U.S. Department of the Interior
U.S. Geological Survey

The Mirror Lake Fractured-Rock Research Site—A Multidisciplinary Research Effort in Characterizing Ground-Water Flow and Chemical Transport in Fractured Rock

USGS

The Need for Research in Fractured Rock

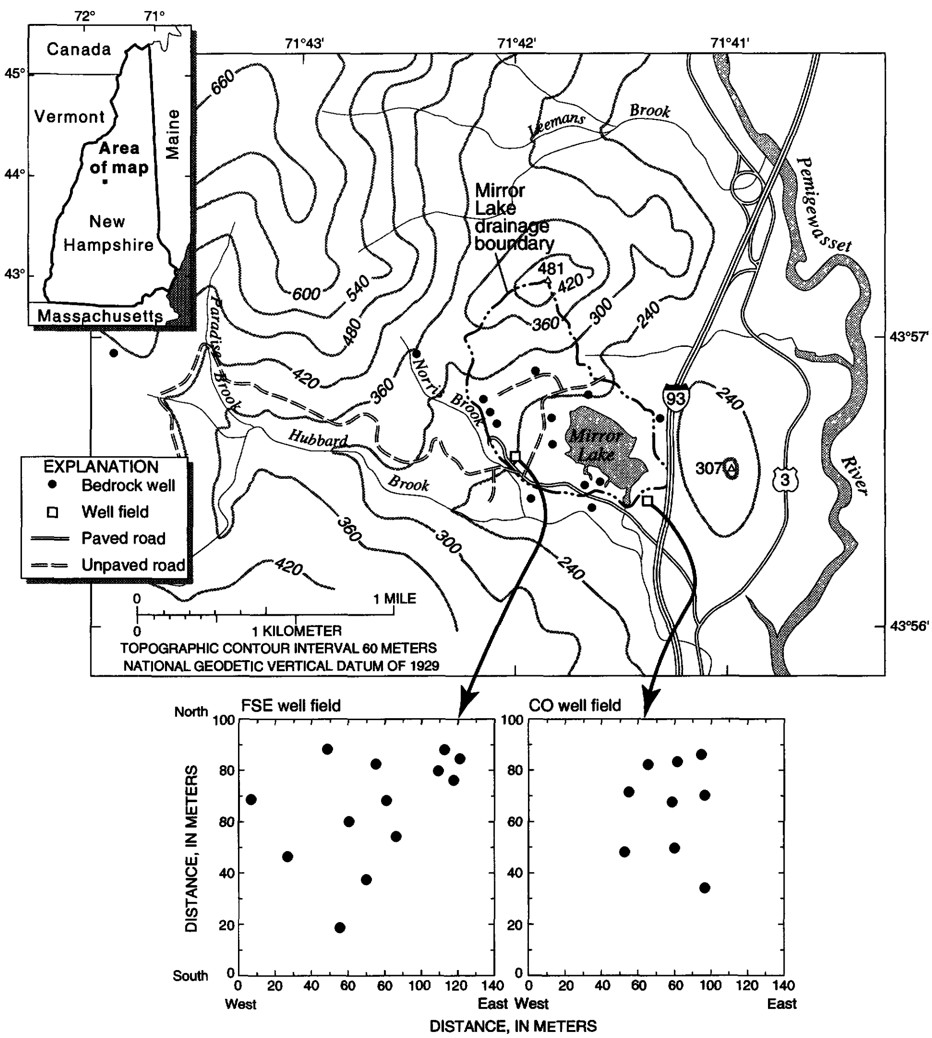
In many areas of the Nation, increasing quantities of water are withdrawn from rock formations where cracks, joints, and faults (collectively referred to as "fractures") are the principal conduits for ground-water flow. Managing these ground-water resources requires the evaluation of the availability of water and the risk of contamination. However, current understanding of ground-water flow in fractured rock is limited. Methods that have been developed to evaluate water resources in unconsolidated sand and gravel formations commonly are not applicable to the complex hydrology and geology of fractured rocks. Rocks do not fracture uniformly, and rates of ground-water flow through fractures can range more than 10 orders of magnitude. Methods of characterizing ground-water flow and the transport of dissolved chemicals need to be developed for the evaluation of water resources in fractured-rock terranes.

In 1990, the Toxic Substances Hydrology Program of the U.S. Geological Survey (USGS) began investigations of the bedrock in the Mirror Lake watershed in Grafton County, New Hampshire, to address the Nation's need for accurate and efficient methods of evaluating ground-water resources in fractured rock. The purpose of this ongoing research is to develop methods to detect fractures and to characterize their ability to transmit water and dissolved chemicals. To meet this goal, the broad spectrum of techniques being applied at the Mirror Lake site includes geologic, geochemical, geophysical, and hydrologic methods. About 25 research scientists from the USGS, universities, and research institutes are engaged in collaborative studies at the Mirror Lake site.

Hydrogeology of the Mirror Lake Area

The Mirror Lake drainage basin, which is about 0.8 square kilometers, is located at the lower end of the Hubbard Brook Valley in the southern White Mountains of central New Hampshire. The Mirror Lake drainage basin lies partly within the Hubbard Brook Experimental Forest, which is an ecosystem research site operated by the U.S. Forest Service. Bedrock in the Mirror Lake area consists primarily of metamorphic rock (schist), which has been extensively intruded by igneous rocks (granite, pegmatite). The bedrock is covered with a combination of silt, sand, cobbles, and boulders (collectively referred to as "glacial drift"), which ranges in thickness from 0 to 55 meters. In the Mirror Lake area, road cuts adjacent to Interstate 93 provide sites for detailed studies of fractures. Study results show that the granite is more densely fractured than the schist and that the fractures in the granite are shorter and more planar than those in the schist.

Because fractures at land surface might not be representative of fractures underground, wells (also referred to as "boreholes") have been drilled into the bedrock. At the Mirror Lake site, wells have been drilled at two densities for two scales of investigations. The local scale investigations focus on two experimental plots, which are referred to as the "FSE" and the "CO" well fields; each occupies a 100- by 100-meter area, where wells are spaced from 10 to 40 meters apart. The regional



The Mirror Lake fractured-rock research site.

scale investigations focus on a 1-square-kilometer area that includes the entire Mirror Lake drainage basin. Wells used in the regional scale investigation are spaced several hundred meters apart. By the end of 1994, 13 wells had been completed in bedrock in the FSE well field, 9 in the CO well field, and 14 at other locations throughout the drainage basin. These wells range in depth from 60 to 300 meters. In addition, more than 40 shallow wells have been installed in the glacial drift throughout the Mirror Lake area to monitor shallow ground water.

Detecting Fractures in Rock

The results of local scale investigations in the FSE and the CO well fields are important to the solution of many problems related to ground-water-resource evaluation, such as evaluating the risk of contamination to domestic water wells and remediating sites of ground-water contamination. Because fractures are the principal conduits for water and chemical movement in rocks, the focus of the local scale investigations is on the development of geophysical and hydrologic testing methods that can be used to identify fractures below land surface and to determine the ability of these fractures to transmit water and dissolved chemicals.

Fractures in the subsurface cannot be observed directly except in boreholes. Therefore, geophysical and hydrologic testing infer the presence of fractures from other information. For example, in geophysical testing, fractures are identified from the physical response of rocks to disturbances, such as radar, seismic, or electrical signals, induced in the rock from either the land surface or through wells.

Surface geophysical methods that use radar, seismic, and electrical signals generated at the land surface are being developed and tested at the Mirror Lake site to identify major water-bearing features, such as fault zones, that may extend over hundreds of meters. In addition, surface geophysical methods are being developed to identify the principal orientation of the smaller, more numerous fractures in the rock.

Geophysical methods also are being developed for use in boreholes. Methods that scan borehole walls to identify fractures are being evaluated. These include a submersible television camera and an acoustic tool that measures the acoustic transmitting response of fractures exposed on borehole walls. Bedrock exposed on borehole walls, however, provides only a small view of the rock volume. Therefore, geophysical methods that image fractures away from boreholes also are being developed and tested. In one method, known as tomography, seismic or radar signals are transmitted from one borehole, and their reception is monitored in an adjacent borehole. The method is similar to the medical industry's use of CAT (computerized axial tomography) scans.

Hydrologic testing, which consists of hydraulic and tracer testing, is the most direct method of measuring the ability of fractures to transmit water and dissolved chemicals. Hydrologic tests generally involve either injecting or withdrawing water or altering the chemical composition of water in the subsurface so that the response can be measured. Methods of conducting hydraulic and tracer tests from boreholes are being designed and evaluated to identify fracture geometry, the hydraulic properties of fractures, and the ability of fractures to transport dissolved chemicals.

Regional Ground-Water Flow and Chemical Transport

Results of regional scale investigations of fractured rock are important in assessing domestic and industrial water supplies and the fate of contamination from point and nonpoint sources of pollution. In regional scale investigations, wells completed in bedrock are less frequently spaced, thus making it impractical to conduct geophysical and hydrologic testing. At the Mirror Lake site, geologic, hydrologic, and geochemical information is being interpreted to identify rates of ground-water flow and chemical transport over distances of several kilometers.

The variability in water levels caused by seasonal changes in recharge is being used to calibrate three-dimensional numerical models of ground-water flow in the fractured rocks of the Mirror Lake area. The calibrated model can be used to simulate ground-water flow under different conditions of natural recharge, such as extended periods of drought, and ground-water withdrawals, such as the pumping of domestic wells.

Research on predicting the transport of dissolved chemicals in the water of fractured rock aquifers is being conducted by using tracers that are part of water (rainfall) that is recharged to the subsurface. For example, tritium derived from atmospheric thermonuclear testing in the 1960's and CFC's (chlorofluorocarbons) released to the atmosphere from the production of coolants, plastics, and other products over the last 40 years are being used to estimate the age and the velocity of ground water in fractured rock.

Benefits of Research in Fractured Rock

Methods of characterizing ground-water flow and the transport of dissolved chemicals developed in the ongoing studies at the Mirror Lake site are the tools needed to manage ground-water resources in fractured-rock terranes. The results of the local scale investigations illustrate that water-bearing fractures can be detected by using a combination of geophysical and hydrologic testing methods. In regional scale investigations, methods of synthesizing hydrologic and geochemical information can be used to predict volumes and rates of ground-water flow. Understanding ground-water flow at these scales of investigation is important in ground-water-management programs, such as planning domestic water supplies and assessing strategies for containing and restoring contaminated ground water.

For More Information

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