SUMMARY OF HYDROLOGIC TESTING OF THE FLORIDAN AQUIFER SYSTEM AT FORT STEWART, COASTAL GEORGIA, 2009–2010

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Abstract. Two test wells were completed at Fort Stewart, coastal Georgia, to investigate the potential for using the Lower Floridan aquifer as a source of water to satisfy anticipated, increased water needs. The U.S. Geological Survey, in cooperation with the U.S. Department of the Army, completed hydrologic testing of the Floridan aquifer system at the study site, including flowmeter surveys, slug tests, and 24- and 72-hour aquifer tests by mid-March 2010. Analytical approaches and model simulation were applied to aquifer-test results to provide estimates of transmissivity and hydraulic conductivity of the multilayered Floridan aquifer system.

Data from a 24-hour aquifer test of the Upper Floridan aquifer were evaluated by using the straight-line Cooper-Jacob analytical method. Data from a 72-hour aquifer test of the Lower Floridan aquifer were simulated by using axisymmetric model simulations. Results of aquifer testing indicated that the Upper Floridan aquifer has a transmissivity of 100,000 feet-squared per day, and the Lower Floridan aquifer has a transmissivity of 7,000 feet-squared per day. A specific storage for the Floridan aquifer system as a result of model calibration was 3E-06 ft^{-1}. Additionally, during a 72-hour aquifer test of the Lower Floridan aquifer, a drawdown response was observed in two Upper Floridan aquifer wells, one of which was more than 1 mile away from the pumped well.

INTRODUCTION

The Floridan aquifer system is the principal source of water in coastal Georgia and consists of the Upper and Lower Floridan aquifers separated by the Lower Floridan confining unit. In coastal Georgia, the Georgia Environmental Protection Division (GaEPD) has implemented pumping restrictions to prevent excessive drawdown in the Upper Floridan aquifer that could accelerate saltwater intrusion in the Hilton Head Island, South Carolina, area (Georgia Department of Natural Resources, Environmental Protection Division, 2006). This restriction includes pumping the Lower Floridan aquifer that may cause drawdown from the Upper Floridan aquifer. Detailed field testing and modeling studies are required to assess the potential for such drawdown effects (Nolton Johnston, Georgia Environmental Protection Division, written commun., January 28, 2003). To meet growing water demand at Fort Stewart, coastal Georgia, the U.S. Geological Survey, in cooperation with the U.S. Department of the Army, is assessing the water-bearing potential and water quality of the Floridan aquifer system.

Method of study

As part of the GaEPD-required field-testing program, hydrologic properties of the Upper and Lower Floridan aquifers and intervening Lower Floridan confining unit were assessed by using borehole geophysical logs, borehole flowmeter surveys, slug tests, collected core samples, a 24-hour aquifer test in the Upper Floridan aquifer, and a 72-hour aquifer test in the Lower Floridan aquifer. Two wells were installed, one in the Lower Floridan aquifer (well 33P028, Fig. 1) and one in the Upper Floridan aquifer (well 33P029, Fig. 1). The two installed wells and an existing well (well 33P025, Fig. 1) were monitored for water levels during the aquifer tests. Before being completed, well 33P028 was a borehole that penetrated both the Upper and Lower Floridan aquifers. Logging was completed in the entire open interval of the borehole and slug tests were completed at selected intervals in the Lower Floridan confining unit. Methods of aquifer-test evaluation and numerical-model simulations are discussed in detail below.

Description of the Study Area

The study area is located in the south-central part of Fort Stewart about 3.5 miles north of Hinesville, Georgia (Fig. 1). Land-surface altitude is approximately 80 ft above sea level (North American Vertical Datum of 1988). Regionally, the study area is underlain by the surficial and Brunswick aquifer systems (Clarke, 2003) and intervening confining units that overlie the Floridan aquifer system (Miller, 1986). The Floridan aquifer system consists of layers of limestone and dolomite that are divided into the Upper and Lower Floridan aquifers in the study area. Most flow in the Floridan aquifer system occurs in discrete permeable zones that are separated by layers of dense limestone or dolomite. Regionally, the Upper and Lower Floridan aquifers are separated by the mapped Lower Floridan confining unit. Based on geophysical logs at the study site, the Upper Floridan aquifer extends from about 440–705 feet (ft) below land surface. The Lower Floridan confining unit extends from the base of the Upper Floridan to about 912 ft below land surface, and the Lower Floridan aquifer extends from the base of the Lower Floridan confining unit to at least 1,250 ft below land surface.

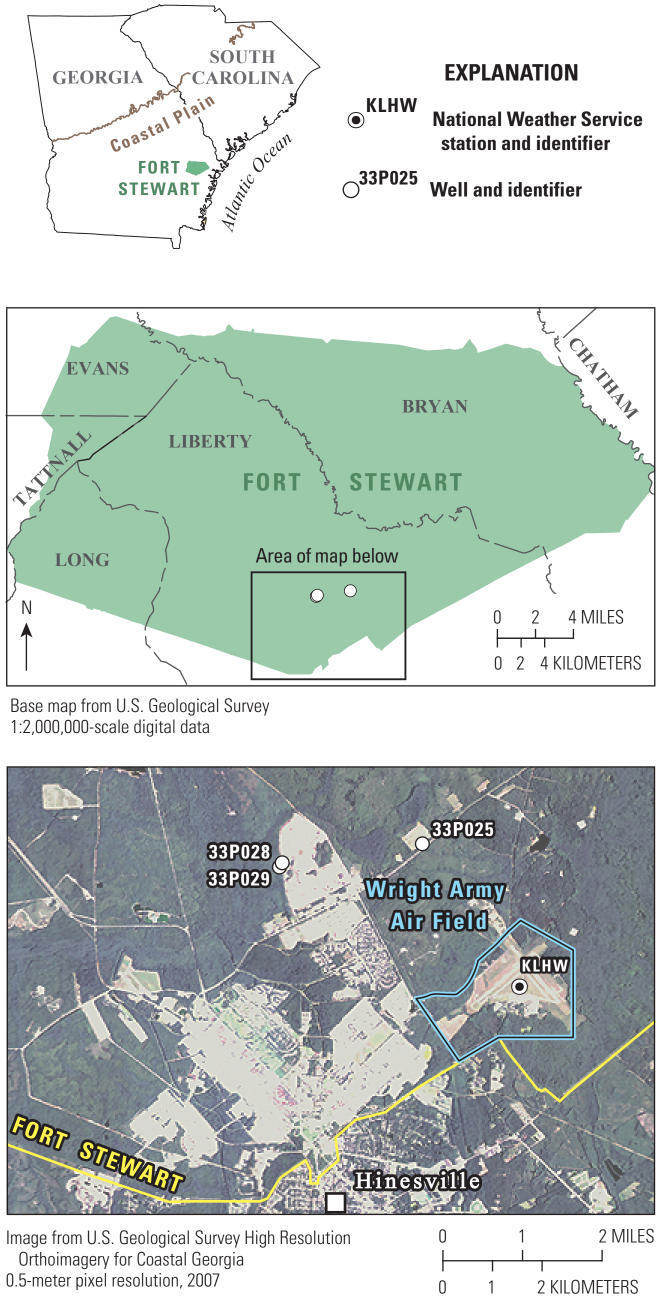

Figure 1. Site well locations, Fort Stewart, Liberty County, Georgia.

SLUG TESTS

Horizontal hydraulic conductivity estimates of the Lower Floridan confining unit were obtained by completing slug tests at four depth intervals in bore hole 33P028: 726.5–733.5 ft, 766.5–773.5 ft, 816.5–823.5 ft, and 876.5–883.5 ft. Each interval was isolated by using straddle packers; then a slug of water was injected into the interval through a 3-inch diameter pipe, and the head was recorded. Pressure transducers were used to monitor water-level response in the isolated interval as well as above and below the zone being tested. Sample frequency was once per second. Data from upper and lower pressure transducers indicated that packers adequately sealed the test intervals.

The Bouwer and Rice (1976) method was used to determine hydraulic conductivity in three of the four packer intervals. The van der Kamp (1976) method was used on one packer interval that responded to the slug event with oscillations. To account for the effect of a prolonged slug event (as long as 30 seconds), water levels of the three packer intervals were simulated through time. Input for the simulation included a static water level (set at zero in Fig. 2), flow rate of slug water into the well column on a per-second basis, and a decay constant (m') to regulate the rate of slug recovery back to pre-test, static water levels. The value m' used to fit simulated water level to measured water-level change was then used with well dimensions and the Bouwer and Rice equation to calculate horizontal hydraulic conductivity. Simulated water levels easily fit very close to measured water levels in the three packer intervals (for example, Fig. 2).

The packer interval at 766.5–773.5 ft below land surface had a slightly underdamped response (oscillation), indicative of higher permeability. Horizontal hydraulic conductivity for this interval was determined by using a slug-test spreadsheet from Halford and Kuniansky (2002), which is based on the van der Kamp (1976) method for oscillating responses. The horizontal hydraulic conductivity value for the 766.5–773.5 ft interval was 70 feet per day (ft/d), whereas values for the other three intervals ranged from 2 to 20 ft/d. The median horizontal hydraulic conductivity for the four packer intervals was 20 ft/d.

AQUIFER TESTS

Aquifer tests were completed at the Fort Stewart study site to estimate the transmissivity of the Upper and Lower Floridan aquifers and to determine the effects of pumping one aquifer on the water levels of the other. A 24-hour aquifer test was conducted in well 33P029, which is open to the Upper Floridan aquifer, during March 3–4, 2010. A 72-hour aquifer test was conducted in well 33P028, which is open to the Lower Floridan aquifer, during March 8–11, 2010. For both tests, water levels were monitored in well 33P028 in the Lower Floridan aquifer, and in wells 33P029 and 33P025 in the Upper Floridan aquifer. Well 33P029 is about 40 ft southwest of well 33P028, and well 33P025 is 9,600 ft east of well 33P028 (Fig. 3).

Water-level data were filtered for effects of barometric pressure, earth tides, and long-term trends by using the procedure from Halford (2006a) to estimate drawdown of the three monitored wells in response to pumping during the two aquifer tests. Barometric-pressure data, which was collected at the well site and from National Weather Service station KLHW at nearby Wright Air Field (Fig. 1) , and water-level data from two offsite background wells were used to aid in filtering out external influence on observed drawdown response.

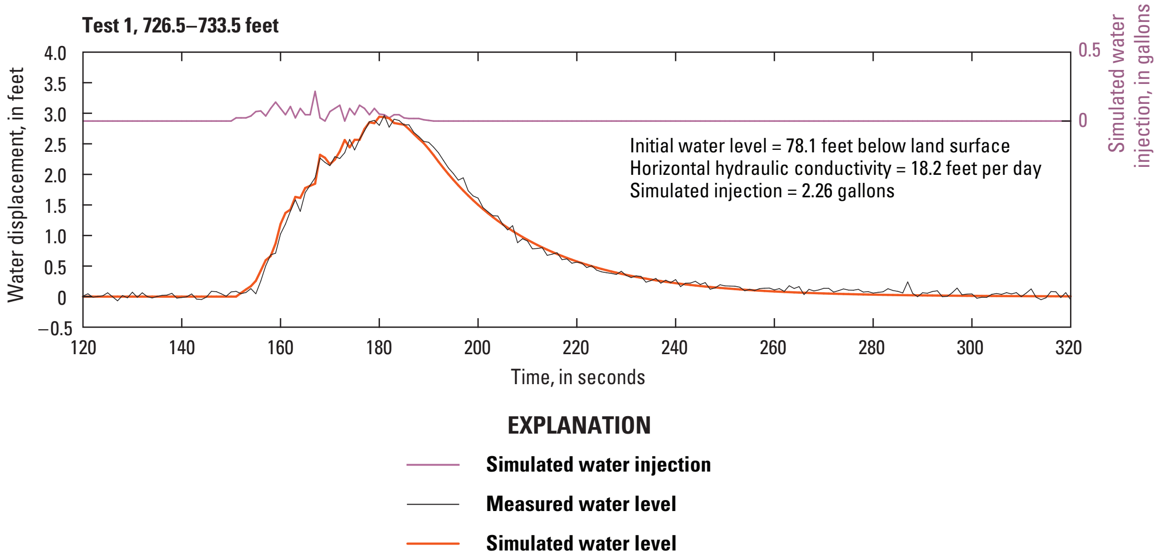

Figure 2. Example of simulated and measured water levels and simulated injection of water, packer-test interval 726.5–733.5 feet; Test 1, 5-gallon slug test; borehole 33P028, Fort Stewart, Georgia, December 5, 2009.

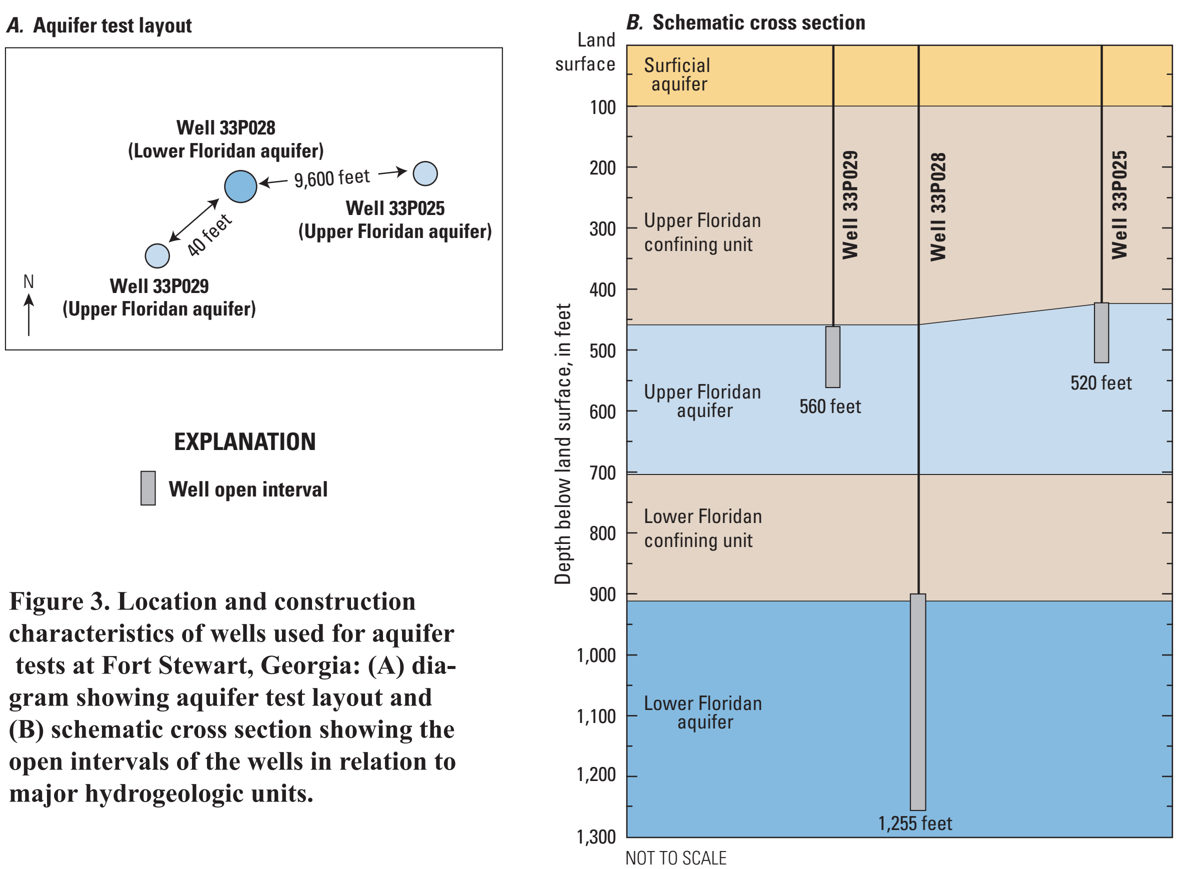

Figure 3. Location and construction characteristics of wells used for aquifer tests at Fort Stewart, Georgia: (A) diagram showing aquifer test layout and (B) schematic cross section showing the open intervals of the wells in relation to major hydrogeologic units.

24-Hour Aquifer Test

The 24-hour aquifer test initially was attempted in the Upper Floridan aquifer well 33P029 on March 2, 2010. Drilling mud, however, affected water-level response and discharge rate. After about 3 hours 45 minutes, the aquifer test was aborted, and the well instead was developed by intermittent pumping until midnight (about 10 hours) when 9 hours of recovery began. The aquifer test was reattempted at 9:00 a.m. the next morning. Further recovery time after well development was not allowed because of time constraints. After well development and almost complete recovery, well 33P029 was pumped at an average rate of 387 gallons per minute (gal/min) during March 3–4, 2010 (Fig. 4).

Correcting for a minor linear trend leads to a 24-hour drawdown in pumped well 33P029 of 4.1 ft. Though water levels in observation wells 33P028 and 33P025 were corrected for barometric-pressure changes and earth tides, pumping during the failed aquifer test and well development period and other external influences complicated the estimation of drawdown. Drawdown in the Lower Floridan aquifer well 33P028 in response to the 24-hour aquifer test in the Upper Floridan aquifer was close to 0.2 ft. Any water-level response in well 33P025 to pumping at well 33P029 was less than 0.1 ft.

The Cooper-Jacob straight-line method (Cooper and Jacob, 1946) was applied to the drawdown data from well 33P029 to determine the transmissivity of the Upper Floridan aquifer (Fig. 4). The data from 90 seconds to 2.5 hours was used to fit the straight line. Transmissivity to one significant figure was determined to be 100,000 feet squared per day (ft^2/d).

72-Hour Aquifer Test

Lower Floridan aquifer well 33P028 was pumped at an average rate of 740 gal/min during March 8–11, 2010. Correcting for a minor linear trend leads to a 72-hour drawdown in well 33P028 of 38.8 ft. Drawdown at the pumped well as a function of log time was nonlinear as indicated by continuously decreasing log cycle of drawdown with time. The nonlinear nature of drawdown on the semi-log plot precluded the viable use of a simple analytical method for estimating the transmissivity of the Lower Floridan aquifer. Total drawdown in the Upper Floridan aquifer observation wells 33P025 and 33P029 was 0.3 and 0.4 ft, respectively. Drawdown in 33P025 indicates that there is measureable drawdown within the Upper Floridan aquifer more than 1 mile away from the pumping source in the Lower Floridan aquifer.

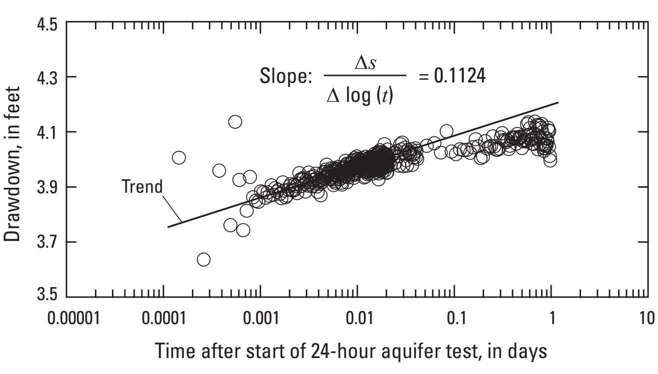

Figure 4. Measured drawdown in well 33P030 at Fort Stewart, Georgia, during a 24-hour aquifer test, March 3–4, 2010.

Transmissivity of the Upper and Lower Floridan aquifers was estimated using the numerical modeling program MODFLOW-96 (McDonald and Harbaugh, 1988; Harbaugh and McDonald, 1996) with the calibration tool MODOPTIM (Halford, 2006b). The aquifer system was simulated by using a two-dimensional, axisymmetric radial, transient, groundwater flow model that incorporated well 33P028 and observation wells 33P029 and 33P025. MODOPTIM (Halford 2006b) estimated hydraulic properties (parameter estimation) by minimizing the weighted sum-of-squares of differences between simulated and measured drawdowns (calibration). Hydraulic properties were horizontal hydraulic conductivity in the Upper Floridan aquifer, Lower Floridan confining unit, and Lower Floridan aquifer; and a single value for the composite specific storage for all model units.

Transmissivity of the Lower Floridan aquifer was estimated to be about 7,000 ft^2/d, which is slightly lower than the 11,000 ft^2/d average transmissivity of the Lower Floridan aquifer, reported at Hunter Army Airfield, about 25 miles northeast of Fort Stewart (Williams, 2010). Transmissivity of the Lower Floridan confining unit was estimated to be about 4,000 ft^2/d. Transmissivity of the Upper Floridan aquifer was estimated to be 90,000 ft2/d, slightly less than the 100,000 ft^2/d transmissivity that was determined using the straight-line method (Cooper and Jacob, 1946) based on drawdown data from the 24-hour aquifer test at well 33P029. These transmissivities translate to horizontal hydraulic conductivity values for the Upper Floridan aquifer of nearly 350 ft/d, for the Lower Floridan confining unit of 17 ft/d, and for the Lower Floridan aquifer of 14 ft/d. Specific storage for the entire Floridan aquifer system was estimated to be about 3E-06 ft^{-1}.

The parameter estimation of the axisymmetric model simulation indicates that at the study site, the Lower Floridan confining unit has hydraulic properties similar to the Lower Floridan aquifer. The results of flowmeter surveys (the Lower Floridan confining unit contains a high-yielding water-bearing unit) and slug tests support the hydrologic similarity between the two units at the study site.

Values of simulated drawdown and recovery were similar to those of measured drawdown and recovery for wells 33P028 and 33P029 (Fig. 5). Values of simulated drawdown were about half the values of measured drawdown for well 33P025. The poor fit of simulated values of drawdown to those of measured drawdown for well 33P025 may be a result of poor drawdown estimation or actual heterogeneity within the Upper Floridan aquifer that was not accounted for within the model.

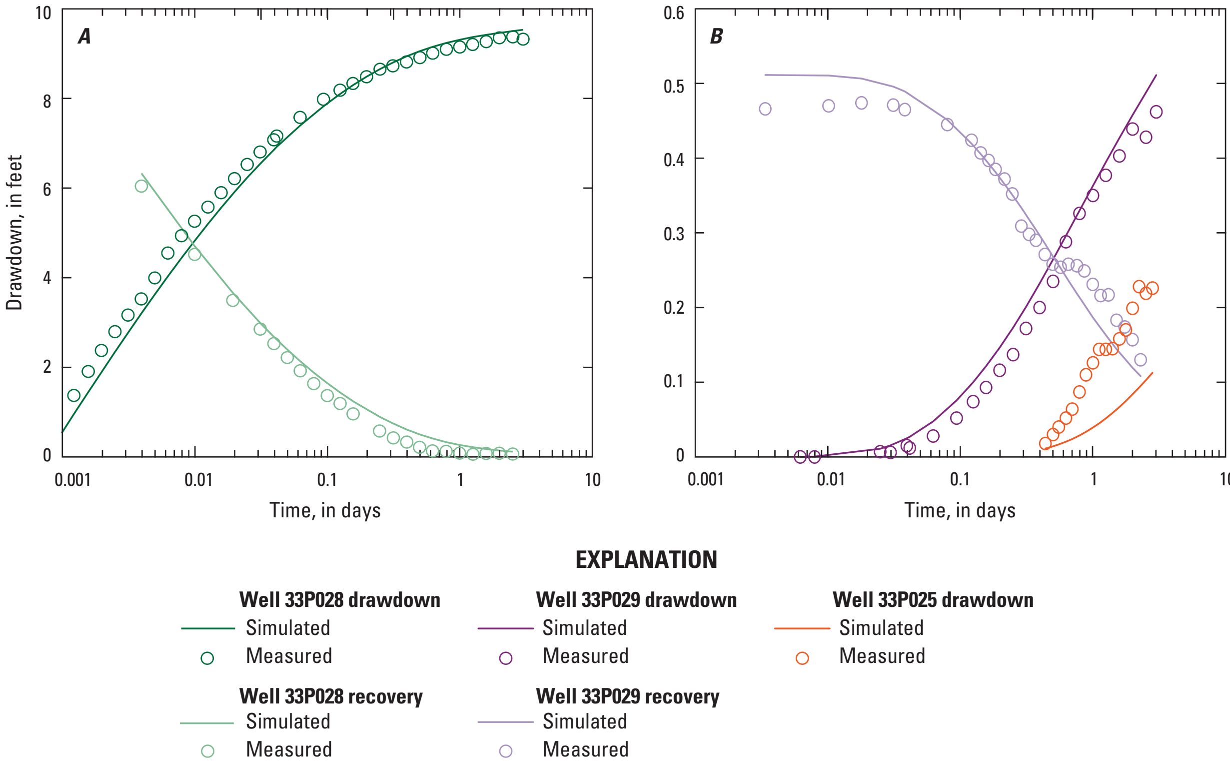

Figure 5. Simulated and measured drawdown and recovery for *(A)* pumped well 33P028 and *(B)* observation well 33P029 and simulated drawdown for observation well 33P025 for the 72-hour aquifer test at Fort Stewart, Georgia, March 8–11, 2010.

CONCLUSIONS

The results of two aquifer tests at the study site consistently indicate that the Upper Floridan aquifer has a transmissivity of about 100,000 feet squared per day (ft^2/d). Transmissivity for the Upper Floridan aquifer translates to a horizontal hydraulic conductivity of 350 feet per day (ft/d). Slug tests and model simulation results indicate that the hydrologic properties for the Lower Floridan confining unit are similar to those of the Lower Floridan aquifer. An axisymmetric model simulation indicates that the Lower Floridan confining unit and Lower Floridan aquifer have values of transmissivity of about 4,000 and 7,000 ft^2/d, respectively. Horizontal hydraulic conductivity in both the Lower Floridan confining unit and Lower Floridan aquifer is essentially the same, about 15 ft/d. Pumping in the Lower Floridan aquifer caused a measurable drawdown response more than 1 mile away in the Upper Floridan aquifer.

ACKNOWLEDGMENTS

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REFERENCES CITED

Bouwer, H., and Rice, R.C., 1976, A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells: Water Resources Research, v. 12, no. 3, p. 423–428.

Clarke, J.S., 2003, The surficial and Brunswick aquifer systems—Alternative ground-water resources for Coastal Georgia, in Hatcher, K.J., ed., Proceedings of the 2003 Georgia Water Resources Conference, April 23–23, 2003, at The University of Georgia: Athens, Georgia, The University of Georgia, CD–ROM.

Cooper, H.H., Jr., and Jacob, C.E., 1946, A generalized graphical method for evaluating formation constants and summarizing well-field history: Transactions of the American Geophysical Union, v. 27, p. 526–534.

Georgia Environmental Protection Division, 2006, Coastal Georgia water & wastewater permitting plan for managing salt water intrusion: Georgia Environmental Protection Division, 52 p., accessed online in December 1, 2010, at *http://www1.gadnr.org/cws/Documents/saltwater_management_plan_june2006.pdf.*

Halford, K.J., 2006a, Documentation of a spreadsheet for time-series analysis and drawdown estimation: U.S. Geological Survey Scientific Investigations Report 2006–5024, 38 p.

Halford, K.J., 2006b, MODOPTIM: A general optimization program for ground-water flow model calibration and ground-water management with MODFLOW: U.S. Geological Survey Scientific Investigations Report 2006–5009, 62 p.

Halford, K.J., and Kuniansky, E.L., 2002, Documentation of spreadsheets for the analysis of aquifer-test and slug-test data, version 1.2: U.S. Geological Survey Open-File Report 02–197, 51 p.

Harbaugh, A.W., and McDonald, M.G., 1996, Progammer's documentation for MODFLOW-96, an update to the U.S. Geological Survey modular finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 96–486, 220 p.

McDonald, M.G., and Harbaugh, A.W., 1988, A modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Techneques of Water-Resources Investigations, book 6, chap. A1, 576 p.

Miller, J.A., 1986, Hydrogeologic framework of the Floridan aquifer system in Florida and in parts of Georgia, Alabama, and South Carolina: U.S. Geological Survey Professional Paper 1403-B, Regional Aquifer System Analysis, 91 p, 33 pls.

van der Kamp, Garth, 1976, Determining aquifer transmissivity by means of well response tests: The underdamped case: Water Resources Research, v. 12, no. 1, p. 71–77.

Williams, L.J., 2010, Summary of hydrologic testing of the Floridan aquifer system at Hunter Army Airfield, Chatham County, Georgia: U.S. Geological Survey Open-File Report 2010–1006, 30 p.