Spring Contributions to Water Quantity and Nitrate Loads in the Suwannee River during Base Flow in July 1995

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Summary

The Suwannee River flows through an area of north-central Florida where ground water has elevated nitrate concentrations. A study was conducted to determine how springs and other ground-water inflow affect the quantity and quality of water in the Suwannee River. The study was done on a 33-mile (mi) reach of the lower Suwannee River from just downstream of Dowling Park, Fla., to Branford, Fla. (fig. 1). Water samples for nitrate concentrations (*dissolved nitrite plus nitrate as nitrogen*) and discharge data were collected at 11 springs and 3 river sites during the 3-day period in July 1995 during base flow in the river.

In the study reach, all inflow to the river is derived from ground water. Measured springs and other ground-water inflow, such as unmeasured springs and upward diffuse leakage through the riverbed, increased the river discharge 47 percent over the 33-mi reach. The 11 measured springs contributed 41 percent of the increased discharge and other ground-water inflow contributed the remaining 59 percent. River nitrate loads increased downstream from 2,300 to 6,000 kilograms per day (kg/d), an increase of 160 percent in the 33-mi study reach. Measured springs contributed 46 percent of this increase and other ground-water inflow contributed the remaining 54 percent.

The study reach was divided at Luraville, Fla., into an 11-mi upper segment and a 22-mi lower segment to determine whether the ground-water inflows and nitrate concentrations were uniform throughout the entire study reach (fig. 1). The two segments were dissimilar. The amount of water added to the river by measured springs more than tripled from the upper to the lower segment. Even though the median nitrate concentration for the three springs in the upper segment (1.7 milligrams per liter (mg/L)) was similar to the median for the eight springs in the lower segment (1.8 mg/L), nitrate concentrations in the river almost doubled from 0.46 to 0.83 mg/L in the lower segment. Only 11 percent of the increase in nitrate load for the study reach occurred in the upper segment; the remaining 89 percent occurred in the lower segment. Measured springs were the major source of nitrate load in the upper reach and other ground-water inflow was the major source in the lower segment.

Differences in nitrate loads between the upper and lower river segments are probably controlled by such factors as differences in the magnitude of the spring discharges, the size and location of spring basins, and the hydrologic characteristics of ground water in the study area.

Introduction

The Suwannee River, important historically and recreationally, is of great interest to the State of Florida and has been designated as an "Outstanding Florida Water." Of particular interest to water-resource agencies is the increase of nitrogen in this valuable river, especially during periods of base flow.

For 20 years (1971-91), nitrate concentrations in the Suwannee River near Branford, Fla., increased at a rate of 0.02 mg/L per year; the median nitrate concentration for that period was 0.5 mg/L (Ham and Hatzell, 1996). Possible sources for nitrate in ground water in the study area are septic tanks, synthetic fertilizers, and animal waste (Andrews, 1994).

The Suwannee River recharges and receives discharge from the Upper Floridan aquifer, the primary source of public and private water supply in the Suwannee River Basin and the surrounding areas (fig. 1). In the northwestern part of the basin in Georgia, direct surface runoff is a significant source of inflow to the basin. In the northeastern and southern parts of the basin, inflow to the river is predominantly from numerous springs and upward diffuse leakage of ground water through the riverbed (riverbed leakage).

Base flow in rivers occurs during natural conditions when ground-water discharge to the river is the primary source of flow. Ground-water influence on water quality in the river is more pronounced during base flow and in the river reaches having the greatest number of springs and the least tributary inflow (Hull and others, 1981). The Suwannee River directly recharges ground water in the Upper Floridan aquifer when river levels are above the adjacent ground-water levels. The pattern reverses during periods of base flow, when the ground-water levels are above the river water levels and ground-water

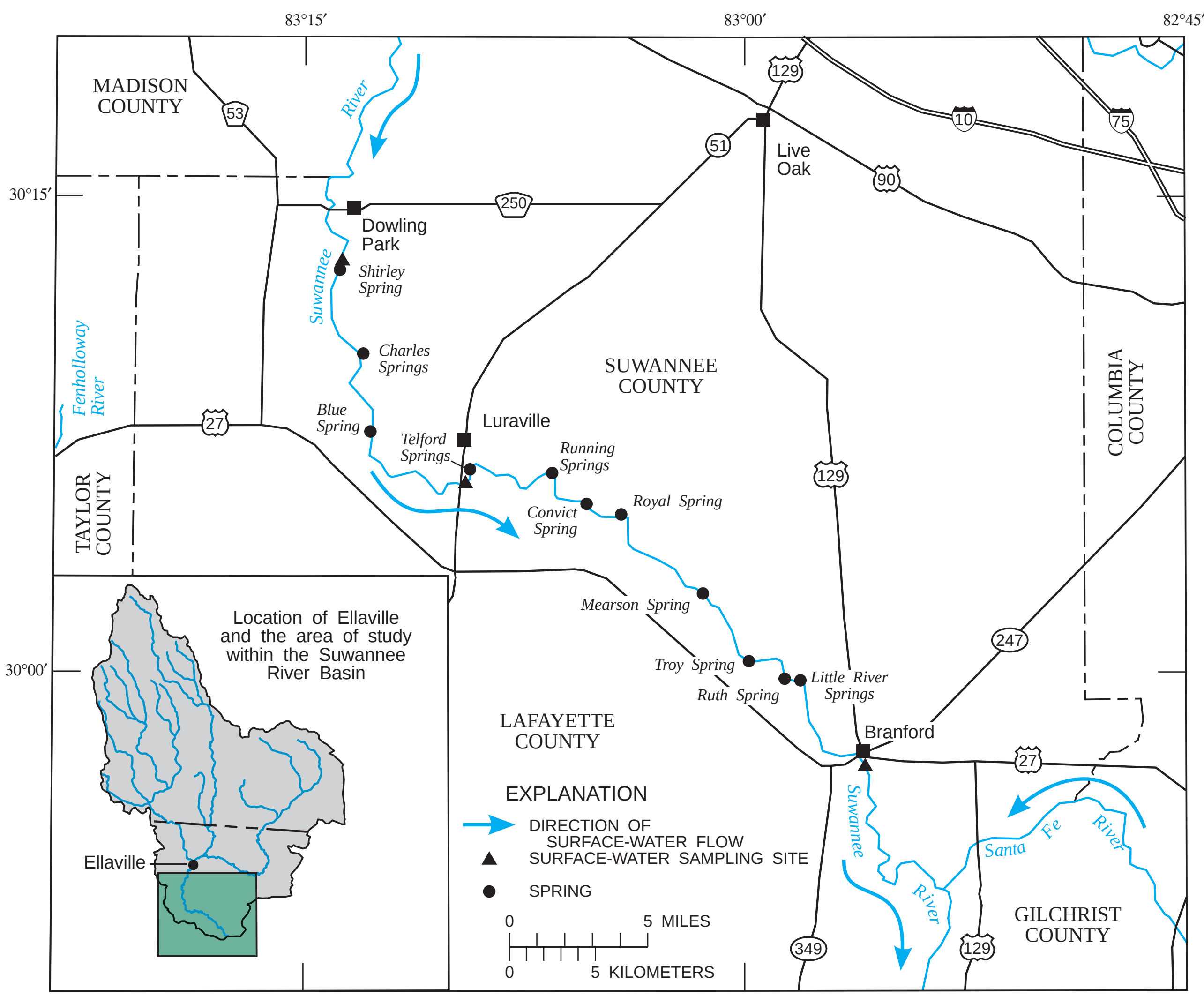

Figure 1. Location of 11 springs and 3 surface-water sampling sites along the Suwannee River in north-central Florida.

discharges to the river through numerous springs and from riverbed leakage. These gains and losses from the river can be simultaneous in adjoining parts of the river as ground-water discharges to the river in one part while the river recharges the ground water in another part (Crane, 1986).

The median nitrate concentration for ground water in north-central Florida is low (0.01 mg/L nitrate as nitrogen; Katz, 1992). However, mean nitrate concentrations ranged from less than 0.5 to greater than 4 mg/L in ground water in the vicinity of the Suwannee River between Ellaville, Fla., and Branford, Fla. (Ceryak and Hornsby, 1996). These elevated nitrate concentrations increase the likelihood that ground-water inflow from springs and riverbed leakage can increase nitrate concentrations and loads in the lower Suwannee River.

Study Design

A study was conducted in July 1995 to determine how springs and other ground-water inflow affect the quantity and quality of water in the Suwannee River during base flow. The study area was a 33-mi reach of the lower Suwannee River, extending from 1.2 mi south of the bridge at State Road 250 near Dowling Park, Fla., downstream to the bridge at U.S. Highway 27 at Branford, Fla. (fig. 1). This river reach was selected because all inflow to the river is from ground water. The study reach includes Troy Spring, which is a first magnitude spring, and about 25 other named springs. Eleven springs along the reach were selected for discharge measurements and water-quality sampling (fig. 1). Criteria for spring selection were based on a variety of spring properties, such as the amount of discharge, previous nitrate concentrations, size of the spring run, location along the reach, and land uses in the vicinity of the orifice. Spring discharge measurements were made by standard U.S. Geological Survey methods for wadeable channels (Buchanan and Somers, 1969). Three river discharge measurement and sampling sites were also selected (fig. 1). River discharge measurements were made with a broad band acoustic Doppler current profiler (Simpson and Oltmann, 1993).

Contributions to river discharge from measured springs and other ground-water inflow (unmeasured springs and upward diffuse leakage through the riverbed) can be determined by calculating the gain in river discharge within the reach when two conditions are met. First, there should be no surface-water inflow to the study reach from tributaries. The reach of the Suwannee River from just downstream of Dowling Park to Branford was selected because of the lack of surface-water tributaries as well as the high density of springs. Second, the river discharge in the reach should be nearly stable throughout the measurement period. Near-stable flow conditions (less than 10 percent change in river discharge) usually occur during base flow when sustained periods of little or no precipitation occur in the drainage basin.

Hydrographs of the Suwannee River at Ellaville and Branford indicated that the river was at base flow during late July 1995 (fig. 2). The stream gaging station at Ellaville (station 02319500) is 17 river miles upstream from the beginning of the study reach. The station at Branford (station 02320500) is at the downstream end of the study reach.

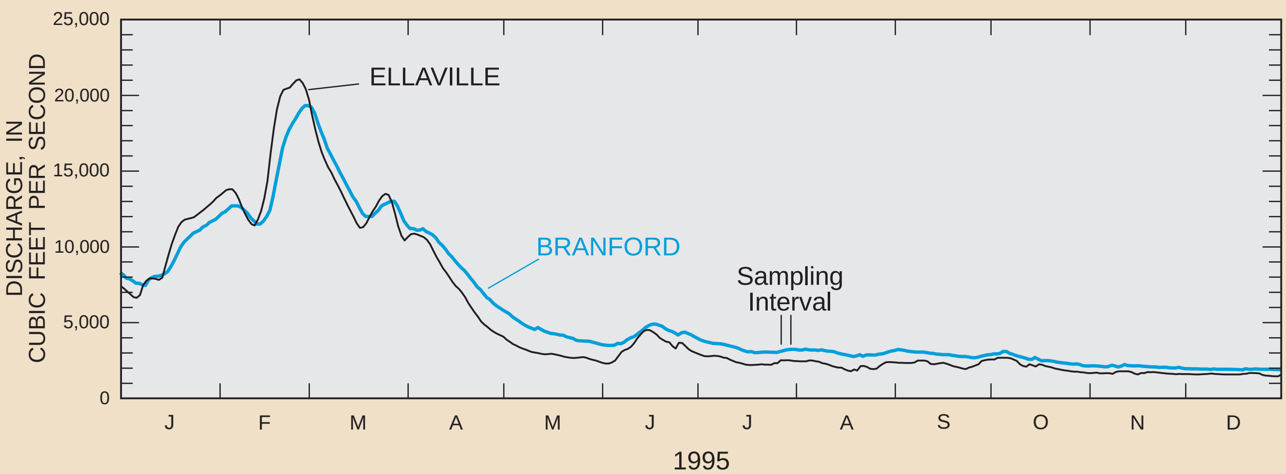

Figure 2. Hydrographs of Suwannee River at Ellaville and Branford, Fla.

The 33-mi study reach was divided into an 11-mi upper (upstream) segment and a 22-mi lower (downstream) segment to determine whether the measured springs and other ground-water inflows and nitrate contributions were relatively constant in each segment or if one segment provided more inflow and nitrate per river mile than the other. River and spring discharge measurements were made and water-quality samples were collected sequentially during July 25-27, 1995, beginning at the upstream site near Dowling Park and ending at the most downstream site at Branford, as follows:

- River discharge was measured and water-quality samples were collected at the site near Dowling Park (station 301259083143700).
- Spring discharge was measured and water-quality samples were collected at three springs (table 1) in the upper segment, which is between Dowling Park and Luraville.
- River discharge was measured and water-quality samples were collected at Luraville (station 02320000).
- Spring discharge was measured and water-quality samples were collected at eight springs (table 1) in the lower segment, which is between Luraville and Branford.
- Lastly, river discharge was measured and water-quality samples were collected at the site at Branford (station 02320500).

Table 1. Discharge, nitrate concentrations, and nitrate loads contributed to the Suwannee River during July 25-27, 1995

[ft^3/s, cubic feet per second; mg/L, milligrams per liter; kg/d, kilograms per day. Values for river and spring locations were measured; values for other ground-water inflow were calculated]

River segment	Location and station number	Discharge (ft^3/s)	Nitrate concentration (mg/L)	Nitrate load (kg/d)
Upper	Suwannee River near Dowling Park, Fla. (301259083143700)	2,020	0.46	2,300
	Shirley Spring (301240083144200)	1.5	1.7	6
	Charles Springs (02319900)	7.5	2.2	40
	Blue Spring (02319950)	77	1.7	320
	Other ground-water inflow	264	0.05	34
	Suwannee River near Luraville, Fla. (02320000)	2,370	0.46	2,700
Lower	Telford Springs (02320003)	33	2.5	200
	Running Springs (02320060)	17	2.0	83
	Convict Spring (02320100)	1.7	8.2	34
	Royal Spring (02320130)	16	1.3	51
	Mearson Spring (02320240)	30	1.7	120
	Troy Spring (02320050)	132	1.7	550
	Ruth Spring (02320260)	9.9	3.4	82
	Little River Springs (02320400)	67	1.4	230
	Other ground-water inflow	293	2.7	1,950
	Suwannee River at Branford, Fla. (02320500)	2,970	0.83	6,000

After all water-quality sampling was completed, a discharge measurement for the river was made at the initial site downstream of Dowling Park to determine whether near-stable flow conditions had occurred throughout the sampling period.

Spring water-quality samples were collected by lowering Teflon tubing directly into the spring orifices and pumping the sample water into sample bottles using a peristaltic pump. River water-quality samples were collected using a weighted bottle sampler. The river cross-section was divided into three sections of equal width and the sampling boat was maneuvered to the center of each section during sample collection. One subsample of river water was collected in each of the three sections of the channel and the three subsamples were composited prior to filling the sample containers. Water temperature, pH, specific conductance, and dissolved oxygen were measured onsite. Water samples were analyzed for nutrients and major constituents. In this report, the term nitrate refers to dissolved nitrite plus nitrate nitrogen.

Nitrate concentrations at springs (except for Convict Spring) were generally lower than those reported for ground water in the same area.

The nitrate load is the mass of nitrate per unit of time. An instantaneous load, expressed in kilograms per day, was calculated by multiplying the nitrate concentration in the water sample by the instantaneous discharge, which is the discharge measured when the sample was taken. Although the data collected in this study are insufficient to determine the long-term variability of spring discharge and nitrate load, calculating the instantaneous load is helpful in understanding the amounts of nitrate added to the river from the ground water during the 3-day sampling period.

For other ground-water inflow from unmeasured springs and riverbed leakage, discharge and nitrate loads were calculated by subtracting the sum of the spring values from the increase in the segment. Nitrate concentrations for this other ground-water inflow were estimated by dividing the calculated load by the calculated discharge and adjusting for units.

River and Spring Discharge

River discharge increase over the entire 33-mi study reach (just downstream of Dowling Park to Branford) was 950 cubic feet per second (ft^3/s), or about 47 percent (table 1). Measured springs contributed 41 percent of the increase in discharge, whereas other ground-water inflow contributed the remaining 59 percent (fig. 3). River discharge increased 350 ft^3/s in the upper segment of the reach between Dowling Park and Luraville. In this 11-mi segment, 25 percent of the increase in river discharge was contributed by measured springs, whereas 75 percent was contributed by other ground-water inflow (fig. 3). River discharge increased 600 ft^3/s in the lower segment of the reach between Luraville to Branford. In this 22-mi segment, 51 percent of the increase in discharge was contributed by measured springs, whereas 49 percent was contributed by other ground-water inflow.

Little River Springs above Branford, Fla.

The difference in segment lengths must be addressed to compare the increases in river discharge between the two segments of the study reach. One way to compare the amount of water entering the river in the two segments is to compare the amount of increase in discharge per river mile. This is calculated by dividing the change in river discharge per segment by the number of river miles in the segment. The increase in discharge per river mile is 32 $(ft^3/s)/mi$ for the upper segment between Dowling Park and Luraville, and is 27 $(ft^3/s)/mi$ for the lower segment between Luraville and Branford. Even though more springs occur in the lower segment, the springs did not increase the discharge per river mile in the lower segment relative to the upper segment.

Discharge in the Suwannee River at the upstream site downstream of Dowling Park increased about 11 percent during the 3-day sampling period, whereas discharge at Branford remained stable throughout the sampling period. The stable condition at Branford indicated that the increase in discharge at Dowling Park had not yet occurred throughout the entire sampling reach; thus, stable conditions existed during the sampling period. Because of the increase in discharge at the upstream site of the study reach, calculations of contributions from the two segments of the river reach are considered approximate values. The changes in river discharge between Dowling Park and Branford are attributed to discharge from the measured springs and other ground-water inflow, such as unmeasured springs and riverbed leakage, as well as the possible small error introduced by the 11 percent increase in flow entering the study reach.

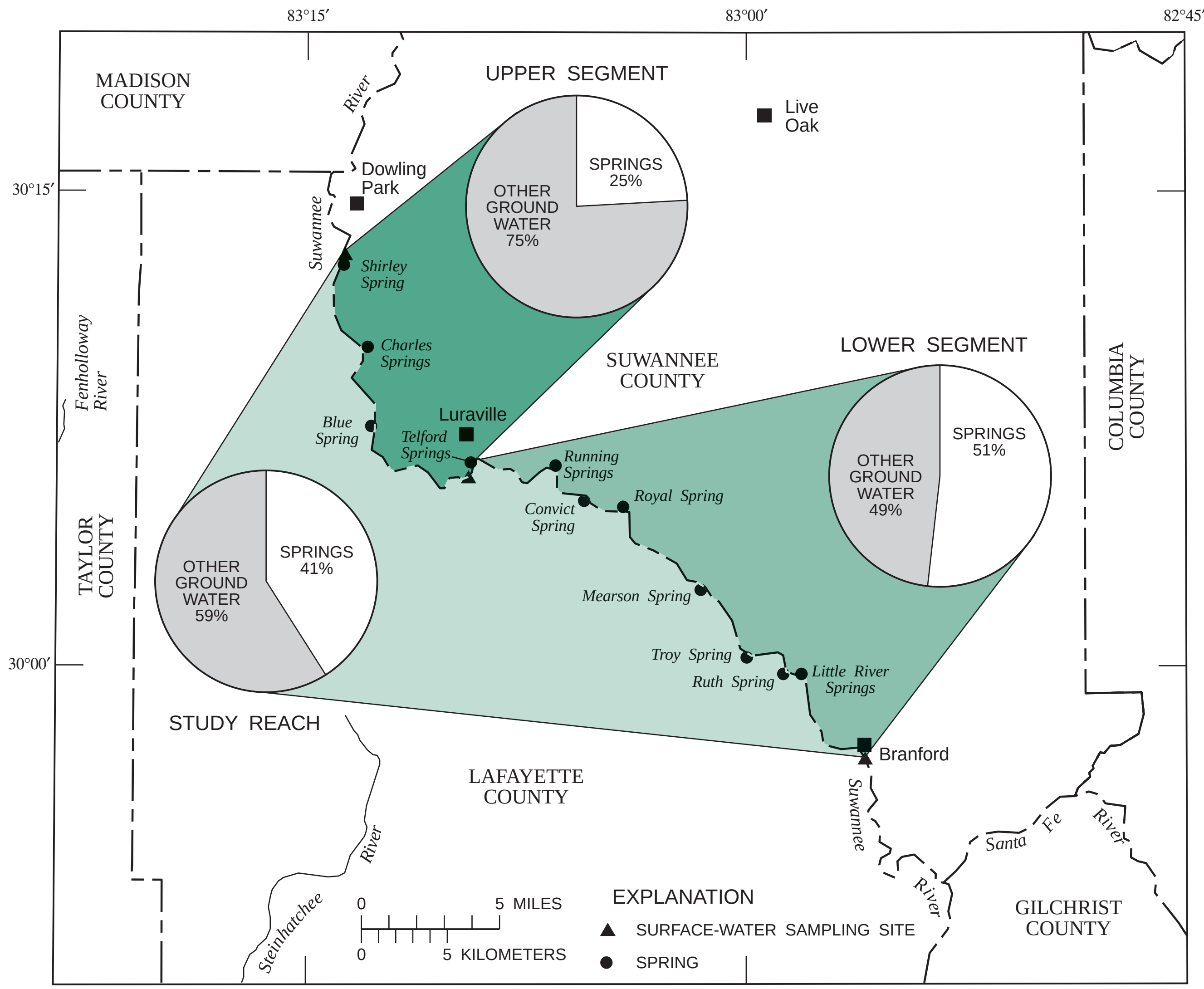

Figure 3. Contributions of measured springs and other ground-water inflow (unmeasured springs and riverbed leakage) to increases in river discharge.

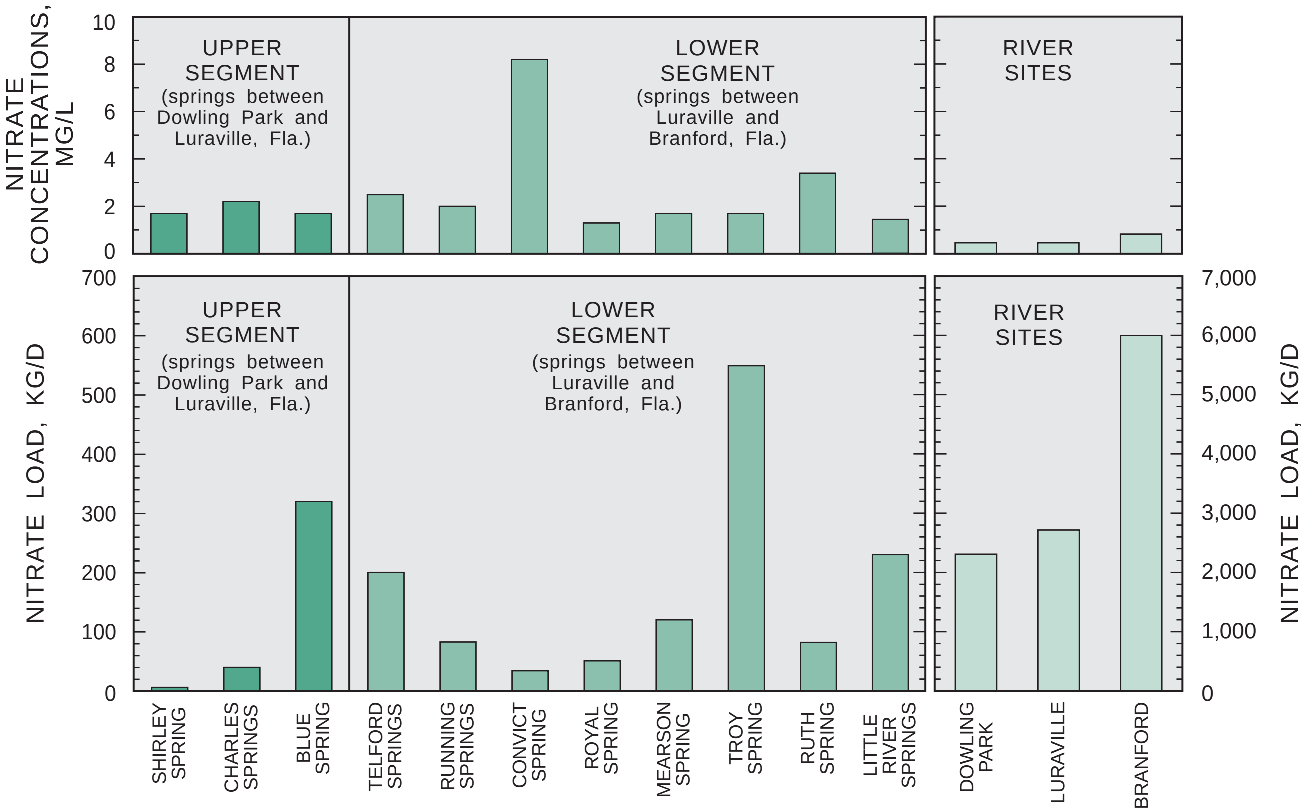

Figure 4. Nitrate concentrations and loads in the Suwannee River and 11 springs discharging to the river reach between Dowling Park and Branford, Fla. (River nitrate loads are an order of magnitude larger than spring loads.)

Nitrate Concentrations

Nitrate concentrations in the measured springs ranged from 1.3 to 8.2 mg/L (table 1; fig. 4). The highest nitrate concentration was measured at Convict Spring, a low discharge spring, which has a history of higher nitrate concentrations than other springs in the area (Hornsby and Mattson, 1997, p. 124). This elevated nitrate concentration may be derived from leachate from septic tanks at a development surrounding the spring, or it may be from fertilized cropland several hundred feet south of the spring (Andrews, 1994). In contrast, Blue Spring, a high discharge spring located within a county park that uses septic tanks for the groundskeeper residence and public restrooms, has a nitrate concentration of 1.7 mg/L. Nitrate concentrations at springs other than Convict Spring were generally lower than those reported for ground water in the same area (Ceryak and Hornsby, 1996, p. 22).

Nitrate concentrations at the three river sites were lower than nitrate concentrations at the springs (fig. 4). The nitrate concentration in the river was 0.46 mg/L at the upstream site just downstream of Dowling Park, remained unchanged at Luraville, and increased to 0.83 mg/L at Branford (table 1). Although nitrate concentrations in the river almost doubled from Luraville to Branford, there was little appreciable difference in median nitrate concentrations of springs in the upper and lower segments. Median nitrate concentration in the three springs sampled in the upper segment was 1.7 mg/L, whereas the median nitrate concentration in the eight springs sampled in the lower segment was 1.8 mg/L.

The estimated nitrate concentrations (table 1) for other ground-water inflow (unmeasured springs and riverbed leakage) were different for the two segments. In the upper segment, the estimated nitrate concentration was 0.05 mg/L, which is much lower than that of the measured springs but of the same magnitude as the median nitrate as nitrogen concentration of 0.01 mg/L for ground water in north-central Florida (Katz, 1992). In contrast, the estimated nitrate concentration for other ground-water inflow in the lower segment was 2.7 mg/L, which is within the range of the concentrations for the measured springs (table 1).

Nitrate Loads

Nitrate loads for the springs varied nearly two orders of magnitude, ranging 6 kg/d at Shirley Spring to 550 kg/d at Troy Spring (table 1; fig. 4). A comparison of nitrate loads for the springs provides a different perspective than the comparison of nitrate concentrations in the springs. For example, Convict Spring had the highest nitrate concentration (8.2 mg/L), but because of its low discharge the nitrate load was only 34 kg/d. Royal Spring had the lowest nitrate concentration (1.3 mg/L), but because of a higher discharge had a higher load (51 kg/d) than Convict Spring.

River nitrate loads increased 160 percent (3,700 kg/d) in the entire 33-mi study reach downstream of Dowling Park to Branford (fig. 4). Measured springs contributed 46 percent of this increase and other ground-water inflow from unmeasured springs and riverbed leakage contributed the remaining 54 percent (fig. 5).

The nitrate loads in the upper and lower segments of the river reach are very different; with most of the increase in nitrate load occurring in the lower segment. Only 11 percent (400 kg/d) of the nitrate load increase occurred in the upper segment; the remaining 89 percent (3,300 kg/d) occurred in the lower segment (fig. 4). Percentages of discharge and

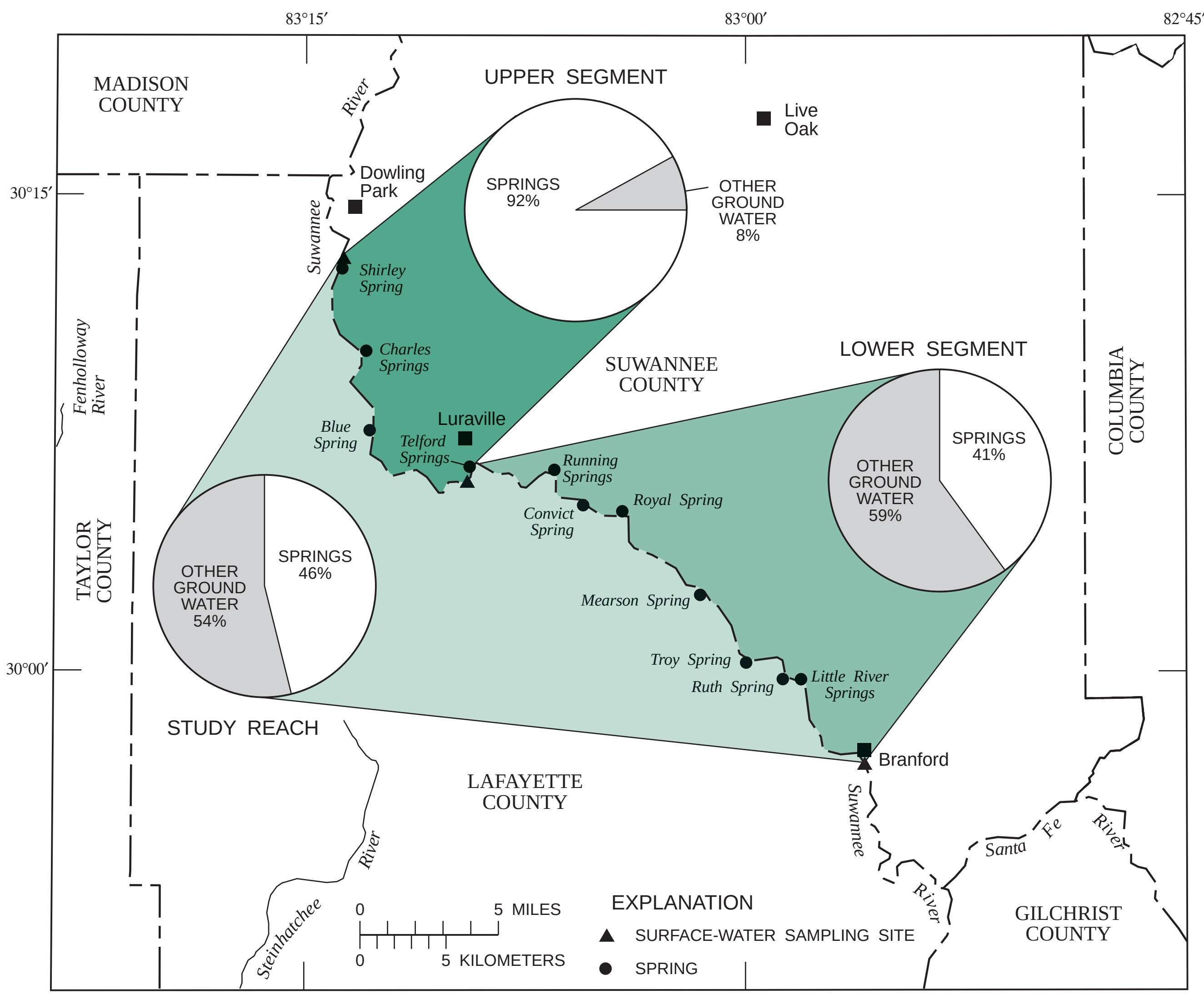

Figure 5. Contributions of measured springs and other ground-water inflow (unmeasured springs and riverbed leakage) to increases in river nitrate load.

nitrate load coming from measured springs and other ground-water inflow (figs. 3 and 5) were nearly the same in the entire study reach.

Measured springs, especially Blue Spring, are the major sources of nitrate loads in the upper segment, whereas other ground-water inflow is the major source in the lower segment (fig. 4, table 1). Although measured springs contributed only 25 percent of the river discharge in the upper segment, they contributed 92 percent of the river nitrate load. In the lower segment, measured springs contributed 51 percent of the discharge but only 41 percent of the river nitrate load (figs. 3 and 5).

Differences between the 11-mi upper and 22-mi lower segment are also evident in the nitrate load added per river mile. The upper segment added approximately 36 (kg/d)/mi of nitrate with 33 (kg/d)/mi contributed by measured springs and 3 (kg/d)/mi contributed by other ground-water inflow. The lower segment added approximately 150 (kg/d)/mi of nitrate, with 61 (kg/d)/mi contributed by measured springs and 89 (kg/d)/mi contributed by other ground-water inflow.

Suwannee River above Branford, Fla.

Only 11 percent increase in nitrate load for the Suwannee River study reach occurred in the upper segment; the remaining 89 percent occurred in the lower segment.

The increase in nitrate load in the study reach is related to the effects of land use on ground water. Because the Upper Floridan aquifer is unconfined in the vicinity of the Suwannee River, nitrate from animal wastes, fertilizers, septic tanks, and other sources can readily enter the ground water by downward percolation through surface soils into the upper part of the aquifer. Numerous sinkholes associated with the karstic terrain in north-central Florida also provide portals for rapid downward movement of water. Ground water containing nitrate enters the river through springs and by upward diffuse leakage through the riverbed.

Differences in the nitrate concentrations and loads between the two river segments are related to several factors that interact with effects of land use, such as differences in (1) the magnitude of the spring discharge in the two segments, (2) the size and location of the spring basins, and (3) the ground-water hydrology.

In the upper segment, only one spring (Blue Spring) had a discharge greater than 25 ft^3/s, whereas four springs (Telford, Mearson, Troy, and Little River Springs) in the lower segment had discharges greater than 25 ft^3/s (table 1). Of these four springs, Troy Spring (a first magnitude spring) accounted for 41 percent of the nitrate load from measured springs in the lower segment. The nitrate load contributed by Troy Spring is greater than the entire increase in nitrate load in the 11-mi upper segment (table 1; fig. 4).

Spring basins are defined by the area contributing water to the discharge of the springs. The range in nitrate concentrations among the springs in the lower segment indicates that the types and intensity of land use may be more variable among the spring basins in the lower segment compared to those in the upper segment. Little information is available concerning the size and locations of the spring basins in the study area. For some of the springs in the study reach, a large part of the spring basin may even be on the opposite side of the river from the spring orifice.

Ground-water hydrologic characteristics, such as differences in water levels between the river and the aquifer, and the water-transmitting properties of the aquifer determine the amounts of ground water inflowing to the river from springs and riverbed leakage. The ground water may be derived from shallower or deeper parts of the Upper Floridan aquifer as well as from locations near or far from the river. Differences in the source of the ground water may contribute to the differences in the increase in nitrate loads between the two river segments. The larger percentage of increase in discharge, and the lower calculated nitrate concentrations from other ground-water inflow (unmeasured springs and riverbed leakage) in the upper segment compared to the lower segment, indicate that the contributing ground water may be different for the two segments.

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