Photo by Tim Trumble

Paul Westerhoff

Honored With 2020 A.P. Black Research Award

The A.P. Black Research Award, established in 1967 in honor of Alvin Percy Black, is given on an as-deserved basis to recognize a researcher for outstanding research contributions to water science and water supply rendered over an appreciable period of time.

The recipient of the 2020 A.P. Black Research Award is Paul Westerhoff. He is a Regents Professor and Fulton Chair in the School of Sustainable Engineering and the Built Environment in the Ira A. Fulton Schools of Engineering at Arizona State University (ASU), in which he served as the founding director. He has a bachelor's degree from Lehigh University in Bethlehem, Pa., a master's degree from the University of Massachusetts–Amherst, and a PhD from the University of Colorado–Boulder.

As listed in his nomination for the award,

> Paul has made well-regarded and widely cited contributions to areas as diverse as characterization of natural organic matter, control of nitrogenous organics, removal of pharmaceuticals and personal care products, performance of membrane processes, and especially nanotechnology … Paul is simply one of the most productive and collaborative researchers in our field today. He is known around the world and his active participation is highly sought by conference organizers, research center directors, and thought leaders in the water sector.

Kenneth Mercer, editor-in-chief of *Journal AWWA*, interviewed Westerhoff to learn about his research background, professional influences, and interest in a wide range of innovative technologies. The transcript of the interview to follow has been edited for clarity and length.

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

My lab group enjoys "looking in water to see what is there" and then "improving our understanding of how to remove constituents from water that impact water treatment goals."

During my undergraduate years, I interned at Malcolm Pirnie Inc., where my father, Gary Westerhoff, was part of the leadership. I had the good fortune to spend the summer of 1988 in Phoenix, Ariz., helping two outstanding water professionals and all-around good people—Zaid Chowdhury and David Hildebrandt—operate an ozone pilot plant at the Val Vista Water Treatment Plant. Hot summer days in Phoenix, with temperatures exceeding 115 °F, provided many learning opportunities. Although it was challenging, that experience allowed me to understand what engineers really did as a profession and showed me that our sector provides an essential commodity and service that enables our way of life.

This call to service focused my choice on graduate school and then a first job at CH2M Hill in Denver, Colo. I had the opportunity to work with stellar mentors in that office, including Glen Daigger, Brock McEwen, Bob Chapman, and Bill Bellamy. I recall that one day I spoke with Glen and commented that he had the best job in the company because he could ask why a water treatment plant did not run properly, unlike many others who focused on how to build or fix facilities. He encouraged me to return to graduate school to pursue a PhD and "seek the meaning of life" by focusing on understanding how things work.

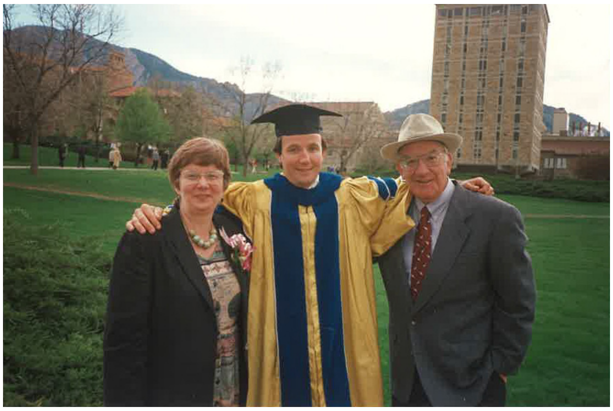
I have continued to focus on how things work for the nearly 25 years that have followed, studying everything from algae in reservoirs to mechanisms of contaminant removal during wastewater reuse. Somewhere along the way, it became evident to me that the harder we look, the more "things" we find in water—but even in the developed world, we still rely on Victorian-era processes to treat water. This spurred a desire to discover new processes that overcome barriers that plague too many water treatment processes. So now much of my research group focuses on patenting new processes, and I've even started a company, H2O Insights, that has a project funded with the National Aeronautics and Space Administration to develop stellar new technologies.

What drew you to water research?

Growing up, water was part of my favorite hobbies. Fishing, boating, and swimming all revolved around liquid water, while skiing focused on the frozen variety. During college, a visiting lecturer from the United Kingdom taught a junior-level hydrology class, and for the first time everything came together. He used my favorite math (geometry) to understand how to place rain gauges across a landscape to predict river flows—something that really influenced my fishing and other hobbies. After that, it was clear to me that I wanted to do something related to water.

Along the way, my interests drifted between water treatment and studying natural biogeochemical processes, and I almost went to work for the US Geological

Paul Westerhoff and Jean Debroux summiting a fourteener in Colorado during the waning days of their PhD research together at the University of Colorado. Fortunately, their advisor, Gary Amy, allowed freedom of thought and encouraged free time. *Photo courtesy of Paul Westerhoff*



Paul after obtaining his PhD from the University of Colorado in 1995 with his parents, Helga and Gary Westerhoff. *Photo courtesy of Paul Westerhoff*

Survey (USGS) to study metal cycling by clams in the San Francisco Bay area. But sometimes life provides a road map for you. After obtaining my PhD in Colorado, with lots of rivers to fish and mountains to ski, I moved to the Arizonan desert. Thinking I would stay only one to two years in such a water-deficient place, I soon learned it was the perfect place to study water—because everyone cares about what little water is available here. On top of that, the university I joined (ASU) was undergoing radical changes as the population of Arizona grew; ASU was transforming from a commuter college to a world-class research university. Being part of this transformation gave me unique leadership opportunities while simultaneously reinforcing the importance of interdisciplinary research, which was always appealing to me.

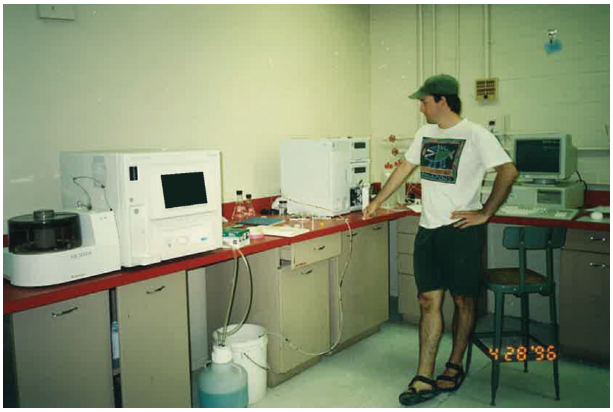
ASU offered me opportunities to be a department chair, founding director of the School of Sustainable Engineering and the Built Environment, associate and vice dean for Research in Engineering, and vice provost for the university. These experiences broadened my views on science, collaboration, and the "business" of advancing science. I was exposed to outstanding researchers from botany, anthropology, ecology, sociology, and other sciences, who showed endless excitement for discovering how the world works. Naturally, this rubbed off on me, and understanding both the similarities (such as a reliance on statistics) and differences (such as time scales or length scales of importance) helped me formulate unique approaches that allowed my research group to flourish and attract outstanding young talent.

How has your own curiosity informed your research agenda? How much of it has been driven to address specific challenges?

My group has been fortunate in that we have published nearly 300 journal papers and have given more than 500 conference presentations. I really like to look at the environment and see and listen to what's new out there. We try to listen to reviewers and audiences while disseminating our research, and use feedback to drive our next endeavors. That has led to collaborations with outstanding analytical chemists, and perhaps one-third of my papers focus on developing tools to measure unconventional "things in water." These projects have included using fluorescence to characterize sources of natural organic matter, using liquid chromatography–mass spectrometry to assess the efficiencies of water treatment plant (WTP) processes to remove contaminants of concern (CECs), and working with atmospheric chemists (like Pierre Herckes) who are willing to help detect engineered nanoparticles in water, lung tissue, and food. My research group at ASU continues to find new detection methods to track important bulk properties and trace constituents in water.

The more you look, the more you find. The more you find, the more confusing life becomes. Sometimes I need to step back so I can better see and understand patterns at the landscape scale rather than nanogram-per-liter or nanometer scale. For example, it is no surprise today when analytical chemists find a new pharmaceutical or residue from industrial processes in wastewater effluents discharged to rivers. However, my group was curious to see if we could

Paul in his new office during his first year as an assistant professor at Arizona State University. *Photo courtesy of Paul Westerhoff*



Paul setting up his new lab at Arizona State University in 1996. Before he could move into the lab, he had to remove 5,000 lb of lead bricks that were used previously to study radiation safety. For the first four years at ASU, his research group was concerned about ambient radiation exposures. *Photo courtesy of Paul Westerhoff*

Paul initially focused on understanding the water supply in the desert Southwest. Research partners at Arizona's Salt River Project allowed him unique access to the canal system, which included turning the canal pink while studying mixing lengths of nitrate-containing wells that pump into the canal. *Photo by Paul Westerhoff*

Escaping hot Arizona summers was key for Paul and his young family, and trips to the Colorado high country occurred every year. *Photo by Paul Westerhoff*

predict the levels of these types of wastewater-derived CECs in rivers and WTP raw water supplies using *big data* rather than high-tech instruments.

I recall a PhD recruiting day when I spoke with Jacelyn Rice-Boayue (then a prospective student, currently an assistant professor at the University of North Carolina at Charlotte), and we joked that what happens in Vegas doesn't really stay in Vegas because CECs end up downstream in the Colorado River, where we drink it in Arizona. That motivated us to develop the De Facto Reuse in our Nation's Consumable Supply (DRINCS) geospatial watershed model, which predicts the amount of wastewater in downstream drinking water intakes. This is called de facto reuse. For example, a 5% level of de facto reuse equates to a 20:1 dilution of any wastewater-derived CECs. Applying this DRINCS model across the entire United States opened my eyes to the next frontier of water data informatics back in the early 2010s. I remain curious about where data will take our industry and am trying to stay at the leading edge of this transformational change.

Has a success or failure in your career set you on your path or influenced it?

We all have failures. An early memorable failure came near the end of my PhD coursework when a mentor of mine from the USGS (George Aiken) and I submitted a paper to a prestigious journal (*Environmental Science & Technology*). It was flat-out rejected by three "experts." Clearly, my work was a failure. George assured me the paper was actually quite good and that we should just submit to another journal (*Water Research*), which we did. All three reviews came back saying not only to accept the paper, but two stated it was the best paper they had read in several years. Clearly not a failure. Today, that paper has been cited nearly 1,000 times. Looking back, what made it difficult for initial reviewers to accept, I think, is that I did not follow the traditional ways of doing things in engineering. Instead, we adopted methods from ecology and physics to explain an important oxidation process in water treatment (i.e., hydroxyl radical reaction rates with different sources of natural organic matter).

Of course, there have been many other failures, but I always try to find an upside to each, because I've found that when my confidence is challenged or my ego takes a hit, innovation abounds. It reminds me of a T-shirt my brother's friend gave me in high school that boldly stated, "Question authority." I take this not to question the rule of law but to question the status quo of how and why research is done.

Fast forward a few decades from that failure at publishing, and in 2020 I now serve as an executive editor for *Environmental Science & Technology*; one of my roles involves reviewing manuscripts for potential impact before sending them out to reviewers. I hold dear my early and subsequent failures, and I try to use them to find new ideas for the water community.

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

Among today's challenges can sometimes be simply trying to understand what is really important. For example, nitrate has a maximum contaminant level (MCL) to protect the health of infants, but new research indicates nitrate has a stronger correlation with bladder cancer than trihalomethanes. Just because communities meet today's nitrate MCL doesn't mean there is no risk. What does this mean for any compound or class of compounds that is not regulated? By no means do people think there is no risk, but it becomes difficult for utilities and researchers to prioritize which pollutants or pathogens to study and address.

Beyond our small world of individual chemicals in water, another challenge relates to stakeholders. Politics, economics, nongovernmental organizations, researchers, industry, consultants—these various groups all have different motivations and goals. The most challenging group of stakeholders for me to work with tends to be those who want to change people's behavior as opposed to, for example, adding a new technology at a water treatment plant.

Another challenge emerges from artificial boundaries. For example, water utilities can and should guarantee that water reaching a service connection meets regulations. However, the public drinks, bathes, and cooks with water from premise plumbing in houses, apartment buildings, restaurants, health care facilities, and other buildings. Placing the responsibility for public health beyond the street-service connection can create conflict between different stakeholders, the largest of which centers on point-of-use (POU) water treatment. POU devices can be used for "polishing" water quality and improving aesthetics, but many utilities and public water research groups seem to view research on POU devices as somehow taboo. The POU market is actually larger than the global desalination market, and it has more influence on public health and acceptance of safe water.

In short, recognizing and acknowledging the viewpoints of different stakeholder groups is among the most challenging aspects of drinking water research.

You've published research papers on many topics, including characterization and/or control of constituents, membranes and advanced oxidation processes, and nanotechnology. Which topic most defines your research contributions and how did you become interested in it?

A theme from my first project as a university researcher through today is nitrogen. I have tried advancing science related to not only nitrate removal from drinking water, but also in constructed wetlands for polishing wastewater effluents. My research group has studied inorganic and organic chloramines, and we have pioneered analysis of dissolved organic nitrogen in drinking water. We were also among the first to customize organic nitrogen fraction of natural organic matter and to show how nitrogen-enriched organic matter behaves differently with hydroxyl radicals and other oxidants during water treatment. We have identified three major pools of organic nitrogen that contribute to nitrosamine formation in the presence of chloramines—watershed, effluent, and cationic polymer sources—and we have studied their effects on other nitrogenous disinfection byproducts. We analyzed free and total amino occurrence and removal during water treatment, as well as the inefficiency of coagulation or granular activated carbon to preferentially remove organic nitrogen during water treatment.

Not all nitrogen is bad, though. We recently patented an innovative technology using silica dioxide nanoparticles that are coated with amines to allow them to bind onto glass optical fibers in a way that scatters ultraviolet light to make "germicidal glowsticks." Within our National Science Foundation–supported Nanotechnology-Enabled Water Treatment center, I have made nitrate treatment in drinking water one of the highest priorities, not only because of potential health impacts but because nitrate reduction to innocuous byproducts (e.g., N_2 gas rather than ammonia) represents a significant scientific challenge. If we can figure how to treat drinking water for nitrate, it could lead to breakthroughs in treatment of many other "oxidized" pollutants that exist in our waters.

While these contributions have advanced our understanding of nitrogen management, perhaps some communities see my contribution more so from the viewpoint of understanding emerging classes of potential pollutants. The work of my group related to environmental nanomaterials is highly cited, starting with papers on nanosilver release from socks (yes, socks) during washing to titanium dioxide nanoparticles in food that eventually end up at wastewater treatment plants. I see my work here less as the reporting of a new emerging class of "pollutants" and more as contributing to a better understanding of how all water sources are interconnected. What we do in society affects wastewater treatment plants, rivers, and downstream water treatment plants; I feel this is my contribution to the "one water" paradigm.

On any of the topics you've researched, is there something you want to point out to the readers?

I see a new generation of students motivated to solve water challenges everywhere across North America and around the globe by developing—and seeking to patent—new technological widgets ranging from single-use paper filters to devices that suck humidity out of the air and make "clean" drinking water. I see industries (banking, social networking) that are fundamentally changing society because they discovered ways to monetize "data" on the internet. The water industry has enormous data sets, yet few people have found ways to monetize water data informatics beyond helping a utility save money—but these could transform society. I don't know how to do it quite yet, but I am investing personal intellectual capital—along with many others in our field—in conducting research that leverages water data to solve our pressing issues.

How has your research affected regulations? How have regulations affected your research?

There have been few new drinking water regulations in the United States since the arsenic MCL was lowered in 2001. However, regulations definitely create momentum for funding, which ultimately drives research. This is the case for *N*-nitrosodimethylamine, hexavalent chromium, per- and polyfluoroalkyl substances, and many other emerging contaminants. I see a new trend though, developing in part because there have been so few new regulations in the United States for two decades; that trend is driven more by public loss of confidence. I don't mean a general fear of what is in our water, but rather the uncertainty that particular pollutants create at the levels we find in our systems—microplastics are a good example of this paradigm.

Of course, research from our group contributes just one part of the complex debate around regulations, but I hope we have contributed to advancing our knowledge of the efficacy of treatment processes to remove certain classes of pollutants.

I want our work to more broadly inform the regulatory process, to move away from individual contaminants and the *contaminant du jour* approach and move toward more of a risk-binning or watershed-risk-based approach that encourages best available technologies rather than lowering concentrations of a limited set of known pollutant levels. Why? Because of the unknowns. The switch of more than half of the US population from free chlorine to chloramines fundamentally changed the landscape of exposure to potential pollutants. We don't know if chloraminated water is "safer" than free chlorine, and there are many examples where the changes likely imparted new risks (e.g., lead, nitrosamines, *Legionella*). We hope that data science, including our DRINCS model and more advanced technology simulations, can be used in the future to holistically reduce risk rather than focus only on lists of pollutants.

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

We examined how much drinking water could be produced, and the quality of that water, if society moved to a hydrogen economy. Moving around hydrogen means you move only one-ninth the mass of water. If all the energy in a typical home came from hydrogen by using a fuel cell, the byproduct is H_2O because H_2 combines with O_2 from the air while generating electricity. This would produce roughly 10–12 gallons of ultraclean water per day—enough for drinking and cooking purposes. Hydrogen is considered a "clean fuel" because it doesn't produce greenhouse gases, and some researchers are currently exploring hydrogen as a type of battery where sewage is electrolyzed via solar energy during the day throughout a sewershed to produce hydrogen that is used at night. We have continued to look for other novel sources of water and believe even tighter interplay between water and energy sectors could mean potentially revolutionary solutions to provide clean and safe water in the future.

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

Initially, I thought all graduate students would approach research the same way I did. Only after participating in several Myers–Briggs-like personality profiles did I recognize people think and learn differently.

Building a strong team meant understanding student personalities and how to minimize the stress of interactions among them. I know it sounds funny, but I give each of my students a personality profile tool. This helps them understand differences within our group and helps me figure out if people are "quick starts" or "fact finders" or one of many other personality profiles that exist. This helps me decide if they like getting lists of things to do, enjoy writing literature reviews, or are motivated by hands-on experimentation. Recognizing that people learn differently helps in the classroom and in the lab. Running a large research group can be similar to running a small company—you have only so much bandwidth, so you try to optimize ways for the team to operate at peak productivity and creativity.

What do you remember about presenting your first paper at an AWWA conference?

It was a regional AWWA meeting in Quebec—probably winter of 1990—and my talk was based on my master's research. We still used transparencies for presentations at the time, and I had a deck of perhaps 20 sheets that I flipped by hand on the machine. Being a prepared engineer, I also made a deck of 20 index cards with notes on what to say. Naturally, I was set up for a disaster—I had to talk, flip transparencies, and shuffle index cards. On about the fifth transparency, my index cards fell to the floor in an unorganized mess.

I know my face had the "deer in headlights" look, and I remember looking up at my advisor (John Tobiason) as he mouthed, "You know this. Leave the cards." I finished the talk without the index cards and there was some clapping after the talk. I realized that giving a talk was not about getting everything right but about trying to tell a story as you understand it, which may be a better understanding than almost everyone in the room.

To this day, no matter how good or bad a presentation is, I look for one nugget of insight that the presenter is trying to convey. Giving a talk isn't easy, and I feel it is my responsibility as a listener to engage and learn. Some 500 presentations later, I don't need index cards and we are way beyond transparencies, but I still try to tell a good story.

Share how you strike a work–life balance and how your family supports you in your work life.
Still trying to learn how to do this one. I do work hard and travel a lot, but it is important to me to have dinner together as a family. Overall, my family has been very supportive of my work and nothing would have been possible without their support.

We also try to escape the Phoenix area for at least a few weeks during the hot summer months. Fresh minds yield fresh ideas. Escaping summer heat in Phoenix seems logical, and escaping to mountains with snow, rivers, and fresh scents has always been revitalizing. For several weeks each summer, our family rented a house in the mountains. We hiked, fished, and just lived a different lifestyle for a while. I would often work in the mornings and then get out during the day. These breaks in time—in the mountains or during weekend runs—are often where new ideas pop into my mind. Nature has a lot to teach us and being in nature can provide a fresh perspective.

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