

KRYPTON TRACER TEST TO CHARACTERIZE THE RECHARGE OF HIGHLY FRACTURED AQUIFER IN LAWRENCEVILLE, GEORGIA

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Abstract. The City of Lawrenceville uses a high yield well located in Rhodes Jordan Park to supplement its drinking water supplies. This area has been investigated by the U.S. Geological Survey, the University of Georgia, and the City of Lawrenceville since 1994 to identify the fracture system and recharge to the well. This study reports on gas tracer tests that provide additional insight into the natural flow field at the site. The tracer experiment involved diffusing krypton gas into a bedrock observation well on-site and monitoring the response of krypton in the production well. This procedure was performed using bedrock observation wells situated in different directions from the production well. The results indicate that a larger fracture aperture exists in the direction that is at right angles to the regional strike.

INTRODUCTION

Characterizing the hydrogeologic properties of fractured bedrock aquifers is a complex and challenging task. The crystalline rock aquifers in the Piedmont and Blue Ridge region consist of high grade regional metamorphic rocks. Overlying this bedrock is saprolite that has weathered in place, and retains the relict structure of the parent rock. The primary porosity of the underlying crystalline bedrock is very low. Therefore, the groundwater flow is controlled by fractures, often associated with open foliation planes and joints, lithologic contacts, and faults. Characterizing these fractures in terms of type, orientation, spatial distribution, frequency, and transmissivity is required to understand local fluid-transport processes. Research efforts at other sites have ranged from laboratory scale studies of discrete fractures to field-scale studies of fracture networks to basin-scale studies of regional

groundwater systems (Wang, 1991).

Traditional methods, such as pump and slug tests, are poorly suited for studying crystalline bedrock fractures. Instead, tracers are often used to facilitate the determination of flow paths and fracture apertures. Many tracers are not suitable for use in a public drinking water supply. Organic dyes can often cause unpleasant side effects such as discoloration, smell, or other health effects and are often absorbed by the rock medium. Ionic tracers may lead to objectionable taste and odor problems. Krypton gas has many advantages such as low background level in groundwater, low molecular diffusion coefficients, high solubility, and ease of use. Also, it is inert, non-toxic, and non-sorbing. The purpose of this paper is to describe the use of krypton gas as a tracer to characterize subsurface fractures in a high yield productive aquifer in Lawrenceville, Georgia.

BACKGROUND

During peak summer months, the City of Lawrenceville uses 2.7 million gallons per day (MGD) of potable water, mostly from surface water supplies (City of Lawrenceville Water Department, 1998). Although high yield wells are unusual within the fractured bedrock aquifer of the Georgia Piedmont, they do exist in some areas, including Rhodes Jordan Park (Figure 1) near downtown Lawrenceville. One production well (14FF10), drilled in 1912, was the first municipal well in Lawrenceville. The other well was drilled in 1945 (14FF16) about twelve feet from 14FF10. Both wells were used in the past as a water supply, then were abandoned and partially back-filled. Well 14FF10 was reactivated as a production well in 1990. In 1998, Well 14FF16 replaced well 14FF10 as the production well.

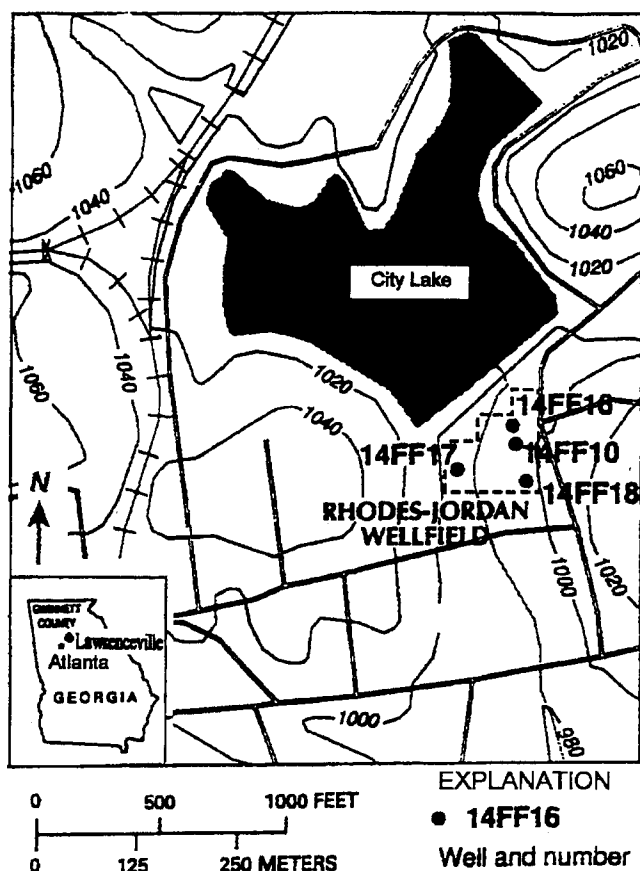


Figure 1. Location of the Lawrenceville study area and the Rhodes Jordan well field (modified from Tharpe et al., 1997).

The bedrock at the site is characterized by sheared and jointed amphibolite overlain by a combined fill/soil/saprolite layer 20 to 35 feet thick. A NE-SW regional trend of the amphibolite and other lithotectonic units is typical for the area. Borehole geophysical data of the well field show more than 60 fractures within the bedrock with complex foliation and joint orientation (Chapman and Lane, 1996; Chapman et al., 1997). Changes in groundwater levels during pumping of the production well indicate the presence of a connecting fracture system between the wells at a distance of at least one mile (Tharpe et al., 1997). This direction is consistent with the principal direction deduced from a geochemical study (Schirmer, 1996).

The well field includes two production wells and eight observation wells, of which four are in crystalline bedrock and four in saprolite. All of these observation

wells were drilled between 1990 and 1995. The production wells, located 12 feet apart, are well-connected and can be pumped at 300 gallons per minute (gal/min) (14FF10) or 500 gal/min (14FF16). Currently, well 14FF16 is being pumped at an average rate of 350 gal/min. The bedrock observation wells respond within 10 minutes to pumping of the production well (Tharpe et al., 1997). The saprolite wells are also influenced by the production well, but their response is more delayed.

EXPERIMENTAL DESIGN

A pump was used to bring water from the bottom of the observation well to a container where krypton was diffused into the water, then the water was returned to the well bore. This created water circulation in the well bore that enhanced uniform mixing of the krypton gas, but did not affect the adjacent groundwater levels. After one hour, krypton-dosed water was added to the observation well at the rate of 0.5 liter/min, with a total of 0.75 well volumes added. This caused the krypton to be injected into the adjacent fractures, but did not significantly affect the existing gradient. After the experiment was terminated, 2.5 well volumes of clean water were added to flush the system. Water from the production well (14FF16) was collected using an in-line sampler to minimize krypton loss. The production well was sampled every hour for 36 hours, followed by every 4 hours for 2 days, and finally twice a day until the krypton concentration in the production well reached background. The samples were analyzed in a random order to minimize bias. Samples were placed in a vacuum extraction line (Culp et al., 1996; Jones, 1996) to separate dissolved noble gases from the water sample. The eluted noble gases (argon and krypton) were then analyzed with a GC-MS.

RESULTS AND DISCUSSION

The first tracer test was conducted from well 14FF17, which is aligned along the principal axis of flow identified by Schirmer (1996). The second test was conducted from well 14FF18, which is at right angles to the first test. The breakthrough curves are shown in Figure 2.

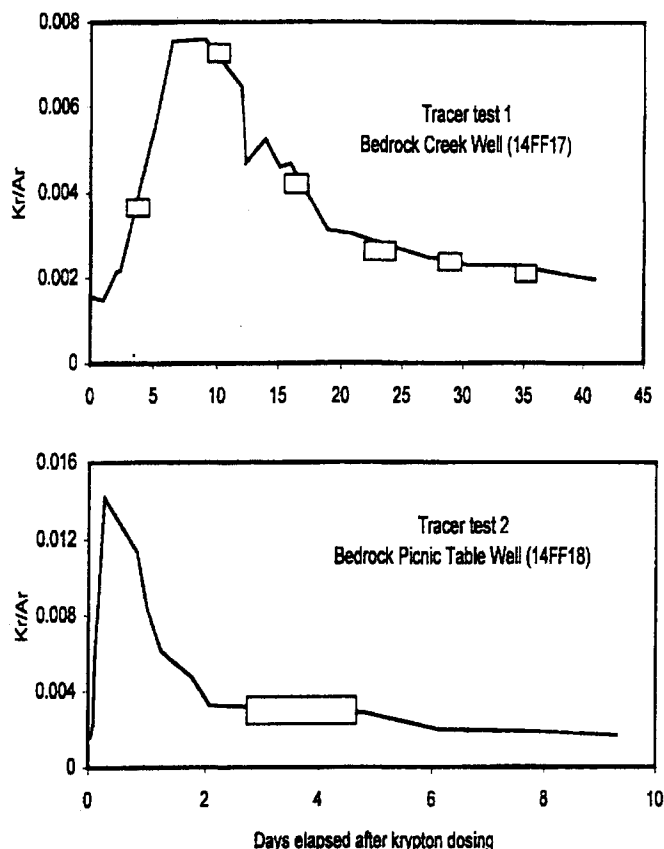


Figure 2. Gas tracer experiment results showing krypton breakthrough curves; Non-pumping periods of the production well (14FF16) during weekends are shown by rectangles.

First occurrence of krypton for test 1 (well 14FF17) was after two days; for test 2 (14FF18) it was after two hours. The peak concentration for test 1 was one half that of test 2.

These results demonstrate that the advective velocity is greater from 14FF18 even though this well is "off-strike". Water level measurements show there is very little gradient in the fractures, since water levels are controlled by pumping of the production well. Therefore, these tracer results imply that the fracture aperture is larger between 14FF18 and the production well. This result is consistent with an earlier krypton tracer test done by Jones (1996) between well 14FF18 and 14FF10. This well also loses krypton more rapidly, indicating a better connection between it and the production well.

The tracer results and the geochemical results observed by Schirmer are not consistent. Schirmer concludes that 80 percent of the flow to the production well is along strike in the direction of well 14FF17, yet the tracer velocity appears to be much slower in that direction. Two possibilities are suggested. It may be that fewer fractures exist in the off-strike direction, even though the major fracture(s) are larger. Therefore the mass flux of water in the on-strike direction is greater, even though the velocity is slower. Or, it may be that production well 14FF16 intersects different fractures than well 14FF10, which was the production well in operation during the Schirmer study.

CONCLUSIONS

This study illustrates why fracture flow is difficult to determine and why several independent approaches are needed. Water levels in the bedrock observation wells show the wells are well connected to the production well. The geochemical data from Schirmer's study suggest, based upon end-member mixing, that eighty percent of the flow comes from the NW-SE direction along strike of well 14FF17. This study shows that the fracture aperture is larger in the NE-SW direction towards well 14FF18.

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