosilica may be even more effective for PFBA than PFOA at concentrations in the ppb range (Horst et al., 2018). Mesoporous organosilicas are commercially available as both a bulk adsorbent (Osorb) and a coated filtration sand medium (PuraSorb) (Horst et al., 2018).

Hydrophobic polymers constitute a third category of innovative sorbents for PFAS. One such hydrophobic polymer, PA-F 2600, had higher adsorption capacity for PFOS than activated carbon or anion exchange resins in the environmentally relevant μg/L range (Schuricht et al., 2017). This is because adsorption in water requires replacement of the previously adsorbed species – water, in the case of activated carbon, or monovalent ions in ion exchange resins. At low concentrations, the driving force of PFOS adsorption may be too weak to displace the water or ions effectively. However, due to the high hydrophobicity PA-F2600, water molecules are easily replaced by PFOS. PA-F 2600 is also more mesoporous than activated carbon (Schuricht et al., 2017), which has benefits for PFAS sorption as described above. This innovative sorbent has not yet been tested to determine if its superior performance at environmentally relevant concentrations of PFOS extends to short-chain PFAS.

Approach. Three innovative sorbents (CD-PFAS, Osorb, and PA-F 2600), will be compared to a reference PAC for short-chain PFAS removal from groundwater, surface water, and wastewater effluent. Selected waters will span a range of TOC concentrations to probe competitive effects. Each water will be spiked with 200 ng/L of each PFAS (Table 2). Batch tests will be conducted to determine the dose of each sorbent required to remove all short-chain PFAS by at least 90% in both wastewater effluents. Samples will be collected after 0.5 hours and 24 hours of mixing time, representative of PAC contact times in conventional treatment and superpulsators. To the extent possible, equal particle diameters will be used for all sorbents so that any differences in sorption rate reflect different properties among the sorbents and not merely differences in particle diameter. If results from batch tests are promising, innovative sorbents will also be evaluated in bench-scale column tests using the most challenging of the above water matrices. Breakthrough bed volumes will be determined for each sorbent and PFAS, and the rank order of most effective

sorbents will be compared between batch and column testing. Results from column tests will be compared to those obtained with GAC in Task 4.1.4.

4.5. SPAC/MF Introduction (CSM leads) - Super-fine powdered activated carbon (SPAC) has the potential to be a superior adsorbent due to an increased quantity of mesopores and macropores on wet milled carbons as well as a smaller particle size that enhances PFAS adsorption kinetics (Dudley, 2012). These advantages could result in a lower quantity of activated carbon being used for PFAS adsorption as well as faster adsorption kinetics requiring shorter contact times (Yu et al., 2009). Adsorbability of PFAS is often chain-length dependent with short-chained PFAAs (<C6 for sulfonic acids; <C8 for carboxylic acids) being more resistant to treatment compared to longer-chained PFAS (Appleman et al., 2014; Sun et al., 2016; Buck et al., 2011) Factors associated with the preferential adsorption of longer-chained PFAS and natural organic matter present in source water can lead to a faster breakthrough of the shorter-chained PFAS (Appleman et al., 2014). In addition, there is currently little understanding of the removal mechanisms of additional intermediate PFAS that have received limited attention, including polyfluorinated precursor chemicals. The purpose of this task is to evaluate SPAC/MF on a variety of source waters for the removal of short-chained PFAS as well as longer-chained PFAS including PFAAs, GenX and precursors.

CSM has been conducting experiments with a SPAC/MF product from Aqua-Aerobics (subsidiary of METAWATER) fro treatment of contaminated groundwater and fire-fighting training area run-off. Wood-based SPAC was compared to bituminous coal based GAC for treating PFAS from a contaminated groundwater sample. Results indicate that the SPAC/MF system provided a significantly higher adsorption capacity (based on PFAS adsorbed/mass carbon to 10% breakthrough) than the best performing GAC product (F400, Calgon Carbon Corporation; Table 3). Additional testing on highly contaminated fire-fighting training area water showed that SPAC was approximately 100 times more effective than GAC.

Table 3. Adsorption mass loading rate (μg PFAA/g activated carbon) for SPAC/CMF and GAC tested with contaminated groundwater.

	PFOS	PFHxS	PFBS	C8	C7	C6	C5	Sum PFAAs
GAC	≥2.4	2.2*	0.015*	0.86*	0.0033*	0.43*	0.12*	6.2
SPAC/CMF	≥3.8	3.3	0.043*	1.5	0.49	1.2	0.90	11.0

*Indicates that 10% breakthrough was observed

Task 4.5.1 – Identification of best PAC/SPAC product. Work to date has been performed with a wood-based SPAC (Aqua-Aerobics); however, SPAC sourced from other materials may provide better adsorbability. The research team will work with activated carbon vendors to obtain additional SPAC samples for PFAS removal during the course of the proposed project.

Task 4.5.2 – Evaluation of operating conditions. Limitations associated with the SPAC/MF system include energy requirements associated with cross-flow filtration, limited understanding of the exhausted SPAC wasting rate, and critical permeate flux to minimize fouling. Once a promising SPAC product has been identified for short-chain PFAS removal, experiments will be conducted to determine the optimal cross-flow velocity and permeate flux to minimize energy requirements while estimating the SPAC wasting rate based on exhaustion. This information will be used to develop a cost comparison between GAC and IX, and SPAC/MF.

Approach. Water samples used for this task will be based on Tasks 4.1 and 4.2 to compare use rates of SPAC to those of IX and GAC for removal of PFAS with a wide range of properties (Table 2). For this work, a lab-scale ceramic MF (CMF) system will be used for experimentation. Approximately 80 L of source water will be fed into a 10-L conical feed SPAC adsorption tank at the rate of CMF permeate flux. SPAC doses between 100 – 1,000 mg/L will be evaluated, and experiments will be performed to evaluate effective cross-flow velocities and permeate flux set-points on membrane operation, as well as long-term PFAS/SPAC adsorbability. If required, short-chain PFAS and fluorinated replacements will be spiked into source water at 200 ng/L. PFAS adsorption capacity at breakthrough (e.g., μg-PFAS/g-SPAC) will be used as a metric of comparison to GAC and IX treatment systems.

4.6. Nanofiltration (NF) and Reverse Osmosis (RO) Introduction (CSM leads) - High-pressure membrane technologies can provide an efficient PFAS barrier and are commonly used for treatment of a variety of water resources (Appleman et al., 2014). Prior bench-scale results from co-PI Bellona show that NF and RO membranes effectively reject short-chain PFAS, such as C4 (Appleman et al., 2014), and a recently completed pilot study at one of our utility participants shows that RO membranes also reject PFEA, including GenX and PFMOAA, the PFEA with the lowest molecular weight in Table 2. However, there are discrepancies regarding the rejection of short-chain PFAS based on past research (Appleman et al., 2014; Steinle-Darling and Reinhard, 2008). The main drawback to RO and NF is the continuous production of a retentate or concentrate stream requiring treatment and/or disposal. NF provides a significant advantage over RO as it can operate at significantly lower pressure and generally does not result in inorganic scaling. Fouling of membranes and requirements for high operating pressures can lead to high costs and energy needs. The ultimate goal of this task is develop a robust dataset with the goal of reporting on the removal of short-chain PFAS by NF and RO membranes for a variety of source waters.

For this work, we will leverage an ongoing project funded by the Air Force Civil Engineering Center (AFCEC) entitled: 'Sequential nanofiltration with UV destructive treatment' (AFCECBAA 16-001-031). In this project, we are testing a variety of NF and RO products for the removal of a broad-range of PFAS (including short-chain PFAS and PFAS with the potential to adsorb to membranes) from several different source waters at both the bench- and pilot-scale. Pictures of CSM bench- and pilot-scale membrane testing systems are provided in Figure 4.

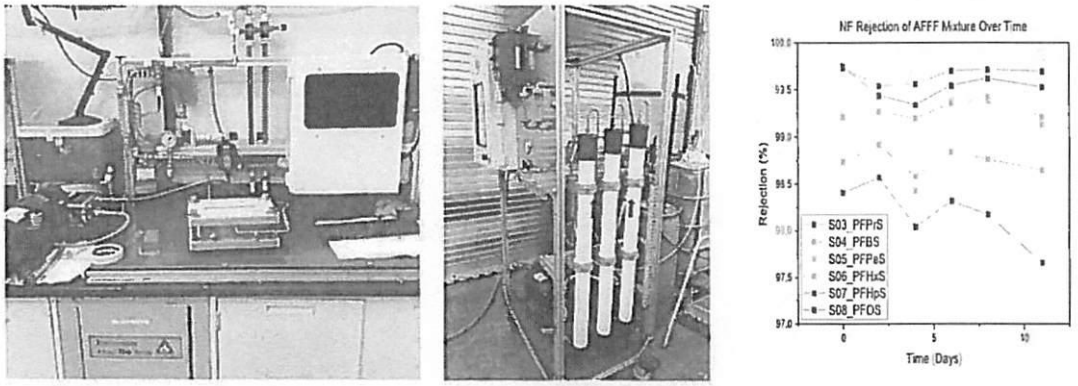


Figure 4. (Left) bench-scale membrane system at CSM, (middle) pilot-scale membrane system at CSM, (right) rejection of PFAS as a function of time by NF270.

We diluted an AFFF formulation to 30 μg/L PFOS and evaluated the effectiveness of NF (NF270, Dow/Filmtec) and RO (ESPA2, Hydranautics) for PFAS removal at the pilot-scale. Greater than 97% removal of the quantified PFAS was achieved (Figure 4, right). For this project, we will build on our ongoing research to further investigate removal of short-chain PFAS, including fluorinated replacements by NF and RO.

Work being conducted at CSM in conjunction with an AFCEC project has been evaluating commercially available NF and RO products for the removal of short- and long-chain PFAS, including precursors. Outcomes of this task include (1) treatability data and (2) a protocol (step-by-step instructions) for laboratory-scale treatability testing. This protocol will assure accurate and comparable treatability tests. Based on past membrane-based projects, the team has selected the NF-270 (NF; Dow/Filmtec) and the ESPA2 (RO; Hydranautics) as promising membrane products. Based on ongoing and future work, the team may evaluate additional membrane products if necessary.

Currently, the team is evaluating the influence of operating parameter on PFAS rejection, including permeate flux, recovery and water chemistry (e.g., pH, ionic strength). In particular, CSM has been diluting AFFF formulations, adding it to our NF/RO system feed container and running experiments evaluating permeate flux and recovery for the identified NF and RO membranes. Removal of short-chain PFAS during this work will be summarized and included in the final report for this project.

Approach. Beyond AFCEC sponsored work, effectiveness of NF/RO for removal of short-chain PFAS will be evaluated in this study with up to three PFAS-impacted waters (preliminarily, utilities G, W and AF; groundwater, surface water impacted by GenX, and treated wastewater, respectively). The rejection of PFAS including short-chain compounds and fluorinated replacements will be evaluated using the aforementioned bench-scale membrane testing system. PFAS (Table 2) will be spiked into feed solutions at 200 ng/L each. Membrane experiments will be conducted to evaluate the influence of operating parameters including permeate flux (10, 20, 30 LMH) and recovery (up to 85%) on PFAS removal. Operating parameters will be continually monitored by a SCADA system to evaluate flux decline due to fouling and energy requirements for filtration. Long-term filtration experiments will also be conducted to evaluate the rejection of solutes with potential solute-membrane interactions.

4.7. IX Resin Regeneration and PFAS Destruction in Spent Regenerant Brine (CDM leads, CSM supports) - While several studies have demonstrated that IX resins can be effective for PFAS removal, short-chain PFAS (e.g., PFBS, C4) break through long before long-chain PFAS (Zaggia, 2016; Woodard, 2017). Thus, if short-chain PFAS are present, the longevity of the IX resins will be greatly diminished, resulting in frequent and costly changeouts. ZagNessgia (2016) showed that use of a brine solution consisting of NH_4OH + NH_4Cl was effective for regenerating IX resins impacted by C8, PFOS, C4, and PFBS, thus substantially increasing their treatment lifetime. However, more comprehensive testing of IX regeneration using a wide range of PFAS in natural waters has not, to our knowledge, been performed. Our approach is to investigate IX resin regeneration using brine for a wide range of PFAS, thereby serving as a means to extend IX resin lifetime when short-chain PFAS are present.

Task 4.7.1 – IX resin regeneration. Spent IX resin used in both the pilot- and bench-scale tests (described in Task 5.2 and 4.2) will be regenerated using a caustic brine solution. Based on previous studies (Zaggia et al., 2016), such solutions are expected to be effective for removing

short-chain PFAS from the IX column. Here, we will focus on using both conventional chloride salt brine solutions, as well as carbonate-based solutions (Ness and Boyer, 2017), as the carbonate-based solution will not facilitate the formation of chlorate and perchlorate during subsequent electrochemical treatment. It is expected that regeneration will require approximately 10 bed volumes of flushing, followed by 5 bed volumes of clean water flushing. A mass balance approach will be used to determine the percentage removal of PFASs from the resin, and the regenerated resin will be subsequently tested to confirm its capacity for PFAS treatment in further pilot and bench-scale testing.

Task 4.7.2 – Efficiency of selected destruction methods for short-chain PFAS destruction. After assessing IX resin regeneration using the various brine solutions, electrochemical treatment will be used for destruction of the PFAS in the regeneration fluid. Electrochemical treatment is ideally suited for the high PFAS concentrations and high salinity expected in the regeneration fluid, as confirmed in preliminary studies performed by Liang et al. (2018). A bench-scale electrochemical system (Schaefer et al., 2017) using commercially-available electrochemical cells will be used to evaluate treatment of the IX regeneration fluids. Boron doped diamond anodes, as well as other commercially available anode materials currently being evaluated in SERDP Project ER-2424 (e.g., magneli phase Ti_4O_7 anodes), will be tested with respect to their ability to treat PFASs mixtures in IX regenerant solutions. PFAS removal and defluorination, as well as treatment energy demand, will be carefully evaluated using experimental methodology we have previously developed (Schaefer et al., 2017). Our own experiments (Schaefer et al., 2017) show effective oxidation of PFOA and PFOS in solutions amended with sodium sulfate, although the concentrations added were still much lower than the 0.5-10 wt% solutions expected for regenerant brines.

Task 5: Validation of promising treatment approaches at the pilot-scale and full-scale

Pilot-scale validation of promising treatment approaches for short-chain PFAS removal will be conducted through several approaches: 1) collecting and summarizing short-chain PFAS removal data from existing pilot-scale systems, 2) summarizing data from project team's past pilot-scale projects, and 3) performing additional pilot-scale testing during the course of the project. In addition, limited full-scale experiments will be conducted. Table 1 includes a list of utilities that will contribute pilot-scale data. PFAS removal data from these systems will be summarized during the course of this project; when possible, additional samples will be collected to probe whether PFAS (Table 2) are present that are not monitored for currently. The following sections highlight pilot-scale projects that will be conducted during this project. During the course of the project, the team will search for additional opportunities to collect pilot-scale data on short-chain PFAS removal by a variety of treatment processes.

Task 5.1 - American Water Pilot-Scale Studies. We will compare the performance of a single-use IX resin and GAC for the removal of PFAS, with focus on short-chain PFAS. Single-use resins eliminate the regeneration step once the PFAS removal capacity of the material is exhausted. The economic feasibility of single-use IX resins for full-scale operations treating various water qualities needs to be evaluated. AW is working with Purolite to assess the efficiency of single-use ion exchange resin (PFA694E) and compare its performance against two types of GAC typically used by AW. Pilot units will be installed at two utilities (X and Z in Table 1) operated by AW. For the latter, matching bench-scale tests will be conducted in Task 4. The wells at the two utilities present similar alkalinity but different TDS concentrations and PFAS fingerprints. Elevated concentrations of PFAS, most likely released from different types of

sources, have been consistently detected in both systems. The pilot-units will be operated for approximately 12 months. During this time, column flow will be monitored at least every three (3) days and adjusted as needed. Pre-filters will be changed out every two (2) weeks or more frequently if excessive solids build-up is observed. To prevent the development of biological activity, the pilot columns will be covered from sunlight. Background water quality parameters (e.g. pH, TOC, turbidity, alkalinity, TDS) and PFAS will be analyzed in the influent and effluent from the columns (resin and two types of GAC). Flow rate and cumulative throughput at the time of sampling will be also recorded. The research team will establish the sampling frequency prior to the start-up of the pilot-units.

Task 5.2 - CSM Pilot-Scale Studies. Researchers at CSM have several opportunities to compile pilot-scale short-chain PFAS removal data. Systems include a pilot-scale GAC/IX system operating at the City of Fountain, CO, a pilot-scale SPAC/CMF project at the City of Fountain, and a pilot-scale NF system with concentrate PFAS destruction at Peterson Air Force Base. While these studies are ongoing, CSM is collecting data regarding the efficacy of short-chain PFAS removal. In addition, CSM has recently constructed a modular column system to side-by-side test established and emerging adsorbents, which will be deployed to treat contaminated groundwater at the City of Fountain. Depending on results from laboratory-scale testing, CSM will select best performing GAC and IX resin products for pilot-scale testing for the removal of short-chain as well as additional PFAS. In addition, one goal is to test not only novel adsorbents but also novel configurations including GAC followed by IX as well as mixed-media beds (GAC with IX). Additionally, spent IX resin will be regenerated through various methods (e.g., bicarbonate brine, brine with methanol) to assess the option of treating IX brine with destructive technologies (see Task 4.7).

Task 5.3 - Ann Arbor Pilot-Scale and Full-Scale Studies

Task 5.3.1 – Pilot-scale. In 1999, the City of Ann Arbor Water Treatment Plant commissioned construction of six pilot-scale filters to replicate performance of its full-scale filters. The pilot plant was recommissioned in 2017 for WRF4743 and is fully functional. This project will use the 6 pilot filter columns to test promising GAC and IX media as identified in Task 4. While the pilot filters were designed to mimic the operational parameters of the City's full scale filters, they also have the flexibility to operate at greater media depths. The work proposed will take advantage of this feature to evaluate the effects of EBCT (5, 10, and 20 minutes for GAC; 1.5, 3, and 6 minutes for IX) on sorbent use rates. Pilot-scale testing will be conducted in two rounds. In round 1, the pilot columns will receive settled water to mimic GAC performance in filter adsorber mode. In round 2, pilot columns will receive filtered water from a full-scale adsorber containing spent GAC to mimic GAC performance in post-filter adsorber mode. These results will show whether filter adsorber performance for PFAS removal is impacted by higher influent turbidities and a greater backwash frequency. Also, if GAC/IX process trains show promise in Task 4, the City will evaluate the effectiveness of a GAC/IX treatment train at the pilot scale. Using a pilot-scale ion exchange columns built by NCSU, the City will install the IX column in series after the GAC columns. This scenario will quantify the improved media life of the ion exchange resins resulting from the reduced loading by following GAC.

Task 5.3.2 Full-scale. The City of Ann Arbor, MI operates a 50 MGD lime softening water treatment plant that serves 125,000 people in Ann Arbor and its surroundings. The treatment plant was built in 1938 and modified over the years to its current treatment configuration illustrated in Figure 3. One key feature of the City's water treatment plant is the blending of two

water sources prior to treatment. The primary source of water for the City is the Huron River where the City has detected C4, C5, C6, C7, C8, PFBS, and PFOS at combined concentrations up to approximately 60 ppt. The City also has a series of wells that comprise approximately 15% of the source water requirements to the plant. The City has not detected any PFAS in its groundwater supply.

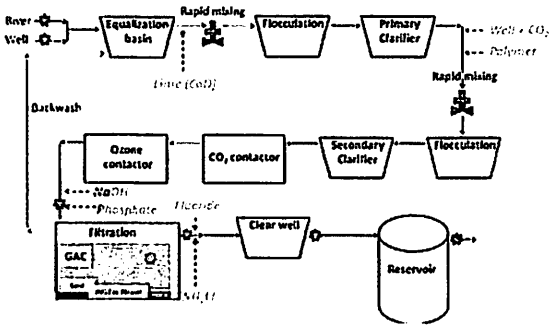


Figure 3. City of Ann Arbor Water Treatment Plant

The City has been experimenting with different filter configurations to address removal of PFAS from its source water. The City has 26 filters, with different combinations of GAC and sand that range from 24 to 28 in. deep, with 18 to 24 in. comprising GAC and the remainder sand. Two of the 26 filters are full bed GAC with no sand. Five of the filters use Calgon F400 GAC and the remainder have Calgon F300. The City typically replaces GAC every 5 years in its filters, but is evaluating the impact on effective life if the media is used for PFAS removal. As part of this proposal, the City intends to dedicate two to five of its filters to explore the impact empty bed contact time (EBCT) and GAC type on PFAS removal. The City normal loads its filters at 1.5 gpm/ft^2, but can operate up to 3.0 gpm/ft^2 to explore the effect of EBCT (5-10 min) at the full scale. These EBCTs are typical for utilities considering GAC filter adsorbers for PFAS removal.

Task 6: Development of quantitative structure-property relationships to predict PFAS removal by activated carbon, anion exchange, and membrane treatment processes (NCSU leads, CSM supports). The proposed research is designed to provide a comprehensive understanding of the removal of short-chain PFAS by state-of-the-science treatment approaches. The resulting data sets provide an opportunity to fill a significant need: to develop approaches to predict treatment performance *a priori*. The research team has developed, and through this project will continue to develop treatment databases to develop structure-activity relationships to aid in the selection of treatment processes. We will build on our past research and findings from this project to develop multi-linear regression models that link short- (and long-)chain PFAS removal to PFAS properties, background water matrix constituents, and treatment process parameters. For example, in a prior TWRF study (Summers et al. 2014, Kennedy et al. 2015), we developed a model to predict GAC service life to 10% breakthrough for a diverse set of micropollutants. In this model, micropollutant properties that determined adsorbability included the pH-dependent octanol:water partition coefficient (log D) and two Abraham solvation parameters (S, representing the compound's polarity/polarizability and V, representing the compound's molecular volume). In addition, the influent DOC concentration to the GAC contactor was an important factor controlling the volume of water that could be treated to 10% breakthrough. By developing data sets for a large number of PFAS and background water matrices, we expect to identify PFAS properties, background water characteristics, and process operating conditions that are strong predictors of PFAS removal. We expect to develop models describing PFAS removal by GAC, IX, and high-pressure membrane treatment processes. For GAC and IX treatment processes, bench- and pilot-scale data will first be described by the pore-surface diffusion model to develop breakthrough curves and estimates to targeted levels of breakthrough. Resulting model input parameters will also serve to quantitatively discuss factors

that influence PFAS removal performance in different background water matrices and by different sorbents.

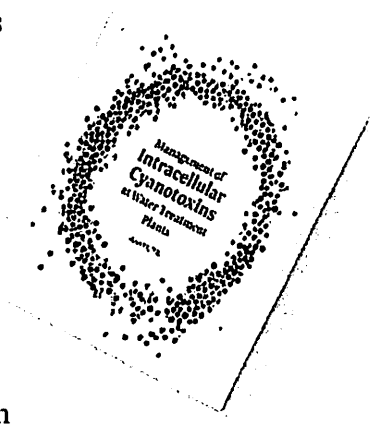
Task 7: Comparison of treatment approaches using life cycle analysis and cost models (CSM leads with significant support from NCSU, Hazen, CDM, and SNWA). Work performed on life-cycle analysis (LCA) and life-cycle costing (LCC) will build on several ongoing projects, including our recently funded ESTCP project comparing treatment technologies, as well as several projects evaluating the costs of individual treatment technologies. To evaluate the benefits and identify possible tradeoffs and disadvantages of different treatment technologies, we will employ a life cycle and systems-based analysis approach. Direct and indirect impacts (costs, environmental and human health impacts, etc.) will be quantified and compared for each treatment technology. Our team will work with technology development companies to develop cost matrices. Each sub-model or treatment system model will characterize the material and energy inputs and outputs as required to operate the entire treatment system over 20 years (all technologies will be normalized by the same timeframe and account for differences in chemical and energy use as well as material and system lifetimes), and it will include: chemical type and mass, energy type and mass, material (e.g., steel reactor) type and mass, and waste type, mass, and treatment/disposal requirements. The technology sub-models will all be combined into one meta-analysis systems model that will then be evaluated using multiple life cycle metrics. Fundamental development of this model is taking place in a separately funded ESTCP project, and this work will be leveraged and expanded upon to address the needs of the water treatment community for short-chain PFAS removal.

Task 8. Development of a decision support tool for treatment process selection (led by Hazen)

To most effectively assist water providers with developing effective strategies for PFAS treatment, it is critically important to effectively disseminate the results of this study to multiple audiences, including utility managers, engineers, regulators, and communications staff.
Data surrounding treatment strategies for PFAS is often incomplete and sometimes inconclusive. For example, the impacts of water quality on PFAS treatment via common sorbents such as GAC and IX remains poorly understood. Some studies have reported substantial impacts of DOC on PFAS removal (e.g., Yu et al., 2012) while other studies have not shown a strong correlation between DOC levels and PFAS removal (e.g., McCleaf et al., 2017). In addition, recent studies have shown that several PFAS compounds not routinely monitored are poorly removed by GAC (Xiao et al., 2017), leading to questions from regulators and the public about effective removal strategies.
To clarify these and other concerns, the results of this study will be used to develop general guidelines for evaluating treatment effectiveness. Specific areas that will be addressed include:

- Up-to-date PFAS analyte list (including short-chain) and analytical reproducibility
- Effectiveness of potential treatment approaches based on background water quality
- Clarity regarding conflicting information focused on GAC and IX treatment technologies
- Guidelines on appropriate bench scale testing methods for potential treatment strategies
- Applying results from bench-scale testing
- Determining representativeness of water used for testing, within natural variability
- QSAR to extend the result of the study to unmonitored PFAS
- LCA and cost models to evaluate feasibility of treatment

The results of the study will be presented with two audiences in mind. The tools provided in the final report will include detailed specifics gleaned from the research performed within the study, and will be presented in appropriate detail to meet the needs of design engineers and researchers interested in advancing technologies. A second document, a summary guidance manual, will be targeted to utility manager and communications staff. This document will present high level concepts from the study, suitable for garnering public and regulatory trust in the evaluation, design, and implementation process undertaken by utilities in determining their best treatment options. Hazen will lead the effort of developing this second document, utilizing an approach similar to that currently being implemented in TWRF 4692: Release of Intracellular Cyanotoxins during Oxidation of Natural and Lab Cultured Cyanobacteria.



Evaluation Criteria

The project can be evaluated relative to specific project objectives and the ability of the Project Team to provide data and deliverables associated with each objective. Thus, corresponding with each objective, the Foundation and PAC can use these benchmarks and/or deliverables to evaluate project progress:

1. Objective 1:We will identify effective sorbents by completing (1) a literature review and a review of existing bench-, pilot-, and full-scale data (Task 1), (2) completion of bench-scale tests in a wide range of water matrices (Task 4), and (3) pilot- and full-scale experiments (Task 5). The resulting treatment database will highlight effective sorbents as well as limitations that may be associated with certain background water quality parameters.
2. Objective 2: Similar to the first objective, we will identify effective membranes by developing a treatment database through completion of a literature review and review of existing data (Task 1) and (2) completion of bench-scale and pilot-scale tests (Tasks 4 and 5).
3. Objective 3:The effectiveness of short-chain PFAS removal will be evaluated through the completion of full-scale sampling of utilities with a wide range of background matrices (Task 3) as well as bench- and pilot-scale experimentation with water from selected utility participants (Task 4 and 5).
4. Objective 4: Through completion of bench-scale tests in Task 4, we will explore the effects of PAC, MIEX, and ozone on carbon use rates for short-chain PFAS removal
5. Objective 5: We will explore several bench-scale testing approaches for GAC and IX (Task 4) and compare results to matching pilot-scale tests (Tasks 1 and 5). These comparisons will allow us to identify suitable bench-scale testing approaches for sorbent selection and scale-up.
6. Objective 6: Through completion of a literature review (Task 1) and experimentation in Tasks 4 and 5, we will develop information about residuals management (spent resin and GAC through Task 1, destruction of PFAS in brine through Tasks 4 and 5).
7. Objective 7: Through completion of Task 6, we will develop predictive models for short-chain PFAS removal by adsorption, anion exchange, and membrane processes
8. Objective 8: Using models being developed in a separately funded ESTCP project, we will develop life-cycle cost and environmental impact information for short-chain PFAS treatment alternatives (Task 7). This information will be summarized in a guidance manual for water treatment professionals.

Applications Potential

In 2016, the USEPA issued health advisory levels for PFOA and PFOS for drinking water at a sum concentration of 70 ng/L. Recently, the Agency for Toxic Substances and Disease Registry (ATSDR) released for public comment Minimal Risk Levels (MRLs) for four long-chain PFASs: PFOA, PFOS, PFHxS, and PFNA (ATSDR 2018). Drinking water equivalent levels corresponding to the MRLs would be 11 ng/L for PFOA, 7 ng/L for PFOS, 74 ng/L for PFHxS, and 11 ng/L for PFNA. Adoption of the MRLs would greatly expand the number of drinking water providers that would need to consider PFAS treatment options. However, as long-chain PFAS chemistries are being abandoned, industry is moving towards (1) short-chain PFAS chemistries and (2) fluorinated replacements. There have been a significant number of recent publications proposing the treatment of PFASs through a variety of methods. The majority of this work has focused on long-chain PFAS including PFOA and PFOS. However, there is emerging interest in the removal of short-chain PFAS and fluorinated replacements. Currently, there are significant data gaps for the removal of short-chain PFAS from water, making the selection of effective treatment approaches difficult.

The overarching objective of this proposed project is to develop guidance to the drinking water community on the occurrence and treatment of short-chain PFAS. Research conducted during this project will culminate not only in the development of a comprehensive Final Report, but also in the development of a project synopsis designed to provide summary guidance to utility managers, design engineers, and regulators regarding the prevalence of short-chain PFAS and fluorinated replacements as well as practical options for effective treatment. Our focus will be on readily implementable treatment solutions, given the immediate treatment needs faced by many utilities. Additionally, the research team will actively disseminate project findings through conference presentations, journal publications and AWWA/TWRF webinars.

We have amassed a project team with significant expertise regarding the management and monitoring of utilities and water systems, analysis of a diverse set of PFAS (including fluorinated replacements), and various treatment options for PFAS removal. Beyond researcher expertise, a large emphasis has been placed on utility involvement and the team has approximately 40 utilities involved with the proposed project not including additional clients from Hazen and Sawyer. Through the interface between research, engineering and stakeholder involvement, the research team will identify and vet the most promising short-chain PFAS treatment approaches, and conduct life cycle analyses to provide practitioners with guidance on treatment process selection.

To ensure success, the team has developed a robust work plan that will build on a myriad of past and existing projects regarding the analysis, occurrence, fate, and treatment of PFAS. Characterizing short-chain PFAS and fluorinated replacement occurrence and treatment efficiency will be accomplished through several approaches including: 1) full-scale treatment plant sampling campaigns, including evaluations of GAC media and operating conditions, 2) bench-scale experimentation, and 3) ongoing and planned pilot-scale studies. Through this work, the team will fill in numerous knowledge gaps related to short-chain PFAS treatment, including refined analytical methods, the impact of water chemistry and pretreatment on treatability, scalability of lab derived data, and overall efficiency of a variety of treatment options. Data generated through these efforts will be used to develop predictive models for treatment process selection, and most importantly, metrics (i.e., life-cycle costs) to aid utilities and practitioners in the selection of effective treatment approaches.

Quality Assurance/Quality Control

Overview. North Carolina State University (NCSU), Colorado School of Mines (CSM), Southern Nevada Water Authority (SNWA), and American Water (AW) maintain comprehensive QA/QC programs, which describe the policies, procedures, and accountabilities to ensure the samples collected are representative, and the data reported from the research are reliable, accurate, precise, and nonbiased. This program includes sample collection aspects (sample location, number of analyses, sampling frequency, sampling time, etc.), laboratory analysis (method evaluation, sensitivity, data acquisition, method blanks, replicates, calibration checks, laboratory-fortified matrix samples, etc.), as well as data management and reporting.

Modified versions of U.S. EPA Method 537 will be employed among NCSU, CSM, SNWA and AW laboratories. Extraction and analysis will be performed, where possible, via isotope dilution liquid chromatography-tandem mass spectrometry (LC-MS/MS). PFAS target analytes for the project are listed in Table 1 of this QA/QC document. For Task 2, a laboratory round-robin validation study will be performed, since standard methods have not been established for some of the target short-chain PFAS. The goal of this validation study will be to harmonize methods among team laboratories and to recommend method(s) for the analysis of short-chain PFAS.

Individual responsible for quality assurance (QA) and quality control (QC). PI Knappe (NCSU) will be responsible for QA/QC for this project. He will work with co-PIs Bellona (CSM), Dickenson (SNWA), Marfil-Vega (AW), Rosenfeldt (Hazen and Sawyer), Schaefer (CDM Smith) and Steglitz (Ann Arbor) to ensure QA/QC procedures are followed during sample collection, transport, storage, and analysis by each participant. Care will be taken to ensure the accuracy and quality of all collected data as described below.

Sample Collection. Protocols for the collection of PFAS samples will be based on EPA Method 537 (USEPA 2009a) and EPA SOP EMAB-113.0 (USEPA 2009b). Throughout the course of this project, significant numbers of samples will be collected and shipped to research centers from partner consultants and utility sites. Experimental planning and communication will be key to efficient use of laboratory staff and student time, and will ensure that all samples are received and processed in a timely manner consistent with method-specific QA/QC protocols. Each laboratory will create a master calendar to schedule sample shipping dates, experimental procedures, instrument needs, and relevant project deadlines. Sample tracking via Chain of Custody forms will be a standard practice with paper records kept at each institution conducting specific analyses.

Samples will be collected in either 250-mL polypropylene (PP) bottles (EPA Method 537) or 1000-mL Nalgene high-density polyethylene (HDPE) bottles (EMAB-113.0) with PP or HDPE lids. Samples will be concentrated by solid-phase extraction as described below. Samples from bench-scale experiments will be collected in 15-mL polypropylene centrifuge tubes. Following sample preparation, these samples will be analyzed by large-volume direct injection. Sampling personnel will be provided instructions to wear Nitrile gloves during experiments and avoid touching and breathing on the samples, since trace (ng/L) levels are being measured.

Sample Preservation. To prevent microbial growth in samples, samples will be either acidified with 5 mL 35% HNO_3/L of sample (EPA EMAB 113.0) or with 1 g sodium azide/L of sample (SNWA). If samples contain a disinfectant residual, samples will be dechlorinated with 50 mg ascorbic acid/L sample. Sample will be stored at room temperature (EPA EMAB 113.0) and will

be extracted within 14 days of collection. Samples from bench-scale experiments will not be preserved (Sun et al. 2016). These samples will be analyzed within 7 days by large-volume direct injection LC/MS-MS or LC/QToF-MS.

Sample Preparation. An isotope dilution approach will be followed for sample extraction and analysis. Matched mass-labeled internal standards are available for many of the PFASs shown in Table 1, permitting a true isotope dilution approach that minimizes matrix effects for the quantification of 13 PFASs. For the remaining 26 PFASs, analytes will be matched with mass-labeled internal standards that elute most closely to the analyte in the MS analysis, as specified in Appendix B of the DoD Quality Systems Manual (DoD 2017). It is expected that mass-labeled compounds for at least some of the remaining 26 PFASs will become available during the project, in which case they will be included as additional internal standards.

Sample preparation will be based on protocols defined in (i) EPA Method 537, (ii) QC requirements specified in Appendix B of the DoD Quality Systems Manual (DoD 2017), and (iii) EPA SOP EMAB-114.2 (hereafter EMAB-114.2, USEPA 2016). EPA Method 537 was developed for the analysis of drinking water while DoD QC requirements and EMAB-114.2 were developed for environmental waters.

Solid-phase extraction (SPE). Samples will be concentrated using either HLB (EPA Method 537) or WAX (EPA EMAB 114.2) SPE cartridges. NCSU's experience is that recovery of short-chain PFASs and PFEAs is superior with WAX cartridges. For laboratories using HLB cartridges, adjustments to existing protocols will be made if deemed necessary based on initial round robin testing as described in Task 2 of the Project Description.

Sample Filtration. EPA Method 537, which was developed for drinking water samples, does not require a filtration step because the turbidity of drinking water samples is low. For the analysis of surface waters, a filtration step will be used prior to SPE and LC-MS/MS analysis. As specified in EMAB-114.2, mass-labeled internal standards will be added to water samples prior to filtration through a glass-fiber filter.

SPE Eluate Evaporation. Evaporation to dryness (specified in EPA Method 537) may lead to analyte losses (USEPA 2016). We will follow an alternative approach, in which we evaporate SPE eluates to 0.5-1.0 mL as specified in EMAB-114.2 (USEPA 2016).

Instrumental Analysis. Table 2 in this QA/QC document summarizes the instrumental methods and equipment used by each of the team's laboratories.

Table 1. Target compounds for analysis.

Name	CAS #	Formula	Formula Weight
Short-chain compounds			
Short-chain perfluoroalkylcarboxylic acids without an ether group ($C_nHF_{2n-1}O_2$)			
Perfluoroacetic acid (PFAA=C2)[+]	76-05-1	$C_2HF_3O_2$	114.0
Perfluoropropanoic acid (PFPrA=C3)[+]	422-64-0	$C_3HF_5O_2$	164.0
Perfluorobutanoic acid (PFBA=C4)*	375-22-4	$C_4HF_7O_2$	214.0
Perfluoropentanoic acid (PFPeA=C5)*	2706-90-3	$C_5HF_9O_2$	264.0
Perfluorohexanoic acid (PFHxA=C6)*	307-24-4	$C_6HF_{11}O_2$	314.1
Short-chain perfluoroalkylcarboxylic acids with one ether group ($C_nHF_{2n-1}O_3$)			
Perfluoro-2-methoxyacetic acid (PFMOAA)	674-13-5	$C_3HF_5O_3$	180.0
Perfluoro-2-methoxypropanoic acid (PFMOPrA branched)	13140-29-9	$C_4HF_7O_3$	230.0
Perfluoro-3-methoxypropanoic acid (PRMOPrA linear)	377-73-1	$C_4HF_7O_3$	230.0
Perfluoro-2-ethoxypropanoic acid (PFEOPrA branched)	N/A	$C_5HF_9O_3$	280.0
Perfluoro-3-methoxybutanoic acid (PFMOBA) linear	863090-89-5	$C_5HF_9O_3$	280.0
Perfluoro-2-propoxypropanoic acid (PFPrOPrA) = hexafluoropropylene oxide-dimer acid (HFPO-DA = "GenX")*	13252-13-6	$C_6HF_{11}O_3$	330.1
Short-chain perfluoroalkylcarboxylic acids with multiple ether groups			
Perfluoro-3,5-dioxahexanoic acid (PFO2HxA)	39492-88-1	$C_4HF_7O_4$	246.0
Perfluoro-3,5,7-trioxaoctanoic acid (PFO3OA)	39492-89-2	$C_5HF_9O_5$	312.0
Perfluoro-3,5,7,9-tetraoxadecanoic acid (PFO4DA)	39492-90-5	$C_6HF_{11}O_6$	378.1
Short-chain perfluoroalkylsulfonic acids without an ether group ($C_nHF_{2n+1}SO_3$)			
Perfluoroethane sulfonic acid (PFEtS)[+]	354-88-1	$C_2HF_5O_3S$	200.1
Perfluorobutane sulfonic acid (PFBS)*	375-73-5	$C_4HF_9O_3S$	300.1
Perfluoropentane sulfonic acid (PFPeS)	2706-91-4	$C_5HF_{11}O_3S$	350.1
Short-chain polyfluoroalkylsulfonic acid with one ether group			
NVHOS	88986-19-0	$C_4H_2F_8O_4S$	298.0
Short-chain precursor compounds			
4:2 fluorotelomer sulfonic acid (4:2 FtS)*	757124-72-4	$C_6H_5F_9O_3S$	328.2
4:2 fluorotelomer unsaturated carboxylic acid	70887-90-0	$C_6H_2F_8O_2$	258.1
6:2 fluorotelomer unsaturated carboxylic acid	70887-88-6	$C_8H_2F_{12}O_2$	358.1
Un(der)studied long-chain compounds and long-chain reference compounds			
Long-chain perfluoroalkylcarboxylic acids without an ether group ($C_nHF_{2n-1}O_2$)			
Pefluoroheptanoic acid (PFHpA=C7)*	375-85-9	$C_7HF_{13}O_2$	364.1
Perfluorooctanoic acid (PFOA=C8)*	335-67-1	$C_8HF_{15}O_2$	414.1
Perfluorononanoic acid (PFNA=C9)*	375-95-1	$C_9HF_{17}O_2$	464.1
Perfluorodecanoic acid (PFDA=C10)*	335-76-2	$C_{10}HF_{19}O_2$	514.1
Long-chain per- and polyfluoroalkylcarboxylic acids with one or more ether groups ($C_nHF_{2n-1}O_4$)			
Perfluoro-4-dimethylmethoxybutanoic acid (PFDMMOBA)	801212-59-9	$C_7HF_{13}O_3$	380.1
Perfluoro-4,8-dioxa-3H-perfluorononanoic acid (ADONA parent acid)	919005-14-4	$C_7H_2F_{12}O_4$	378.1
Perfluoro-3,6,9-trioxadecanoic acid (PFO3DA)	151772-59-7	$C_7HF_{13}O_5$	412.1
Perfluoro(3,6-dioxadecanoic) acid (PFO2DA)	137780-69-9	$C_8HF_{15}O_4$	446.1
Perfluoro(3,6,9-trioxatridecanoic) acid (PFO3TDA)	330562-41-9	$C_{10}HF_{19}O_5$	562.1
Long-chain perfluoroalkylsulfonic acids without an ether group			
Perfluorohexane sulfonic acid (PFHxS)*	355-46-4	$C_6HF_{13}O_3S$	400.1
Perfluoroheptane sulfonic acid (PFHpS)	375-92-8	$C_7HF_{15}O_3S$	450.1
Perfluorooctane sulfonic acid (PFOS)*	1763-23-1	$C_8HF_{17}SO_3$	500.1
Long-chain per- and polyfluoroalkylsulfonic acids one or more ether groups			
Nafion by-product 1	29311-67-9	$C_7HF_{13}O_5S$	443.9
Nafion by-product 2	749836-20-2	$C_7H_2F_{14}O_5S$	463.9
Nafion by-product 4	N/A	$C_7H_2F_{12}O_6S$	441.9
F-53B	73606-19-6	$C_8HClF_{16}O_4S$	532.7
Long-chain precursor compounds			
6:2 fluorotelomer sulfonic acid (6:2 FtS)*	6164-3-06	$C_8H_5F_{13}O_3S$	428.2
8:2 fluorotelomer unsaturated carboxylic acid	70887-84-2	$C_{10}H_2F_{16}O_2$	458.1

[+] percent removal measurements, but no quantitation of concentrations

* matched mass-labeled internal standard available

Version: 03/01/2018 (previous versions are obsolete and will not be accepted for review).

Table 2. LC-MS/MS specifications for each participating laboratory.

Specification	SNWA	NCSU[a]	CSM	AW
Guard Cartridge(s)	4X10 mm Hypercarb, 4.6X30 mm Synergi Max-RP C12	Acquity PFC Isolator Column	SecurityGuard™ C18, Zorbax DIOL	4.6X50 mm Agilent Eclipse C18
Separation Column	4.6X150 mm 4 µm pore size Synergi Max-RP C12	2.1X50 mm 1.7 µm pore size Acquity UPLC BEH C18	3X100mm 5 µm pore size Gemini C18	2.1X50 mm 1.8 µm pore size Agilent Eclipse C18
Gradient	(A) 5 mM ammonium acetate in water (B) 100% methanol	(A) 95:5 v/v% water:methanol with 2.5 mM ammonium acetate (B) and 5:95 v/v% water:methanol with 2.5 mM ammonium acetate	(A) 20 mM ammonium acetate in water (B) 100% methanol	(A) 2mM ammonium acetate (B) 100% acetonitrile
LC Autosampler	HTC-PAL	Waters Acquity Sample Manager	HTC-PAL	Agilent 1260 Multisampler
Injection Volume (µL)	10	50	1000	50
MS/MS Instrument	Sciex API 4000 triple-quadrupole MS	Waters Quattro Premier XE triple quadrupole	Sciex X500R QTOF-MS	Agilent 6470 triple quadrupole MS

[a]In July and August 2018, installation of two new instruments will take place at NCSU. The first instrument is an Agilent 1290/6545 liquid chromatograph/quadrupole time-of-flight high resolution mass spectrometer equipped with a Multisampler and the second instrument is an Agilent 1260/Ultivo liquid chromatograph/triple quadrupole mass spectrometer equipped with Flexible Cube/Multisampler. NCSU will migrate methods to the new instruments in August and September of 2018. These instruments are expected to be significantly more sensitive than the current instrument.

Performance Evaluation. Quantitation will be performed using isotope dilution with an isotopically labeled analogue and with a seven-point calibration. Instrument protocols (e.g., mass calibration, tune check, mass spectral acquisition rate, ion transitions), calibration and verification procedures (e.g., linear and branched PFAS standards, initial calibration, instrument sensitivity check, initial and continuing calibration verification, instrument blanks), and analysis of quality control samples (e.g., method blank, laboratory control sample, matrix spike, travel blank, duplicates) will be based on established methods (USEPA 2009a, USEPA 2016) and quality control requirements (DoD 2017). Formal approaches for minimum reporting levels (MRLs) will be followed (USEPA 2009a, DoD 2017).

A minimum reporting level (MRL) is defined as the lowest level achievable within specified limits of precision and accuracy during routine laboratory operating conditions by a given method. MRLs are based on method detection limits (MDL) calculated from seven replicate measurements of deionized water samples fortified with analytes and extracted as described above. A MDL is defined as the minimum concentration of an analyte that can be identified,

measured, and reported with 99% confidence that the value obtained is greater than zero. MDLs are a statistical determination based on the standard deviation of the quantitation of the analytes using Student's t-distribution with 6 levels of freedom and 99% confidence level. MRLs for each analyte are set equal or greater than (i.e., five times) the MDL in consideration of known and unanticipated background sources. Accounting for concentration via SPE, MRLs are set generally between 0.1 to 5.0 ng/L for targeted PFAS.

A minimum of seven calibration standards will be used to construct a calibration curve for each analyte, with at least one calibration standard analyzed at or below the method MRL. Correlation coefficients are required to be at least 0.990 but they typically exceed 0.995 using linear regression. When the level of an analyte is greater than that of the highest standard in the calibration curve, the sample is diluted and rerun. In some cases, samples are run both straight and diluted to quantify a series of analytes over a wide range of concentrations.

A laboratory reagent blank (LRB) is an aliquot of reagent water or other blank matrix that is treated exactly as a sample including exposure to all glassware, equipment, solvents, reagents, internal standards, and surrogates that are used with other samples. A travel blank is the same as the LRB, but it is collected in the field along with samples. A LRB and a travel blank will be included in each extract batch and will be analyzed at the beginning of each analytical batch to demonstrate low system background. Acceptance criteria for a data batch requires any observable compound peaks in blanks to remain <1/3 MRL or else results will be flagged and compound MRL adjusted for all samples in the batch.

Laboratory fortified reagent blanks (calibration check standard), laboratory fortified matrix (LFM) spikes, and a sample duplicate (DUP) will be incorporated into each extract batch to monitor analytical performance and determine whether the laboratory can make accurate and precise measurements. The calibration check standard is analyzed at the beginning and at the end of each analytical batch and after every 10th sample to verify system calibration. LFM matrix spikes help determine whether the sample matrix contributes bias to the analytical results. The background concentrations of the analytes in the sample matrix must be determined in a separate aliquot and the measured values in the LFM corrected for background concentrations.

A LFM and DUP are analyzed with each batch of ten environmental samples to demonstrate accuracy and precision. Precision is the reproducibility or the degree of agreement among replicate measurements of the same quantity, such as duplicate samples. It measures how far an individual determination may be from the mean of replicate measures. It is stated in terms of relative percent difference (RPD) or relative standard deviation (RSD). The RPD of the results of the duplicate samples should be less than or equal to 20% for all analytes. Accuracy is the degree of difference between the measured or calculated values to known true values, such as for a LFM sample, which measures the analytical bias due to systematic errors. It is expressed as a percentage recovery. For samples fortified at or above their ambient concentration, recoveries should range between 80 and 120% for all analytes. When QC acceptance criteria are not met, corrective actions are taken to identify the problems and samples are rerun. For analytes that are not often detected, replicate LFM samples are analyzed to generate both precision and accuracy data.

Signal counts for internal and surrogate standard peaks are required to remain above 10% when compared to average peak counts in calibrators. Samples that do not meet these criteria will be reanalyzed and diluted for matrix reduction as needed. Samples where efforts do not produce acceptable QC criteria required will be flagged as such.

The initial demonstration of capability (IDC) is used to demonstrate an analyst's competence in the performance of a method before the analyst is permitted to perform reportable work. An initial demonstration of acceptable accuracy and precision will be accomplished by (1) analysis of an MDL determination and (2) a minimum of seven replicates of a mid-level check standard on separate days. Before processing any samples, an analyst will perform an IDC to demonstrate his or her competence with the methods.

Data Management. Data management includes acquisition, reduction, validation, and reporting. It provides a system of internal checks and balances to ensure that laboratory generated data are properly validated, reviewed, and reported for completeness, consistency, and accuracy before release to data users. Data management also ensures that applicable data quality objectives (precision, accuracy, completeness, comparability, and representativeness) are adequately identified and within specified control limits. The review of data quality involves multiple levels of evaluation: bench/peer review, and senior review. Only data that have passed data review processes will be reported.

Types of Data. Data to be collected in the proposed research are described in the project description. The primary data resulting from the proposed activities are water quality data (concentrations of perfluoroalkyl substances (PFASs) as well as common background water matrix parameters) obtained from the analysis of bench-scale experiments and water samples collected in the field. Acceptance criteria for experimental data are based on rigorous QA/QC protocols developed from published EPA methods. The data will be in the form of hand-written notes in laboratory notebooks, raw data files from sample analyses, and experimental analysis data files as follows:

1. Laboratory notebooks: Experimental conditions and observations will be recorded in numbered and dated laboratory notebooks. In addition, certain measurements will be recorded by hand in the laboratory notebooks (e.g. pH, temperature, UV absorbance).
2. Raw data: PFAS data will be captured by software controlling the LC-MS/MS. In addition, some background water quality parameters (e.g. total/dissolved organic carbon) will be captured by instrument software.
3. Experimental analysis data files: Any derivative data (e.g. processed LC-MS/MS data, standard curves) will be developed in Microsoft Excel.

Data Formats and Metadata. Raw data collected by LC/MS-MS, LC/QToF-MS, and other software-driven instrumentation will be stored in the format specific to the software controlling the instrument. Any derivative data (e.g. standard curves, processed LC-MS/MS data) will be prepared in Microsoft Excel format. All experimental procedures, designs and observations will be clearly described and recorded in dated and numbered laboratory notebooks. SNWA and AW also use HORIZON Laboratory Information Management System (LIMS) to manage PFAS data. Metadata files will be prepared in Excel format and will contain the following information: date data were gathered, the name of the investigator who obtained the data, a short description of the

experiment, chromatographic peak areas, standard curves, calculated concentrations, and additional derivative results such as adsorption capacities. A detailed description of the data and experimental conditions will be included in an accompanying laboratory notebook description. Metadata will be created as soon as raw data are collected, thus allowing efficient management and rapid sharing of the data with others.

Data Archiving and Preservation. All study partners will exercise great care to maintain the integrity of the data collected during the course of research. Data will be backed-up at defined time intervals to protect data. Electronic document and data control procedures ensure that the team knows and has access to the array of electronic files that are developed during the course of a study. All raw and derivative data and documentation generated during this grant will be archived at North Carolina State University using existing IT infrastructure. Long-term data storage is available from NC State's Office of Information Technology Shared Services group. Data are stored on a highly scalable, resilient (no single point of failure) storage system. Data are backed up at a data center ~15 miles from the data center where the storage system is located.

Project Monitoring and Oversight. All project deliverables will undergo review prior to submittal to the PAC and Foundation. The lead researchers have experience in terms of study design, data collections, and processing, modeling, and evaluation. Peer review throughout the course of the study ensures a clearly focused technical direction that is consistent with objectives of the study.

Progress Reports and Briefings. An important part of the QA/QC process is the delivery of progress reports and discussion briefings with the PAC and Foundation. Feedback received from these interactions will ensure that the study is progressing as planned and will provide opportunities to identify problem areas and solutions. Our team will have frequent communication during the project and we believe that collaboration with the PAC and Foundation is key to meeting study objectives and defining project success.

Management Plan

Team Experience

To conduct the proposed research, we assembled a multidisciplinary research team of scientists, engineers and practitioners, who have extensive research experience on PFAS occurrence and treatment as well as project experience with TWRF. The PFAS project experience of the team is outlined in Figure A, which also highlights various recent and ongoing collaborations among team members. Team members were selected for their complementary expertise and the ability to integrate into the project vision. Team responsibilities were developed considering the core strengths of each team member to efficiently deliver results to TWRF and its subscribers.

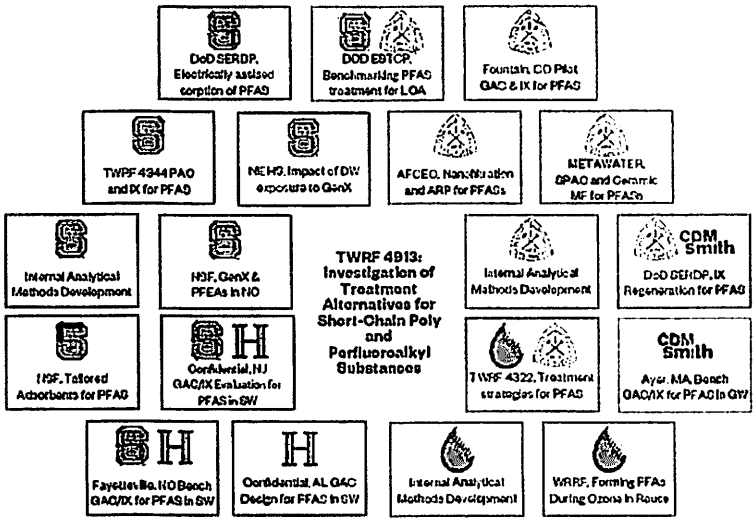


Figure A: Summary of Project Team PFAS Experience and Collaborations

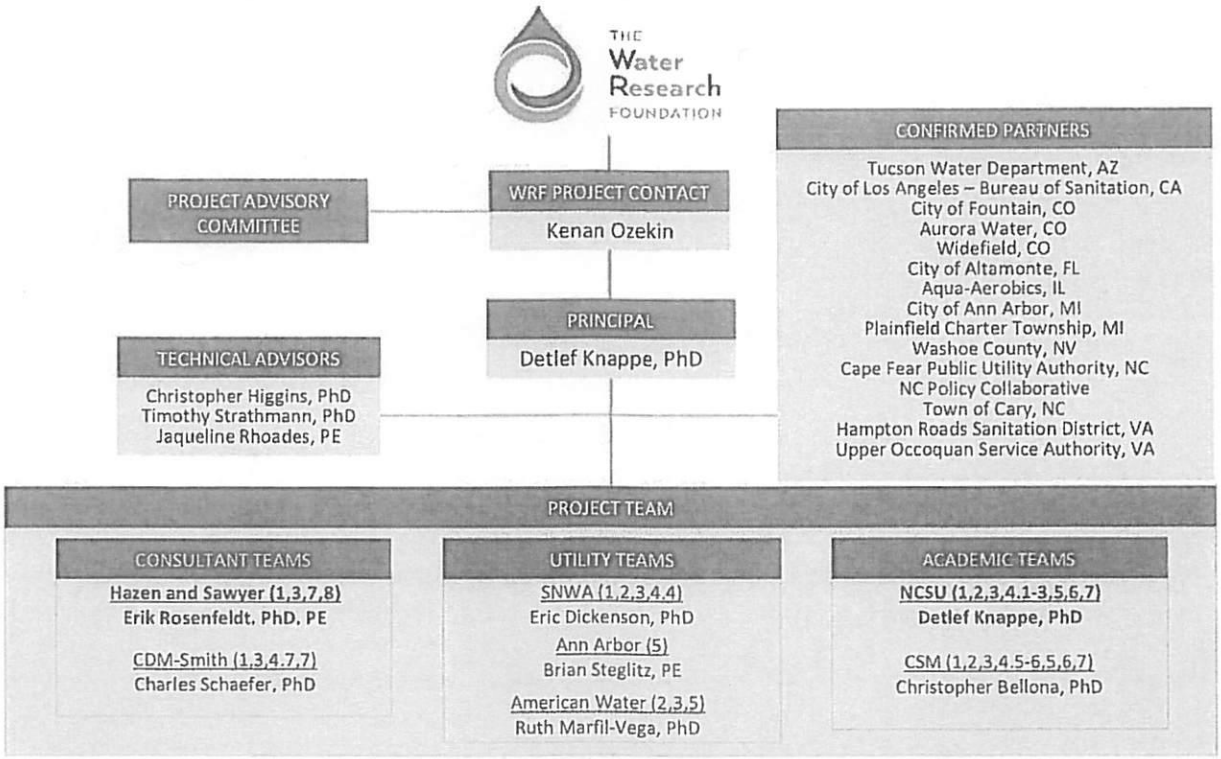
Project Team Responsibilities

The project organization is shown in Figure B, and is intended to facilitate a collaborative network within the team, and provide a summary of project task responsibilities. The existing, close working relationships between project team members allows for an open flow of communication and is essential for implementation of the project tasks and ensures efficient knowledge transfer and creative analysis to develop meaningful content and mechanisms for project deliverables. **Recognizing the importance of this project, all team members have verified that their current commitments allow for sufficient time and resources to be allocated to this project.**

Principal Investigator (PI): Dr. Detlef Knappe of North Carolina State University will serve as PI. Project deliverables, budget, schedule, and contracting to TWRF, as well as communications with the co-PIs, the project advisory committee, technical advisors, and utility partners, will be his responsibility. Dr. Knappe's lab will also perform significant technical work for the project, including leading the round-robin methods validation (Task 2), bench testing of GAC and IX (Tasks 4.1-3), developing QSAR models (Task 6), and supporting the LCA and cost model development (Task 7). Technical efforts associated with the project complement currently funded research projects, allowing Dr. Knappe's lab to address the proposed new research objectives promptly using developed methods. To reduce the project management burden, Hazen will administer the bulk of the technical subcontracts.

Co-PIs: **Dr. Bellona**'s lab will lead bench-scale testing of sPAC/MF and NF/RO processes (Tasks 4.5-6) as well as extensive pilot testing efforts at CSM and a local utility partner to integrate promising PFAS removal technologies (Task 5.2). He will also support the analytical methods validation (Task 2), the evaluation of destructive methods (Task 4.7), and the LCA and cost model development (Task 7). This arrangement mirrors ongoing collaboration between the Knappe/Bellona labs associated on an ESTCP project. **Hazen** and **CDM-Smith** will provide full- and pilot-scale data (Task 1) and support the full-scale evaluation (Task 3) by coordinating client participation. In addition, Hazen will lead development of the LCA and guidance documents (Tasks 7 and 8). CDM-Smith will lead the evaluation of destructive PFAS technologies (Task 4.7) through a collaboration with the Bellona lab, mirroring an ongoing DoD project arrangement. SNWA will lead the evaluation of innovative sorbents (Task 4.4) and will support Task 4 by conducting bench-scale experiments with treated wastewater. **SNWA** will participate in the round-robin analytical methods validation (Task 2), coordinate full-scale data collection for water reuse plants (Task 3) and will help gather full-scale and pilot-scale data from water reuse plants (Task 1). **AW** will support Task 2 and will play a key role in collecting full-scale data from impacted AW plants (Task 3) and conducting two pilot-scale studies (Task 5). Finally, **Ann Arbor** will play a key role in evaluating GAC and IX at both pilot and full scales (Task 5). Finally, we will have a group of technical advisors, who have extensive experience in PFAS analytical methods, destructive treatment technologies, and water treatment.

Figure B: TWRF 4913 Organization Chart. NCSU and Hazen (bold) will be responsible for administering project subcontracts. Task Numbers in parenthesis indicate key task leads/participation



Communication Plan

PFAS present a uniquely difficult water quality challenge for drinking water providers. PFAS occur widely, are difficult to remove from water, and are of health concern at low ng/L levels based on minimal risk levels just released by the ATSDR for public comment. As a result, PFAS are receiving intense public, political, and regulatory interest. Sources of PFAS are often linked to industrial or military facilities, leading to easy association with historical environmental disasters. As a result, public outcry for "safe water" is becoming more common, and utilities need to respond quickly and often with only limited information. For these reasons, timely and effective communication of the results of this study is critical.

Internal Communication: With a large and geographically diverse project team, internal communication is critical to ensure effective collaboration. Data sharing and communication will be fostered by developing a secure project site, where team members can store and share data as it is developed. All team members will be provided access to the project site, and permissions can be granted for PAC members and Foundation project management staff. In addition, hour-long monthly project progress conference calls will be held with all team members, with more intense quarterly updates occurring concurrent with report development.

Communication of technical findings: Results of this study are critically important to utilities currently developing solutions to meet PFAS water quality challenges. Technical findings will be delivered targeting water professionals (e.g. utility managers, consulting engineers, researchers, regulators) via several mechanisms, including:

- *Final Project Report:* The report is anticipated to serve as a design resource for water professionals. The report will include guidance for process selection that will consider such factors as PFAS removal targets and background water quality. Attention will be given to clearly conveying the wealth of information gathered in this project.
- *Summary Guidance:* In addition to the detailed Final Report, we will prepare a project synopsis (~20 pages) that provides summary guidance to water professionals. This synopsis will be made available to TWRF for distribution via their web page. Co-PI Rosenfeldt has developed similar documents for recent projects, including TWRF 4692: Release of Intracellular Cyanotoxins during Oxidation of Natural and Lab Cultured Cyanobacteria.
- *Conferences:* PIs will share information developed in this project at conferences such as the AWWA Annual Conference, WQTC, AWWA section conferences, WateReuse Annual Symposium, National Meetings of the ACS, and the biennial Emerging Contaminants Summit.
- *Webcasts:* The project team will provide a final project webcast through TWRF and/or AWWA. In addition, the PIs may conduct a preliminary webcast to present vetted findings specifically aimed at state and federal regulators and utilities interested in potential implications for future system design and compliance.
- *Publications:* The team will ensure that results of this research enter the foundational record of science through peer-reviewed journals. Given the scope and breadth of this project, we envision 3 – 4 journal articles from this study.

Foster "cross-industry" communication: The research team is involved in many PFAS focused projects, funded by federal agencies, utilities, and industry. We realize the cross-industry potential of this research and will seek to present results of this work at venues that focus, for example, on groundwater remediation (e.g., SERDP/ESTCP Symposium organized by the Department of Defense, Battelle Conference). These conferences provide opportunities for new collaborations designed to best protect community drinking water supplies.

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Schedule

The project team anticipates that the proposed project will commence on 10/1/2018 and conclude at the end of September 2020. The following schedule (Figure S.1) details the timeline for the completion of the project and individual project tasks. Progress reports will be submitted every quarter (3 month increments) and the draft final report will be submitted at the completion of the project.

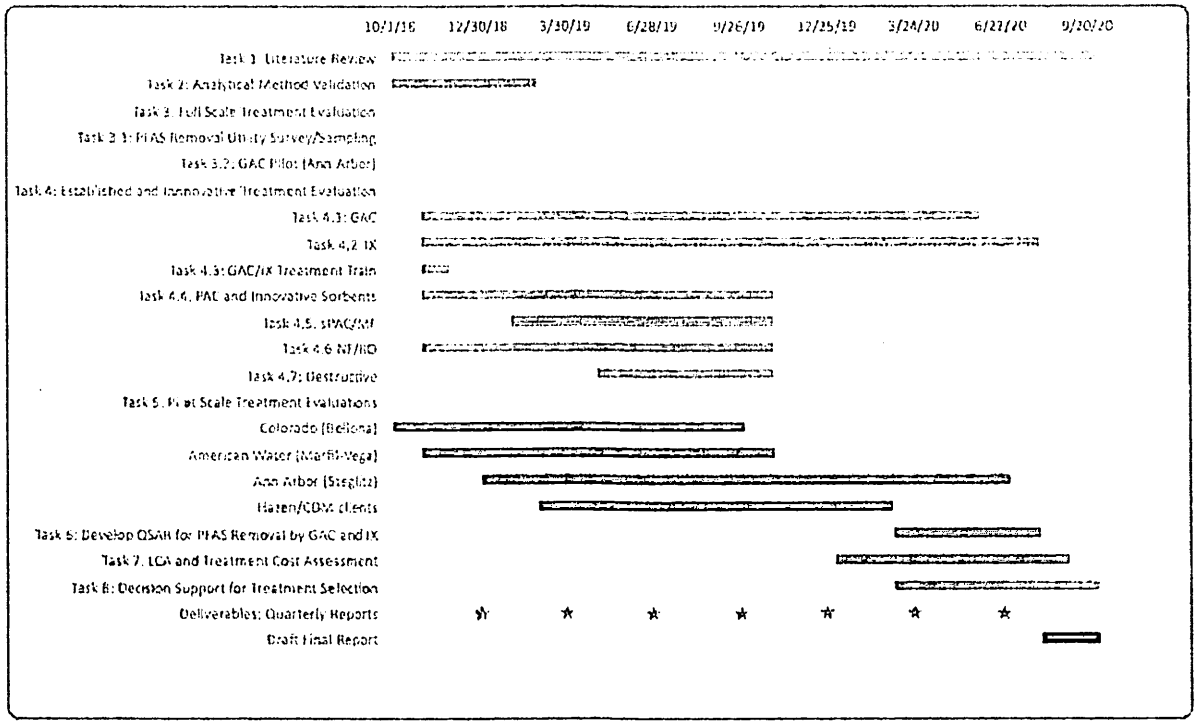

Figure S.1. Anticipated project schedule.

Current and Pending Form

This form must be completed for the Principal Investigator and for each Co-Principal Investigator. Failure to provide this information may result in disqualification of your proposal.

Investigator: Detlef Knappe

Other agencies to which this proposal has been/will be submitted: none

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Support: [X] Current [ ] Pending [ ] Submission Planned in Near Future [ ] Transfer of Support*

Project/Proposal Title: Assessing Impact of Drinking Water Exposure to GenX (hexafluoropropylene dimer acid) in the Cape Fear River Basin, North Carolina (PI: Hoppin)

Source of Support: National Institute of Environmental Health Sciences (NIEHS)

Total Award Amount: $430,100 Total Award Period Covered: 11/01/17-10/31/19

Location of Project: NC State University

Person-Months Per Year Committed to the Project: 1.2

Support: [X] Current [ ] Pending [ ] Submission Planned in Near Future [ ] Transfer of Support*

Project/Proposal Title: Electrically Assisted Sorption and Desorption of Per- and Polyfluoroalkyl substances (PI: Call)

Source of Support: US Department of Defense (DoD SERDP)

Total Award Amount: $200,000 Total Award Period Covered: 5/16/18-5/15/19

Location of Project: NC State University

Person-Months Per Year Committed to the Project: 0.5

Support: [X] Current [ ] Pending [ ] Submission Planned in Near Future [ ] Transfer of Support*

Project/Proposal Title: Collaborative Research: EAGER: Tailored Sorbents for the Removal of Emerging Per- and Polyfluoroalkyl Substances from Water (PI: Knappe)

Source of Support: National Science Foundation (NSF)

Total Award Amount: $35,000 Total Award Period Covered: 9/15/17-12/31/18

Location of Project: NC State University

Person-Months Per Year Committed to the Project: 0.2

Support: [X] Current [ ] Pending [ ] Submission Planned in Near Future [ ] Transfer of Support*

Project/Proposal Title: Water Sustainability through Nanotechnology: Nanoscale Science and Engineering at the Solid-Water Interface (PI: Jones)

Source of Support: NCSU Game-Changing Research Incentive Program

Total Award Amount: $575,000 Total Award Period Covered: 1/1/17-12/31/19

Location of Project: NC State University

Person-Months Per Year Committed to the Project: 0.5

Support: [X] Current [ ] Pending [ ] Submission Planned in Near Future [ ] Transfer of Support*

Project/Proposal Title: Effects of Contaminated Soil and Groundwater on Subsurface Utilities, Surface Water and Drainage (PI: Pour-Ghaz)

Source of Support: North Carolina Department of Transportation

Total Award Amount: $345,381 Total Award Period Covered: 8/16/16-7/31/19

Location of Project: NC State University

Person-Months Per Year Committed to the Project: 1.0

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*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.
USE ADDITIONAL SHEETS AS NECESSARY

Version: 03/01/2018 (previous versions are obsolete and will not be accepted for review).

Current and Pending Form

This form must be completed for the Principal Investigator and for each Co-Principal Investigator. Failure to provide this information may result in disqualification of your proposal.

Investigator: Detlef Knappe

Other agencies to which this proposal has been/will be submitted: none

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Support: ☐ Current x ☐ Pending ☐ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title: Occurrence of Pesticides in North Carolina Private Drinking Water Wells and Identification of Point-of-Use Treatment Options (PI: Knappe)

Source of Support: Water Resources Research Institute (selected for funding)

Total Award Amount: $120,000 Total Award Period Covered: 7/1/18-6/30/20

Location of Project: NC State University

Person-Months Per Year Committed to the Project: 0.5

Support: ☐ Current x ☐ Pending ☐ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title: Field Demonstration and Comparison of Ex-Situ Treatment Technologies for Poly- and Perfluoroalkyl Substances (PFASs) in Groundwater (PI: Fulmer)

Source of Support: The Water Research Foundation (Prime: US Department of Defense (DoD ESTCP) (selected for funding)

Total Award Amount: $200,011 Total Award Period Covered: 7/1/18-6/30/20

Location of Project: NC State University

Person-Months Per Year Committed to the Project: 0.5

Support: ☐ Current x ☐ Pending ☐ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title: Collaborative Research: Cyclodextrin-Based 2-D Materials for the Treatment of Legacy and Emerging Per- and polyfluoroalkyl substances (PI: Gao)

Source of Support: National Science Foundation (NSF) (selected for funding

Total Award Amount: $180,000 Total Award Period Covered: 8/15/18-8/14/21

Location of Project: NC State University

Person-Months Per Year Committed to the Project: 0.2

Support: ☐ Current x ☐ Pending ☐ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title: Optimizing Analytical and Sampling Techniques to Characterize PFAS Contamination in Environmental Waters (PI: Yuncu)

Source of Support: US Department of Defense (DoD SERDP)

Total Award Amount: $490,380 Total Award Period Covered: 5/16/19-5/15/22

Location of Project: NC State University

Person-Months Per Year Committed to the Project: 0.5

Support: ☐ Current x ☐ Pending ☐ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title: Natural and Enhanced Attenuation of Insensitive and High Explosives (Borden)

Source of Support: US Department of Defense (DoD SERDP)

Total Award Amount: $1,194,961 Total Award Period Covered: 5/16/19-5/15/22

Location of Project: NC State University

Person-Months Per Year Committed to the Project: 0.2

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*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.
USE ADDITIONAL SHEETS AS NECESSARY

Version: 03/01/2018 (previous versions are obsolete and will not be accepted for review).

Current and Pending Form

This form must be completed for the Principal Investigator and for each Co-Principal Investigator. Failure to provide this information may result in disqualification of your proposal.

Investigator: Detlef Knappe

Other agencies to which this proposal has been/will be submitted: none

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Support: ☐ Current x ☐ Pending ☐ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title: Predicting the Fate and Transport of Legacy and Emerging Explosives in Landfills (PI: Barlaz)
Source of Support: US Department of Defense (DoD SERDP)
Total Award Amount: $1,094,114 Total Award Period Covered: 5/16/19-5/15/22
Location of Project: NC State University
Person-Months Per Year Committed to the Project: 0.2

Support: ☐ Current x ☐ Pending ☐ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title: PFAS UNITEDD (PI: Higgins)
Source of Support: Colorado School of Mines (Prime: USEPA
Total Award Amount: $700,000 Total Award Period Covered: 1/1/19-12/31/21
Location of Project: NC State University
Person-Months Per Year Committed to the Project: 1.3

Support: ☐ Current x ☐ Pending ☐ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title: Investigation of Treatment Alternatives for Short-Chain Poly- and Perfluoroalkyl Substances (PI: Knappe) (this proposal)
Source of Support: The Water Research Foundation
Total Award Amount: $350,000 Total Award Period Covered: 10/1/18-9/30/20
Location of Project: NC State University
Person-Months Per Year Committed to the Project: 1.3

Current and Pending Form

This form must be completed for the Principal Investigator and for each Co-Principal Investigator. Failure to provide this information may result in disqualification of your proposal.

Investigator: Bellona

Other agencies to which this proposal has been/will be submitted: None

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Support: ☑ Current

Project/Proposal Title: Sequential nanofiltration with UV destructive treatment
Source of Support: Air Force Civil Engineering Center
Total Award Amount: $960,000 Total Award Period Covered: 8/17 - 8/20
Location of Project: Colorado School of Mines
Person-Months Per Year Committed to the Project: 0.5

Support: ☑ Current

Project/Proposal Title: Comparison of treatment technologies for PFAS removal through life-cycle analysis and analysis
Source of Support: DoD ESTCP
Total Award Amount: $1,090,4451 Total Award Period Covered: 7/1/18 - 7/1/21
Location of Project: Colorado School of Mines
Person-Months Per Year Committed to the Project: 0.5

Support: ☑ Current

Project/Proposal Title: Pilot-scale study of the effectiveness of PFAS removal by GAC for the City of Fountain
Source of Support: City of Fountain, Colorado
Total Award Amount: $100,000 Total Award Period Covered: 12/16 - 12/18
Location of Project: Colorado School of Mines
Person-Months Per Year Committed to the Project: 0.1

Support: ☑ Current

Project/Proposal Title: Alternative potable reuse treatment trains
Source of Support: National Science Foundation
Total Award Amount: $350,000 Total Award Period Covered: 8/1/15 - 8/1/20
Location of Project: Colorado School of Mines
Person-Months Per Year Committed to the Project: 0.5

Support: ☑ Pending

Project/Proposal Title: Superfine active carbon adsorption with ceramic microfiltration for removal of PFAS
Source of Support: DoD ESTCP
Total Award Amount: $670,000 Total Award Period Covered: 7/1/19 - 10/1/22
Location of Project: AQUA-AEROBICS, INC
Person-Months Per Year Committed to the Project: 0.25

Support: ☑ Pending

Project/Proposal Title: WRF-17-05: Understanding the impacts of wastewater treatment performance on advanced water treatment processes and finished water quality
Source of Support: Water Research Foundation
Total Award Amount: $300,000 Total Award Period Covered: 10/1/18- 10/1/20
Location of Project: Carollo
Person-Months Per Year Committed to the Project: 0.25

Support: ☑ Pending

Project/Proposal Title: Accelerating development of biogas-utilizing microorganisms for tunable hydroxyalkanoates and flexible production of fuels and chemicals
Source of Support: Department of Energy
Total Award Amount: $1,200,000 Total Award Period Covered: 10/1/18- 10/1/21
Location of Project: Carollo
Person-Months Per Year Committed to the Project: 0.15

Current and Pending Form

This form must be completed for the Principal Investigator and for each Co-Principal Investigator. Failure to provide this information may result in disqualification of your proposal.

Investigator: Rosenfeldt

Other agencies to which this proposal has been/will be submitted: N/A

Support: ☐ Current ☑ Pending ☐ Submission Planned in Near Future

☐ Transfer of Support*

Project/Proposal Title: Investigation of Treatment Alternatives for Short-chain PFASs

Source of Support: The Water Research Foundation

Total Award Amount: $550,000 Total Award Period Covered: ~10/18 - 9/20

Location of Project: North Carolina State University

Person-Months Per Year Committed to the Project: 1/2

Support: ☑ Current ☐ Pending ☐ Submission Planned in Near Future

☐ Transfer of Support*

Project/Proposal Title:

Modes of Action for Bromate-Induced Health Effects and Bromate Formation in Conventional and Advanced Water Treatment

Source of Support: The Water Research Foundation - Tailored Collaboration

Total Award Amount: $471,000 Total Award Period Covered: 6/18 - 5/20

Location of Project: Washington State University - Pullman

Person-Months Per Year Committed to the Project: 1/2

Support: ☑ Current ☐ Pending ☐ Submission Planned in Near Future

☐ Transfer of Support*

Project/Proposal Title:

Assessing the Role of Water Reuse and Conservation Practices for Improving Human and Ecological Health in the Potomac River Watershed

Source of Support: EPA STAR / TWRF / DC Water

Total Award Amount: $850,000 Total Award Period Covered: 6/16 - 6/19

Location of Project: University of Maryland, College Park

Person-Months Per Year Committed to the Project: 1

Support: ☑ Current ☐ Pending ☐ Submission Planned in Near Future

☐ Transfer of Support*

Project/Proposal Title:

Remote Sensing of Current and Future Vulnerability to Eutrophication and Algal Blooms in NY

Source of Support: NYSERDA

Total Award Amount: $250,000 Total Award Period Covered: 1/17 - 12/18

Location of Project: SUNY Binghamton

Person-Months Per Year Committed to the Project: 1/4

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.
USE ADDITIONAL SHEETS AS NECESSARY

Current and Pending Form

This form must be completed for the Principal Investigator and for each Co-Principal Investigator. Failure to provide this information may result in disqualification of your proposal.

Investigator: Eric Dickenson

Other agencies to which this proposal has been/will be submitted:

Support: ☑ Current ☑ Pending ☐ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title: Per- and Polyfluoroalkyl Substances: National Ecosystems and Human Exposures in Surface Waters

Source of Support: USEPA

Total Award Amount: $2,500,000 Total Award Period Covered: 01/04/2019-01/04/22

Location of Project: Water Research Foundation/Arizona State University/Southern Nevada Water Authority

Person-Months Per Year Committed to the Project: 0.25

Support: ☑ Current ☐ Pending ☐ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title: Plant Uptake of Contaminants of Emerging Concern in Agroecosystems Irrigated with Reclaimed Water

Source of Support: USDA

Total Award Amount: $295,691.00 Total Award Period Covered: 01/01/2017 - 12/31/2019

Location of Project: Desert Research Institute/University of Nevada Las Vegas

Person-Months Per Year Committed to the Project: 0.15

Support: ☑ Current ☐ Pending ☐ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title: Occurrence Survey of Bromide and Iodide in Water Supplies

Source of Support: The Water Research Foundation

Total Award Amount: $638,121.00 Total Award Period Covered: 11/01/2017-10/31/2019

Location of Project: Arizona State University

Person-Months Per Year Committed to the Project: 0.05

Support: ☑ Current ☐ Pending ☐ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title: Biofiltration Guidance Manual for Rapid-Rate Filtration Facility

Source of Support: The Water Research Foundation

Total Award Amount: $430,263.00 Total Award Period Covered: 10/01/2017-03/01/2019

Version: 03/01/2018 (previous versions are obsolete and will not be accepted for review).

Location of Project: Carollo Engineers, CA

Person-Months Per Year Committed to the Project: 0.10

Support: ☐ Current ☑ Pending ☐ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title:

Rapid Site Profiling of Organofluorine: Quantification of PFASs by Combustion Gas Analysis

Source of Support: DOD/SERDP

Total Award Amount: $784,382.00 Total Award Period Covered: 01/01/2019-12/31/2021

Location of Project: University of Nevada Reno

Person-Months Per Year Committed to the Project: 0.20

Support: ☑ Current ☐ Pending ☐ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title: Understanding the Impacts of Wastewater Treatment Performance on Advanced Water Treatment Processes and Finished Water Quality

Source of Support: The Water Research Foundation

Total Award Amount: $430,263.00 Total Award Period Covered: 10/01/2017-03/01/2019

Location of Project: Carollo Engineers, TX

Person-Months Per Year Committed to the Project: 0.20

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*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.
USE ADDITIONAL SHEETS AS NECESSARY

Current and Pending Form

This form must be completed for the Principal Investigator and for each Co-Principal Investigator. Failure to provide this information may result in disqualification of your proposal.

Investigator: Ruth Marfil-Vega

Other agencies to which this proposal has been/will be submitted: none

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Support: ☐ Current ☐ Pending ☒ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title: Utility Responses to Cyanobacterial/Cyanotoxin Events; Case Studies and Lessons Learned

Source of Support: Water Research Foundation

Total Award Amount: TBD Total Award Period Covered: TBD

Location of Project: Hazen & Sawyer

Person-Months Per Year Committed to the Project: 1.2

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title: Sources and Fate of Taste-and Odor Causing Compounds in the Missouri River

Source of Support: Water Research Foundation

Total Award Amount: 4125,000 Total Award Period Covered: 12/2016-6/2019

Location of Project: Corona Environmental Consulting

Person-Months Per Year Committed to the Project: 1

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title: Hospital Wastewater Practices and Contaminants of Emerging Concern in Water

Source of Support: Water Research Foundation

Total Award Amount: $100,000 Total Award Period Covered: 1/2016-5/2018

Location of Project: American Water

Person-Months Per Year Committed to the Project: 2.4

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title: Optimization of ozone-BAC treatment processes for potable reuse applications

Source of Support: Water Research Foundation

Total Award Amount: $240,000 Total Award Period Covered: 7/2015-9/2018

Location of Project: American Water

Person-Months Per Year Committed to the Project: 2.4

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*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.
USE ADDITIONAL SHEETS AS NECESSARY

Current and Pending Form

This form must be completed for the Principal Investigator and for each Co-Principal Investigator. Failure to provide this information may result in disqualification of your proposal.

Investigator: Charles Schaefer

Other agencies to which this proposal has been/will be submitted: none

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Support: X Current ☐ Pending ☐ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title: *Investigating Electrocatalytic and Catalytic Approaches for the In Situ Treatment of Perfluoroalkyl Contaminants in Groundwater*
Source of Support: *US Department of Defense (SERDP)*
Total Award Amount: $1.6M Total Award Period Covered: 10/2014 - 9/2019
Location of Project: Lawrenceville, NJ
Person-Months Per Year Committed to the Project: 1.5

Support: X Current ☐ Pending ☐ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title: *Biogeochemical Processes that Control the Natural Attenuation of Trichloroethylene in Low Permeability Zones*
Source of Support: US Department of Defense (*SERDP*)
Total Award Amount:$413K Total Award Period Covered: 9/2015 - 6/2019
Location of Project: Bellevue, WA
Person-Months Per Year Committed to the Project: 2

Support: X Current ☐ Pending ☐ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title: *Low Energy Chemical Treatment for Graywater Reuse: Mitigating Disinfection Byproducts and Recovering Cathodically Generated Hydrogen for Energy*
Source of Support: US Department of Defense (ESTCP)
Total Award Amount:$672K Total Award Period Covered: 7/2016-7/2019
Location of Project: Monterey, CA
Person-Months Per Year Committed to the Project: 1

Support: X Current ☐ Pending ☐ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title: *Perfluorochemical Treatment by Nanofiltration plus Sequential UV Oxidative/Reductive Treatment of Reject Water*
Source of Support: USAF
Total Award Amount:$63K Total Award Period Covered: 1/2017 - 1/2020
Location of Project: Golden, CO
Person-Months Per Year Committed to the Project: 0.5

Support: X Current ☐ Pending ☐ Submission Planned in Near Future

☐ Transfer of Support*

Project/Proposal Title: *Key Fate and Transport Processes Impacting the Mass Discharge, Attenuation, and Treatment of Poly- and Perfluoroalkyl Substances and Comingled Chlorinated Solvents or Aromatic Hydrocarbons*
Source of Support: *US Department of Defense (SERDP)*
Total Award Amount: $300K Total Award Period Covered: 8/2017- 8/2020
Location of Project: Bellevue, WA
Person-Months Per Year Committed to the Project: 1.5

Support: ☐ Current X Pending ☐ Submission Planned in Near Future

☐ Transfer of Support*

Project/Proposal Title: *Insights into the Long-Term Mass Discharge & Transformation of AFFF in the Unsaturated Zone*
Source of Support: US Department of Defense (*SERDP*)
Total Award Amount:$1.5M Total Award Period Covered: 9/2018 - 9/2021
Location of Project: Bellevue, WA
Person-Months Per Year Committed to the Project: 1.5

Support: ☐ Current X Pending ☐ Submission Planned in Near Future

☐ Transfer of Support*

Project/Proposal Title: *A Mechanistic Understanding of PFASs in Source Zones: Characterization and Control*
Source of Support: *US Department of Defense (SERDP)*
Total Award Amount: $198K Total Award Period Covered: 8/2017- 8/2020
Location of Project: Bellevue, WA
Person-Months Per Year Committed to the Project: 0.7

Support: ☐ Current X Pending ☐ Submission Planned in Near Future

☐ Transfer of Support*

Project/Proposal Title: *Regenerable Resin Sorbent Technologies with Regenerant Solution Recycling for Sustainable Treatment of Per- and Polyfluoroalkyl Substances (PFASs)*
Source of Support: US Department of Defense (*SERDP*)
Total Award Amount:$274K Total Award Period Covered: 9/2018 - 9/2021
Location of Project: Bellevue, WA
Person-Months Per Year Committed to the Project: 0.7

Support ☐ Current x☐ Pending ☐ Submission Planned in Near Future

☐ Transfer of Support*

Project/Proposal Title: *Field Demonstration and Life Cycle Comparison of Ex-Situ Treatment Technologies for Poly- and Perfluoroalkyl Substances (PFASs) in Groundwater*
Source of Support: US Department of Defense (*ESTCP*)
Total Award Amount:$56K Total Award Period Covered: 9/2018 - 9/2021
Location of Project: Bellevue, WA
Person-Months Per Year Committed to the Project: 0.2

Support ☐ Current x☐ Pending ☐ Submission Planned in Near Future

☐ Transfer of Support*

Project/Proposal Title: *Complete Reductive Defluorination of Poly- and Perfluoroalkyl Substances (PFASs) by Hydrated Electrons Generated from 3-Indole-acetic-acid in Chitosan-Modified Montmorillonite*
Source of Support: US Department of Defense (*SERDP*)
Total Award Amount:$47K Total Award Period Covered: 7/2018 - 7/2019
Location of Project: Bellevue, WA
Person-Months Per Year Committed to the Project: 0.3

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*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.
USE ADDITIONAL SHEETS AS NECESSARY

Current and Pending Form

This form must be completed for the Principal Investigator and for each Co-Principal Investigator. Failure to provide this information may result in disqualification of your proposal.

Investigator:

Brian Steglitz

Other agencies to which this proposal has been/will be submitted:

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title: Investigation of Treatment Alternatives for Short Chain PFASs
Source of Support: The Water Research Foundation
Total Award Amount: $35,000 Total Award Period Covered: 11/18 - 11/20
Location of Project: Ann Arbor, MI
Person-Months Per Year Committed to the Project: 1.0

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title: Optimizing Filter Operation in an Ozone Biofiltration Plant to Reduce Selection for Opportunistic Pathogens
Source of Support: The Water Research Foundation
Total Award Amount: $100,000 Total Award Period Covered: 9/17 - 9/19
Location of Project: Ann Arbor, MI
Person-Months Per Year Committed to the Project: 1.0

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title:
Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ Transfer of Support*

Project/Proposal Title:
Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project:

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*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.
USE ADDITIONAL SHEETS AS NECESSARY

Hazen *Memorandum*

June 18, 2018

Detlef Knappe
Professor
Department of Civil, Construction, and Environmental Engineering
North Carolina State University
Campus Box 7908
Raleigh, NC 27695-7908

Re: Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances (RFP #4913)

Dear Professor Knappe,

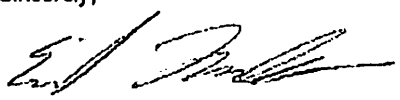
Hazen and Sawyer is pleased to support your proposal in response to The Water Research Foundation's RFP 4913 entitled "Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances." Short-chain PFAS, are an important challenge at several of our water treatment facilities We anticipate that your proposed research on treatment options, such as activated carbon adsorption, anion exchange, and membrane treatment will result in much needed information to effectively design removal processes for PFAS.

Hazen and Sawyer is a water-focused consulting firm, providing advanced solutions for water quality challenges to municipal clients throughout the United States. Recently, we have worked with several clients (confidential and publically acknowledged) to work through PFAS challenges with advanced drinking water treatment strategies. We will be bringing these experiences and facilitating partnerships between the project team and utility partners, as well as assisting in project management and deliverable development, to the project effort.

We are also supportive of your efforts to develop structure-property relationships that will permit removal predictions of PFASs that are yet to be discovered. Also, we welcome your idea to integrate the data developed in the research effort proposed here into your ongoing efforts to develop life cycle assessment and costing models for PFAS removal technologies.

We estimate the value of support at $4,500 as in-kind contributions in the way of staff time, communication, access to reports and data as needed, and project facilitation (ie developing a secure data storage and project communications sharepoint site). We also will be participating as a project subcontractor with a budget allocation of $45,000 to cover costs associated with managing subcontracts with Southern Nevada Water Authority, Ann Arbor, American Water, and CDM-Smith, coordinating full-scale data collection at client utilities, and treatment optimization using our proprietary HazenGAC treatment model. Please contact Erik Rosenfeldt at erosenfeldt@hazenandsawyer.com if you have any questions. We sincerely look forward to working with your team on this important research topic.

Sincerely,



Erik J. Rosenfeldt, Ph.D., P.E.
Director of Drinking Water Process Technology | Hazen and Sawyer
1555 Roseneath Rd., Richmond, VA 23230
804 545-5098 (direct) | 571 505-6601 (cell)
erosenfeldt@hazenandsawyer.com | hazenandsawyer.com

AMERICAN WATER

1025 Laurel Oak Road
Voorhees, NJ 08043
P: 856-727-6232
F: 856-727-6198
C: 646.599.3164
Ben.Stanford@amwater.com

Detlef Knappe
Professor
Department of Civil, Construction, and Environmental Engineering
North Carolina State University
Campus Box 7908
Raleigh, NC 27695-7908

May 25, 2017

Re: Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances (RFP #4913)

Dear Professor Knappe,

American Water is pleased to support your proposal in response to The Water Research Foundation's RFP 4913 entitled "Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances (PFAS)". Short-chain PFAS potentially impact most of our states with regulated water utilities. We anticipate that your proposed research on treatment options, such as activated carbon adsorption, anion exchange, and membrane treatment will result in much needed information to effectively design removal processes for PFAS.

Perfluoroalkyl substances (PFAS) have been in the news at increasing frequency over the past several months. News reports from the past two weeks have indicated that new information may be forthcoming from the Federal Government that could lower health advisories for selected PFAS and impact six times more American Water systems than are currently impacted (from 8 to 49) across 13 of our regulated states. To prepare for this, we are already beginning to use the new analytical capabilities within Technology and Innovation to confirm which systems may be impacted and screen for short chain PFAS and next generation PFAS, pilot test a new PFAS ion exchange resin from Purolite that can remove next generation PFAS compounds better than our currently-used GAC treatment, and conduct a potential cost impact analysis. The results from our sampling efforts, pilot testing, and cost analysis will be provided as in-kind efforts to support this proposal and project moving forward. Additionally, the project team will have access to any of the 49 identified locations that consist of groundwater and surface water sites across our regulated footprint (see map on the following page).

We are also supportive of your efforts to develop structure-property relationships that will permit removal predictions of PFASs that are yet to be discovered. Also, we welcome your idea to integrate the data developed in the research effort proposed here into your ongoing efforts to develop life cycle assessment and costing models for PFAS removal technologies. The research you are proposing matches well with American Water's priorities and will benefit the water utility community as a whole.

AMERICAN WATER

We estimate the value of support at $100,000 as in-kind contributions in the way of staff time, communication, pilot testing and equipment, and access to reports and data as needed. We also will be participating as a project subcontractor with a budget allocation of $20,000 to cover costs associated with the pilot from Purolite. Please contact Ben Stanford at (856) 727-6232 if you have any questions or comments. We sincerely look forward to working with your team on this important research topic.

Best Regards,

Benjamin D. Stanford

Benjamin D. Stanford
Sr. Director
Water Research and Development

SOUTHERN NEVADA WATER AUTHORITY
SOUTHERN NEVADA WATER SYSTEM
River Mountains Water Treatment Facility
1299 Burkholder Boulevard • Henderson, NV 89015
MAILING ADDRESS: P.O. Box 99954 • Las Vegas, NV 89193-9954
(702) 856-3500 • snwa.com

June 20, 2018

Detlef Knappe
Professor
Department of Civil, Construction, and Environmental Engineering
North Carolina State University
Campus Box 7908
Raleigh, NC 27695-7908

Re: Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances (RFP #4913)

Dear Professor Knappe,

The Southern Nevada Water Authority (SNWA) is the Co-Principal Investigator for the proposed study in response to the Water Research Foundation RFP entitled, "Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances". We recognize PFAS are potentially an important challenge for drinking water treatment systems treating contaminated surface or groundwaters and potable reuse and we anticipate the research on treatment options, such as activated carbon adsorption, anion exchange, membrane and alternative treatment will result in much needed information to effectively design removal processes for PFAS.

SNWA has been examining the occurrence and treatment of PFAS in water treatment systems for the last decade. The SNWA R&D laboratory, and its experienced team of chemists, is a leader for the development and application of low-level methods for PFAS in wastewater, water reuse and drinking water systems. SNWA led the noteworthy WRF project (#4322) that measured the occurrence of PFAS in U.S. drinking waters and revealed the lack of treatment of PFAS within conventional full-scale drinking water systems.

SNWA will provide, as in-kind, up to the amount of $23,000; labor/nonlabor costs associated with PFAS analysis as described in the proposal. We will also participate as a subcontractor with a budget allocation of $70,000 of WRF funds to cover costs associated with analytical support and personnel support for oversight of SNWA activities and conducting bench- and pilot-scale testing as described in the proposal.

Please contact me at (702) 856-3664, if you have any questions or comments. We sincerely look forward to working with your team on this important research topic.

Sincerely,

David J. Rexing
SNWA W.Q. R&D Manager
P.O. Box 99954 MIS 1970
Las Vegas, NV 89193-9954
702.856.3664 T
702.856.3647 F
Dave.Rexing@SNWA.com

CDM Smith

100 Pringle Avenue, Suite 300
Walnut Creek, CA 94596
tel: 925-933-2900
fax: 925-933-4174

June 18, 2018

Proposals – RFP 4913
Water Research Foundation
6666 Qunicy Avenue
Denver, CO 80235

Subject: Letter of Commitment for Proposed Foundation Project 4913 – INVESTIGATION OF TREATMENT ALTERNATIVES FOR SHORT-CHAIN POLY AND PERFLUOROALKYL SUBSTANCES

Dear Dr. Detlef Knappe,

CDM Smith, Inc. (CDM Smith) is committed to successfully completing the Water Research Foundation (WRF) project "Investigation of Treatment Alternatives for Short-Chain Poly and Perfluorinated Substances," as described in RFP 4913. We are excited to be a part of the project to evaluate innovative and alternative methods for treating per- and polyfluoroalkyl substances (PFASs). As detailed in our cost proposal, CDM Smith will perform electrochemical testing to assess PFAS treatment of anion exchange (IX) regeneration fluid; PFAS analysis will be performed at North Carolina State University (NCSU). We will also collaborate with several of our utility partners, with whom we have previously investigated the treatment efficacy of PFASs, by providing PFAS treatment data to NCSU from on-going or previously performed bench, pilot-, or full-scale processes. The WRF funding share requested for CDM Smith's services totals $40,000 and CDM Smith's in-kind contribution totals $10,000. CDM Smith is pleased to support this drinking water research project. If I can provide any additional information, please contact me at (213) 457-2146.

Very truly yours,

Hampik Dekermenjian, PE
Senior Vice President
CDM Smith Inc.

CITY OF ANN ARBOR
PUBLIC SERVICES ADMINISTRATION

June 18, 2018

Detlef Knappe
Professor
Department of Civil, Construction, and Environmental Engineering
North Carolina State University
Campus Box 7908
Raleigh, NC 27695-7908

Re: Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances (RFP #4913)

Dear Professor Knappe,

The City of Ann Arbor is pleased to support your proposal in response to The Water Research Foundation's RFP 4913 entitled " Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances."

The City of Ann Arbor is interested in furthering the research in developing and optimizing treatment technologies for both short and long-chain PFAS. The City has detected low levels of these substances in both its raw and finished water and remains interested in developing solutions that will improve the City's finished water quality as well as help to guide utilities faced with similar water quality concerns. Participation in this project with this outstanding team, under your direction, would be an honor for the City of Ann Arbor. We anticipate that your proposed research on treatment options, such as activated carbon adsorption, anion exchange, and membrane treatment will result in much needed information to effectively design removal processes for PFAS.

In addition to offering access to a staff with decades of applied water treatment knowledge and skills, the City will offer use of both full scale and pilot scale filtration processes during this project. The City operates 26 mixed media filters, several of which could be used to assess different granular activated carbon products. At the pilot scale, the City has six pilot filter columns that can be used to test different operating scenarios as wells as different media, including granular activated carbon, anion exchange resins, and innovative sorbents that show promise in bench-scale experiments. Use of both pilot and full scale filtration infrastructure will allow principles developed at the bench scale to be vetted at a working on-line, water treatment plant. This opportunity will help ensure that recommendations developed through this research can be both applied and scaled to plant production level.

Water Treatment Plant, 919 Sunset Road, Ann Arbor, Michigan 48103-2924
(734) 994-2840 • Fax (734) 994-0151
http://www.a2gov.org

CITY OF ANN ARBOR
PUBLIC SERVICES ADMINISTRATION

We are also supportive of your efforts to develop structure-property relationships that will permit removal predictions of PFASs that are yet to be discovered. Also, we welcome your idea to integrate the data developed in the research effort proposed here into your ongoing efforts to develop life cycle assessment and costing models for PFAS removal technologies.

We estimate the value of support at $25,000 as in-kind contributions in the way of staff time, communication, pilot testing and equipment, and access to reports and data as needed. We also will be participating as a project subcontractor with a budget allocation of $35,000 to cover costs associated with the pilot study. Please contact Brian Steglitz at (734) 794-6426 ext. 43905 or bsteglitz@a2gov.org if you have any questions or comments. We sincerely look forward to working with your team on this important research topic.

Sincerely,

Brian Steglitz, P.E.
Water Treatment Services Unit Manager
City of Ann Arbor
919 Sunset Road
Ann Arbor, MI 48103

NC Policy Collaboratory ▪ collaboratory.web.unc.edu ▪ 400 Roberson Street, Carrboro, NC 27510

June 1, 2018

Detlef Knappe, PhD
Professor
Department of Civil, Construction, and Environmental Engineering
North Carolina State University
Campus Box 7908
Raleigh, NC 27695-7908

Re: Investigation of Treatment Alternatives for Short-Chain Poly- and Perfluoroalkyl Substances (RFP #4913)

Dear Professor Knappe,

I am writing this letter in support of your proposal in response to The Water Research Foundation's RFP 4913 entitled, "Investigation of Treatment Alternatives for Short-Chain Poly- and Perfluoroalkyl Substances." Short-chain PFAS, such as GenX, have been emitted into both the air and water within the State of North Carolina and are an important challenge to numerous drinking water utilities in our State. We anticipate that your proposed research on treatment options, such as activated carbon adsorption, anion exchange, and membrane treatment, will result in much needed information to effectively design removal processes for PFAS. We are also supportive of your efforts to develop structure-property relationships that will permit removal predictions of PFAS that are yet to be discovered. We also welcome your idea to integrate life-cyclee assessment and costing models for PFAS removal technologies.

The research you are proposing fits well into the NC Policy Collaboratory's mission and mandate established by the NC General Assembly. Should your proposal be selected by the WRF, we will be able to contribute to the matching requirement by providing additional support in the amount of $131,250.

Sincerely,

Jeffrey Warren, PhD
Research Director

Cape Fear
Public Utility Authority
Stewardship. Sustainability. Service.

June 8, 2018

Dr. Erik Rosenfeldt, Ph.D., P.E.
Hazen and Sawyer
1555 Roseneath Road
Richmond, VA 23226

RE: Letter of Participation Support for The Water Research Foundation RFP#4913

Dear Dr. Rosenfeldt,

The Cape Fear Public Utility Authority (CFPUA) would be pleased to participate in your proposal in response to The Water Research Foundation RFP #4913: "Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances". We understand the need for better understanding treatment options and operational parameters for the treatment of conventional PFASs (PFOA and PFOS) along with short-chain PFAS compounds, including GenX.

CFPUA's contribution consists of participation at the bench-scale treatability level. We currently have two sources impacted by short-chain PFASs (Sweeney WTP and our Aquifer Storage and Recovery Well). This is a unique situation with similar mixes of PFAS, but significantly different water quality. Our participation would include providing the project team with access to water, input on technology testing to be performed (i.e. GAC media selection, operational impacts, water quality impacts, etc.), reviewing collected data, and reviewing interim/final reports. In addition, we have collected a large amount of data on treatability of PFASs in our Sweeney WTP over the last year. We will provide access to this historical water quality and treatment data as part of this project.

Our project support is will be an in-kind contribution of up to $30,000. This contribution is to be provided as described above, including access to our facility, provision of historical and current water quality data, and staff time for review. Please contact me at (910)-332-6654 if you have any questions.

We look forward to working with your team on this important research topic.

Sincerely,

Carel Vandermeyden, P.E.
Director of Engineering

235 Government Center Drive, Wilmington, NC 28403
t: 910-332-6560 f: 910-332-6353 www.cfpua.org

June 19, 2018

Detlef Knappe
Professor
Department of Civil, Construction, and Environmental Engineering
North Carolina State University
Campus Box 7908
Raleigh, NC 27695-7908

Re: Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances (RFP #4913)

Dear Professor Knappe,

The City of Fountain is pleased to support your proposal in response to The Water Research Foundation's RFP 4913 entitled "Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances". Short-chain PFAS, are an important challenge at several of our water treatment facilities. We anticipate that your proposed research on treatment options, such as activated carbon adsorption, anion exchange, and membrane treatment will result in much needed information to effectively design removal processes for PFAS.

We have been working with Dr. Chris Bellona for about a year evaluating granular activated carbon and ion-exchange for the removal of PFASs from contaminated groundwater. We understand Dr. Bellona's research group would like to continue testing at our facility and agree to support CSM's efforts during the course of this project. Our operator's will assist in monitoring treatment systems and collecting samples during the project.

We are also supportive of your efforts to develop structure-property relationships that will permit removal predictions of PFASs that are yet to be discovered. Also, we welcome your idea to integrate the data developed in the research effort proposed here into your ongoing efforts to develop life cycle assessment and costing models for PFAS removal technologies.

We estimate the value of support at $10,000 as in-kind contributions in the way of staff time, communication, and assisting in pilot testing. Please contact me at (719) 322-2088 or MFink@fountaincolorado.org if you have any questions or comments. We sincerely look forward to working with your team on this important research topic.

Sincerely,

Michael Fink, P.E.
Water Superintendent
City of Fountain, Colorado

PLAINFIELD CHARTER TOWNSHIP

PUBLIC SERVICES

WATER • SEWER • STORMWATER • ENGINEERING

June 20, 2018

Detlef Knappe
Professor
Department of Civil, Construction, and Environmental Engineering
North Carolina State University
Campus Box 7908
Raleigh, NC 27695-7908

Re: Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances (RFP #4913)

Dear Professor Knappe,

Plainfield Charter Township Water is pleased to support your proposal in response to The Water Research Foundation's RFP 4913 entitled " Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances." Short-chain PFAS are an important challenge at our water treatment plant. We anticipate that your proposed research on treatment options, such as activated carbon adsorption, anion exchange, and membrane treatment will result in much needed information to effectively design removal processes for PFAS.

We have had a wellfield impacted, and subsequently taken out of service, by PFAS contamination likely caused by landfill leachate. Our remaining wellfields have low levels of multiple PFAS compounds and we are currently evaluating GAC filter treatment methods

We are also supportive of your efforts to develop structure-property relationships that will permit removal predictions of PFASs that are yet to be discovered. Also, we welcome your idea to integrate the data developed in the research effort proposed here into your ongoing efforts to develop life cycle assessment and costing models for PFAS removal technologies.

We estimate the value of support at $8,000 as in-kind contributions in the way of staff time, communication, pilot testing and equipment, and access to reports and data as needed. Please contact me at (616) 363-9660 if you have any questions or comments. We sincerely look forward to working with your team on this important research topic.

Sincerely,
Plainfield Charter Township

Rick Solle, P.E.
Director of Public Services

UTILITIES DEPARTMENT

June 21, 2018

Detlef Knappe
Professor
Department of Civil, Construction, and Environmental Engineering
North Carolina State University
Campus Box 7908
Raleigh, NC 27695-7908

Re: Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances (RFP #4913)

Dear Professor Knappe,

The Town of Cary is pleased to support your proposal in response to the Water Research Foundation's RFP 4913 titled, "Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances." Treatment of short-chain PFAS is an emerging and important challenge at our water treatment facility. We anticipate that your proposed research will provide useful information to improve the design of treatment processes for PFAS removal.

We also support your efforts to develop structure-property relationships that will enable removal predictions for PFAS that have yet to be identified. The data developed in the research effort proposed here should support your ongoing efforts to develop life-cycle assessment and cost models for PFAS removal technologies. Accurate cost analysis is an important component of technology selection for facilities considering options for PFAS removal.

The Town of Cary has detected short-chain PFASs in its source water. We have completed a full-scale evaluation of short-chain PFAS removal by powdered activated carbon adsorption, and we are in the process of starting a pilot study to compare the effectiveness of granular activated carbon adsorption, anion exchange, and reverse osmosis treatment for PFAS removal.

We estimate the value of support as contributions in the way of staff time, communication, pilot testing and equipment set up for existing project work, and access to reports and data as needed. Please contact Alexandra Jones at alexandra.jones@townofcary.org or 919-362-5504 if you have any questions or comments. We sincerely look forward to working with your team on this important research topic.

Sincerely,

E. Alexandra Jones, P.E.
Water System Manager

CITY OF
TUCSON
TUCSON WATER
DEPARTMENT

June 21, 2018

Detlef Knappe
Professor
Department of Civil, Construction, and Environmental Engineering
North Carolina State University
Campus Box 7908
Raleigh, NC 27695-7908

Re: Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances (RFP #4913)

Dear Professor Knappe,

Tucson Water is pleased to support your proposal in response to The Water Research Foundation's RFP 4913 entitled "Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances." Short-chain PFAS, are an important challenge at several of our water treatment facilities We anticipate that your proposed research on treatment options, such as activated carbon adsorption, anion exchange, and membrane treatment will result in much needed information to effectively design removal processes for PFAS.

Tucson Water will participate in the following, but not limited to, a survey, share existing water quality data, provide water samples for bench scale testing (the cost would be an in-kind contribution to the project).

We are also supportive of your efforts to develop structure-property relationships that will permit removal predictions of PFASs that are yet to be discovered. Also, we welcome your idea to integrate the data developed in the research effort proposed here into your ongoing efforts to develop life cycle assessment and costing models for PFAS removal technologies.

We estimate the value of support at $5,500 as in-kind contributions in the way of staff time, communication, pilot testing and equipment, and access to reports and data as needed. Please contact Jeff Biggs at (520) 837-2111 and/or jeff.biggs@tucsonaz.gov if you have any questions or comments. We sincerely look forward to working with your team on this important research topic.

Sincerely,

Jeff B. Biggs
Administrator, Strategic Initiatives Division
Tucson Water

Aurora Water
City of Aurora
Binney Water Purification Facility
5070 S Robertsdale Way
Aurora, Colorado 80016
303.739.4700
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June 20, 2018

Detlef Knappe
Professor
Department of Civil, Construction, and Environmental Engineering
North Carolina State University
Campus Box 7908
Raleigh, NC 27695-7908

Re: Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances (RFP #4913)

Dear Professor Knappe,

Aurora Water (City of Aurora, CO) is pleased to support your proposal in response to The Water Research Foundation's RFP 4913 entitled, "Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances". PFAS are potentially an important challenge for potable reuse trains. We anticipate that your proposed research on treatment options, such as activated carbon adsorption, anion exchange, and membrane treatment will result in much needed information to effectively design removal processes for PFAS.

We will provide PFAS data and samples for PFAS analysis from our full-scale advanced oxidation, biofiltration and granular activated carbon processes for our Binney Water Purification Facility (BWPF). We will provide additional staff time, as needed, to review and provide feedback on data provided. We reserve the right that our participation is kept anonymous in reports, journal publications and presentations because of this project. We estimate the value of our support up to $5,000 as in-kind contributions in the way of our staff time, communication and historical data. Please contact Kevin Linder at (720) 427-3912 if you have any questions or comments. We sincerely look forward to working with your team on this important research topic.

Sincerely,

Kevin D. Linder
Binney WPF Supervisor
5070 S Robertsdale Way
Aurora, CO 80016
klinder@auroragov.org

CITY OF ALTAMONTE Springs

June 22, 2018

Detlef Knappe
Professor
Department of Civil, Construction, and Environmental Engineering
North Carolina State University
Campus Box 7908
Raleigh, NC 27695-7908

Re: Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances (RFP #4913)

Dear Professor Knappe,

The City of Altamonte Springs is pleased to support your proposal in response to The Water Research Foundation's RFP 4913 entitled, "Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances". PFAS are potentially an important challenge for potable reuse trains. We anticipate that your proposed research on treatment options, such as activated carbon adsorption, anion exchange, and membrane treatment will result in much needed information to effectively design removal processes for PFAS.

We will provide PFAS data and samples for PFAS analysis from our pilot system consisting of ozone/BAC/UF/GAC/UV. We will provide additional staff time, as needed, to review and provide feedback on data provided. We reserve the right that our participation is kept anonymous in reports, journal publications and presentations because of this project. We estimate the value of our support up to $5,000 as in-kind contributions in the way of our staff time, communication and historical data. Please contact Jo Ann Jackson at (407) 571-8712 or JAJackson@altamonte.org if you have any questions or comments. We sincerely look forward to working with your team on this important research topic.

Sincerely,

Jo Ann Jackson, P.E.
City of Altamonte Springs
Division Director Water, Wastewater & Reuse

CITY OF LOS ANGELES
CALIFORNIA

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June 19, 2018

Detlef Knappe, Ph.D.
Department of Civil, Construction, and Environmental Engineering
North Carolina State University
Campus Box 7908
Raleigh, NC 27695-7908

Dear Dr. Detlef Knappe,

INVESTIGATION OF TREATMENT ALTERNATIVES FOR SHORT-CHAIN POLY AND PERFLUOROALKYL SUBSTANCES (RFP #4913)

LA Sanitation is pleased to support your proposal in response to The Water Research Foundation's RFP 4913 entitled, "Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances". PFAS are potentially an important challenge for potable reuse trains. We anticipate that your proposed research on treatment options, such as activated carbon adsorption, anion exchange, and membrane treatment will result in much needed information to effectively design removal processes for PFAS.

LA Sanitation has experience operating pilot ozone/BAC-based and RO-based treatment processes within our Donald C. Tillman Groundwater Replenishment Advanced Water Purification Facility. We will plan to perform bench-scale GAC experiments to understand GAC effectiveness as an additional treatment barrier for chemical contaminant removal, including PFAS removal.

We will provide PFAS data and samples for PFAS analysis from our pilot- and bench-scale systems. We will provide additional staff time, as needed, to review and provide feedback on data provided. We reserve the right that our participation is kept anonymous in reports, journal publications and presentations because of this project. We estimate the value of our support up to $10,000 as in-kind contributions in the way of our staff time, communication, historical data, and on-going pilot testing

activities. Please contact Roshanak Aflaki at (818) 778-4120 if you have any questions or comments. We sincerely look forward to working with your team on this important research topic.

We look forward to participating with you in this important project.

Sincerely,

ROSHANAK AFLAKI, Division Manager
Water Reclamation Division
LA Sanitation

RA: lm

HRSD

Cleaning wastewater every day for a better Bay.

June 20, 2018

Detlef Knappe
Professor
Department of Civil, Construction, and Environmental Engineering
North Carolina State University
Campus Box 7908
Raleigh, NC 27695-7908

RE: HRSD Support for Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances (RFP #4913)

Dear Professor Knappe:

Hampton Roads Sanitation District supports your proposal in response to The Water Research Foundation's RFP 4913 entitled, "Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances".

As a wastewater treatment authority that is quickly delving into advanced treatment for indirect potable reuse, we anticipate that your proposed research on treatment options, such as activated carbon adsorption, anion exchange, and membrane treatment will result in much needed information to effectively design removal processes for PFAS.

HRSD recently initiated the Sustainable Water Initiative for Tomorrow (SWIFT) program in Eastern Virginia. This program will add advanced treatment to many of our treatment plants in order to produce a highly treated effluent that will be used to replenish the Potomac Aquifer, which is rapidly being depleted by excessive groundwater withdrawals. This program will not only reduce the rate of land subsidence in the region, but will also greatly reduce the amount of nitrogen and phosphorus that is discharged by HRSD into the Chesapeake Bay.

In order to ensure that SWIFT water is safe for indirect potable reuse within the aquifer, HRSD has carefully monitored the quality of water produced at an initial pilot facility and now at our demonstration facility, where one (1.0) million gallons per day (MGD) of purified water is currently being used to recharge the aquifer. Currently, we have confirmed that the O_3/BAC/GAC treatment train we have in place is effective at removing PFOS and PFOA. However, we understand that there are still many unknowns regarding effective treatment of PFAS, in particular short chain PFAS. The work proposed by your group will help to fill current research gaps and will provide us with additional information needed to make more informed decisions about PFAS treatment and risk.

In addition, HRSD recognizes that there is a lack of information on the occurrence, fate and transport of these substances and has therefore conducted various studies over the years looking at a variety of PFAS related questions. Previous work has investigated PFAS content in wastewater influent and effluent samples collected seasonally in the spring, summer, and fall. In addition, sequencing batch reactor (SBR) studies conducted in-house have shown that aqueous film forming foam (AFFF) may inhibit biological nutrient removal (BNR) processes when it is present in influent wastewater.

Our initial AFFF findings are currently being followed up with a more comprehensive research project focused on potential wastewater treatment inhibition caused by AFFF. While we do not accept AFFF waste from our industrial customers, these research objectives will help us understand how to minimize treatment impacts if an accidental discharge were to occur. Current study objectives include:

- Determining potential inhibition of nitrification, denitrification and biological phosphorus removal using SBRs configured to mimic various BNR treatment configurations (Fully nitrifying, Modified Ludzack-Ettinger (MLE), and 5-stage Bardenpho)
- Determining the fate and transport of PFAS by collecting samples during the laboratory based SBR studies and analyzing PFAS content using a modified version of EPA Method 537
- Investigating potential impacts on microbial populations when AFFF inhibition is documented within the SBR studies

HRSD is very supportive of your proposal in response to the Water Research Foundation's RFP 4913, and we would be willing to provide information about our current AFFF/PFAS studies, treatment processes, feedback on the project and its outputs, and water samples from treatment plants to test and analyze as needed to inform this project. In addition we will provide $25,000 in cash to fund sample analysis in support of the 1 MGD SWIFT pilot facility and other HRSD PFAS related studies. In total, we estimate the value of cash, as well as in-kind staff time, communication and historical data to be $35,000. In the interest of a collaborative partnership on this project, we would appreciate the opportunity to review and comment on draft project deliverables such as reports, manuscripts, and presentations, particularly when HRSD is identified as a participant.

We look forward to working with you closely in the future. If you need any other information, please do not hesitate to contact us.

Sincerely,

Christopher A. Wilson, Ph.D., P.E.
Chief of Process Engineering and Research
Hampton Roads Sanitation District
cwilson@hrsd.com

Adjunct Professor
Charles E. Via, Jr. Department of
Civil and Environmental Engineering
Virginia Tech, Blacksburg, Virginia

Dana J. Gonzalez, Ph.D.
HRSD Chemist
Hampton Roads Sanitation District
dgonzalez@hrsd.com

Civil Engineering Masters Student
Charles E. Via, Jr. Department of
Civil and Environmental Engineering
Virginia Tech, Blacksburg, Virginia

Upper Occoquan Service Authority

Leader in Water Reclamation and Reuse

14631 COMPTON ROAD, CENTREVILLE, VIRGINIA 20121-2506
(703) 830-2200

June 21, 2018

Detlef Knappe
Professor
Department of Civil, Construction, and Environmental Engineering
North Carolina State University
Campus Box 7908
Raleigh, NC 27695-7908

Re: Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances (RFP #4913)

Dear Professor Knappe,

The Upper Occoquan Service Authority (UOSA) is pleased to support your proposal in response to The Water Research Foundation's RFP 4913 entitled, "Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances". PFAS are potentially an important challenge for potable reuse trains. We anticipate that your proposed research on treatment options, such as activated carbon adsorption, anion exchange, and membrane treatment will result in much needed information to effectively design removal processes for PFAS.

We will provide PFAS data from a recent pilot ozone/BAC study that we performed. We will provide additional staff time, as needed, to review and provide feedback on data provided. We reserve the right that our participation is kept anonymous in reports, journal publications and presentations because of this project. We estimate the value of our support up to $10,000 as in-kind contributions in the way of our staff time, communication and historical data. Please contact me at (703) 830-2200 ext. 1286 or bob.angelotti@uosa.org if you have any questions or comments. We sincerely look forward to working with your team on this important research topic.

Sincerely,

Robert W. Angelotti, P.E.
Deputy Executive Director
Technical Services Division
UOSA

WASHOE COUNTY
COMMUNITY SERVICES DEPARTMENT
Engineering & Capital Projects

1001 EAST 9TH STREET
PO BOX 11130
RENO, NEVADA 89520-0027
PHONE (775) 328.3600
FAX (775) 328.3699

June 20, 2018

Professor Detlef Knappe, PhD.
Department of Civil, Construction, and Environmental Engineering
North Carolina State University
Campus Box 7908
Raleigh, NC 27695-7908

Re: Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances (RFP #4913)

Dear Dr. Knappe,

Washoe County is pleased to support your proposal in response to The Water Research Foundation's RFP 4913 entitled, "Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances". PFAS are potentially an important challenge for potable reuse trains. We anticipate that your proposed research on treatment options, such as activated carbon adsorption, anion exchange, and membrane treatment will result in much needed information to effectively design removal processes for PFAS.

Through our advanced water treatment technology research and innovation work being conducted in collaboration with the University of Nevada Water, Reno's Water Innovation Campus for indirect potable reuse demonstrations, we will provide PFAS data and samples for PFAS analysis from our pilot- and bench-scale ozone / BAC/ GAC systems. We will provide additional staff time, as needed, to review and provide feedback on data provided. We reserve the right that our participation is kept anonymous in reports, journal publications and presentations because of this project.

We estimate the value of our support up to $5,000 as in-kind contributions in the way of our staff time, communication, historical data, and on-going pilot testing activities.

Please contact Rick Warner at (775) 954-4621 or rwarner@washoecounty.us, or Lydia Peri at LPeri@washoecounty.us if you have any questions or comments. We sincerely look forward to working with your team on this important research topic.

Sincerely,

Dave Solaro Arch., P.E.
Assistant County Manager

UNC CHARLOTTE

The WILLIAM STATES LEE COLLEGE *of* ENGINEERING

9201 University City Boulevard
3252 EPIC
Charlotte, NC 28223-0001

Department of Civil and
Environmental Engineering

704/687-1219
FAX: 704/ 687-0957

June 22, 2018

Detlef Knappe
Professor
Department of Civil, Construction, and Environmental Engineering
North Carolina State University
Campus Box 7908
Raleigh, NC 27695-7908

Re: Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances (RFP #4913)

Dear Professor Knappe,

The University of North Carolina at Charlotte is pleased to support your proposal in response to The Water Research Foundation's RFP 4913 entitled "Investigation of Treatment Alternatives for Short-Chain Poly and Perfluoroalkyl Substances." Short-chain PFAS are an important challenge for water treatment facilities. Targeted and non-targeted analyses may capture only a fraction of the total PFAS concentration. Developing estimates of the total PFAS concentration in a water supply and in treated water can support a more comprehensive assessment of treatment performance and process selection. At UNC-Charlotte, we have the capacity to analyze adsorbable organic fluorine in aqueous samples using combustion ion chromatography (CIC). The CIC analysis provides a simple and quick estimation of total PFAS, and has been validated by researchers in Europe (e.g., Wagner et al. 2013). A Mitsubishi furnace (AQF-2100H), a carbon adsorption module (TXA04), a solid sample changer (ASC-240S) and an automatic gas absorption unit (AU-250), all from Cosa Xentaur, as well as a Dionex ICS-3000 ion chromatograph from Thermo Scientific, are available in our lab for conducting the analysis. The laboratory protocol for the CIC analysis of adsorbable organic halogen has been established, and we have been using this method to analyze water samples from various utilities.

Should your proposal be selected for funding, we can support your project by conducting up to 50 adsorbable organic fluorine measurements. Please contact Mei Sun at mei.sun@uncc.edu or

704-687-1723 if you have any questions or comments. We sincerely look forward to working with your team on this important research topic.

Sincerely,

Mei Sun

Mei Sun
Assistant Professor
Department of Civil and Environmental Engineering
University of North Carolina at Charlotte
Energy Production and Infrastructure Center 3163
9201 University City Blvd | Charlotte, NC 28223

Budget Narrative

Salaries
Support for PI Knappe is requested at 0.35 months each in years 1 and 2. Detlef Knappe will lead the overall research team and will supervise one PhD level graduate research assistant, who will be supported by a cash match by the North Carolina Policy Collaboratory as described below. The PhD student will be responsible for conducting bench-scale PFAS adsorption and anion exchange experiments and for developing the quantitative structure-property relationship. PI Knappe will spend additional time overseeing and managing the project at no cost to the sponsor.

Fringe Benefits
NCSU fringe benefits for PI Knappe (Worker's Compensation, health insurance, etc.) are calculated at 33% of budgeted salary.

Materials and Supplies
Laboratory consumables are requested in the amount of $2,605. Additional laboratory consumable purchases will be supported by the cash match as described below. Consumables include sample vials, chemicals (including analytical standards), and liquid chromatography columns.

Travel
Domestic travel expenses ($2,500) are budgeted for attendance of one national conference each in Year 1 and Year 2 by the PI and/or the PhD student to present research results. At the conference, research team meetings will also be held.

Subcontracts
Funds are requested to support research activities at the Colorado School of Mines ($89,994), the City of Ann Arbor ($35,000), and Hazen and Sawyer and its subcontractors ($155,000).

The budget for the **Colorado School of Mines (CSM)** breaks down as follows:

> **Personnel:** CSM is requesting a total of 0.15 months of summer salary for Dr. Bellona covering his time over years 1 and 2. This calculation is based on a 9-month contract salary of $88,174 and the total summer salary requested for Dr. Bellona is $2,992 to be spread out over the project. Dr. Bellona will be responsible for helping with literature reviews, setting up experimental plans and supervising a graduate student. We are also requesting salary for a graduate student 1-year at an annually rate of $24,000. We are requesting salary for a graduate student for 3-months during year 2 of the project for a total of $6,153.
>
> **Fringe Benefits:** CSM uses a published pooled rate when estimating these charges for cost proposals. A rate of 42.2% has been applied for faculty summer salary. For complete information about CSM's fringe costs, please visit: https://inside.mines.edu/ORA-Proposal-Fringe-Benefit-Rates-Indirect-Costs. The total fringe benefits requested for Dr. Bellona amount to $1,272. Fringe benefits for the graduate student include tuition, fees and health insurance and total $33,919 over the proposed project.

Materials and Supplies: We request $4,360 for supplies related to the research including testing system supplies and analytical consumables.

Travel: No travel funds are requested.

Indirect Costs: CSM has a negotiated F&A rate of 50.5% effective 7/1/17. This rate has been negotiated by the Office of Naval Research (cognizant agency). The current negotiated rate agreement is available at: https://inside.mines.edu/UserFiles/File/finance/researchAdmin/about/ONR-IDC-rates.pdf. Indirect cost is calculated based on a modified total direct cost (MTDC) base, which includes salary and fringe benefits. The MTDC is $37,259, which results in indirect costs of $18,816.

The budget for the **City of Ann Arbor** is as follows:

Personnel and fringes: $30,000 is requested to support a student at $20/hour for 1,500 hours to operate and maintain the pilot plant.

Materials and Supplies: $5,000 is requested for materials to maintain the pilot plant.

In-kind Contributions: In-kind contributions consist of donated time by co-PI Brian Steglitz ($5,000), Water Quality Manager Sarah Page ($4,800), and the lab supervisor ($6,000) to oversee on-site sample collection and analytical measurements. Fringes for personnel are calculated at 17% of salary ($2,700). Additional cost-share ($6,000) includes materials and supplies as well as travel to present research results at a local conference.

The budget for **Hazen and Sawyer** breaks down as follows:

Co-Principal Investigator: Erik Rosenfeldt, PE, PhD will be co-PI and will devote 5 percent of his time to this project. Dr. Rosenfeldt brings access and knowledge of several facilities that will be piloting technologies during the length of this project. Dr. Rosenfeldt's contribution to the project will include providing technical input on bench, piloting, and full-scale testing tasks, coordinate client involvement in the project, as well as managing subcontracts with Southern Nevada Water Authority, CDM-Smith, Ann Arbor, and American Water and lead Hazen's project support team.

Technical Advisor: Ms. Jacqueline Rhoades, PE will serve as a technical advisor for the project, providing groundwater treatment expertise, focusing on feasibility, cost, and constructability of well-based treatment solutions. Ms. Rhoades brings years of experience in addressing groundwater quality issues through well-based treatment strategies incorporating advanced technologies.

Project Support: Ms. Elisa Arevalo will serve in a project engineer role for the project, and will support Dr. Rosenfeldt with the coordination of data and water collection from

participating utilities. She will also lead data management efforts for the evaluation, including cataloguing, quality review, and providing access to this information for the project team.

Modeling Lead: Dr. Worley-Morse will lead a process modeling effort to support the life cycle analysis. Using Hazen's internal GAC model (HazenGAC), Dr. Worley-Morse will simulate site-specific water characteristics for various treatment scenarios to achieve treatment targets while also minimizing costs associated with GAC design and operation. He will also lead the expansion of the tool to include additional technologies (e.g. IX) in the cost optimization.

Salaries and Wages ($23,746): Hazen and Sawyer rates are based on current salaries (July 2018).

Fringe Benefits ($14,611): Fringe benefits were budgeted at Hazen's established rate of 61.53 percent.

Equipment: None.

Materials and Supplies: None.

Travel: No travel is budgeted for this project. Participation in a project advisory committee meeting will either be timed to coincide with conference or previously planned travel, or attendance will be managed via conference call.

Subcontracts: Subcontractors to Hazen and Sawyer are the Southern Nevada Water Authority ($70,000) and CDM Smith ($40,000). Additional details for Hazen Subcontractor budgets are provided below.

Other Direct Costs: None.

Indirect Costs ($6,643): Indirect costs are budgeted at 116.09 percent of direct labor, based on an audit performed in 2017.

In-Kind Support: Hazen and Sawyer is providing engineering fee (calculated as 10% of project budget = $4,500) as in-kind support for the project.

The budget for the **Southern Nevada Water Authority** breaks down as follows:

Direct Labor and Fringe Benefits: The salary rates of the professional research staff and associates are established by the Southern Nevada Water Authority (SNWA) and their Board of Directors. The rate for fringe benefits for salary employees is established by the Southern Nevada Water Authority and is currently 40%.

Eric Dickenson, the Principal Investigator will devote his time (includes fringe benefit: $10,613) to manage SNWA project activities, review data and prepare reports and

publications. Brett Vanderford, Principal Research Chemist, will devote his time (includes fringe benefit: $4,099) to review analytical data. A Postdoctoral Researcher will devote his/her time (includes fringe benefit: $11,200) and a Graduate Intern will devote his/her time ($7,600) to provide literature support and perform experimental testing at SNWA. The total cost for personnel will be $33,512.

Equipment: None

Supplies: The labor and nonlabor costs of analytical work will be $56,488 with $23,000 of that as in-kind services.

Travel: A $3,000 travel budget is allocated for travel to a conference out of state to present project results.

Indirect Costs: SNWA will not charge indirect costs for this project.

Subcontracts: None

The budget for **CDM Smith** breaks down as follows:

Co-Principal Investigator: Dr. Charles Schaefer will be co-principal investigator (co-PI) and will devote 5 percent of his time to this project. He will provide review support for project tasks and provide oversight of bench testing anion exchange (IX) resin regeneration treatment. Dr. Shaefer will author portions of the final report and provide technical expertise for project decisions, participate in team conference calls, and provide review and technical input for the final deliverables. It is anticipated that Dr. Shaefer's time will be expended primarily in the execution of laboratory bench IX resin regeneration testing, coordination with utilities, and in development and review of the report (draft and final deliverables). All of his time will be supported by the Foundation.

Project Management: Mr. Michael Zafer, PE will support Dr. Shaefer with CDM Smith's project management activities. He will lead budget tracking and invoicing and provide technical review of CDM Smith-developed portions of deliverables and guidance documents. Two percent of Mr. Zafer's time will be devoted to the project and it is anticipated that his time will be expended uniformly over the duration of the project. All of Mr. Zafer's time will be supported by ***in-kind contributions***.

Engineering Support: Ms. Jennifer Hooper, PE will assist the project team by leading development of CDM Smith's portion of the periodic reports, lead CDM Smith's coordination efforts with providing historical monitoring/testing results from several utilities, and provide review of bench testing activities. Approximately 4 percent of Ms. Hooper's time will be devoted to the project, anticipated to be allocated uniformly over the project duration. All of Ms. Hooper's time will be supported by the Foundation.

Laboratory Support: Dr. Dina Drennan will assist the project team with executing bench testing experiments to evaluate alternative treatment technologies, such as

electrochemical treatment, of IX resin regeneration waste. Dr. Drennan will also support production of CDM Smith's portion of the periodic reports, and contribute to relevant sections of project deliverables. Approximately 7 percent of her time will be devoted to the project and it is anticipated that her time will be expended primarily during bench testing and production of the report. All of Dr. Drennan's time will be supported by the Foundation.

Ms. Daniella Tran will support Dr. Dina Drennan in execution of the bench laboratory testing of IX resin regeneration waste treatment. Ms. Tran will allocate approximately 7 percent of her time, which will all be supported by the Foundation.

Contract Administration: Ms. Mojgan Moini will be the contract administrator and will be responsible for accounting matters. Ms. Moini will prepare CDM Smith's invoices in the format required by WRF. Approximately 0.5 percent of her time will be devoted to the project, expended periodically throughout the project in conjunction with developing invoicing. Her time will be supported by ***in-kind contributions*** from CDM Smith.

Salaries and Wages: The salary rates of CDM Smith employees are based on current salaries as of July 2018, escalated by 5 percent (based on anticipated mid-point of the project's schedule).

Fringe Benefits: Normal accounting practices of CDM Smith include fringe benefits established at 38.83 percent.

Equipment: None.

Materials and Supplies: Supplies for execution of the bench laboratory testing is budgeted as $5,000. This is will cover consumables and waste disposal.

Travel: No travel is anticipated for this project. Participation in a project advisory committee meeting will either be timed to coincide with a conference or Dr. Schaefer will attend via conference call.

Subcontract: None.

Other Direct Costs: None.

Indirect Costs: Normal accounting practices for CDM Smith include fringe benefits and overhead costs as indirect costs. Indirect costs are budgeted at 128 percent of direct labor, based on an audit performed in 2017.

Other Direct Costs

Funds are requested for shipment of water samples for PFAS analysis ($2,000). Other direct costs in this category (tuition, adsorbable organic fluorine analysis, and NCSU laboratory use fee) will be cost-shared as described below.

Indirect Costs
The NCSU, federally approved Facilities & Administrative rate of 52% (for on-campus research) will be charged on all direct costs, with the exception of GRA tuition. For subcontracts, overhead is charged on the first $25,000.

Cost-share (Cash match by NC Policy Collaborative to NCSU)
As indicated in the letter of support, the NC Policy Collaborative will provide a cash match of $131,250 to support the proposed research. These funds are budgeted as follows.

Support will be available for one PhD level graduate research assistant is requested at 50% time for years 1 and 2. The PhD student will work under the direction of PI Knappe. The PhD student will earn $26,400 per year during year 1 and $27,000 during year 2.

NCSU fringe benefits for the PhD student (Worker's Compensation, health insurance, etc.) are calculated at 16% of budgeted salary.

Funds for supplies (laboratory consumables such as LC columns, analytical standards, mass-labeled internal standards, glassware for bench-scale experiments, sample vials, filters) in the amount of $18,000 will be available to conduct the proposed research.

Funds are available to support adsorbable organic fluorine measurements at the University of North Carolina at Charlotte ($10,275).

The laboratory user fee is $521 per person per month, and the budget line item is based on the anticipated laboratory activities of one PhD student for a period of 15 months. This fee covers general laboratory activity such as service contracts for the water purification system, dish washing, routine chemicals, gases, and scale calibration.

The tuition was calculated for 1 graduate student at the following rates for Year 1: $9,342 (2018-2019) in-state tuition + $4,256 out-of-state tuition. The budget also includes 50% of the total required fees for $2,219. A 10% inflationary increase has been budgeted for Year 2 to cover the costs associated with an anticipated tuition increase. Under the University Graduate Student Support Plan, Tuition Remission (TR) is the difference between in-state and out-of-state tuition.

Investigation of Treatment Alternatives for Short-Chain Poly- and Perfluoroalkyl Substances

Proposal Comments

1. **Literature Review** – The research team should include in the literature review and guidance manual the status of emerging efforts to destructively remove PFAS rather than only sequestering them.

   Response: We will include the most current status of destructive technologies in the literature review and guidance manual.

2. **Task 2 – Round-Robin Testing** – There are four labs with substantial involvement in measuring PFAS compounds. Does the research team have a back-up plan if round-robin is not successful? Also, after the round-robin what ongoing comparisons will be established.

   Response: Based on split sampling we have done with commercial laboratories, we do not expect issues. If results among laboratories do not agree well in terms of absolute concentrations (i.e. is the PFHxA concentration 100 or 150 ng/L?), we would expect that percent removal determinations would still be accurate because percent removal does not require quantification and can rely on peak areas alone. In response to the last question, we will analyze on a quarterly basis unknown samples that will be prepared for the research team by Dr. Mark Strynar at US EPA. These samples will be sent out as blind samples, analyzed by each lab, and results returned to Dr. Strynar to assess accuracy in terms of (1) detected PFAS analytes and (2) determined concentrations.

3. **Task 4.7 – Electrochemical Treatment** – Research team is planning to use electrochemical treatment for destruction of the PFAS in the IX regeneration fluid. Can the research team test membrane concentrate treatment as well?

   Response: CSM and CDM-Smith are currently collaborating on an AFCEC-sponsored project looking at NF and RO reject treatment using destructive methods including electrochemical treatment and a UV reductive technology. We will include findings from these efforts in the literature review and guidance manual.

4. **Budget** – Time commitment of the PI is very low which may cause project management issues.

   Response: PI Knappe will cost-share an additional month of his time each year to support this project. This will be documented in quarterly budget updates.

Water Research Foundation
Research Project Budget

Download Instructions for budget preparation at http://www.waterrf.org/funding/Pages/proposal-guidelines.aspx

*** Required fields are highlighted in yellow.**

*** Required fields are highlighted in yellow.**

Sub-recipient (organization name): North Carolina State University
PI Name: Detlef Knappe
Project Title: Investigation of Treatment Alternatives for Short-Chain Poly- and Perfluoroalkyl Substances
Preparation/Revision Date: 6/27/2018
RFP # (if applicable): 4913

Note: The information above will carry over to subsequent pages/worksheets.

Sources of Award, Cost Share, and Non-Cash In-Kind Contributions (Insert rows to list more third parties.)		Award			Cost Share		Third-Party Non-Cash In Kind
		Foundation Funds	*Sub-recipient*	*Third-Party Cash to Foundation*	*Sub-recipient*	*Third-Party Cash to Sub-recipient*	
Water Research Foundation		350,000	n/a	n/a	n/a	n/a	n/a
Sub-recipient (including subcontract contributions)		n/a		n/a		n/a	n/a
Third Parties	North Carolina Policy Collaboratory	n/a	n/a		n/a	131,250	
	American Water	n/a	n/a		n/a		100,000
	City of Ann Arbor, MI	n/a	n/a		n/a		25,000
	CDM-Smith	n/a	n/a		n/a		10,000
	Hazen and Sawyer	n/a	n/a		n/a		4,500
	Southern Nevada Water Authority (SNWA), Henderson, NV	n/a	n/a		n/a		23,000
	Cape Fear Public Utility Authority, Wilmington, NC	n/a	n/a		n/a		30,000
	City of Los Angeles - Bureau of Sanitation, CA	n/a	n/a		n/a		10,000
	Fountain, CO	n/a	n/a		n/a		10,000
	Plainfield Charter Township, MI	n/a	n/a		n/a		8,000
	Aurora Water, CO	n/a	n/a		n/a		5,000
	Hampton Roads Sanitation District, VA (includes $25,000 cash to SNWA)	n/a	n/a		n/a	25,000	10,000
	Upper Occoquan Service Authority, VA	n/a	n/a		n/a		10,000
	Tucson Water Department, AZ	n/a	n/a		n/a		5,500
	Town of Cary, NC	n/a	n/a		n/a		0
	Washoe County Community Services Department, Reno, NV	n/a	n/a		n/a		5,000
	City of Altamonte Springs, FL	n/a	n/a		n/a		5,000
		n/a	n/a		n/a		
		n/a	n/a		n/a		
		n/a	n/a		n/a		
	Subtotal	***350,000***	***0***	***0***	***0***	***156,250***	***261,000***
Total Award, Cost Share, and Third-Party Non-Cash In Kind		**350,000**			**156,250**		**261,000**
Total Project Value		**767,250**					

Water Research Foundation
Research Project Budget

Sub-recipient (organization name): North Carolina State University
PI Name: Detlef Knappe
Project Title: Investigation of Treatment Alternatives for Short-Chain Poly- and Perfluoroalkyl Substances
Preparation/Revision Date: 6/27/2018
RFP # (if applicable): 4913

OK
OK

Note: All amounts below will be automatically populated from the following pages/worksheets.

		Total	Award	Cost Share
A	Key Personnel	13,294	13,294	0
B	Other Personnel	61,944	0	61,944
	Total Direct Labor and Fringe Benefits	*75,238*	*13,294*	*61,944*
C	Equipment Rental	0	0	0
	Special Equipment	0	0	0
D	Materials and Supplies	20,605	2,605	18,000
E	Travel	2,500	2,500	0
F	Subcontracts	304,994	279,994	25,000
G	Other Direct Costs	53,306	2,000	51,306
	Total Direct Costs	*456,643*	*300,393*	*156,250*
H	Indirect Costs	49,607	49,607	0
I	Fee	0	0	0
J	Surveys	0	0	0
	Total Direct and Indirect Costs	***506,250***	***350,000***	***156,250***
	Third-Party Non-Cash In Kind	**261,000**	n/a	n/a
	Total Project Value	**767,250**		

Water Research Foundation
Research Project Budget

* Required fields are highlighted in yellow.

Sub-recipient (organization name): North Carolina State University
PI Name: Detlef Knappe
Project Title: Investigation of Treatment Alternatives for Short-Chain Poly- and Perfluoroalkyl Substances
Preparation/Revision Date: 6/27/2018
RFP # (if applicable): 4913

A. Key Personnel *(PI and Co-PIs. Sub-recipient's employees only. †)*

Name	Project Role	Number of Hours	Direct Hourly Rate	% Time Allocated to Project	Subtotal Direct Labor	Fringe Benefit % of Direct Labor	Subtotal Fringe Benefits	Total	Award	Cost Share
Detlef Knappe	Principal Investigator	124.00	80.61	3.0%	9,996	33.00%	3,299	13,294	13,294	0
					0		0	0		0
					0		0	0		0
					0		0	0		0
					0		0	0		0
		Total Key Personnel			9,996		3,299	13,294	13,294	0

B. Other Personnel *(Sub-recipient's employees only.)*

Name/Position	Project Role	Number of Hours	Direct Hourly Rate	% Time Allocated to Project	Subtotal Direct Labor	Fringe Benefit % of Direct Labor	Subtotal Fringe Benefits	Total	Award	Cost Share
Graduate Research Assistant	Conduct proposed experiments and analyses	2,080.00	25.67	50.0%	53,400	16.00%	8,544	61,944	0	61,944
					0		0	0		0
					0		0	0		0
					0		0	0		0
					0		0	0		0
					0		0	0		0
					0		0	0		0
					0		0	0		0
					0		0	0		0
					0		0	0		0
					0		0	0		0
					0		0	0		0
					0		0	0		0
					0		0	0		0
		Total Other Personnel			53,400		8,544	61,944	0	61,944

† PI and co-PIs that are not Sub-recipient's employees must **NOT** be listed here. Describe their project roles and responsibilities in the Budget Narrative under ***Category F, Subcontracts***.

Water Research Foundation
Research Project Budget

Sub-recipient (organization name): North Carolina State University
PI Name: Detlef Knappe
Project Title: Investigation of Treatment Alternatives for Short-Chain Poly- and Perfluoroalkyl Substances
Preparation/Revision Date: 6/27/2018
RFP # (if applicable): 4913

C. Equipment Rental and Special Equipment Purchase

Equipment Rental (*List items and dollar amount for each item exceeding $1,000*)	Total	Award	Cost Share
			0
			0
			0
			0
			0
Total Equipment Rental	0	0	0

Special Equipment Purchase (*List items and dollar amount for each item exceeding $5,000*)	Total	Award	Cost Share
			0
			0
			0
			0
			0
Total Special Equipment Purchase	0	0	0

Water Research Foundation
Research Project Budget

Sub-recipient (organization name): North Carolina State University
PI Name: Detlef Knappe
Project Title: Investigation of Treatment Alternatives for Short-Chain Poly- and Perfluoroalkyl Substances
Preparation/Revision Date: 6/27/2018
RFP # (if applicable): 4913

D. Materials and Supplies	**Total**	**Award**	**Cost Share**
Glassware for bench-scale experiments, sample vials, LC columns, chemicals, standards, mass-labeled internal standards	20,605	2,605	18,000
			0
			0
			0
			0
			0
			0
			0
Total Materials and Supplies	**20,605**	**2,605**	**18,000**

E. Travel	**Total**	**Award**	**Cost Share**
Travel support for PI to attend one domestic conference (ACE, ACS) each in year 1 and year 2	2,500	2,500	0
			0
			0
			0
			0
			0
			0
			0
Total Travel	**2,500**	**2,500**	**0**

Water Research Foundation
Research Project Budget

Sub-recipient (organization name): North Carolina State University
PI Name: Detlef Knappe
Project Title: Investigation of Treatment Alternatives for Short-Chain Poly- and Perfluoroalkyl Substances
Preparation/Revision Date: 6/27/2018
RFP # (if applicable): 4913

F. Subcontracts	Total	Award	Cost Share
Colorado School of Mines	89,994	89,994	0
Hazen and Sawyer (with subcontacts to CDM-Smith and SNWA)	180,000	155,000	25,000
City of Ann Arbor	35,000	35,000	0
			0
			0
			0
			0
			0
Total Subcontracts	**304,994**	**279,994**	**25,000**

G. Other Direct Costs	Total	Award	Cost Share
Tuition	33,216	0	33,216
Adsorbable organic fluorine measurements (UNC-Charlotte)	10,275	0	10,275
NCSU Laboratory Use Fee	7,815	0	7,815
Shipping of water and samples	2,000	2,000	0
			0
			0
			0
			0
Total Other Direct Costs	**53,306**	**2,000**	**51,306**

Water Research Foundation
Research Project Budget

Sub-recipient (organization name): North Carolina State University
PI Name: Detlef Knappe
Project Title: Investigation of Treatment Alternatives for Short-Chain Poly- and Perfluoroalkyl Substances
Preparation/Revision Date: 6/27/2018
RFP # (if applicable): 4913

H. Indirect Costs *(Attach copy of federally approved rates or detailed basis for rates)*

Cost Category	Rate %	Base $	Total	Award	Cost Share
NCSU Indirect Cost	52%	95,399	49,607	49,607	0
			0		0
			0		0
			0		0
			0		0
		Total Indirect Costs	49,607	49,607	0

I. Fee	%	Base $	Total	Award	Cost Share
			0		0
		Total Fee	0	0	0

J. Survey	Total	Award	Cost Share
			0
			0
			0
			0
			0
			0
Total Survey Costs	0	0	0

Exhibit B
Project 4913

Title: Investigation of Treatment Alternatives for Short-Chain Poly- and Perfluoroalkyl Substances

TASK	DUE DATE
Project Start	March 1, 2019
Scope of Work	April 1, 2019
Proof of Insurance	April 1, 2019
Notification of Subcontractor Agreement(s) Executed	May 1, 2019
Periodic Report 1 – electronic copy & Invoice	June 1, 2019
Periodic Report 2 (Technical Summary & Web Update) & Invoice	September 1, 2019
Periodic Report 3 & Invoice	December 1, 2019
Periodic Report 4 (Technical Summary & Web Update) & Invoice	March 1, 2020
Periodic Report 5 & Invoice	June 1, 2020
Periodic Report 6 (Technical Summary & Web Update) & Invoice	September 1, 2020
Periodic Report 7 & Invoice	December 1, 2020
Draft Report & Invoice	March 1, 2021
Final Report	July 1, 2021
Assignment of Copyright - Exhibit E	July 1, 2021
Letter of Confirmation from each participating utility review & IK	July 1, 2021
Final Invoice	July 1, 2021
Project End & Foundation Publication Date	March 1, 2022

Note: Please submit one electronic copy of each Periodic Report and Draft Report. Submit the Final Report in electronic copy in *MSWord format*. For each report an invoice shall be submitted for payment using Exhibit D – printed on your company letterhead. All Reports and Invoices should be sent to the Research Manager and Project Coordinator identified in Exhibit B WRF Key Contacts.

Title: **Investigation of Treatment Alternatives for Short-Chain Poly- and Perfluoroalkyl Substances**

WRF Key Contacts:

The Water Research Foundation
6666 West Quincy Avenue
Denver, CO 80235

Name:	Title:	Phone:	Email:
Kenan Ozekin, PhD	Sr. Research Manager	303.734.3464	kozekin@WaterRF.org
Valerie Roundy	Project Coordinator	303.347.6124	vroundy@WaterRF.org
Christine Conville	Contracts Manager	303.734.3424	cconville@WaterRF.org

Sub-recipient Key Contacts:

Name/Title:	Project Role:	Organization/Address:	Phone:	Email:
Detlef Knappe, PhD	PI	North Carolina State University Dept CC&EE 2501 Stinson Drive Raleigh, NC 27695-7908	919.515.8791	knappe@ncsu.edu
Sherrie Settle, Director of Sponsored Programs	Authorized Rep / Contracts	North Carolina State University Research Admin/SPARCS 2701 Sullivan Dr, Admin Box 7514 Raleigh, NC 27695-7514	919.515.2444	sps@ncsu.edu
Justo Torres, Director of C&G	Accounting	North Carolina State University 2701 Sullivan Dr Admin Services III, Box 7214 Raleigh, NC 27695-7214	919.515.2153	cngacctsrec@ncsu.edu

Co-Principal Investigator(s):

Name/Title:	Project Role:	Organization/Address:	Phone:	Email:
Christopher Bellona, Asst. Professor	Co-PI	Colorado School of Mines Dept C & EE 1500 Illinois Street Golden, CO 80401	303.273.3061	cbellona@mines.edu
Erik Rosenfeldt, Dir. of Drinking Water Process Technology	Co-PI	Hazen and Sawyer 1555 Roseneath Rd Richmond, VA 23230	804.545.5098	erosenfeldt@hazenandsawyer.com
Eric Dickenson, R&D Project Manager	Co-PI	Sothern Nevada Water Authority PO Box 99954 Las Vegas, NV 89193-9954	702.856.3668	Eric.dickenson@lvvwd.com
Ruth Marfil-Vega, Sr. Scientist, Technology & Innovation	Co-PI	American Water 1115 S. Illinois Belleville, IL 62220	618.222.4075	Ruth.marfilvega@amwater.com
Charles Schaefer, Dir., Bellevue research & Testing Lab	Co-PI	CDM Smith 110 Fieldcrest Ave, #8 (6th floor) Edison, NJ 08837	732.590.4633	schaeferce@cdsmith.com
Brian Steglitz, Manager, Water Treatment Services	Co-PI	City of Ann Arbor 919 Sunset R. Ann Arbor, MI 48103	734.794.6000 x-43905	bsteglitz@a2gov.org

Each party shall provide written notice of changes in contact persons, addresses, telephone, and email addresses. The Principal Investigator, Co-Principal Investigator, or any Subcontractor may only be changed with the prior written approval of The Water Research Foundation.

BUDGET SUMMARY

Exhibit C
Project 4913

Sub-recipient:	North Carolina State University

Title: Investigation of Treatment Alternatives for Short-Chain Poly- and Perfluoroalkyl Substances

Project Start Date 3/1/2019 **End Date:** 3/1/2022

Financial Obligations for Project

a. WRF agrees to provide Award Funds:	$350,000.00
b. Sub-recipient agrees to provide Cost Share:	$156,250.00
c. Sub-recipient agrees to provide in-kind:	$261,000.00
d. Co-funder(s) agree to provide to WRF:	$0.00
e. Total Project budget is:	$767,250.00

All amounts are in U.S. dollars.

ORGANIZATION	Award Amount	Cost Share	In-Kind Amount
Participants			
Cape Fear Public Utility Authority	$0.00	$0.00	$30,000.00
City of Aurora Utilities, CO	$0.00	$0.00	$5,000.00
Tucson Water	$0.00	$0.00	$5,500.00
Hampton Roads Sanitation District	$0.00	$25,000.00	$10,000.00
North Carolina Policy Collaboratory	$0.00	$131,250.00	$0.00
City of LA Bureau of Sanitation	$0.00	$0.00	$10,000.00
City of Fountain, CO	$0.00	$0.00	$10,000.00
Plainfield Charter Township	$0.00	$0.00	$8,000.00
Upper Occoquan Service Authority	$0.00	$0.00	$10,000.00
Town of Cary, NC	$0.00	$0.00	$0.00
Washoe County Community	$0.00	$0.00	$5,000.00
City of Altamonte Springs	$0.00	$0.00	$5,000.00
Univ N. Carolina at Charlotte	$0.00	$0.00	$0.00
Co-PI			
American Water	$0.00	$0.00	$100,000.00
City of Ann Arbor, MI	$0.00	$0.00	$25,000.00
CDM Smith Inc	$0.00	$0.00	$10,000.00
Hazen and Sawyer	$0.00	$0.00	$4,500.00
Southern Nevada Water	$0.00	$0.00	$23,000.00

Sub-recipient			
N. Carolina State University	$0.00	$0.00	$0.00
The Water Research Foundation	$350,000.00	$0.00	$0.00
TOTALS	**$350,000.00**	**$156,250.00**	**$261,000.00**
Total Project Budget	**$767,250.00**		

Award Funds Not To Exceed:	**$350,000.00**
10% of Project Funds Advance:	**$35,000.00**
Draft Report & Invoice Retainage:	**$35,000.00**
Final Report & Invoice Retainage:	**$35,000.00**

Exhibit D
Project 4913

Title: Investigation of Treatment Alternatives for Short-Chain Poly- and Perfluoroalkyl Substances

Exhibit D – Invoice Form

For access to The Water Research Foundation website please see:
http://www.waterrf.org

To download Exhibit D – Invoice Form please see the WRF's website:
http://www.waterrf.org/funding/ContractMaterials/Invoice_ExhibitD.pdf

Exhibit E
Project 4913

Title: Investigation of Treatment Alternatives for Short-Chain Poly- and Perfluoroalkyl Substances

Assignment of Interest in Copyrighted Works for Work Product

Whereas, _____ whose address is _____ ["Assignor"] makes this assignment having full ownership and authority to make such assignment [or being authorized to make such assignment by _____].

Whereas, Assignor has created and authored the original, tangible expressions of ideas described as follows: _____ (hereafter the "Works"); and

Whereas, the Assignor and represents to own all right, title and interest in and to the Works, including the copyright; and

Whereas, The Water Research Foundation (WRF) whose principal place of business is located at 6666 W. Quincy Avenue, Denver, Colorado 80235 U.S.A. ["Assignee"] is desirous of obtaining all rights in and to the Works, including the copyright.

NOW, THEREFORE, in return for grants provided to Assignor by Assignee for research, said Assignor does hereby assign unto the said Assignee all world-wide right, title and interest in and to the said Works, including the right to transfer any registration of copyright, or file application for copyright registration for such Works as Owner.

By: Date	Approved and authorized individual by Date
Title For	Title for Legal Department For
Assignor Name/Entity	Assignor Name/Entity

State of _____ }
} ss
County of _____ }

On this _____ day of _____, 201_, _____ [Assignor or authorized agent] appeared before me, the person who signed this instrument, and of his/her own free will executed this document [on behalf of the identified corporation or other entity with authority to do so].

_____
Notary Public Comm'n. Exp.