GROUNDWATER MODELING TO EVALUATE INTERAQUIFER LEAKAGE IN THE FLORIDAN AQUIFER SYSTEM NEAR HUNTER ARMY AIRFIELD AND FORT STEWART, GEORGIA

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REFERENCE: *Proceedings of the 2011 Georgia Water Resources Conference*, held April 11–13, 2011, at the University of Georgia.

Abstract. Simulations using a modified regional groundwater-flow model were used to determine the amount of leakage from the Upper Floridan aquifer (UFA) through the Lower Floridan confining unit (LFC) into the Lower Floridan aquifer (LFA) resulting from pumping about 1 million gallons per day at newly constructed LFA production wells at Hunter Army Airfield and Fort Stewart in coastal Georgia. Simulated steady-state drawdown at each of the LFA production wells closely matched observed drawdown during a 72-hour aquifer test with the observed water levels reaching steady-state by the end of the test period. However, simulated drawdown was greater than observed drawdown in the UFA because of the short duration of the aquifer test and the time required for groundwater movement through the LFC into the LFA. Steady-state simulations provide an estimate of leakage based on the long-term continuous operation of each production well. Results of model simulations indicate that interaquifer leakage accounts for 48 percent of the flow to the well at Hunter Army Airfield, and 98 percent of the flow to the well at Fort Stewart. Simulated results near the Hunter Army Airfield production well indicated that 65 percent of the leakage from the UFA to the LFA occurs within a 1-mile radius, whereas simulated results near the Fort Stewart production well indicated 80-percent leakage from the UFA to the LFA within the same radius. The greater amount of leakage to the production well near Fort Stewart can be attributed to the higher transmissivity of the UFA and higher vertical hydraulic conductivity in the LFC near the well.

INTRODUCTION

To assess the water-supply potential of the Lower Floridan aquifer (LFA) in coastal Georgia, the U.S. Geological Survey (USGS), in cooperation with the U.S. Department of the Army, conducted investigations at Hunter Army Airfield (HAAF) and Fort Stewart during 2009–2010 to determine the hydrogeology and water quality of the Floridan aquifer system and the effects of pumping the LFA on the Upper Floridan aquifer (UFA). Fort Stewart is near Hinesville in Liberty County, and HAAF is near the city of Savannah in Chatham County, Georgia (Fig. 1). Water supply at both installations is derived from the UFA and recent expansion plans has the U.S. Department of the Army evaluating the LFA as an alternative water supply because of tighter restrictions by the Georgia Environmental Protection Division (GaEPD) on permitted groundwater withdrawals from the UFA. Restrictions on water withdrawal in the UFA are the result of concern over saltwater intrusion at Hilton Head Island, South Carolina, which could be affected by pumping near the city of Savannah. The development of alternative water supplies such as the LFA has been encouraged by GaEPD, but State guidelines stipulate that permit applicants must determine any adverse effects pumping the LFA might have on the UFA. Pumping from the LFA may increase head gradients locally between the UFA and LFA, lower water levels in the UFA, and induce groundwater leakage from the UFA to the LFA. Under the current GaEPD interim strategy, once leakage from the UFA to the LFA has been determined the applicant must offset, or reduce, pumping in the UFA so that there is "no net negative impact."

Evaluation of the hydrogeology at HAAF and Fort Stewart included the construction of test wells in the LFA, geophysical logging, aquifer testing, and groundwater-modeling studies. The focus of this paper is on the application of information, including hydraulic-input parameters, obtained from the new LFA test wells to a modified regional groundwater model with a more refined grid configuration. The refined grid is needed to accurately simulate the cone of depression near the LFA pumping well and provide the best possible estimate of leakage from the UFA through the Lower Floridan confining unit (LFC) into the LFA.

REGIONAL GROUNDWATER-FLOW MODEL AND MODIFICATIONS

A regional groundwater-flow model (Payne and others, 2005) for the coastal region of Georgia and adjacent parts of South Carolina and Florida was modified and used to simulate the effects of pumping from the LFA at HAAF and Fort Stewart, Georgia. The coarse-grid regional model (Payne and others, 2005), using MODFLOW-2000 (Harbaugh and others, 2000), was used previously to simulate flow in the surficial, Brunswick, and Floridan aquifer systems, which encompass an area of 42,155 square miles (mi^2) that includes the coastal plain of Georgia, northeastern Florida, southwestern South Carolina, and the adjacent offshore area (Fig. 1*A*). Two revised models were developed with small grid cells representing areas of pumping at HAAF (model A; Fig. 1*B*) and Fort Stewart

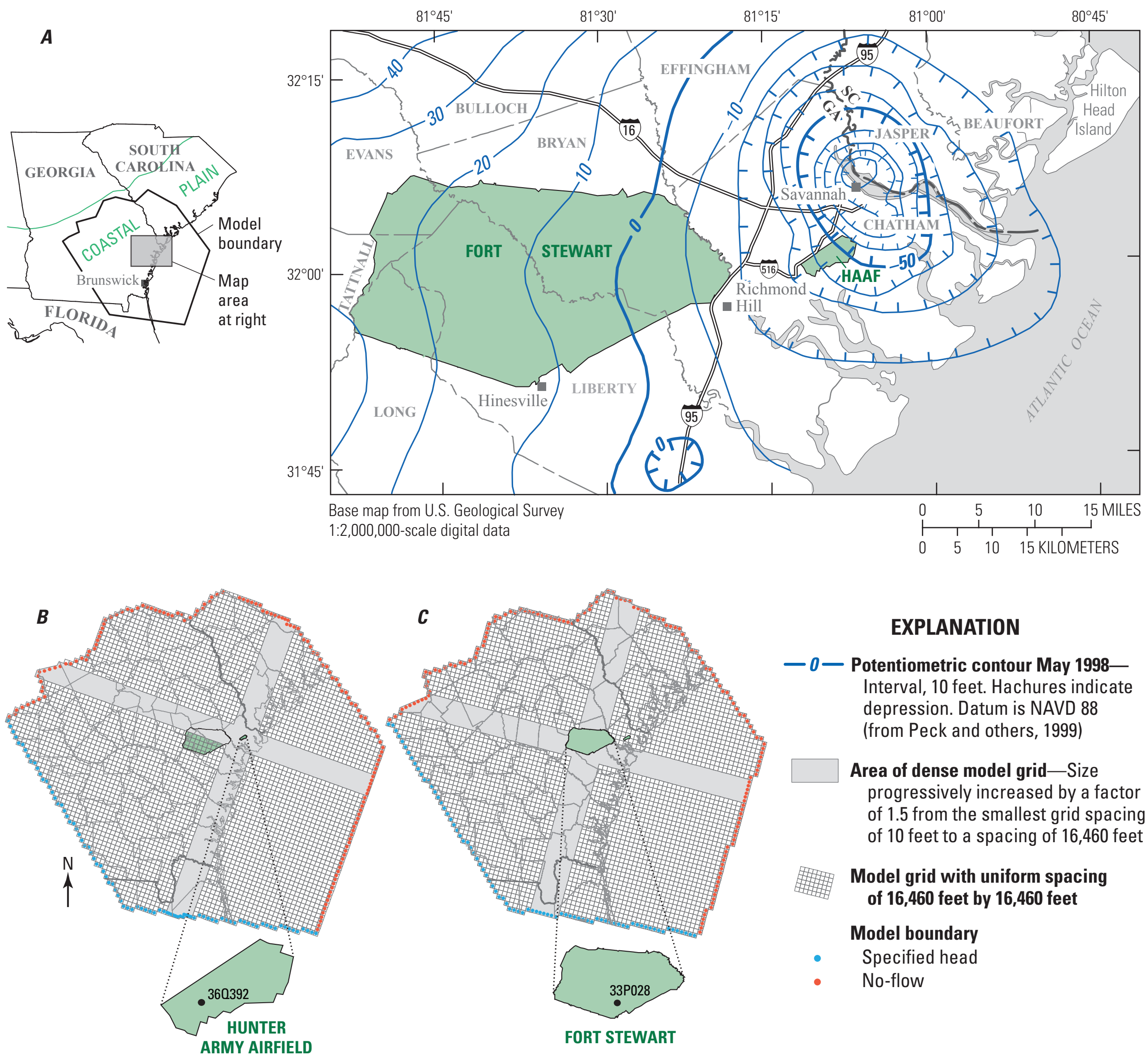


Figure 1. ***(A)*** **Location of the study area and potentiometric surface contours for the Upper Floridan aquifer, and groundwater-flow model grids for** ***(B)*** **well 36Q392 at Hunter Army Airfield (HAAF) and** ***(C)*** **well 33P028 at Fort Stewart in coastal Georgia.**

(model B; Fig. 1*C*). The revised models also incorporated a revised hydrogeologic framework of the Floridan aquifer system in the northern part of coastal Georgia (Williams and Gill, 2010; Fig. 2). Both revised models include new hydraulic-property zones based on the revised hydrogeologic framework and results from the 72-hour aquifer tests at both sites.

The coarse-grid regional model and revised models A and B consist of the following seven model layers and corresponding hydrogeologic units (Fig. 2) in descending order:

- Layer 1: Confined upper and lower water-bearing zones of the surficial aquifer system;
- Layer 2: Brunswick aquifer system confining unit;
- Layer 3: Upper and lower Brunswick aquifers, which compose the Brunswick aquifer system;
- Layer 4: Upper Floridan confining unit;
- Layer 5: Upper Floridan aquifer (UFA);
- Layer 6: Lower Floridan confining unit (LFC); and
- Layer 7: Lower Floridan aquifer (LFA).

The coarse-grid model was discretized using variably spaced grid and cell sizes ranging from approximately 4,000 × 5,000 feet (ft; 0.7 mi^2) to 16,500 × 16,500 ft (9.8 mi^2) with higher density of cells in areas of groundwater pumping near the cities of Savannah and Brunswick. For the revised models, grid-cell dimensions were decreased to the smallest grid spacing of 10 ft near the new LFA wells at HAAF and Fort Stewart and increased by a factor of 1.5 to a maximum spacing of about 16,400 ft away from the wells (Fig. 1).

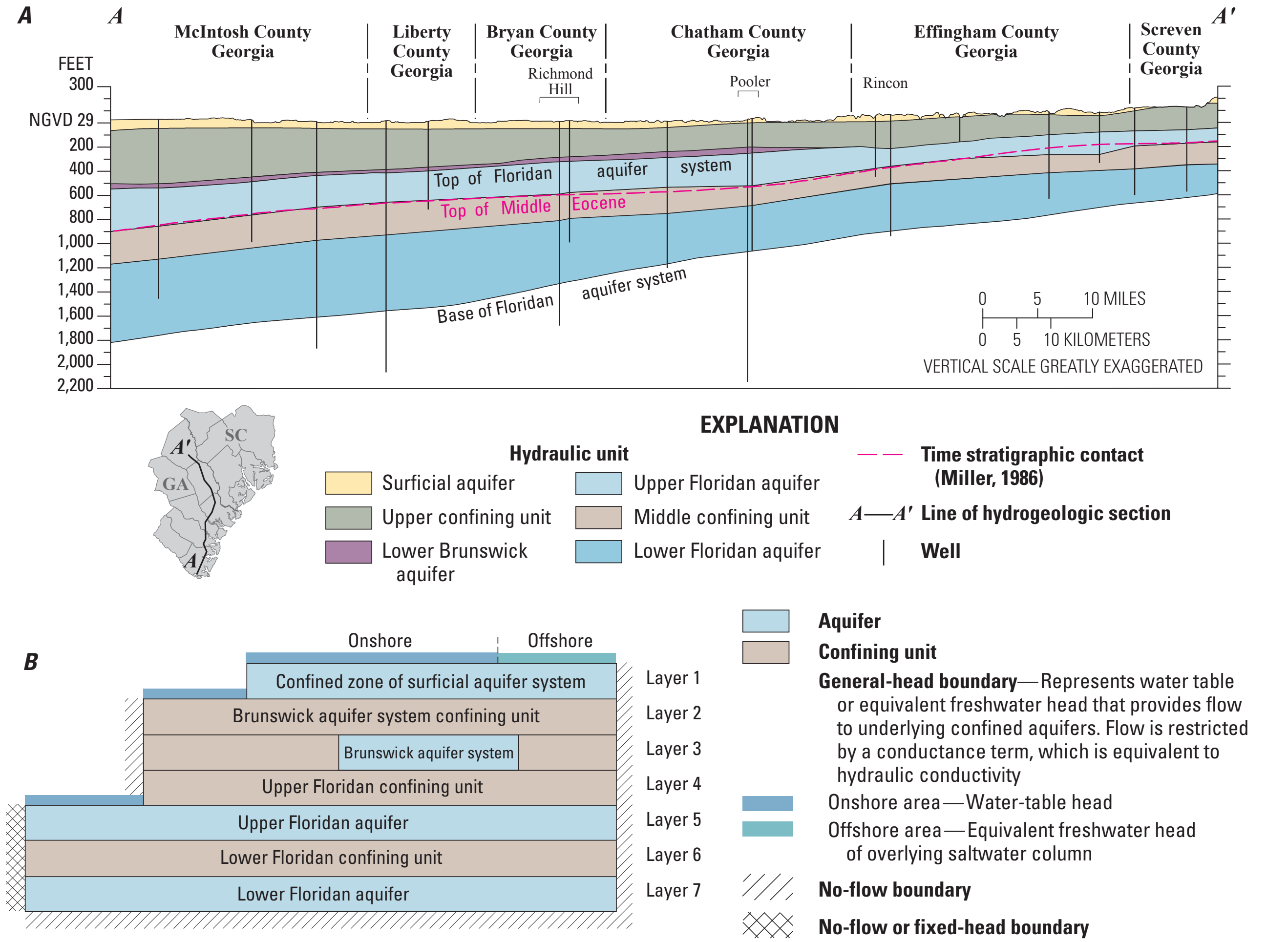


Figure 2. Hydrogeologic cross section *A–A′* (modified from Williams and Gill, 2010) showing aquifers and confining units of the Floridan aquifer system and model layers and boundary conditions (from Payne and others, 2005).

The boundary conditions of the coarse-grid model were used for the revised models. Lateral boundaries for all layers were designated as no flow except the southern and southwestern sides of layers 5, 6, and 7 (UFA, LFC, and LFA, respectively), which were designated as specified head. Heads assigned to specified-head cells were based on estimates of UFA head derived from the potentiometric-surface map for 1998 (Peck and others, 1999; Fig. 1). The lowermost boundary was designated as no flow, and the uppermost boundary was designated as a general-head boundary representing the confined zone of the surficial aquifer system (Fig. 2).

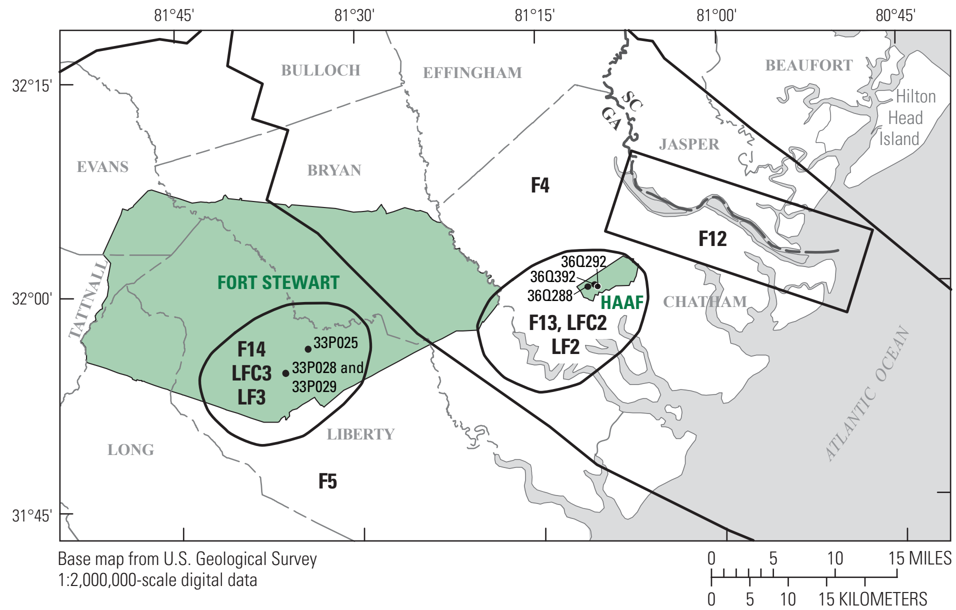
Estimates of mean annual pumpage were assigned in the regional coarse-grid model based on county aggregate and site-specific data. Steady-state simulations were developed for 1980 and 2000 by assigning pumping to model layers 3 (Brunswick aquifer system), 5 (UFA), and 7 (LFA) based on the open interval of wells. Total pumpage simulated by the regional model was 692 million gallons per day (Mgal/d) for 1980 and 798 Mgal/d for 2000. For the revised models, the pumping rates for 2000 were used for the model area and actual mean pumping rates for the production wells during 2010 at HAAF and Fort Stewart.

Results of field investigations at HAAF and Fort Stewart (Clarke and others, 2010; Williams, 2010: John Clarke, U.S. Geological Survey, written commun., 2010) provided the basis for revisions to the hydraulic-property zones that were assigned to these areas of the Floridan aquifer system in the coarse-grid model. Adjustments were made to the UFA (layer 5), LFC (layer 6), and LFA (layer 7) on the basis of aquifer tests, slug tests, and core analysis. Modifications to the coarse-grid model were applied first to revised model A for the HAAF area, and then with additional modifications to revised model B for the Fort Stewart area. New hydraulic-property zones were added as follows (Fig. 3):

- UFA (layer 5)—zone F13 was added at HAAF, and zone F14 was added at Fort Stewart.
- LFC (layer 6)—zone LFC2 was added at HAAF, and zone LFC3 was added at Fort Stewart.
- LFA (layer 7)—zone LF2 was added at HAAF, and zone LF3 was added at Fort Stewart.

Each of the new hydraulic-property zones encompass a 114-mi^2 study area that includes the area of highest grid resolution and all wells evaluated by model simulations.

Figure 3. New hydraulic property zones for model layers 5–7 (modified from Payne and others, 2005; Clarke and others, 2010).



Unit	Layer	Payne and others (2005) Hydraulic property zone	K_h (ft/d)	K_v (ft/d)	Clarke and others (2010) Hydraulic property zone	K_h (ft/d)	K_v (ft/d)	T (ft²/d)
UFA	5	F4	70	70	F4	70	70	—
		F5	394	394	F5	394	394	—
		F12	25	25	F12	25	25	—
		—	—	—	F13	76	76	40,000
		—	—	—	F14	398	398	100,000
LFC	6	All	0.02	0.02	LFC1	0.02	0.02	—
					LFC2	0.20	0.02	—
					LFC3	10	0.20	—
LFA	7	All	10	10	LF1	10	10	—
					LF2	100	10	7,000
					LF3	15.8	1.6	5,000

K_h, horizontal hydraulic conductivity in feet per day (ft/d)
K_v, vertical hydraulic conductivity in feet per day
T, transmissivity, in feet squared per day (ft²/d)
—, not applicable
Note: Zones LFC1 and LF1 cover areas outside zones LFC2, LFC3, LF2, and LF3

Water-level residuals (simulated minus observed head) of revised models A and B were similar to those of the coarse-grid model (Payne and others, 2005), which was expected because the revisions to the coarse-grid model were applied over a 114-mi² area at each installation. The root mean square (RMS) of residuals for layer 5 was similar for the coarse-grid model (9.94 ft) and for revised models A (10.2 ft) and B (10.0 ft). The RMS of residuals for layer 7 was 9.91 ft for revised model A and 7.74 ft for revised model B, both of which were lower than the RMS value (9.15 ft) for the coarse-grid model. Although the RMS of water-level residuals for layer 3 in revised models A (11.0 ft) and B (13.8 ft) were higher than the value (5.91 ft) for the coarse-grid model the values were considered acceptable because the focus of the study was on simulating flow in the UFA and LFA.

Simulated water budgets for the coarse-grid model and for revised models A and B were similar, with most differences occurring in layers 1 and 5. The revised models indicated decreases in recharge from and discharge to the overlying general-head boundary (layer 1) and decreased outflow and increased inflow along lateral specified-head boundaries (layer 5). This simulation of 2000 conditions without pumping at either of the new LFA wells (36Q392 and 33P028) was considered the "base case" and was used for comparing drawdown and changes in water budget in all subsequent simulations.

SIMULATED RESULTS AND DISCUSSION

Long-term steady-state changes in water levels and water budget caused by increased pumping in the LFA at HAAF and at Fort Stewart were simulated by using revised models A and B, respectively. At HAAF, a new LFA well (36Q392) was assigned a pumping rate of 748 gallons per minute (gal/min; 1.08 Mgal/d) in model A. Simulated drawdown of 36.2 ft was close to the observed drawdown of 36.3 ft during a 72-hour aquifer test

(Clarke and others, 2010; Williams, 2010). Observed drawdown values of 0.76 ft in UFA observation well 36Q292 and 0.43 ft in UFA observation well 36Q288 were less than the simulated drawdown values of 2.03 ft and 1.9 ft, respectively (Clarke and others, 2010; Fig. 4). The match of simulated steady-state drawdown in the LFA to observed drawdown is reasonable because test data indicated that water levels had nearly stabilized at the end of the 72-hour pumping period. In the two UFA observation wells, test data indicated that water levels had not stabilized at the end of the 72-hour pumping period, which may explain the higher simulated steady-state drawdown. Simulated drawdown in the UFA as a result of leakage through the LFC was greater than 1 ft over a 141-mi^2 area surrounding LFA well 36Q392 (Clarke and others, 2010; Fig. 4).

In model B, LFA well 33P028 at Fort Stewart was assigned a pumping rate of 740 gal/min (1.07 Mgal/d). The simulated drawdown of 38.6 ft matched the observed drawdown of 38.8 ft from a 72-hour aquifer test (John Clarke, U.S. Geological Survey, written commun., 2010). Observed drawdown in two UFA observation wells (33P029 and 33P025) was 0.4 ft and 0.3 ft, respectively, compared with simulated drawdown of 1.12 ft and 0.81 ft, respectively (John Clarke, U.S. Geological Survey, written commun., 2010; Fig. 4). As in the HAAF simulations, the good match of simulated to observed LFA drawdown and the higher simulated than observed UFA drawdown could be expected in that these results reflect differences in the time required for the UFA and LFA to reach steady-state conditions. Simulated drawdown in the UFA resulting from leakage through the LFC was greater than 1 ft over a 1.4-mi^2 area surrounding well 33P028 (John Clarke, U.S. Geological Survey, written commun., 2010; Fig. 4).

Leakage from the UFA through the LFC to the LFA occurred over a smaller area near Fort Stewart than at HAAF because horizontal hydraulic conductivity in the LFC was 50-times higher in the vicinity of Fort Stewart than at HAAF, and transmissivity of the UFA was 2.5-times higher in this area than at HAAF (Fig. 3). Higher hydraulic conductivity enables movement of water from the UFA through the LFC and into the LFA.

The simulated steady-state water budget was evaluated by using the MODFLOW postprocessor ZONEBUDGET (Harbaugh, 1990), which sums simulated flow entering and leaving a designated area of the model domain. The year 2000 "base case" condition was used for comparisons of changes in flow to specified areas for each simulation (Fig. 5).

Simulated pumping at well 36Q392 (1.08 Mgal/d) at HAAF was derived from increased inflow and decreased outflow from the general-head boundary in layer 1 (41 percent); the majority of flow was derived from increased lateral flow in the LFA (48 percent; simulated as decreased flow from layer 7 to layer 6) and from increased leakage through the LFC (48 percent; Clarke and others, 2010; Fig. 5). The sum of these percentages is greater than 100 percent because inflow and outflow from the general-head boundary in layer 1 are included as increased leakage through the LFC. Simulated results near well 36Q392

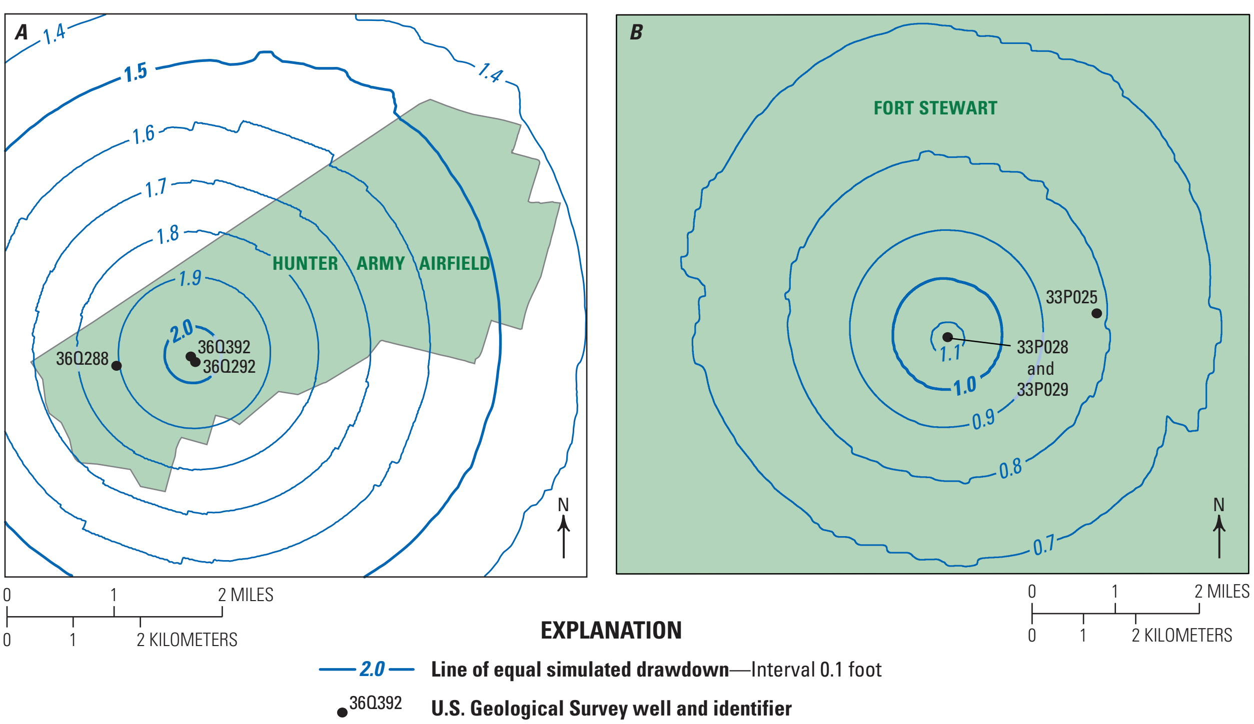


Figure 4. Simulated steady-state drawdown in the Upper Floridan aquifer resulting from pumping Lower Floridan wells *(A)* 36Q392 at 748 gallons per minute, Hunter Army Airfield and *(B)* 33P028 at 740 gallons per minute, Fort Stewart, Georgia (modified from Clarke and others, 2010; John Clarke, U.S. Geological Survey, written commun., 2010; see Fig. 3 for locations).

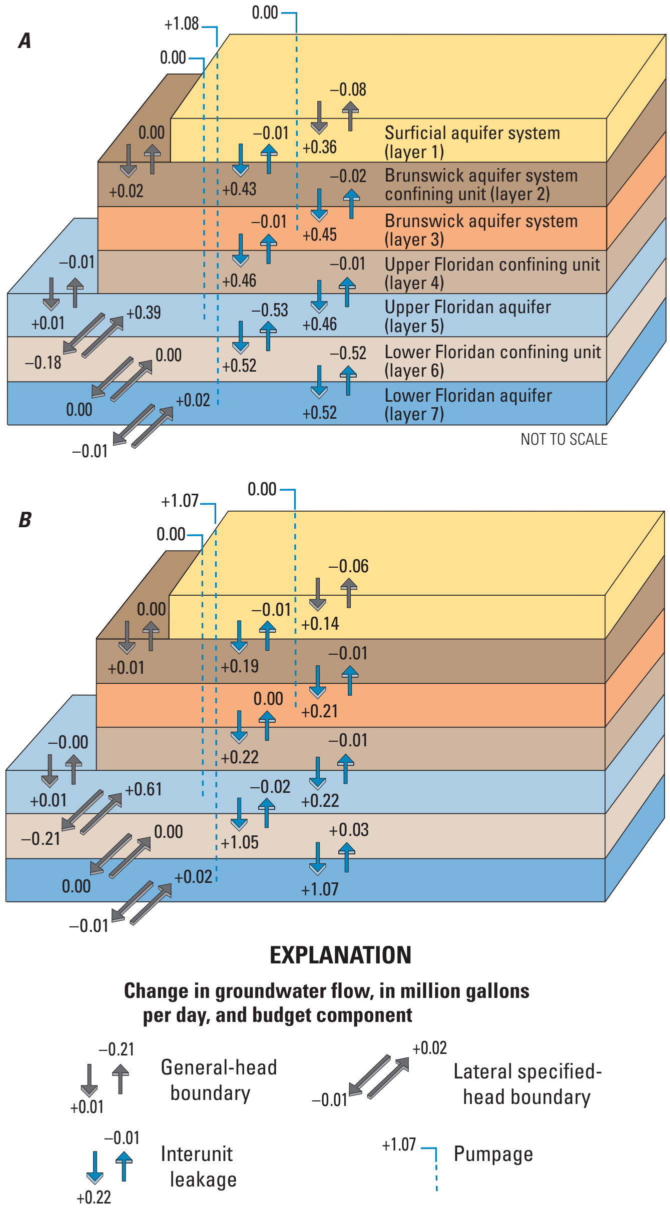


Figure 5. Change in simulated steady-state water budget from initiation of pumping at wells (A) 39Q392, Hunter Army Airfield, and (B) 33P028, Fort Stewart, Georgia (modified from Clarke and others, 2010; John Clarke, U.S. Geological Survey, written commun., 2010).

indicated 65 percent of the leakage from the UFA to the LFA occurs within a 1-mile radius, with the remaining 35 percent occurring from outside this area (Clarke and others, 2010).

Simulated pumping at well 33P028 (1.07 Mgal/d) at Fort Stewart resulted in increased inflow and decreased outflow from the general-head boundary in layer 1 (19 percent); the majority of the flow was derived from increased lateral inflow from the UFA specified-head boundary (57 percent) and decreased lateral outflow through the same boundary (20 percent; John Clarke, U.S. Geological Survey, written commun., 2010; Fig. 5). The UFA and layers above are the sources of 98 percent of all inflows, transmitted through the LFC, created by simulated pumpage (1.07 Mgal/d) in the LFA. The inflows and outflows through the UFA model boundary are an indication that the influence of pumping well 33P028 extends beyond the model boundaries in the UFA. Simulated results near well 33P028 indicates 80 percent of the leakage from the UFA to the LFA occurs within a 1-mile radius, and the remaining 20 percent occurs from outside this area (John Clarke, U.S. Geological Survey, written commun., 2010). Low horizontal hydraulic gradients and high transmissivity in the UFA allow the groundwater to move from great distances toward the well until the steep vertical hydraulic gradients near the well allow the water movement from the UFA through the LFC into the LFA.

REFERENCES

Clarke, J.S., Williams, L.J., and Cherry, G.S., 2010, Hydrogeology and water quality of the Floridan aquifer system and effect of Lower Floridan aquifer pumping on the Upper Floridan aquifer at Hunter Army Airfield, Chatham County, Georgia: U.S. Geological Survey Scientific Investigations Report 2010-5080, 56 p., available online at *http://pubs.usgs.gov/sir/2010/5080/*.

Harbaugh, A.W., 1990, A computer program for calculating subregional water budgets using results from the U.S. Geological Survey modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 90–392, 46 p.

Harbaugh, A.W., Banta, E.R., Hill, M.C., and McDonald, M.G., 2000, MODFLOW-2000, The U.S. Geological Survey modular ground-water model—User guide to modularization concepts and the ground-water flow process: U.S. Geological Survey Open-File Report 00–92, 121 p., available online at *http://pubs.er.usgs.gov/usgspubs/ofr/ofr2000-92*.

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, 91 p., 33 pl.

Payne, D.F., Abu Rumman, Malek, and Clarke, J.S., 2005, Simulation of ground-water flow in coastal Georgia and adjacent parts of South Carolina and Florida—Predevelopment, 1980, and 2000: U.S. Geological Survey Scientific Investigations Report 2005–5089, 91 p., available online at *http://pubs.usgs.gov/sir/2005/5089/*.

Peck, M.F., Clarke, J.S., Ransom, Camille, III, and Richards, C.J., 1999, Potentiometric surface of the Upper Floridan aquifer in Georgia and adjacent parts of Alabama, Florida, and South Carolina, May 1998, and water-level trends in Georgia, 1990–98: Georgia Geologic Survey Hydrologic Atlas 22, 1 sheet.

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 2010–1066, 30 p., available online at *http://pubs.usgs.gov/of/2010/1066/*.

Williams, L.J., and Gill, H.E., 2010, Revised hydrogeologic framework of the Floridan aquifer system in the northern coastal area of Georgia and adjacent parts of South Carolina: U.S. Geological Survey Scientific Investigations Report 2010–5158, 103 p., 3 pls., available online at *http://pubs.usgs.gov/sir/2010/5158/*.