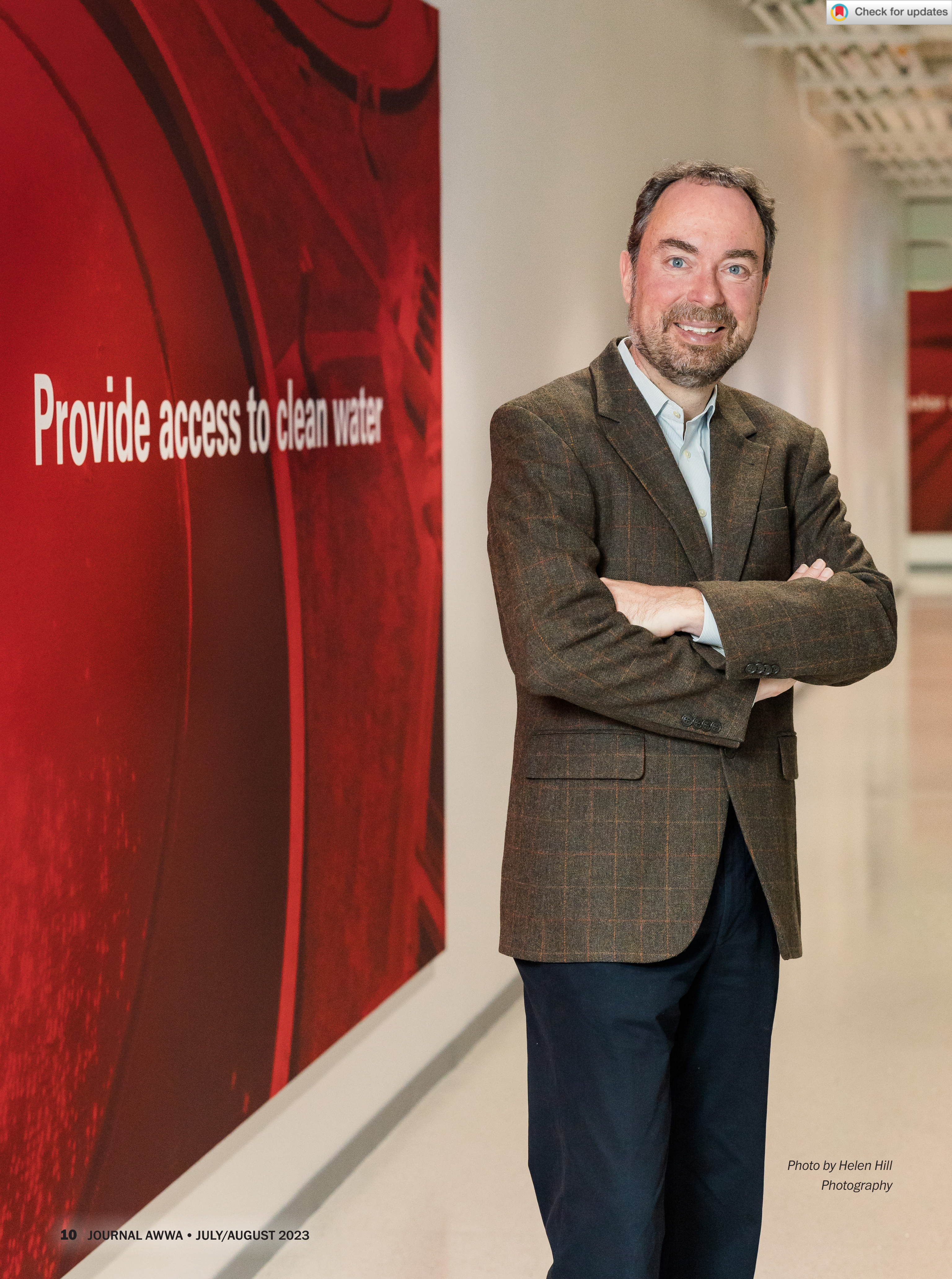


Photo by Helen Hill Photography

Detlef Knappe

Honored With 2023 A.P. Black Research Award

The A.P. Black Research Award was established in 1967 in honor of Alvin Percy Black to recognize outstanding research contributions to water science and water supply rendered over an appreciable period of time.

The recipient of the 2023 A.P. Black Award is Detlef Knappe. He is the S. James Ellen Distinguished Professor of Civil, Construction, and Environmental Engineering at North Carolina State University. From 2016 through 2022, Detlef was a trustee of AWWA's Water Science and Research Division, and he currently serves as associate editor for *AWWA Water Science*. He also serves on AWWA's Organic Contaminants Research Committee and the Standards Committee for Activated Carbon. Detlef received a BS degree in civil engineering and MS and PhD degrees in environmental engineering from the University of Illinois at Urbana-Champaign.

Detlef has more than 30 years of experience conducting research on water quality and treatment, and he is internationally recognized for his research in adsorption processes for the removal of organic compounds from drinking water. Detlef's research efforts have advanced our fundamental understanding of activated carbon adsorption, resulting in improved best practices for carbon selection for the removal of specific organic contaminants from drinking water. More recently, his research on environmental analytical chemistry has highlighted the importance of unregulated contaminants in drinking water sources. With more than 90 published research articles and more than 60 graduate students and postdocs who have gone on to become academics, scientists in government agencies, and practicing engineers, Detlef has helped to advance, in his work and leadership, the state of the science in the drinking water industry.

Kenneth Mercer, editor-in-chief of *Journal AWWA*, interviewed Detlef to learn about his entrance into water research and the water community, his career path and research interests, and his perspectives on influences and challenges for research and the water industry as a whole. The interview that follows has been edited for clarity and length.

What is the mission statement or driving theme of your lab group? How have your professional and research missions evolved over time?

The overarching mission of my research group at North Carolina State University is to reduce human exposure to organic contaminants. Traditionally, our group has focused on physical–chemical water treatment processes, such as granular activated carbon (GAC) adsorption, as a means for exposure reduction. In this context, we focused on improving our fundamental understanding of the mechanisms that control adsorption of organic contaminants from complex water matrices.

I think GAC is a fascinating material that is still poorly understood after more than a century of research. Activated carbon adsorption of organic micropollutants was the focus of my PhD research and continues to be an important component of my group's research portfolio today.

Beginning in about 2010, my research group became increasingly interested in source water protection, especially in the context of preventing sources of unregulated contaminants from entering water supplies. I had become aware of elevated levels of bromide and per- and polyfluoroalkyl substances (PFAS) in the Cape Fear River basin of North Carolina, and during the US Environmental Protection Agency's (EPA's) Third Unregulated Contaminant Monitoring Rule (UCMR 3), we learned about high levels of 1,4-dioxane in the same watershed. As a result, environmental analytical chemistry became an additional focus of our research group, and we are now developing and applying analytical methods to characterize a wide range of matrices relevant to human exposure, including water, air, and food. The aim of these methods is to improve our understanding of human exposure to organic contaminants and to support interventions that reduce exposure and risk.

What initially drew you to water research? Did you always know that potable water was a topic you wanted to explore?

I grew up in a small town called Freudenstadt (literally translated as "City of Joy") in the Black Forest region of Germany, where I lived for the first 19 years of my life. As a teenager, I learned a lot about a phenomenon called *Waldsterben* (forest death) associated with acid fog, rain, and snow. During my last two years in high school, my interest in environmental engineering crystalized, and my motivation was to help solve the acid rain problem.

After high school, I initially had planned to study environmental engineering at the Technical University of Berlin. But through a family friend, I became aware of an opportunity to spend a year in the United States at Highland Community College (HCC) in Freeport, Ill. My goal was to improve my spoken English for a year and return to Germany, but a field trip to the University of Illinois at Urbana-Champaign (UIUC) changed my path.

When I arrived on campus in 1986 (this was before the internet), I had no idea what to expect. The first thing I did was visit the quad (a grassy open space in the heart of the university), which was beautiful. I then went to the bookstore and looked up the course catalog (everything was in print back then!). I saw courses in environmental engineering that looked really exciting, so I asked for directions to the civil engineering department. I showed up unannounced and asked the administrative assistant in the main office whether I could speak with a faculty member in the environmental engineering area. She made a call and sent me to Dick Engelbrecht's office.

I don't know what he saw in me, but Dick took an hour of his day to talk with me about UIUC's environmental engineering program and even helped me make an appointment with an associate dean to talk about scholarships. I left thinking, "This is where I would like to study!" After completing my associate's degree at HCC in 1987, I enrolled with a transfer student scholarship at UIUC.

In the spring of 1988, I took an introductory water and wastewater treatment course at UIUC with Professor Vernon Snoeyink—a course that transformed my interests. I was fascinated by the subject and enjoyed Vern's storytelling teaching style. He also told the class about AWWA, which led me to join as a student member. For the topic of my course paper, I chose membrane treatment and became fascinated with advanced water treatment processes. To this day, I find research on water quality and treatment exciting and fulfilling.

As a young professional, can you recall a specific teacher or mentor who influenced your career? What was their best advice and/or lesson(s) that you learned from them?

The first teacher who really influenced my career was my high school chemistry teacher, Mr. Roth. He inspired my interest in chemistry and provided me with an excellent foundation to build on. Also, Mr. Roth was a true nature lover and conservationist who was very engaged in saving the endangered western capercaillie, a rare bird in the grouse family that is native to the Black Forest and is featured in the coat of arms of my home county. Mr. Roth taught me the importance of environmental stewardship.

My most important mentor—and the one who got me truly excited about drinking water quality and treatment—was Vern Snoeyink. I still vividly remember taking his introductory water and wastewater treatment course in the non-air-conditioned engineering hall across from the

Illini Union. Vern's teaching style and seemingly endless knowledge about drinking water truly inspired me. He was very accessible, and I recall having many long conversations outside of class with him, exploring different approaches to and philosophies of drinking water treatment.

Vern and I kept in touch after the semester was over, and I expressed my interest in research and continuing my studies at the graduate level. Vern gave me the opportunity to join his research group, which set me on a course to study thermal reactivation of GAC for my master's research, and then atrazine adsorption by activated carbon, with a focus on predicting the service life of GAC adsorbers, for my PhD research.

I was drawn to both mentors because of their dedication. They were excellent teachers and mentors, and they genuinely cared for their students. To this day, they are role models for me.

Other key mentors who have influenced my life include my first department head, Downey Brill, from whom I learned so much about academia; Mort Barlaz, who has been a wonderful collaborator and always helped me see the big picture; Scott Summers, whom I met at my first AWWA conference in 1991, when we both stayed in the Drexel dorms in Philadelphia (he and I have shared a fascination for activated carbon adsorption—and good food and wine—for decades); Yoshihiko Matsui, who helped me understand adsorption models (and introduced me to sushi); and Andy Lindstrom and Mark Strynar, who taught me so much about PFAS and analytical chemistry.

How has your own curiosity informed your research agenda, and how much of your research focus has been to address specific challenges?

I think the great thing about being a faculty member is that my curiosity and the curiosity of people around me—my colleagues, my students and postdocs, water treatment professionals, people in communities affected by pollution—can drive the research agenda. Faculty members have the freedom to formulate research questions and shape the future.

As an environmental engineer, I am interested in solving problems and conducting research that makes a difference in the way we assess water quality, treat water, and reduce exposure to contaminants of concern. Our research group's curiosity has led to the discovery of many unregulated contaminants in North Carolina drinking water sources. But the discoveries have also identified specific challenges that drinking water providers and people in affected communities are facing. Therefore, our research group is also deeply involved in helping address specific challenges, such as developing rapid bench-scale tests to predict the full-scale performance of water treatment processes, identifying sources of contamination, and identifying opportunities for exposure reduction.

Detlef with PhD advisor Vernon Snoeyink at his May 1996 commencement at University of Illinois Urbana-Champaign.

Is there a particular success or failure in your career that set you on your path or influenced it greatly?

The discovery of high levels of PFAS in the Cape Fear River basin of North Carolina had a dramatic impact on my path. Beginning in 2017, when PFAS contamination in North Carolina became widely known, my group's research portfolio became much more collaborative and diverse. Before 2017 our research generated interest primarily in academic circles and among water treatment professionals working on physical–chemical treatment processes. However, since 2017 there has been an urgency to fill many information gaps that are critical to water professionals, regulators, and people in affected communities.

I have been able to work collaboratively on a much broader range of topics, from PFAS uptake into food, to air emissions, to biomarkers of human exposure. While this has made the research very interesting and rewarding, there are also many more things on my to-do list now.

What are some of the challenges of conducting research that combines science, engineering, and public health?

In my view, a key challenge is that we try to manage risk one chemical at a time, but in reality, we are exposed to contaminant mixtures. Our current risk assessment approaches characterize risk associated with a small fraction of known, quantifiable chemicals in these mixtures. PFAS are a good example, where current EPA methods target only 29 of the thousands of PFAS that are on EPA's PFAS Master List. Another example is disinfection byproducts, the majority of which remain unidentified.

People often ask me, "Is the water safe to drink?" Currently, we lack the tools to answer this question. Meeting regulations does not equate to "safe," and many people understand that. Another challenge is to better understand different routes of exposure. People are passionate about drinking water, but other routes of exposure may be equally or more important yet remain poorly understood.

I think a concerted interdisciplinary effort is needed to advance risk assessment and management in a more comprehensive manner. Ideally, such efforts would culminate in policy decisions that reduce exposure to harmful chemicals in meaningful ways.

How did you initially become interested in PFAS (and GenX specifically)?

I started reading about PFAS in the early 2000s. A paper that influenced me greatly was a 2007 publication in *Environmental Science & Technology*, "Perfluorinated Compounds in the Cape Fear Drainage Basin in North Carolina" (https://doi.org/10.1021/es070792y). EPA scientists Mark Strynar and Andy Lindstrom (among others) coauthored this paper, which showed that PFAS levels were elevated in a large portion of this North Carolina watershed. PFAS levels near one drinking water intake were close to 1,000 ng/L, with PFOA (perfluorooctanoic acid) dominating the PFAS signature.

In 2010, I thought it would be interesting to propose a study to investigate factors that control PFAS adsorption to activated carbon. At the time, I did not have a liquid chromatography–mass spectrometry (LC–MS) instrument in my lab, so I reached out to Mark and Andy and asked whether they would be interested in collaborating on this project. They agreed, the proposal was funded by The Water Research Foundation, and Mark and Andy graciously opened their lab to my students and taught them—and me—the fundamentals of PFAS analysis.

Visiting Mark and Andy's lab always led to thought-provoking conversations. Around 2012, we became curious about GenX after DuPont published a pamphlet that included the GenX structure. Mark was able to obtain an analytical standard for GenX and included it in the LC–MS method. For a separate bromide study, we had many field samples that had been collected in polypropylene containers and that we began analyzing for PFAS. Results showed that GenX was present at high levels downstream from the DuPont (now Chemours) plant near Fayetteville, N.C.

Further on PFAS, what are some key points that all water professionals should understand?

The PFAS class of chemicals has several thousand members, but EPA Methods 533 and 537.1 cover only 29 compounds. Complementary analytical methods, such as the total oxidizable precursor (TOP) assay and adsorbable organic fluorine (draft EPA Method 1621), are needed to more comprehensively understand PFAS occurrence in drinking water sources. If TOP assay and/or adsorbable organic fluorine results differ from those obtained by targeted methods, suspect screening and nontargeted methods can help identify the missing organic fluorine. I think it is important for water professionals to be proactive and always question what contaminants may be present in a system's water source and customer's finished drinking water.

I think it is also important to understand that some PFAS are highly bioaccumulative. Even low levels (nanograms per liter) in water can lead to substantial elevation of PFAS levels in human blood serum. For example, if the

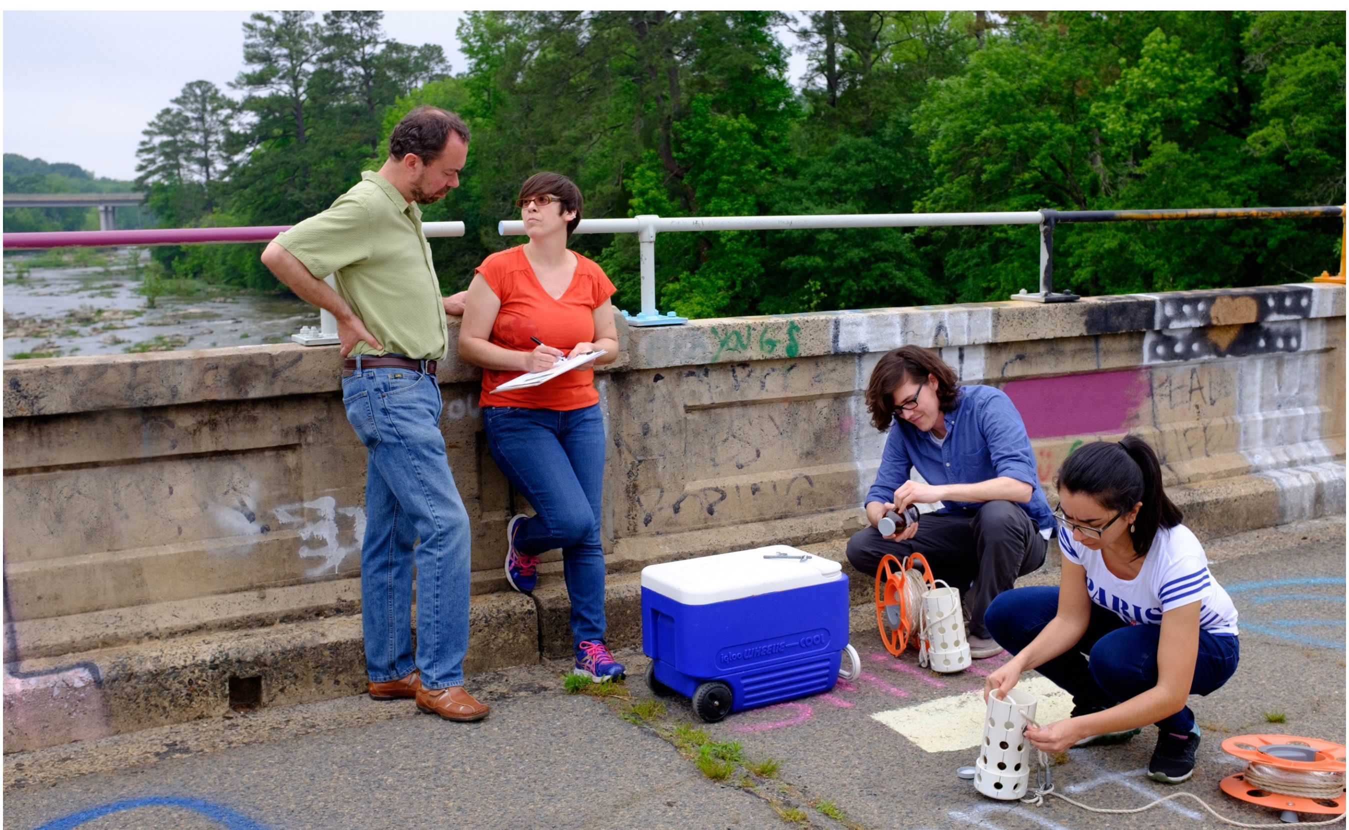
PFOA concentration in drinking water is 20 ng/L, blood serum levels of PFOA are expected to exceed 4 ng/mL (4,000 ng/L), a value that is twice that expected for people drinking water that contains nondetectable levels of PFOA, in which case exposure comes from other sources. EPA's proposed maximum contaminant level (MCL) of 4 ng/L for PFOA would only minimally raise PFOA levels in human blood serum—from 2 ng/mL (background levels) to 2.16 ng/mL (see the PFAS calculator hosted by Scott Bartell of the University of California, Irvine: www.ics.uci.edu/~sbartell/pfascalc.html).

I think one of the most important lessons from the UCMR 3 data set was that it completely missed the high levels of PFAS found in the Cape Fear River of North Carolina. Only six PFAS were targeted in UCMR 3, and in the lower Cape Fear region, PFHpA (perfluoroheptanoic acid) was the only PFAS that was detected above the UCMR 3 method reporting limits at a maximum concentration of 27 ng/L. In 2019, we showed that an archived sample from 2015 contained a PFAS concentration of approximately 130,000 ng/L.

I think it is important for water professionals to advocate for a phaseout of nonessential uses of PFAS. PFAS are pervasive in consumer products, and in most cases, are added for convenience at best. For example, PFAS are found in the following products:

- Nonstick cookware/bakeware
- Dental floss
- Toilet paper
- Cosmetics
- Antifog sprays
- Food contact materials such as paper plates
- Stain and water repellents
- Ski waxes

PFAS production, use of PFAS in consumer goods, and disposal of PFAS-containing products have led and continue to lead to widespread water, air, and soil pollution in the United States and around the globe.



Detlef collecting samples in May 2016 from the Haw River on the Bynum Bridge near the drinking water intake for the Town of Pittsboro, N.C., working alongside lab alumni (from left to right): Amie McElroy, Zack Hopkins, and Catalina López.

Many PFAS, including replacements for PFOA and PFOS, do not break down in the environment, leading to PFAS cycling among different environmental compartments, often involving passage through landfills, wastewater treatment plants, and ultimately drinking water treatment plants. An important way to break the PFAS cycle is to prevent the introduction of more PFAS into the environment by phasing out these nonessential uses of PFAS.

PFOA and PFOS have been phased out, but regrettable substitutions such as GenX are similarly toxic, persistent, and mobile. It is only a matter of time before GenX becomes as ubiquitous as PFOA. Detections of GenX in drinking water sources across the United States are increasing, and with continued use of GenX and other similar substitutes, I expect it will become widely detected around the globe unless meaningful policies for the phase-out of nonessential uses of PFAS are developed quickly. If not, water utilities—and ultimately the ratepayers—will get stuck with the bill.

It is also important to recognize that air emissions from PFAS manufacturers have contaminated thousands of private wells and soils in large swaths surrounding PFAS manufacturing facilities. Often, these plants are in rural areas, and people living in these areas are now stuck with this contamination for decades to come.

As consumers, we can make a difference by trying to purchase PFAS-free products, which is not always easy because PFAS usually are not listed on labels, or labels are added that are misleading. A nonstick pan with a "No PFOA" label simply means it was made with GenX. Some resources exist to help us make informed choices, such as this guide to PFAS-free products: https://pfascentral.org/pfas-free-products.

How have you observed your research driving regulations, and alternatively, how have regulations driven your research?

I think the discovery of GenX and other fluoroethers in the Wilmington, N.C., area was a wakeup call for regulators. It led EPA to complete a human health toxicity assessment, which provides the basis for regulating GenX as a drinking water contaminant. EPA's health advisory level of 10 ng/L for GenX is substantially lower than the 140 ng/L health goal that had been developed quickly by the North Carolina Department of Health and Human Services in 2017.

Also, a consent order was signed in 2019 in North Carolina that stipulates pollution control and remediation actions the fluorochemical manufacturer must implement to drastically reduce PFAS emissions. They have contaminated not only the Cape Fear River but also more than 5,000 private wells over an area that exceeds 100 square miles. The North Carolina Department of Environmental Quality enforces the consent order.

Regulations also affect the way in which we interpret and contextualize our research results. For example, we have been using state MCLs and advisory levels, and now the proposed federal MCL, as treatment criteria for establishing GAC and ion-exchange resin use rates for PFAS control in water sources, with a wide range of background water matrix constituents.

What is your favorite research project that those in the water industry have probably not heard about?

I am a co-investigator on a GenX exposure study that tracks blood serum PFAS levels in more than 1,000 people in the Cape Fear River basin. This research is being led by my colleague, Jane Hoppin, an epidemiologist at North Carolina State University (NCSU). This project is one of my favorites because it directly links decreases in drinking water PFAS levels to decreases in blood serum PFAS levels. The data clearly show that source reduction and associated decreases in drinking water PFAS levels are leading to lower PFAS levels in an important biomarker of exposure.

In another study funded by EPA, I am collaborating with Chris Higgins at the Colorado School of Mines and Owen Duckworth at NCSU to understand PFAS uptake into fruits and vegetables by conducting both a field survey near a North Carolina fluorochemical manufacturer and controlled greenhouse studies. The field survey shows that backyard garden crops can be an important additional PFAS exposure route for people living near the fluorochemical plant.

How have your international experiences influenced your research? Do you have a particular international experience that was especially influential on your thinking, research, or practice?

One international experience that had an important influence on my research was my sabbatical in Urs von Gunten's research group at Eawag in Dübendorf, Switzerland. From Urs, I learned how to conduct oxidation experiments and interpret the resulting data using kinetic models. While our treatment research focuses primarily on adsorption processes, I occasionally have students interested in research involving advanced oxidation processes. I was able to be a better mentor for these students, thanks to my experiences at Eawag.

Also, my stay in Switzerland influenced my thinking about the importance of wastewater treatment plants as entry points of unregulated pollutants into drinking water supplies. At the time, pharmaceuticals and personal care products (PPCPs) were an important research focus, and Switzerland was developing policies to reduce PPCP discharges from wastewater treatment plants.

Another important international experience was my two trips to Hokkaido University in Japan, where I visited Yoshi Matsui. We had known each other from the time he had visited the Snoeyink research group during my PhD studies. Yoshi is a very skilled experimentalist and modeler, and he has greatly influenced my thinking about fundamental aspects of organic micropollutant adsorption in the presence of dissolved organic matter, including the mathematical description of adsorption data.

How has your approach to managing students changed over the years?

As an assistant professor, I feel I was at times too prescriptive in the way I mentored my graduate students. There was a sense of urgency to rapidly obtain publishable data because I felt the tenure clock ticking. Over time, my mentoring style has progressively shifted to involve my students and postdocs more in the creative aspects of research, be it developing experimental designs, developing ideas for data interpretation and visualization, or supporting proposal development. I feel fortunate to have worked with many bright students over the years, and I feel the most exciting projects were the ones that involved student-driven ideas.

What do you remember about presenting your first paper at an AWWA conference, and do you have any recollections about meeting or interacting with colleagues afterward?

I vividly remember my first AWWA conference, at which I presented a poster describing the results of my master's research. My research poster focused on the thermal reactivation of GAC—specifically the effects of the role of

Detlef visiting Yoshihiko Matsui in March 2014 at Hokkaido University in Sapporo, Japan.

Detlef enjoying the beach in October 2004 with his wife Martha and daughters Sophia and Silvia while visiting North Carolina's Outer Banks.

Detlef hiking in July 2005 with his wife Martha and daughters Sophia and Silvia in Germany's Black Forest.

calcium as a catalyst in reactions between steam and the GAC surface.

The conference was a great networking opportunity, and I got to know some people during my poster presentation, others at receptions, and yet others through introductions by Vern. I was amazed that seemingly everyone at this large conference knew him! Probably the most memorable moment of the conference was meeting Scott Summers, who was staying with his large group of students at the Drexel University dorm (yes, AWWA organized student housing at conferences back then!). It was the beginning of a long friendship that continues today.

On the personal side, please comment on how you strike a work–life balance and how your family supports you in your work life.

Entering academic life, I thought the hardest stretch would be the time as an untenured assistant professor. But looking back, my work–life balance back then was a lot better than it is now. Over time, I have taken on more and more responsibilities, and once PFAS came into full public light here in North Carolina in 2017, my job certainly became more demanding. But I find my work very exciting and meaningful, mentoring the next generation of engineers and scientists, and contributing to improving drinking water quality. I always tell students and postdocs who are interested in academia that there has not been a day since I started my job at NCSU in January 1996 that I felt like I did not want to go to work.

I met my wife, Martha Cardona, at UIUC, and we have been married for more than 26 years now. Martha, who was born in Colombia, graduated from UIUC with a PhD in civil engineering and works as a water resources engineer. As you can imagine, water is an important topic in our family—maybe so much so that our daughters decided to pursue different paths. Our older daughter Silvia studied electrical engineering and computer science, staying true to the STEM (science, technology, engineering, and mathematics) theme, and our younger daughter is studying cello performance, moving us into the STEAM realm (the "A" standing for the arts).

Being a parent has certainly provided balance for me, and we always took time to eat together as a family. We took trips together, often visiting family in Germany, Colombia, and Ecuador. We also felt it was important that our daughters learn our native tongues by consistently speaking with them only in Spanish (Martha) and German (me); they now speak effortlessly with our families back home.

It has been such a joy to see our two daughters grow into the amazing people they are today. Martha and I are empty nesters now, which gives us time to explore the Raleigh restaurant scene and go on little trips around the beautiful state of North Carolina while keeping up with the demands of our jobs.

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