PHYSICAL AND HYDROCHEMICAL EVIDENCE FOR LAKE LEAKAGE IN LAKE SEMINOLE, GEORGIA

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Abstract. Major ions, nutrients, radon-222, and stable isotopes of hydrogen and oxygen were collected from 30 wells, 7 lake locations, and 5 springs in the Lake Seminole area, southwestern Georgia and northwestern Florida, during 2000. These were used to investigate lake-aquifer interaction including surface-water mixing with ground water from the underlying Upper Floridan aquifer, lake leakage beneath Jim Woodruff Dam, and karstic dissolution of the limestone aquifer matrix. Solute and isotopic tracers indicate that in-lake springflow evolves along ground-water and surface-water pathways, and that the fractions of these two source waters present in springflow varies with spring location and season. Leakage from Lake Seminole into the Upper Floridan aquifer is evidenced by upwelling in the channel bottom of the Apalachicola River about 300 yards downstream of the dam, where lake water "boils" up at rates that range from about 140 to 220 cubic feet per second. Dye tracing performed by the U.S. Army Corps of Engineers indicates that this "river boil" receives water from multiple sources that include a similar "boil" on land, which joins flow from a spring-fed ground-water discharge zone before flowing into a sinkhole adjacent to the river. Isotopic data from the river boil indicate about a 13-to-1 mixing ratio of lake water to ground water. The saturation index of calcite in surface-water samples indicates a higher potential for dissolution of the limestone matrix from late fall through early spring than in summer.

INTRODUCTION

Lake Seminole is a 37,600-acre human-made surface-water impoundment located at the junction of the Chattahoochee and Flint Rivers in southwestern Georgia and northwestern Florida (Fig. 1). The lake is emplaced in the karstic plains of the lower Apalachicola-Chattahoochee-Flint (ACF) River Basin where it is in hydraulic connection with the underlying Upper Floridan aquifer (Torak and others, 1996). The interconnected aquifer-stream-reservoir flow system (Fig. 2) creates a complex geochemistry in which physical, chemical, and isotopic data were used to investigate mixing of Upper Floridan aquifer ground water with surface water from Lake Seminole, lake-water leakage beneath Jim Woodruff Lock and Dam entering the Apalachicola River at the river boil, and karst conduit stability in and around the lake.

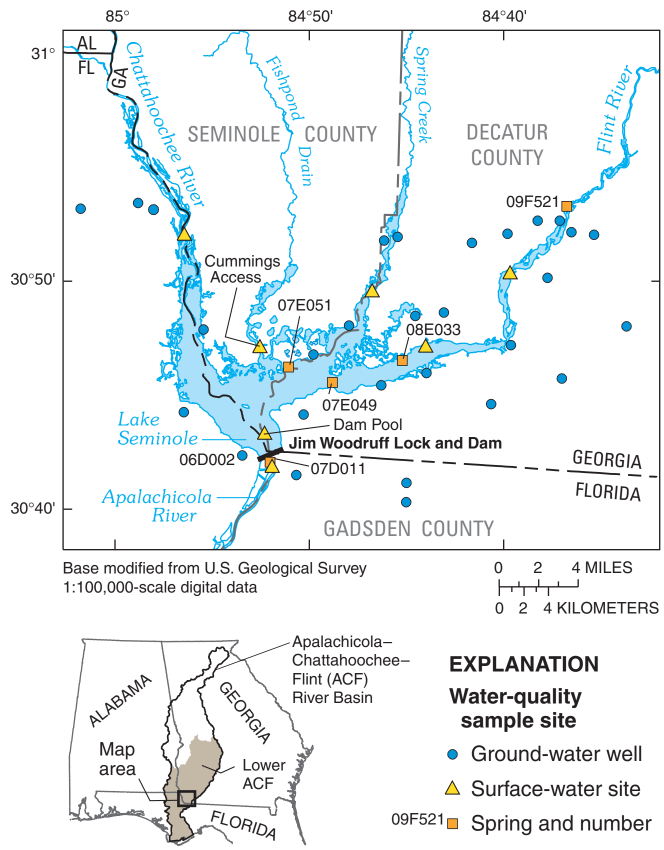

Figure 1. Study area and location of water-quality sample sites.

METHODS

Water-quality samples were collected from 30 wells, 7 lake locations, and 5 springs (Fig. 1) in the Lake Seminole area during March, June, September, and December 2000. Ground-water samples were collected using standard U.S. Geological Survey (USGS) sampling techniques (Wilde and others, 1998). Lake water was sampled at mid-channel and at mid-depth in the impoundment arms using a Van Dorn-type sampler (Wilde and others, 1998). In-lake springs were identified from *in situ* temperature, specific conductance, pH, and dissolved-oxygen data, and samples at or near spring orifices were collected in a Van Dorn sampler. Although the Van Dorn sampler is designed to collect an instantaneous discrete (point) sample, uncertainty associated with locating in-lake springs and positioning the sampler exactly at the spring orifices can result in the collection of a mixed ground-water and surface-water sample. In addition, seasonal variation in springflow and the degree of mixing around the spring orifice can result in the collection of a mixed-water sample instead of a single-source sample; the uncertainty of this occurrence cannot be quantified but is being studied further.

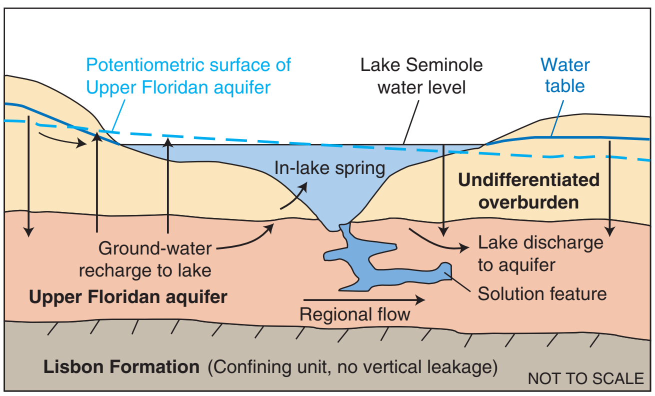

Figure 2. Schematic representation of the interconnected aquifer-stream-reservoir flow system around Lake Seminole.

Chemical analyses were performed at the USGS National Laboratories in Ocala, Fla., and Denver, Colo., for major ions, nutrients, total organic carbon, and radon-222 (Fishman and others, 1994). Isotopic analyses were performed at the USGS Stable Isotope Laboratory in Reston, Va. (accessed on January 19, 2003, at URL: http://isotopes.usgs.gov). During 2000, temperature profiles were recorded continuously at 26 lake sites, including in-lake springs, using 100 probes installed at multiple depths.

Data Analysis. The fraction of ground water in a sample is determined by using the following binary mixing equation (Crandall and others, 1999):

$$fgw = (Csw - Cm) / (Cgw - Csw), \quad (1)$$

where fgw is the fraction of ground water, and Csw, Cm, and Cgw are the isotopic concentrations in surface water, the mixture (spring), and in ground water, respectively.

Equations for the dissolution of calcite and the solubility product ($K_{sp\,(calcite)}$) of the reaction in a dilute solution are given as (Drever, 1988):

$$CaCO_{3\,(Calcite)} = Ca^{2+} + CO_3^{2-}, \quad (2)$$

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$$K_{sp\,(calcite)} = (a_{Ca2+}\ a_{CO32-})/(a_{CaCO3}) = 10^{-8.48}, \quad (3)$$

where a_{Ca2+}, a_{CO32-}, and a_{CaCO3} are activities of calcium and carbonate ions, and of calcite, respectively, and $K_{sp\,(calcite)}$ is the solubility product at 25 degrees Celsius. The mineral saturation index (SI) is given as:

$$SI = \log (IAP/K_{sp}), \quad (4)$$

where IAP is the ion activity product.

RESULTS

Physical Evidence of Lake Leakage

Lake leakage from Lake Seminole is evident a short distance downstream from Jim Woodruff Lock and Dam, where lake water "boils" up from a limestone ledge in the Apalachicola River. Acoustic Doppler current profiling (ADCP; Lipscomb, 1995), conducted by the USGS in October 1999 and April 2000, determined that water continually discharges from the river boil (07D011) at rates of 140 and 220 cubic feet per second, respectively. Dye tracing by the U.S. Army Corps of Engineers indicates several subsurface flowpaths contributing to the river boil that originate in the lake. Travel times along the various flowpaths from the lake to the river boil ranges from 5 to 7 hours (James H. Sanders, Jr., Geologist, U.S. Army Corps of Engineers, Mobile District, written commun. with Lynn Torak, August 2001) at velocities approaching 500 feet per hour.

Leakage of ground water into Lake Seminole from in-lake springs is evident in temperature data from water-quality samples (Fig. 3) and lake-temperature profiles. These data indicate cold springflow enters Lake Seminole from May to November 2000, with the inference that the lake receives more ground water during those months than during the rest of the year.

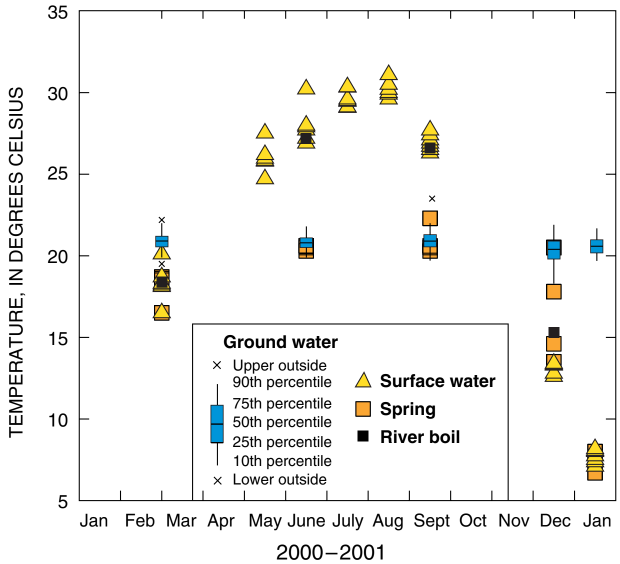

Figure 3. Seasonal temperature variation for ground water, surface water, and springs.

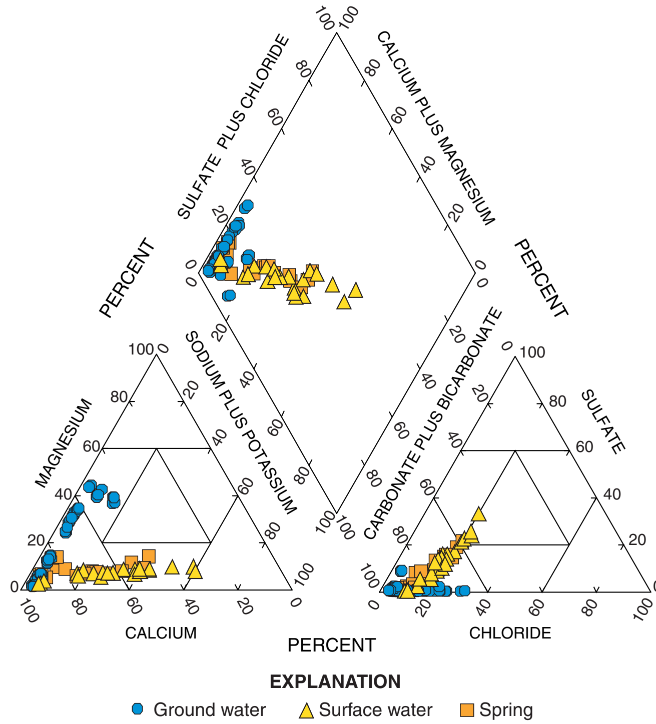

Figure 4. Trilinear diagram of mojor-ion composition of ground water, surface water, and spring water.

Hydrochemical Evidence of Lake Leakage

Hydrochemical-facies plots of water-quality data (Fig. 4) show in-lake springflow chemically varies from a surface-water-like calcium-sodium bicarbonate water during March and December to a ground-water-like calcium-magnesium bicarbonate water during June and September. Concentrations of naturally occurring stable isotopes of hydrogen and oxygen (deuterium and oxygen-18) in spring-water samples indicate a similar variation between ground-water and surface-water pathways. Deuterium concentrations in ground water are scattered along the Global Meteoric Water Line (Fig. 5), more than can be attributed to the 2-per-mil analytical precision (accessed on January 19, 2003, at URL: http://isotopes.usgs.gov). Although scattered, isotopic concentrations in ground water tend to be clustered by sample location and season, perhaps due to local variations in geology and recharge. Surface-water isotopic values are enriched during summer and fall because of evaporation. Lake water from Cummings Access (Fig. 1) is more enriched isotopically than other surface-water sites because of low-flow conditions in that impoundment arm of the lake (Fig. 5).

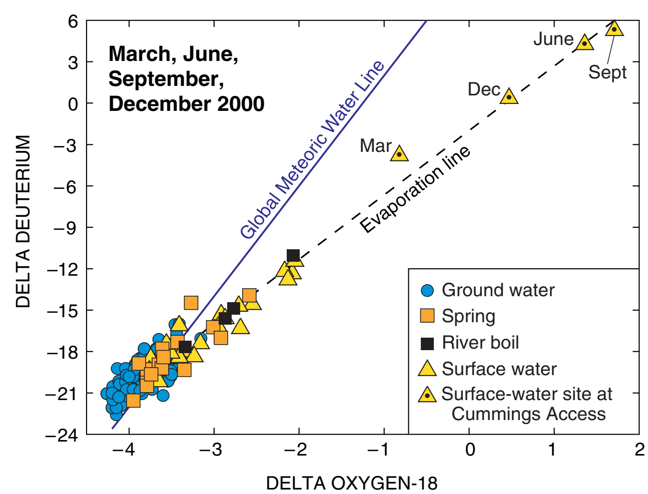

Figure 5. Plot of deuterium and oxygen-18 for ground water, surface water, and spring water.

Isotope-Mixing Analysis. The distinct isotopic signatures of ground water and surface water in the study area make deuterium and oxygen-18 suitable constituents for calculating the percent composition of spring water. An isotope-mixing line projected from a surface-water end member to a spring can be used to identify potential ground-water origins related to that spring (Fig. 6).

The isotopic-mixing ratio of the river boil is particularly useful for identifying leakage from Lake Seminole into the Upper Floridan aquifer and Apalachicola River (Fig. 6). For the river boil, isotopic-mixing analysis indicates about a 13-to-1 mixing ratio (Fig. 6) of lake water (from the dam pool; Fig. 1) to ground water (site 06D002; Fig. 1). Mixing ratios for other springs in the study area varied with location and season (Table 1). The relative contribution of ground water and lake water in the springs was difficult to determine from samples collected in December and March, partly because some springs stopped flowing during this time and because the lake was well-mixed vertically. Therefore, in general, a larger ground-water contribution to springflow can be discerned from mixing analyses performed on samples collected from late spring to fall than during other times of the year.

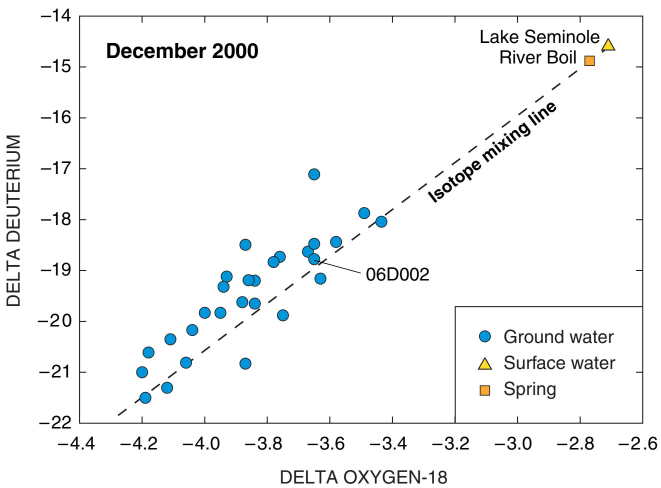

Figure 6. Plot of deuterium and oxygen-18 with isotope mixing line for the river boil.

Table 1. Mixing ratios of ground water to surface water in Lake Seminole springs

[ID, identification]

Spring	Site ID (Figure 1)	Mar 2000	June 2000	Sept 2000	Dec 2000
Sealy's Spring	07E051	4:1	3:1	9:1	2:1
Wingate Spring	08E033	1:4	1:1	—	—
Shakelford Spring	07E049	2:1	2:1	2:1	—
State Dock Spring	09F521	1:4	2:1	9:1	1:4
River Boil	07D011	1:9	1:13	1:9	1:13

Limestone Matrix Dissolution

The saturation of calcite in ground water, surface water, and springs in the study area was calculated using the USGS geochemical modeling program NETPATH (Plummer and others, 1994). Model results show less-saturated conditions during December, indicating a higher potential for karstic dissolution from late fall through early spring than in summer (Fig. 7). The pronounced undersaturation of calcite in lake water during December can be attributed to a lower ground-water contribution than the other samples collected during 2000. The reduced ground-water flow to the lake from in-lake springs can be attributed to a combination of agricultural pumpage that had reduced ground-water levels to record lows by fall 2000 and continued drought conditions into winter 2000.

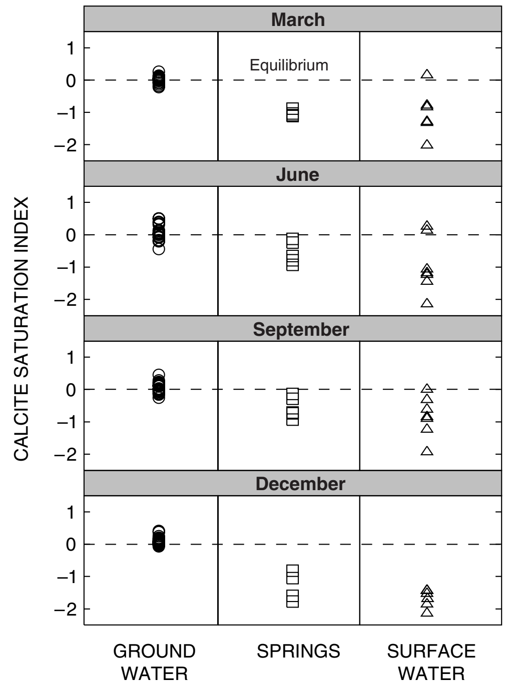

Figure 7. Calcite-saturation indices for ground water, surface water, and springs.

CONCLUSIONS

Physical, chemical, and isotopic data indicate a larger ground-water component to in-lake springflow exists from late spring through fall than in winter and early spring. Ground water entering Lake Seminole from in-lake springs can be identified during May to October using deuterium and oxygen-18; isotope-mixing ratios give the relative composition of the spring sample, which can indicate when springs flow during the year. The fractional composition of spring water from winter through early spring was difficult to determine due to mixing of spring and lake water at the point of sampling and reduced flow from the springs.

Isotopic data indicate about a 13-to-1 mixing ratio of lake water to ground water in the river boil. The complexity of ground-water flow in the karstic region and numerous possible sources to the river boil make it difficult to identify sources with hydrochemical and physical data.

Calcite-saturation indices indicate a potential for limestone dissolution during winter. Dissolution is associated with the amount of ground water entering the lake by springflow and diffuse leakage across the lake-aquifer boundary, which is affected by recharge from precipitation and agricultural pumpage. The relatively short residence time (5–7 hours) and rapid flow velocity (nearly 500 feet per hour) for lake water to leak into the aquifer and exit at the river boil suggests that this water would not reach chemical equilibrium while in transit.

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