GROUNDWATER and fractured crystalline bedrock in Wisconsin's National Forest

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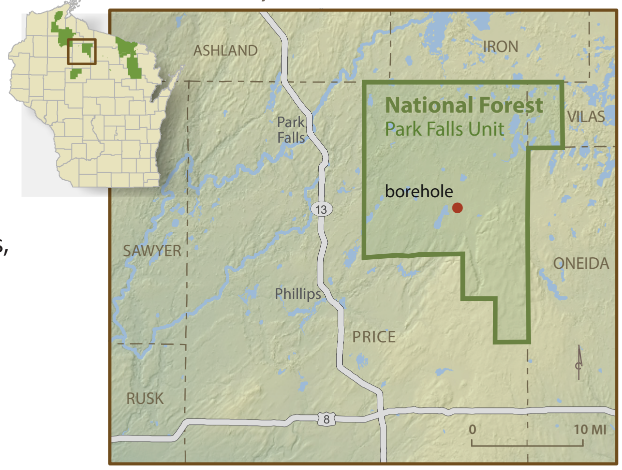
Groundwater is an important resource for the Chequamegon-Nicolet National Forest in northern Wisconsin. It is stored in and moves through aquifers composed of sand and gravel or bedrock. It supplies flow to the forest's numerous springs, streams, and lakes and provides drinking water across this region.

In many parts of the forest, a shallow sand-and-gravel aquifer provides groundwater. But where this aquifer is missing, groundwater is limited to the underlying bedrock aquifer where yields to wells are often low. Groundwater flows easily through pores in sand and gravel, but in crystalline bedrock, the pore spaces are very small and groundwater can often only flow through fractures in the rock.

Understanding groundwater flow in fractured bedrock can be challenging because information about the aquifer is sparse; the water supply wells which typically provide information about the aquifer are more commonly drilled in places with better well yield.

Location of 1,000-ft borehole



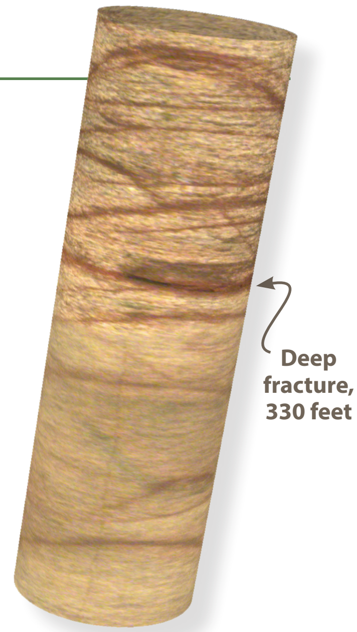


Figure 1. Borehole location. Pictures taken inside the hole revealed many fractures (dark bands) present in the bedrock. The fracture found at 330 feet was unusual for the large volume of water flowing from it.

Exploratory borehole—a window into the bedrock

An exploratory borehole drilled deep into the granite bedrock in Price County (fig. 1) provided a rare opportunity to investigate groundwater flow in fractured bedrock in the National Forest.

The 1,000-foot deep borehole was drilled in 2013 as part of a Department of Energy project to investigate geothermal energy in Wisconsin. The Wisconsin Geological and Natural History Survey (WGNHS) measured temperatures and flow in the borehole. These measurements showed us how groundwater can move through the granite bedrock.

Groundwater flow in the borehole

We observed fractures throughout the borehole, but only a few produced groundwater flow. Notably, groundwater flowed into the open borehole through a deep fracture at 330 feet, then upwards and out of the borehole through fractures at about 100 feet (near the top of the bedrock).

There was enough pressure in the deep fracture that, if the upper fractures hadn't been present,

Wisconsin's crystalline bedrock aquifer: *Did you know?*

- **About 1 in 5 domestic wells** in the Park Falls Unit of the Chequamegon-Nicolet National Forest rely on the bedrock aquifer for groundwater.
- **Wells finished in bedrock** typically produce about 1⁄10th the water produced by wells finished in sand and gravel.
- **Bedrock fractures** are common in much of northern Wisconsin, but are not always connected. Many fractures provide no measurable groundwater flow.
- **Most groundwater flow** in crystalline bedrock occurs in shallow fractures; fractures deeper than a few hundred feet rarely provide significant flow.

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Kenneth R. Bradbury, *Director and State Geologist*

groundwater would have flowed out of the top of the borehole as an artesian well, meaning the water level for the fracture is *above* the land surface. How is this possible when the local water table is several feet *below* the land surface? The deep fracture isn't connected to the nearby shallow water table. This suggests the presence of a network of fractures that connects the deep fracture to an area of higher elevation but does not connect to shallower fractures near the borehole. Figure 2 illustrates how this might work.

Below the deep fracture at 330 feet, the borehole produced no measureable flow, even though other fractures were present. In fact, the bottom 670 feet of the borehole did not produce enough water to supply a home. This low yield below several hundred feet is typical for wells in Wisconsin's crystalline bedrock.

Using the borehole for ongoing research

To continue studying groundwater in bedrock, two water-level monitoring wells were installed in the borehole. These wells are screened in the shallow and deep fracture zones (fig. 2) and have been added to the Wisconsin groundwater monitoring network (tinyurl.com/groundwater-network).

The water level in the deep well, which is connected to the deep fracture, is consistently about 5 feet higher than in the shallow well. The deep well also responds more slowly to precipitation, suggesting that groundwater follows a longer flow path to reach that well. Conversely, the shallow well likely has a better connection to the local water table.

Insights into bedrock-groundwater interactions

The data collected at this borehole provide insights into how groundwater flows through fractured bedrock that can be applied to groundwater management in bedrock aquifers.

- Most fractures don't have measurable groundwater flow.
- Well yield and groundwater discharge are dependent on how fractures are connected.
- Fractures can connect in surprising ways. Here the deep fracture is connected to the surface several thousand feet from the borehole and didn't connect to the much closer fracture just 200 feet directly above it.
- Groundwater fracture flow is most common in the top several hundred feet of bedrock.

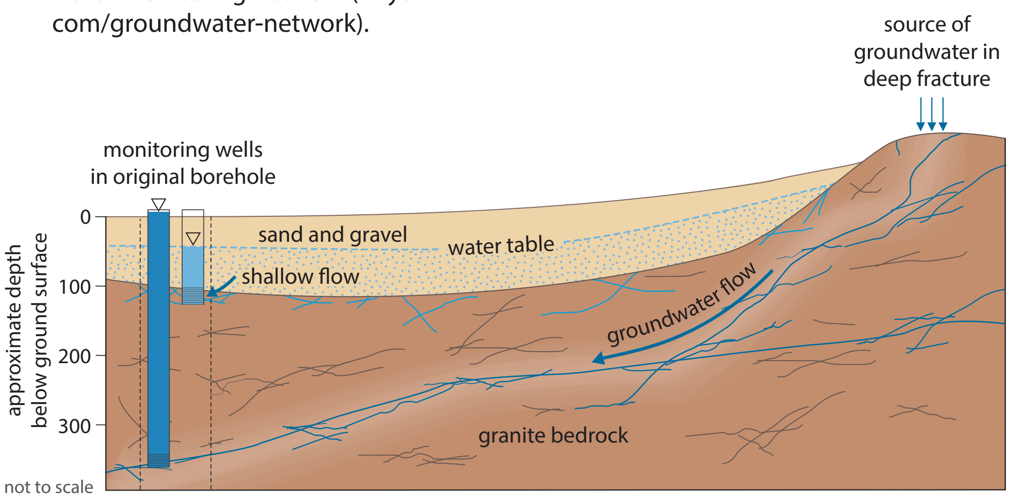

Figure 2. Diagram showing how groundwater could flow from an area of higher elevation to the deep monitoring well through a network of fractures (dark blue). This network is not connected to the sand-and-gravel aquifer or to the shallow bedrock fractures near the well (light blue). Some fractures (gray) are not connected to either system and therefore have little to no groundwater flow. This figure only shows the upper 350 feet of the borehole; the rest of the hole was filled in.

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