Construction and Use of a Fractured-Rock Simulator to Test Horizontal Borehole Flow-Measuring Technologies

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Abstract

Measurements of horizontal flow directions and velocities of ground water in bedrock aquifers that have significant secondary porosity can be invaluable to many hydrologic investigations. Calibration studies to evaluate performance of several horizontal flow-measuring technologies have been done in a simulated unlithified aquifer but have not been done in a fractured-rock simulator. This study describes the construction and initial use of a fractured-rock simulator to calibrate horizontal flow-measuring technologies.

During 2007, a fractured-rock simulator was built at the U.S. Geological Survey Hydrologic Instrumentation Facility. The fracture was simulated by two parallel, horizontal plates of 0.875-inch-thick plexiglass, sealed along the long dimension by a flexible gasket. The plates were 42 inches wide by 60 inches long. Screw adjustments allowed the fracture aperture to be uniformly opened. One 4- and one 6-inch well casing intersected the upper and lower plates. Both wells were completely open to the fracture. The hydraulic gradient across the fracture length was controlled precisely by adjusting water levels in reservoirs connected to the up-gradient and down-gradient ends of the fracture plates. A dye manifold was installed near the water inlet to the fracture to permit visual observation of flow lines.

Horizontal ground-water velocity magnitude and direction were measured in the 4- and 6-inch wells with five horizontal flow-measuring technologies. The technologies consisted of an acoustic Doppler velocimeter, a heat-pulse flowmeter, a colloidal borescope flowmeter, a scanning colloidal borescope flowmeter, and a hydrophysical logging system. Each horizontal flow-measuring technology was used to measure the water velocity magnitude and direction in both wells, except the hydrophysical logging system, which measures velocity magnitude only.

Various flow simulations were established by managing the hydraulic gradient and the fracture aperture. The tested range of hydraulic heads ranged from 0.0006 ft/ft to 0.0028 ft/ft. Measurements were made at fracture apertures of 0.039, 0.118 and 0.394 in. The linear velocity of water through the fracture was computed from tank discharges at the down-gradient end of the fracture and ranged from 605 to 6,120 ft/day.

Results indicated that the horizontal flow-measuring technologies were capable of measuring ground-water vectors at velocities less than 3,800 ft/d. Evaluation of the performance of individual technologies, however, was not possible because the simulator was determined to have some unforeseen inadequacies. Water leaked from the fracture gasket at two locations, possibly affecting the flow measurements. Ferrous metal weights, used to counteract the buoyancy of the upper fracture plate, may have interfered with magnetometer-based measurements of the flowmeter and flow orientation. Future plans call for repairs and adjustments to the fractured-rock simulator to address these issues, followed by retesting of the horizontal flow-measuring technologies in 2008 over a similar range of hydraulic conditions.