Ground Game

How the Water We Can't See Can Harm the Chesapeake Bay

Rona Kobell

When raindrops fall, where do they go?

Some fall directly into streams, rivers, and the Chesapeake Bay. Some slide down roofs and driveways and flow into storm drains, which often release this runoff, and all it carries, into nearby bodies of water. And some will hit the ground and sink in, where they may be drawn up by the roots of plants or sink deeper to collect in underground reservoirs, called aquifers.

A raindrop that enters the ground in Frederick, Maryland, could make its way through limestone and quartz formations. In Western Maryland, it could travel through shale and steep gorges. On the Eastern Shore, the drop could work its way quickly through sandy, permeable soils and into the underground basins. While raindrops may look alike as they fall from the sky, each has a different impact under the ground. And wherever they fall, raindrops may refill, or recharge, aquifers.

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This journey is important for all of us—half of the United States' population gets its drinking water from these supplies, which are aptly called groundwater. In the Chesapeake Bay watershed, groundwater supplies nearly one-third of Marylanders, or nearly 1 million people, with their drinking water. Towns, homeowners, farmers, and businesses can drill wells into aquifers and pump out the water, and we often rely on groundwater to irrigate crops that provide the food we eat.

But what's crucial for survival can also be a conduit for excess nutrients. Groundwater feeds streams, and rainwater replenishes the supply to both. In rare instances, streams also feed groundwater. But whichever way the waters flow, they can carry many things with them, including nutrients. Scientists from several universities are assessing the groundwater across the watershed, from central Pennsylvania forests to urbanized streams near Baltimore, to determine how it moves under different geologic formations and the consequences of that flow.

Groundwater in Gambrill State Park, Frederick County, Maryland. *Photo, J. Adam Frederick*

"Once it's in there, the problem is you really can't get it out," Scott Phillips, a hydrologist with the U.S. Geological Survey (USGS) who coordinates the Chesapeake Bay Program's groundwater work, said of the nutrient load in the groundwater. "Eventually all groundwater wants to, and will come back to, a stream—along with the pollutants it carries."

Slightly less than half of the Chesapeake Bay's nitrogen pollution comes from rural-derived sources—mainly manure and conventional fertilizer. Nitrogen, when combined with oxygen, becomes nitrate, which can enter surface water as well as groundwater. When nitrate in the groundwater is too high, it can cause human health problems when ingested, especially in infants, by decreasing hemoglobin's ability to transport oxygen to tissues and contributing to a condition called methemoglobinemia, or blue baby syndrome.

Groundwater quantity and quality go hand in hand. When farmers, municipalities, and industry withdraw groundwater, they deplete aquifers. Less water in an aquifer increases the potential for more saltwater intrusion and less dilution of it or any other contaminants that may enter the system. The Maryland Department of the Environment manages both quantity and quality in conjunction with local jurisdictions; some states have separate managing agencies.

MAPPING THE GROUNDWATER

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Confined and unconfined aquifers are also partners in groundwater management. The USGS defines an unconfined aquifer as "an aquifer whose upper water surface (water table) is at atmospheric pressure, and thus is able to rise and fall," while a confined aquifer is "below the land surface that is saturated with water, with layers of impermeable material are both above and below, causing it to be under pressure so that when the aquifer is penetrated by a well, the water will rise above the top of the aquifer." (See “Mapping the Groundwater”). When it rains, water seeps into both the water table and the confined aquifer through fissures in the rock. So, the quality of an area’s groundwater depends on the frequency of rain, the quantity it holds, and the kinds of geographic formations that confine it.

Grounding the Model

It helps to think of groundwater as a delivery mechanism instead of a separate source of nutrients to the Chesapeake Bay, said Gary Shenk, a USGS hydrologist based at the Chesapeake Bay Program. So how do you count it?

It has become tricky for scientists to measure and count groundwater as a contributor to nutrient pollution, in part because it can remain in the water for decades. After the initial Chesapeake Bay Agreement in the 1980s—when leaders of six states and Washington, D.C., agreed to reduce Bay pollution—scientists began modeling pollution-reduction strategies to see how far certain practices would get them. For example, if a town of 10,000 residents upgraded its wastewater treatment plant to reduce nitrogen and phosphorus, the model could provide an idea of how much of a reduction that would be. But groundwater is not straightforward.

“It is so complicated,” said Susan Brantley, Distinguished Professor of Geosciences and director of the Earth and Environmental Systems Institute at Penn State University. “A lot of nitrate goes into the groundwater, and it can be decades before it gets into the rivers.”

It can take decades for nitrogen that enters groundwater to flow through the system and reach the Chesapeake Bay. For example, fertilizer applied during the Reagan Administration could still be working its way through the system, and the model would not have accounted for that lag time of when fertilizer applied in the 1980s might actually enter the Bay. So an effort, or best management practice, a farmer does today to catch or reduce the nitrogen flowing off their fields into the

Bay might stop those nutrients today, but not the nitrogen added and trapped in the groundwater decades ago. The slow movement of this "legacy" nitrogen through groundwater and into the Bay is called lag time.

Shenk's fellow hydrologists at the USGS, Phillips among them, worried that the Bay cleanup model could not accurately predict how much nitrogen best management practices would remove if it did not account for groundwater lag times.

"We can bring nutrients down, but the unanswered question is, how long does it take for the system to respond?" Shenk said. "How long will it take for groundwater to work through the system? It has not been a top priority for the Bay Program, and we haven't had the model to answer for it until now."

The latest Chesapeake Bay Program Watershed Model, the sixth such iteration, came out in 2017, and it is the first to factor in the pace at which groundwater moves in different geographic areas. (The Bay Program has models to measure air and sediment also, but those don't look at groundwater.) Having the lag times in the model gives the program greater certainty of when cleanup goals will be met.

MODEL METHODS

Read more about how the latest Chesapeake Bay Program Watershed Model factors in groundwater…

https://arcg.is/0DajKP

The Chesapeake Bay's Total Maximum Daily Load (TMDL) cleanup plan states that all land management practices to reduce pollution in the watershed must be in place by 2025, but Shenk points out that doesn't mean they will produce the desired effect by then. A forest buffer—an area of trees, shrubs, and other vegetation bordering a waterway that helps absorb nutrients before they can enter the water—takes years to grow to full effectiveness. It can also take years to obtain improved water quality by reducing the amount of nitrogen and phosphorus applied to the soil. Because groundwater can move slowly, water that is 20 to 30 years old and full of excess nutrients could just be entering streams now, even as better land management practices are reducing the amount of nutrients being applied today to the land’s surface.

It matters, too, where the groundwater comes from. Ward Sanford, a research hydrologist with the USGS Water Resources Discipline National Research Program, modeled the groundwater features, and the subsequent lag times in the Potomac River and the Eastern Shore’s portion of the Coastal Plain region. The Potomac River, stretching across four Maryland geologic regions, the Piedmont, Blue Ridge, Ridge and Valley, and Appalachian Plateau, represented one data set, while the Coastal Plain represented a second data set. All five regions have distinct rock characteristics and varying groundwater lag times. With these data Shenk said, they had the needed information to effectively model the whole watershed's groundwater inputs accounting for the different features and lag times for nutrient inputs.

Shenk expects the newest model will become more refined, but it’s a start for developing a more accurate picture of when we will see the results of efforts to reduce nutrient pollution.

“This won’t change what we’re asking people to do in terms of their nitrate reductions,” he said, “but it will change how fast we will see the results.”

Too Much Salt

Scientists aren’t sure how climate change will complicate the groundwater picture—only that it will. Already, municipal water supplies are grappling with saltwater intrusion impacting groundwater supplies in coastal areas. If municipalities or industries located in areas near the bay and the ocean pump out too much freshwater, then denser saltwater may move in, infiltrating the wells and making the water too salty for drinking. With the Chesapeake Bay’s sea level rise among the highest in the nation, the frequency and levels of saltwater flooding, as storm surges push saltwater inland and onto cropland, could increase due to climate change. More intense precipitation events from climate change may help replenish aquifers, though aquifer recharge is most effective with a steady, light rainfall, rather than a deluge that sends the water running off the surface. And warmer water temperatures could mean more evapo-transformation—more water entering the air—making less available for groundwater recharge.

John Swaine stands near the road at his Eastern Shore farm. In recent years, he's noticed saltwater intrusion harming his fields. *Photo, Nancy Averett*

For decades, the Swaine family has farmed corn, soybeans, and wheat on 1,200 acres in Royal Oak, near the Oxford–Bellevue Ferry in Talbot County. For almost as long, a Swaine has been watching the weather, including the tides. John Swaine Jr. was one of the state's 37 certified weather watchers; his son, John Swaine III, took over the tradition when his father died in 2012.

Three to four times a month, the tide is high enough so its saltwater sits on the land and infiltrates the crops. He's lost about 10 to 12 acres to salt this year. But not far from his mind is Hurricane Isabel, when he lost his well water due to saltwater infiltration. The tide came up enough to submerge the well. Swaine had it pumped out, but he says he would have done things differently to prepare for future saltwater intrusion if he'd known then what he knows now.

"I wish we would have put it in a different location," he said. "We could have put it on the other side of the house, on higher ground."

Swaine is not the only farmer watching his wells. Researchers have long noticed that saltwater is ruining some farm fields when tides rise and don't quickly recede. But the saltwater can also come from below the surface. Saltwater is denser than freshwater, and it can seep into groundwater aquifers through cracks in rocks and remain there until it's pumped up. It doesn't take much salt to change a water supply from freshwater to saltwater, and withdrawals can contribute to higher salinity levels. Depleting groundwater creates a cone of depression around wells, which leaves room for increased flow of brackish water into aquifers. That means farmers struggling with the impacts of climate change, such as cycles of heavy rain and drought, will have to rely more on groundwater to irrigate their crops. If salt contaminates that water, it can ruin those crops.

Research from Kate Tully, an assistant professor of agroecology at the University of Maryland, shows that few crops can grow in sustained conditions of salinity more than 2 parts per thousand—far below the salt content in many fields with saltwater intrusion. Tully and her team have worked with many farmers on the Shore, but she said the research is still inconclusive as to how much of the salt is coming from the surface and how much is coming up from shallow aquifers, and whether the saltwater will eventually harm deeper drinking-water wells.

Kate Tully, an assistant professor of agroecology at the University of Maryland, measures the amount of saltwater intrusion on an Eastern Shore farm.

"The creek water that you see is groundwater and it's tidal water—it's already both, it's already mixed," she said. "You're pouring two different cups of water in the same bath—it's hard to determine which one comes from which source."

When rain mixes with the saltwater that has seeped up through the ground, it produces new complications for nutrient-reduction efforts. Saltwater can extract legacy nitrogen and phosphorus from agricultural lands long after they have been abandoned, delivering additional loads of those nutrients to the groundwater and Chesapeake Bay, according to research conducted by Tully and several colleagues, including Keryn Gedan of George Washington University.

Tully and Gedan can see the saltwater is coming, but they can't yet predict where it will go next—in part, said Gedan, because the aquifer maps are "woefully out of date" and ecosystems and connectivity have changed since they were drawn in the 1980s. She and colleagues are monitoring Shore wells to help prepare farmers for a future in which some crops can't be grown and irrigation water is contaminated with salt.

"I have come to see [saltwater intrusion and groundwater] as a much more important piece of the puzzle," she said.

Smart Management

The Chesapeake Bay watershed has its groundwater challenges, but also some advantages. Coordination among six watershed states and the District of Columbia ensures that the principals involved in water quality and quantity are talking. Maryland manages its groundwater and surface water jointly, with the state's Department of the Environment overseeing both and the Maryland Department of Natural Resources weighing in on fish and habitat. Peter Goodwin, president of the University of Maryland Center for Environmental Science and a hydraulic engineering specialist, came to Maryland from the University of Idaho and said he noticed the cooperation almost instantly.

"Maryland is good at that—at coming together with agencies to solve problems collaboratively," Goodwin said. "Managing groundwater and surface water conjunctively is one example."

Other states have seen communities, farmers, and water authorities take legal action against each other to protect their groundwater withdrawal rights. Idaho has been a flash point, with a state court recently settling on how much different users could take.

On the quality side, said Goodwin and Phillips, Maryland's environmental focus and cooperative nature is also helpful. Some areas, like Fort Meade in Anne Arundel County, have issues with groundwater contamination, but expensive mandatory cleanup efforts have lessened the problems, Phillips said. An extensive monitoring project near Phillips' office at the University of Maryland, Baltimore County, is also providing a lot of information about what can pollute groundwater in suburban settings.

The speed at which Maryland officials developed a working group focused on a saltwater intrusion plan is a positive sign as well, Goodwin said. The legislature requested that the Maryland Department of Planning (MDP) lead a study on the saltwater threat, and the agency brought in a diverse group of scientists to do so along with lead writer Jason Dubow, MDP's manager of resource conservation.

It took decades to get stakeholders to pay more attention to what's under their feet. Now that they have become more aware, geologists say, we need to maintain that focus.

“We can't create water, and we can't destroy it,” Goodwin said, “so we have to manage what we have got in a much better way.”

Header photo: Millbrook Marsh Nature Center in State College, Pennsylvania, is a 62 acre park featuring a two-acre calcareous fen, a rare habitat fed by groundwater seeping through limestone bedrock. Photo, Will Parson / Chesapeake Bay Program

Kate Tully photos by Edwin Remsberg

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