In the Tales Told by Sewage, Public Health and Privacy Collide

Sewage epidemiology has been embraced in other countries for decades, but not in the U.S. Will Covid change that?

Visual: Tim Robinson for Undark

BY MIRANDA WEISS (HTTPS://UNDARK.O AUTHOR/MIRANDA-WEISS/)

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I**N EARLY MARCH 2020**, as Covid-19 cases were accelerating across the globe, the American aircraft carrier U.S.S. Theodore Roosevelt made its way to Da Nang, Vietnam for a scheduled stop to celebrate the 25th anniversary of diplomatic relations between the nations. Nearly 100,000 cases of Covid-19 had been confirmed worldwide, and more than 3,000 people had died from it, when thousands of sailors poured off the ship for five days to mingle with locals, posing shoulder to shoulder for photos, overnighting in local hotels, and shooting hoops with Vietnamese kids.

Less than two weeks after pulling anchor, three crew members tested positive for SARS-CoV-2, the virus that causes Covid-19. In the ensuing weeks, the illness zipped through the vessel, eventually infecting (https://www.nejm.org/doi/full/10.1056/NEJMoa2019375? query=TOC) 1,271 of the nearly 5,000 sailors, along with the ship's captain. Twenty-three sailors were hospitalized, with four admitted into intensive care. One died. The acting secretary of the Navy fired the captain for skirting the chain of command when he begged for help with the crisis, before the acting secretary himself resigned.

Thousands of miles away, landlocked in a suburb of curving roads and sunbaked backyard pools, Christian Daughton, a retired environmental scientist from the Environmental Protection Agency, followed the unfolding disaster online from an office nook in his kitchen. The former branch chief at what had been one of the EPA's foremost environmental chemistry labs in the country knew that something could have been done — that there was a tool out there to help. Through an EPA colleague, Daughton contacted the office of the chief of naval operations to inform the Navy about the tool, which could decisively detect the virus onboard ships before sailors felt sick — and, crucially, before the virus exploded among the rest of the crew.

But it was as if Daughton had rowed up in a dinghy to the ship's towering bow and tapped on its hull. He got no response. Daughton, 72, was frustrated but not surprised. For years, government officials had overlooked his work.

The tool Daughton was eager to share with the Navy begins at the toilet. He first proposed it 20 years ago: analyzing sewage to see what it says about public health. The field, called wastewater-based epidemiology, began in the early 2000s with researchers isolating the residues of illegal drugs to understand community-wide use. But over the last two decades, wastewater-based epidemiology expanded to look at the remains of other substances, such as pharmaceuticals and alcohol; pathogens, to identify existing and emerging infectious diseases; and substances made in the body that illuminate the overall health of a given population. The research can happen at a single wastewater treatment plant, or scale up to capture information from an estimated three-quarters (https://www.epa.gov/sites/production/files/2015-12/documents/cwns_2012_report_to_congress-508-opt.pdf) of the U.S. population and roughly 25 percent (https://www.sciencedirect.com/science/article/pii/S00489 of people worldwide.

Daughton and other experts believe wastewater-based epidemiology — which is fast, inexpensive, and adaptable — could help transform public health in the United States, where, according (https://undark.org/2021/02/01/america-health-trails-other-wealthy-countries/) to a 2013 report (https://www.nap.edu/catalog/13497/us-health-in-international-perspective-shorter-lives-poorer-health) by some of the leading health researchers in the country, residents have shorter life expectancy, higher rates of obesity and chronic disease, and the worst birth outcomes compared to peer countries. Sewage monitoring could help address these challenges by providing unbiased health snapshots of entire communities — regardless of access to health care or participation in testing or surveys.

In the 20 years since Daughton first published the idea, countries all over the world have made wastewater analysis a standard public health measure — and they've been able to use this existing infrastructure during the Covid-19 crisis. But Daughton and others feel that the U.S., which produces 34 billion gallons of wastewater daily, has yet to adequately leverage this health information to fight Covid-19 and other health challenges.

As the first months of the pandemic played out in the U.S. and Daughton read the news over breakfast, he knew that had sewage testing been in place as the pathogen began to spread, it may have saved lives. But, at the time, few American health officials were even familiar with the field. It wasn't until months later that communities in the U.S. began actively looking at sewage to help curb the pandemic — and a media frenzy ensued in late May. But by that time, nearly 2 million (https://www.cnn.com/world/live-news/coronavirus-pandemic-06-01-20-intl/index.html) Americans had been infected by SARS-CoV-2 and 100,000 had died. “It’s been incredibly frustrating, dejecting,” he said.

Although there are some signs of change — including new funding from the National Science Foundation and other federal interest — Daughton sees this as too little, too late. Today, as Covid-19 deaths have surpassed half a million (https://covid.cdc.gov/covid-data-tracker/#datatracker-home) in the U.S., new virus variants are circulating widely, and vaccination campaigns progress, wastewater research will remain relevant.

The history of sewage epidemiology reveals what has shackled its development in the U.S.: concerns over privacy and stigmatization, politicians making decisions about scientific research, and a lack of dedicated funding. Experts believe the field holds enormous potential for tackling existing and future health threats. But even Daughton isn’t sure that the U.S. is finally ready to harness the full potential of sewage analysis. Despite the growing interest, “I would think that for something this important,” he said, “the needle would be moving faster.”

WHEN DAUGHTON JOINED the EPA in 1991, he was in charge of a team of about 20 chemists in a laboratory in Las Vegas. From the get-go, he was an agency scientist who didn't stay in his lane. At the time, the EPA was regulating a list of about 126 toxic substances identified as priority pollutants — namely ingredients in pesticides and industrial chemicals. But the list dated to the 1970s, and only included materials that could be detected by technology that existed at that time. Daughton's team was responsible for developing ways to find these chemicals in soils, such as those at Superfund sites, and water, so that the EPA could effectively regulate them.

But Daughton pushed back against what he felt was an overly narrow focus. "There's a whole world of chemicals out there that people are being exposed to every day," he remembers thinking. But the EPA was hamstrung by enforcing existing regulations, and had little interest in new kinds of substances that might warrant additional controls. Still, Daughton's team of chemists was primed to do more. They had pioneered new analytical techniques that allowed them to identify chemical compounds beyond the 126 on the list. So, alongside their regular EPA duties, Daughton's team began to investigate new substances — a group of chemicals largely overlooked by agency regulations, but which Daughton feared could pose threats to human health and the environment.

Daughton dubbed these materials PPCPs — pharmaceuticals and personal care products. PPCPs are chemicals in products people use every day, such as medications, lotions, and toothpaste, many of which are then flushed down the toilet. Although research has shown that these substances can accumulate in fish and have ecological impacts, today, much remains uncertain about how the ubiquitous, low-dose cocktails of PPCPs in drinking water, rivers, and lakes affect human health. Daughton was concerned that the presence of these substances in wastewater, which had been largely ignored by researchers in the U.S., could slowly, imperceptibly, change whole ecosystems. And he wondered whether exposure to little bits of many of these substances over a long time could make people very sick. But at the EPA, Daughton told Undark, he had a hard time convincing the agency that these chemicals warranted attention and research. And the agency wasn't taking regulatory action (https://www.epa.gov/sites/production/files/2015-10/documents/20120525-12-p-0508_glance.pdf).

But that didn't stop Daughton. He published a stream of papers on PPCPs and gave presentations all over the country highlighting potential risks such as how minute concentrations of antidepressants in waterways could disrupt spawning in aquatic animals. He set up a website to share the information with academics and the general public. And he prodded members of his lab to develop elevator pitches, pithy descriptions that explained the importance of their research in language anyone could understand. His work helped highlight the widespread presence in drinking water of medicine residues, which weren't always removed completely by conventional treatment. The public was alarmed and the pharmaceutical industry took note as well. Daughton remembered getting a call from an EPA official in Washington, D.C., whom he believes was feeling pressure from pharmaceutical lobbyists to curtail the research. "I took it as an attempt at intimidation. They were warning me," Daughton said. (The EPA told Undark that it has no record of the call.)

Daughton continued on, and a few years into his work on PPCPs, he expanded his approach. Rather than only considering chemicals in wastewater as pollutants, he wanted to use them as tools. In 2001, Daughton proposed that researchers look to substances in wastewater in order to gauge human behavior. He suggested that by measuring illegal drug residues — such as traces of cocaine — in sewage, researchers could measure collective drug use. This kind of research would form a "rare bridge," Daughton wrote (https://pubs.acs.org/doi/abs/10.1021/bk-2001-0791.ch020) at the time, "between the environmental and social sciences," and provide a "radically innovative" method to gauge the amount of drugs being used in communities across the U.S.

Daughton's proposal was a significant shift from his previous work on PPCPs, where his concern had been on the effects on human and environmental health downstream, after the chemicals had entered wastewater. This new approach looked upstream — in essence, through the public's toilets — to illuminate aspects of human health and behavior that had otherwise remained hidden. He realized the EPA wasn't likely to jump into this work — the agency did not regulate pharmaceutical drug residues in wastewater. But he laid the conceptual framework that he hoped other researchers would run with. A few years later, a group of Italian scientists took up Daughton's idea, and looked for hints of cocaine in sewage and in the county's largest river — the Po River, where treatment plants dump wastewater from about 5 million people.

In 2005, the Italian team released an alarming study (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1190203 that concluded that the Po carried the equivalent of about 160,000 lines of cocaine each day, an amount far higher than national estimates of cocaine use — so high it surprised the scientists themselves. The Italian study, Daughton explained, showed his idea worked and set off an explosion of interest in this new type of wastewater research.

European scientists embraced the approach and founded the Sewage Analysis Core Group Europe, or SCORE, a multinational consortium aiming to launch widespread sewage analysis for drugs. In their first study, published in 2012, SCORE researchers analyzed wastewater (https://pubmed.ncbi.nlm.nih.gov/22836098/)

from 19 cities across 11 countries, essentially conducting a urinalysis of some 15 million people (https://pure.uva.nl/ws/files/1360761/125607_372639.pdf) The EU adopted sewage testing as a standard for monitoring drug use and provided multiyear funding to help SCORE scientists collaborate and establish best practices. SCORE started training graduate students — the next generation of scientists — in this new field, laying the groundwork for a collaborative approach for using wastewater analysis to address public health.

Soon after the project in Italy, the U.S. dipped its toe into wastewater testing for illegal drugs. In 2006, David Murray was chief scientist at the Office of National Drug Control Policy. Tasked with advising the White House and guiding policies to reduce both drug supply and demand, Murray was frustrated by a lack of information. "We had a huge blind spot," Murray explained. "We didn't know how much was being consumed.” At the time — and still today — voluntary surveys were the primary tool the federal government used to quantify drug use and help determine where billions of dollars of public funds are spent. But these surveys reach only about .02 percent of the population and historically rely on door-to-door contact, overlooking people who are homeless, in the hospital, and incarcerated, resulting in an under-reporting of actual drug use.

Murray had been in touch with Daughton and knew about the work in Europe. So he set up a feasibility study at a handful of wastewater treatment plants around Washington, D.C., to look for the signs of cocaine use. “We were very excited,” Murray remembered. If the project was successful, he said, it could give researchers what they lacked when it came to drug control policy: reliable data on consumption.

But it wasn’t long before Murray started getting pushback. No one wanted their city to be labeled the cocaine capital of the country. There also was a public perception of “government scientists looking in your toilet to bust you for smoking a joint,” he said. Even though wastewater testing involved pooled samples that couldn’t identify individuals, households, or even neighborhoods, the perception was that it invaded people’s privacy. Congress killed the project and yanked most of Murray's $40 million research budget. "We lost a real opportunity," he said.

Murray's project was the application Daughton had envisioned when he first proposed that sewage testing be used to understand community-wide drug use. But instead of greenlighting further government investment, the response to the project shut the door on what could have been a national approach to this new science. Over the next decade or so, the field progressed in patchwork fashion in the U.S. largely through a handful of promising but uncoordinated university research and for-profit efforts. "Europe took a coordinated, communal approach to it and we took a fragmented, mixed-market approach to it," said University of Washington epidemiologist Caleb Banta-Green, who has been conducting wastewater analysis to understand drug use since 2008. The result, he said, is that "they have a system and we don't."

Other places were catching on, too. Australia launched (https://www.acic.gov.au/sites/default/files/2020-10/NWDMP_R11%20-%20FINAL.pdf) a national wastewater-testing program for drug residues that today covers about half the country's population. China instituted national wastewater surveillance for illegal drugs as well, and officials there have used wastewater data to help communities understand (https://www.nature.com/articles/d41586-018-05728-3) whether anti-drug campaigns are working and, in at least one case, to help track down and arrest a drug manufacturer.

Gradually, researchers began to look beyond illegal drugs, scouring wastewater for residues of legal substances such as tobacco, alcohol, and prescription medications. And they began to consider the social environment of the data. A study in Greece (https://pubs.acs.org/doi/abs/10.1021/acs.est.6b02417), for example, used wastewater data to understand health impacts from the county's debt crisis that began in 2009. When Greece slashed public health spending and experienced nearly triple the usual unemployment rate, wastewater analysis revealed that the use of antidepressants, drugs used to treat high blood pressure, and ulcer medications shot up. In Australia, researchers tied (https://www.pnas.org/content/116/43/21864#ref-

17) key health factors to socioeconomic and demographic conditions by linking sewage information on drug use, alcohol and tobacco use, diet, and more to census data.

While fears over invasion of privacy and stigmatization of communities blocked the field in the U.S., other countries found ways to address these concerns. In Australia, government officials made drug data public, helping to normalize the program and increase transparency. “Most places are quite open to this if it has benefits to the community,” said Jake O’Brien at the University of Queensland, a partner in that country’s national wastewater testing program for drugs. And in Europe, SCORE established ethical guidelines for wastewater analysis projects, while the EU’s drug monitoring agency continues to publish an annual report on drug use trends informed by sewage data, surveys, and other sources.

While sewage analysis to promote public health was beginning to take off around the globe, Daughton’s work on PPCPs was finally being accepted by EPA officials — helping to spawn a national movement to promote safe disposal of unused medicines and eventually earning him one of the EPA’s top honors. At the same time, he continued to work to propel the field of wastewater-based epidemiology forward. In

2012, he published a paper (https://www.sciencedirect.com/science/article/pii/S0048 that suggested researchers glean novel health information from sewage by looking at the substances created and excreted by the human body. He suggested that the compounds isoprostanes, which are produced in the body and can act as a marker of illness, could be a measure of population-wide health. Sewage analysis, which would pick up isoprostanes excreted in urine, could serve as a sort of doctor's check-up for an entire community in a way that was fast, cheap, and readily scalable.

But using wastewater to investigate broad health measures presented other roadblocks in the U.S., said Rolf Halden, an environmental health engineer at Arizona State University. Halden and colleagues have done some of the most robust wastewater-based epidemiology work in the U.S., investigating exposure to harmful chemicals and developing — in collaboration with the City of Tempe — an online dashboard of sewage-derived opioid data for use by health officials. As Halden explained, federal funding for health research is typically distributed according to which disease or specific health challenge investigators are trying to address, such as cancer, heart disease, or hepatitis. With wastewater research, investigators are often tracking multiple markers of health. “We don’t fit into any of the bins,” he said. Striking out time and again on funding requests, Halden said, “we were doing this on a shoestring.”

Then, a couple years ago, things began to look up for Halden — and the broader field of wastewater-based epidemiology in the U.S. In 2019, the National Institutes of Health granted $1.5 million to his team to develop an early warning system for flu outbreaks, the first effort in the U.S. to leverage national sewage data to track a viral spread. Looking to the sewer to stave off viral outbreaks is not new. Israel and other countries have been monitoring wastewater for the poliovirus for decades, and in 2013, after being declared polio-free, Israel was able to quash a potential outbreak by quickly vaccinating nearly a million children (https://www.thelancet.com/journals/laninf/article/PIIS14 3099(15)00064-X/fulltext) after routine sewage testing detected the virus. As in Israel, Halden and his team aimed to use sewage testing like doppler radar, identifying potential flu hot spots and tracking the movement of the illness across the country.

The researchers also sought to help detect new public health threats by creating a database of viruses pulled from wastewater samples across the country. The team was just ramping up their work when a mysterious pneumonia, later identified as Covid-19, first began sickening people in Wuhan, China.

V**IRUSES ARE UBIQUITOUS** in both raw and treated sewage — and not just during a pandemic. An infected person can shed as many as 10 trillion bits and pieces of virus in a single gram of feces, or about as much poop as it takes to cover the tip of a teaspoon. In some cases, these viruses are defunct, incapable of infecting anyone. But some can be deadly. During the 2003 outbreak of SARS, a cousin to SARS-CoV-2, the virus circulated (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC539564/ through faulty plumbing in a Hong Kong apartment complex, infecting more than 300 residents and killing 33.

Shortly after Chinese researchers isolated SARS-CoV-2 in January 2020, researchers across the globe began to try to figure out how to detect it in wastewater. When Daughton learned of the virus, he saw the danger right away. His first thought: Sewage testing could help stop the spread. He raced to publish a paper on wastewater analysis, submitting it just days after the first stay-at-home orders went into effect in the U.S. in March. The paper (https://www.sciencedirect.com/science/article/abs/pii/S(published in Science of the Total Environment two days later.

"It is critical that governments worldwide be made aware of the important role that sewage epidemiology could play in controlling the spread of Covid-19," Daughton wrote in the paper. Acknowledging that challenges in the field remained — including the fact that the U.S. had less experience with sewage analysis than many peer countries — he was emphatic. It is "imperative" to advance the field for surveillance and early warning, he continued, "not just for controlling Covid-19, but also for future epidemics."

Confirmation of his ideas reached the public a week later. At the end of March, a research team in the Netherlands, which had a decade of experience analyzing sewage for drugs and antibiotic-resistant bacteria, published a pre-print confirming the presence (https://www.medrxiv.org/content/10.1101/2020.03.29.200

of the new virus in wastewater from a railway hub in Amersfoort six days before the first clinically-confirmed case. (They published (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7254611 the peer-reviewed version of their paper in the journal Environmental Science and Technology letters in May.)

By early summer, Daughton's approach was in use on six continents and in nearly every U.S. state. As researchers all over the world jumped into wastewater testing, they realized that sewage provided a picture of the virus in communities days — sometimes even up to two weeks if clinical test results were delayed — before clinical tests and could give officials a jump start in responding.

Wastewater analysis could reach entire populations, especially in places that lacked the resources for adequate Covid-19 testing. It was also comparatively cheap. One study (https://www.sciencedirect.com/science/article/pii/S0048 estimated that nearly three-quarters of the U.S. population could be tested for Covid-19 through sewage analysis in as little as 48 hours, at a cost 15,000 times less than the current gold-standard, PCR testing. Data from sewage analysis would include infected people who showed no symptoms — people who weren't likely to be otherwise tested, but whom the CDC has estimated (https://www.cdc.gov/coronavirus/2019-ncov/more/masking-science-sars-cov2.html) are responsible for about half of all SARS-CoV-2 transmissions. While wastewater sampling can't identify who is infected, the results could help officials direct testing supplies and alert local health officials to upcoming spikes in the virus before patients crowded into hospitals.

As sewage testing for SARS-Cov-2 took off, journalists from across the U.S. and as far away as Germany began contacting Daughton about the field of wastewater-based epidemiology. By May, sewage testing was inspiring evocative headlines in local newspapers all over the country as communities from Alaska to Florida and states in between rushed to test their sewage. In Arizona, in May, Halden's team identified a Covid-19 hotspot in the wastewater of the town of Guadalupe, a small Native American and Hispanic community where many families live in multigenerational homes, and many workers couldn’t telecommute. Within weeks of targeted public health assistance, the presence of the virus in Guadalupe’s wastewater dropped.

In his 50-year science career, Daughton said he had never witnessed so much interest in wastewater-based epidemiology in the U.S. But he didn’t see much in the way of a federal response, except acknowledgement in late March that the EPA was “working on this very idea” in consultation with CDC, an EPA representative wrote to him by email. (Numerous requests for additional information to the EPA from Undark resulted in limited and delayed responses.)

Lack of transparency had become a hallmark of the EPA, said Bill Kovarik, a former environmental reporter of more than 30 years and current professor of journalism at Radford

University. Kovarik and numerous other journalists (https://archives.cjr.org/feature/transparency_watch_a_clo that the EPA clamped down on science information beginning in the George W. Bush administration, when the agency increasingly required high-level permission for media interviews and, when interviews were granted, insisted that press officers monitor them. “There very definitely is a wedge that has been driven between the public and science,” Kovarik said. Daughton watched as the agency shut down his public website on PPCPs, which likely had been the most complete source of information on the subject worldwide. The agency migrated only a fraction of the information to an official agency site as part of a move to ensure that the EPA’s science websites included only research conducted within the agency itself, Daughton explained. After he retired, the agency took down its own PPCP site.

As contact with the media was curtailed, Daughton saw the agency running out the clock on interview requests. “Eventually it got to the point where you couldn’t say anything,” Daughton said. Last spring, as health officials scrambled for tools to fight the pandemic, the public was once again left in the dark when it came to federal involvement in wastewater-based epidemiology.

By mid-summer 2020, temperatures and Covid-19 case levels were peaking in the Las Vegas area. Daughton feared for his family's health, including a relative who has an autoimmune disease.

As Las Vegas and other communities grappled with the spread of the virus, the lack of a national agency leading the charge on wastewater testing meant that towns and municipalities were left to fend for themselves. In order to look at local sewage data, many communities relied on CARES Act funding and partnered with universities for analysis. Hundreds of towns and cities in 43 states and provinces participated in a free wastewater testing program offered by Boston-area startup Biobot Analytics, which bills itself as the first company in the world to commercialize data from sewage. The firm, which ran pilot programs before Covid-19 hit to work with communities to measure opioid residues in wastewater, pivoted quickly to look for SARS-CoV-2 in the spring and raised $4.2 million (https://www.forbes.com/sites/katiejennings/2020/04/24/spinoff-raises-42-million-to-estimate-scope-of-coronavirus-cases-by-analyzing-wastewater/?sh=3278c5e11a27) in venture capital to work with local governments on sewage surveillance for the virus.

But the mix of new researchers and no federal oversight meant that there weren't standard ways to analyze the data. "It's a little bit like the Wild West," Halden said. "Everyone is out there claiming these outrageous things." Despite scientific consensus that sewage data can't be translated into numbers of Covid-19 cases, Biobot sent out potentially alarming reports to communities across the country estimating the number of people infected by Covid-19 in those locales — 1,800 cases in Moscow, Idaho (https://dnews.com/coronavirus/company-ups-estimate-to-1-800-cases-of-covid-19/article_d08da09b-79ab-58cb-849d-170b99edf7da.html) in July, which has a population of 25,000 (https://data.census.gov/cedsci/all?q=moscow,%20idaho); 5,500 new cases in Chattanooga, Tennessee (https://connect.chattanooga.gov/wp-content/uploads/2020/09/Chattanooga-Biobot-

COVID-19-Report-September-2-2020.pdf) in September. Last spring, the company's free sewage-testing program was the closest the U.S. has come to a national wastewater surveillance program, yet in November, Biobot was still working to refine how to turn sewage data into case estimates.

Even with these uncertainties, more states, municipalities, prisons, and universities jumped into sewage analysis as the pandemic spread. Scientists across the country cast aside their usual research to focus on Covid-19 and wastewater, working to hammer out best practices in sampling techniques and data analysis. "We have rushed through about two decades in about nine short months," Halden said. Daughton was encouraged by the sewage testing projects being run in communities across the country. But, he remembered thinking, "we're still missing the most important part," which is federal government involvement.

There are some hints at a change. Starting last spring, the NSF granted hundreds of thousands of CARES Act dollars to wastewater-based epidemiology projects focused on SARS-CoV-2, including establishing the first Research Coordinated Network in the field, a NSF-funded effort to support collaboration among researchers. "It's been like a gold rush," said

Halden. The EPA released information to the public about a pilot wastewater analysis project the agency was conducting in Ohio involving multiple treatment plants in Cincinnati and prisons in the state. The goal of the project was "to work out some of the kinks" in methods, according to Jay Garland, a senior research scientist at the EPA. And the CDC announced a plan to ramp-up a national wastewater surveillance database by the end of 2021.

It's not yet clear whether these efforts will translate into the kind of nationwide, government-supported programs already in place abroad, which Daughton and others believe will be vital to create a viable system of wastewater-based epidemiology in the U.S. "We can't get there if the focus remains on local projects," he said. Halden agrees. "The informational power of wastewater is horribly underestimated in the U.S.," he said, and a countrywide effort is "direly missing." A national program would also help to standardize methods, said Joan Rose, a water microbiologist at Michigan State University who, along with a team of researchers (https://www.covid19wbec.org/) across the globe, is coordinating and promoting wastewater analysis during the pandemic. Leadership and funding, she added, should be incorporated into a national plan.

There are still uncertainties in how to use wastewater-based epidemiology to help with the Covid-19 crisis. Sewage data, for instance, still can't be translated into numbers of infected people. And because viral concentrations may change with temperature or with time — whether a virus travels through one mile of pipe or 20 — wastewater data from different places and from different times aren't easy to compare.

As conditions during the pandemic have changed, so has the potential role of wastewater-based epidemiology. Now that the virus is ubiquitous across the U.S., sewage testing might be most effective in more contained communities like college campuses, nursing homes, prisons, and naval ships — as Daughton had understood a year ago — where groups of people are more clearly defined and officials can sample closer to the source.

Today, wastewater analysis could also help locate the presence and spread of new SARS-CoV-2 variants. As of January, the U.S. had analyzed less than 1 percent of virus samples to detect such variants. Sewage testing could rapidly scale up those efforts. This is already happening in scattered efforts across the U.S., such as at Biobot, the University of California, Berkeley, and the University of Nevada, Las Vegas. These data could prove essential as vaccine makers contemplate updating their recipes and adding booster shots to vaccine protocols. And once vaccines begin to control the spread of the virus, wastewater surveillance could help reveal new hot spots.

Wastewater testing may help reveal the origins and spread of the virus — Italian researchers, for instance, reportedly found (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7428442 SARS-CoV-2 in sewage samples dating back to mid-December 2019, two months earlier than the country’s first confirmed Covid-19 case. Because sewage testing is the only practical way to capture total viral infections in a given population, wastewater data may also be crucial (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7299382 for calculating the fatality rate of the disease. Such research could also inform the response to the next pandemic.

Daughton wants researchers to take it a step further. The number of Covid-19 deaths gives only part of the story, as researchers have estimated that 10 percent (https://www.bmj.com/content/370/bmj.m3026) or perhaps as many as 24 percent (https://www.medrxiv.org/content/10.1101/2020.10.07.202 of cases — millions of people worldwide — result in long term health consequences (https://www.cdc.gov/coronavirus/2019-ncov/long-term-effects.html?ACSTrackingID=USCDC_425-DM42580&ACSTrackingLabel=Weekly%20Summary%3A%2 19%20Healthcare%20Quality%20and%20Worker%20Safety% DM42580) such as breathlessness, fatigue, heart problems, and brain fog. Because there's no reasonable way to track all of the people suffering from lingering sequelae, Daughton's idea is to identify specific markers of these chronic conditions that can be found in human waste to gauge the extent of the pandemic's effect on long-term health.

With the new buzz around wastewater-based epidemiology in the U.S., some researchers may listen this time. “People are absolutely seeing this as an exciting opportunity for a new way to address infectious public health challenges,” said Marlene Wolfe, a researcher at Stanford, who has been analyzing sewage from Palo Alto and San Jose for SARS-CoV-2.

Researchers are already using wastewater analysis to identify hot spots of antimicrobial resistance, which sickens 2.8 million people and kills more than 35,000 in the U.S. each year (https://www.cdc.gov/drugresistance/index.html#:~:text=
Other projects may look at the opioid epidemic, which kills tens of thousands of people annually (https://www.hhs.gov/opioids/about-the-epidemic/index.html) in the U.S., as well as population-wide exposure to environmental toxins in household products, pesticides, and industrial chemicals. And, following Australia’s lead, U.S. researchers could tie wastewater information on drug consumption, chemical exposures, and other health measures to census data in order to unravel some of the gaping health disparities laid bare by the pandemic.

But not everyone is willing to have their sewage monitored. Already, some U.S. communities, such as a handful in North Dakota, are refusing to participate in wastewater testing because of concerns over privacy. “Nobody wanted it,” said Natalie Bugbee, a city commissioner in Tioga, North Dakota, where town officials rejected an offer from the state to test sewage for SARS-CoV-2. Because a sizable population of workers from out of town come and go on nearby oilfields, “it wouldn’t be a fair analysis of our local community,” Bugbee said. Locals also worried that sewage testing could trigger a shutdown of the town.

Privacy concerns and stigmatization issues are likely to remain challenges to sewage analysis in the U.S. “People are rightly or wrongly suspicious when you have government testing,” said Margaret Foster Riley, an expert on health care law at the University of Virginia.

“What we need to do is have public discussions about what it may mean to have your wastewater tested,” she added.

These types of public discussions are just what Daughton said were missing while he was at the EPA. One of the lessons in the story of wastewater-based epidemiology, he added, is that there isn’t enough communication from scientists. While at the agency, he said that he felt beholden to communicate his work to the people who paid for it: the general public. Public attention could catalyze action, he said, as it did in spurring the EPA to create regulations around safe ways to dispose of unused medicines.

It will take open communication, Daughton said, to show how combing through sewage can improve community health. In his view, no one has yet made a clear enough case to rally public support, which will involve showing what larger scale wastewater analysis projects can do. While the field is just beginning to gain traction in the U.S., Daughton and others believe it will take a national effort to make use of the rich dataset hiding in the sewers. "I think we've barely started," he said.

Miranda Weiss is a science and nature writer in Homer, Alaska. She is the author of "Tide, Feather, Snow: A Life in Alaska" and her work can be found in The Atlantic, The Economist, and elsewhere.