NC PFAST NETWORK FINAL REPORT

Summary of Key Recommendations

Based on research results (details are in subsequent sections) obtained over the 2.5-year NC PFAS Testing Network study, a total of 60 key scientific recommendations are summarized here focusing on the following PFAS topics: (1) water sampling and PFAS analysis of NC municipal drinking water sources; (2) private well contamination risk modeling; (3) PFAS removal technologies performance testing; (4) air emissions and atmospheric deposition of PFAS; (5) novel inputs of PFAS into the environment; (6) health effects following PFAS exposure; (7) bioaccumulation of PFAS in aquatic environments; (8) construction of computer-based predictive models; and (9) inventory of aqueous film forming foams (AFFF) used for firefighting. These 60 recommendations form the basis for 2 overarching (major) recommendations included at the end of this section.

KEY SCIENTIFIC RECOMMENDATIONS

Water Sampling and PFAS Analysis of NC Municipal Drinking Water Sources:

Rec. 1: Testing should be expanded to include additional groundwater sources to capture spatial variability among wells, and account for cases where municipalities draw from multiple groundwater well sources.

Rec. 2: Testing should continue to capture temporal variability of impacted sources (e.g., Pittsboro had summed PFAS concentrations = 54 ng/L in round 1, and 837 ng/L in round 2).

Rec. 3: Testing should be initiated to better understand PFAS sources in the Cape Fear and Neuse River basins, with special emphasis on the Haw River basin.

Rec. 4: Toxicological studies are urgently needed, especially beyond PFOS and PFOA, for: (1) PFAS most frequently detected; (2) PFAS detected at highest concentrations; and (3) PFAS studied in mixtures.

Rec. 5: Adsorbable Organic Fluorine (AOF) should continue as a valuable screening tool to prioritize drinking water samples for further analysis.

Rec. 6: Non-targeted chemical analysis should continue to be used to uncover unknown/emerging PFAS and their associated transformation products.

Private Well Contamination Risk Modeling:

Rec. 7: Future work should further couple groundwater age-dating and PFAS analyses to better estimate timescales for natural flushing of PFAS from contaminated aquifers by groundwater flow.

Rec. 8: Gauging stations are needed on streams such as Georgia Branch and Willis Creek to monitor the rate of PFAS export to the Cape Fear River over time and during storms.

Rec. 9: Refinements should be made to the predictive model and additional private well testing in areas at highest risk, including data on well depth and year of construction.

PFAS Removal Technologies Performance Testing:

Ion Exchange (IX) Resins:

Rec. 10: PS-DVB (polystyrene divinyl benzene) resins are effective for PFAS removal in water treatment.

Rec. 11: Resins need to be changed frequently if the treatment goal includes removing short-chain PFAS.

Rec. 12: When using universal resins to remove PFAS, the impact of water matrix, such as inorganic anions or organic matter, needs to be further investigated.

Rec. 13: Disposal of exhausted resins need to be further explored.

Granular Activated Carbon (GAC):

Rec. 14: Re-agglomerated, subbituminous coal-based GAC is recommended for PFAS removal.

Rec. 15: Increasing empty bed contact time (EBCT) from 10 to 20 minutes results in lower operation and maintenance costs because the GAC use rate is lower.

Rec. 16: Enhancing background organic matter removal from water prior to GAC treatment promotes PFAS removal by lowering GAC use rate and hence treatment costs.

Rec. 17: Management options for spent GAC need to be studied to assure that PFAS and other accumulated contaminants are not re-introduced into the environment.

Membranes:

Rec. 18: Selection of membranes should strike a balance between required PFAS removal and water productivity (flow) for each use scenario.

Rec. 19: Further studies are needed to develop membrane modification methods that improve rejection of PFAS by high water flux membranes (e.g., nanofiltration) without detriment to water productivity.

Electrochemical Processes:

Rec. 20: Electrochemical reactors need to be designed with high anode area to sample volume ratio to ensure high PFAS destruction efficiency.

Rec. 21: Further studies are needed to resolve the unknown PFAS formed during electrochemical treatment.

Novel Ionic Fluorogels:

Rec. 22: Ionic fluorogel resins are a promising novel material for PFAS removal and should be investigated further.

Rec. 23: Further evaluation of ionic fluorogels in flow-through and up-scaled systems is needed.

Point-of-Use (POU) Systems:

Rec. 24: While not all POU filters are 100% effective, any activated carbon filter will remove some PFAS and reduce PFAS exposure; regular maintenance and frequent cartridge exchange are recommended.

Rec. 25: For homes served by public water systems, purchasing whole-house activated carbon filtration systems is not recommended to minimize bacterial buildup in pipes.

Air Emissions and Atmospheric Deposition of PFAS:

Rec. 26: Continuous sampling should continue for a minimum of one year to better constrain PFAS deposition in specific air masses to calculate annual PFAS deposition.

Rec. 27: Investigation of atmospheric partitioning/deposition with synchronous sampling and analysis of aqueous-, particle-, and gas-phase samples is needed.

Rec. 28: Additional studies are needed to better constrain atmospheric PFAS sources through source tracking (e.g., isomers).

Rec. 29: Atmospheric PFAS transformations in controlled laboratory experiments should be studied to better understand sources and predict concentrations.

Rec. 30: Studies are needed to measure PFAS indoors (a major exposure location) since consumer product use might lead to elevated concentrations.

Novel Inputs of PFAS into the Environment:

Contributions from Municipal Solid Waste:

Rec. 31: POTW operators and landfill owners should be considered as part of a team that manages society's waste with leadership from the state Department of Environmental Quality.

Rec. 32: Regulatory support is needed to enable facility sampling, especially since several facilities denied requests to sample during this project.

Rec. 33: Public education is required to explain that PFAS are present in the products that we use in society and that POTWs and landfills do not themselves generate PFAS.

Rec. 34: In cases where landfill leachate is a significant contributor to PFAS, PFAS-specific treatment may be required on a case-by-case basis.

Rec. 35: Landfill operators should be required to report leachate quantity and flow data annually.

Rec. 36: The extent to which construction and demolition (C&D) landfills are resulting in surface and groundwater PFAS contamination should be assessed.

Rec. 37: The release of volatiles (gases) from landfills and from leachate evaporation systems should be quantified.

Rec. 38: Methods are needed to measure (and quantify) PFAS destruction efficiency in flares and engines typically used to treat landfill gas.

Rec. 39: Non-domestic PFAS sources in wastewater influent should be identified and pre-treatment requirements evaluated; other inputs to POTWs should also be analyzed.

Rec. 40: The impact of PFAS that are discharged from POTWs to surface water varies and site-specific/watershed-specific management strategies are appropriate.

Rec. 41: Estimates of wastewater releases from POTWs with non-discharge permits should be developed.

Rec. 42: In areas where POTW effluent is released to soil, samples of soil and vegetation on wastewater discharge area should be collected.

Rec. 43: An inventory of quantities and fates of wastewater treatment biosolids in NC should be developed, and vegetation, soil and wildlife impacted by land-applied biosolids should be analyzed for PFAS.

Uptake and Distribution of PFAS in Crop Plants:

Rec. 44: Additional plant uptake studies, including those still in progress, are needed to evaluate plant species differences and translocation of PFAS to seed and fruit.

Rec. 45: Additional studies should probe PFAS occurrences in foods not studied here.

Rec. 46: Exposure models should incorporate diet in their assessment.

Rec. 47: Biosolids and irrigation water should be evaluated for their possible PFAS contribution to agricultural products.

Health Effects Following PFAS Exposure:

Immunotoxicity in Laboratory Mice:

Rec. 48: Additional studies are needed with underexamined PFAS (especially beyond PFOS and PFOA) that have been detected in NC.

Rec. 49: Mixtures studies should be conducted to better understand how these PFAS influence one another since real-world exposures are often to PFAS mixtures.

Rec. 50: Urinary PFAS concentrations need to be evaluated to estimate biological half-lives (blood concentrations were low).

Rec. 51: Further studies are needed to identify molecular changes associated with antibody suppression in understudied PFAS compared to changes induced by legacy PFAS.

Impact of PFAS on Human Placental Health and Birth Outcomes:

Rec. 52: PFAS measurements needed in drinking water among pregnant women.

Rec. 53: PFAS effects on trophoblast stem cell differentiation *in vitro* should be investigated, and the mechanistic target needs to be determined.

Rec. 54: Studies are needed to measure PFAS-induced gene expression changes *ex vivo* using human placental explants.

Rec. 55: Investigate how PFAS change the molecular communication between trophoblasts and maternal immune cells (process may contribute to preeclampsia).

Bioaccumulation of PFAS in Aquatic Environments (Fish and Alligator Exposures):

Rec. 56: Studies should continue to measure PFAS exposure, bioaccumulation and biomagnification in consumed fish.

Rec. 57: Evaluation of immune and other adverse effects in Alligators at Greenfield Lake should continue.

Rec. 58: Analysis of alligator exposure monitoring and health effects should extend to all populations of alligators across the state of NC.

Construction of Computer-Based Predictive Models:

Rec. 59: Physiologically-based pharmacokinetic (PBPK) modeling efforts could be improved with additional time-course tissue-level or serum-level data.

Aqueous Film Forming Foam (AFFF) Inventory:

Rec. 60: NC Office of the State Fire Marshal should update and review annually their directory of fire departments and continue working with the Collaboratory to develop and implement an easy-to-use interface for any fire department using PFAS-containing AFFFs to report every incident of AFFF discharge. The state should also require annual inventory reporting of foam type and volume to help identify PFAS-containing foam that could be collected and disposed of properly.

OVERARCHING (MAJOR) RECOMMENDATIONS

Rec. 1: Continued Funding for Statewide PFAS Research

Additional funding to continue PFAS research is strongly suggested utilizing the expertise, instrumentation and collaborative enterprises at statewide universities. Additional sampling and analyses are needed to better understand spatial and temporal PFAS distributions found in surface waters and groundwater. Currently ongoing mammalian toxicology studies should be expanded to include lung cell models for assessing the adverse human health effects associated with inhalation exposures to airborne PFAS. These studies can provide health-based data that often form the basis for advisories and guidelines to protect human health.

Research funding could focus on (at a minimum): (1) a basic program for statewide water sampling, testing, and monitoring; (2) coupled toxicology work in cellular and mammalian models based on the water and air results; and (3) support for data management and community engagement. In addition, continued efforts in chemical synthesis are critically needed in order to aid in these proposed areas of future research funding. Furthermore, regulatory and/or legislative action may be needed to ensure that researchers can gain access to starting materials needed to synthesize critical PFAS compounds. Many of these compounds are not readily available and manufacturers are not always able/willing to share/provide starting materials needed for synthesis.

Other PFAS research topics may include: air transport sampling, testing, and modeling to constrain sources of legacy PFAS and abiotic formation/degradation processes of emerging PFAS emitted into air; private well and groundwater sampling, testing, and modeling; PFAS signatures found in soils; performance testing of PFAS removal of existing technologies; continued development and testing of new PFAS removal technologies; and other projects of opportunity and collaborations with state and federal partners.

Rec. 2: Scientific Data Transparency

It is recommended that any future PFAS guidance, policies, or regulations clearly cite the data used to establish any numerical standards, limitations, thresholds, etc., by including a reference to the dataset(s) in the actual language of the regulation itself. As the scientific data and understanding of these compounds continues to grow, it will be more straightforward to identify when a regulation may have to be revised based on newer data and/or an evolving state of understanding of cited data. This broad philosophy for scientific transparency (e.g., raw data, processed data, study design, technology used for data measurements, concepts, original or alternate hypotheses, assumptions, etc.) utilized for policy-making decisions certainly can be extended beyond PFAS-related issues.