HYDRAULIC PROPERTIES OF THE KARSTIC UPPER FLORIDAN AQUIFER NEAR ALBANY, GEORGIA

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Abstract. A multi-well aquifer test was conducted to determine the hydraulic characteristics of and vertical connection within the Upper Floridan aquifer in the Albany, Ga., area as part of a hydrogeologic investigation being conducted by the U.S. Geological Survey, in cooperation with the Albany Water, Gas, and Light Commission. The test site consisted of a production well and five clusters of observation wells (one deep, intermediate, and shallow well in each cluster). Flow-meter tests conducted in the production well between the depth interval of 110 to 140 feet (ft) below land surface show that the interval between 118 and 124 ft contributes the largest portion of the total yield to the well.

A 49-hour aquifer test was conducted in February 1995, at a constant rate of 3,300 gallons per minute (gal/min). The maximum drawdown measured in any observation well was about 2.4 ft at a distance of 330 ft from the pumped well. Measurable drawdown was not observed at distances greater than about one mile from the pumped well. The hydraulic characteristics of the Upper Floridan aquifer were evaluated using the Hantush-Jacob curve-matching and Jacob straight-line methods. Using the Hantush-Jacob method, values for transmissivity (T) ranged from about 108,000 to 460,000 feet squared per day (ft^2/d), values for storage coefficient (S) ranged from $1.4x10^{-4}$ to $6.3x10^{-4}$, and values for vertical hydraulic conductivity of the overlying confining unit (K′) ranged from 4.9 to 11.4 feet per day (ft/d). Geometric averages for these values of T, S, and K′ were calculated to be 211,000 ft^2/d, $2.7x10^{-4}$, and 7.3 ft/d, respectively. If dual porosity (fracture flow plus matrix flow) is assumed instead of leakage, and the Jacob straight-line method is used with late time-drawdown data, the calculated T of the fractures ranged from about 222,000 to 462,000 ft^2/d and S of the fractures plus the matrix ranged from $2x10^{-5}$ to $3x10^{-2}$.

INTRODUCTION

Long-term pumping from the Claiborne, Clayton, and Providence aquifers in the Albany area has resulted in ground-water-level declines of as much as 140 ft in the Clayton aquifer since 1940 (Hicks *et al.*, 1987). Concerned that future declines could be even greater, the Albany Water, Gas, and Light Commission decided to investigate the shallower Upper Floridan aquifer as a source of water to augment increasing municipal water demands. An area southwest of Albany and west of the Flint River in Dougherty County was selected for further study (Figure 1).

Purpose and scope

This paper presents the results of an aquifer test conducted in February 1995 in an area of potential ground-water development and describes the hydrogeology of the Upper Floridan aquifer and its confining units. The paper also presents water-level changes observed during the aquifer test, analyses of the aquifer-test data, and estimates of the hydraulic characteristics of the Upper Floridan aquifer.

Description of study area

The 64-square mile study area lies in the Dougherty Plain district of the Coastal Plain physiographic province in Dougherty County, Ga., just southwest of Albany (Figure 1). Topography in the area is relatively flat and land-surface altitude ranges from about 160 to 200 ft. The Dougherty Plain is characterized by karst topography and contains numerous sinkholes and depressional wetlands. Although no sinkholes were identified in the study area, several depressions that seasonally contain water occur within about 1,000 ft of the pumped well (well 12K147, Figure 1).

Previous studies

Several hydrogeologic investigations have been conducted in the Albany area, many of which described the Upper Floridan aquifer. Mitchell (1981) presented basic hydrologic and geologic data; and analyses and results of aquifer tests conducted in the Upper Floridan aquifer in and adjacent to the Dougherty Plain. Hicks *et al.*, (1987) described the hydrogeology of the Albany area, assessed the chemical quality of ground water in the Upper Floridan aquifer, evaluated the development potential of the Upper Floridan aquifer, and identified the areas of greatest potential for development of ground-water resources in the Albany area. Torak *et al.*, (1993) constructed a ground-water-flow model which indicated that in much of the Albany area, the Upper Floridan aquifer could produce large quantities of ground water without creating significant areal water-level decline. Torak *et al.*, (1993) also reported values for transmissivity and hydraulic conductivity for the lower water-bearing zone of the Upper Floridan aquifer in the southwest Albany area.

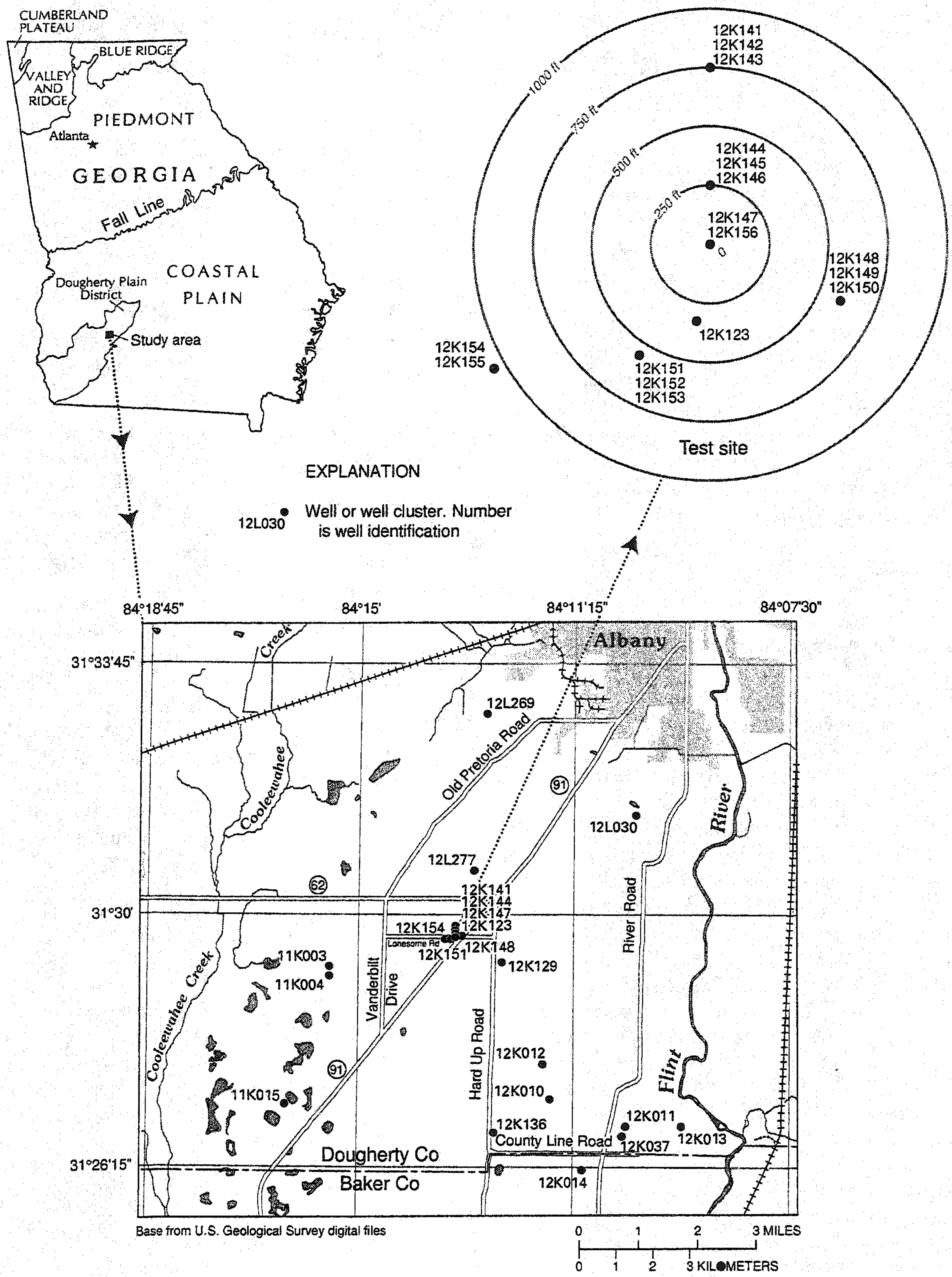

Figure 1. Location of study area and wells near Albany, Georgia.

HYDROGEOLOGY OF STUDY AREA

In the study area, the Upper Floridan aquifer primarily is comprised of the upper Eocene Ocala Limestone. The Upper Floridan aquifer is confined below by the middle Eocene Lisbon Formation and above by the low permeability sediments of the undifferentiated Quaternary overburden that consist of discontinuous residuum and lensoidal deposits of clay and clayey sand (Figure 2). The aquifer has been subdivided into upper and lower water-bearing zones based on different hydrologic properties (Figure 2) (Hicks *et al.*, 1987). The upper water-bearing zone generally consists of dense, highly weathered limestone (Hicks *et al.*, 1987). At the test site, this zone ranges in thickness from about 40 to 80 ft.

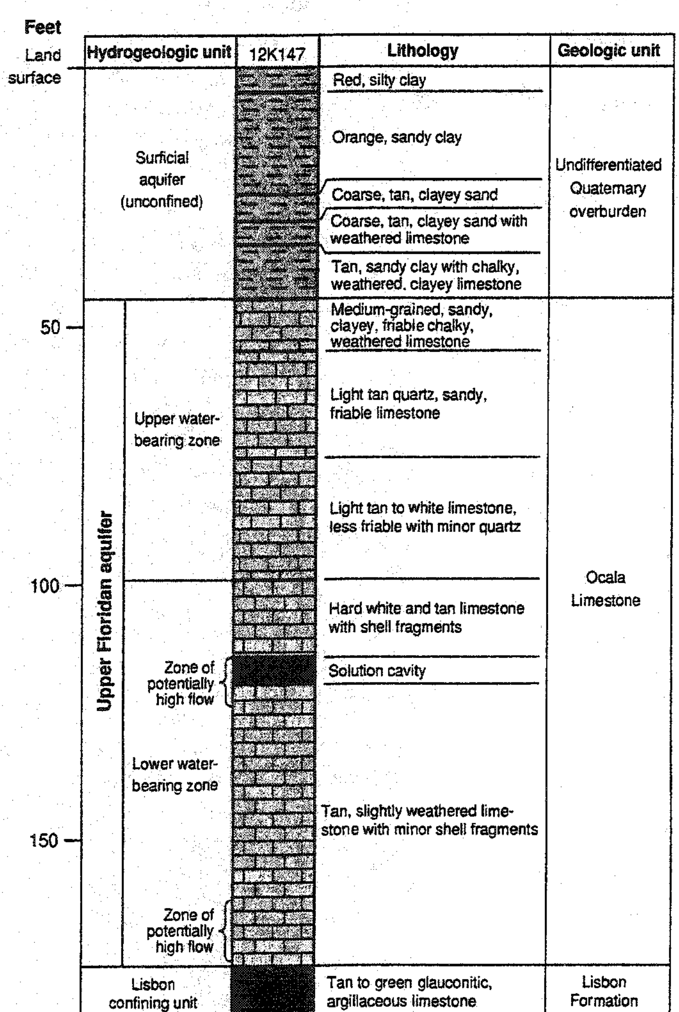

Figure 2. Lithology and hydrogeology of the undifferentiated overburden, Ocala Limestone, and Lisbon Formation (described from cuttings from well 12K147).

The lower water-bearing zone ranges in thickness from about 60 to 80 ft at the test site. In well 12K147, the upper 20 ft of the lower zone consists of hard limestone with shell fragments overlying 55 ft of slightly weathered limestone with minor shell fragments (Figure 2). Limestone in the lower water-bearing zone generally is harder than the limestone in the upper water-bearing zone; and thus, is more fractured and more prone to solutioning. This solutioning creates preferential ground-water-flow paths and a higher degree of secondary permeability. The secondary permeability largely is responsible for the higher yields that are typical of wells open to the lower water-bearing zone (Torak *et al.*, 1993). Based on the hydrogeologic information collected prior to and during this study, the Upper Floridan aquifer probably is best characterized as a leaky, fracture-flow system in the study area.

Two potentially high-flow zones (Figure 2) were identified in the lower water-bearing zone using borehole geophysical and borehole video surveys. The borehole geophysical surveys include gamma-ray, electrical resistivity, caliper, and fluid resistance logs. The upper high-flow zone occurs near the contact with the upper water-bearing zone and the lower water-bearing zone, and ranges in thickness from about 10 ft at well 12K144 to about 25 ft at well 12K147. The lower high-flow zone occurs near the bottom of the lower water-bearing zone and ranges in thickness from about 10 ft at well 12K144 to about 20 ft at well 12K148. A spinner flow-meter test indicates that the largest part of total yield in well 12K147 (Figure 2) comes from the highly fractured interval between 118 and 124 ft below land surface and corresponds to the upper high-flow zone.

DESCRIPTION OF AQUIFER TEST AND DETERMINATION OF HYDRAULIC PROPERTIES

Aquifer-test design

The aquifer test site consists of 16 observation wells (12K123, 12K141–146 and 12K148–156) and one production well (12K147) (Figure 1). The 24-inch-diameter production well is completed to a depth of 185 ft and is open only to the lower water-bearing zone of the Upper Floridan aquifer. The observation wells were installed in five sets (five locations), each set consisting of three wells—a shallow well tapping the undifferentiated overburden; an intermediate well open to the upper water-bearing zone; and a deep well open to the lower water-bearing zone. Well 12K123 was an existing well whose lower portion was filled with cement so that it was only open to the Upper Floridan aquifer. This enabled well 12K123 to be used as an additional observation well. Each set of observation wells was placed at a different distance and orientation from well 12K147 (the pumped well) to define the cone of depression resulting from pumping.

The wells shown in Figure 1 were used to monitor the potentiometric surface of the Upper Floridan aquifer during the aquifer test. Well 12K147 was pumped at a constant rate of 3,300 gal/min for about 49 hours. Water-level data were collected in wells 12L269 and 12L277 throughout the aquifer test, to evaluate areal effects of pumping (Figure 1). Water-level measurements were taken in all observation wells before, during, and after pumping. Because it is located outside the area of influence of pumping and the area of influence of the Flint River, well 11K015 was used to monitor background water-level trends in the area. Hydrographs from one observation well cluster site (wells 12K141, 12K142, and 12K143), measured throughout the drawdown and recovery phases of the aquifer test, are shown in Figure 3.

Water-level change

Water-level data collected before pumping and after about 49 hours of pumping were subtracted and corrected for regional trends to determine total water-level changes related to the aquifer test. Water-level declines in the lower water-bearing zone ranged from 2.4 ft in well 12K123, located 330 ft from the pumping well; to 0.5 ft in well 12K154, located about 1,040 ft from the pumping well. Water-level declines in the upper water-bearing zone of the Upper Floridan aquifer ranged from about 0.4 ft at well 12K155, located about 1,040 ft from the pumping well; to 0.7 ft at well 12K142, located about 750 ft from the pumping well. Water-level declines in the surficial aquifer ranged from about 1.5 ft in well 12K156, located about 10 ft from the pumping well; to about 0.4 ft in well 12K153, located in the southwestern part of the wellfield (Figure 1). At distances greater than about 1 mile from the pumping well, there was no measurable effect from pumping on water levels in the Upper Floridan aquifer.

Water levels were measured in the pumped well and in each of the observation wells at the test site for several hours after the termination of pumping. Within a few minutes after termination of pumping, water levels recovered to within 10 percent of their static levels. After a few hours, water levels had recovered to background levels (Figure 3).

Analysis of data

The drawdown data were fitted to type curves based on equations developed by Hantush and Jacob (1954) for analyzing test data from aquifers receiving leakage across confining units. Previous investigators also used this method of analysis for aquifer tests conducted in the study area (for example, Mitchell, 1981). An example of time-drawdown data collected at observation well 12K151 fitted to the curve of r/B=0.3 is shown in Figure 4. The value r/B is the dimensionless parameter associated with leakage (Hantush and Jacob, 1954). Using the Hantush-Jacob equations, the calculated transmissivity (T) at all observation wells ranged from about 108,000 to 460,000 ft^2/d; the calculated storage coefficient (S) ranged from 1.4×10^{-4} to 6.3×10^{-4} (Table 1); and the calculated vertical hydraulic conductivity of the overlying confining unit (K′) ranged from 4.9 to 11.4 ft/d. Geometric averages for these ranges of values for T, S, and K′ were calculated to be about 211,000 ft^2/d, 2.7×10^{-4}, and 7.3 ft/d, respectively. Torak *et al.*, (1993) reported a value of 178,000 ft^2/d for T in the lower water-bearing zone of the Upper Floridan aquifer from an aquifer test conducted at a site located about 9 miles south of Albany. This reported value of T is similar to the geometric average of the T's calculated using the Hantush-Jacob method for this study. Torak *et al.*, (1993) also reported a range for K′ for the undifferentiated overburden at well 12K123 from laboratory analyses of 0.011 to 11.3 ft/day. The geometric average of K′ calculated using the Hantush-Jacob method for this study is within the range reported by Torak *et al.*, (1993).

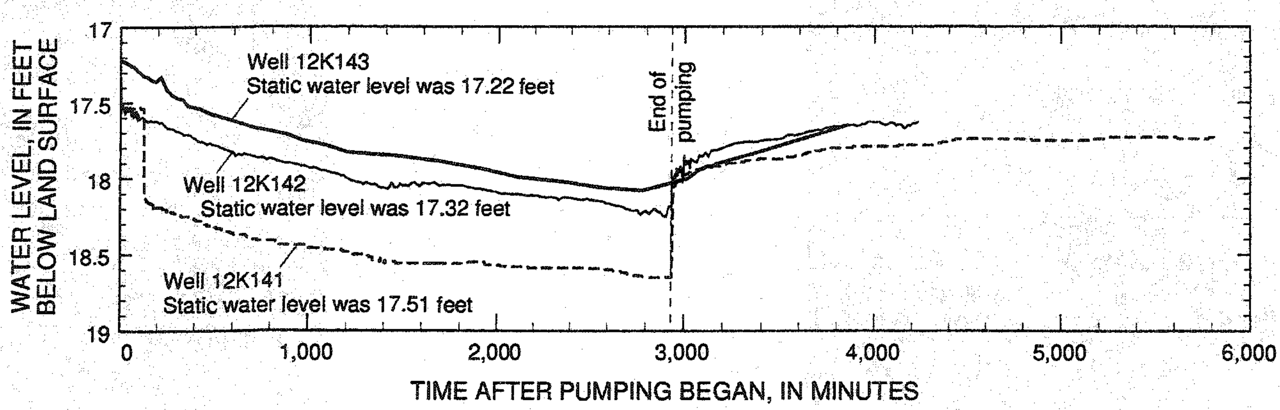

Figure 3. Water-level fluctuations in wells 12K141, 12K142, and 12K143, February 21–24, 1995.

Table 1. Estimated transmissivity (T) and storage coefficient (S) of the lower water-bearing zone of the Upper Floridan aquifer using data from selected wells in the wellfield southwest of Albany, Georgia, February 1995

Well number	Transmissitivy (T) (ft^2/d)	Storage coefficient (S)
12K141	181,000	$1.7x10^{-4}$
12K144	120,000	$1.7x10^{-4}$
12K148	108,000	$5.9x10^{-4}$
12K151	389,000	$6.3x10^{-4}$
12K154	460,000	$1.4x10^{-4}$

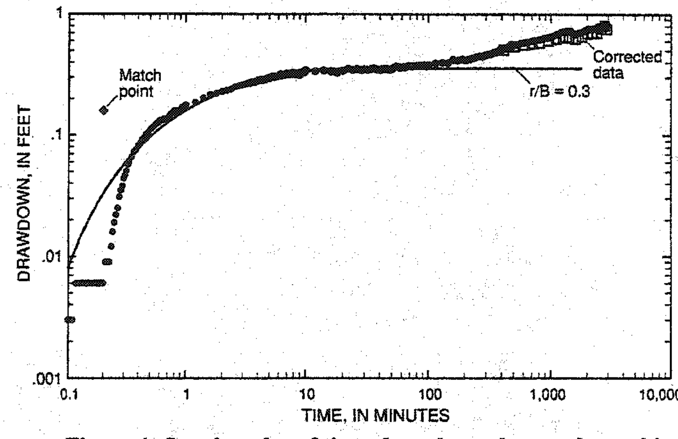

Figure 4. Log-log plot of time-drawdown data and matching Hantush-Jacob type curve of r/B = 0.3 for well 12K151, February 21-23, 1995.

The time-drawdown data from the observation wells (like that shown in Figure 4) and the borehole geophysical data suggest that the hydrogeology of the Upper Floridan aquifer in the well-field area is complex. The time-drawdown data from all of the observation wells deviate from the Theis curve and flatten out soon after pumping began (from about one to three minutes). According to the Hantush-Jacob analyses, this early deviation and flattening suggest that the aquifer is receiving leakage from confining units. Results of the Hantush-Jacob method may be misleading, suggesting more leakage than is actually occurring if the flattening of the time-drawdown curves is being caused by some other factor. One other explanation of the deviation from the Theis curve is fracture flow, resulting in a dual-porosity response. The time-drawdown data for well 12K151 (Figure 4) deviate from the Theis curve at about 3 minutes, then indicate an increase in drawdown from about 100 minutes until the end of pumping. Data shown in Figure 4 can be divided into three groups—early time that fits the Theis curve (about 0.3 to 3 minutes); intermediate time that flattens out from the Theis curve (about 3 to 100 minutes); and late time that shows a second increase in drawdown (greater than 100 minutes). The three response intervals are evident on a semi-log plot of time-drawdown data (Figure 5) as three different slopes. In this dual-porosity model, the first slope represents flow from the fractures, the second slope represents a time when the aquifer is in a period of transition, and the third slope (later-time data) represents a combination of fracture and matrix flow (Kruseman and deRidder, 1990). During the transition period, the hydraulic potential along the fracture boundaries changes, and the aquifer matrix begins to contribute recharge to the fractures.

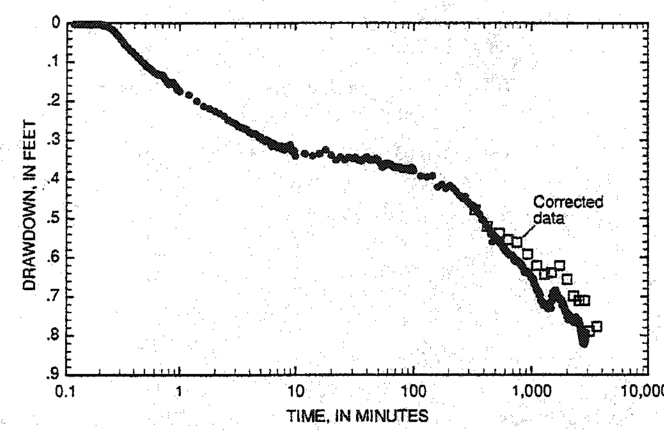

Figure 5. Semi-log plot of time versus drawdown data for well 12K151, February 21-23, 1995.

The late time-drawdown data, which indicate a secondary increase in drawdown, suggest that the system may be responding to dual porosity. As an alternative to the Hantush-Jacob approach for leaky aquifers, the Jacob straight-line method was used with the late time-drawdown data (greater than about 100 minutes on Figure 5) (Jacob, 1950). Using late time-drawdown data, the transmissivity of the fracture system, and the storage coefficient of the fracture system plus that of the aquifer matrix were computed (Kruseman and deRidder, 1990). Applying this approach to test data from all of the deep observation wells at the test site, values for T of the fracture system ranged from 222,000 to 462,000 ft^2/d, and values for S of the fractures plus the matrix ranged from $2x10^{-5}$ to $3x10^{-2}$.

CONCLUSIONS

Hydraulic properties of the Upper Floridan aquifer were evaluated at a test site south of Albany, Ga. A 49-hour aquifer test was conducted at the test site in February 1995, with a single well pumped at 3,300 gal/min. The pumping well and 16 observation wells completed in the upper and lower water-bearing zones of the Upper Floridan aquifer, and in the overlying undifferentiated overburden constitutes the test site.

In the Albany area, the Upper Floridan aquifer has been subdivided into an upper water-bearing zone and a much higher permeability lower water-bearing zone. The upper water-bearing zone consists of friable, weathered limestone and the lower water-bearing zone is made up of harder, fractured limestone. Secondary permeability is largely responsible for higher yields that are typical of wells open to the lower water-bearing zone. The Upper Floridan aquifer is characterized by leaky, fracture flow.

Borehole geophysical and borehole video surveys were used to identify two potentially high ground-water flow zones in the lower water-bearing zone. A spinner flow-meter test in the pumped well indicated that the highly fractured borehole interval between 118 and 124 ft below land surface contributes the largest part of the total yield.

Water-level declines in the surficial aquifer ranged from about 1.5 ft near the pumping well to about 0.4 ft in a well located in the southwestern part of the test site. Water-level declines in the upper water-bearing zone were similar to those observed in the surficial aquifer and ranged from about 0.4 to 0.7 ft. Water-level declines in the lower water-bearing zone ranged from about 2.4 ft in well 12K123 to about 0.5 ft in well 12K154. At distances greater than about 1 mile from the pumped well, there were no measurable effects from pumping. After pumping ceased, the water levels returned to within 10 percent of their static levels within a few minutes and continued to recover slowly for the next several hours.

Analyses of the aquifer-test data provided estimates for transmissivity and storage coefficient for the lower water-bearing zone of the Upper Floridan aquifer and vertical hydraulic conductivity of the upper confining unit in the study area. Estimates of T using the Hantush-Jacob method for aquifers receiving leakage across confining units, ranged from 108,000 to 460,000 ft^2/d, estimates of S ranged from 1.4×10^{-4} to 6.3×10^{-4}, and estimates of K' ranged from 4.9 to 11.4 ft/d. Geometric averages for these ranges of T, S, and K' were calculated to be 211,000 ft^2/d, 2.7×10^{-4}, and 7.3 ft/d, respectively. Using the Jacob straight-line method and late time-drawdown data, T of the fractures was calculated to range from 222,000 to 462,000 ft^2/d and estimates of S of the fractures plus the matrix ranged from 2×10^{-5} to 3×10^{-2}.

LITERATURE CITED

Hantush, M.S., and Jacob, C.E., 1954, Plane potential flow of ground-water with linear leakage: *Transactions American Geophysical Union*, 35:917-36.

Hicks, D.W., Gill, H.E., and Longsworth, S.A., 1987, Hydrogeology, chemical quality, and availability of ground water in the Upper Floridan aquifer, Albany area, Georgia: U.S. Geological Survey Water-Resources Investigations Report 87-4145, 52 p.

Jacob, C.E., 1950, Flow of ground-water, *in* Rouse, H., *ed.*, Engineering Hydraulics: New York, John Wiley, p. 321-386.

Kruseman, B.P., and de Ridder, N.A., 1990, Analysis and evaluation of pumping test data: Wageningen, The Netherlands, International Institute for Land Reclamation and Improvement (*2nd ed.*), 377 p.

Mitchell, G.D., 1981, Hydrogeologic data of the Dougherty Plain and adjacent areas, southwest Georgia: Georgia Geologic Survey Information Circular 58, 124 p.

Torak, L.J., Davis, G.S., Strain, G.A., and Herndon, J.G., 1993, Geohydrology and evaluation of water-resource potential of the Upper Floridan aquifer in the Albany area, southwestern Georgia: U.S. Geological Survey Water-Supply Paper 2391, 59 p.