SLUG-TEST RESULTS FROM A WELL COMPLETED IN FRACTURED CRYSTALLINE ROCK, U.S. AIR FORCE PLANT 6, MARIETTA, GEORGIA

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Abstract. Storativity in fractured crystalline rock typically is low; as a result, small amounts of injection to or discharge from wells completed in such rocks can have a measurable effect on water levels in the surrounding subsurface. Aquifer tests may be difficult in areas where ground water is contaminated because pumping may affect ground-water contamination plumes, and also result in the need to dispose of pumped contaminated water. Slug tests can be used to estimate hydraulic conductivity of the near-well region without pumping. Additionally, with adequate monitoring in a well field, slug tests can be used to assess aquifer interconnectivity between wells.

Slug tests were performed in selected wells at U.S. Air Force Plant 6, Marietta, Ga., while nearby wells were monitored for water-level change. Preliminary results of one slug test show hydraulic conductivity in fractured crystalline rock at the site is small (0.1 feet per day) and that the aquifer at this location may be anisotropic. In the example presented herein, a well 108 feet northwest of the test well was more responsive than a well 11 feet north-northeast of the test well.

INTRODUCTION

U.S. Air Force Plant 6 (AFP6) (Fig. 1) has specialized in aircraft manufacture and repair since 1942. Various chemicals including trichloroethene (TCE) have been used during plant operation. Within AFP6, multiple TCE releases have resulted in TCE migration to ground water. During 1985, the U.S. Environmental Protection Agency (USEPA) declared several parts of AFP6 a Resource Conservation and Recovery Act (RCRA) site (Lisa S. Stewart, U.S. Geological Survey, written commun. with Gerard Gonthier, 2003).

Aquifer assessment and subsurface sampling currently are under way at AFP6 to determine how TCE is moving through the subsurface crystalline rock. The open intervals of wells completed in bedrock commonly are boreholes, devoid of casing. Conventional methods of characterization of fractured crystalline rock include the use of tools to hydraulically isolate portions of the borehole (the open interval of the well) so that investigations can focus on single, discrete fractures or fracture zones. This approach is costly, however, and reconnaissance of available wells open to the bedrock is being conducted. Slug tests provide an efficient way to estimate hydraulic conductivity and the interconnectivity between wells.

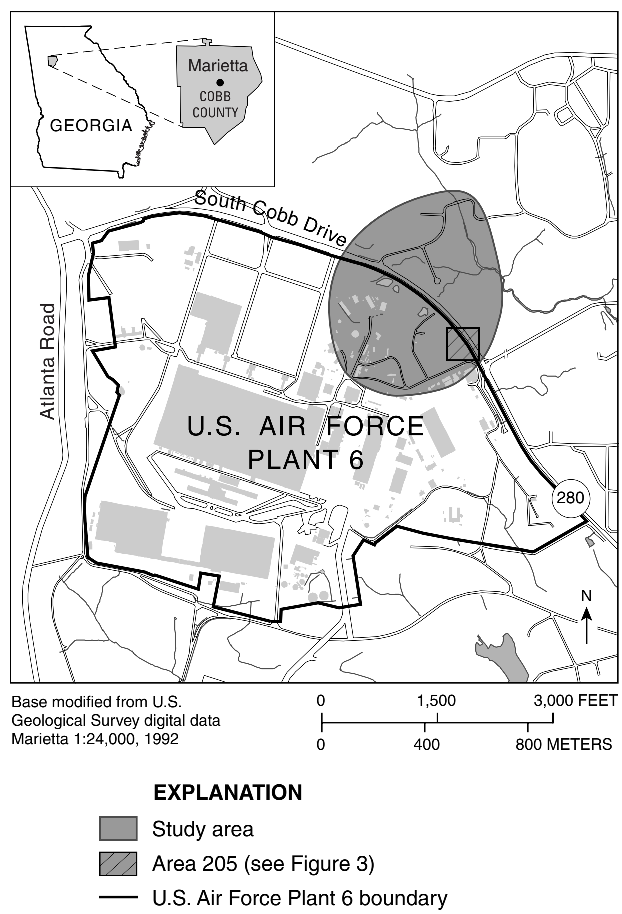

Figure 1. Area 205, U.S. Air Force Plant 6, and study area, Marietta, Georgia.

Within the study area (Fig. 1), 40 monitoring wells open to crystalline rock were instrumented to monitor water-level fluctuations. During reconnaissance of subsurface hydraulic properties, slug tests were performed in wells while water-level data simultaneously were collected in nearby wells.

This paper presents an example of the usefulness of monitoring water levels in nearby wells during slug tests performed in fractured crystalline rock. Results of one slug test using six nearby monitoring wells (Area 205 on Fig. 1) are described. The U.S. Geological Survey (USGS), in cooperation with the U.S. Air Force Center for Environmental Excellence, is currently conducting this project.

Physical Setting

AFP6 is located in the Central Uplands district of the Piedmont Province of north Georgia (Fenneman, 1938). Topography consists of low northeast-trending ridges separated by valleys. Altitude in the study area ranges from approximately 950 to 1,075 feet. AFP6 encompasses approximately 720 acres of a 3,336-acre military complex that includes Dobbins Air Reserve Base.

The Powers Ferry Formation, composed of fractured biotite schist and biotite gneiss, comprises the bedrock beneath the study area (Higgins and others, 1988). The hydrogeology of the study area is complex. Ground water generally flows outward from the small plateau on which AFP6 is located (International Technology Corporation, 1999). Within the study area, ground water generally flows to the northeast.

Ground-Water Movement in Fractured Crystalline Rock

Fractured crystalline rock is difficult to characterize; thus, ground-water flow is difficult to predict. Flow in crystalline rock occurs in fractures, but not all fractures conduct water. Actual flow through the bedrock mostly is along the portions of fractures that are connected to a source of water and can conduct fluid flow (Fig. 2). Flow through a fracture mostly occurs in sinuous slabs of permeability within irregular fracture planes or along linear voids associated with fracture intersections (Committee on Fracture Characterization and Fluid Flow, 1996). Determining the precise location of slabs of permeability and other water-bearing voids is necessary to understand fluid flow. Such a determination using current technology and methods is challenging.

Storativity usually is low compared to hydraulic conductivity of fractured crystalline rock. The porosity in fractured crystalline rock typically is much smaller than in porous media—about 1 percent as compared to about 25 percent, respectively (Freeze and Cherry, 1979).

Slug Tests in Fractured Crystalline Rock

The method of slug testing is to instantaneously increase or decrease the water level in a well and monitor the subsequent water-level recovery. Analytical solutions can then be applied to hydrographs of water-level recovery and to well characteristics to determine hydraulic conductivity of the subsurface rock surrounding the well (Bouwer and Rice, 1976; Cooper and others, 1967).

Slug tests usually are single-well tests that give estimates of hydraulic conductivity near the bore or screen of the test well. A few studies have monitored the water level in observation wells during slug tests in porous media (Belitz and Dripps, 1999; McElwee and others, 1995). These studies indicate that monitoring water levels in observation wells improves estimates of several hydraulic properties including specific storage.

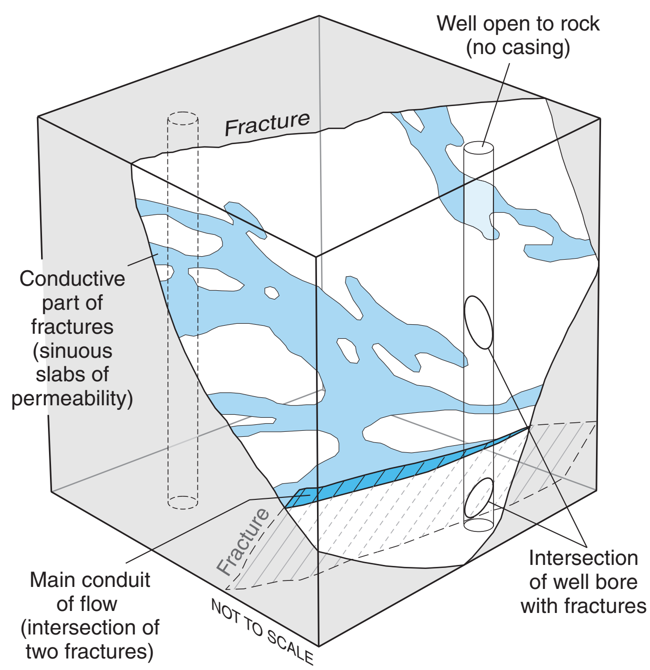

Figure 2. Hypothetical setting within fractured crystalline rock showing the complexity of flow. Neither of the two wells shown in the example is hydraulically connected to a water-bearing fracture within the above example volume. Concepts depicted in this illustration are based on discussion presented in Committee on Fracture Characterization and Fluid Flow (1996).

Unlike porous media, the diffusivity (transmissivity/storativity) of fractured crystalline rock typically is high. Therefore, within fractured crystalline rock the effects of a slug can extend from the test well to nearby observation wells. Slug tests in wells open to fractured crystalline rock usually are performed in fracture zones isolated by borehole packers (Committee on Fracture Characterization and Fluid Flow, 1996).

Methods

Slug tests at wells within the AFP6 study area (including well OB205A, Fig. 3) were performed by quickly submerging a cylindrical slug. The test wells were not packed off during the test. The water level was then measured and recorded every second for the first several minutes with the measuring frequency decreased during a period of about 6 hours to once every 15 minutes. Water-level data for the slugged wells were analyzed for hydraulic conductivity using the method of Bouwer and Rice (1976) and software developed by Halford and Kuniansky (2002). Water levels in several observation wells were monitored during each slug test. Monitoring wells were not packed off to prevent the effects of well-bore storage.

During a day during autumn 2002, a 1,194-cubic-inch polyvinyl chloride cylinder (about 6 feet long and 4 ½ inches in diameter), filled with sand, was plunged below the water level in well OB205A, which is 8 inches in diameter and 200 feet deep. Six observation wells located 10 to 300 feet from well OB205A were monitored during the slug test (Fig. 3). All 6 observation wells are 8 inches in diameter and range between 180 and 200 feet deep.

SLUG-TEST RESULTS AT WELL OB205A, AIR FORCE PLANT 6

Using the Bouwer and Rice (1976) method, the data from well OB205A resulted in an estimate of hydraulic conductivity of 0.1 feet per day, a low-hydraulic conductivity at the lower end of the range for a fractured crystalline-rock environment (Freeze and Cherry, 1979). The response of water levels in the observation wells to the slug was not directly related to observation-well distance from the test well. Water levels in three of the six observation wells responded to the slug (Fig. 4). Well RW205 (Fig. 4), 11 feet north-northeast of the test well, showed little response; the water level rose only slightly above the background water levels. The water level in well OB205B, 52 feet west-southwest the test well, did not respond to the slug. The water level in well OB204C (Fig. 4), 108 feet northwest of the test well, was more responsive to the slug than well RW205. The water level in well RW204 (Fig. 4), 176 feet northwest of the test well, also responded to the slug. The water levels in well OB204B, 216 feet northwest of the test well, and in well OB206A, 300 feet southeast of the test well, did not respond to the slug.

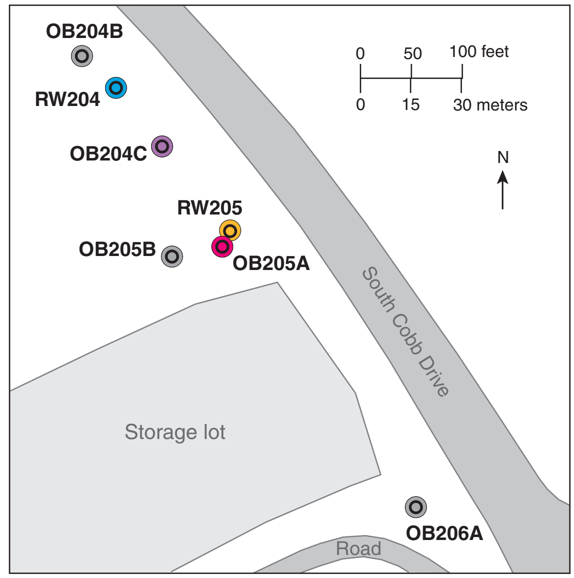

Figure 3. Location of slugged well (OB205A) and observation wells, Air Force Plant 6, Marietta, Georgia. Water levels for the four wells with a detectable response (the slugged well and three of the six observation wells) are shown in figure 4 (gray colored wells had no detectable response).

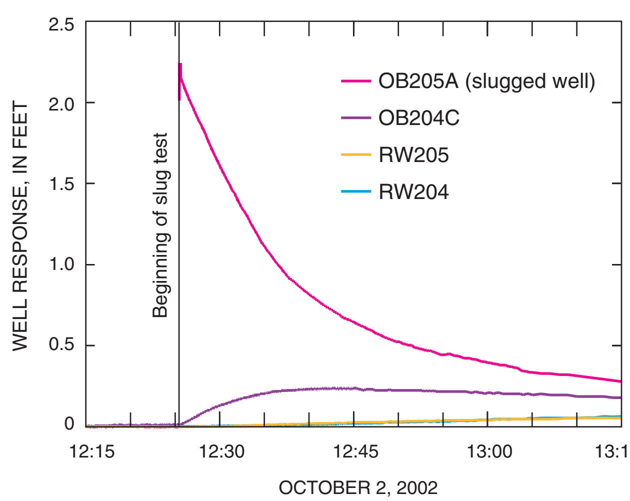

Figure 4. Water-levels in wells affected during slug test of well OB205A.

SUMMARY

Results from this study indicate that small-volume slug tests performed in wells open to fractured crystalline rock at U.S. Air Force Plant 6, Marietta, Ga., can produce a detectable water-level response, even in open boreholes, providing preliminary information about aquifer interconnectivity between wells. The water-level responses in nearby observation wells indicate that ground-water flow in fractured crystalline rock may be anisotropic. Because of the high diffusivity of fractured crystalline rock, slug testing can be used, in conjunction with observation wells, to determine preliminary information about hydraulic properties and the interconnectivity of fractures within crystalline rock.

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