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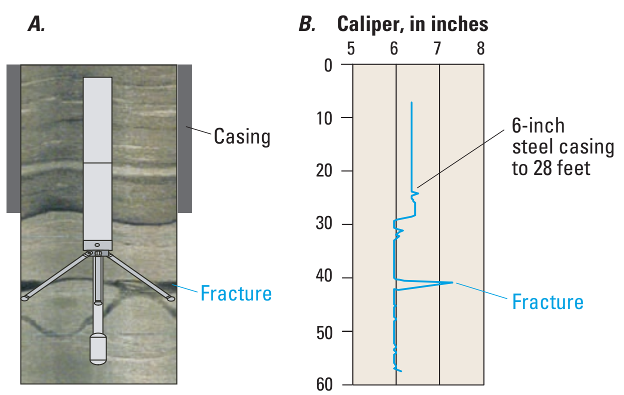
Borehole Geophysical Logging of Water-Supply Wells in the Piedmont, Blue Ridge, and Valley and Ridge, Georgia

Crystalline and carbonate-rock aquifers in northern Georgia provide water to an ever-increasing number of private and public wells in the region. Understanding the depth and yield of water-bearing zones in such wells is crucial for the development and long-term sustainability of ground-water resources and for keeping wells in good operating condition. Portable geophysical logging units are now widely available and have greatly increased the ability of geoscientists to obtain subsurface information from water wells.

What Is Borehole Geophysical Logging?

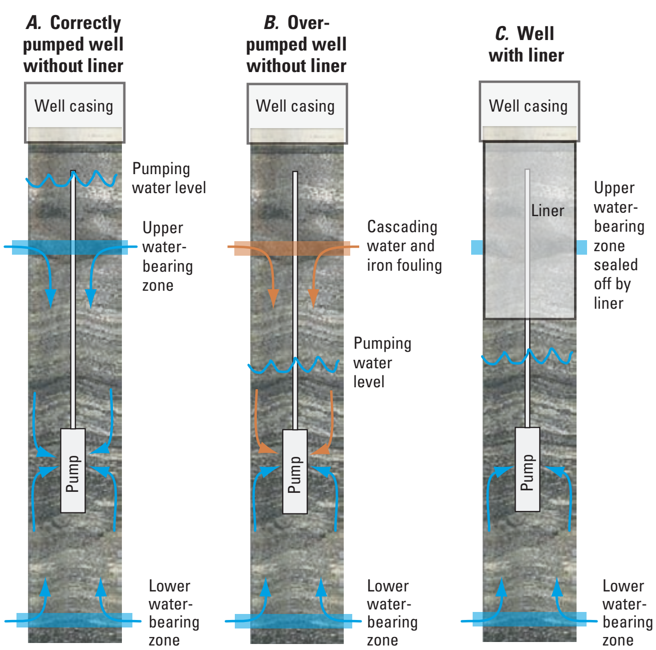
Many different types of tools are used to collect subsurface data in wells (Haeni and others, 2001; Keys, 1990, 1997). These include submersible cameras and highly sophisticated instruments that measure water quality, detect lithologies, and measure formation properties. Geophysical logging tools are lowered into a well by a long cable and continuously record the physical properties of the rock and fluid. Resulting data are presented in graphs called borehole geophysical logs. A caliper log, for example, is a continuous record of the well diameter that can be used to detect fracture openings or changes in well construction.



(A) As the caliper tool crosses a fracture, the arms open slightly, creating the inflection on the caliper log *(B)*. This example log shows a fracture at about 42 feet below land surface.

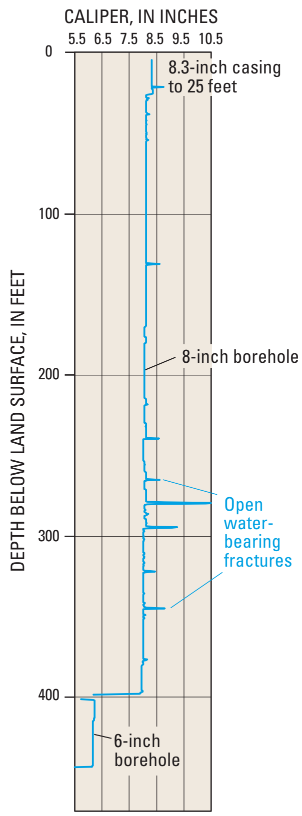
Why Log a Well?

Geophysical logs are extremely important to gain a better understanding of the aquifer system and fractures supplying a well. Drilled wells in northern Georgia are almost always constructed with an "open hole," which means the borehole is unlined and open to the bedrock below the surface casing (sketch *A*, right). Water enters the well through fractures and other openings in the otherwise solid rock. In such open-hole wells, it is important to ensure that water-bearing fractures are not exposed to air due to overpumping or declining water levels. Iron fouling and water-quality degradation may result if the water level is lowered below a water-bearing fracture and water cascades into the open portion of the well and mixes with air (sketch *B*, below). This situation can be avoided by maintaining the pumping level above any water-bearing zone *(A)* or using a casing or liner above the fracture (sketch *C*, below). Although the depths of some water-bearing zones are known from the driller's log, not all zones are detected. Borehole geophysical logs help locate all of the water-bearing zones in a well. With this information, a well can be constructed or refurbished to prevent water from entering the borehole from undesirable locations. Logs also are used to evaluate casing condition; well construction; grouting seal of new, old, or refurbished wells; lithologic or geologic units; relations among water-producing zones and lithologic units; and water-quality problems as described on the following pages.

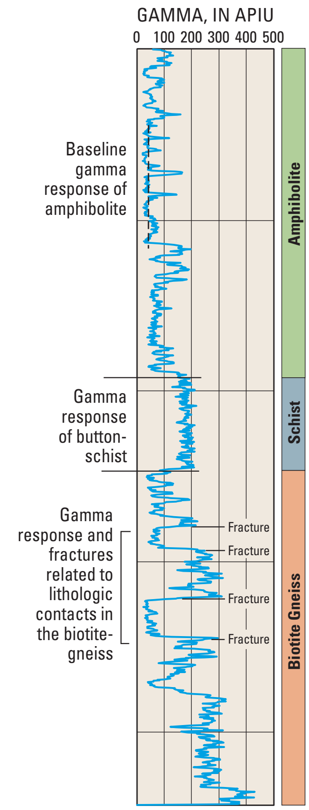


Geophysical logs can be used to detect and prevent water-bearing zones from being exposed in the open portion of the borehole. *(A)* shows a correct pumping water level, (*B*) shows an over-pumped well without a liner, and *(C)* shows a liner that seals off shallow-water zones.

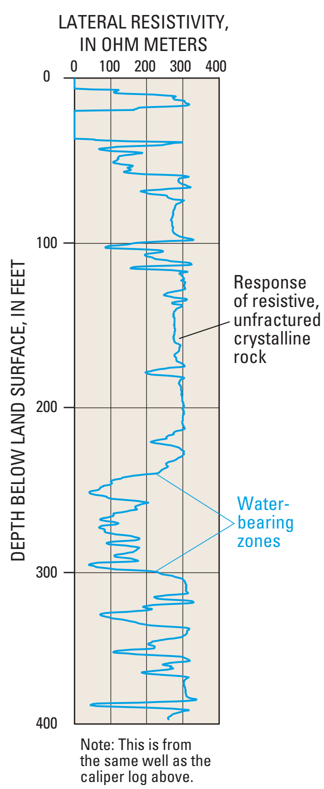
Caliper logging continuously records well diameter and can be used to detect fracture openings or changes in borehole diameter. A log is collected by lowering the tool to the bottom of a well, opening the arms, and then pulling it up the borehole, allowing the spring-loaded arms to open or close as they pass borehole enlargements, or restrictions (Keys, 1990). Changes in the borehole diameter may be related to fractures, changes in lithology, borehole construction, or hole integrity. A caliper log mainly is used to locate fracture openings in the bedrock as shown in this caliper log obtained from a crystalline-bedrock well.



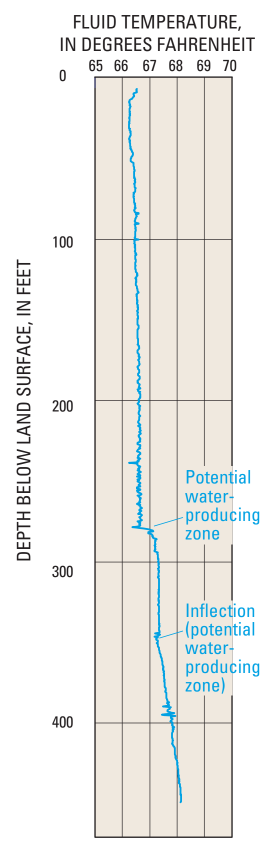
Natural gamma logging measures gamma radiation emitted by subsurface rock layers and is recorded in American Petroleum Institute units (APIU). This tool can be run in either open or cased holes and is used to determine lithology. Typically, slight changes in the APIU baseline may be observed for igneous and metamorphic rocks. The tool also may be used to detect the presence of radioactive zones, which may degrade water quality in a well.



Long- and short-normal and lateral resistivity logging measures the apparent resistivity in ohm meters. The tool applies a constant current across two electrodes while measuring the potential between two other electrodes. All three resistivity logs are collected simultaneously and can be compared. Long- and short-normal logs measure the resistivity over a larger area surrounding a borehole. Lateral resistivity measures resistivity close to a borehole. In hard, resistive crystalline bedrock, water-bearing zones typically are indicated by low resistivity. This example lateral resistivity log helps distinguish the water-bearing zones in a crystalline-bedrock well.

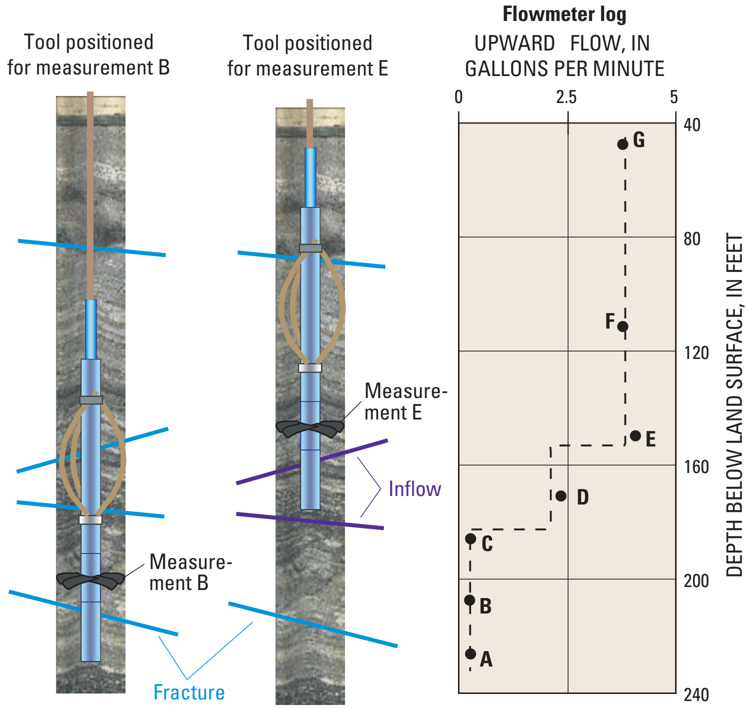


Fluid logging methods measure properties of the water column in a borehole and typically include the simultaneous measurement of fluid resistivity and temperature. Changes or inflections in the fluid temperature or resistivity are an indication of possible water-producing and water-receiving zones in a well. Fluid logs also can be collected during pumping to identify water-bearing zones. Borehole grab samples may be used to collect water samples at discrete depths.



Flowmeter logging measures the direction and magnitude of vertical fluid flow within a borehole, making it an ideal tool to identify water-producing or water-losing fractures in a well. Flowmeter measurements are collected at discrete locations, usually above and below fractures identified using logs, or as a continuous log in a trolling mode (Paillet, 1998, 2000).

How flowmeter logging works. The example to the right shows measurements taken at discrete locations. The measurements taken above and below the bottom fracture (at locations A and B) are both near zero, indicating no measurable flow from that zone. Measurements taken straddling the next fracture (C and D) show an increase in vertical flow from 0 to about 2.5 gallons per minute (gal/min); therefore, that fracture produces 2.5 gal/min. The next pair of measurements show an increase of about 1.5 gal/min indicating another water-bearing zone (between D and E). Flow measurements above E indicate no additional contribution to flow in the well (F and G).



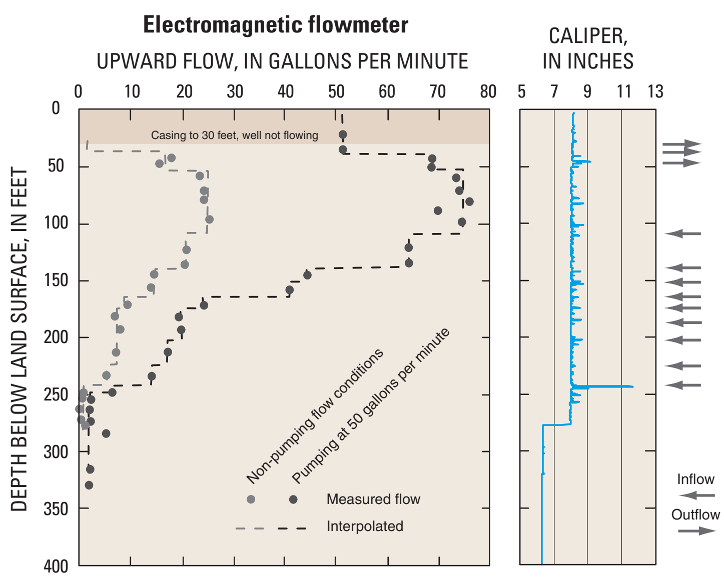
Flowmeter types:

The *electromagnetic flowmeter* with a flow diverter can measure flows between 0.1 and 15 gal/min. Greater flows (100 gal/min or more) can be measured with proper calibration of the flowmeter while using an underfit flow diverter that allows some of the vertical flow to bypass the tool (Paillet, 2000).

The *heat-pulse flowmeter* with a flow diverter can measure flows as small as 0.01 +/– 0.005 gal/min and as great as 1.5 gal/min. The heat-pulse flowmeter uses a thermal trace to measure the direction and rate of vertical flow in a borehole (Paillet, 2000).

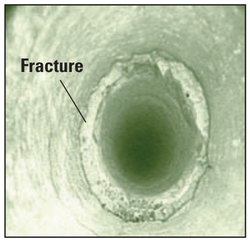
The *spinner flowmeter* measures vertical flow by recording the rotation rate of an impeller. The lowest velocity a typical spinner flowmeter can measure is about 5 feet per minute, which limits its use to higher flow rates.

The *electromagnetic flowmeter log* shown below was collected under both nonpumping and pumping conditions. Under non-pumping conditions, water enters the borehole through multiple fractures between 100 and 250 feet and exits the borehole into shallow fractures near the base of the casing (30 feet). Under pumping conditions, the flow contribution from various zones was determined; however, pumping did not change the flow relations in the well and water continued to exit the borehole near the base of the casing. A deeper casing was added to rectify this problem.

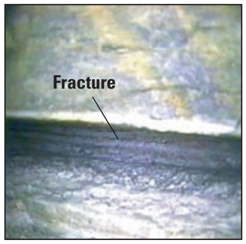


Camera logging records both downhole and side-looking views of a borehole and permits direct inspection of the borehole wall and details of the well construction. The images can be used to identify changes in rock type and small-scale geologic structures, locate and describe fractures, and identify problems with borehole integrity and possible signs of contamination (Johnson and Dunstan, 1998). This method of borehole imaging is relatively cost-effective and logs can be collected quickly. However, detailed interpretation of video logs can be time-consuming.

Downhole view

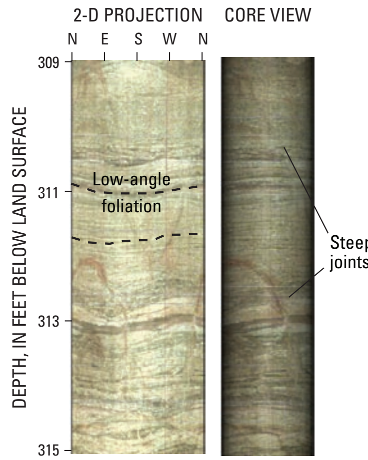


Side-looking view



Borehole camera images showing views of water-producing fracture.

Optical televiewer (OTV) logging produces high-resolution, oriented color digital images of a borehole wall. This method of imaging is relatively time-consuming; however, it is preferred over camera logging in open bedrock wells because of the ability to map lithologic units and fractures using a single log. Because it is an optical tool, the log can be only run in relatively clear water. Acoustic televiewers (not shown) can be run in both water and mud-filled holes.



This example OTV log shows lower angle foliation or layering cut by steeper joints in the borehole. The location and orientation of fractures in relation to rock fabric can be particularly useful in water-resource evaluations.

Geophysical Log Database

Geophysical logs provide a basis for larger-scale evaluations of the occurrence and availability of ground-water resources throughout Georgia. Paper copies and digital records of well-log data for wells in Georgia are stored at the U.S. Geological Survey (USGS) office in Atlanta. New logs are being collected in cooperation with State and local water agencies and communities through the USGS Cooperative Water-Resources Program (Clarke, 2006).

Summary

When planning for the long-term use of a ground-water source, borehole geophysical logs are extremely important to gain a better understanding of the aquifer system and water-bearing fractures supplying a well. Logs are used to

- locate and describe fractures and rock units;
- evaluate relations among rock types and yield;
- measure yield and water quality of producing zones;
- identify water-quality problems; and
- check casing condition, well construction, and grouting seal of new, old, or refurbished wells.

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For more information on the USGS Geophysical Logging Program

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