



photography by Deborah Rose, DNR

By Michael A. Kallok

Mapping Subterranean Waters

*A seven-year project to learn more about southeastern Minnesota's hydrology brings **new awareness** to the interconnectedness of land and water.*

A RAW APRIL WIND scatters ice pellets across the bare soil of a southeastern Minnesota farm field where Department of Natural Resources hydrologist Jeff Green assesses a bathtub-sized depression. "This is a sinkhole," he declares with an enthusiasm that seems exaggerated for such an unremarkable-looking natural feature. But to Green this is an entry point for understanding the way water moves underground in this geologically unique corner of the state.

Lakes are absent here, but more than 700 miles of designated trout streams flow through this dramatic landscape of steep bluffs, caves, and wooded valleys. The cold water that supports trout flows from springs. In order to protect these springs from potential

DNR hydrologist Jeff Green sprays water into a sinkhole in an Olmsted County farm field as part of research aimed at protecting ground water.



A dye trace begins when a nontoxic organic dye (above) is poured into a sinkhole or other karst feature. Water is then used to flush the dye into the sinkhole. Springs in the area of the sinkhole are monitored for traces of the dye.

threats—pollution, demand for more water to irrigate farm fields, and land-use changes such as sand mining—it’s important to know where a spring’s water comes from and how it gets there.

With money from the Environment and Natural Resources Trust Fund, Green and University of Minnesota hydrogeologist Calvin Alexander recently concluded a seven-year project to map many of the region’s springsheds, or basins where springs originate. In this terrain of sinkholes and porous underground rock, that work confirmed that ground water is particularly vulnerable to contamination from poor agricultural prac-

tices, land development, and chemical spills. Most significantly, the project uncovered evidence that water deep underground is more susceptible to contaminants, such as nitrates and pesticides, than previously thought.

Fortunately, the springshed research is also leading to partnerships with counties as they look to better protect water resources.

Green’s primary tool for following the complex intermingling of surface and ground water is a technique known as dye tracing. On this day, he’s preparing to flush a liter of dark red organic dye and 1,000 gallons of water into the sinkhole we’re standing over.

“We’re about to watch surface water become ground water, right before our eyes,” says Green. “There aren’t many places you can do that in Minnesota.”

It’s possible to see that movement here because southeastern Minnesota is free of

the hundreds of feet of sand, gravel, and silt deposited across the rest of the state during the last glaciation some 12,000 years ago. Not far below the soil under our feet is a layer cake of sandstone, shale, dolomite, and limestone.

Where we’re standing in this field near Eyota, limestone is closest to the surface. When precipitation mixes with carbon dioxide in air and soil, it becomes acidic enough to dissolve limestone. Over time, vertical channels form in the limestone. Sinkholes appear when water and gravity carry soil into these channels.

This dynamic landscape of soluble rock is known as karst. It’s found in other places around the world. Occasionally, karst’s most characteristic feature makes the news. In 2014 a sinkhole beneath the National Corvette Museum in Bowling Green, Ky., swallowed eight classic sports cars. The odds of losing valuable property in a sinkhole here are pretty remote, says Green. A more realistic concern is an accidental spill of manure into one of these direct connections to ground water.

Olmsted County feedlot technician Martin Larsen, who joins us, worries about this possibility. He has trailered a large water tank here for the dye trace. After



Green conducts a dye trace (top) at the bottom of a rubbish-filled sinkhole. Since the 1970s the practice of using sinkholes as dump sites has declined. Because the land around them can’t be farmed, large sinkholes (above) appear as islands of trees and vegetation.



rolling hose out to the edge of the sinkhole, Larsen starts a gas-powered pump. In a matter of minutes, the water and dye have disappeared underground through an opening in the exposed limestone visible at the bottom of the sinkhole.

On this day Green and Larsen pour dye and water into four sinkholes. One at the base of a sunken fencepost is no larger than a five-gallon pail; another is a steep, rubbish-filled depression large enough to swallow a small house. The type of dye used, the time, and a GPS location are recorded at each.

Green has been dye tracing since 1990, so he has a good idea where the dye might reappear. For these dye traces, Larsen has placed mesh bags of charcoal, about the size of a deck of cards, at 16 nearby springs. Organic dye will cling to the charcoal in these packets, known as bugs. Larsen will replace the bugs weekly for the next six weeks. Bugs removed from the springs are mailed to a University of Minnesota hydrogeology lab. There a device that measures fluorescence can confirm the presence of specific organic compounds found in the special dyes used by Green.

One bug was placed at Bear Creek spring about a mile northwest of the first sinkhole we visited. Typically, by the time dye reaches a spring, it's too diluted to be seen. But six hours later, the landowner calls Larsen to say his spring is running blood-red.

None of the other springs monitored turned colors, but eventually dye from all four traces is recovered. The springs where

dye turned up provide Green with enough information to map three new springsheds.

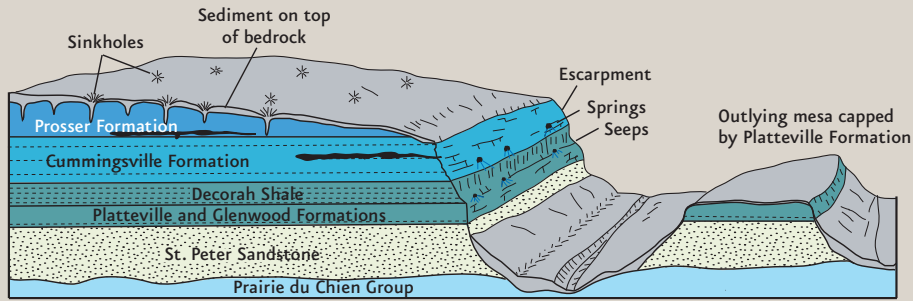
The connection between springs and sinkholes is why the Minnesota Pollution Control Agency has specific regulations for where manure can be stored or spread in proximity to karst features. To farmers, Larsen says, "Sinkholes are like a wart. Nobody wants them, and nobody wants to say where they are."

Larsen is a farmer himself, which gives him credibility with landowners. And dye tracing often provides them with an incentive to do the right thing. "It makes farmers aware of what they're applying manure around," says Larsen. "They can see what they do on their ground affects the neighbor's ground water, the neighbor's spring, the neighbor's well."

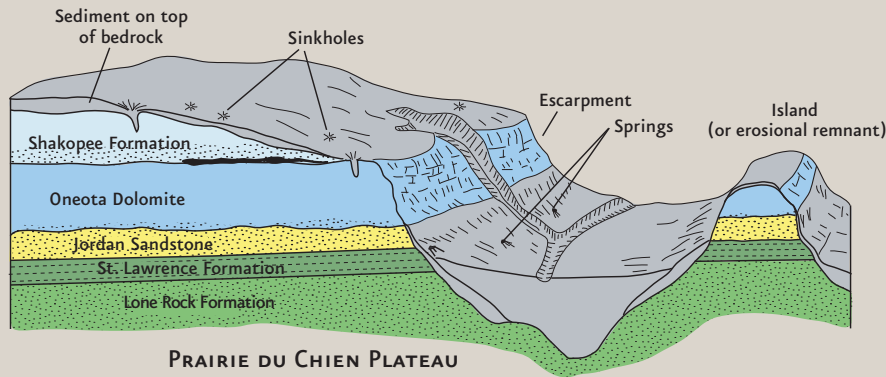
After lunch we take Larsen up on an offer to visit McConnell spring, where he has placed a bug. To get there we drive to the end of a field road, then make our way into a woods. Near the edge of a steep valley known as a coulee, we begin hiking in switchback fashion until we arrive at a small seep. Stepping carefully over slick rocks, we move toward the sound of rushing water. An alcove interrupts the coulee wall on our right. At the corner, the spring's 25-foot-high grotto comes into view. Clear water pools at its base, then tumbles in a narrow streambed over several cascades before disappearing around a bend. The grotto provides a cross-section view of part of a group of rocks known as the Galena formation.

The Galena is characterized by rapid underground flow through big conduits. Mystery Cave, for example, occurs in it.

The upper portion of McConnell spring's grotto wall is limestone. The lower portion from which the water flows is recessed because it is a mixture of limestone and shale, which erodes more easily.



UPPER CARBONATE PLATEAU



PRAIRIE DU CHIEN PLATEAU

ILLUSTRATION COURTESY OF MINNESOTA GEOLOGICAL SURVEY

Paleozoic Plateau is the term geologists use when referring to the region known as the Driftless Area. In southeastern Minnesota, the local geography is further subdivided into the Upper Carbonate and Prairie du Chien plateaus. Sinkholes form in the soluble limestone of the Prosser formation (top illustration) and the soluble dolomite of the Shakopee and Oneota layers (bottom illustration). Atop both these plateaus, there is very little surface water because precipitation quickly moves through the thin soil into cracks in the bedrock and sinkholes. Springs are natural discharges for ground water, and they occur in the Paleozoic Plateau where an incised valley cuts deep enough into the landscape to expose a layer of water-bearing rock.

Green says that during rain events here, water moves quickly from the surface to springs, making them susceptible to warming or contamination. Ultimately this runoff reaches trout streams such as Kinney Creek, which is fed by McConnell spring. The creek's water flows into the North Branch of the Root River and quickly makes its way to the Mississippi River.

In deeper formations, water's path is harder to trace.

Southeastern Minnesota has two distinct plateaus of karst. Galena limestone crowns the Upper Carbonate plateau. East of Rochester along Interstate 90 is a lower step known as the Prairie du Chien plateau, which is topped by soluble dolomite. Karst features

such as sinkholes and porous streambeds, or sinking streams, are common here.

Exit on Highway 76 and head south toward the Root River and deeper formations are visible in roadside outcrops. Beneath the heather-gray dolomite is orange-hued, coarse-grained Jordan sandstone. Next, a pale coppery green signifies the transition to very fine siltstone, shale, and sandstone—known as the St. Lawrence formation. Farther south, just upstream of Corey Creek, a mix of fine-grained sandstone, siltstone, and dolomite is visible. This formation is known as Lone Rock.

On the highway's west side, a tidy white farmhouse with a red steel roof overlooks a pair of ponds. Upstream is a steep hillside faced with a wall of stacked limestone and a wooden door. Behind the door, a spring flows out of the Lone Rock formation. It feeds cold, clean water to the brook trout in Corey Creek. A pump and pressure tank deliver spring water to Harvey and Mary Krage.

The Krages are naturally curious about their spring. Since 1989 they have allowed the DNR to monitor its flow. "We've known from the get-go that the gem of this property is the spring," says Mary Krage. "People ask why do we let the DNR on our property. Our refrain



Harvey, Justin, and Mary Krage (top) stand in front of their springhouse, which was constructed in the late 1800s. Near the springhouse, Green measures the flow of the Krages' spring by timing how long it takes to fill a five-gallon bucket. The DNR has been monitoring the flow of this deep spring in the Lone Rock formation since 1989.



Green stands in the Campbell Creek valley where a small stream (above) sinks underground into the St. Lawrence formation. Green determined via dye tracing that water from this disappearing stream travels underground for about a mile before emanating from a boiling sand spring (opposite page) in the Lone Rock formation. The dye trace conducted at this location was the first to confirm Lone Rock springs are vulnerable to contamination from water sinking into the St. Lawrence formation.

has always been because we want to know more about it.”

The monitoring has produced valuable data for DNR hydrologists on how deep Lone Rock springs respond to periods of drought and flood, according to Green. “It helped us figure out this system of rain falling on the landscape, raising the pressure of the aquifer, and pushing out the water,” he says.

In August 2007, record-setting rains in-

undated 28 southeastern Minnesota counties. Torrential floods took seven lives and caused extensive property damage. The Krages’ spring, which normally delivers 100 gallons per minute, jumped to 700 gallons per minute. Their springhouse was damaged, but the water piped from the spring to their home remained safe to drink. Most likely, Green says, the source of the Krages’ Lone Rock spring isn’t directly connected to the surface.

Following the flood, the city of Rushford discovered contamination in two of its three wells. Six miles north of the city, a trapper noticed something peculiar: The water in Ahrensfield Creek was disappearing underground as if its bed were a sieve. When the trapper notified the city, officials wondered if surface water was somehow ending up in Rushford’s wells and contaminating them.



Performing a dye trace on Ahrensfield Creek, Green found none of the dye ended up in Rushford’s wells. But to his surprise, the dye showed up within weeks in springs at the bottom of the St. Lawrence formation.

“It’s not supposed to do that,” says Green, because the formation was long thought to be an impermeable rock layer, or aquitard.

Subsequent dye tracing found that even the deeper Lone Rock springs had connections to surface runoff via sinking streams in the St. Lawrence formation. While shallower aquifers in the Prairie du Chien and Jordan have long been plagued with nitrate contamination from agricultural runoff, this finding was “really significant because we thought these St. Lawrence and Lone Rock springs were protected. . . . We didn’t know they were connected to the land surface.”

Because the sinking streams of the St. Law-

rence formation are not considered karst, there aren’t any regulations on where and how manure can be stored in the fields where these windows to ground water are found.

“These springs are a lot more sensitive than we thought,” says Green. He notes the discovery has begun to spur discussion with counties and the MPCA about how to protect the deep aquifers that sustain trout streams and provide many local residents with drinking water.

Growing demand for silica sand helped spur the Legislative–Citizen Commission on Minnesota Resources to recommend trust-fund dollars for the DNR springshed mapping project. The oil and gas industry prizes the large, hard, uniform grains of Jordan sandstone for propping open cracks in deep, hydraulically fractured oil wells. The spring-



Jordan sandstone's relatively round grains of quartz (top) were shaped as winds blew the sand across the Earth's surface some 500 million years ago. Jordan sandstone aquifers are water-rich because loosely cemented grains of Jordan sandstone (above) act like a sponge.

Water rushes from a Jordan sandstone spring alongside Highway 76 (right) in the Richard J. Dorer Memorial Hardwood State Forest midway between Caledonia and Houston.

shed map Green created will be used to help inform whether a proposed sand mine could disrupt the flow of underground water to a spring.

But the prospect of so-called "frac sand" mining in places where it wouldn't harm springs isn't Green's primary concern. "This landscape is more fragile than people realize, but it's not fragile in the way some people think," says Green. While silica sand mining may affect ground water in some locations, he says agriculture is already having a very large regional impact on water.

As we hike up the coulee away from McConnell spring, Larsen admits that visiting such places is one perk of his job, but more satisfying is helping landowners learn how to protect them.

"Nothing makes me happier than when I've worked with someone, and I drive by and I see a recommendation to not spread manure within a sinkhole watershed was followed," says Larsen. He hopes that awareness of the land's geology will lead a landowner "to be a good neighbor, to be a good steward." 