Detecting Chemical Clues

Researchers develop tracers to track water originating from septic systems

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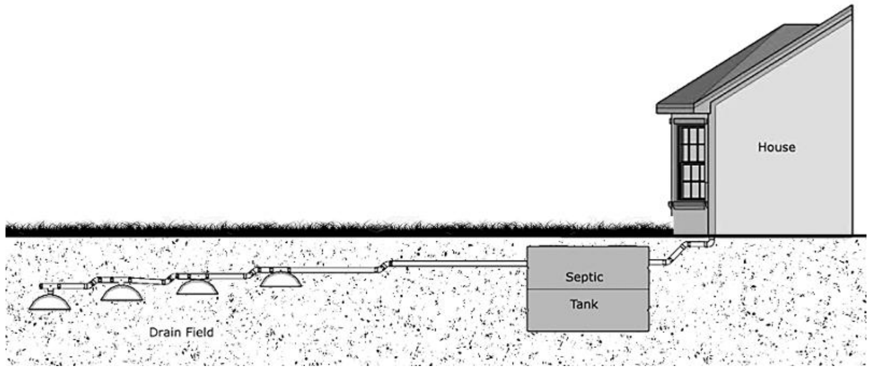
Flushing a toilet is part of our daily routine. We pull a handle, or push a button, or an infrared sensor does the work automatically as we exit a bathroom stall. Water is released and the contents swirl away, carrying waste through the plumbing network to a place where it is treated. In urban areas, it is connected to a municipal sewer that drains to a wastewater treatment plant. In older suburban or rural areas, it likely connects to a septic system—a small, self-contained underground wastewater treatment system.

These on-site septic systems use natural processes to treat the wastewater, which travels slowly through a tank and into a drainfield, where it eventually percolates through layers of gravel and soil. These layers act as biological filters for the water as it seeps through before entering groundwater reserves below. While greases, oils, and solids settle out of the wastewater in the septic tank, some compounds remain throughout its journey to the groundwater, where they may ultimately end up in nearby streams and waterways.



A basic schematic showing a traditional septic system—waste drains from a home into a septic tank, where greases, oils, and solids settle out before wastewater slowly travels out into a drainfield. The size and configuration of these systems vary based on the use and square footage of the dwelling and the geology of the site. *Graphic, Matthew Amey*

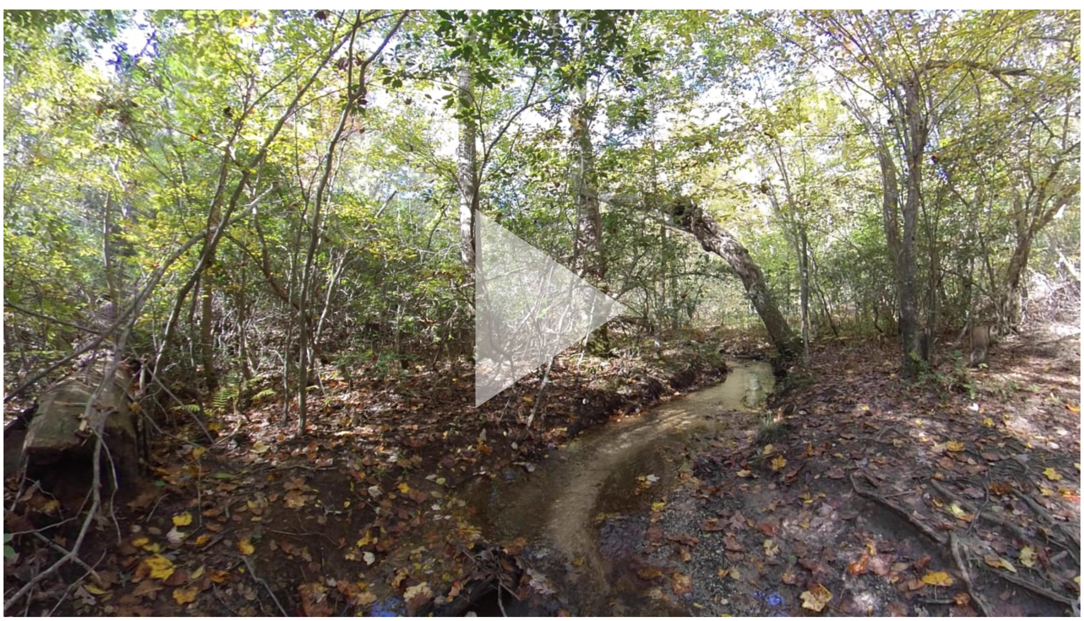
These chemical fingerprints are clues chemists can use to try to determine where water may have originated. Michael Gonsior is one of these chemists. He, along with a team of researchers at University of Maryland Center for Environmental Science's Chesapeake Biological Laboratory (UMCES-CBL), has been working to develop organic tracers to track water coming from septic systems using a combination of traditional nutrient measurements, chemical signatures, and sophisticated new analytical techniques. Identification of these tracers will help determine if discharge from septic tank systems has affected neighboring or adjacent watersheds.

As Gonsior, an analytical and environmental chemist, states, "It's a simple question that is not so easy to answer: Are these streams impacted by septic water?"

Seeking Sources of Nitrogen

Why is this important to determine? Wastewater can contain ammonium and other forms of organic nitrogen from urine, garbage disposal waste, and cleaning products. As this septic system discharge, or effluent, passes through the system and into the drainfield, bacteria can convert the ammonium to nitrate, a process called nitrification. From there the nitrate may be taken up and used by plants in the immediate area or filtered out by the soil, depending on a number of factors including the rate of effluent release, the quality of the soil, and the size and depth of the drainfield. But those removal methods vary widely in effectiveness, and much of the nitrogen percolates down into groundwater, largely in the form of nitrate.

For this reason, septic systems are a potential nonpoint source of nitrogen pollution; in other words, they are one of many disconnected sources of pollutants that can be hard to trace back to the source. By the time these nutrients enter a waterway, it is difficult to determine their origin. Nitrogen in a creek or stream can come from a variety of sources—in addition to soaking through the ground from septic drainfields into groundwater, it can flow off the land as runoff from fertilizer applications or animal waste, or be deposited from the air as a result of the burning of fossil fuels. And once it is in a waterway, it can cause problems. Excess nitrogen can lead to an explosion of algae that form toxic algal blooms, and decaying algae can rob the water of oxygen, creating oxygen-free uninhabitable dead zones.



Small creeks like this one in Calvert County can be impacted by a variety of sources, including nutrients and chemicals from urban and agricultural runoff and surrounding septic systems. Take in a 180-degree view as co-principal investigator Andrew Heyes and graduate student Katie Martin collect a water sample.

As a result, lowering nitrogen input to the Chesapeake Bay watershed has been an ongoing effort in Maryland, and with approximately 420,000 septic systems in the state, part of that effort has focused on determining their impact. Development of a chemical fingerprint to detect nitrogen pollution from septic systems would enable scientists to calculate their contribution to the total nitrogen load in local waterways that feed into the Bay. It could also help measure the efficacy of new septic system designs that use advanced technologies to remove nitrogen from water.

According to the Maryland Department of the Environment, conventional septic systems remove just 10 to 20 percent of the nitrogen in wastewater and deliver approximately 23.2 pounds of nitrogen to groundwater per year. In comparison, new systems equipped with nitrogen-removing Best Available Technology (BAT) units can reduce nitrogen load by 50 to 75 percent. The state offers financial incentives, through its Bay Restoration Fund, to encourage BAT septic system upgrades, particularly for residents in Critical Areas—those defined by the state as land within 1,000 feet of tidal waters and wetlands. Therefore, developing a way to understand and measure the effectiveness of these advanced systems is important.

“I think that local planners can use this information to prioritize investments from the Bay Restoration Fund into septic system upgrades—that would be a great use,” said Lora Harris, an estuarine ecologist at UMCES-CBL and co-principal investigator on the septic tracer project. “Eventually, I would hope it could also help to identify nitrogen hotspots in the landscape and help folks understand what the sources might be. In combination with isotopic tracers, this could help differentiate wastewater from agricultural sources, which would be useful.”

Finding a Chemical Fingerprint

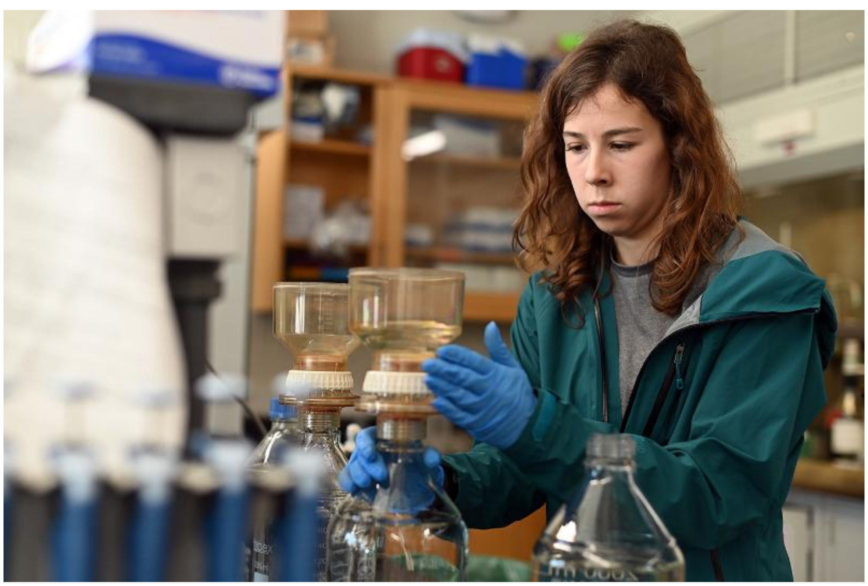
The UMCES-CBL project team—Harris, Gonsior, co-principal investigator Andrew Heyes, and graduate student Katie Martin—began by collecting water samples in Calvert County each month for a year as part of a Maryland Sea Grant-funded project. The majority of the county’s approximately 90,000 residents are served by traditional septic systems.

In the Field

Co-principal investigator Andrew Heyes and graduate student Katie Martin collect water samples at a creek in Calvert County that the team used as a reference site.

The team targeted nine streams in the county, choosing six that had potentially been impacted by septic systems and three that were in wooded sections further removed from developed areas, which they identified as reference sites. They also collected water samples directly at the outflow sites of old and new BAT septic systems in each area. They filtered all samples to extract and concentrate the organic components, and then performed chemical analyses to identify the complex mixture of compounds. The analysis provided the chemical fingerprint of each organic sample, revealing compounds that occur naturally in forests and streams—and also those that do not, including chemicals that pass through the body or are washed down the drain, such as soaps, cleaners, medications, and artificial sweeteners. These were the tracers that the researchers were looking for to develop methods to quantify chemicals that indicate the presence of wastewater, and the latter proved to be key.

Sample analysis showed high levels of sucralose in some of the streams. An artificial sweetener sold under the brand name Splenda, sucralose is found in soft drinks, chewing gum, candy, and various other products. Marketed as a calorie-free sugar substitute, it mostly passes through the body rather than being broken down and absorbed during digestion. Its stability makes it a good wastewater tracer.



Graduate student Katie Martin filters creek water samples to extract and concentrate the organic components from them at University of Maryland Center for Environmental Science's Chesapeake Biological Laboratory.

The researchers compared concentrations of sucralose in samples taken at adjacent septic tanks in an effort to make a direct connection to the specific systems and calculate how much water originated from each.

“The idea was, this is mostly a quantification of known wastewater tracers, which hasn’t been applied in Calvert County,” Gonsior said. “So we were really first looking at this in the streams. Artificial sweeteners like sucralose, which is a very stable molecule, are not degrading effectively in the environment, so it’s what we call a conservative tracer.”

The team used a multi-tracer approach, said Gonsior, to confirm the presence of other wastewater tracers, such as surfactants from soaps and detergents, caffeine, and ibuprofen. Using sucralose as the stable conservative tracer, they could then look at the rate at which these other compounds were degrading in wastewater in relation to the sucralose. This information allowed the researchers to measure how much processing potentially had happened at any point in the sampling, providing an idea of how “aged” that signal is.

“Let’s take caffeine, for example, or acetaminophen or ibuprofen. For a time they would degrade, but at different rates,” Gonsior said. “So relating the different rates of degradation to sucralose itself, a very stable compound, gives us an idea about how important this signature we’re seeing is, in terms of relating it again back to the nitrogen loading. This data correlates quite well with the nitrogen loading, so we have indirect correlation that the nitrogen we see is likely to be coming from the septic systems.”

Water samples are pulled through filters, leaving behind organic material to analyze.

The team measured dissolved nitrogen in the streams and found higher levels in those with more septic systems in their catchment areas: the higher the density of septic systems, the higher the total nitrogen loading. They also looked at the stable isotope on nitrogen with a collaborator at the UMCES Appalachian Laboratory. Stable isotopes are a form of an element that do not decay, and therefore their abundance stays the same over time; in this case, the team found that it aligned well with the wastewater signature they had observed in other tracer work. This allowed them to distinguish it from nitrogen that originated from atmospheric deposition or fertilizers, which have different distinctive isotopic signatures.

“So the effect is interesting, in this case, that actually the nitrogen load you’re seeing in those streams are quite well correlated with our tracers—for septic systems specifically,” Gonsior said.

By knowing the tracer concentrations in both the septic tank and the adjacent stream, the researchers can calculate how much water in the stream originates from the system. It’s still impossible, however, to identify how much nitrogen the septic system alone is delivering to the stream, because there are other contributing sources of nitrogen. Gonsior said they can infer that the systems are a source, but they are doing more analytical work using isotope ratios to identify exactly how much of the nitrogen load comes directly from septic wastewater.

Take a look around the laboratory that graduate student Katie Martin uses to run advanced chemical analysis of the samples her team collects.

The forensic tools being developed in Maryland will have application nationwide, said Harris, especially in older, high-density residential communities with a legacy of septic systems not connected to public wastewater treatment plants. Their work will also be an important tool for implementing and measuring the impacts of restoration efforts.

“As an ecologist, I am also always curious about the source of nitrogen that a particular water body experiences, because it tells me about the restoration potential for that system—what is realistic,” Harris said. “If the source is something local, like septic systems, there is the potential to motivate policy, investment in septic upgrades, et cetera. As someone who does a lot of advising, and monitoring, and research around poor water quality issues, we are asked all the time for advice on restoration. Knowing whether septic or wastewater is the source can be a big help in those conversations.”

Header photo: Graduate student Katie Martin prepares a sample for chemical analysis in the laboratory.

Photos and videos by Lisa D. Tossey / MDSG

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