Ground-Water Quality in Three Urban Areas in the Coastal Plain of the Southeastern United States, 1995

By Marian P. Berndt, David R. Galeone, Timothy B. Spruill, and Christy A. Crandall

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Abstract

Ground-water quality is generally good in three urban areas studied in the Coastal Plain of the southeastern United States—Ocala and Tampa, Florida, and Virginia Beach, Virginia. The hydrology of these areas differs in that Ocala has many karst depressions but virtually no surface-water features, and Tampa and Virginia Beach have numerous surface-water features, including small lakes, streams, and swamps. Samples were collected in early 1995 from 15 wells in Ocala (8 in the surficial aquifer and 7 in the Upper Floridan aquifer), 17 wells in Tampa (8 in the surficial aquifer and 9 in the Upper Floridan aquifer), and in the summer of 1995 from 15 wells in Virginia Beach (all in the surficial aquifer).

In the surficial aquifer in Ocala, the major ion water type was calcium bicarbonate in five samples and mixed (no dominant ions) in three samples, with dissolved-solids concentrations ranging from 78 to 463 milligrams per liter. In Tampa, the water type was calcium bicarbonate in one sample and mixed in seven samples, with dissolved-solids concentrations ranging from 38 to 397 milligrams per liter. In Virginia Beach, water types were primarily calcium and sodium bicarbonate water, with dissolved-solids concentrations ranging from 89 to 740 milligrams per liter. The water types and dissolved-solids concentrations reflect the presence of carbonates in the surficial aquifer materials in the Ocala and Virginia Beach areas. The major ion water type was calcium bicarbonate for all 16 samples from the upper Floridan aquifer in both Florida cities. Dissolved-solids concentrations ranged from 210 to 551 milligrams per liter in Ocala, with a median of 287 milligrams per liter, and from 187 to 362 milligrams per liter in Tampa, with a median of 244 milligrams per liter.

Concentrations of nitrate nitrogen were highest in the surficial aquifer in Ocala, and one sample ex-ceeded 10 milligrams per liter, the U.S. Environmental Protection Agency maximum contaminant level for drinking water. Median nitrate concentrations were 1.2 milligrams per liter in Ocala and only 0.06 and 0.05 milligram per liter in Tampa and Virginia Beach, respectively. In Florida, some background water-quality data were available for comparison. The median nitrate concentration in Ocala was much higher than the median nitrate concentration of 0.05 milligram per liter in the background data. Median nitrate concentrations were 0.33 and 0.05 milligram per liter in samples from the Upper Floridan aquifer in Ocala and Tampa, respectively, and 0.05 milligram per liter in background samples.

Of the 47 pesticides and 60 volatile organic compounds analyzed, only five pesticides and five volatile organic compounds were detected. The most commonly detected pesticide was prometon, a broad-scale herbicide, detected in samples from eight wells in Ocala (at concentrations ranging from 0.009 to 1.8 micrograms per liter), three

wells in Virginia Beach (at concentrations ranging from 0.19 to 10 micrograms per liter), and from one well in Tampa (0.01 microgram per liter). The most commonly detected volatile organic compound was chloroform, which was detected four times at concentrations ranging from 0.3 to 2.2 micrograms per liter in Ocala and Tampa. Seven volatile organic compounds were detected in one sample in Virginia Beach; most were compounds associated with petroleum and coal tar.

INTRODUCTION

The Georgia-Florida Coastal Plain and the Albemarle-Pamlico Basin study units were selected as 2 of 20 U.S. Geological Survey’s (USGS) National Water-Quality Assessment (NAWQA) Program study units to begin data collection in 1991. The NAWQA program is designed to assess the status and trends of the quality of the Nation’s ground- and surface-water resources and to associate the status and trends with an understanding of the natural and human factors that affect the quality of water (Gilliom and others, 1995). Ground-water quality is being assessed by three primary study components designed to examine ground-water quality at a range of spatial scales:

- Using existing wells, study-unit surveys are conducted to assess the water quality of major aquifers within the study unit.
- Using observation and other selected wells, land-use studies are conducted to assess the water quality of recently recharged ground water associated with specific land use and hydrogeology.
- Using groups of clustered observation wells, flow-path studies are conducted to examine relations among land-use practices, ground-water flow, contaminant occurrence and transport, and ground- and surface-water interaction (Gilliom and others, 1995).

The three urban land-use studies discussed in this report were conducted in 1995 to provide preliminary baseline information on ground-water quality in shallow Coastal Plain aquifers of the southeastern United States. Ground-water samples were collected in Ocala and Tampa, Fla., in January and February 1995, and in Virginia Beach, Va., in July and August 1995 from existing wells. These wells were often located in relatively unimpacted areas of the city, such as school grounds and State property. Also, some of the wells sampled were screened substantially below the water table; however, effects from land use would most likely be detected at or below the water table. As a result, many of the samples may not reflect the effect of urban land use on shallow ground-water quality. However, these data can be used as preliminary or background water-quality data for these urban areas.

The Georgia-Florida Coastal Plain NAWQA study unit (fig. 1) covers nearly 62,000 square miles (mi^2) predominantly in the Coastal Plain physiographic province. The majority of the land is forested and agricultural, although several major cities are located in the study unit, including Jacksonville, Orlando, and Tampa, Fla., and parts of Atlanta, Ga. The Albemarle-Pamlico Basin NAWQA study unit (fig. 1) covers an approximately 28,000-mi^2 drainage basin in North Carolina and southern Virginia. The basin is drained by four major rivers—the Chowan, the Roanoke, the Tar-Pamlico, and the Neuse Rivers and includes four major physiographic provinces. The majority of the study unit is covered by forested and agricultural land, although three major urban areas (Roanoke, Va., Raleigh, N.C., and Virginia Beach, Va.) and smaller developed towns are scattered throughout.

Purpose and Scope

The purpose of this report is to present an overview of ground-water-quality data from a regional perspective on three medium-sized southeastern Coastal Plain cities—Tampa and Ocala, Fla., and Virginia Beach, Va. Fifteen wells in Ocala, 17 wells in Tampa, and 15 wells in Virginia Beach were sampled for this study. This report summarizes the ground-water quality and occurrence and distribution of selected field properties, major inorganic constituents, pesticides, and volatile organic compounds in the three urban areas. In the two Florida urban areas, data are compared to background water-quality data. The distribution of selected trace elements in the two Florida urban areas also is presented.

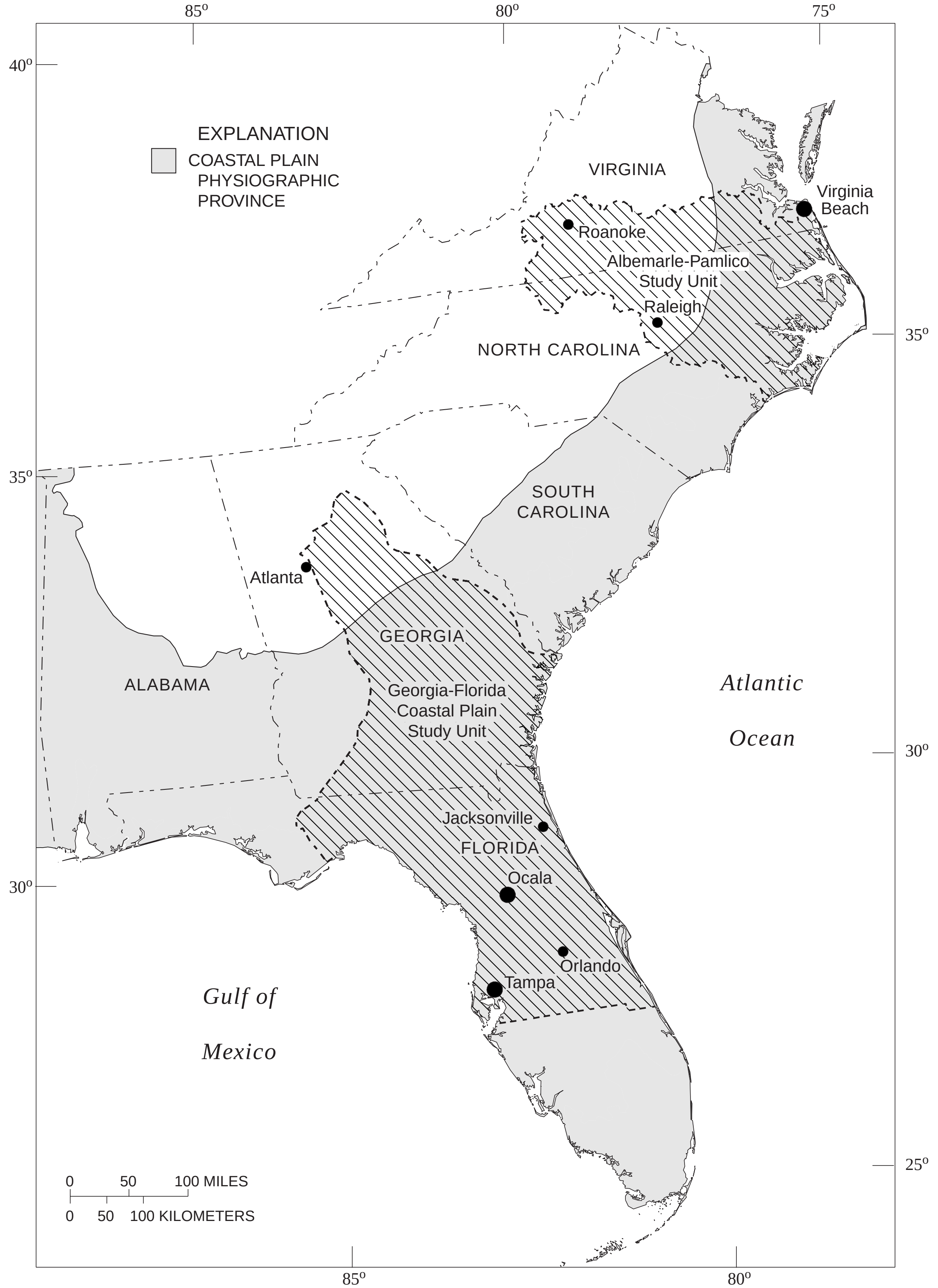

Figure 1. Locations of the southeastern Coastal Plain, the Albemarle-Pamlico and Georgia-Florida National Water-Quality Assessment Program study units, and the Ocala and Tampa, Florida, and Virginia Beach, Virginia, study areas.

Description of Urban Areas

Ocala, Fla., is located in Marion County in central Florida (fig. 2). The wells sampled for the study are located in downtown Ocala. The population of the municipality of Ocala was approximately 42,000 in 1990; the population of the Ocala Metropolitan Statistical Area (MSA), which includes all of Marion County, was nearly 218,000 in 1994 (table 1) (Shermyen and others, 1991; University of Florida, 1995). The Ocala MSA has grown substantially since 1970, with 77-percent growth from 1970 to 1980 and 59-percent growth from 1980 to 1990 (table 1).

Average annual rainfall in Ocala is about 54 inches per year (in/yr), and the average air temperature is 71 degrees Fahrenheit (°F) (Phelps, 1994). More than 50 percent of the rainfall occurs in the four summer months from June through September.

The topography of Ocala is characterized by gently rolling hills and karst depressions, caused by dissolution of limestone at or near the land surface (Phelps, 1994). The altitude of land surface ranges

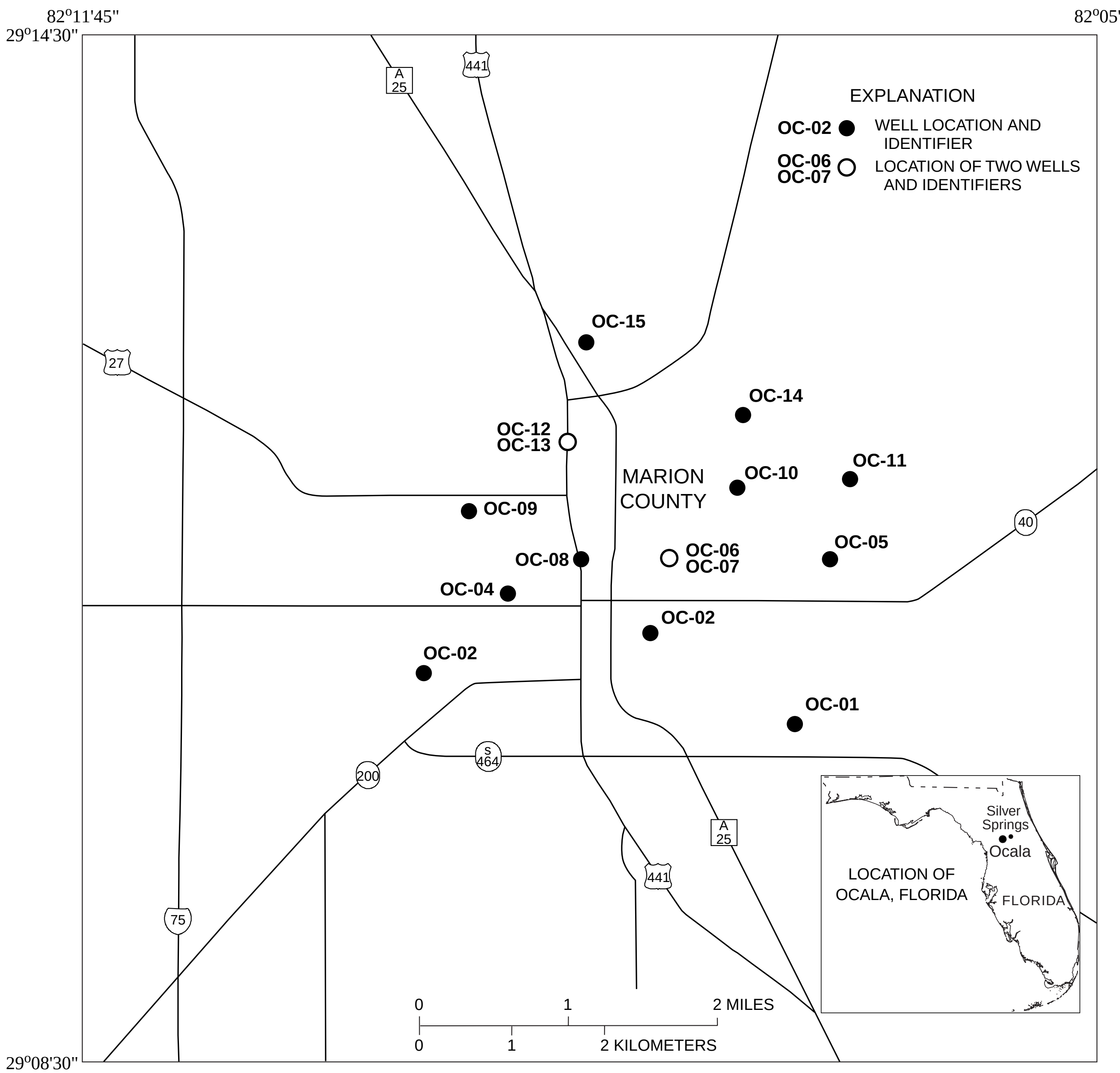

Figure 2. Locations of wells sampled in the Ocala, Florida, study area.

Table 1. Population of Ocala and Tampa, Florida, and Virginia Beach, Virginia, 1970-94

[MSA, Metropolitan Statistical Area; Data from Shermyen and others, 1991, and University of Florida, 1995; Inc., Incorporated area]

	Population				Percent change		
	1994	**1990**	**1980**	**1970**	**1990-94**	**1980-90**	**1970-80**
Ocala (MSA)	217,862	194,835	122,488	69,030	11.8	59.1	77.4
Tampa-St. Petersburg-Clearwater (MSA)	2,163,509	2,067,959	1,613,600	1,105,553	4.6	28.2	46.0
Ocala (Inc.)	42,920	42,045	37,170	22,583	2.1	13.1	64.6
Tampa (Inc.)	283,802	280,015	271,523	277,714	1.4	3.1	-2.2
	1993				**1990-93**		
Virginia Beach	410,607	393,069	262,199	172,106	4.46	49.9	52.3

from about 15 to 165 feet (ft) above sea level, although most of the area has altitudes of about 50 to 80 ft. Surface-water drainage is nearly absent in the Ocala area (fig. 2) because most of the drainage is internal. Much of the water drains into sinkholes and quickly enters the Upper Floridan aquifer. The Ocala study area is located within the drainage area to Silver Springs, a first magnitude spring with a long-term (1933-93) average discharge of about 800 cubic feet per second (ft^3/s) (Spechler and Schiffer, 1995). Silver Springs is located about 30 miles (mi) east of the study area.

The Tampa urban area is in northwestern Hillsborough County in west-central Florida. The population of Tampa in 1994 was nearly 284,000 with a population density of approximately 800 per square mile (University of Florida, 1995). The Tampa urban land-use study area is located on the northern edge of the city (fig. 3).

Average annual rainfall in Tampa is about 48 in/yr, and the average air temperature (1961-90) is about 72 °F (Owenby and Ezell, 1992). The topography of the Tampa study area is low lying with numerous lakes, streams, and swamps. The altitude of the land surface ranges from about 30 ft to about 60 ft, with most of the area at altitudes of 33-50 ft.

The Virginia Beach study area is limited to the northern half of the city of Virginia Beach, which is heavily populated and developed (fig. 4). The population of Virginia Beach was more than 410,000 in 1993, with a population density of 1,583 per square mile (table 1), and Virginia Beach is one of the fastest growing areas along the East Coast. The city includes a variety of land-use types—commercial, residential, and industrial areas, as well as four military bases. Virginia Beach also has 165 farms located mainly in the southern half of the city.

The average annual rainfall in Virginia Beach is nearly 45 in., and average snowfall is about 9 in/yr. Average annual temperature is about 59 °F. Elevations range from sea level to about 25 ft above sea level, with a mean elevation of 12 ft above sea level. Virginia Beach contains several bays and lakes, with a total water-surface area of 51 mi^2. The city is bordered by Chesapeake Bay and the Atlantic Ocean, and has 38 mi of shoreline (fig. 4).

Acknowledgments

Appreciation is extended to Lynn Collar of the City of Ocala, Don Boniol and Jody Lee of the St. Johns River Water Management District, and Eric De Haven of the Southwest Florida Water Management District for providing access to their monitoring wells, maps, and background information about the wells. Appreciation is also extended to Scott Bruce and Jay Owens of the Virginia Department of Environmental Quality for providing access to their wells, maps, and background information about the wells.

HYDROGEOLOGY

The hydrogeology of the urban study areas has been described in previous reports. Faulkner (1970) and Phelps (1994) described the hydrogeology of the Ocala area in detail. Aquifers present in the Ocala and Tampa areas include the surficial aquifer and the Upper Floridan aquifer (figs. 5 and 6). The intermediate confining unit is present in both areas and is located stratigraphically between the surficial and Upper Floridan aquifers (figs. 5 and 6). The thickness of this confining unit varies areally at the two sites and is covered as part of the discussion of the Upper Floridan aquifer.

In the Tampa area, Stewart and Mills (1984) and Corral and Thompson (1988) described the local hydrogeology for the areas covered by two 7.5-minute quadrangle maps (Citrus Park and Sulphur Springs) in which the sampled wells are located. The hydrogeoogy of the Virginia Coastal Plain is described in Cederstrom (1945) and in Meng and Harsh (1988) (fig. 7).

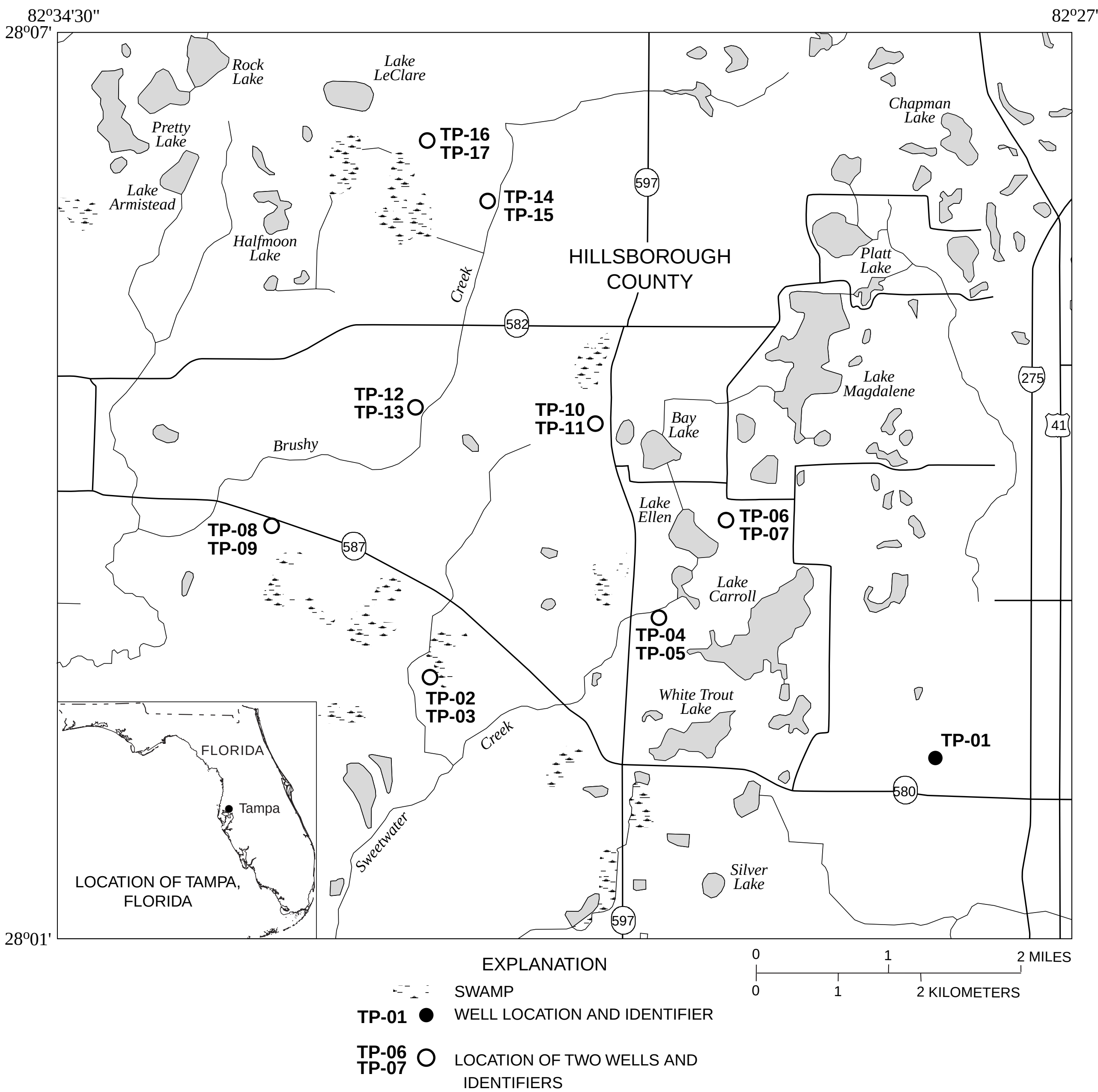

Figure 3. Locations of wells sampled and hydrologic features in the Tampa, Florida, study area.

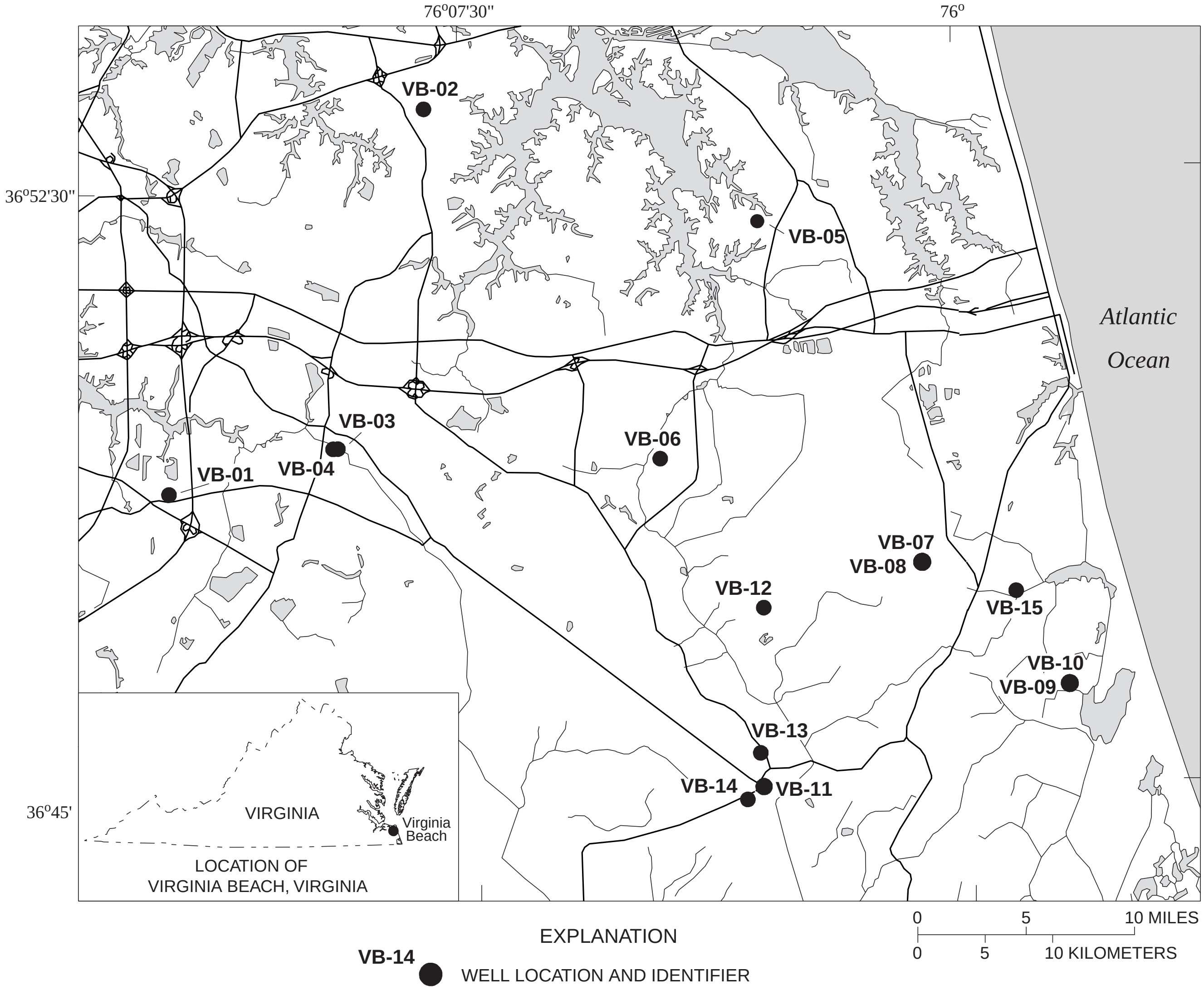

Figure 4. Locations of wells sampled and hydrologic features in the Virginia Beach, Virginia, study area.

Surficial Aquifer

In the Ocala study area, the surficial aquifer consists of nonmarine, clayey sand (Faulkner, 1970), marine and lacustrine sand, shell marl, sandy clay, and some phosphatic limestone (Phelps, 1994). The thickness of the aquifer ranges from about 5 to 50 ft (fig. 5; Phelps, 1994).

In the Tampa study area, Corral and Thompson (1988) described the deposits comprising the surficial aquifer as marine and nonmarine unconsolidated quartz sand, clay, and shells that range in age from Holocene to Pliocene. Stewart and Mills (1984) described the lower part of the aquifer as composed primarily of clay, sandy clay, and clayey sand. The thickness of the aquifer ranges from 20 to 40 ft (fig. 6).

In the Virginia Beach study area, the surficial aquifer is also known as the Columbia aquifer (fig. 7). However, for this report, this unit will be referred to as the surficial aquifer. This aquifer consists of sandy Pleistocene and Holocene sediments, although it may contain some clays in the study area. These sediments generally are characterized by fining-upwards sequences, consisting of a gravelly lag that grades to sands, fine silts, and clays (Meng and Harsh, 1988). The surficial aquifer generally thickens eastward to an approximate thickness of 60 ft at Virginia Beach. The surficial aquifer is not currently used for drinking-water supplies, although it may be used for irrigation. All 15 wells sampled in Virginia Beach are screened in the surficial aquifer, although some of the deeper wells may draw water from the Yorktown-Eastover aquifer, which lies below the surficial aquifer.

Series	Stratigraphic unit	Hydrogeologic unit	Approximate thickness (feet)
Holocene Pleistocene Pliocene	Undifferentiated deposits	Surficial aquifer	5 - 50
Miocene			
	Hawthorn Formation	Intermediate confining unit	5 - 50
Oligocene	Unconformity		
Eocene	Ocala Limestone	Upper Floridan aquifer	1,000 - 1,500
	Avon Park Formation		
		Middle confining unit	50 - 200
	Oldsmar Formation	Lower Floridan aquifer	500 - 650

Figure 5. Holocene through Paleocene-age stratigraphic and hydrogeologic units in Ocala, Florida (from Miller, 1986; Scott, 1988; Phelps, 1994).

Series	Stratigraphic unit	Hydrogeologic unit	Approximate thickness (feet)
Holocene Pleistocene Pliocene	Surficial sand and clay	Surficial aquifer	20-40
Miocene	Hawthorn Formation	Intermediate confining unit	10-40
	Tampa Limestone	Upper Floridan aquifer	1,100
Oligocene	Suwannee Limestone		
Eocene	Ocala Limestone		
	Avon Park Formation	Middle confining unit	300-400
	Oldsmar Formation	Lower Floridan aquifer	1,000

Figure 6. Holocene through Paleocene-age stratigraphic and hydrogeologic units in Tampa, Florida (from Miller, 1986; Corral and Thompson, 1988; Scott, 1988; Phelps, 1994)

Upper Floridan Aquifer

The Upper Floridan aquifer of the Floridan aquifer system is the principal source of water in the Georgia-Florida Coastal Plain. The Upper Floridan aquifer is composed of carbonates of high permeability that are Eocene to late Miocene in age (fig. 5 and 6). A confining unit is present in the middle of the Floridan aquifer system, hydraulically separating it into an Upper and Lower Floridan aquifer. The drinking-water supply for the study area is obtained from the Upper Floridan aquifer.

The Ocala Limestone is the uppermost unit of the Upper Floridan aquifer in the Ocala area and is one of the most productive units in the Upper Floridan aquifer (Faulkner, 1970). The lithology of the Ocala Limestone is marine limestone that is granular, porous, highly fossiliferous, and cherty in places. The lower part of the unit is, in some places, dolomitic, crystalline and porous (Phelps, 1994).

Series	Stratigraphic unit	Hydrogeologic unit	Approximate thickness (feet)
Holocene	Holocene deposits	Surficial (Columbia) aquifer	60
Pleistocene	Pleistocene undifferentiated deposits		
Pliocene	Yorktown Formation	Yorktown confining unit	30
		Yorktown-Eastover aquifer	300
Miocene	Eastover Formation		

Figure 7. Holocene through Miocene-age stratigraphic and hydrogeologic units in Virginia Beach, Virginia (from Meng and Harsh, 1988).

The Tampa Limestone is the uppermost unit of the Upper Floridan aquifer in the Tampa area. The lithology of the Tampa Limestone is "white, cream and gray, hard to soft, sandy limestone," that contains many fossils (Menke and others, 1961).

The degree of confinement of the Upper Floridan aquifer affects recharge, discharge, and ground-water flow. Recharge is much higher in the unconfined and semiconfined areas, and the ground-water flow system is generally more active. In both the Ocala and Tampa study areas, the Upper Floridan contains unconfined and semiconfined areas. There are 42 active drainage wells located in the Ocala area; these wells have depths ranging from 27 to 609 ft (Phelps, 1994), and they supply direct recharge to the Upper Floridan aquifer.

GROUND-WATER QUALITY

Most inorganic constituents in ground water come from the solution of minerals in the aquifer matrix. However, anthropogenic sources may contribute a significant portion of the dissolved material in ground water. Nutrients are elements required for plant growth and include nitrate, ammonia, and phosphorus. Major natural sources of nutrients in ground water include the atmosphere, rainfall, sediments, and leaching from forests and grasslands (Alley, 1993). Nutrient levels may be elevated as a result of many sources, including animal waste, wastewater, and fertilizers. Organic compounds in ground water include carbon compounds from decayed vegetation, industrially manufactured farm pesticides, and solvents.

Sampling and Analytical Methods

In Ocala and Tampa, Fla., wells were selected from a limited number of sites administered by the St. Johns River and Southwest Florida Water Management Districts. Most wells were constructed of 4-inch (in.) polyvinyl chloride casing with locked protective caps, although two wells had steel casing material. Well diameters ranged from 2 to 8 in. (table 2). Fifteen wells were sampled in Ocala, with depths ranging from 25 to 75 ft. Seventeen wells were sampled in Tampa, with depths ranging from 12 to 250 ft. In Virginia Beach, Va., the 15 wells sampled are now or were formerly part of the Virginia Department of Environmental Quality State Observation Well Network. The wells range between 35 and 90 ft in depth (table 2). Eight of these wells were formerly used for water supply on elementary and high school properties. The remaining seven wells were drilled for observation and are located on residential, industrial, and city park properties.

Wells were sampled according to USGS sampling protocols (Koterba and others, 1995). Prior to sampling, the volume of water present in the well casing was determined, and approximately three well-casing volumes of water were pumped using a stainless steel and Teflon pump. Then field properties, including pH, temperature, dissolved oxygen, and specific conductance, were measured at approximately 10-minute intervals until stable readings (less than 10-percent difference in consecutive measurements) were obtained. Samples were then collected using a system designed to minimize contact of the ground-water sample with the atmosphere.

The ground-water samples were analyzed for alkalinity, major ions (including calcium, magnesium, sodium, potassium, chloride, and sulfate), nutrients (nitrogen and phosphorus compounds), 18 trace elements (in Florida samples), dissolved organic carbon, 60 volatile organic compounds (VOC's), and 47 pesticides. Trace elements were not measured in samples collected from the two wells with steel casing material. All samples were shipped on ice and analyzed at the USGS National Water-Quality Laboratory in Denver, Colo. The data described in this report are stored in the National Water Information System of the USGS.

Descriptive and nonparametric statistics were used in this report to summarize the concentrations of field parameters, major inorganic constituents, and selected trace elements in the ground-water samples. The nonparametric Wilcoxon rank-sum test (SAS Institute, Inc., 1990; Helsel and Hirsch, 1992) was used to test for differences in values or concentrations between two groups of data.

Major Ions and Trace Constituents in the Surficial Aquifer

Major water types are characterized by the proportions of major ion concentrations, including calcium, magnesium, sodium, potassium, bicarbonate,

Table 2. Descriptions of wells sampled in Ocala and Tampa, Florida, and Virginia Beach, Virginia

[Wells are constructed of polyvinyl chloride unless otherwise noted; --, unknown]

Well identifier	Site identification number	Latitude	Longitude	Diameter, in inches	Type of open interval	Length of interval, in feet	Depth, in feet	Aquifer
Ocala (OC) urban area								
OC-01	291025082070401	291025	0820704	4	Screen	10	60	Upper Floridan
OC-02	291043082093201	291043	0820932	4	Screen	10	40	Surficial
OC-03	291057082080201	291057	0820802	4	Screen	10	35	Surficial
OC-04	291111082085801	291111	0820858	4	Screen	10	40	Surficial
OC-05	291123082065001	291123	0820650	4	Screen	10	57	Upper Floridan
OC-06	291123082075401	291123	0820754	4	Screen	10	30	Surficial
OC-07	291123082075402	291123	0820754	4	Screen	10	70	Upper Floridan
OC-08	291123082082901	291123	0820829	4	Screen	10	35	Surficial
OC-09	291140082091401	291140	0820914	4	--	--	35	Surficial
OC-10	291148082072702	291148	0820727	4	Screen	10	75	Upper Floridan
OC-11	291151082064201	291151	0820642	4	Screen	10	55	Upper Floridan
OC-12	291204082083601	291204	0820836	4	--	--	54	Upper Floridan
OC-13	291204082083602	291204	0820836	4	Screen	10	25	Surficial
OC-14	291214082072501	291214	0820725	4	Screen	10	25	Surficial
OC-15	291239082082702	291239	0820827	4	Screen	10	40	Upper Floridan
Tampa (TP) urban area								
TP-01	280215082280001	280210	0822803	8	Open hole	208	250	Upper Floridan
TP-02	280235082313501	280241	0823147	4	Screen	10	22	Surficial
TP-03	280235082313502	280241	0823147	4	Screen	9	45	Upper Floridan
TP-04	280305082300501	280305	0823005	4	Screen	10	17	Surficial
TP-05	280305082300502	280305	0823005	4	Screen	9	54	Upper Floridan
TP-06	280310082291001	280344	0822936	4	Screen	10	17	Surficial
TP-07	280310082291002	280344	0822936	4	Screen	20	70	Upper Floridan
TP-08	280341082325701	280341	0823257	6	Open hole	5	20	Surficial
TP-09	280341082325702	280341	0823257	6 [a]	Open hole	50	150	Upper Floridan
TP-10	280437082303001	280422	0823034	6	Screen	5	20	Surficial
TP-11	280437082303002	280422	0823034	6 [a]	Open hole	56	150	Upper Floridan
TP-12	280500082313501	280428	0823154	4	Screen	10	20	Surficial
TP-13	280500082313502	280428	0823154	4	Screen	20	52	Upper Floridan
TP-14	280550082312201	280550	0823122	4	Screen	7	17	Surficial
TP-15	280550082312202	280550	0823122	4	Open hole	20	60	Upper Floridan
TP-16	280614082314901	280614	0823149	2	Screen	10	12	Surficial
TP-17	280614082314902	280614	0823149	4	Open hole	23	65	Upper Floridan
Virginia Beach (VB) urban area								
VB-01	364850076120701	364850	0761207	6[a]	Screen	5	78	Surficial
VB-02	365327076080501	365327	0760805	6[a]	Screen	5	40	Surficial
VB-03	364920076093202	364920	0760932	3	Screen	10	80	Surficial
VB-04	364920076093601	364920	0760936	6[a]	Screen	5	71	Surficial
VB-05	365158076030401	365158	0760304	6[a]	Screen	5	57	Surficial
VB-06	364906076043901	364906	0760439	6[a]	Screen	5	67	Surficial
VB-07	364745076004303	364745	0760043	3	Screen	10	35	Surficial
VB-08	364745076004304	364745	0760043	3	Screen	10	75	Surficial
VB-09	364613075583202	364613	0755832	1.25	Screen	5	35	Surficial
VB-10	364613075583201	364613	0755832	1.25	Screen	5	54	Surficial
VB-11	364504076031301	364504	0760313	4	Screen	5	65	Surficial
VB-12	364715076030801	364715	0760308	4	Screen	5	58	Surficial
VB-13	364529076031501	364529	0760315	6[a]	Screen	5	55	Surficial
VB-14	364550076032801	364455	0760328	6[a]	Screen	10	65	Surficial
VB-15	364722075591802	364722	0755918	3	Screen	10	90	Surficial

[a]Steel casing

chloride, sulfate, and fluoride. Stiff diagrams (Stiff, 1951) were generated to illustrate water types in the three urban areas (figs. 8-10). In Ocala, the major ion water type was calcium-bicarbonate in five samples; three samples had mixed (no dominant ions) water type (fig. 8). In Tampa, only one sample had calcium-bicarbonate water type, and seven samples had mixed water type (fig. 9). In Virginia Beach, nine samples had calcium-bicarbonate water type (fig. 10). Two wells in Virginia Beach, VB-02 and VB-12, had sodium-bicarbonate water type (fig. 10), although total mineral content was quite low as indicated by the specific conductance of 221 and 227 µS/cm in wellsVB-02 and VB-12, respectively. In the Virginia Coastal Plain, this water type is typically a result of the exchange of calcium in hard bicarbonate waters for sodium cations.

The source of calcium and bicarbonate ions in shallow ground water may be from one or more sources. Calcium and bicarbonate ions can occur in ground water from recharge water (precipitation) dissolving carbon dioxide generated from plant respiration to form carbonic acid, which then dissolves calcium and carbonate material from aquifer

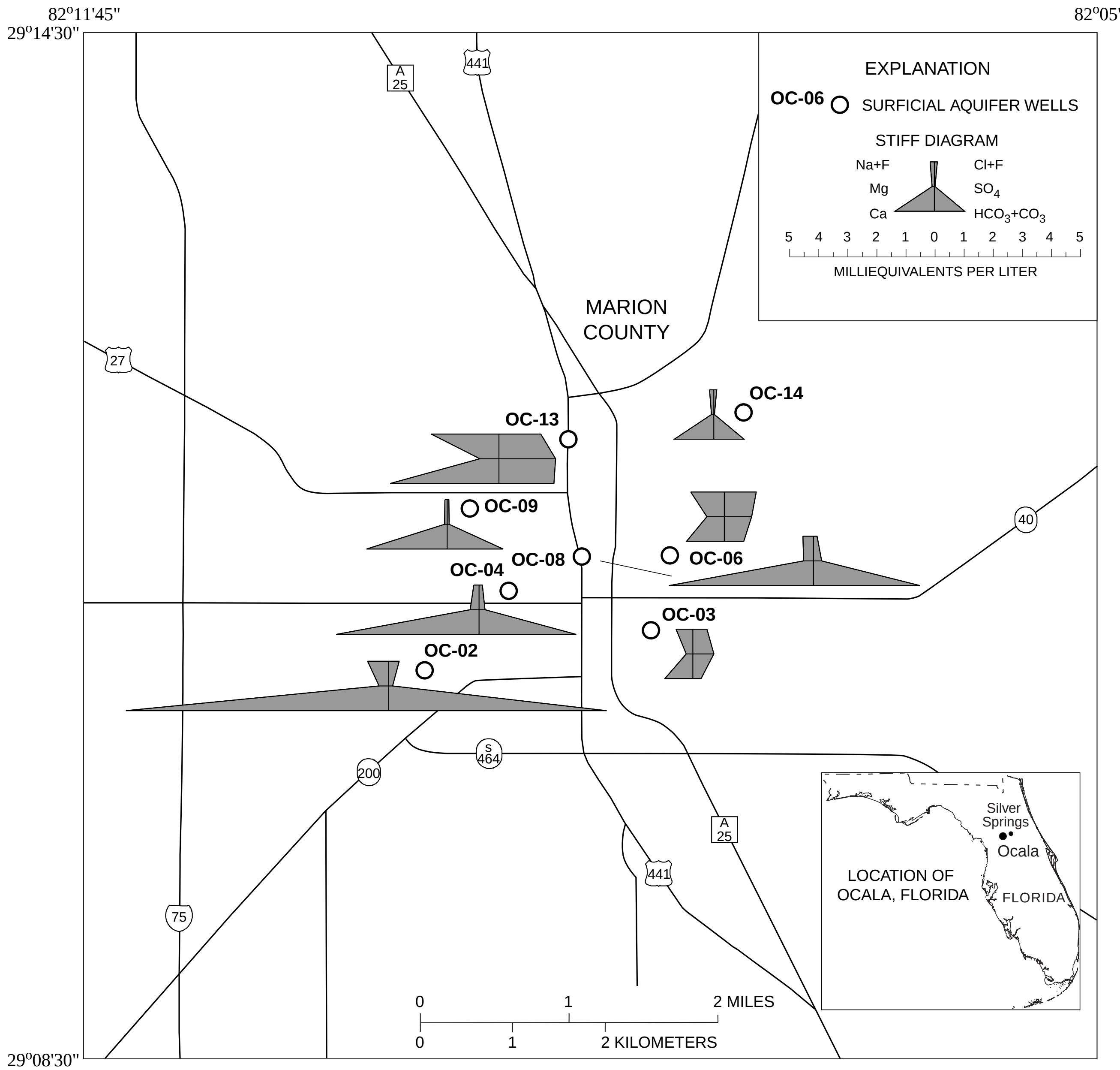

Figure 8. Stiff diagrams showing major ion concentrations in water from wells in the surficial aquifer, Ocala, Florida, study area.

sediments. This mechanism probably best explains the occurrence of calcium bicarbonate water in Ocala. However, most of the sediments composing the surficial aquifer in Virginia Beach are of fluvial origin, and no carbonate material is mentioned in either Cederstrom (1946) or Meng and Harsh (1988). Two other mechanisms are more likely the main source of calcium and bicarbonate in shallow ground water in Virginia Beach. The presence of significant dissolved organic carbon derived from organic material in surficial aquifer sediments in shallow ground water can allow denitrification and produce bicarbonate ions (Korom, 1992)—the low nitrate concentrations (<0.05 mg/L) and relatively high median dissolved organic carbon concentrations (1.8 mg/L) observed in Virginia Beach (discussed later in this report) are

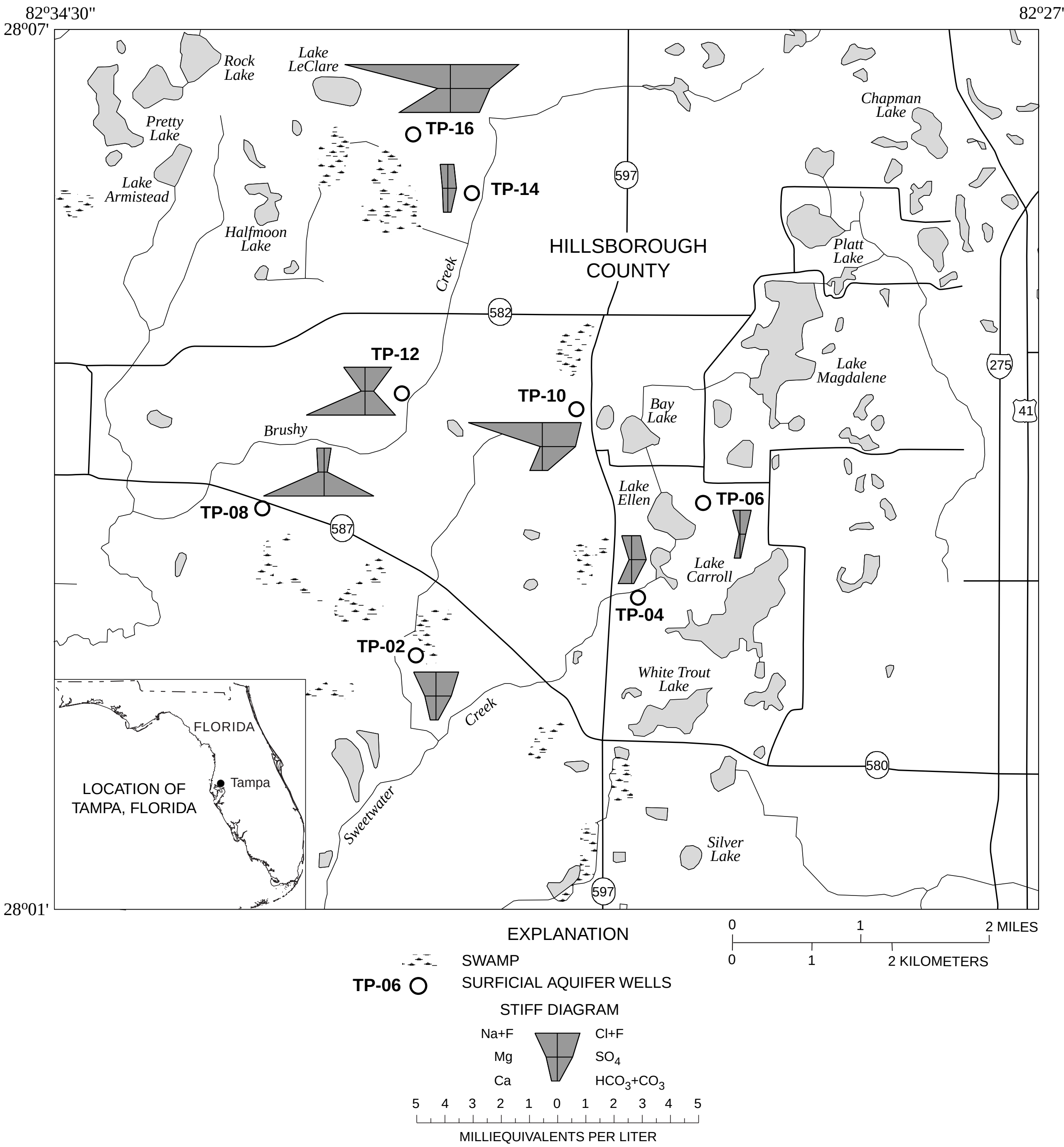

Figure 9. Stiff diagrams showing major ion concentrations in water from wells in the surficial aquifer, Tampa, Florida, study area.

consistent with this mechanism. In Virginia Beach, the more likely source of calcium and bicarbonate is the regional discharge of water which contains relatively high concentrations of bicarbonate from underlying aquifers to the surficial aquifer. Cederstrom (1946) indicates that flowing wells were once common before extensive ground-water development, indicating an upward gradient for deep aquifers over much of what is now Virginia Beach. Therefore, movement of deep ground water discharging upward through the Yorktown-Eastover aquifer and confining unit, which contains shell beds (Meng and Harsh, 1988), into the surficial aquifer could result in elevated calcium and bicarbonate (as well as other constituents) in the lower saturated zone of the surficial aquifer.

Dissolved-solids concentrations had similar ranges for water from the surficial aquifers in Ocala and Virginia Beach, but were lower in Tampa. Dissolved-solids concentrations ranged from 78 to 463 mg/L in Ocala, with a median concentration of 214 mg/L, and ranged from 89 to 740 mg/L in Virginia Beach, with a median concentration of 216 mg/L (table 3). In Tampa, the dissolved-solids

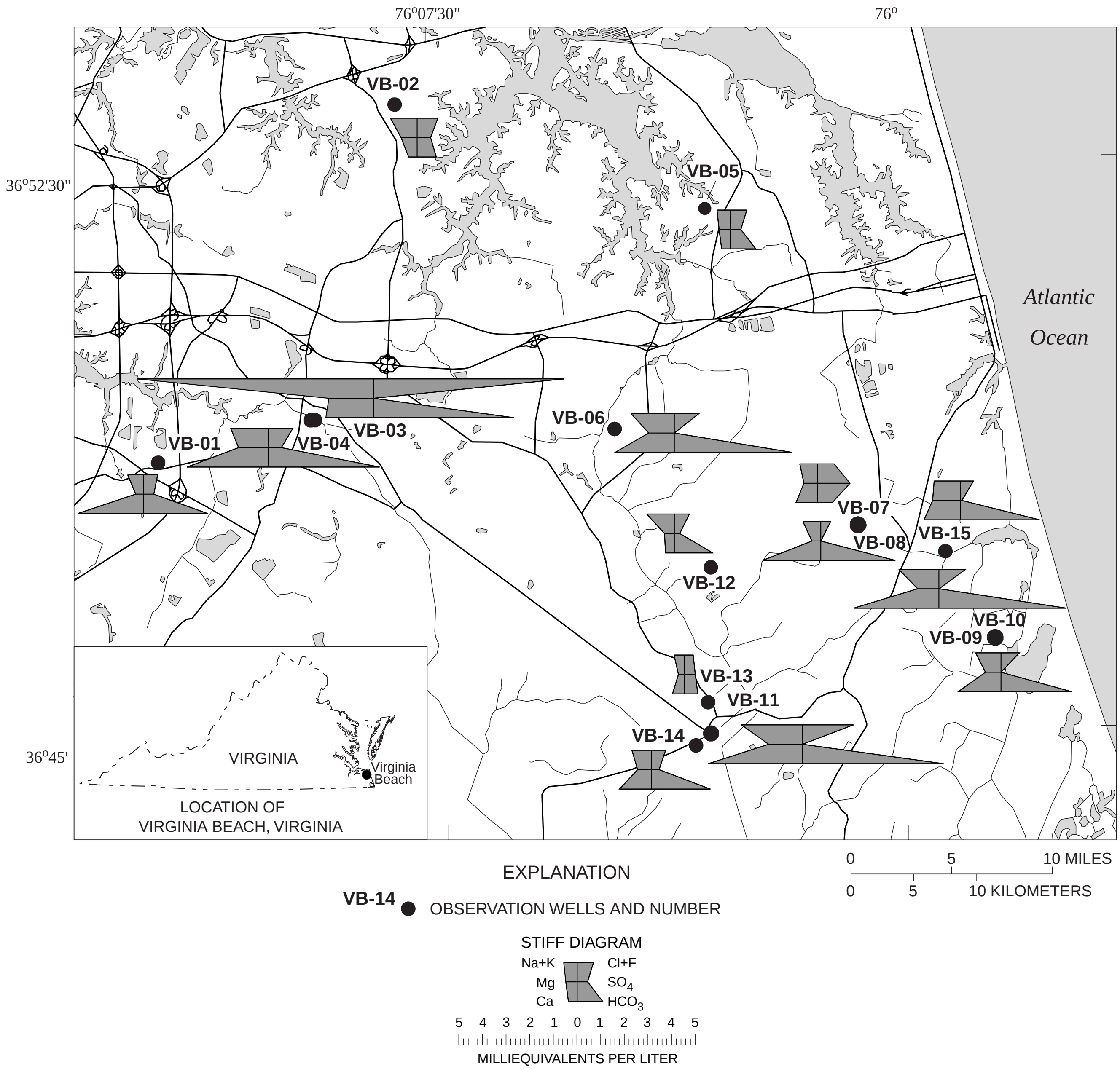

Figure 10. Stiff diagrams showing major ion concentrations in water from wells in the surficial (Columbia) aquifer, Virginia Beach, Virginia, study area.

Table 3. Summary of ground-water quality in the surficial aquifer in three urban areas, 1995

[ft, feet; °C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; pCi/L, picocuries per liter; -- , not determined]

	Ocala, Fla. Surficial aquifer Number of samples = 8			Tampa, Fla. Surficial aquifer Number of samples = 8			Virginia Beach, Va. Surficial aquifer Number of samples = 15		
	Median	Minimum	Maximum	Median	Minimum	Maximum	Median	Minimum	Maximum
Depth of well (ft)	**35**	25	40	**18**	12	22	**65**	35	95
Temperature (°C)	**23.9**	22.7	24.4	**23.5**	21.7	24.1	**19.5**	17.5	23
pH (pH units)	**6.9**	5.5	7.4	**5.4**	4.8	6.2	**7.1**	5.8	7.6
Specific conductance (µS/cm)	**380**	145	801	**195**	73	593	**321**	153	1,360
Dissolved solids (mg/L)	**214**	78	463	**121**	38	397	**216**	89	740
Bicarbonate (mg/L)	**126**	18	493	**10**	1.5	116	**154**	15	326
Dissolved oxygen (mg/L)	**2.9**	.6	4.9	**.35**	.2	2.8	**.15**	.1	5.6
Calcium (mg/L)	**57.5**	17	160	**8.1**	2.8	38	**33**	6.6	73
Magnesium (mg/L)	**3.4**	.9	7.0	**1.75**	.34	4.8	**7.2**	2.8	21
Sodium (mg/L)	**8.1**	.7	44	**10.1**	3.5	69	**21**	8.7	200
Potassium (mg/L)	**1.15**	.3	6.4	**2.80**	.1	12	**2.3**	.9	17
Chloride (mg/L)	**7.15**	1.2	45	**18.5**	6.6	76	**22**	12	260
Sulfate (mg/L)	**10.3**	1.1	83	**17.5**	4.8	60	**10**	.1	60
Dissolved organic carbon (mg/L)	**.65**	.3	1.5	**3.55**	1.2	39	**1.8**	.5	4.4
Silica (mg/L)	**7.5**	1.9	14	**5.0**	1.1	7.5	**42**	11	68
Iron (µg/L)	**14**	5	200	**155**	8	3,900	**3,800**	450	23,000
Manganese (µg/L)	**4.5**	1	34	**6.5**	1	14	**110**	50	940
Bromide (mg/L)	**.075**	<.01	.17	**.030**	.01	.19	**.14**	.03	.85
Fluoride (mg/L)	**.25**	<.10	.40	**<.10**	<.10	<.10	**.2**	.1	.4
Nitrate plus nitrite as N (mg/L)	**1.2**	.05	12	**.06**	.05	9.2	**.05**	.05	2.2
Ammonia as N (mg/L)	**.02**	.02	.06	**.11**	.02	.79	**.38**	.04	2
Phosphorus as P (mg/L)	**.28**	.03	1.3	**.015**	.01	.03	**.06**	.01	2.3
Orthophosphate as P (mg/L)	**.31**	.03	1.3	**.01**	.01	.02	**.06**	.01	1.1
Radon (pCi/L)	**3,850**	810	40,000	**725**	250	2,200	**--**	--	--
Aluminum (µg/L)	**8**	< 1	62	**120**	10	512	**--**	--	--
Antimony (µg/L)	**< 1**	< 1	< 1	**< 1**	< 1	4	**--**	--	--
Arsenic (µg/L)	**< 1**	< 1	1	**< 1**	< 1	2	**--**	--	--
Barium (µg/L)	**2**	< 1	12	**15**	3	44	**--**	--	--
Beryllium (µg/L)	**< 1**	< 1	< 1	**< 1**	< 1	< 1	**--**	--	--
Cadmium (µg/L)	**< 1**	< 1	< 1	**< 1**	< 1	< 1	**--**	--	--
Chromium (µg/L)	**3**	2	11	**2**	< 1	7	**--**	--	--
Cobalt (µg/L)	**< 1**	< 1	1	**< 1**	< 1	< 1	**--**	--	--
Copper (µg/L)	**1**	< 1	3	**< 1**	< 1	2	**--**	--	--
Lead (µg/L)	**< 1**	< 1	< 1	**< 1**	< 1	< 1	**--**	--	--
Molybdenum (µg/L)	**< 1**	< 1	5	**< 1**	< 1	5	**--**	--	--
Nickel (µg/L)	**8**	4	21	**1**	< 1	10	**--**	--	--
Selenium (µg/L)	**< 1**	< 1	< 1	**< 1**	< 1	< 1	**--**	--	--
Silver (µg/L)	**< 1**	< 1	< 1	**--**	--	--	**--**	--	--
Uranium (µg/L)	**< 1**	< 1	22	**< 1**	< 1	2	**--**	--	--
Zinc (µg/L)	**1.5**	< 1	5	**1**	< 1	3	**--**	--	--

concentrations ranged from 38 to 397 mg/L, with a median concentration of only 121 mg/L. This also reflects the presence of carbonate units in the Ocala and Virginia Beach areas. Median concentrations of other major inorganic constituents, including calcium, magnesium, sodium, chloride, sulfate, and silica, were generally low (less than 20 mg/L) in samples from the surficial aquifer, although the median silica concentration in Virginia Beach was 42 mg/L compared to only 7.5 mg/L in Ocala and 5.0 mg/L in Tampa (table 3).

One sample from Virginia Beach (VB-03) had a very high specific conductance (1,360 µS/cm), due mainly to the high sodium-chloride content of the sample. The chloride content in this water was 260 mg/L, which is above the U.S. Environmental Protection Agency's (USEPA) Secondary Maximum Contaminant Level (SMCL) of 250 mg/L (U.S. Environmental Protection Agency, 1995). The SMCL's were established by the USEPA for constituents which do not have known health effects but do have effects on the aesthetic properties of the water (color, odor, taste). It is possible that the high sodium and chloride concentrations in water from well VB-03 result from saltwater intrusion, because this well is 80 ft deep and pumping wells are located nearby.

Concentrations of iron and manganese were generally high in Virginia Beach (relative to SMCL's) and low in Ocala and Tampa. Iron concentrations in Virginia Beach ranged from 450 to 23,000 micrograms per liter (µg/L), and the minimum iron concentration (450 µg/L) was above the SMCL of 300 µg/L (table 3). Manganese concentrations in Virginia Beach ranged from 50 to 940 µg/L. This minimum manganese concentration is equal to the SMCL (table 3). In contrast, median iron concentrations were only 14 and 155 µg/L in Ocala and Tampa, respectively, and median manganese concentrations were 4.5 and 6.5 µg/L in Ocala and Tampa, respectively. Concentrations of bromide and fluoride were low in all three urban areas (table 3).

Nitrate concentrations were generally low in the surficial aquifer, although some elevated nitrate concentrations were detected. The median nitrate plus nitrite concentration was 1.2 mg/L in Ocala, 0.06 mg/L in Tampa, and 0.05 mg/L in Virginia Beach. The reasons for the higher nitrate concentrations in Ocala are currently unknown. The drinking-water standard of 10 mg/L was exceeded in only one sample from the surficial aquifer in the Ocala area. Maximum contaminant levels (MCL's) are established by the USEPA for elements and compounds which have known health effects. This sample also contained the highest concentrations of sodium, chloride, and sulfate of the Ocala samples. This sample was from a well 25 ft deep and located across the street from a wastewater-treatment plant. A sample from an adjacent, deeper well (54 ft deep) had a nitrate plus nitrite concentration below the detection limit of 0.05 mg/L.

Ammonia concentrations were higher than nitrate concentrations in Virginia Beach, with a median of 0.38 mg/L and a maximum of 2 mg/L. This pattern of low nitrate coupled with higher ammonia in Virginia Beach is consistent with an aquifer having low dissolved-oxygen concentrations (median of 0.15 mg/L) and the presence of an electron donor, such as carbon—both of which are requirements for denitrification (Korom, 1992). In addition, many of the Virginia Beach sites do not have an obvious nearby source of nitrate, such as fertilizer or septic systems.

Dissolved phosphorus and orthophosphate concentrations also were generally low in Tampa and Virginia Beach, with median concentrations less than 0.10 mg/L (table 3). In Ocala, median phosphorus and orthophosphate concentrations were higher—about 0.30 mg/L (table 3)—and probably reflect the presence of some phosphate minerals in the surficial aquifer there. One relatively high value of dissolved phosphorus, 2.3 mg/L, was measured from VB-15, the deepest well sampled at Virginia Beach (table 2), and may be a result of contributions from deeper formations which contain phosphate deposits (Harned and others, 1995). Nitrate and phosphorus concentrations at Virginia Beach are similar to those reported for the outer Coastal Plain in the Albemarle-Pamlico drainage basin (Harned and others, 1995).

In Florida, background water-quality data for the surficial aquifer are available (Berndt and Katz, 1992) for comparison to the data collected during this study. The Florida Department of Environmental Protection has established a network of wells for background water-quality sampling in locations selected to avoid areas of known contamination. Nitrate and orthophosphate concentrations in Ocala were elevated compared to background water quality for the surficial aquifer, but median concentrations for most other constituents in both Ocala and Tampa were lower than in the background data (table 4). Median major ion

Table 4. Summary of background ground-water quality in the surficial aquifer in Florida

[ft, feet; °C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; pCi/L, picocuries per liter]

	Number samples	Median	Minimum	Maximum
Depth of well (ft)	186	**30**	6	240
Temperature (°C)	183	**24.5**	20.6	29.6
pH (pH units)	186	**6.8**	3.8	8.6
Specific conductance (µS/cm)	179	**553**	42	2,825
Dissolved solids (mg/L)	186	**341**	26	6,892
Bicarbonate (mg/L)	186	**260**	.1	774
Calcium (mg/L)	186	**86.6**	.24	367
Magnesium (mg/L)	186	**4.4**	.1	255
Sodium (mg/L)	185	**18**	.9	2,585
Potassium (mg/L)	186	**1.2**	.01	85
Chloride (mg/L)	186	**29.7**	.6	4,480
Sulfate (mg/L)	185	**11**	.1	595
Total organic carbon (mg/L)	156	**22.0**	.1	380
Silica (mg/L)	128	**11.7**	1.0	67
Nitrate plus nitrite as N (mg/L)	166	**.04**	<.01	52
Orthophosphate as P (mg/L)	143	**.06**	<.01	11
Radon, (pCi/L)	8	[2]**433**	[2]30	[2]1,400

[1]From Berndt and Katz, 1992.

[2]Radon values are samples from Tampa urban area wells (Paul Hansard, Florida Department of Environmental Protection, written commun., 1995).

concentrations in the background data were more similar to the data from the Ocala study area than from the Tampa study area, probably because the Tampa study area wells were more shallow (18-ft median depth) than either the Ocala study area wells (35-ft median depth) or the background wells (30-ft median depth).

Major ion water type was calcium-bicarbonate for 55 percent and mixed for 35 percent of the background samples. Median nitrate and orthophosphate-phosphorus concentrations were much higher in the Ocala urban area than in the Tampa urban area or in the background data. In Ocala, the median orthophosphate concentration was 0.31 mg/L, compared to 0.01 mg/ L and 0.06 mg/L for Tampa and the background samples, respectively (tables 3 and 4). Sources of nitrate and phosphorus in ground-water samples from the Ocala urban area include fertilizer, treated wastewater, and phosphatic sediments in the surficial aquifer.

Uranium concentrations were generally low and radon[1] values were high in samples from the surficial aquifer in Ocala and Tampa. Concentrations of uranium were mostly less than 1 µg/L (table 3). Only three samples had concentrations greater than the detection limit—1 µg/L, 2 µg/L, and 22 µg/L. The 22-µg/L concentration of uranium was in a sample which also had a bicarbonate concentration of 492 mg/L and a dissolved-oxygen concentration of 0.6 mg/L. Uranium is known to be most soluble in ground water with a high bicarbonate concentration under oxidizing conditions (Zapecza and Szabo, 1988). Radon concentrations ranged from 250 to 40,000 picocuries per liter (pCi/L), with medians of 3,850 pCi/L and 725 pCi/L in Ocala and Tampa, respectively (table 3). Higher radon values in the Ocala area are probably because of phosphatic limestone near the land surface. Rocks containing phosphate have high radon-producing potential (Gundersen and Peake, 1992).

The analyses of ground water for trace-element concentrations showed that most samples had concentrations less than analytical detection limits (1.0 µg/L, in most cases). Only 8 of the 16 trace elements had median concentrations above the detection limit—aluminum, barium, chromium, copper, iron,

[1]Radon is a radioactive decay product of uranium-238 with a short half-life of 3.8 days.

manganese, nickel, and zinc (table 3). Concentrations of aluminum, barium, iron, and nickel were significantly different in Ocala and Tampa; higher median concentrations of aluminium, barium, and iron were detected in the Tampa study area (table 3). The SMCL for iron of 300 μg/L was exceeded in three samples from the Tampa study area. Concentrations of aluminum in samples from Ocala and Tampa were negatively correlated with pH (p-value < 0.01).

Organic Compounds in the Surficial Aquifer

Dissolved organic carbon (DOC) in ground water comes from surface organic matter or from kerogen, the organic material present in rocks or sediments of the aquifer. Typically, organic carbon in ground water consists of a variety of many complex compounds, including fulvic and humic acids, carbohydrate hydrophilic acids, carbohydrates, carboxylic acids, amino acids, and hydrocarbons (Thurman, 1985). The median DOC concentration in ground water is 0.7 mg/L (Thurman, 1985). In the surficial aquifer in Tampa and Virginia Beach, the median DOC concentrations were significantly higher—3.55 mg/L and 1.8 mg/L, respectively—compared to 0.65 mg/L in Ocala (table 4). The higher concentrations in Tampa and Virginia Beach are probably caused by recharge of ground water from organic-rich surface water from the numerous surface-water features, including lakes, swamps, and streams (figs. 3 and 4). In contrast, the Ocala area has virtually no surface-water features (fig. 2). Surface-water recharge is a common source of elevated DOC in ground water in semi-tropical climates of the southeastern United States (Thurman, 1985).

Although high concentrations of organic carbon can occur naturally in ground water, particularly in the Southeast, many compounds that are manufactured for industrial purposes, occur in petroleum, or are used as pesticides can occur in ground water as contaminants. Volatile organic compounds (VOC's) typically include solvents and compounds used in manufacturing. Occurrence of VOC's in ground water is almost entirely attributable to human activity, and many of these compounds are known to cause cancer, birth defects, or are toxic. Pesticides include several classes of compounds, many of which have known carcinogenic, mutagenic, or toxic properties. Maximum contaminant levels (MCL's) have been established by the USEPA for VOC's and pesticides (U.S. Environmental Protection Agency, 1995). Most samples from the three urban study areas were analyzed for 60 VOC's and 47 commonly used pesticides.

Most of the surficial aquifer samples analyzed for pesticides and VOC's had concentrations below analytical reporting levels. Only 3 pesticides—atrazine, desethylatrazine, and prometon—and 12 VOC's—chloroform, tetrachloroethylene (PCE), cis-1,2-dichloroethene, pseudocumene, mesitylene, isopropylbenzene, xylene, ethylbenzene, toluene, n-propylbenzene, vinyl chloride, and napthalene—were detected in ground-water samples from the surficial aquifers at concentrations above analytical reporting levels (table 5). Many of the concentrations detected were near the reporting level. Pesticides or VOC's were detected in 6 of 8 samples in Ocala, 5 of 15 samples in Virginia Beach, and 1 of 8 samples in Tampa.

The most commonly detected pesticide in the urban areas was prometon, which was present in 4 of 8 samples collected in the Ocala area and in 3 of 13 samples collected at Virginia Beach. Prometon is a nonselective triazine herbicide, generally applied to control most annual, broadleaf weeds and grasses for a full season around buildings and rights-of-way (Sine, 1991). Prometon was detected in samples from the surficial aquifer at concentrations ranging from 0.025 to 10 μg/L (table 5). Desethylatrazine was detected in two samples, but concentrations were extremely low and did not exceed 0.48 μg/L. Atrazine was detected in one sample from Ocala (well OC-13) at a concentration of 0.056 μg/L, and in one sample from Virginia Beach (well VB-13) at a concentration of 4.2 μg/L that exceeds the MCL of 3 μg/L (table 5). Well VB-13 also had a prometon concentration of 10 μg/L. These occurrences of pesticides in well VB-13 are probably due to localized contamination, primarily because the well was located in a well house in which lawn chemicals were stored.

Concentrations of VOC's in the surficial aquifers did not exceed any MCL's in the three urban areas (table 5). VOC's were detected in only three wells in Ocala and in one well in Tampa. Chloroform was detected in two wells in Ocala and in one well in Tampa at concentrations ranging from 0.3 to 2.2 μg/L. Nine VOC's were detected in samples from three wells in Virginia Beach. All of the VOC's detected in the Virginia Beach ground-water samples, with the exception of vinyl chloride, are associated with petroleum or coal tar. One sample (from well VB-05) contained seven of the compounds which are associated with petroleum or coal tar. The sources of these compounds are not known. Toluene occurred in water from well VB-14, although the concentration (0.3 μg/L) is well below the existing MCL. Vinyl chloride occurred in well VB-15 at a concentration of 1.5 μg/L.

Table 5. Occurrence of pesticides and volatile organic compounds in the three urban study areas of Ocala and Tampa, Florida, and Virginia Beach, Virginia, 1995

[STORET, U.S. Environmental Protection Agency Storage and Retrieval system; µg/L, micrograms per liter; --, no established standard]

Organic compound	STORET code	Concentration, µg/L	Reporting level, µg/L	Maximum contaminant level, µg/L	Well	Aquifer
Pesticides						
Atrazine	39632	0.039	0.017	3	OC-11	Upper Floridan
Atrazine	39632	.056	.017	3	OC-13	Surficial
Desethylatrazine	04040	.013	.003	--	OC-01	Upper Floridan
Desethylatrazine	04040	.009	.003	--	OC-05	Upper Floridan
Desethylatrazine	04040	.009	.003	--	OC-10	Upper Floridan
Desethylatrazine	04040	.025	.003	--	OC-11	Upper Floridan
Desethylatrazine	04040	.006	.003	--	OC-13	Surficial
Simazine	04035	.031	.008	4	OC-05	Upper Floridan
Prometon	04037	1.8	.008	--	OC-01	Upper Floridan
Prometon	04037	.22	.008	--	OC-04	Surficial
Prometon	04037	.081	.008	--	OC-05	Upper Floridan
Prometon	04037	.32	.008	--	OC-09	Surficial
Prometon	04037	.009	.008	--	OC-11	Upper Floridan
Prometon	04037	.24	.008	--	OC-12	Upper Floridan
Prometon	04037	.025	.008	--	OC-13	Surficial
Prometon	04037	.200	.008	--	OC-14	Surficial
Cyanazine	04041	.02	.013	1[a]	TP-13	Upper Floridan
Desethylatrazine	04040	.009	.003	--	TP-01	Upper Floridan
Prometon	04037	.01	.008	--	TP-07	Upper Floridan
Atrazine	39632	4.2	.017	3	VB-13	Surficial
Desethylatrazine	04040	.48	.007	--	VB-13	Surficial
Prometon	04037	.45	.008	--	VB-02	Surficial
Prometon	04037	10	.008	--	VB-13	Surficial
Prometon	04037	.19	.008	--	VB-14	Surficial
Volatile organic compounds						
Chloroform	32106	.4	.2	100[b]	OC-03	Surficial
Chloroform	32106	.3	.2	100[b]	OC-06	Upper Floridan
Chloroform	32106	2.2	.2	100[b]	OC-13	Surficial
Tetrachloroethylene (PCE)	34475	.2	.2	5	OC-02	Surficial
Tetrachloroethylene (PCE)	34475	.3	.2	5	OC-05	Upper Floridan
cis-1,2-dichloroethene	77093	.6	.2	70	OC-02	Surficial
methyl-tert-butyl ether (MTBE)	78032	.5	.2	--	OC-01	Upper Floridan
Chloroform	32106	.6	.2	100[b]	TP-10	Surficial
Tetrachloroethylene (PCE)	34475	.4	.2	5	TP-01	Upper Floridan
Trichloroethylene (TCE)	39180	.5	.2	5	TP-01	Upper Floridan
cis-1,2-dichloroethene	77093	.2	.2	70	TP-01	Upper Floridan
Toluene	34010	.3	.2	1,000	VB-14	Surficial
Ethylbenzene	34371	1.0	.2	700	VB-05	Surficial
Napthalene	34696	.3	.2	--	VB-05	Surficial
Vinyl chloride	39175	1.5	.2	2	VB-15	Surficial
Pseudocumene	77222	1.4	.2	--	VB-05	Surficial
Isopropylbenzene	77223	.30	.2	--	VB-05	Surficial
n-propylbenzene	77224	.6	.2	--	VB-05	Surficial
Mesitylene	77226	.30	.2	--	VB-05	Surficial
Xylene	81551	2.4	.2		VB-05	Surficial

[a] Maximum contaminant level goal.
[b] Proposed rule for disinfectants and disinfection by-products is that total combined cannot exceed 80 µg/L.

Major Ions and Trace Constituents in the Upper Floridan Aquifer

The inorganic chemistry of water from the Upper Floridan aquifer was similar in Ocala and Tampa. The major-ion water type was calcium-bicarbonate for all 16 samples from the Upper Floridan aquifer in both cities (figs. 11 and 12). Dissolved-solids concentrations ranged from 210 to 551 mg/L in Ocala, with a median of 287 mg/L, and from 187 to 362 mg/L in Tampa, with a median of 244 mg/L (table 6). Only seven constituents—bicarbonate, dissolved oxygen, chloride, sulfate, silica, nitrate, and ammonia—showed significant differences in concentration between the two cities (table 6). Of these, the median concentrations of bicarbonate, dissolved oxygen, sulfate, and nitrate were higher in samples from Ocala; whereas, median temperature and median concentrations of chloride, silica, and ammonia were higher in samples from Tampa (table 6).

The data used in this study are from background water-chemistry studies done by Katz (1992) for the Upper Floridan aquifer based on data obtained from the Florida Department of Environmental Protection Groundwater Quality Monitoring Network. Data from 302 wells in unconfined and semiconfined areas were used from Katz's data.

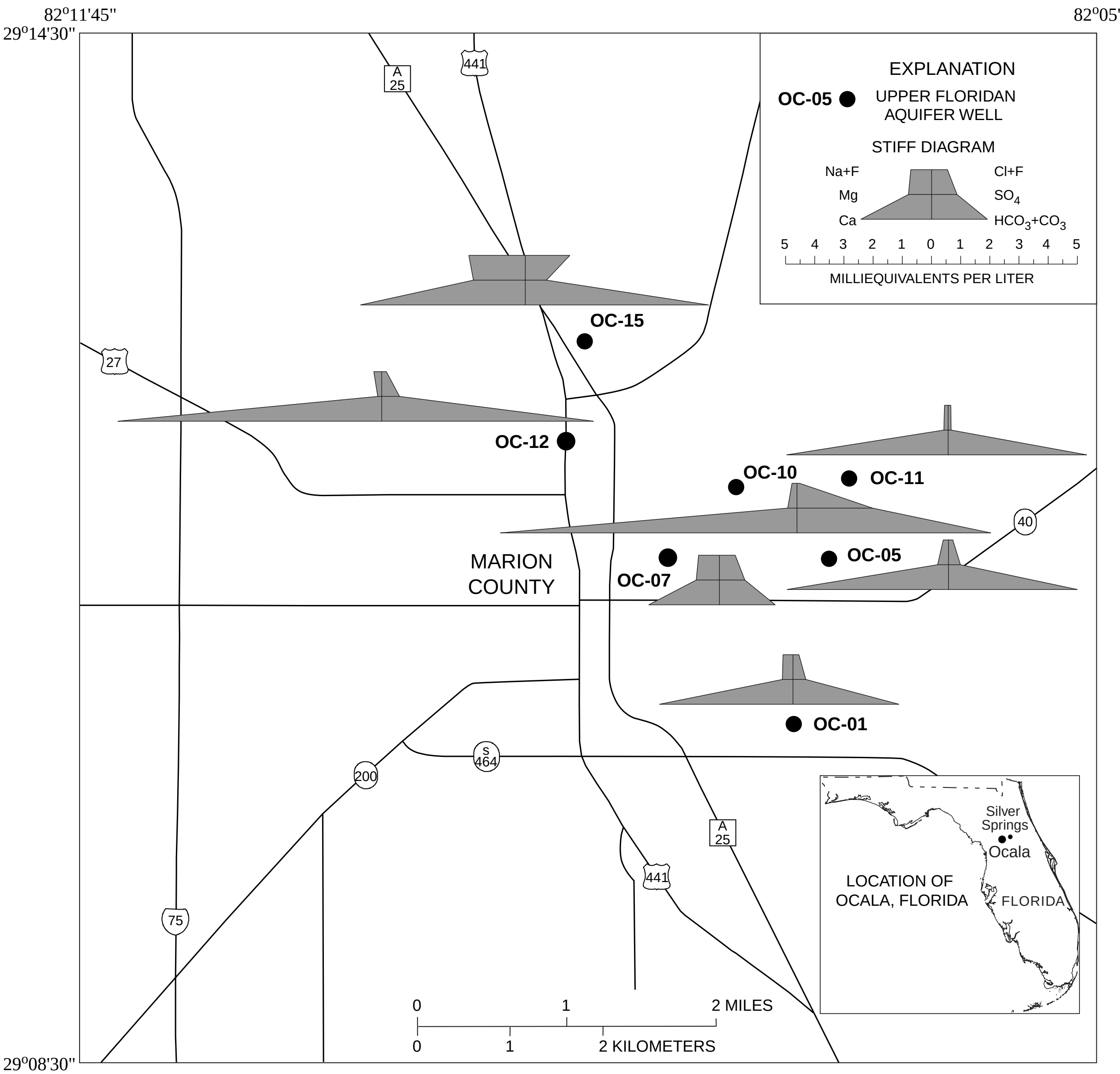

Figure 11. Major ion concentrations in water from wells in the Upper Floridan aquifer, Ocala, Florida, urban area.

Nitrate, ammonia, phosphorus, and orthophosphate concentrations were generally low in samples from the Upper Floridan aquifer and were consistently lower than in the surficial aquifer. Median concentrations in the Upper Floridan aquifer were less than 0.20 mg/L for each of these constituents, except for nitrate, in both cities. The highest concentrations of nitrate in the surficial aquifer were 12 and 9.2 mg/L in Ocala and Tampa, respectively (table 3); in the Upper Floridan aquifer, the highest concentrations of nitrate were only 1.2 and 0.74 mg/L in Ocala and Tampa, respectively (table 6). Median nitrate concentrations were 0.33 and 0.05 mg/L in samples from Ocala and Tampa, respectively, and 0.05 in background samples (table 6). Thus, surface activities contributing nitrate to ground water in the surficial aquifer do not appear to be affecting the Upper Floridan aquifer in these two areas, despite the unconfined conditions and the presence of drainage wells in the Ocala area.

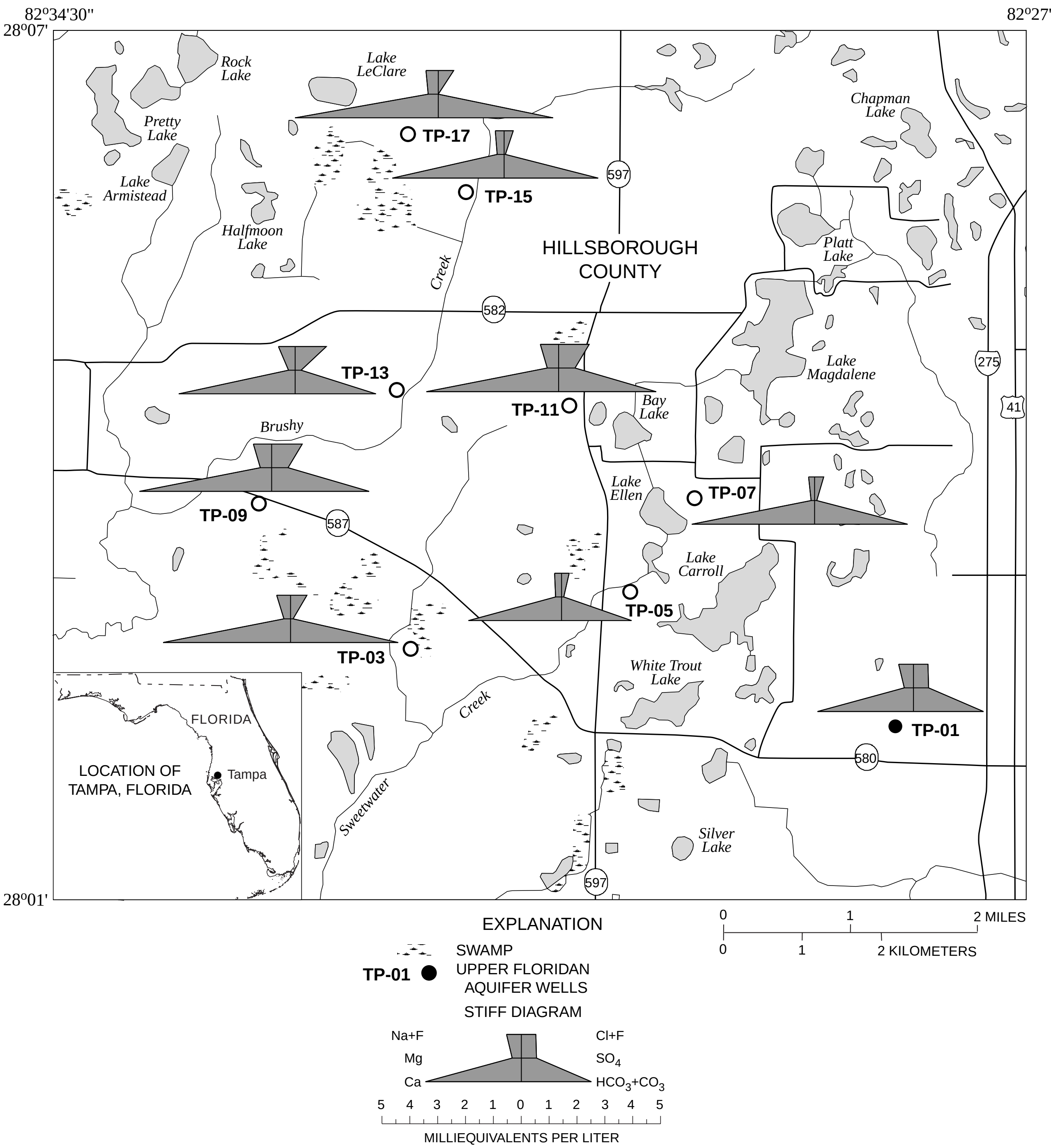

Figure 12. Major ion concentrations in water from wells in the Upper Floridan aquifer, Tampa, Florida, urban area.

Table 6. Summary of ground-water quality in the Upper Floridan aquifer in two urban areas, 1995

[Statewide data from Katz, U.S. Geological Survey, written commun., 1995; significance of p-value is less than 0.05; °C, degrees Celsius; µS/cm, microsiemens per centimeter; --, not determined; mg/L, milligrams per liter ; µg/L, micrograms per liter]

	Ocala, Florida Upper Floridan aquifer Number of samples = 7			Tampa, Florida Upper Floridan aquifer Number of samples = 9			Wil-coxon rank-sum test	Statewide--Background Unconfined and semiconfined Upper Floridan aquifer			
	Median	Minimum	Maximum	Median	Minimum	Maximum	p-value	Number samples	Median	Minimum	Maximum
Depth of well (ft)	**57**	40	75	**65**	45	250	0.43	302	**104**	8	250[a]
Temperature (°C)	**22.9**	20	24.5	**24.2**	23.9	25.0	0.01	236	**23.0**	20.0	28.0
pH (pH units)	**7.0**	6.0	7.2	**6.9**	6.7	7.5	0.43	287	**7.3**	4.9	11
Specific conductance (µS/cm)	**493**	335	845	**449**	323	553	0.17	--	--	--	--
Dissolved solids (mg/L)	**287**	210	551	**244**	187	362	0.19	244	**210**	4.0	10,500
Bicarbonate (mg/L)	**312**	126	477	**222**	165	287	0.04	302	**183**	9.7	549
Dissolved oxygen (mg/L)	**2.1**	.3	4.3	**.2**	.02	.4	<0.01	--	--	--	--
Calcium (mg/L)	**98**	43	180	**78**	59	100	0.09	302	**66**	2.3	300
Magnesium (mg/L)	**3.9**	1.4	19	**2.6**	1.4	4.4	0.31	302	**5.2**	.05	430
Sodium (mg/L)	**5.3**	1.6	39	**10.0**	4.2	13	0.40	302	**5.2**	.2	3,200
Potassium (mg/L)	**.90**	.1	1.5	**.50**	.3	1.4	0.42	302	**.5**	.04	130
Chloride (mg/L)	**4.80**	2.3	47	**17.0**	8.4	35	0.05	302	**8.3**	1.0	5,200
Sulfate (mg/L)	**26.0**	4.2	110	**3.6**	.1	25	0.01	300	**5.4**	.2	2,200
Dissolved organic carbon (mg/L)	**.50**	.3	2.8	**1.60**	.8	3.5	0.07	224	**3.7**[b]	.1[b]	66[b]
Iron (µg/L)	**5**	3	10,000	**470**	12	5,600	0.14	--	--	--	--
Manganese (µg/L)	**< 1**	< 1	83	**12.5**	4	84	0.13	--	--	--	--
Silica (mg/L)	**7.9**	5.3	18	**14**	9.0	19	0.04	45	**10**	2.1	22
Bromide (mg/L)	**.04**	.03	.26	**.06**	.03	.11	0.67	--	--	--	--
Fluoride (mg/L)	**.20**	<.10	.50	**<.10**	<.10	.20	0.10	--	--	--	--
Nitrate plus nitrite as N (mg/L)	**.33**	.05	1.2	**.05**	.05	.74	0.05	278	**.05**	<.01	15
Ammonia as N (mg/L)	**.02**	<.02	.13	**.10**	.09	.12	0.02	--	--	--	--
Phosphorus as P (mg/L)	**.03**	.01	1.2	**.13**	.01	.22	0.15	229	**.17**	<.01	2.8
Orthophosphate as P (mg/L)	**.04**	.01	1.2	**.07**	.01	.25	0.56	--	--	--	--
Radon (pCi/L)	**1,400**	320	4,000	**1,400**	720	3,900	0.15	9	**1,436**[c]	46[c]	2,640[c]
Aluminum (µg/L)	**3**	< 1	104	**3**	< 1	7	0.79	--	--	--	--
Antimony (µg/L)	**< 1**	< 1	< 1	**< 1**	< 1	< 1	--	--	--	--	--
Arsenic (µg/L)	**< 1**	< 1	2	**< 1**	< 1	2	--	--	--	--	--
Barium (µg/L)	**7**	2	22	**22**	16	86	0.02	--	--	--	--
Beryllium (µg/L)	**< 1**	< 1	< 1	**< 1**	< 1	< 1	--	--	--	--	--
Cadmium (µg/L)	**< 1**	< 1	< 1	**< 1**	< 1	< 1	--	--	--	--	--
Chromium (µg/L)	**4**	4	11	**2**	1	3	0.01	--	--	--	--
Cobalt (µg/L)	**< 1**	< 1	2	**< 1**	< 1	< 1	--	--	--	--	--
Copper (µg/L)	**< 1**	< 1	3	**< 1**	< 1	< 1	--	--	--	--	--
Lead (µg/L)	**< 1**	< 1	< 1	**< 1**	< 1	< 1	0.99	--	--	--	--
Molybdenum (µg/L)	**< 1**	< 1	1	**< 1**	< 1	7	--	--	--	--	--
Nickel (µg/L)	**10**	7	23	**5**	2	9	<0.01	--	--	--	--
Selenium (µg/L)	**< 1**	< 1	1	**< 1**	< 1	1	--	--	--	--	--
Silver (µg/L)	**< 1**	< 1	< 1	**--**	--	--	--	--	--	--	--
Uranium (µg/L)	**< 1**	< 1	2	**< 1**	< 1	3	--	--	--	--	--
Zinc (µg/L)	**< 1**	< 1	14	**< 1**	< 1	< 1	--	--	--	--	--

[a] Samples from wells deeper than 250 ft were not included.

[b] Values are total organic carbon.

[c] Radon values are from same Tampa wells (Paul Hansard, Florida Department of Environmental Protection, written commun., 1995).

The samples collected from Ocala and Tampa had higher median concentrations than the background samples for several constituents, including dissolved solids, bicarbonate, and calcium (table 4). This is probably because the samples collected in Ocala and Tampa reflect local hydrogeology, whereas the statewide background data represent a wider range of hydrogeologic conditions. The two urban areas contain porous or sandy limestone that may be more readily dissolved than the limestones found in other unconfined and semiconfined areas in Florida. Major ion water type was calcium-bicarbonate for 73 percent of the background samples compared to 100 percent of the urban samples.

Uranium concentrations were extremely low, and radon values were high in the samples from the Upper Floridan aquifer. The highest uranium concentration was 3 μg/L, and most samples (11 of 15) had uranium concentrations less than 1 μg/L (table 6). Median radon values in the Upper Floridan aquifer were 1,400 pCi/L in both cities (table 6). Radon values were less variable in the Upper Floridan aquifer than in the surficial aquifer.

Analyses of trace-element concentrations in the Upper Floridan aquifer indicated that most concentrations were less than analytical detection limits (1.0 μg/L, in most cases) (table 6). Only six trace elements—iron, manganese, aluminum, barium, chromium, and nickel—had median concentrations greater than the analytical detection limit, although the median concentration of manganese was below the detection limit in Ocala. Concentrations of barium, chromium, and nickel were significantly different in Ocala and Tampa, with higher concentrations of barium and iron in Tampa and higher concentrations of chromium and nickel in Ocala (table 6).

Organic Compounds in the Upper Floridan Aquifer

Median DOC concentrations in the Upper Floridan aquifer were 0.5 mg/L in Ocala and 1.6 mg/L in Tampa (table 6). The higher DOC concentrations in the Upper Floridan aquifer at Tampa are probably caused by surface-water recharge, which also causes increased DOC concentrations in the surficial aquifer at Tampa.

Five pesticides—atrazine, desethylatrazine, cyanazine, prometon, and simazine—and four VOC's—chloroform, tetrachloroethylene (PCE), methyl-tert-butyl-ether (MTBE), and trichloroethylene (TCE)—were detected in the Upper Floridan groundwater samples (table 5). Pesticides or VOC's were detected in six of seven samples in Ocala and in three of nine samples in Tampa.

The most commonly detected pesticides in the Upper Floridan aquifer were desethylatrazine in four wells in Ocala and in one well in Tampa, and prometon in four wells in Ocala and in one well in Tampa. Prometon and desethylatrazine were detected together in wells OC-01, OC-05, OC-11, and OC-13 (fig. 11). Most of the pesticides detected in the Upper Floridan were at concentrations near the detection limit, except for one prometon detection of 1.8 μg/L in well OC-01 (table 5).

Volatile organic compounds (VOC's) were detected in only three wells in Ocala and in one well in Tampa. All VOC detections in the Upper Floridan aquifer were extremely low, with a maximum of 0.5 μg/L. One well in Tampa (TP-01) contained three different VOC's—PCE, TCE, and cis-1,2-dichloroethene. MTBE was detected in well OC-01, but the concentration was only 0.5 μg/L (table 5). There is currently no MCL established for MTBE.

SUMMARY AND CONCLUSIONS

The Georgia-Florida Coastal Plain and the Albemarle-Pamlico Basin study units are 2 of 20 U.S. Geological Survey NAWQA Program study units chosen in 1991 to assess the status and trends of the quality of the Nation's ground- and surface-water resources, and to associate the status and trends with an understanding of the natural and human factors that affect water quality. The Georgia-Florida Coastal Plain NAWQA study unit covers nearly 62,000 mi^2. The majority of the land is forested and agricultural, although several major cities are located in the study unit, including Jacksonville, Orlando, and Tampa, Fla., and parts of Atlanta, Ga. The Albemarle-Pamlico Basin NAWQA study unit covers approximately 28,000 mi^2 in North Carolina and southern Virginia. The majority of the study unit is covered by forested and agricultural land, and includes three major urban areas—Roanoke, Va., Raleigh, N.C., and Virginia Beach, Va.

Ground-water samples were collected from wells in the urban areas of Ocala and Tampa, Fla., in January and February 1995 and in Virginia Beach, Va., in July and August 1995. Only available existing wells were used in this study. These wells are located in relatively unimpacted areas of the city, such as school grounds and State property. Also, some of the wells sampled are screened substantially below the water table; however, effects from land use would most likely be detected at or below the water table. The data can be used as preliminary or background water-quality data for medium-sized urban areas in the Coastal Plain of the eastern United States.

The aquifers sampled include the surficial aquifers in each of the three urban areas, and the Upper Floridan aquifer in Ocala and Tampa. In the Ocala area, the surficial aquifer is about 5 to 50 ft thick and consists of non-marine, clayey sand, marine and lacustrine sand, shell marl, sandy clay, and some phosphatic limestone. In the Tampa area, the surficial aquifer consists of similar material but is less than 20 to more than 40 ft thick. At Virginia Beach, the surficial aquifer is also known as the Columbia aquifer and is characterized by fining-upwards sequences, consisting of a gravelly lag that grades to sands, fine silts, and clays. The surficial aquifer is about 60 ft thick at Virginia Beach.

The Ocala Limestone is the uppermost unit of the Upper Floridan aquifer in the Ocala area. This unit is a marine limestone that is granular, porous, highly fossiliferous, and cherty in places. The Tampa Limestone is the uppermost unit of the Upper Floridan aquifer in the Tampa area and consists of white, cream and gray, and hard to soft, sandy limestone that contains many fossils. In the surficial aquifer in Ocala, the major ion water type was calcium bicarbonate in five samples and mixed (no dominant ions) in three samples, with dissolved-solids concentrations ranging from 78 to 463 mg/L. In Tampa, the water type was calcium bicarbonate in one sample and mixed in seven samples, with dissolved-solids concentrations ranging from 38 to 397 mg/L. In Virginia Beach, water types were primarily calcium and sodium bicarbonate water, with dissolved-solids concentrations ranging from 89 to 740 mg/L. The water types and dissolved-solids concentrations reflect the presence of carbonates in the surficial aquifer materials in the Ocala area and carbonates in subcropping materials in the Virginia Beach area.

Concentrations of nitrate nitrogen were highest in the surficial aquifer in Ocala, and one sample exceeded 10 mg/L, the U.S. Environmental Protection Agency maximum contaminant level for drinking water. Median nitrate concentrations were 1.2 mg/L in Ocala and only 0.06 and 0.05 mg/L in Tampa and Virginia Beach, respectively. In Florida, some background water-quality data were available for comparison. The median nitrate concentration in Ocala was much higher than the median nitrate concentration of 0.05 mg/L in the background data.

The major ion water type was calcium bicarbonate for all 16 samples from the Upper Floridan aquifer in both Florida cities. Dissolved-solids concentrations ranged from 210 to 551 mg/L in Ocala, with a median of 287 mg/L, and ranged from 187 to 362 mg/L in Tampa, with a median of 244 mg/L. Median nitrate concentrations were 0.33 and 0.05 mg/L in samples from Ocala and Tampa, respectively, and 0.05 mg/L in background samples. Although the nitrate concentrations are above background concentrations, they are significantly below the drinking-water standards.

Of the 47 pesticides and 60 volatile organic compounds analyzed, only five pesticides and five volatile organic compounds were detected. Organic compounds were detected in 12 of 15 samples in the Ocala area compared to only 4 of 15 samples in Virginia Beach and only 4 of 17 samples in Tampa. The most commonly detected pesticide was prometon, a broad-scale herbicide, detected in samples from eight wells in Ocala (at concentrations ranging from 0.009 to 1l8 μg/L), three wells in Virginia Beach (at concentrations ranging from 0.19 to 10 μg/L), and from one well in Tampa (0.01 μg/L). The most commonly detected volatile organic compound was chloroform which was detected four times at concentrations ranging from 0.3 to 2.2 μg/L in Ocala and Tampa. Seven volatile organic compounds were detected in one sample in Virginia Beach; most were compounds associated with petroleum and coal tar.

Because well coverage was limited and the wells sampled were generally located in relatively protected urban areas, the sampling results do not specifically represent residential, commercial, and industrial land uses which would be likely to cause ground-water contamination. These data represent a first step in the evaluation of impacts from urban land uses and, therefore, provide valuable baseline ground-water quality data for surficial aquifers. The occurrence of organic compounds in the shallow wells could indicate contamination of shallow ground water which could move downward to aquifers that are used for water supply. If ground water is to be used in the future for water-supply purposes in these urban areas, an evaluation of surficial ground-water quality, particularly in the proximity of potential well fields, could be used to effectively evaluate future potential water-quality problems.

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