A PEEK BENEATH THE SURFACE

The porosity and permeability of bedrock determine how water moves through it. This photo is from southwestern Wisconsin where sandstone and dolomite is the principal aquifer. The cross-sectional illustration shows how Wisconsin's four main aquifer types are stacked on top of each other. The green layer represents crystalline, gray is sandstone and dolomite, brown is eastern dolomite and gold is sand and gravel.

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WISCONSIN GEOLOGY REVEALS INTERESTING HISTORY.

Eric Verbeten

Take an imaginary walk down into Wisconsin's "basement" and have a look around; some interesting history awaits. Inspect the walls of the foundation and a few things are obvious. For one, the walls are made up of different materials and they are warped, full of cracks and weren't poured at the same time. These craggy rock formations that make up the underbelly of the state formed hundreds of millions of years ago, but still play a major role today, impacting the quality and availability of groundwater. Along with the sand and gravel left behind by the glaciers, these geologic formations provide groundwater to over two-thirds of the people living in Wisconsin.

Few are more intrigued by this historic blueprint than Department of Natural Resources Hydrogeologist Larry Lynch, who has worked on many groundwater-related issues during his more than 30 years with DNR.

"In order to know what is happening with water at the faucet, it's essential to know what we're dealing with underground," says Lynch. "We need to understand how different geologic formations interact with water and how water moves through them. When looking at a rock formation, we have to understand two keywords — porosity and permeability."

Porosity measures how much empty space is between the solid particles in the rock, meaning the more hollow spaces it has in it, the more porous the substance. On the flip side, permeability measures how connected those void spaces are. Each characteristic alone doesn't tell the whole story about the rock, but in combination they can answer a lot of questions about the presence and movement of groundwater, like where it is found, how much is available and how quickly it will replenish from water trickling in from the surface.

For example, a mixture of sand and gravel is both porous and permeable because water can move easily through the well-connected pores between the rounded sand grains and gravel-sized rocks. Clay, like that found in the bottom of a lake, has a very high porosity but a low permeability because the clay particles are flat but not necessarily neatly stacked. There is more empty space between the clay particles but water can't move as easily through the plate-shaped particles.

Digging deeper, the foundation gets older and is often more dense. Igneous rocks like granite are massive, not granular. Very little water is contained within the rock, but instead accumulates in cracks and crevices.

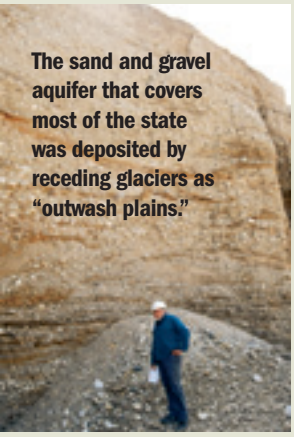
Let's take a more in-depth look at the rock types that make up Wisconsin's basement foundation and ultimately determine how much groundwater is available by location.

Wisconsin aquifers

An aquifer is a rock or soil formation that can store or transmit water. Wisconsin's groundwater reserves are held in four main types of aquifers: sand and gravel, eastern dolomite, sandstone and dolomite and crystalline bedrock.

Sand and gravel aquifer – The sand and gravel aquifer is the sediment covering most of the state except parts of southwest Wisconsin. As the name suggests, it is made up mostly of sand and gravel deposited from glacial ice or in river floodplains. Glacial deposits are loose and referred to as soil — but they include much more than just a few feet of topsoil. These deposits are more than 300 feet thick in some places in Wisconsin.

Glaciers, formed by the continuous accumulation of snow hundreds of thousands of years ago, played an interesting role in Wisconsin's geology. Snow turned into ice, which reached a maximum thickness of almost 2 miles. The ice sheet spread over Canada and part of it flowed south toward Wisconsin and neighboring states. As the ice flowed, it ground up the underlying rock and carried it along in what is known as glacial drift. As the ice melted, large amounts of sand and gravel were left behind, forming "outwash plains." Pits formed in the outwash where buried blocks of ice melted, forming what are now lakes.



The sand and gravel aquifer that covers most of the state was deposited by receding glaciers as "outwash plains."

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The sand and gravel aquifer was deposited within the past million years, with its outwash plains forming some of the best aquifers in Wisconsin. Many of the irrigated agricultural lands in central, southern and northwestern Wisconsin use the glacial outwash aquifer. Other glacial deposits are also useful aquifers, but in some places, large glacial lakes accumulated thick deposits of clay. These old lake beds of clay, however, do not yield or transport much water.

Due to the sand and gravel aquifer's dual role of being part groundwater storage and also the land we walk on, it is highly susceptible to human-induced and naturally occurring pollutants.

Eastern dolomite aquifer – This aquifer runs from Door County to the Wisconsin-Illinois border and consists of a layer of dolomite underlain by a layer known as Maquoketa shale. These rock formations were deposited 400 to 425 million years ago. Dolomite is a rock similar to limestone in that it holds and transports groundwater through interconnected cracks and fractures. The amount of water a well can draw from this aquifer depends on how many fractures intersect with the well and how well-connected the fracture network is. As a result, it's not unusual for nearby wells to vary greatly in the amount of water they can draw from this layer. Some wells hit the network, some do not.

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The eastern dolomite aquifer is similar to limestone and holds and transports groundwater through cracks and fractures.

Groundwater in shallow portions of the eastern dolomite aquifer can easily become contaminated in places where the fractured dolomite occurs at or near the land surface. In those areas (such as parts of Door, Kewaunee and Manitowoc counties) there is little soil to filter pollutants carried by precipitation from the land surface. Little or no filtration takes place before the water reaches large fractures in the dolomite. Groundwater quality problems, such as bacterial and viral contamination from human and animal wastes, can result in these "karst" areas, where sinkholes and caves are known to occur.

The Maquoketa shale layer beneath the dolomite was formed from clay that doesn't let water through easily. Therefore, its importance is not as a major water source, but as a barrier or shield between the eastern dolomite aquifer and the deeper sandstone and dolomite aquifer.

Sandstone and dolomite aquifer – This aquifer consists of layers of sandstone and dolomite bedrock that vary greatly in their water-yielding properties. In dolomite, groundwater mainly exists in cracks and fractures. In sandstone, water occurs in pore spaces between loosely cemented sand grains. These formations can be found over the entire state, except in the north central portion.

In eastern Wisconsin, this aquifer sits below the eastern dolomite aquifer and the Maquoketa shale layer. In other areas, it lies beneath the sand and gravel aquifer. These rock types gently dip to the east, south and west, away from north central Wisconsin, becoming much thicker and extending to greater depths below the land surface in the southern part of the state.

The rock formations that make up the sandstone and dolomite aquifer were deposited between 425 and 600 million

LOCATIONS OF WISCONSIN AQUIFERS

THOMAS SENATORI (BASED ON MAP BY DAVE HART, WGNHS)

These maps show the location of three types of bedrock aquifers in Wisconsin. A fourth, the sand and gravel aquifer, is the sediment covering most of the state except parts of the southwest.

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The crystalline bedrock aquifer is Wisconsin's basement, composed of hard rocks like granite, gneiss, basalt and quartzite.

years ago. The sandstone and dolomite aquifer is the principal bedrock aquifer for the southern and western portions of the state and can produce large amounts of water. In eastern Wisconsin, most users of substantial quantities of groundwater, such as cities and industries, tap this deep aquifer to meet their water needs.

Crystalline bedrock aquifer – This is the oldest of the four aquifers and is composed of different types of rock formed during the Precambrian Era. This era lasted from the time the Earth cooled more than 4,000 million years ago, until 600 million years ago, when the rocks in the sandstone and dolomite aquifer began to form. During this lengthy period a lot of change happened: sediments rich in iron were deposited in ancient oceans, volcanoes blasted ash and lava all over the globe, mountains were built up and then slowly ground down, molten rocks from the Earth's core flowed up through cracks in the upper crust and sank back down.

All this activity played a role in shaping the aquifers we have today, and what remains are many different hard and crystalline rocks (granite, gneiss, basalt and quartzite) underlying the entire state as a "basement." But they peek out in areas like the north central region, where they rise up and are the only rocks found beneath the shallow sand and gravel top coat.

The cracks and fractures in the crystalline bedrock aquifer transport and store water, in some areas more than others. Some are full of interconnected cracks while others contain very few. To obtain water, a well must intersect these cracks where the water accumulates; the amount of water available to a well can vary greatly, even within the area of a single homesite. In general, the fracture networks in this aquifer are poorly connected when compared to the eastern dolomite aquifer. As a result, this aquifer rarely provides adequate quantities of water for larger municipalities, large dairy herds or industries.

Wells in the crystalline bedrock aquifer can provide good quality but limited quantities of water. Most wells tap the upper part of the aquifer because that is where most of the fractures are found. Where overlying sediments are thin, the aquifer can be susceptible to contaminants from the land surface.

To a large extent, the composition and configuration of Wisconsin's aquifers determine where we build our homes, cities and businesses. Read the story about the challenges Wisconsin faces in protecting groundwater and providing clean, pure drinking water to maintain our economy, environment and health in "Groundwater: Powering Wisconsin's Economy," inserted in this issue.

Eric Verbeten was formerly a communications specialist with Wisconsin DNR. He now works for the UW-Madison Space Science and Engineering Center. Portions of this story appeared in previous versions of "Groundwater: Wisconsin's Buried Treasure."

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Cathy Stepp, *Secretary*
Wisconsin Department of
Natural Resources

Dear Readers,

I'm honored and pleased to introduce our very popular groundwater insert for *Wisconsin Natural Resources* magazine's February 2017 issue.

Over the years, we've seen interest in this document grow — this is the fourth edition of the insert since its first release in the 1980s, and every time it comes out our readers snap up the thousands of copies we print. That speaks not only to the great following our magazine has, but also to how much our citizens care about safe, clean drinking water for everyone in the state.

In this edition, we take you through a snapshot review of our groundwater resources in "Groundwater by the numbers." Our readers can also learn the important role groundwater plays in keeping our businesses going with "Powering Wisconsin's economy," viewing different economic profiles of Wisconsin businesses.

In our "Challenges and solutions" section, we talk about some of the critical groundwater issues of the day we face as our state continues to change and grow. Finally, private well owners can learn how to keep their drinking water safe.

We hope you enjoy this edition of the groundwater insert, and thank you for your continued support of the DNR and our great natural resources. We are committed to keeping our state's groundwater and surface waters clean and safe, and we will continue to work together with all our state and local partners and stakeholder groups to address water quality issues across Wisconsin now and in the future.