tx H$_2$O

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WATER & HEALTH

Inside: Zooming in on pathogens, poverty, PFAS and other water-health issues and developing potential solutions

Texas A&M AgriLife Research | Texas A&M AgriLife Extension Service | Texas A&M University College of Agriculture and Life Sciences

Working to make every drop count

Water, often called 'the elixir of life,' in its pure form is a tasteless, odorless, colorless liquid that provides no nutritional value. However, water is critical to the survival of life on Earth. According to the Mayo Clinic, water makes up about 60% of the adult body, and adults should replenish it by consuming between 91 to 125 ounces of fluid daily.

What's in that water though can have significant health impacts if unsafe contaminant levels are present. The Safe Drinking Water Act describes water contaminants as any physical, chemical, biological (bacteria, parasites, viruses) or radiological substance or matter present. Repeated or sustained exposure to chemical and radiological contaminants through consumption or contact can cause skin discoloration, organ or nervous system damage, developmental problems, reproductive issues and cancer. Biological contaminants typically cause gastric illness, headaches, fever and more.

Biological contaminants have always been present in the environment and long understood, but threats remain. Modern water treatment processes largely mitigate these threats, but population increases will force an increase in water reuse making effective water treatment more important. Monitoring and treatment technologies must evolve to ensure that water used for drinking, food processing and agricultural irrigation are safe.

Analytical technology advances have allowed increased detection capabilities, but critical exposure thresholds and long-term exposure effects of chemical, radiological or biological contaminants remain largely unknown. What is known is that many of these contaminants are pervasive and persistent in the environment. Humans created many of these contaminants (for example, polyfluoroalkyl substances, pharmaceuticals and personal care products, disinfection byproducts, etc.) and are only now beginning to investigate and realize the human health implications. Whatever the contaminant, not having access to safe, reliable, affordable water can have far-reaching effects on physical and even mental health.

Researchers from Texas A&M University, other universities and agencies are asking questions about the effects of water contaminants and water insecurity on human health, developing solutions and strategies to manage these issues, and educating the public about how to ensure their water resources are safe. This issue of *txH2O* highlights these efforts, diving deeper into the challenges of providing safe water now and in the future.

As always, please join us in "making every drop count."

Lucas Gregory, Ph.D.
Senior Research Scientist

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To protect water quality, researchers examine water problems and potential solutions. Photo and illustrations from Pixabay and FreePick.

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Texas Water Resources Institute
make every drop count

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The La Nana Bayou is part of the Angelina and Neches River Basin in East Texas. Photo by Ed Rhodes, TWRI.

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Story by Chantal Cough-Schulze

PERVASIVE PROBLEM

Texas researchers are taking on the task of removing long-lasting PFAS from the environment

On Sunday, March 17, 2019, a fire started at the International Terminals Company (ITC) petrochemical plant in Deer Park, Texas. For four days, the fire burned, damaging 11 storage tanks and sending a huge plume of black smoke into the sky. High levels of the carcinogenic chemical benzene forced school closures and shelter-in-place orders in the Deer Park area.

On the third day, researchers led by Texas A&M School of Public Health research assistant professor Dr. Garett Sansom began collecting water, air and soil samples to understand the fire's impact as part of an ongoing effort at the Texas A&M Superfund Research Center. In addition to benzene, they were looking for per- and polyfluoroalkyl substances, or PFAS, which would have resulted not from the fire, but from the firefighting foam used to put out the fire — and they found them.

Forever Chemicals

PFAS are a diverse group of more than 4,700 man-made chemicals defined by their bonds between carbon and fluorine molecules, one of the strongest known chemical bonds. Those bonds make them so good at persisting in the environment and the human body that they've earned the nickname "forever chemicals." PFAS are also highly heat resistant and repel both water and oil, which is why they are used in firefighting foam.

Dr. Kung-Hui "Bella" Chu, a professor in Texas A&M University's Zachry Department of Civil and Environmental Engineering, said that PFAS are critical ingredients in aqueous film-forming foams used in fighting high-hazard flammable liquid fires.

"PFAS act as surfactants to assist with putting out fire because they modify the surface tension of the flammable liquids quickly and cut off the oxygen, preventing reignition," said Chu, who studies biodegradation and treatment of PFAS and other emerging contaminants.

PFAS were first introduced in the 1940s, when DuPont, an American chemical company, used a type of PFAS as an ingredient in the nonstick coating Teflon. Soon after DuPont invented Teflon, the 3M Company created Scotchgard, a stain- and water-repellant product for fabric, using a different kind of PFAS. By the 1960s, the Navy was working with 3M to develop PFAS-containing firefighting foam. PFAS have since found their way into a variety of household products, from food packaging to carpet.

The qualities that first made PFAS so useful in things like firefighting foam can also make them problematic, Sansom said. ⇨

PFAS are critical ingredients in aqueous film-forming foams used in fighting high-hazard flammable liquid fires. Photo by Shutterstock.

"We have used PFAS in everything. They have certain really valuable chemical characteristics," he said. "But we've been using them before fully understanding them. And now we're playing catch up."

PFAS' strong chemical bonds protect them from degradation; the more carbons a PFAS chemical has, the better it is at persisting in the environment. PFAS can enter people's systems via drinking water and some foods, and once in the body, PFAS' ability to repel oil and water makes them difficult for the body to secrete, as they stick to fatty tissue.

By the 1960s, both DuPont and the 3M Company expressed concerns about the toxicity of the PFAS they were using. In the late 1980s, the 3M Company found elevated cancer levels in PFAS workers. According to the U.S. Environmental Protection Agency (EPA), PFAS exposure is linked to a range of adverse health outcomes in humans. EPA also states that animal studies have shown that the two most well-known types of PFAS, perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS), can cause reproductive, developmental, liver, kidney and immunological effects, as well as tumors. As people are exposed to more PFAS, they accumulate PFAS faster than their bodies can excrete them in a process called bioaccumulation. Eventually, people reach a level of PFAS where they may experience adverse health effects. The exact level of exposure at which people begin experiencing the health effects is not yet known.

A little goes a long way

EPA recommends having no more than 70 parts per trillion of PFAS in drinking water. For comparison, one part per trillion is roughly equivalent to one drop of water in 20 Olympic-sized swimming pools of drinking water.

To express the smallness of the recommendation, Sansom compared it to the limit for lead, which is measured in parts per billion.

"The recommended maximum level of PFAS is an entire three orders of magnitude smaller than for lead. It doesn't take much PFAS to be a problem," he said.

All agree that PFAS are a problem, but how much of a problem is uncertain; thus more study is needed.

A 2018 draft report from the Department of Health and Human Services' Agency for Toxic Substances and Disease Registry found that the recommended maximum level for PFAS of 70 parts per trillion should actually be 7 to 10 times smaller.

A 2016 study from the Harvard School of Public Health found that six million U.S. residents' drinking water had confirmed levels of PFAS higher than EPA's recommended maximum level. Other estimates suggest that the number of people with PFAS-contaminated drinking water could be up to 18 times higher. As of 2017, data from the U.S. Department of Defense (DOD) and Northeastern University's Social Science Environmental Health Institute suggests that nearly 500,000 Texans live within a 3-mile radius of sites where groundwater is contaminated at levels 100 times EPA's recommended maximum level of PFAS.

One of the principle ways PFAS enter the environment is via PFAS-containing firefighting foam, according to EPA. After firefighting foam is used — most commonly on military bases and at commercial airports — it can seep into the ground or run off into nearby bodies of water, Sansom said. That is what happened during the ITC petrochemical fire when a protective barrier to the Houston Ship Channel failed.

PFAS can also enter the environment when rainwater percolates through PFAS-containing waste in landfills, leaching out the PFAS. That PFAS-containing water, called landfill leachate, either unintentionally seeps into the ground beneath the landfill or is pumped out of the landfill and released into the environment after being treated — but the traditional treatment methods don't remove all the PFAS.

Industrial and domestic wastewater can also contain PFAS. In the wastewater treatment process, water is treated, and solids are concentrated. Because PFAS repel water, they tend to bind to solids over water, concentrating the PFAS in the solids. Those solids, called sewage sludge or biosolids, may be used as fertilizer after treatment, but again, that treatment doesn't get rid of PFAS.

"With our good intentions to put biosolids to good use as land amendments, PFAS in biosolids have found their way into our environment and contribute to widespread PFAS contamination. And if you have some crop growing in biosolid-amended soils, the PFAS can accumulate in the crops and move up the food chain," Chu said.

Treatment train

Tackling the pervasive problem of PFAS requires removing PFAS from the environment, regulating their use and replacing them with safer alternatives, Sansom said.

The effectiveness of different removal methods depends on the concentration of PFAS and the number of carbon bonds a particular type of PFAS has. PFAS with eight or more carbon bonds, called long-chain PFAS, are typically more toxic and accumulate more in humans and other animals than shorter chain PFAS.

Myung "Bo" Hwangbo, a doctoral student in Dr. Kung-Hui "Bella" Chu's lab, explains how sorbents take up PFAS. Photo by Chantal Cough-Schulze, TWRI.

Because different removal methods are helpful for different aspects of the PFAS problem, Chu said tackling PFAS removal requires a "treatment train" of multiple removal methods.

Many of the most common methods of PFAS removal use sorbents, or materials that can collect a liquid or gas, such as activated carbon. Water trickles through the activated carbon, which in turn takes up the PFAS, cleaning the water.

But, Chu said, sorbents such as activated carbon are an imperfect solution. While activated carbon and many other sorbents work well for long-chain PFAS, they typically don't work equally well for short-chain PFAS, she said. After the sorbents are used on contaminated water, such as from landfill leachate or groundwater near heavy firefighting use, the PFAS-laden sorbents are considered hazardous materials. Neither incineration nor the current regeneration methods of the sorbents is cost-effective, she said.

Chu, along with a colleague at Texas A&M, has developed an alternative sorbent to activated carbon: reusable functionalized hydrogels. The hydrogels, which are "like jelly, but with stronger mechanical strength," are reusable, decreasing treatment costs, Chu said. Most importantly, she said, the functionalized hydrogels can effectively remove short- and long-chain PFAS and GenX, a newer PFAS-containing replacement for PFOA, from water, putting them a step ahead of many other sorbents. Once the hydrogels have been used, the collected PFAS are removed from the hydrogels. The PFAS removed from the water must then be safely disposed of, usually by incineration, without re-releasing PFAS into the environment.

Dr. Suresh Pillai, director of Texas A&M AgriLife Research's National Center for Electron Beam Research at Texas A&M, is working on another step in the treatment train. He is researching the use of electron beam technology, or eBeam, to degrade PFAS in contaminated groundwater, wastewater, soil and biosolids.

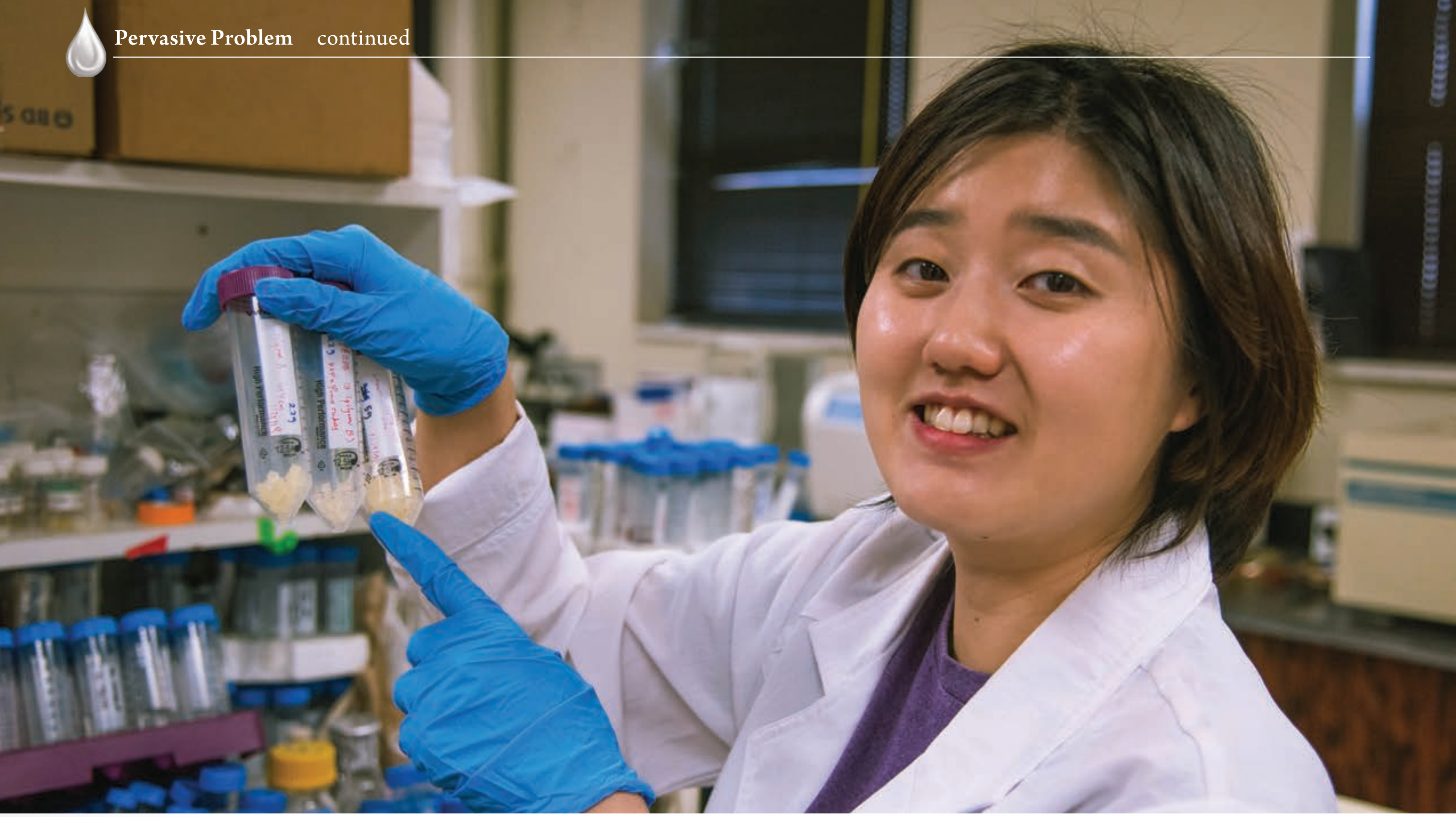
eBeam technology works by accelerating electrons to 99.99% the speed of light and then showering the electrons over the material to be changed.

"eBeam packs a punch. It essentially shreds chemicals," Pillai said.

The technology is already ubiquitous: It is used to colorize diamonds blue and green, sterilize contact lenses and disinfect mangos. When used on PFAS, Pillai said eBeam breaks the PFAS down into smaller byproducts. Research to confirm that those byproducts are completely harmless is ongoing.

The way eBeam works makes it flexible — it can be used either on untreated waste and water or on the PFAS removed with other methods, such as activated carbon or hydrogels.

"With eBeam, you can cover both the degradation and removal of PFAS, instead of using incineration. Moreover, eBeam can be used to degrade PFAS that ⇨



Reusable functionalized hydrogels, like those Hwangbo is holding, can effectively remove short- and long-chain PFAS. Photo by Chantal Cough-Schulze, TWRI.

were removed using other technologies, such as sorbents. So eBeam can either stand alone or work in conjunction with other technologies," Pillai said.

Getting ahead of PFAS with replacements and regulations

Different industries use different types of PFAS, so replacing and regulating PFAS-containing products is not easy, Chu said.

Some major manufacturers of PFAS have phased out their use of long-chain PFAS, and the U.S. military is in the process of phasing out firefighting foam containing long-chain PFAS. Because PFAS' useful qualities are chemically unique, most replacements are also PFAS — just shorter-chain PFAS, which are believed to be less bioaccumulative and easier for the body to secrete, Chu said.

"Anything that doesn't stay in the body like long-chain PFAS do is a good thing," she said.

But, Chu said, short-chain PFAS may cause the same health problems as long-chain PFAS, and they are more mobile than long-chain PFAS, meaning that they can travel farther in water and are therefore harder to catch and remove. It's also unclear whether short-chain PFAS are any less environmentally persistent than long-chain PFAS, she said.

Research is being conducted on entirely PFAS-free firefighting foams. None have yet met DOD's fire-extinguishing speed requirements; PFAS-free firefighting foam was 9 seconds slower than the requirement in U.S. Navy tests in 2004. However, some PFAS-free replacements have successfully been used to control jet fuel fires and match up with PFAS-containing firefighting foam in at least some scenarios. Since 2012, London's Heathrow Airport has successfully switched to using PFAS-free firefighting foam, as have a number of other major European airports.

Though DOD has not settled on a firefighting foam replacement, regulations of PFAS may be upcoming. EPA's current recommended maximum level of PFAS is a health advisory, not a regulation, and therefore is not legally enforceable. (For an explanation of how EPA makes drinking water regulations, see page 8.)

In February 2020, EPA proposed preliminary regulatory determinations for PFOA and PFOS. According to the Federal Register notice submitted by EPA, the preliminary regulatory determination is the beginning of the process for developing regulations, not the end. The notice states that EPA may still decide later on to not regulate PFOA and PFOS. In the meantime, at least nine states have developed their own PFAS standards. In December 2019, Congress finalized the National Defense Authorization Act (NDAA) for fiscal year 2020, which included some PFAS-related provisions, such as expanding PFAS monitoring and phasing out military use of PFAS in firefighting foam and food

packaging. An earlier provision to designate PFAS as hazardous substances under the Superfund law, which would have required most PFAS-contaminated sites to be cleaned up, did not make it into the final NDAA. Work on other potential drinking water and groundwater regulations for certain kinds of PFAS is ongoing.

Winds of change

The sheer diversity and pervasiveness of PFAS is unprecedented, Chu said, and continuing and expanding research on PFAS in Texas is vital.

"If you don't look for something, you probably can't find it," she said. "We might not see all the effects caused by PFAS right now, but for the next generation, we don't know what the problems could be. However, if we are proactive on PFAS issues in terms of treatment and minimizing exposure, many adverse outcomes associated with PFAS contamination can be avoided or minimized."

Pillai, for his part, is optimistic.

"Our data from past PFAS eBeam research is extremely promising," he said. "My optimism comes because I know the capability of this technology. And people are starting to see the value of this research."

In September 2019, EPA awarded more than $1.3 million to Texas universities for research on risks and management of PFAS, including Pillai's research on eBeam technology. Texas Tech University environmental engineering assistant professor Dr. Jennifer Guelfo's research on landfill leachate also received funding.

Following the ITC petrochemical plant fire, Sansom's research team continued sampling for PFAS in the Houston Ship Channel. Immediately after the fire, PFAS levels were above EPA's drinking water maximum recommended level of 70 parts per trillion. By midsummer, PFAS levels in the Houston Ship Channel decreased, indicating that the PFAS were washing out into Galveston Bay and the Gulf of Mexico. When the last samples were taken in August 2019, PFAS levels were still above the drinking water maximum recommended level — but the ship channel is not a drinking water source. Local well water that many people use for drinking water, as well as fish in the ship channel, have not yet been tested for PFAS.

Before the ITC petrochemical plant fire, the baseline levels of PFAS near the ITC petrochemical plant weren't known, Sansom said. The silver lining of the fire, he said, is that now his team's post-fire monitoring data can help increase understanding of PFAS in the area in the future, in case of another similar event.

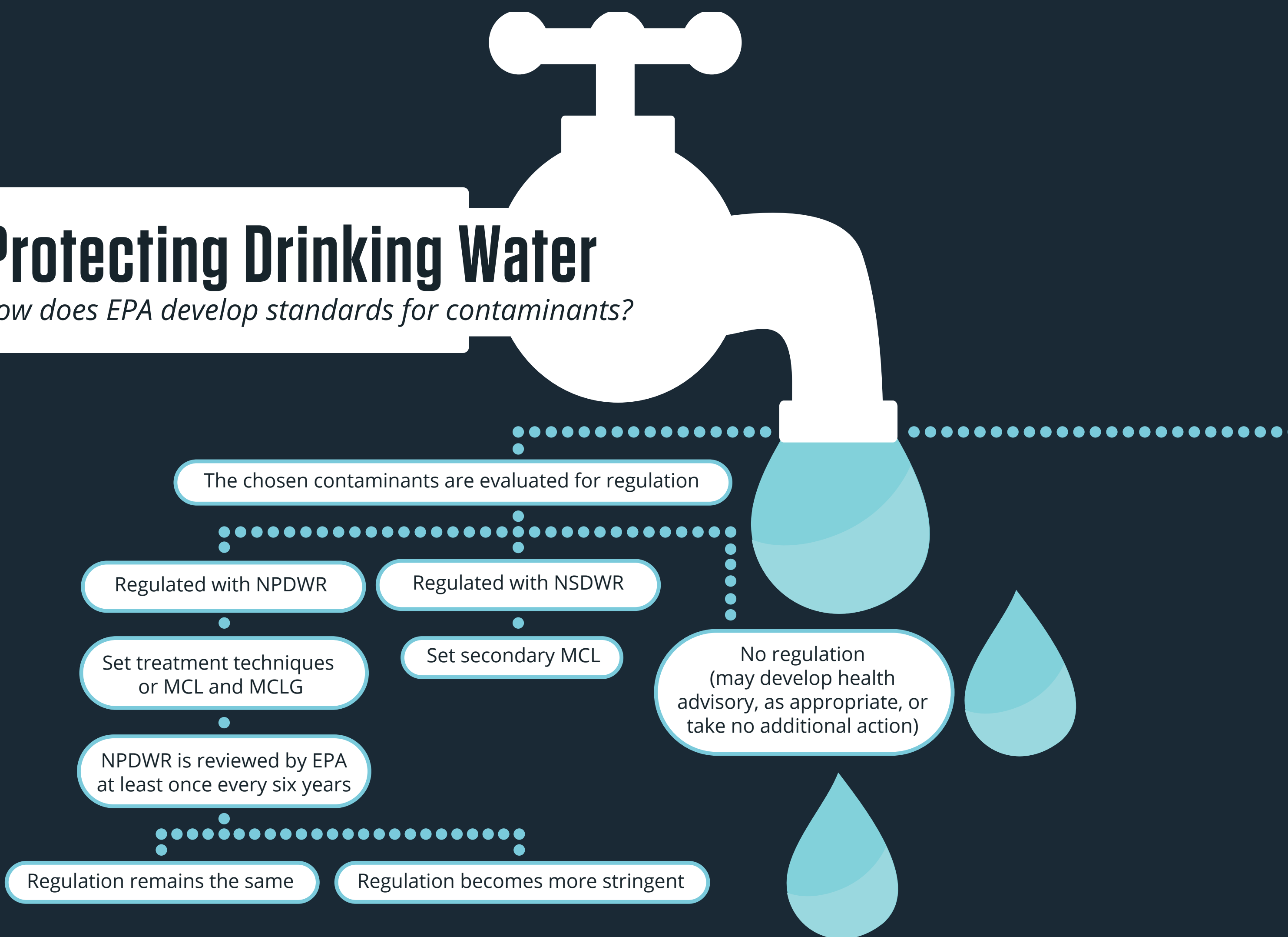
"What are the long-term implications of PFAS in the environment? We don't know yet. And are events like the ITC petrochemical fire going to happen again? Almost assuredly. It's something that we're going to be living with for the foreseeable future," Sansom said. "But change is on the wind."

Public health master's student, Kathleen Aarvig, wears a protective mask while collecting air and water samples following the ITC petrochemical plant fire. Photo by Dr. Garett Sansom.

Story by Chantal Cough-Schulze

Protecting Drinking Water

How does EPA develop standards for contaminants?



Throughout history, arsenic has been known as both a poison and a healer. Nicknamed the "king of poisons and poison of kings" since the time of the Roman Empire, it can cause intestinal problems and death after acute exposure and is linked to cancer, cardiovascular disease and diabetes after long-term exposure.

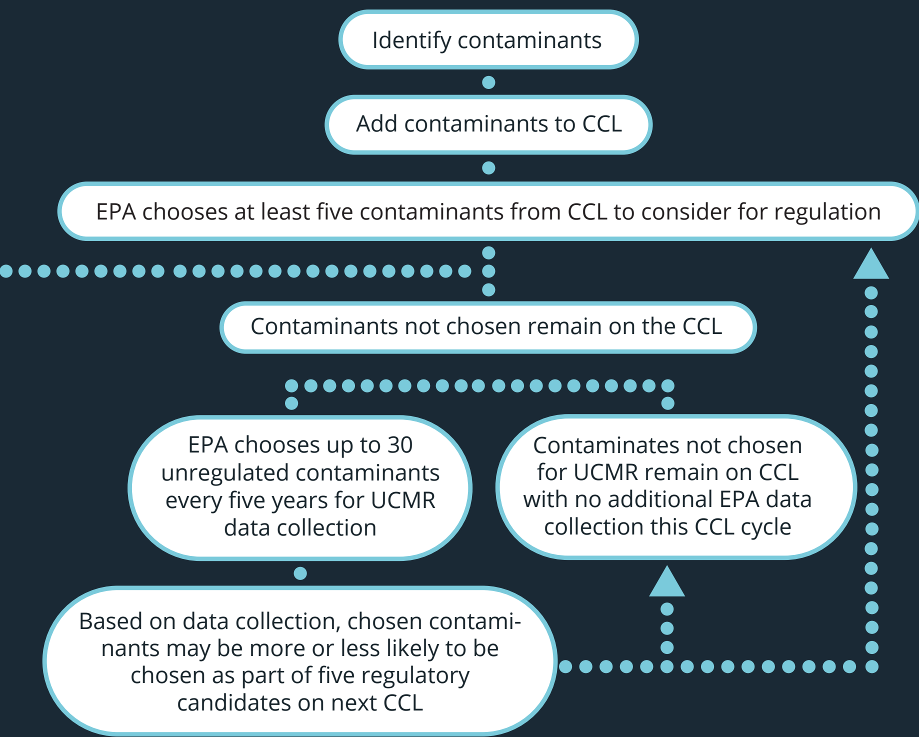
Both naturally occurring in the environment and released through human activity, arsenic was first formally recognized as a problem in the United States in 1942. The U.S. Public Health Service created the first arsenic drinking water standard for interstate water carriers, establishing 0.05 milligrams of arsenic per liter of water as the safe limit.

After the Safe Drinking Water Act (SDWA) was established by the U.S. Environmental Protection Agency (EPA) in 1974, arsenic was one of the first drinking water contaminants to be regulated, upholding the same 0.05 milligrams per liter limit. That limit held all the way through 2001, when the maximum contaminant level (MCL) limit was lowered from to 0.05 milligrams per liter to 0.01 milligrams per liter, or 10 parts per billion (ppb).

Arsenic is just one of the many contaminants that has been regulated by EPA under the SDWA since its establishment. Sometimes, how those regulations are made — and what happens once they're made — can feel like a bit of a black box.

Under the SDWA, EPA sets standards to protect drinking water. When new contaminants are identified, they are added to the Contaminant Candidate List (CCL), which is published every few years. When the new CCL is published, EPA must decide whether to regulate a minimum of five contaminants from the list.

EPA decides what to do about those chosen contaminants based on health risk and high occurrence as well as on whether the EPA Administrator determines that the regulation of the contaminant presents an opportunity for risk reduction. EPA can choose from a couple of options for regulation — or lack thereof.



Some contaminants are regulated with legally enforceable National Primary Drinking Water Regulations (NPDWRs). Currently, there are NPDWRs for 90 drinking water contaminants, including arsenic. Certain treatment techniques (a required process) may be mandated, and an MCL may be established. In addition to setting an MCL, EPA sets a maximum contaminant level goal (MCLG).

MCLs and MCLGs are slightly different. The MCL is the highest contaminant level allowed in drinking water and is an enforceable standard, while the MCLG is the highest drinking water contaminant level for which no negative health effects are known. If there is evidence that chemical contaminants are carcinogenic and there is no dose at which the contaminant is considered safe, then the MCLG is set at zero, as is the case for arsenic. Meanwhile, the MCL — such as 10 parts per billion for arsenic — is set as close to the MCLG as is considered feasible. The MCLG is a public health goal, rather than a legal limit, and is therefore non-enforceable.

Sometimes, establishing an MCL may not be possible, such as when reliably measuring a contaminant at concentrations below those of public health concern isn't possible. For these contaminants, EPA sets treatment techniques, which are enforceable procedures for controlling the contaminant. Controlling corrosion in lead and copper plumbing materials is an example of such a technique.

At least once every six years, each NPDWR comes up for review. During this review period, EPA assesses any new information and technologies related to the contaminant to see whether the regulation should remain the same or become more stringent.

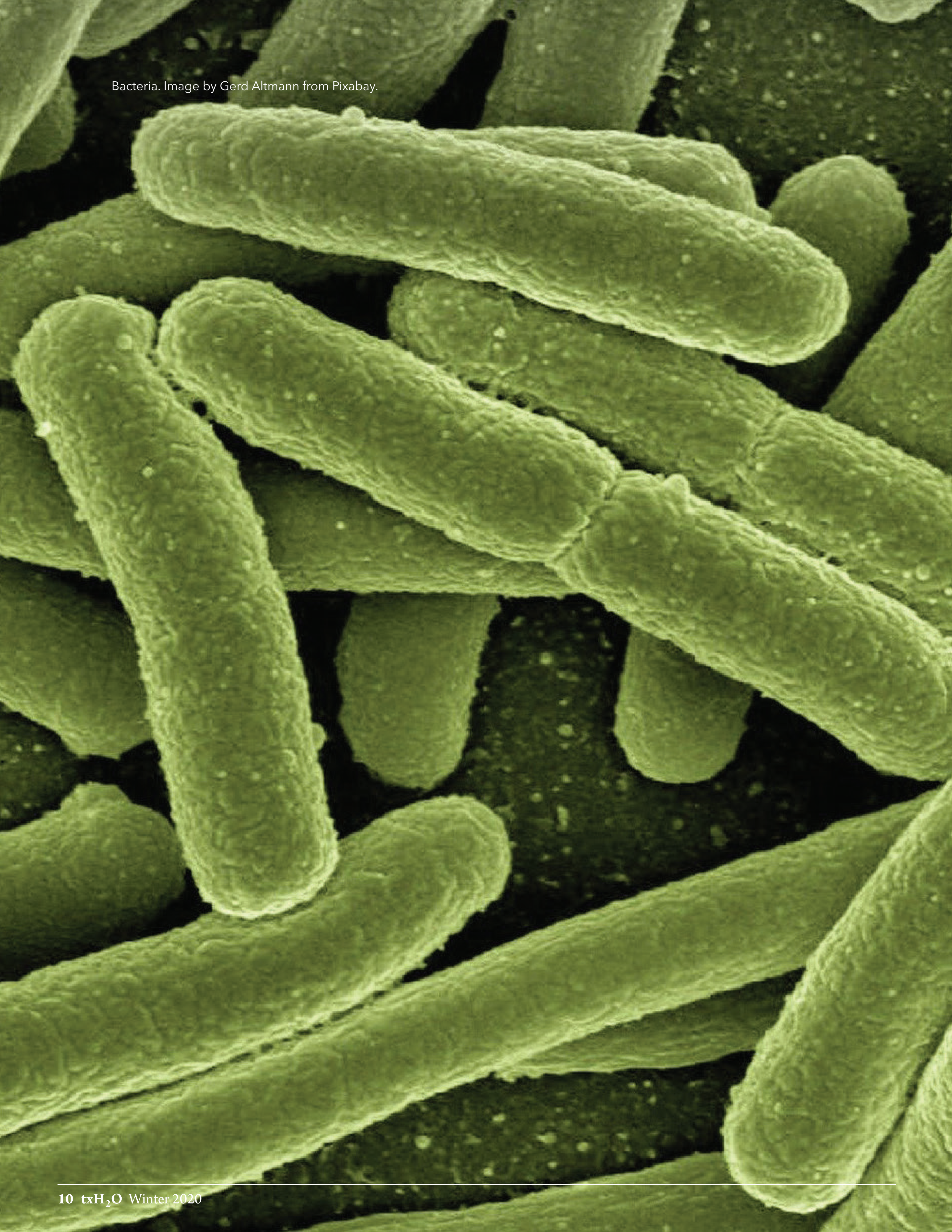
If contaminants aren't chosen for NPDWRs, they may receive a National Secondary Drinking Water Regulation (NSDWR). These contaminants are generally listed because they may cause cosmetic or aesthetic effects: They might discolor people's teeth, like fluoride does, or make the water taste or look different, like iron and manganese do. At the set secondary MCL, these contaminants are not considered a risk to human health, and regulations regarding them are considered non-enforceable guidelines.

But what happens to all of the contaminants that don't make it to the regulation phase? With a minimum of only five contaminants assessed for regulation every year, many contaminants remain on the CCL, sometimes for a long time. Per- and polyfluoroalkyl substances (PFAS), a group of pervasive and potentially carcinogenic chemicals, have been on the list since 2009. (See Pervasive Problem, page 2.)

To help understand the still-unregulated contaminants on the CCL, EPA collects data on a maximum of 30 unregulated contaminants every five years under the Unregulated Contaminant Monitoring Rule (UCMR). Most of those contaminants are chosen based on the CCL. The current monitoring period is from 2017 to 2021 for UCMR 4, with UCMR 5 coming next.

In 2012, six types of PFAS were added to the UCMR 3 list to be monitored and studied. Though they were removed from UCMR 4 in 2016, they remain on the list of candidates for regulation.

CCL 4, the most recent available CCL, is from 2016 and has 97 contaminants on it. In February 2020, EPA proposed preliminary regulatory determinations for two kinds of PFAS from CCL 4. If finalized, those regulatory determinations could result in a NPDWR for those PFAS in the future. The deadline for submitting candidates to the CCL 5 was December 4, 2018. EPA is currently evaluating the nominations and other contaminant data and will later publish a draft CCL 5 for public review and comment.



Bacteria. Image by Gerd Altmann from Pixabay.

DETERMINING FRIEND FROM FOE

Researchers creating new system to screen millions of unknown bacteria, one at a time, to uncover pathogens

A group of Texas A&M University researchers is leading a study to find new ways to quickly determine whether unknown bacteria in soil and water are friends or foes.

The group is part of a $14.2 million, four-year project of the Friend or Foe Program of the Defense Advanced Research Projects Agency (DARPA), a federal agency of the U.S. Department of Defense (DOD).

According to DARPA, the likelihood of military personnel deployed to different areas of the world or global travelers encountering new or unknown pathogens is growing. Its Friend or Foe Program aims to build a platform that rapidly screens many unknown strains of bacteria at once to distinguish harmless organisms — friends — from harmful organisms — foes — as, or before, they threaten the military, the public or even animals.

The problem: millions of unknown environmental bacteria

Even though many pathogens in the environment are very well characterized, there are still millions of bacteria that are either unknown or very little is known about them, according to Dr. Arum Han, professor in Texas A&M's Department of Electrical and Computer Engineering and one of the project's co-principal investigators.

The current understanding, Han said, is that only about 1% of the microorganisms in the environment are known and even among that 1%, only a small percentage is well understood. Of those millions of unknown bacteria, some are "friends," but some may be "foes."

While information learned from this research will potentially help DOD identify possible genetically engineered pathogens that could be used for bioterrorism, Han said the more common application will be identifying new or naturally occurring, but unknown, pathogenic bacteria.

"The chance of having naturally occurring pathogens in the environment causing issues is probably a much higher risk than bioterrorism," Han said. "We know there are way more microorganisms out there. Just probability-wise, there have to be a whole bunch of bad pathogens that we do not have a clue about."

The solution: screening the millions, one at a time, to determine pathogenic properties

To distinguish the pathogens from harmless bacteria, the team is working on defining what characteristics should be measured to determine the pathogenic properties of the bacterial cells as well as a device that can actually measure and screen for these properties rapidly, one cell at a time.

Principal investigator Dr. James Samuel, Regents Professor and head of Texas A&M College of Medicine's Department of Microbial Pathogenesis and Immunology, said the three key words or phrases of the project's screening strategy are high throughput, phenotyping and single cell. Putting those three together "is not trivial and has not been done before," he said.

Samuel said a limited number of available microbiology techniques such as advanced DNA isolation techniques can identify bacteria and their genetic makeup, but they are not high throughput enough and are not phenotype-based identification systems.

High throughput technology means screening done very rapidly for many samples. An organism's phenotype is its observable physical properties or functions, determined by genotype and environmental factors.

"DARPA decided to expand the universe of ways that people can detect bacteria," Samuel said. "The agency is trying to take high throughput technologies and merge them with novel phenotypic assay systems that have not yet been created as high throughput tools."

Phenotypic assay systems measure the presence or activity of an organism's properties, for example, the ability of bacteria to invade a host cell or activate or repress host detection of the bacteria.

Researchers in the microbial pathogenesis and immunology department are providing guidance on understanding the host-pathogen interactions, answering questions such as: Are the bacteria producing toxins? Are they going inside a host cell? Do they survive inside the host? And do they have drug resistance?

Answering these questions at a single cell level, Samuel said, will enable the team to determine the bacteria's phenotype and, with bioinformatic prediction tools, determine if each bacterial cell is predicted to be pathogenic.

Han said his team, based on these biological assays, "is developing tools that actually allow us to measure that host-pathogen interaction one cell at a time and allow us to do that measurement on millions and millions of cells within a very short time period."

To do this, they will build a unique microfluidic lab-on-a-chip device that can rapidly test millions of individual cells, an essential component of the platform DARPA hopes to develop.

Han said a microfluidic device can handle very small volumes of liquid or cells. It has many micrometer-sized fluidic channels that allow millions of single cells to flow through and be controlled very accurately.

"The lab-on-a-chip device is a device where a series of high-precision cell and liquid assay steps can be integrated together to conduct a complex assay on a single chip format, thus the term lab-on-a-chip," Han said.

He said conventional laboratory methods for collecting and measuring cells using pipettes will not work when trying to measure the properties of millions of cells.

"If I have a bacterial cell that is five micrometers in diameter, I cannot use a conventional pipette and select only a single microbe to measure," he said. "But the microfluidic device with a tiny, tiny microfluidic channel allows me to control cells that are only a few micrometers in size and also liquid samples that are pico-liters in volume, allowing us to manipulate cells one cell at a time."

Within the microfluidic device, the bacterial cell will be placed together with a host cell inside a water-in-oil emulsion droplet that functions as a pico-liter-volume bioreactor. Then the device will measure the interaction between the bacterial cell and the host cell.

"How the host cell responds to the bacterial cell or how the bacterial cell behaves in the presence of host cells will allow us to assess whether the bacteria is pathogenic or not," Han said. "Since millions of these cell-encapsulated bioreactors can be rapidly generated and analyzed, screening through millions of cells and their interactions become possible."

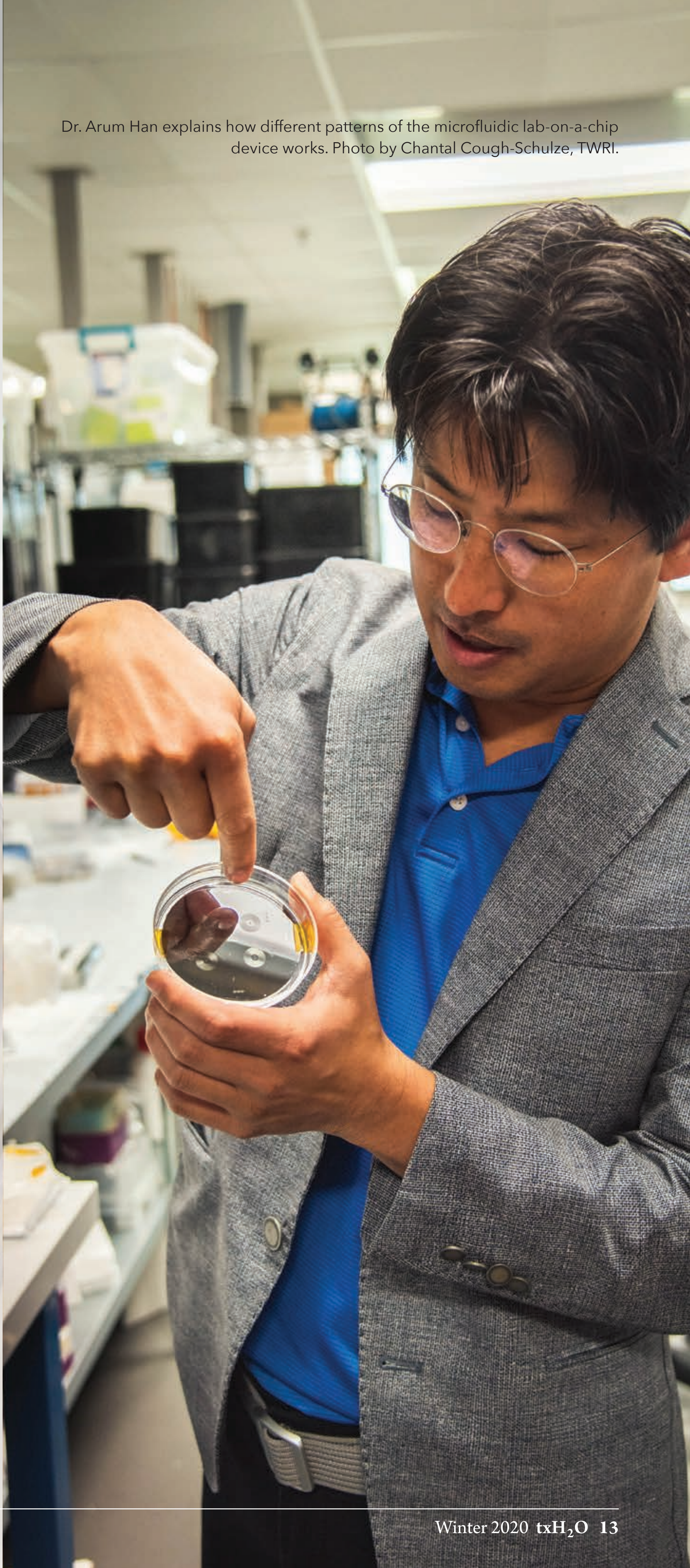
Applying to real-world situations

The group is starting with bacteria from soil samples from an environmental microbiology group from the University of Oklahoma, one of its project partners, but Han said they will eventually apply the technique to water samples.

Other project partners include other researchers from Texas A&M, the University of California San Francisco, the University of Virginia and Argonne National Lab.

Their goal is to have a lot of good data within the first 18 months of the project. "We may not be able to measure everything, but we should be able to measure a good number of characteristics of unknown microorganisms," Han said.

At the end of the project, Han believes the group will have a successful and "first-of-its-kind" proof of concept for the project. ➪



Dr. Arum Han explains how different patterns of the microfluidic lab-on-a-chip device works. Photo by Chantal Cough-Schulze, TWRI.

Micrometer-sized fluidic channels allow millions of single cells to flow through and be controlled very accurately for rapid testing. Photo by Chantal Cough-Schulze, TWRI.

DARPA, probably best known for its groundbreaking work on the precursor to today's internet, funds studies on futuristic research or emerging technologies, or as Han said, "high risk, high reward" projects. DARPA funded projects about 20 years ago, Han said, to develop portable chemical bioweapon detection systems that were eventually used by the military and the U.S. Postal Service.

Han anticipates that once this platform is perfected, it will be developed into a portable pathogen detection system used not only by the military but also the agricultural and food processing industries.

"A portable pathogen detection system, whether that pathogen is known or not, can be highly valuable," Han said.

Samuel agrees such a platform will be valuable and unique.

"The big broad goal of being able to take a soil sample and determine whether there are friends or foes in the sample seems simple conceptually," he said. "But in point of fact, it's way more complicated," adding that it is several orders of magnitude more complicated than what has been done before.

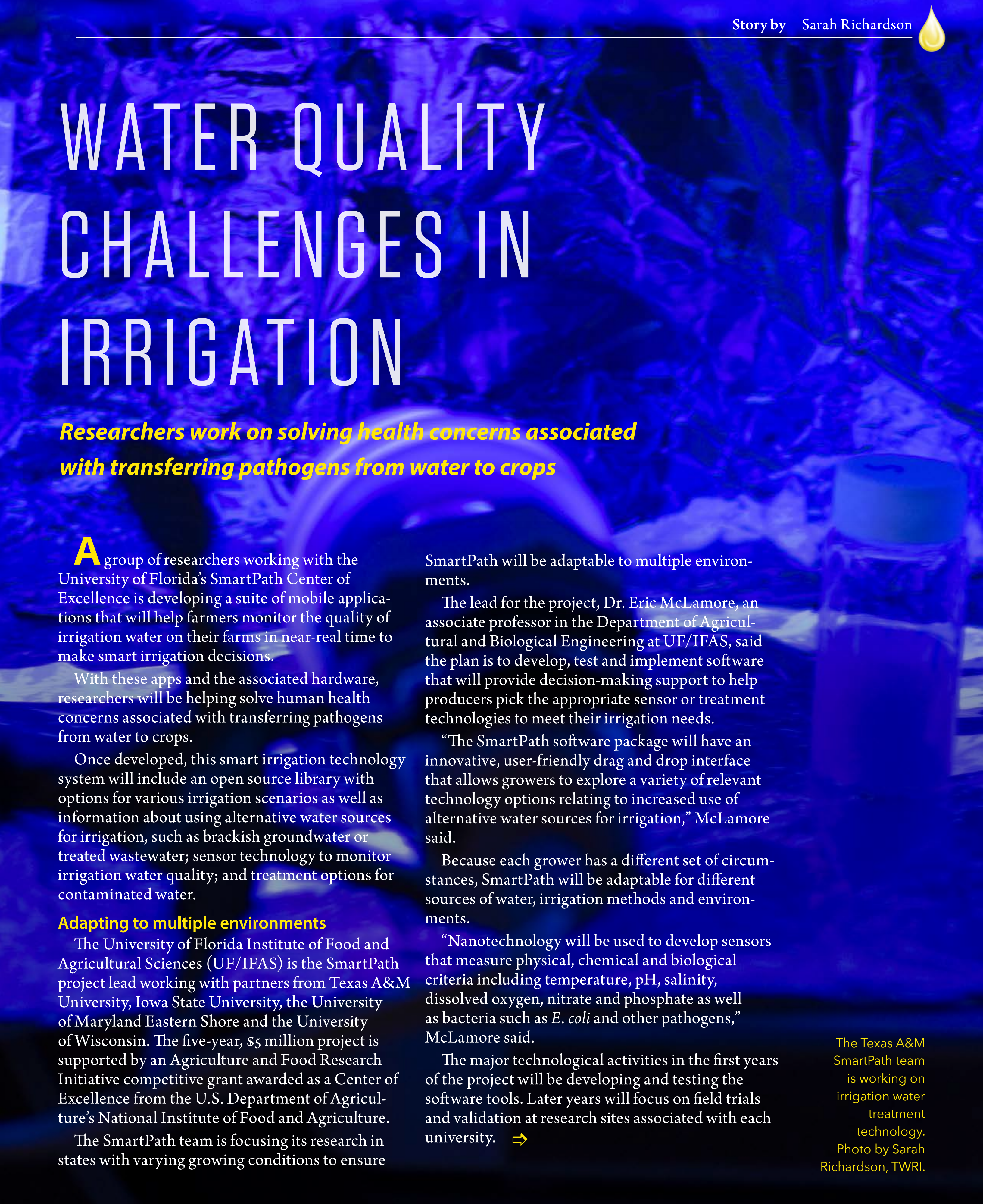
"And if you broke that out into some successful metrics, using, for example, this lab-on-a-chip system, you would be able to significantly advance our ability to remediate many problems inherent in areas of bacterial contamination."

With the lab-on-a-chip device, a series of high-precision cell and liquid assay steps can be integrated together to conduct a complex assay on a single chip. Photo by Chantal Cough-Schulze, TWRI.

Story by Sarah Richardson

WATER QUALITY CHALLENGES IN IRRIGATION

Researchers work on solving health concerns associated with transferring pathogens from water to crops



A group of researchers working with the University of Florida's SmartPath Center of Excellence is developing a suite of mobile applications that will help farmers monitor the quality of irrigation water on their farms in near-real time to make smart irrigation decisions.

With these apps and the associated hardware, researchers will be helping solve human health concerns associated with transferring pathogens from water to crops.

Once developed, this smart irrigation technology system will include an open source library with options for various irrigation scenarios as well as information about using alternative water sources for irrigation, such as brackish groundwater or treated wastewater; sensor technology to monitor irrigation water quality; and treatment options for contaminated water.

Adapting to multiple environments

The University of Florida Institute of Food and Agricultural Sciences (UF/IFAS) is the SmartPath project lead working with partners from Texas A&M University, Iowa State University, the University of Maryland Eastern Shore and the University of Wisconsin. The five-year, $5 million project is supported by an Agriculture and Food Research Initiative competitive grant awarded as a Center of Excellence from the U.S. Department of Agriculture's National Institute of Food and Agriculture.

The SmartPath team is focusing its research in states with varying growing conditions to ensure SmartPath will be adaptable to multiple environments.

The lead for the project, Dr. Eric McLamore, an associate professor in the Department of Agricultural and Biological Engineering at UF/IFAS, said the plan is to develop, test and implement software that will provide decision-making support to help producers pick the appropriate sensor or treatment technologies to meet their irrigation needs.

"The SmartPath software package will have an innovative, user-friendly drag and drop interface that allows growers to explore a variety of relevant technology options relating to increased use of alternative water sources for irrigation," McLamore said.

Because each grower has a different set of circumstances, SmartPath will be adaptable for different sources of water, irrigation methods and environments.

"Nanotechnology will be used to develop sensors that measure physical, chemical and biological criteria including temperature, pH, salinity, dissolved oxygen, nitrate and phosphate as well as bacteria such as *E. coli* and other pathogens," McLamore said.

The major technological activities in the first years of the project will be developing and testing the software tools. Later years will focus on field trials and validation at research sites associated with each university. ⇨

The Texas A&M SmartPath team is working on irrigation water treatment technology. Photo by Sarah Richardson, TWRI.

Niraj Vidwans, a doctoral student under Dr. Sreeram Vaddiraju, SmartPath project lead at Texas A&M University, is working in collaboration with Dr. Terry Gentry to develop irrigation treatment technology. Photo by Sarah Richardson, TWRI.

SmartPath: Sensor and treatment technology

The principal lead of the Texas A&M team is Dr. Sreeram Vaddiraju, associate professor in the Artie McFerrin Department of Chemical Engineering.

Dr. Lucas Gregory, Texas Water Resources Institute senior research scientist and Texas A&M project member, said the SmartPath apps will take growers' irrigation information and give them a list of options for addressing *E. coli* issues on a routine basis.

"Growers will be able to compare sensor and treatment technology from the Cadillac version all the way to the economy car version, depending on their budget," he said.

Gregory said this project hopes to address the regulations stemming from the Food Safety Modernization Act (FSMA), passed in 2011 and implemented by the U.S. Food and Drug Administration. According to the FSMA's Produce Safety Rule, there are science-based standards for the safe growing, harvesting, packing and holding of fruits and vegetables grown for human consumption, and criteria for microbial water quality used for agricultural purposes.

"Growers who are producing crops that are commonly consumed raw have to meet certain water quality standards," Gregory said.

These standards mean that there are maximum thresholds set for *E. coli* in irrigation and other agricultural use water. Gregory said if these thresholds are surpassed, water use must stop, or treatment and management activities are required.

Meeting irrigation water quality standards

Although using alternative sources of water to reduce the use of freshwater is part of the project's goal, for Texas' Lower Rio Grande Valley where Gregory will be working with producers, a large focus will be on testing irrigation water quality, no matter where it comes from.

Gregory said the sensors needed to test irrigation water on a large-scale basis mostly do not exist yet, but the team is developing a suite of sensors to fit different irrigation situations.

"The treatment and sensor technology that you need for groundwater may be very different than the sensor and treatment technology that you need for reclaimed wastewater," he said.

But regardless of the type of water the grower is using for irrigation, Gregory said the goal is for growers to be able to select the sensor and treatment technologies needed through the SmartPath apps, which would send them an alert when a contaminant such as *E. coli* is detected. Likewise, he said the treatment system will also be managed through the apps, allowing growers to turn on the treatment system if they receive an alert that their irrigation water is contaminated.

Currently, growers have to collect samples, drive a long distance to a lab and wait days or weeks for results.

Gregory said using SmartPath will allow growers to monitor their water quality on a real-time or near-real time basis, saving them time and money.

"We're really trying to help growers better manage their systems and get the most out of what they have," Gregory said.

Reducing foodborne pathogen outbreaks

Dr. Terry Gentry, professor in Texas A&M's Department of Soil and Crop Sciences and project member, said the SmartPath apps, once developed and in use, will not only reduce the risk associated with pathogens that contaminate produce, but they will also potentially reduce the magnitude and scale of foodborne pathogen outbreaks.

Gentry said reducing these pathogens from the food supply will increase public health.

"In the Lower Rio Grande Valley, surface water generally has a higher risk (of having pathogens) because there's more potential for fecal material to get in the water," Gentry said. "At the border, one of the big concerns is untreated or inadequately treated sewage getting in the water. Then you have these organisms in water potentially used to irrigate.

"SmartPath is going to put more control back in the producers' hands," he said. "They will have these real-time sensors so they can make management decisions that can, as opposed to dealing with something after the fact, allow them to deal with issues more in real time."

Gentry said SmartPath is only going to become more important in the future, as growers in the United States and other parts of the world don't have enough fresh water for irrigation. In some areas, growers are being pressured to supplement fresh water by combining it with alternative water sources, such as reused water.

"Water reuse is a big deal — and a bigger and bigger deal in the future," Gentry said. "So it becomes even more critical as we start moving toward the reuse of water to test the water. Because the chance of there being an issue increases, the risk potentially increases, so it's even more important that water is tested.

"This technology is desperately needed, and it's going to be more needed 10 years from now, so it's really vital at this time."

Cabbage crop in the Lower Rio Grande Valley in Weslaco, Texas. Photo by Danielle Kalisek, TWRI.

Story by Kathy Wythe

WORKING WONDERS WITH FERRATE

***Virender Sharma's** life mission: Using a natural element to clean water*

Dr. Virender Sharma, professor in the Texas A&M School of Public Health, has spent most of his research life investigating the abilities of a naturally occurring element — iron — to work wonders in cleaning up water and the environment.

By manipulating the chemical composition of iron, Sharma has produced research that demonstrates ferrate, a type of supercharged iron, can be used as a disinfectant and oxidant to inactivate bacteria and viruses and remove antibiotics, pharmaceuticals, toxic metals and other harmful pollutants from water.

Sharma, director of the public health school's Program for the Environment and Sustainability, has conducted research on ferrate for almost 30 years. With more than 320 publications, two patents and eight books authored or edited, Sharma is the most published and cited ferrate researcher in the world and is recognized as the leading expert on ferrate research.

Sharma believes that the use of this simple, abundant and environmentally friendly element can help save lives by providing clean water, and he is passionate about researching and telling others about its properties. That, he says, is his life's mission.

The chemistry of ferrate

Understanding his research takes a brief review of chemistry. Chemical elements have atoms, and each atom is composed of a nucleus that contains neutrons and protons with electrons orbiting the nucleus. Varying the number of protons or electrons changes the composition and properties of the element. If electrons are removed, the element becomes positively charged.

When two electrons are removed from the iron atom, ferrous ion is produced; three removed produces ferric ion. In most of Sharma's research, he has removed six electrons from iron, creating iron(VI), commonly called ferrate.

Dr. Virender Sharma, professor in the Texas A&M School of Public Health and director of the school's Program for the Environment and Sustainability, has conducted research on ferrate for almost 30 years. He is a recognized lead expert on ferrate research. Photo courtesy of Texas A&M School of Public Health.

Because ferrate has lost some of its electrons, Sharma said the ferrate is "hungry for electrons," or looking for another chemical to take electrons from. Ferrate oxidizes, or as Sharma described it, is "tricked" into "taking" electrons away from other chemicals, changing them into inactivated forms or different products, which are not harmful to humans or the environment.

Removing pharmaceuticals from our water supply

Sharma has focused part of his ferrate research on finding ways to remove antibiotics and other pharmaceuticals from the country's water supply because, he said, it is a critical problem.

"It is critical because we produce and consume several billion pharmaceuticals a year in the United States," he said.

About 60% of those pharmaceuticals are not metabolized by the human body and are excreted in urine into the nation's sewage system with many ultimately finding their way into the environment.

While these leftover chemicals can affect the ecological health in rivers and streams, Sharma said they can also potentially affect human health because the water can become a source for drinking water. Of particular concern is antibiotics' ability to potentially create antibiotic-resistant bacteria and genes, one of the biggest problems of the century, according to the World Health Organization.

Sharma said most wastewater treatment plants were not constructed to remove the large amounts of pharmaceuticals found in water today, so they are released into the environment. In addition, chlorine has been used for so long in drinking water treatment systems that bacteria are resisting its disinfection properties.

"We need to find some new ways to treat pharmaceuticals in water as well as solve the problem of antibiotic-resistant bacteria and genes," he said.

In his research, Sharma has shown that ferrate is able to help solve these problems.

"A wide range of micropollutants, such as endocrine disruptors, antibiotics, beta-blockers, antidepressants and cosmetic products commonly found in drinking water resources and wastewater effluents, can be efficiently oxidized by ferrate on a seconds-to-minutes time scale," Sharma said.

Ferrate's newest uses

In yet another refinement of his ferrate research, Sharma has modified the chemistry of ferrate to create activated ferrate, which makes it more reactive with other pollutants or chemicals. This activated ferrate not only increases how rapidly it can remove pharmaceuticals and other organic pollutants but also increases the percent of pollutants removed from water.

Sharma is passionate about seeing ferrate used as a disinfectant in drinking water and hospitals, to eliminate emerging contaminants and reduce disinfection byproducts in water treatment. Photo courtesy of Texas A&M School of Public Health.

Other promising discoveries include the possibility of using ferrate to remove pharmaceuticals in urine.

Sharma said urine contains high concentrations of ammonia, chloride and bicarbonate, which may hinder the wastewater treatment process. While other oxidants react with these constituents, the environmentally friendly oxidant ferrate doesn't react much with them, which makes ferrate free to attack the pharmaceuticals in the urine.

The research also found that the bicarbonate ion, which occurs naturally in water, actually enhances, instead of hinders, ferrate's degradation of some pharmaceuticals.

Degrading pharmaceuticals in urine, Sharma said, would be an efficient way to reduce the harm of pharmaceuticals excreted to the environment.

"Also, to the best of our knowledge, the finding of the bicarbonate enhancement effect during ferrate oxidation is among the first (research to identify and analyze this relationship)," he said.

Sharma has also found that if the six electrons get converted to three electrons in ferrate, it allows the ferrate to remove toxic metals, such as arsenic, present in the water.

Using ferrate to manage disinfection by products

Sharma is also investigating the use of ferrate to manage disinfection byproducts (DBPs) during drinking water treatment.

Disinfectants commonly used by municipal water utilities to purify drinking water — chlorine, chloramine and ozone — can react with inorganic and organic chemicals to produce potentially harmful DBPs. The U.S. Environmental Protection Agency regulates 10 DBPs, including trihalomethanes (THMs) and haloacetic acids (HAAs), though there are thousands of DBPs. Research indicates that DBPs can cause serious health risks to humans, including being linked to bladder cancer and liver, kidney and central nervous system problems.

In its role as a disinfectant, Sharma said, ferrate makes the water less toxic because it minimizes the formation of DBPs.

Transferring to real applications

Before Sharma could use his supercharged iron in real-world applications, he had to stabilize the laboratory ferrate, which is generally solid. Sharma worked for years to develop stable liquid ferrate, and Sharma and Texas A&M University were recently granted a U.S. patent for this liquid ferrate.

Through a National Science Foundation Innovation Corps program grant, Sharma explored the feasibility of using liquid ferrate as a spray disinfectant on hospital surfaces. He is now working with a private company to bring it to the market.

He believes applications in other areas could become a reality in the near future. Sharma is also working with a company to test the use of ferrate to remove organic phosphate in water, which contributes to algal growth.

His path to ferrate research

His path to ferrate research began in a roundabout way. While conducting his doctorate work at the Rosenstiel School of Marine and Atmospheric Sciences at the University of Miami, he studied the chemistry of the ocean. With research supported by a national funding agency, he investigated the interactions between metals in the ocean.

He completed a postdoctorate at Brookhaven National Laboratory, where he began looking at chemical reactions in the human body.

While a faculty member at Texas A&M University-Corpus Christi from 1992 to 1999, Sharma said he realized that he was more interested in becoming an environmental chemist. He decided to study ferrate outside the human body. He served on the faculty of the Florida Institute of Technology from 1999 to 2013 and came to Texas A&M in 2014.

For his years of pioneering work on ferrate, Sharma has accumulated a long list of accomplishments. He is a Fellow of the Royal Society of Chemistry and was named 2019's Outstanding Distinguished Scientist by Sigma Xi, Texas A&M's research honor society. He has received the Certificate of Merit Award from the Division of Environmental Chemistry of the American Chemical Society and a President's International Fellowship awarded by the Chinese Academy of Sciences. He is among the highest cited researchers in the field of environmental science.

With all the articles published, conferences spoken at and students taught, Sharma is passionate about seeing ferrate used as a disinfectant in drinking water treatment and hospitals and to eliminate emerging contaminants and reduce DBPs in water treatment as well as other applications.

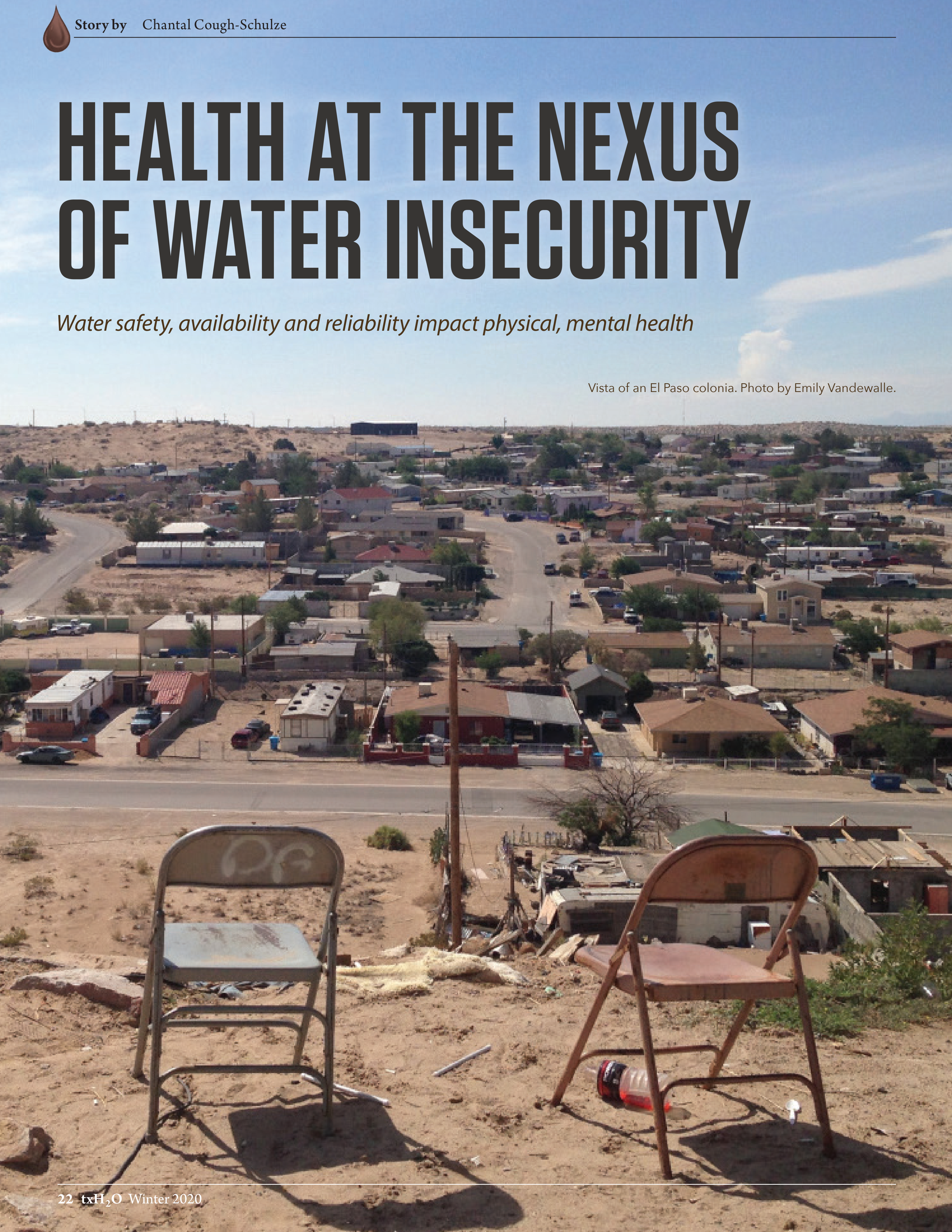
"I want to see real application," he said. "I made it a mission of my life now. I wake up every day, saying 'saving lives, even one life, is my mission.'"

To read more detailed articles of Sharma's research, visit: https://vitalrecord.tamhsc.edu/faculty/virender-sharma/.

Story by Chantal Cough-Schulze

HEALTH AT THE NEXUS OF WATER INSECURITY

Water safety, availability and reliability impact physical, mental health



Vista of an El Paso colonia. Photo by Emily Vandewalle.

Just outside of El Paso, families pay steep prices for trucked-in water to lug home in the Cochran colonia. Cochran is one of 2,300 Texas colonias, which are rural or peri-urban subdivisions along the U.S.-Mexico border that are home to an estimated half a million people. Colonias generally lack the support or resources to connect to nearby water mains. While the average American uses 88 gallons of potable water per day, Cochran colonia residents use a mere 50 to 100 gallons per month.

The colonias' water insecurity was chronicled in a recent report, titled "Closing the Water Access Gap in the United States," from two water-focused nonprofits, DigDeep and the U.S. Water Alliance. According to the report, more than two million people in the United States do not have running water and basic indoor plumbing. All of that water insecurity can have numerous far-reaching health consequences.

Defining water insecurity

People often don't think of water insecurity being a problem in the United States, said Dr. Wendy Jepson, University Professor in Texas A&M University's Department of Geography. As a result, the water insecurity that does exist can get swept under the rug, she said.

"It's not to say that our entire water system has problems. When it works, it works well. But when it doesn't work — yikes," Jepson said.

This misunderstanding of U.S. water insecurity partly results from how people conceptualize water insecurity, said Dr. Garett Sansom, research assistant professor in the Department of Environmental and Occupational Health at the Texas A&M School of Public Health.

"If people think of water insecurity as turning on the faucet and having no water come out, then by that definition, we're not very water insecure in the United States," he said.

But the definition of water insecurity is actually much more complicated, Jepson said.

Jepson, who studies water governance, water security and environmental justice around the world, defines water security as being able to engage with and benefit from the "hydrosocial processes that support human development and well-being." Being water secure, she said, means not only having water come out of the faucet but also having water that is safe, sufficient, affordable and reliable.

Water insecurity in Texas

With a more holistic definition of water insecurity, Sansom said, it is clear that Texas is at the nexus of water insecurity issues in the United States.

"We have evidence that there are pollutants in Texas water systems, including 'forever chemicals' linked to public health issues," Sansom said. "There are issues with older infrastructure and a water purification process that can leach metals out of that older infrastructure. And Texas is at risk of not having enough water to meet the needs of the rising population in the future because of drought and climate change. Moving forward, it's all just going to be more of an issue."

According to the Texas Water Development Board's most recent state water plan in 2017, Texas' existing water sources that can be relied on in the event of another drought of record are expected to decrease by 11% between 2020 and 2070. Over that same time, Texas' population is expected to increase by more than 70%.

Different parts of Texas face different water insecurity issues, and some communities are more heavily impacted than others. The "Closing the Water Access Gap in the United States" report found that in Texas, Latino people are most likely to lack complete plumbing, a measure used to estimate water insecurity.

In Texas' colonias, where the majority of the population is Latino and makes less than half the U.S. median income level, water insecurity issues are a result of a lack of infrastructure and city services. Colonias are often in "donut holes" between other municipalities and utility districts and connecting to water systems can be prohibitively expensive. This results in colonia residents having to rely entirely on expensive trucked-in water and unmonitored private wells. Occasionally, residents will create makeshift water hookups, which can contaminate the source water, adding another layer of water insecurity.

The colonias, Jepson said, are far from alone in being water insecure in Texas.

Kelli Condina, a graduate student in the Texas A&M School of Public Health, studies water insecurity in the Greater Houston area. There, Condina found that the unusually large number of small, fragmented water systems contribute to water insecurity, and that having a low income level was the strongest predictor of being water insecure.

Small water systems are at a disadvantage compared to larger, consolidated water systems, Condina said, because they have fewer resources for improving infrastructure and hiring and keeping qualified staff. Sometimes, providing utilities may ⇨

be the systems' secondary business, such as with mobile home parks. Combined, these factors mean that water utilities may be less reliable and have higher violation levels, she said.

Water quality also comes into play in the Houston area, said Sansom, who is the Health and Environment Discovery lead at Texas A&M's Institute for Sustainable Communities.

Sansom conducted a pilot study on lead levels in the low-income southeast Houston neighborhood of Manchester, along with the institute, Texas Environmental Justice Advocacy Services and a research team from the Texas A&M School of Public Health, College of Architecture and College of Geosciences. The team found that 30% of homes in the neighborhood had lead in their water. Though all the surveyed homes had lead levels below EPA's actionable levels, the levels were still above the water standard goal of zero. (See Lead in Texas Water? page 26; Protecting Drinking Water, page 8.)

Jepson said these issues of water access, affordability, reliability and quality are repeated across Texas.

"Private wells, small systems and communities that are disadvantaged are at higher risk," she said.

And the burden of water insecurity as well as exposure to environmental pollutants such as lead, Sansom said, tend to fall on those who are already the most vulnerable.

"Barriers to water security fall along similar lines as barriers to other resources," Jepson said. "Wherever you have more precarious populations, there's likely to be water insecurity."

What water insecurity means for health

Whatever the cause, water insecurity can have a variety of health impacts. Having insufficient water can lead to dehydration and, eventually, to developmental issues. Drinking contaminated water can potentially lead to, among other things, gastrointestinal diseases and neurological impairments.

However, those conditions account for only some of water insecurity's health impacts. Jepson and Sansom both said not having access to safe, reliable, affordable water can also negatively impact people's mental health.

"If people's water is unsafe or unreliable, they have this constant fear, this thing they're thinking about all the time that they really shouldn't have to think about," Sansom said. "Over and over again I hear people saying they're worried about their families."

That constant stress can have long-term effects, Jepson said, such as high blood pressure, increased risk of cardiovascular disease and compromised immune function.

Water insecurity also leads people to adapt to their circumstances — and those adaptations can also have long-term health impacts.

"There are tradeoffs. When water is cut off, people may buy bottled water, because it's cheaper in the short term than hooking up the water again," Jepson said. "But over time, it's the most expensive water you can buy, leaving less money for other health-related things."

If water is too expensive or unreliable, people may buy more soda, she said, which can have long-term impacts on dental health and diabetes risk. People may also switch to eating foods that require less water to make, which "can have deleterious impacts on nutrition," Jepson said.

All of these health impacts, she said, can feed back into each other.

"I wouldn't want to separate mental health or other factors as stand-alone categories of health impacts," Jepson said. "They're all interconnected in complex ways. We need to identify what those pathways and connections are."

Gathering more data

Identifying and studying the pathways of water insecurity in the United States can be difficult, Sansom said, because much of the past research has focused elsewhere.

"We're only beginning to realize the scope of the issue here in the United States," he said. "So there needs to be more research."

But, Jepson said, knowing where the data isn't sufficient is also important. It demonstrates the need for new ways of thinking about and measuring water insecurity, she said.

In the past, measuring water insecurity has focused on water access. It has often been estimated using census measures such as median income level and complete plumbing, as in the "Closing the Water Access Gap in the United States" report.

Jepson said those measures don't always provide an accurate or complete assessment of water insecurity. The report acknowledges this, stating that complete plumbing does not include whether that plumbing functions well or is reliable and affordable. The accuracy of both measures can also vary based on the assessment location, Condina said.

"If there's a large income disparity in a community, then median income level isn't going to be that helpful for finding water insecurity," Condina said.

Colonias generally lack the support or resources to connect to nearby water mains and therefore rely on expensive trucked-in water and water vending machines like this one in Hidalgo County. Photos by Dr. Wendy Jepson (L) and Emily Vandewalle (R).

To better assess water insecurity across the world, Jepson and her colleagues developed a cross-cultural metric called the Household Water Insecurity Experiences (HWISE) Scale.

The HWISE Scale is based on 8,000 households-worth of data from 23 countries. At 12 questions long, it takes a mere three to five minutes to complete. Since its creation, the HWISE Scale has been adopted by organizations including the United Nations Educational, Scientific and Cultural Organization (UNESCO), United States Agency for International Development and the nonprofit group Oxfam International. By taking into account cultural and ecological differences between assessment locations, the HWISE Scale works in an equivalent way across low- and middle-income countries. Jepson is currently developing research to create a comparable scale for higher income countries, which could be used to study water insecurity in Texas.

"The HWISE Scale assesses water access, reliability, affordability, quality and perception," Jepson said. "It helps us understand the cascading relationships of water insecurity and its contributing factors."

Data gathered using the HWISE Scale can be used to inform policy decisions on investments and interventions to improve water security, Jepson said.

With more data, such as from the HWISE Scale and research like Jepson's, Sansom's and Condina's, it will be more possible to see, study and address the health impacts of water insecurity across the United States.

The human right to water

Moving from measuring water insecurity to reducing it and its health impacts will require a broader change toward a belief that "everyone has the right to water, not just the majority," Jepson said.

"If we don't follow the principle of the human right to water, the studies about who is highest risk mean nothing, and we can only chip away at the problem," she said. "How do we ensure water security in a universal way that is not predicted by your economic status or race or neighborhood?"

If even a small number of people don't have access to safe, affordable, reliable water, Jepson said, that's too many people. The health impacts of water insecurity, from stress-induced high blood pressure to gastrointestinal disease, are universal — so the mitigation work should also be universal, she said.

"Water insecurity is a health crisis. It doesn't matter whether you are in another country, the colonias or Houston. Problems with water insecurity — access, quality, reliability, affordability — have documented impacts on mental and physical health," Jepson said. "So we need to find and help those who are not water secure."

Story by Kathy Wythe

LEAD IN TEXAS WATER?

Texas A&M researchers studying lead in Houston neighborhood's drinking water

Using a water filter pitcher or installing a water filter as part of the kitchen faucet will usually remove any lead. Photo by Shutterstock.

Most people have heard about the infamous Flint, Michigan water crisis where lead leached into the drinking water pipes of some homes after the city's water utility switched water supplies.

Not only did the utility switch where it got its water, but it also changed the disinfectant it was using to purify the water. The disinfectant — chloramine, a group of compounds containing chlorine and ammonia — is used extensively throughout the United States to rid cities' drinking water of infectious waterborne diseases. But as good as it is at killing harmful organisms, if used without an anti-corrosive agent, chloramine can also cause older pipes to corrode, releasing lead, iron and other metals into the drinking water system.

Lead in Texas water?

The lead found in the water of Flint homes was noteworthy because lead, even at low exposure levels, is harmful to human health. According to the U.S. Environmental Protection Agency (EPA), low levels of lead exposure in children have been linked to damages of the central and peripheral nervous system, learning disabilities, shorter stature, impaired hearing and impaired formation and function of blood cells. Although drinking water is not the main source of lead poisoning, lead in water can contribute to the overall levels in a person's body.

EPA's maximum contaminant level goal for lead in drinking water is zero. Its actionable or enforceable level is 15 parts per billion, meaning that drinking water at that level or above requires the utility to make adjustments to reduce the amount of lead. (See Protecting Drinking Water, page 8.)

Not enough studies have been done to know the extent of lead in Texas drinking water, according to Dr. Garett Sansom, research assistant professor in the Department of Environmental and Occupational Health at the Texas A&M School of Public Health.

"It's not as bad as Flint, Michigan, that we know," he said. "But there's not a lot of at-point sampling being done within older homes," which is where lead would be expected to be detected.

Lead pipes are most likely in homes built before 1988. Congress passed a law in 1986 requiring that all drinking water plumbing materials contain no more than 8% lead; the allowable percent has since been reduced to 0.25%.

Discovering lead in homes in a southeast Houston neighborhood

An analogous set of conditions to Flint — older pipe infrastructure and the use of chloramine by Houston to disinfect its drinking water — offered an opportunity for a group of Texas A&M University researchers and others to look at the possibility of lead in the southeast Houston neighborhood of Manchester.

Manchester is one of several low-income neighborhoods along the Houston Ship Channel that researchers within Texas A&M's Institute for Sustainable Communities and Superfund Research Center operate within.

The institute, of which Sansom is the Health and Environment Discovery lead, along with the Texas Environmental Justice Advocacy Services and a research team from the Texas A&M School of Public Health, College of Architecture and College of Geosciences conducted a small pilot study to test for elevated levels of lead in the water of Manchester homes.

The team learned of resident's concern about possible lead in their drinking water because of the ongoing partnerships with these communities. "They're the ones who came to us with the concern," Sansom said.

He said they conducted surveys with 13 residents and collected tap water samples from 22 homes in Manchester. The team found that 30% of the homes had lead in their water, ranging from 0.6 to 2.4 parts per billion. The levels were all below EPA's actionable level of 15 parts per billion, but above the water standard goal of zero.

Of the 13 surveyed residents, Sansom said, about 31% had expressed concerns about their water before the tests; of those, 75% actually did have lead in their water.

Now, Sansom said, the team is expanding the study to survey about 1,000 homes along the Houston Ship Channel in part through support by the National Institute of Environmental Health Sciences of the National Institutes of Health's Superfund Research Program.

Addressing the problem

The Flint crisis increased the attention of the possibility of lead in drinking water, and both governmental entities and researchers are examining ways to better monitor and solve the problem.

EPA recently announced proposed updates to its lead and copper rule that will change how communities test for lead in drinking water.

In EPA's announcement news release, EPA Administrator Andrew Wheeler said the updates will improve protocols for identifying lead, expand sampling and strengthen treatment requirements.

While public water utilities can replace their lead service lines, Sansom said it is very expensive to retrofit an older home that might have lead pipes. The best option, he said, would be to have a program similar to government-led paint abatement programs, which provide funds to homeowners to cover the costs of replacing lead paint in older homes. The U.S. Department of Housing and Urban Development recently granted $28 million to 38 public housing agencies, including the Bryan (Texas) Housing Authority, to test and remove identified lead paint in its public housing.

"It'd be nice if the lead abatement program could be expanded upon and also include homes with older piping," Sansom said.

Getting the lead out of your water

While retrofitting homes and replacing the service lines leading up to the homes are very expensive, Sansom said there are simple things homeowners can do to help remove lead in their water. Using a water filter pitcher or installing a water filter as part of the kitchen faucet will usually remove any lead. Also, he said, turning on the water and letting the faucet run for a few minutes, will cause most of the lead to flow out of the in-home pipes.

Other recommendations, from EPA, include:

- Use cold water for drinking, cooking and making baby formula. Boiling water does not remove lead from it.
- Clean your faucet's screen (also known as an aerator) regularly.
- Consider using a water filter certified to remove lead and know when it's time to replace the filter.
- Flush pipes before drinking water by running the tap, taking a shower or doing laundry or a load of dishes.
- Contact your municipal water system to learn more about sources of lead and removing lead service lines.

Story by Chantal Cough-Schulze

PROTECTING OUR WATER

Institute works with partners to improve water quality in East Texas

Dr. Lucas Gregory grew up playing in the woods and streams of East Texas. He'd bring baby alligators home, putting them in the bathtub and gleefully showing his mother before returning them to the stream. He'd spend hours out in the woods — and sometimes, he'd get thirsty.

"I distinctly remember drinking water out of a pond, watching a cow drinking out of the other side of the pond, and she was peeing in the pond at the same time," Gregory said. "And I was hot and thirsty, my house was two miles away, and I just didn't care. So we both just kept drinking."

Gregory didn't get sick from drinking the water, but the memory stuck with him. He's now a senior research scientist at Texas Water Resources Institute (TWRI), where he works on understanding the drivers of changing surface water quality and restoring impaired waters not unlike the pond he drank from as a child.

East Texas is one of the major geographic areas where Gregory and others from TWRI work to improve water quality. Across East Texas, 32 water bodies are listed on the 303(d) list as impaired because of bacteria levels. The 303(d) list, which is named for the relevant section of the Clean Water Act, is the list of impaired water bodies in a state. According to the Clean Water Act, the pollutants in the water bodies must be identified, and the state is required to take actions to improve them, such as creating a watershed protection plan (WPP).

In recent years, Gregory and TWRI's work has been paying off. The water quality for East Texas' Attoyac Bayou watershed — not far from where Gregory grew up — has been improving, thanks to management strategies included in a 2014 WPP developed by the Attoyac Bayou Watershed Partnership, with assistance from TWRI, Angelina & Neches River Authority (ANRA), Stephen F. Austin State University (SFA), Castilaw Environmental Services, LLC, Texas A&M AgriLife Extension Service and Texas A&M AgriLife Research.

The Attoyac Bayou watershed makes up the northern part of the Lower Angelina River sub-basin, which is in turn part of the larger Neches River Basin. The watershed is nestled in rural pine forests, spanning an over 350,000-acre area from the 440-person town of Mt. Enterprise to Sam Rayburn Reservoir, a popular bass tournament destination. The watershed has long been home to agriculture, forestry and, more recently, oil and natural gas production. At the time the WPP was developed, approximately 13,275 people lived in the Attoyac

Bayou watershed, along with an estimated 23,646 cattle and 10,155 feral hogs.

In the late 1990s, the Attoyac Bayou watershed was found to have levels of *E. coli* higher than Texas' water quality standard for water bodies designated as usable for recreation. By the early 2000s, the bayou was listed on the 303(d) list as impaired because of its high *E. coli* levels.

The *E. coli* itself is not necessarily dangerous — the strain of *E. coli* that researchers like Gregory monitor in the Attoyac Bayou watershed is not harmful to humans. It occurs naturally in the gut system of "everything with hair, fur and feathers," Gregory said, and then it is excreted by those animals.

But the *E. coli* serves as an indicator bacteria: Its presence indicates that there's fecal waste in the water. That fecal waste can contain all sorts of nastier pathogens, such as norovirus and the parasites giardia and cryptosporidium, all of which cause a spectrum of highly contagious gastrointestinal illnesses. Knowing the concentration of *E. coli* in the water allows researchers to statistically estimate the risk of someone engaged in primary contact recreation, such as swimming, contracting a gastrointestinal illness.

Looking at the water, it's hard to tell there's a problem, said Jeremiah Poling, ANRA's information resources manager. ANRA has been monitoring the bayou for over 20 years.

"The issues that we have in the watershed are not visible. There could be raw sewage, and you wouldn't know from looking at the water. And it's diluted enough that you're not going to smell it," Poling said. "You don't see it until you pull it up on a lab test or until you drink some of the water and it causes gastric distress."

To establish the concentration of *E. coli* and determine the water quality in a water body, researchers do routine monitoring. In the Attoyac Bayou watershed, that monitoring is done by researchers from ANRA and SFA. The monitoring team collects data about water flow, temperature, pH and amount of dissolved oxygen, and they bottle samples of water to bring back to the lab.

"With routine monitoring, we're essentially establishing a baseline for the water body. We're not trying to find pollution, but sometimes we do," Poling said.

In the lab, researchers test for everything from chemical compounds, such as ammonia and chloride, to bacteria, such as *E. coli*. During the development of the WPP, they also compared some ⇨

The water quality for the Attoyac Bayou watershed has been improving, thanks to management strategies included in a 2014 watershed protection plan. Photo by Ed Rhodes, TWRI.

of the *E. coli* found to existing samples so the source of the *E. coli* could be identified. This comparison and identification process is called bacterial source tracking, said TWRI research assistant Anna Gitter.

"We get fecal samples in the field and identify the DNA 'fingerprints' of the *E. coli*. We collect water samples and do the same thing," Gitter said. "Then we compare fingerprints and see what sources of *E. coli* are in the water bodies."

The sources of *E. coli* tell a story of the area, the kinds of pollution and the impacts they might have on people living nearby. The Attoyac Bayou watershed is wooded and rural, so wildlife — both native species and nonnative species — are a major contributor. The bayou has more cattle than people; livestock logically make up a good portion of the pollution. People in the area also contribute a great deal of pollution, often via failing septic systems.

Gregory said some sources were easier to address in the Attoyac Bayou Watershed Protection Plan than others were. To address pollution from livestock, the WPP recommends developing water quality management plans for farms and ranches. These voluntary plans — with a small financial incentive — help stakeholders make property-specific improvements to their land, such as increasing livestock's access to water other than the creeks and creating cross fencing to allow for improved rotational grazing management. Both practices decrease the amount of time livestock spend in or near impaired water bodies, resulting in less livestock waste finding its way downstream.

Though wildlife account for a large portion of the *E. coli* found in the bayou, barring them from the water was unrealistic.

"Wildlife are wild — you can't just put up a fence and make the squirrels stay out. They just don't play by the same rules," Gregory said.

He said one wildlife pollution source that the watershed team could address — marginally at least — was feral hogs. Invasive feral hogs, of which there are an estimated 10,155 in the Attoyac Bayou watershed, wallow in and near creeks to cool themselves down, allowing their fecal waste to get into the water. With East Texas' tree cover, feral hogs have many places to hide, making mass removal efforts difficult, said Dr. Matthew McBroom, a professor of hydrology at SFA who has worked on East Texas water issues for nearly 25 years.

"There's no one magic bullet for managing feral hogs," McBroom said, but limiting food resources can help keep the population under control. In 2011, AgriLife Extension scientists found that constructing a particular kind of 28-inch high fence effectively excluded feral hogs from accessing deer feeders, which are an important source of food.

In addition, pollution from humans, Gregory said, was one of the most important sources to address.

"What is most likely to harm you as a human is something from a human," he said. "That virus, protozoa or bacterium is adapted to the human system.

"Pollution from humans is something we caused in the first place. But it's something that we can manage fairly easily."

According to local stakeholders, the biggest human-caused pollution source in the Attoyac Bayou watershed is failing or nonexistent septic systems.

"When a septic system fails, there's basically no treatment of the sewage coming out of the house. In the worst-case scenario, there might just be a pipe running out the back of the house into the creek, which is illegal," Gregory said. "That's a direct deposition of *E. coli* going right into the water."

Several factors contribute to those septic system failures. Maintenance can be an issue; septic systems are not a "put it in the ground and leave it thing," Gregory said. Many of the systems are 50-60 years old, so in some cases, they've just outlived their workable lifespan.

The older septic systems also process wastewater differently. Most older systems are conventional systems, which are distinct from newer, aerobic systems. Conventional septic systems work by pushing wastewater into a drain field and "letting microbes in the dirt deal with it," Poling said. But that relies on the soil being permeable enough for the wastewater to percolate through — which many East Texas soils are not.

"If the soil is really dense, wastewater can't be readily absorbed, and it never really gets treated. The untreated wastewater just bubbles up to the surface somewhere and may drain into the creek," Poling said.

To address the septic system problems, ANRA and TWRI started a program to repair and replace failing septic systems. This often involves putting in aerobic septic systems, which work better in East Texas soils. Aerobic septic systems treat waste in a series of tanks, and the treated wastewater is then sprayed out onto vegetation and absorbed into the soil.

Though aerobic systems are better for the area, Poling said they're also more expensive to put in. Many residents of the Attoyac Bayou watershed are low-income, so septic system repairs and replacements are funded by Texas Commission on Environmental Quality (TCEQ) through a Clean Water Act Section 319 grant from the U.S. Environmental Protection Agency and Supplemental Environmental Projects funds from TCEQ.

"You can knock on the door almost anywhere in the watershed and just say, 'Hey, is your septic system

working?' The answer is probably going to be 'Well, kind of.' And if you ask if they can afford to fix it, the answer is going to be no," Poling said. "That's what makes these grant projects so appealing."

The management strategies in the WPP are working: In the five years since the plan was published, the amount of pollution has begun to decrease. As of the 2016 303(d) list, *E. coli* concentrations in the lower portion of the Attoyac Bayou watershed dipped below the maximum allowed amount for the first time since it was added to the list. Concentrations in other parts of the bayou are also decreasing.

That decrease, Gregory said, is thanks to not only the implementation of good management strategies, but also to community involvement. Without the community's go-ahead, good management strategies might never have gotten off the ground.

"The big difference from before the watershed protection plan is that we've got a stakeholder group that's come together, talked about local issues and solutions and worked towards implementing those solutions," Gregory said.

But early conversations with stakeholders didn't always go smoothly. Some stakeholders were worried that decisions would be made for them without their input. At an early stakeholder meeting with a large panel of scientists, McBroom recalled a local man standing up and expressing many people's fears.

"The man said, 'You're going to be making some cooking here that you don't have to eat. You're going to make these rules, but we're the ones who have to live with them. Where's your skin in the game?'"

McBroom, whose family has lived in the Attoyac Bayou watershed for roughly the past 100 years, sympathized. He was working on the WPP because he had skin in the game, he told the man. And local involvement, he said, is what would make all the difference.

"Ninety-five percent of Texas is privately owned. If you're going to make a difference on water quality, then you've got to start with the private landowners," McBroom said. "The best way to do that is to have local people at the table making local decisions. And that's what a watershed protection plan does."

The changes being made in the Attoyac Bayou watershed have impacts beyond just the bayou, he said, both in terms of the environment and economics.

"It's always cheaper to prevent pollution than to clean it up after the fact, so by being proactive, we end up saving money," McBroom said. "People own land here because they love the land. They could sell it and live in a condo in Houston, but they don't, because they love the land. We have the opportunity to do good here in East Texas by improving water quality."

Seeing some successes also helped inspire other stakeholders.

"After we replaced maybe 12 septic systems, word started to get out, and we would have residents from three or four houses on one street all coming forward ⇨

Stephen F. Austin State University students working with Dr. Matthew McBroom collect water samples in the Attoyac Bayou watershed. Photo by Chantal Cough-Schulze, TWRI.

saying, 'This system has been in the ground for 30 years, and it's really not working right,'" Poling said.

As of February 2020, TWRI and ANRA have repaired or replaced 49 failing septic systems in the Attoyac Bayou watershed, and they've secured funding for another 15 more. There's now a waiting list for people who want their septic systems replaced, and a series of education and outreach programs about septic system maintenance are being held, Gregory said.

The work in the Attoyac Bayou watershed has provided a successful model for improving water quality and has paved the way for similar work in other East Texas watersheds, such as in La Nana Bayou and the middle and lower Neches River basins.

Even with all the changes, Gregory said there's no way to absolutely ensure that water bodies like those in the Attoyac Bayou watershed will stay off the 303(d) list forever. So the work to improve and maintain water quality must be ongoing.

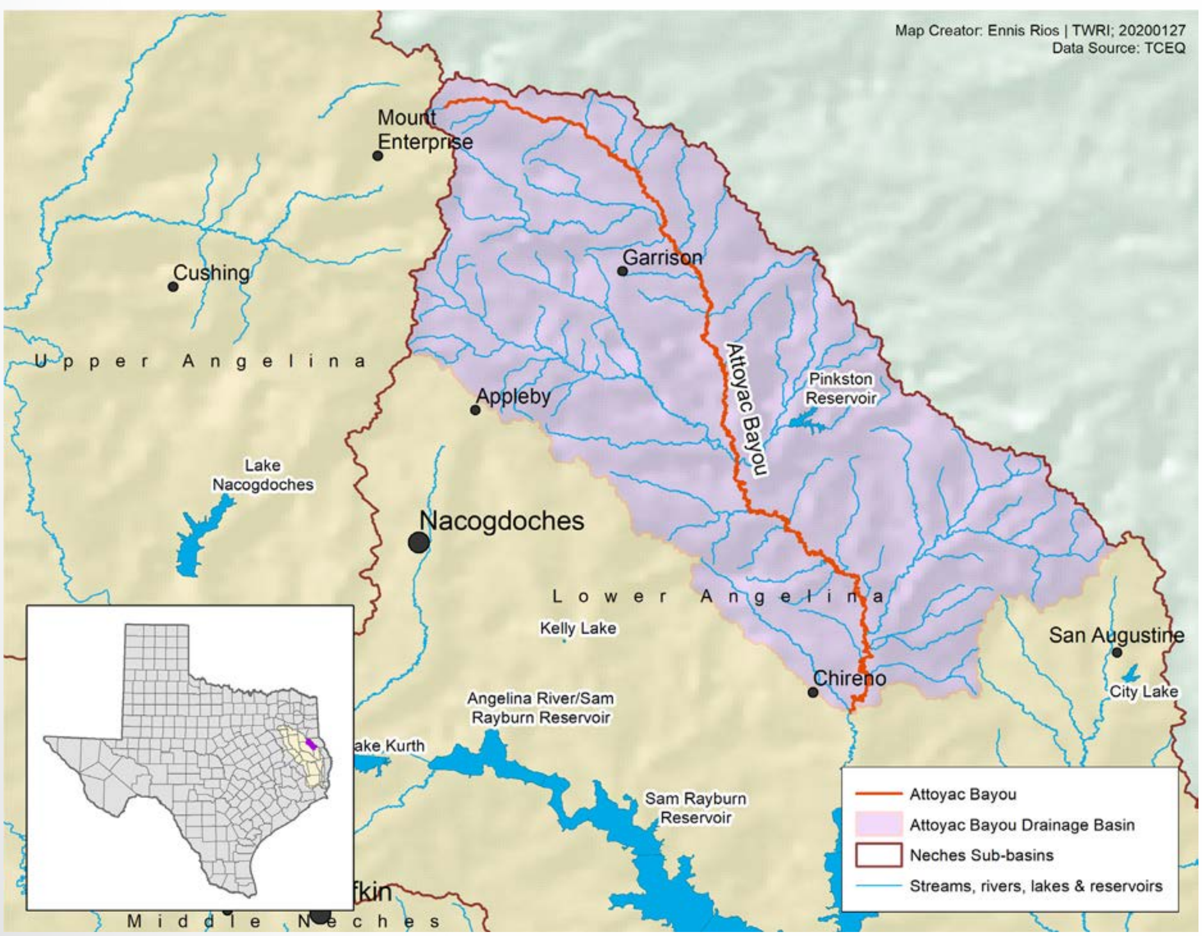
"There are too many variables, and there's so much out there you don't see. Just because this one part of the watershed has improved, it doesn't mean we should stop by any means," Gregory said. "But we're moving in the right direction."

Those steps in the right direction matter, Gregory said. There will always be more children playing in the woods and water just like he used to.

"You can't keep kids out of water; they are drawn to it, almost magnetically. They're much more likely to slip into or take a drink of nasty water," Gregory said. "So we'll keep working with stakeholders to improve the landscape and water quality for today and tomorrow."

Protecting the water for future generations of stakeholders is part of what motivates McBroom as well. When he was growing up in East Texas, he used to play in a creek not far from an old, silted-in water wheel from a defunct grist mill.

"I remember looking at the water wheel and thinking, wow, people have been here for what seemed to me like forever. We've got a history here, and we're a part of it," he said. "When I have grandkids, the Attoyac will still be here. And our job is to be good stewards of it."



The Attoyac Bayou watershed, in purple, is home to approximately 13,275 people, along with 23,646 cattle and 10,155 feral hogs, as of 2014. Map by Ennis Rios, TWRI.

KATHY WYTHE'S TWRI WATER FOOTPRINT

Kathy Wythe, TWRI communications manager for nearly 15 years, retired January 31, 2020. In light of her retirement, her TWRI colleagues wanted to pay tribute to her and her work.

For a little over four years now, I have been fortunate to work with so many talented and dedicated people. I quickly realized that TWRI is a very cohesive organization, which only happens by having people who serve as "glue" to bind together TWRI's wide range of people and programs. Kathy is definitely the super glue for TWRI; she touches everyone and helps them see how their work is linked to TWRI's mission and why it is important to the citizens of Texas. The culture Kathy helped create here will live on long into the future. ~ **John C. Tracy, director**

Kathy has been a fixture in the TWRI office since I began 11 years ago. By working with Kathy, I have gained valuable experience. **~ Allen Berthold, senior research scientist**

Since I started at TWRI as an intern, Kathy has guided, challenged and trusted me, in turn helping me to trust and challenge myself. She gave me the freedom to follow my ideas down rabbit holes and helped pull me out when I went down the wrong one. I'm grateful for the lessons, brainstorming sessions, laughs and new dance steps. I could not have asked for a better mentor to introduce me to science communication in the real world. ~ **Chantal Cough-Schulze, communications specialist II**

Kathy has been such an integral part of the TWRI team and a true joy to work with. I appreciate all the help she has given me my past two years here. ~ **Stephanie DeVille-neuve, research assistant**

Kathy has always been not only willing to help me improve communications on my projects but also taught me to grow my own skills. From simple things like taking a good photo at an event to how to order information in a press release, Kathy's helpful hints are engraved in my mind. I can't remember a day I haven't chatted or messaged Kathy. ~ **Clare Escamilla, research associate**

When I first started, I was overwhelmed to realize I had to write a bi-monthly email, a newsletter, a *txH2O* article and more. Kathy reassured me that I could do it, and she would help. She was the consummate professional and great editor. She was always looking for the next story and made sure articles were written, edited and submitted on time. Kathy helped me become a better writer and gain a better understanding of the craft of writing. **~ Jaime Flores, program coordinator**

Kathy's constant kindness, advice and assistance creating all the wonderful educational and outreach materials for my many TWRI projects has been greatly appreciated. I wish Kathy a happy, well-deserved retirement. ~ **Nathan Glavy, extension program specialist I**

Kathy has been nothing short of great and has been instrumental in putting and keeping TWRI on the forefront of the water map. She always strove to convey the intended message as eloquently as possible, and that can be tough working with hardheaded scientists like me! Kathy was always able to translate science into an interesting and relative story that anyone can understand and enjoy. **~ Lucas Gregory, senior research scientist**

It's hard to put into just a few words how much Kathy has impacted me, not only in our years at TWRI together but also as a journalism teacher when I was in college at Texas A&M University. She has been instrumental in making sure we get our word out in a professional, timely manner and makes our work look nice and read well. She also helped edit our work, tightening it up and helping things sound better. She's a great friend and person to work with. ~ **Danielle Kalisek, grant administrator II**

The biggest thing about Kathy that sticks out to me is that she made sure I knew that the work we are doing is story-worthy and that our story should be told. She is great at picking out all the important details to highlight in a story that I might take for granted! ~ **Emily Monroe, extension program specialist I**

Having been with Texas A&M AgriLife for many years, I had seen Kathy's work peripherally through the publication of *txH2O*. After coming to TWRI, I have had the pleasure to work with her directly. Her professionalism, writing and attention to detail have made her an invaluable resource for TWRI and to the water resources of our great state and nation. ~ **Ed Rhodes, research associate**

I'd like to thank Kathy not only for her instrumental role in promoting and expanding the impact of TWRI but also for her wit, thoroughness and professionalism that made her a joy to work with. ~ **Michael Schramm, research specialist III**

Kathy has been an irreplaceable mentor as a communications manager and journalist. She has been an encouraging editor and provided priceless guidance about how to be a professional while achieving career- and life-long success. She has contributed to many strong foundations of students and coworkers alike, molding us all to carry out the institute's mission. We will miss her serving spirit and sage advice on the TWRI communications team! ~ **Sarah Richardson, communications specialist I**

Thank you, Kathy, for all you've done, and we wish you all the best in the future! We will miss having you in the office!
~ The Texas Water Resources Institute Staff

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