SIMULATED EFFECTS OF IMPOUNDMENT OF LAKE SEMINOLE ON SURFACE- AND GROUND-WATER FLOW IN SOUTHWESTERN GEORGIA AND ADJACENT PARTS OF ALABAMA AND FLORIDA

L. Elliott Jones and Lynn J. Torak

AUTHORS: Hydrologists, U.S. Geological Survey, 3039 Amwiler Road, Suite 130, Peachtree Business Center, Atlanta, Georgia 30360-2824.
REFERENCE: *Proceedings of the 2003 Georgia Water Resources Conference*, held April 23–24, 2003, at the University of Georgia. Kathryn J. Hatcher, editor, Institute of Ecology, The University of Georgia, Athens, Georgia.

Abstract. Hydrologic implications of the impoundment of Lake Seminole in southwest Georgia and its effect on components of the surface- and ground-water-flow systems of the lower Apalachicola-Chattahoochee-Flint (ACF) River Basin are being investigated using ground-water modeling. Simulations of pre- and post-impoundment conditions were performed using a modified version of the U.S. Geological Survey finite-element model that was developed for a previous study of the lower ACF River Basin. Results of ground-water modeling were used to describe and quantify the stream-aquifer-flow system as it existed prior to impoundment and to identify any changes in the surface- and ground-water-flow regime after the lake was filled during 1955–1957. Comparison of simulation results of post-impoundment drought conditions (October 1986) with results of hypothetical preimpoundment conditions (a similar drought prior to 1955) provide a qualitative measure of the changes in hydraulic head and ground-water flow to and from streams and Lake Seminole and across state lines caused by the impoundment.

INTRODUCTION

Lake Seminole (Fig. 1), in extreme southwestern Georgia and northwestern Florida, is located at the confluence of the Chattahoochee and Flint Rivers, which forms the Apalachicola River. The 37,600-acre lake was filled during 1957, 2 years after the construction of Jim Woodruff Lock and Dam by the U.S. Army Corps of Engineers (Corps). Lake Seminole is in the Dougherty Plain district of the Coastal Plain physiographic province, which is the recharge area of Eocene and Oligocene karst limestones of the Upper Floridan aquifer. A more thorough discussion of the hydrogeology of the Lake Seminole area is included in Torak and others (1996) and Torak (2003).

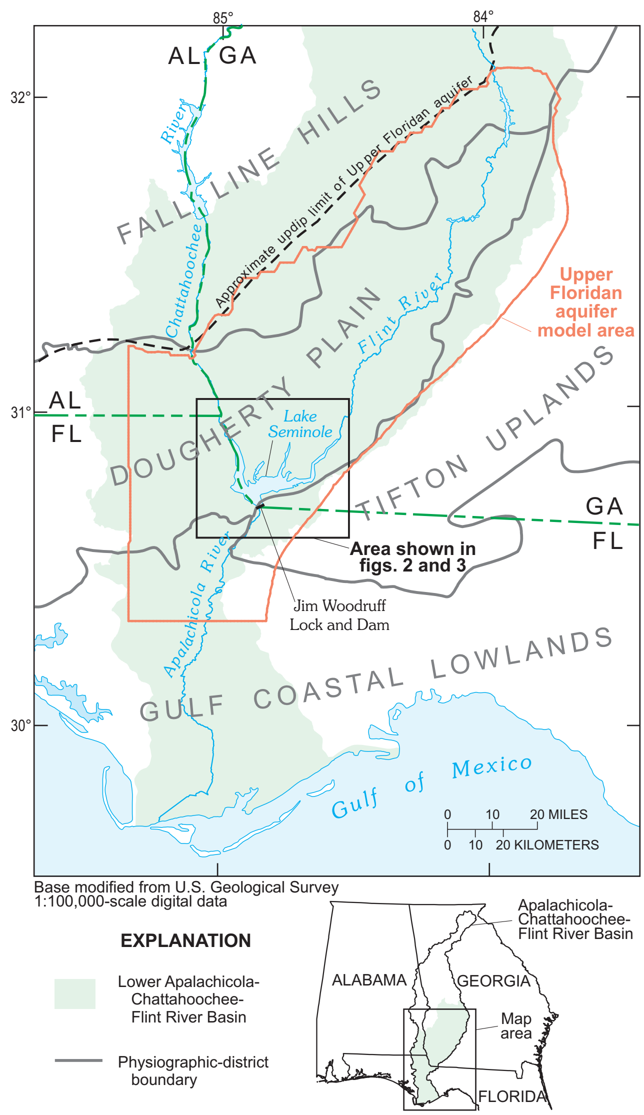

Figure 1. Location of study area, Upper Floridan aquifer model area, lower Apalachicola-Chattahoochee-Flint River Basin area, and physiographic districts of the Coastal Plain Province (modified from Torak and others, 1996).

The U.S. Geological Survey (USGS)—in cooperation with the Corps, Alabama Department of Economic and Community Affairs, Northwest Florida Water Management District, and Georgia Department of Natural Resources, Environmental Protection Division (GaEPD)—developed a digital model of ground-water flow in the Upper Floridan aquifer in the lower ACF River Basin (Torak and others, 1996). The digital model uses the standardized finite-element simulation program MODFE (Cooley, 1992; Torak, 1993a,b) for an aquifer that is hydraulically connected to streams. The digital model was intended, in part, to define stream-aquifer relations in the lower ACF River Basin and to determine the effects of ground-water pumping on streamflow. For model calibration, hydrologic conditions of October 1986 were chosen based on the assumption that the drought of 1986–1988, which was most severe during October 1986, represented a worst-case scenario with respect to the effects of aquifer stresses on streamflow.

During 1999, the USGS, in cooperation with the GaEPD, began a study to evaluate the water resources of Lake Seminole and the surrounding area. One of the objectives of this study is to compare current and pre-Lake Seminole ground-water- and surface-water-flow regimes to determine whether the volume of ground water flowing out of Georgia has changed significantly after construction of the Jim Woodruff Lock and Dam and the filling of the lake. This objective is addressed by comparing simulation results from the existing calibrated digital model of the lower ACF River Basin under drought conditions of October 1986 (Torak and others, 1996) with results of a new simulation under hypothetical pre-Lake Seminole conditions. The new simulation represents hydrologic conditions of October 1986, with respect to drought and pumping stresses, except that the lake was replaced by streams.

METHODS

The digital model of the lower ACF River Basin (Torak and others, 1996) simulates ground-water flow in the Upper Floridan aquifer, lake- and stream-aquifer interaction, lateral-boundary flow, and vertical leakage from the overlying undifferentiated overburden. Leakage to the Upper Floridan aquifer from the overburden and Lake Seminole both are represented by a steady, nonlinear, head-dependent vertical-leakage boundary. The vertical-leakage boundary is areally distributed among zones of elements based on estimated vertical hydraulic conductance (vertical hydraulic conductivity divided by thickness) of the overburden or lake bed. Vertical hydraulic conductance (1) was zero where overburden is absent, (2) ranged from 8.4×10^{-10} to 9.8×10^{-4} feet per day per foot (ft/d/ft) in areas where undifferentiated overburden is present, and (3) was 8.0×10^{-3} ft/d/ft for the bed of Lake Seminole (Torak and others, 1996, Table 4, Plate 5). For zones representing the overburden, head in the overburden was estimated from water levels in wells; for the zone representing Lake Seminole, head was set equal to the pool elevation of Lake Seminole during October 1986 (75.66 ft).

Minor modifications to values of vertical hydraulic conductance from those used in the existing digital model (Torak and others, 1996) were made to reflect current understanding of the occurrence of undifferentiated overburden in the Lake Seminole area. Recent analysis of well records and field reconnaissance in the area indicate that the undifferentiated overburden probably is absent near the channels of the Flint River, Spring Creek, and Fishpond Drain north of Lake Seminole (Fig. 2). To reflect the absence of overburden in the digital model, vertical hydraulic conductance in selected elements along these stream reaches was set to zero, whereas vertical hydraulic conductance in element zones north of Lake Seminole had been nonzero and nearly uniform in the original digital model. The effect of this change on simulated head in the Upper Floridan aquifer was minimal—the maximum simulated change from the calibrated model was 0.04 ft. For preimpoundment conditions, the undifferentiated overburden also was assumed to be absent beneath Lake Seminole; in the digital model, the vertical hydraulic conductance in the area representing Lake Seminole was set to zero.

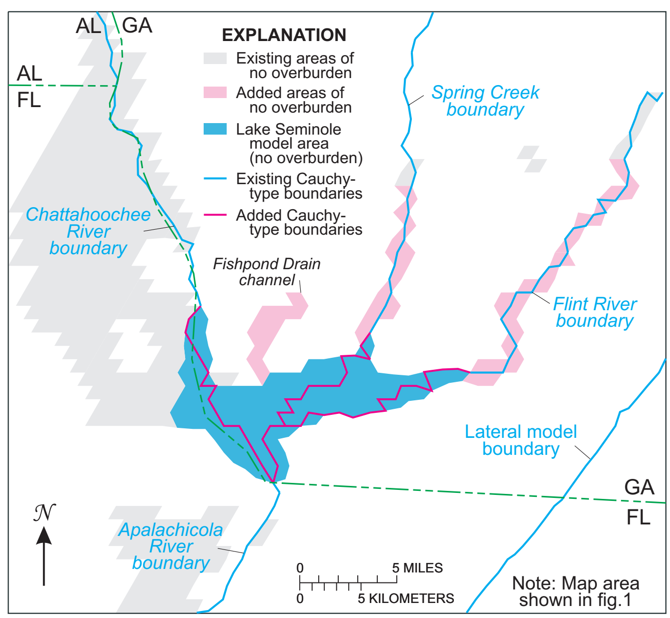

Figure 2. Boundary conditions of the digital ground-water model of the Upper Floridan aquifer in the Lake Seminole area showing modifications made to simulate preimpoundment conditions.

Upstream of Lake Seminole, the Chattahoochee and Flint Rivers and Spring Creek are represented in the model by head-dependent Cauchy-type boundaries. Such boundaries mathematically relate the flow rate across the streambed to the head difference between the aquifer and stream and to hydraulic characteristics of the streambed (Torak and others, 1996, p. 38–40). Near Lake Seminole, for the postimpoundment simulation, head at these boundaries was set to the stages in these streams during October 1986, which were influenced by the impoundment. To represent preimpoundment conditions, historic streamflow data and associated stage-discharge rating curves from the Chattahoochee, Flint, and Apalachicola Rivers prior to 1955 (U.S. Geological Survey, unpublished records) were used to estimate the stage that corresponds to streamflow along these three streams during a drought similar to that of October 1986. In the digital model, head at the Cauchy-type boundaries was lowered accordingly. Head-dependent Cauchy-type boundaries representing the preimpoundment channels of these streams in the area of Lake Seminole, downstream to the site of Jim Woodruff Lock and Dam, also were added and assigned head in a similar manner (Fig. 2). Because the purpose of this exercise was to investigate only the effects of impoundment of Lake Seminole on ground-water and surface-water flow, other model stresses were not changed. Thus, pumpage for the hypothetical preimpoundment simulation was input at the same rate as that used in the calibrated model of October 1986 conditions (Torak and others, 1996, p. 43–44), even though irrigation pumpage is known to have increased considerably during the period 1957–1986.

SIMULATION RESULTS

Water-budget components for the original October 1986 calibrated simulation (Torak and others, 1996), postimpoundment (October 1986 modified) simulation, and hypothetical preimpoundment simulation are compared in Table 1. For the October 1986 calibrated simulation, the percent of total discharge or recharge was computed and listed for each water-budget component. Eliminating overburden leakage in selected elements along the lowest reaches of the Flint River, Spring Creek, and Fishpond Drain north of Lake Seminole had minimal effect on water-budget components, as indicated by change and percent change for the postimpoundment simulation. For the postimpoundment simulation, total change in simulated flow rates, from the October 1986 calibrated simulation, of all components in the water budget is about 3 million gallons per day (Mgal/d), which is less than 0.1 percent of the total discharge or recharge (about 3,580 Mgal/d). For the hypothetical preimpoundment simulation, simulated recharge to the Upper Floridan aquifer was increased by about 350 Mgal/d, of which about 240 Mgal/d is from regional flow (mostly along the head-dependent Cauchy-type boundary at the lateral model boundary east of Lake Seminole) and by about 110 Mgal/d from leakage from the undifferentiated overburden over postimpoundment conditions. These recharge components mostly offset increases in discharge to streams and in-channel springs (about 400 Mgal/d), which occur primarily along the lowest reaches of the Chattahoochee and Flint Rivers. The remaining increase in discharge to streams and in-channel springs for the hypothetical preimpoundment

Table 1. Water-budget components for lower ACF River Basin model simulations

[Figures may not add to totals because of independent rounding; volumetric flow rate and change, in millions of gallons per day]

Water-budget component	October 1986 calibrated		Postimpoundment (October 1986 modified)			Hypothetical preimpoundment		
	Volumetric flow rate	Percent of total	Volumetric flow rate	Change from calibrated	Percent change from calibrated	Volumetric flow rate	Change from postimpoundment	Percent change from postimpoundment
Discharge, by component								
Streams and in-channel springs	2,427	67.6	2,425	–2	–0.1	2,828	402	16.6
Wells	475	13.2	475	0	0.0	475	0	0.0
Off-channel springs	333	9.3	333	0	0.0	333	0	0.0
Regional flow	304	8.5	304	0	0.0	261	–42	–13.9
Undifferentiated overburden	50	1.4	49	–1	–2.7	36	–13	–26.3
Total	**3,588**		**3,585**	**–3**		**3,932**	**347**	
Recharge, by component								
Undifferentiated overburden	2,489	69.4	2,486	–3	–0.1	2,594	108	4.3
Regional flow	933	26.0	933	0	0.0	1,169	236	25.3
Upper Floridan aquifer outcrop	141	3.9	141	0	0.0	144	3	2.1
Streams	25	0.7	25	0	0.0	25	0	1.9
Total	**3,588**		**3,585**	**–3**		**3,932**	**347**	

simulation mostly is accounted for by decreased regional outflow across lateral model boundaries (about 40 Mgal/d) and decreased vertical leakage to the undifferentiated overburden (about 10 Mgal/d) (Table 1).

Comparison of maps showing simulated water levels and flow lines in the Upper Floridan aquifer for pre- and postimpoundment conditions (Fig. 3*A* and *B*, respectively) indicates that the impoundment of Lake Seminole increased the amount of water stored in the aquifer and altered the direction of ground-water flow. Increased ground-water storage is indicated by a rise in ground-water level by as much as 25 ft. The greatest change in ground-water-flow directions due to the impoundment occurs southeast of Lake Seminole and east of the Apalachicola River. In this area, under hypothetical preimpoundment conditions, ground water flows northwestward from Florida, discharging to the Flint River; under postimpoundment conditions, ground water flows southwestward from Georgia, discharging to the Apalachicola River. There is a smaller area southwest of Lake Seminole and west of the Apalachicola River where under hypothetical preimpoundment conditions, ground water flows northeastward from Florida, discharging to the Chattahoochee River; under postimpoundment conditions, ground water flows southeastward, discharging to the Apalachicola River. Also under postimpoundment conditions, water levels in the aquifer near Spring Creek are higher than the streambed, and the aquifer discharges water to the creek, as evidenced by the flow lines ending at Spring Creek and the bending of contours in the simulated potentiometric surface. Under preimpoundment conditions, little ground water discharges to Spring Creek.

For the purposes of discussion of state-line flows, in Figure 3*A* and *B* the Georgia State line in the model area is divided into three sections: (1) the Georgia-Alabama and Georgia-Florida State lines from the lateral model boundary southward to Lake Seminole, (2) the Georgia-Florida State line in the Chattahoochee River impoundment arm of Lake Seminole downstream to Jim Woodruff Lock and Dam, and (3) the east-west trending part of the Georgia-Florida State line (southeast of Lake Seminole) from Jim Woodruff Lock and Dam to the lateral model boundary. For both the simulations that are compared, in section 1 ground-water flow converges at the Chattahoochee River (Fig. 3*A,B*) and results in outflow to the Chattahoochee River, which is represented by a Cauchy-type boundary. In the postimpoundment simulation, in the northwestern part of section 2, ground water flows under a low gradient from Florida southeastward into Georgia; and in the southeastern part of section 2, ground water flows under a slightly higher gradient from Georgia southward back into Florida (Fig. 3*A*). In the preimpoundment simulation, in section 2, ground-water flow converges and results in outflow to the Chattahoochee River at the added Cauchy-type boundary. In section 3 under postimpoundment conditions near Lake Seminole ground water flows under a low hydraulic gradient southwestward from Georgia into Florida, but near the lateral boundary of the model, ground water flows generally parallel to the Georgia-Florida State line, not across it (Fig. 3*A*).

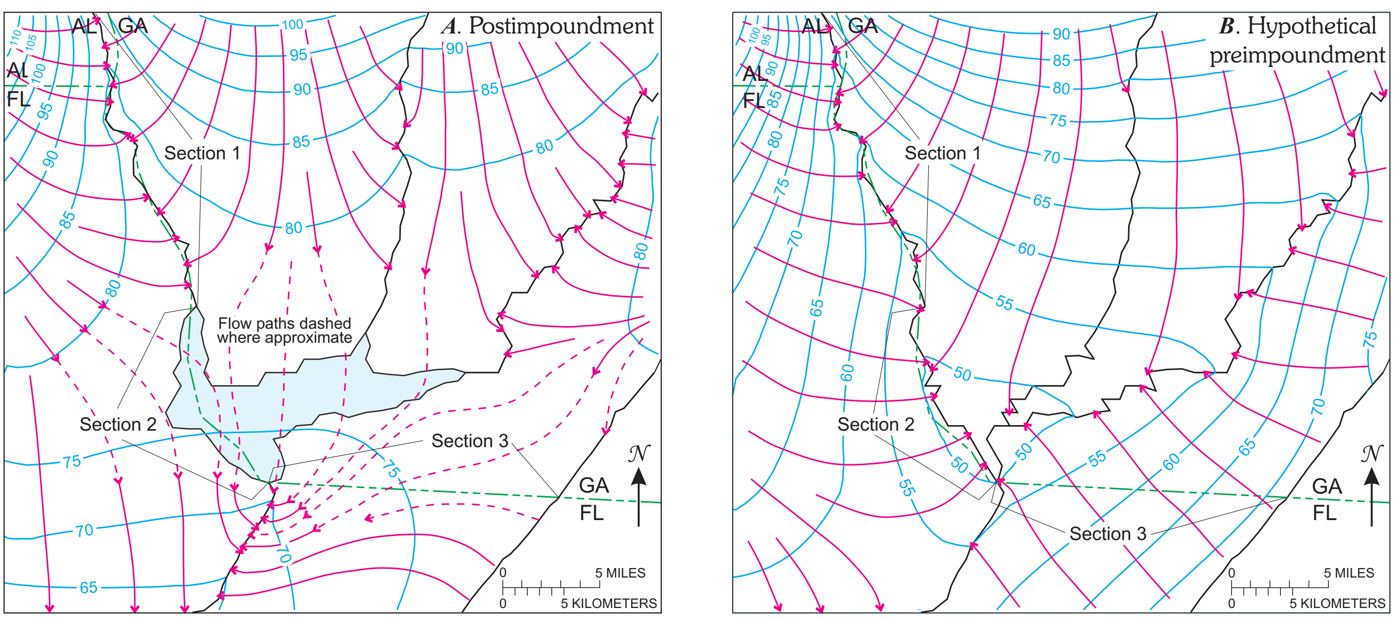

Figure 3. Simulated heads (blue contours) and ground-water-flow paths (red vectors) in the Upper Floridan aquifer in the Lake Seminole area (*A*) postimpoundment (October 1986 modified); and (*B*) hypothetical preimpoundment. Map area shown in Fig. 1; model boundaries identified in Fig. 2. Ground-water flow along numbered state-line sections described in text.

Under hypothetical preimpoundment conditions, along the east-west trending part of the Georgia-Florida State line, ground water flows under a relatively high gradient northwestward from Florida into Georgia (Fig. 3*B*).

LIMITATIONS

Records of ground-water levels and pumpage for the Upper Floridan aquifer prior to the construction of Jim Woodruff Lock and Dam and the impoundment of Lake Seminole are scarce, particularly in the area south of Lake Seminole. Consequently, the accuracy of the hypothetical preimpoundment simulation cannot be verified through a calibration procedure that matches simulated and measured water levels and stream baseflows. Also, under hypothetical preimpoundment conditions, simulated recharge to the aquifer from regional flow is greater than the recharge simulated for October 1986 postimpoundment conditions (Table 1). The increased simulated recharge under hypothetical preimpoundment conditions mostly occurs along the lateral head-dependent Cauchy-type boundary located to the southeast of Lake Seminole (Figs. 2, 3*B*). Head-dependent Cauchy-type boundaries usually are used where the aquifer extends beyond the boundary, but where storage effects in this external aquifer region can be ignored. Also, such boundaries are used where the contribution of flow across this mathematical boundary would not vary significantly from flow that would occur if the model were extended to include this external area. For the original digital model, this boundary was placed at a ground-water divide that existed in that area in 1986. It is not known whether the divide existed prior to impoundment of Lake Seminole or whether preimpoundment water levels in this area were similar enough to those during postimpoundment, to ensure that the hypothetical preimpoundment simulation does not violate any assumptions of the boundary. These assumptions probably are not violated, however, because steady-state simulations were performed, which do not compute aquifer-storage effects, and because an estimated predevelopment surface of the Upper Floridan aquifer (Johnston and others, 1980) shows a similar ground-water divide having similar water levels in that area.

Extremely low observed and simulated hydraulic gradients in the Lake Seminole area during postimpoundment conditions cause the potentiometric surface near the lake to be flat and almost horizontal. Slight differences in computed hydraulic head at nodes in elements in this area are responsible for the ground-water-flow paths shown in Figure 3*A* (dashed vectors); therefore, ground-water-flow paths in the Lake Seminole area can only be considered approximate, because neither the model nor the hydrologic data on which the model was developed contain sufficient detail to identify accurately ground-water-flow directions. Because the potentiometric surface is relatively flat near the lake, small changes to model input data—such as updated pumping estimates or improved estimates of aquifer properties—would alter the direction and magnitude of simulated ground-water-flow vectors described herein.

LITERATURE CITED

Cooley, R.L. 1992. A MODular Finite-Element model (MODFE) for areal and axisymmetric ground-water-flow problems, Part 2: Derivation of finite-element equations and comparisons with analytical solutions. U.S. Geological Survey Techniques of Water-Resources Investigations, Book 6, Chap. A4, 108 pp.

Johnston, R.H., R.E. Krause, F.W. Meyer, P.D. Ryder, C.H. Tibbals, and J.D. Hunn. 1980. Estimated potentiometric surface for the Tertiary limestone aquifer system, southeastern United States, prior to development. U.S. Geological Survey Open-File Report 80-406, 1 plate.

Torak, L.J. 1993a. A MODular Finite-Element model (MODFE) for areal and axisymmetric ground-water-flow problems, Part 1: Model description and user's manual. U.S. Geological Survey Techniques of Water-Resources Investigations, Book 6, Chap. A3, 136 pp.

———1993b. A MODular Finite-Element model (MODFE) for areal and axisymmetric ground-water-flow problems, Part 3: Design philosophy and programming details. U.S. Geological Survey Techniques of Water-Resources Investigations, Book 6, Chap. A5, 243 pp.

———2003. Assessment of karst features underlying Lake Seminole in southwestern Georgia and northwestern Florida using orthorectified photos of preimpoundment conditions and hydrographic surveys. *In* Proceedings of the 2003 Georgia Water Resources Conference, April 23–24, 2003, K.J. Hatcher (ed.), Institute of Ecology, The University of Georgia, Athens, Georgia.

Torak, L.J., G.S. Davis, G.A. Strain, and J.G. Herndon. 1996. Geohydrology and evaluation of stream-aquifer relations in the Apalachicola-Chattahoochee-Flint River Basin, southeastern Alabama, northwestern Florida, and southwestern Georgia. U.S. Geological Survey Water-Supply Paper 2460, 95 pp.

U.S. Geological Survey. Unpublished records. Chief, Hydrologic Monitoring & Analysis Section, Water Resources Discipline, Georgia District, Atlanta, Ga.