Water Quality of Surficial Aquifers in the Georgia–Florida Coastal Plain

By Christy A. Crandall and Marian P. Berndt

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CONVERSION FACTORS, VERTICAL DATUM, ABBREVIATIONS, AND ACRONYMS

Multiply	By	To obtain
inch (in.)	2.54	centimeter
inch per year (in/yr)	2.54	centimeter per year
gallon per minute (gal/min)	0.06309	liter per second
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
million gallons per day (Mgal/d)	0.04381	cubic meter per second
foot squared per day (ft^2/d)	0.09290	meter squared per day

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = 5/9 \times (°F - 32)$$
$$°F = (1.8\ °C) + 32$$

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviations

mg/L = milligrams per liter
µg/L = micrograms per liter
pCi/L = picocuries per liter
< = less than
> = greater than

Acronyms

FGWQMNP = Florida Department of Environmental Protection’s Ground Water Quality Monitoring Network Program
GAFL = Georgia–Florida Coastal Plain
MCL = maximum contaminant level
NAWQA = National Water Quality Assessment
PVC = polyvinal chloride
TU = tritium units
VOC = volatile organic compounds
USEPA = U.S. Environmental Protection Agency
USGS = U.S. Geological Survey

FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for a specific contamination problem; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 60 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study area and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Chief Hydrologist

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By Christy A. Crandall *and* Marian P. Berndt

Abstract

The National Water Quality Assessment Program of the U.S. Geological Survey established the Georgia–Florida Coastal Plain study unit in 1991. The ground-water study-unit survey was conducted in 1993 to provide a broad overview of water quality in surficial aquifers. Three land resource provinces were included in the Georgia–Florida Coastal Plain study-unit survey: the Central Florida Ridge, the Coastal Flatwoods, and the Southern Coastal Plain. The U.S. Geological Survey sampled 37 wells in surficial aquifers, 18 in the Coastal Flatwoods and 19 in the Southern Coastal Plain. The Florida Department of Environmental Protection sampled 27 wells tapping surficial aquifers in the Central Florida Ridge as part of the background ground-water quality monitoring network from 1985 through 1989. The data were used to characterize water quality in surficial aquifers of the Central Florida Ridge.

Results of the study-unit survey indicated that dissolved solids concentrations in ground water were mostly less than 100 mg/L (milligrams per liter). Higher medians of pH, specific conductance, and concentrations of calcium, bicarbonate, and dissolved solids were measured in samples from the Central Florida Ridge compared to the Southern Coastal Plain and Coastal Flatwoods, probably because of a greater percentage of carbonate minerals in aquifer materials. The U.S. Environmental Protection Agency secondary maximum contaminant level for iron of 300 μg/L (micrograms per liter) in drinking water was exceeded in 15 of 45 samples.

Concentrations of nitrate as nitrogen were less than 3.0 mg/L in most samples (74 percent), indicating little or no influence from human activity. Only five samples (9 percent) had concentrations above 10 mg/L, the U.S. Environmental Protection Agency maximum contaminant level for nitrate concentration in drinking water. Significantly lower median concentrations of nitrate were measured in samples from polyvinyl chloride monitoring wells with diameters less than 6 inches than in large diameter, uncased, or iron-cased wells. The median nitrate concentration was 0.05 mg/L in water from monitoring wells, 1.0 mg/L in samples from iron cased wells, and 2.0 mg/L in samples from uncased wells.

Concentrations of volatile organic compounds were mostly less than the detection levels and exceeded 1 μg/L in only four samples. Compounds detected at concentrations greater than 1 μg/L were: tetrachloroethane (8.77 μg/L), toluene (23 μg/L) and chloromethane (21 μg/L). Atrazine, desethyl-atrazine, and metolachlor were the only pesticides detected; concentrations were less than 0.02 μg/L, except for metolachlor (2.5 μg/L). Detection of organic compounds in surficial aquifers may be associated with specific activities or sources near the well.

Concentrations of radon exceeded the U.S. Environmental Protection Agency proposed maximum contaminant level of 300 picocuries per liter (pCi/L) in 33 samples from wells on the Coastal Flatwoods and the Southern Coastal Plain. Concentrations as high as 13,000 pCi/L were detected in northern Florida. Although uranium

concentrations were less than 1 µg/L in all but one sample (1.3 µg/L) from the Southern Coastal Plain, elevated radon concentrations indicate that uranium is present in aquifer material. Uranium is most likely sorbed to iron oxides and clays in subsurface materials. Tritium concentrations indicated that ground water was recharged by precipitation during the past 40 years. Higher concentrations of tritium in ground water were found in the northern part of the study area and may be related to Savannah River Nuclear Facility.

INTRODUCTION

The U.S. Geological Survey implemented the National Water Quality Assessment (NAWQA) program of the Georgia–Florida Coastal Plain (GAFL) study unit in 1991. The physical setting of this Study Unit is described in “Environmental Setting and Factors that Affect Water Quality in the Georgia–Florida Coastal Plain Study Unit”, by Berndt and others (1996). The objectives of the NAWQA ground-water studies are to: determine which ground-water-quality constituents are of significant concern to each study unit; determine the spatial distribution of a wide range of physical and chemical characteristics of ground water in surficial aquifers recharging major water supply aquifers, and evaluate variations in ground-water quality, both areally and with depth; and determine and compare the concentration and distribution of water-quality constituents in surficial aquifers underlying areas of different land uses (Gilliom and others, 1995). Ground-water quality is being assessed by the study-unit survey, the land-use study, and the flow-path study. The study-unit survey is designed to broadly characterize ground-water quality across the study unit. The land-use and flow-path studies are at the local scale, to increase the understanding of casual relations and processes affecting ground-water quality (Gilliom and others, 1995).

The GAFL NAWQA study-unit survey began in July 1993. The large scope of the study area required that the study-unit survey rely on existing wells and, wherever possible, existing data collected by other agencies and programs. This allowed the GAFL NAWQA to focus on sampling surficial aquifers in Georgia, where very little water-quality data are available. Surficial aquifers were studied rather than the deeper aquifers, because, as the uppermost water-bearing zone, they are generally more susceptible to contamination than deeper aquifers and they provide recharge to deeper aquifers that are used for water supply. For purposes of this study, surficial aquifers are defined as the first water-bearing zone present in the mostly unconsolidated sand and sandy clays <100 feet (ft) below land surface.

Purpose and Scope

This report describes water-quality of surficial aquifers in the GAFL NAWQA study unit and examines water quality in relation to land use and well construction characteristics. The GAFL NAWQA study-unit survey began in 1993. Surficial aquifers, rather than deeper aquifers used for public, domestic and irrigation water supply, were selected for research because surficial aquifers, being the uppermost water-bearing zones, are generally more susceptible to contamination than deeper aquifers.

To characterize water quality within the study area, the area was divided into three subunits (hereafter referred to as land resource provinces) based on general soil types: the Coastal Flatwoods, the Southern Coastal Plain, and the Central Florida Ridge (fig. 1). A random site-selection program (Scott, 1990) was used and field reconnaissance was performed to locate existing wells tapping surficial aquifers within each land resource province. Thirty-seven mostly domestic wells were selected and sampled by the U. S. Geological Survey (USGS) from July through October, 1993 (19 wells in the Southern Coastal Plain and 18 wells in the Coastal Flatwoods).

Water-quality data from 27 surficial aquifer wells were used from the Florida Department of Environmental Protection’s Ground Water Quality Monitoring Network Program (FGWQMNP). These data, from samples collected from 1985 through 1989, were used to characterize surficial water quality of the Central Florida Ridge.

Constituents analyzed in samples collected by the USGS and the FGWQMNP included: field parameters, major ions, nitrogen and phosphorus species, and selected pesticides and volatile organic compounds (VOC). Uranium, radon, and tritium were analyzed in samples collected by the USGS. Ground water was age dated using tritium.

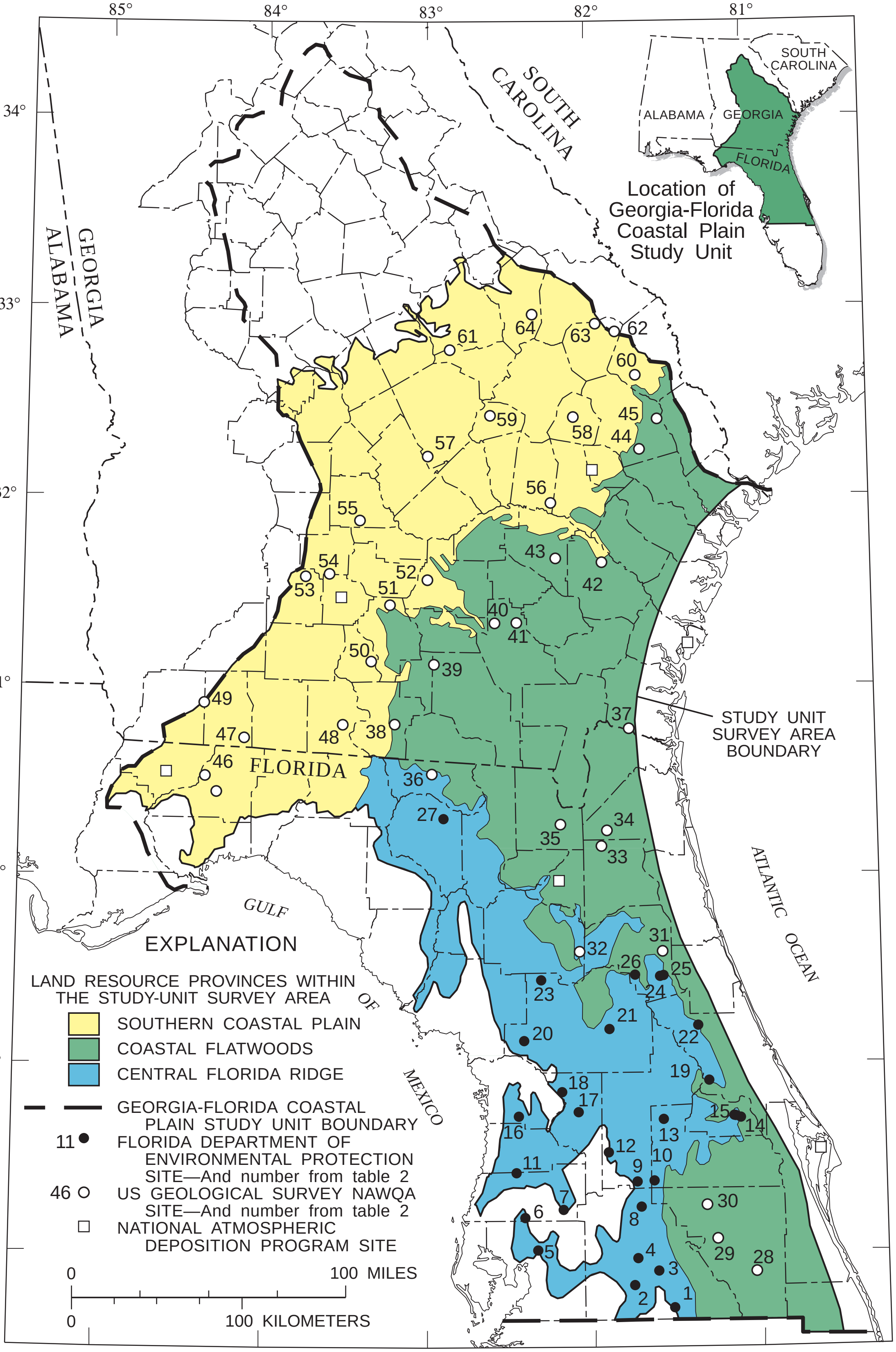


Figure 1. Georgia–Florida study unit, land resources provinces, study-unit survey area, location of USGS sampled wells, FGWQMNP wells and rainfall collection sites.

Acknowledgments

The authors would like to thank all the residents in south Georgia and north Florida, the Florida Department of Environmental Protection Ground Water Quality Monitoring Network Program, including Rick Copeland, Dave Ouellette, Cindy Cosper, Paul Hansard, and Jay Silvanima; the St. Johns River Water Management District, including Don Boniol and Jody Lee; the South Florida Water Management District, including Jeff Herr, and the Suwannee River Water Management District, including Ron Ceryak, for allowing us to sample their wells and use their data. We would also like to thank Mr. Harry Blanchard, a USGS retiree, who located surficial wells in south Georgia.

Description of the Study Area

The GAFL study unit is located along the southeastern coast of the United States and encompasses about 62,000 mi^2 (square miles). The entire GAFL study unit extends south and east from Atlanta and Athens, Ga., to include most of coastal Georgia, parts of panhandle and peninsular Florida, and extends south to include Hillsborough, Polk, Osceola, and Indian Rivers Counties in Florida (fig. 2). The GAFL ground-water study-unit survey study area (hereafter known as the study area) encompasses about 41, 200 mi^2. Areas within about 20 mi (miles) of the Atlantic Coast and up to 60 mi from the Gulf of Mexico were excluded from the study area because they are generally ground-water discharge areas of the Upper Floridan aquifer (Miller, 1986). The northern boundary of the study area coincides with the northernmost extent of the Upper Floridan aquifer.

Climate

The climate of the study area ranges from subtropical in the south and along the Gulf-Coast to temperate in the north and is primarily influenced by the Gulf of Mexico or the Atlantic Ocean. Mean annual temperature over the study area ranges from 61.3 °F in Atlanta, Ga., to 72.4 °F in Tampa, Fla. (Owenby and Ezell, 1992a,b). The lowest temperature normally occurs during January and the highest in July in Georgia (Hodler and Schetter, 1986). Principle sources of moisture to the study area are delivered from subtropical air masses originating in the Gulf of Mexico or the Atlantic Ocean (Bridges and Franklin, 1991). Precipitation amounts peak during the summer due to convective storms. A secondary peak occurs in late winter in northern Florida and southern Georgia due to frontal system movement (Golden and Hess, 1991). Average annual rainfall varies from about 48 to 64 in/yr (inches per year) across the study area (Bush and Johnston, 1988). Evapotranspiration ranges from about 30 to 40 in/yr in Georgia and increases from the north to the south over the study area as average temperature increases (Carter and Hopkins, 1986: Bush and Johnston, 1988).

Hydrogeology

Surficial aquifers are present throughout most of the study area (Miller, 1986) and defined as “the permeable hydrologic unit contiguous with the land surface that is principally composed of unconsolidated to poorly indurated, siliciclastic deposits” (Southeastern Geological Society, 1986). Deposits comprising surficial aquifers of the Coastal Plain of the southeastern United States were formed by the progression and recession of sea level, and entirely composed of marine and fluvial sediments deposited during the evolution of the Atlantic and Gulf coasts. Surficial aquifers in the study area generally consist of unconsolidated deposits of sand, silt, clay, and shell ranging from late Miocene to Holocene in age and are often glauconitic, carbonaceous, or locally phosphatic (Bush and Johnston, 1988; Gundersen and Peake, 1992). Some minor limestone beds as well as iron oxides may also occur in the iron rich sandy clay soils present in some areas (Bush and Johnston, 1988).

The thickness of the surficial aquifers vary over the study area, but are generally <100 ft. Thicknesses of 100 to 200 ft are common in Indian River County in the southeastern part of the study area (Schiner and others, 1988). A thickness of 325 ft was recorded for a surficial well in Coffee County, Ga. (Miller, 1986). The lower limit of the surficial aquifer coincides with the top of a laterally and vertically extensive bed of much lower permeability (Scott and others, 1991).

Water in surficial aquifers is usually unconfined, although semiconfined conditions may exist locally where clay beds are present. In general, surficial aquifers include zones of confined conditions where clay lenses are present and where the aquifers are thick (Clarke and others, 1990). Water enters surficial aquifers as precipitation and reverts to the atmosphere by evapotranspiration due to the proximity of the water table to the land surface (Miller, 1986). The remaining water either moves laterally and discharges to streams

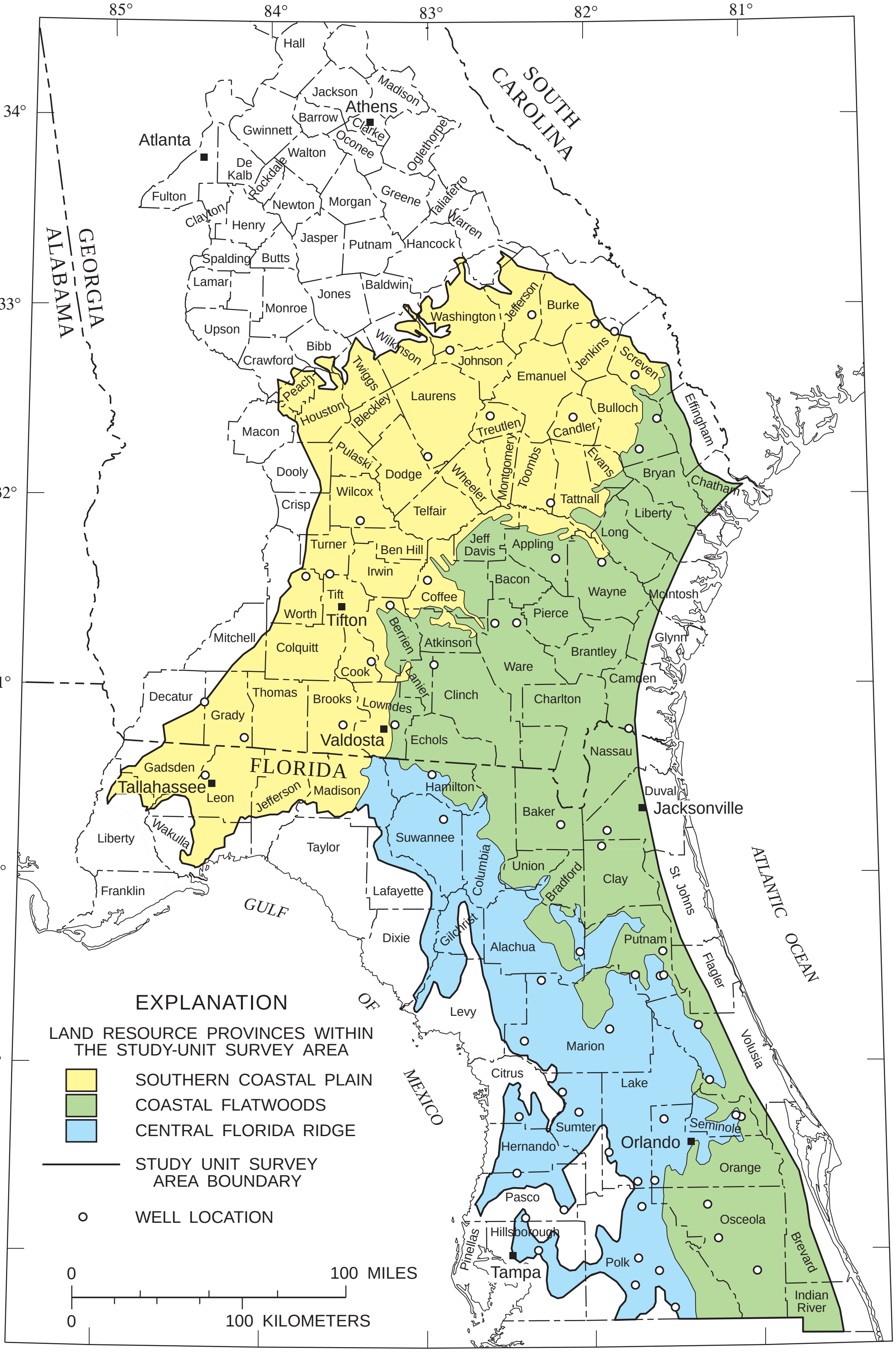


Figure 2. The Georgia Florida Coastal Plain ground-water study-unit, survey study area, and major cities and counties.

or percolates downward to recharge the Upper Floridan aquifer (Miller, 1986). Alternatively, in discharge areas of the Floridan aquifer system, water from the Floridan aquifer system may move upward into surficial aquifers. As stated previously, discharge areas of the Floridan aquifer system are not included in this report.

Generally, the water-table of a surficial aquifer is a subdued replica of the land surface topography, having steeper gradients between ridges and nearby streams and gentle gradients in broad interstream areas. Water levels fluctuate seasonally and respond rapidly to rainfall (Miller, 1986). In coastal areas, water moves toward the nearest adjacent surface-water body; however, locally the water-table surface may be very irregular with the direction of ground-water flow changing markedly within a short distance, especially in karst regions.

Transmissivities of surficial aquifers are extremely variable. Reported values range from 1,000 to 10,000 ft^2/d (feet squared per day) (Berndt and Katz, 1992). Well yields range from <1 gal/min (gallon per minute) in parts of Georgia, to 450 gal/min in St. Johns County, Fla., to 1,200 gal/min in Indian River County, Fla., (Schiner and others, 1988).

Total freshwater use within the study unit is approximately 5,000 Mgal/d (million gallons per day), with 2,900 Mgal/d coming from ground water. The primary source of domestic water supply in the study area is the Upper Floridan aquifer; 91 percent of domestic water supplies from ground water came from the Upper Floridan aquifer in 1990. Surficial aquifers supplied about 3 percent of the ground water to domestic wells during 1990 (Marella, 1995) and are important sources of water supply when depths to the underlying Upper Floridan aquifer make drilling costs prohibitive, or when the Upper Floridan aquifer contains nonpotable water. Areas dependent on a surficial aquifer for limited municipal or commercial uses include the coastal counties of St. Johns, Flagler, Brevard, and Indian River in the Florida part of the study area. Hand-dug wells of 50 ft or less are common in southeastern Georgia. Historically, surficial aquifers in Georgia were used extensively for domestic supply but are now mostly limited to providing water for livestock.

Land Resource Provinces

Land resource areas of Florida (Caldwell and Johnson, 1982) and soil provinces of Georgia (Perkins and Shaffer, 1977) based primarily on general soil maps of Georgia and Florida were combined and used to subdivide the study area into three land resource provinces (Berndt and others, 1996). They are: the Coastal Flatwoods, the Southern Coastal Plain, and the Central Florida Ridge (fig. 1).

The Coastal Flatwoods includes the coastlines of Georgia and Florida within the study unit and varies inland from 5 to 100 mi. This land resource province consists of nearly level plains, marshes, and barrier islands, along with low terraces and is generally a ground-water discharge zone for the Upper Floridan aquifer near the coasts. The dominant soil types are spodosols, and ultisols that are frequently poorly drained (Soil Conservation Service, 1975). The altitude ranges from sea level to about 300 ft (U.S Geological Survey, 1979a; Perkins and Shaffer, 1977). Rivers of this province have high dissolved organic matter (black water), low gradients, wide flood plains and frequently originate in and flow through extensive wetlands.

The Southern Coastal Plain is situated in central and south Georgia and the panhandle of Florida, and ranges from approximately 50 to 100 mi wide. This land resource province consists of broad interstream areas with shallow to deeply incised valleys. The dominant soils are ultisols (Soil Conservation Service, 1975) underlain by marine or fluvial sands, loam, or clays (Perkins and Shaffer, 1977; Caldwell and Johnson, 1982). The altitude ranges from 200 to 500 ft (U.S. Geological Survey, 1978).

The Central Florida Ridge comprises much of the central uplands of Florida. This province is characterized by hills, ridges, terraces, and many lakes, and is marked by karst topography--numerous sinks, sinkhole lakes, sinking streams, and springs (Caldwell and Johnson, 1982). Parts of the Central Florida Ridge have very few streams, because runoff directly recharges ground water due to the highly permeable soils. Dominant soil types are entisols and spodosols (Soil Conservation Service, 1975) that are sandy, and often excessively drained in the southern part of the region. The altitude ranges from 40 to 250 ft (U.S. Geological Survey, 1979b).

Land Use

Land use upgradient of wells can affect ground-water quality especially in unconfined and semiconfined aquifers. Data from the USGS classification system for land use and land cover, hereafter referred to as “USGS land use” (Anderson and others,1976; Mitchell and others, 1977), were used with some modifications to determine the locations of various land uses and the general proportions of land use and land cover in the study area (Hitt, 1994). General land use and land cover in the study area include forest (47 percent), agriculture (29 percent), wetland (14 percent), urban (5 percent), rangeland and "other" (3 percent) (Anderson and others, 1976) (table 1). The category "other" includes mines, quarries, and beaches. The geographic extent of the urban, forest, and agricultural land use are shown in figure 3. The percent of land in each major land use category is compared by land resource province and by land use near the well identified at the time of sampling (table 1). Land use near the well was determined at the time of sampling by noting predominant land use within 100 ft and a 0.25 mi radius of the well.

Observed land use near the sampled wells differed somewhat from the percent of land use in each land use category based on the USGS land use. This is because the study was restricted to existing wells and the sample size was relatively small. For example, 37 percent of the wells in the Central Florida Ridge were located in urban areas, whereas, according to USGS land use, only 11 percent of the area is urban in that land resource province (table 1). The percentage of wells located in forested areas strongly correlated with the percentage of land covered by forests according to USGS land use. Not unexpectedly, very few existing wells were located in wetlands, rangeland, or "other" areas.

METHODS

Existing wells were selected for sampling by using a stratified aerially weighted random statistical method in the Southern Coastal Plain and Coastal Flatwoods. Wells were sampled by USGS personnel using NAWQA sampling protocols. Additionally, data from 27 FDEP FGWQMNP monitoring wells were used to assess the water quality of surficial aquifers in the Central Florida Ridge. Non-parametric statistical analyses were used to compare water quality among land resource provinces. tritium was used to estimate the age of water.

Well Site Selection

Ground-water sampling sites were chosen in the Southern Coastal Plain and Coastal Flatwoods land resource provinces of Georgia by using a stratified aerially weighted random statistical method (Scott, 1990). Potential sampling sites were located in the Southern Coastal Plain and Coastal Flatwoods land resource provinces by dividing each land resource province into equal area cells. A target well site and two alternate well sites were identified within each cell. Existing domestic surficial wells located near the target sites were identified by USGS personnel. Ideally, a candidate well would be located within a 2 mi radius of the target site; otherwise, the search radius was extended to 3 mi. If no candidate wells were located within 3 mi of the target site, then existing surficial wells near the first alternate sites were located. If no candidate wells were located within 3 mi of the first alternate site, then existing wells were located near the second alternate site. Approximately 77 candidate well sites were located throughout Georgia by the USGS and 27 wells were sampled.

Ground-water sampling sites were also chosen in the Southern Coastal Plain and Coastal Flatwoods land resource provinces of Florida by using the stratified aerially weighted random statistical method. Within each equal area cell, the target location was identified on the map and then an existing monitoring well, tapping surficial aquifers and located near the target site, was selected from the wells included as part of the FGWQMNP (fig. 1) (Maddox and others, 1992). In all, 10 FGWQMNP wells in the Coastal Flatwoods and the Southern Coastal Plain were sampled by the USGS.

Wells completed in the surficial aquifer were selected for inclusion into this study based on several factors including: depth of well, diameter of well, screened interval, pump type, and sampling point location in relation to holding tank (Gilliom and others, 1995). Well depth was not to exceed 100 ft below land surface (the depth of the deepest well). The preferred diameter was 2 to 4 in. (inches), but the actual diameters ranged from 2 to 48 in. In addition, wells with jet pumps or wells that could not be sampled before the water entered a holding tank were not sampled. Most of the sampled wells in Georgia were uncased or constructed of steel, concrete, or brick, whereas wells sampled in Florida were predominantly monitoring wells constructed of polyvinyl chloride (PVC). Characteristics of the sampled wells are listed in table 2.

The data used in this report to describe water quality in surficial aquifers of the Central Florida Ridge consist of information collected and compiled as part of the FGWQMNP, a statewide program designed to study the hydrogeology and water chemistry of the aquifer systems of Florida. Wells, selected for the

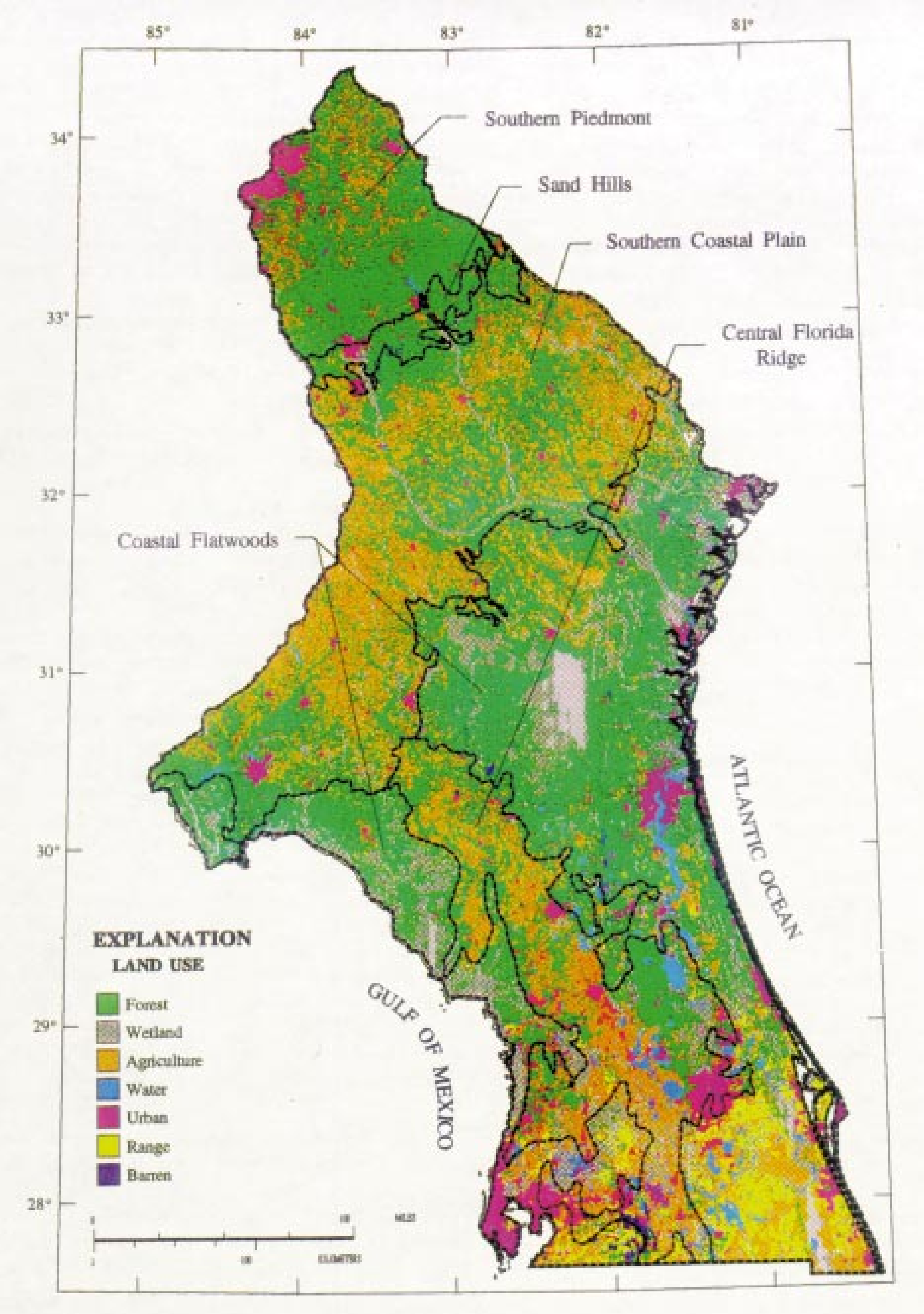


Figure 3. Land use in the Georgia–Florida Coastal Plain, 1972-1976.

Table 1. USGS percent land-use/land-cover (1972-76) of GAFL ground-water study area and principal land-use around each well in the study-unit survey by land resource province (1993)

[--, no wells in category; ( ), number of well; USGS land use data collected 1972-76; land use near well identified at time of sampling; From Anderson and others (1976); Mitchell and others (1977)]

	Land-use/Land-cover classifications					
	Forest	Wetland	Agriculture	Urban	Rangeland	Other
Percent of study area (USGS)	46.5	13.8	29.4	4.9	2.6	2.8
Central Florida Ridge						
Percent of area (USGS)	35	11	35	11	2	6
Percent and (number) of wells sampled (1985-1989)	30(8)	7(2)	7(2)	37(10)	12(3)	7(2)
Coastal Flatwoods						
Percent of area (USGS)	51	23	14	4	6	2
Percent and (number) of wells sampled (1993)	44(8)	--	39(7)	--	17(3)	--
Southern Coastal Plain						
Percent of area (USGS)	49	7	40	2	1	1
Percent and (number) of well sampled (1993)	47(9)	--	53(10)	--	--	--

Table 2. Well number, casing material and diameter, well depth, land use, and land resource province of wells in the study-unit survey

[Florida Ground Water Quality Monitoring Network Program monitoring wells in the Central Florida Ridge, 1-27; Florida Ground Water Quality Monitoring Network Program monitoring wells in the Coastal Flatwoods, 28-36; Florida Ground Water Quality Monitoring Network Program monitoring wells in the Southern Coastal Plain, 46; U.S. Geological Survey sampled domestic wells in the Coastal Flatwoods and Southern Coastal Plain, 37-45 and 47-64; PVC, polyvinyl chloride; --, data not available]

Well number (fig. 1)	Well ID number	Casing material	Casing diameter (inches)	Well depth (feet)	Land use near well
Central Florida Ridge					
01	274225081315201	Black Steel	--	62.0	Agriculture
02	274940081455901	PVC	--	50.0	Barren
03	275411081372003	PVC	--	40.0	Urban
04	275815081444201	Galvanized Steel	--	26.0	Urban
05	280058082202202	PVC	--	10.0	Wetland
06	281120082245501	PVC	--	19.0	Urban
07	281350082111001	PVC	--	35.0	Urban
08	281440081431702	Steel	--	18.0	Wetland
09	282241081443902	PVC	2	35.0	Barren
10	282257081383201	Steel	20	83.0	Urban
11	282540082275702	Galvanized Steel	--	10.0	Urban
12	283204081544902	Iron	6	30.0	Agriculture
13	284230081345302	PVC	2	40.0	Forest
14	284247081070802	PVC	2	50.0	Agriculture
15	284320081090001	PVC	2	37.0	Forest
16	284339082270402	Steel	--	41.0	Forest
17	284456082053101	PVC	2	40.0	Range
18	285121082112202	PVC	--	10.0	Range
19	285442081181402	PVC	2	30.0	Urban
20	290739082245701	Black Steel	--	46.0	Forest
21	291117081540502	PVC	2	10.0	Urban
22	291216081215602	PVC	2	25.0	Forest
23	292655082184001	Galvanized Steel	--	16.0	Forest
24	292758081353201	PVC	3	55.0	Forest
25	292815081341501	PVC	4	44.0	Urban
26	292824081443302	PVC	4	45.0	Forest
27	301810082540801	PVC	4	39.0	Agriculture
Coastal Flatwoods					
28	275347081022601	PVC	2	60.0	Range
29	280418081160401	PVC	2	100.0	Range
30	281506081194601	PVC	2	78.0	Range
31	293554081342602	PVC	2	83.0	Forest
32	293556082043403	PVC	4	52.0	Forest

Table 2. Well number, casing material and diameter, well depth, land use, and land resource province of wells in the study-unit survey--Continued

Well number (fig. 1)	Well ID number	Casing material	Casing diameter (inches)	Well depth (feet)	Land use near well
Coastal Flatwoods--Continued					
33	300925081561701	PVC	4	71.0	Forest
34	301422081541205	PVC	4	36.0	Forest
35	301618082110903	PVC	4	60.0	Forest
36	303220082582201	Black Steel	2	32.5	Forest
37	304635081454201	Stainless Steel	36	10.5	Forest
38	304808083120201	PVC	4	65.0	Forest
39	310709082573601	Uncased	36	21.8	Agriculture
40	312012082345801	Uncased	48	23.0	Agriculture
41	312020082265501	uncased	36	15.3	Forest
42	313917081550001	Concrete	24	25.5	Forest
43	314037082121501	Concrete	24	28.3	Agriculture
44	321455081402901	Uncased	48	16.6	Agriculture
45	322432081334401	Uncased	36	19.2	Agriculture
Southern Coastal Plain					
46	303142084214602	Steel	6	54.0	Forest
47	304346084073501	Concrete	40	21.2	Forest
48	304802083311401	Tile	9	27.7	Forest
49	305452084222501	Concrete	24	18.4	Forest
50	310807083204701	Steel	4	75.0	Agriculture
51	312558083135601	Uncased	36	27.0	Forest
52	313354083000301	Tile	12	38.0	Agriculture
53	313458083451901	Tile	12	25.1	Agriculture
54	313549083362501	Tile	12	56.4	Agriculture
55	315241083250901	Uncased	36	23.7	Agriculture
56	315813082135601	Concrete	24	17.5	Agriculture
57	321256082595601	Concrete	24	57.4	Forest
58	322513082051401	Concrete	24	24.0	Forest
59	322547082362501	Uncased	36	30.2	Forest
60	323822081414201	Uncased	36	22.8	Agriculture
61	324634082513201	Tile	30	31.2	Agriculture
62	325208081491401	Concrete	24	33.0	Agriculture
63	325438081563801	Uncased	36	32.3	Forest
64	325738082202801	Uncased	40	22.9	Agriculture

FGWQMNP by the water management districts and the Alachua County Department of Environmental Services, were specifically designated to characterize water-quality conditions in the aquifer systems and were chosen to avoid areas of known ground-water contamination (Maddox and others, 1992). The criteria for selection of wells in the FGWQMNP were based in part on site history and information on exact well location and well construction (Humphreys and others, 1986). Water samples included in this report were collected from 1985 through 1989.

Collection and Analysis of Water-Quality Samples

Water was collected by the USGS from 37 wells in the Southern Coastal Plain and Coastal Flatwoods land resource provinces (well numbers 28-64; table 2) according to the NAWQA ground-water sampling protocols (Wood 1976; Koterba and others, 1995). In large diameter wells, each well was evacuated by one or more well casing volumes of water, and field parameter stabilization was achieved before sampling. A 2-inch submersible stainless steel and Teflon pump was used to collect most samples; however, water samples were collected directly from the spigot on two wells that had built-in submersible pumps and sealed wellheads.

Constituents sampled and analyzed by USGS personnel included: field measurements and hydrogen sulfide, major inorganic constituents, nutrients, dissolved organic carbon, 47 pesticides (see appendix) (Zaugg, and others, 1995), 60 VOCs (see appendix) (Rose and Schoeder, 1994), tritium (Thatcher and others, 1977), radon (American Society for Testing and Materials, 1995b), and uranium (American Society for Testing and Materials, 1995a). In addition, quality assurance samples were collected as part of the NAWQA protocol, including blanks, duplicates, and spiked samples. Generally, water sample collection and analysis procedures from the FGWQMNP were similar to USGS methods. Contract and water-management district laboratories followed quality assurance measures that included the analysis of duplicate samples, laboratory and equipment blanks, and field blanks. If multiple water samples existed for a given well, the most recent sample was used. Detailed methods for collection and analysis of water samples for the FGWQMNP are included in Quality Assurance Project Plans on file with FDEP (S. Labbie, Florida Department of Environmental Protection, written commun., 1990).

Samples from 27 wells on the Central Florida Ridge were analyzed for some or all of the following: field measurements, major inorganic constituents, and nutrients. Samples from 14 wells were analyzed for 30 VOCs and 2 pesticides (this report includes only those organic compounds that matched USGS analyses) (see appendix). Concentrations of calcium, magnesium, sodium, potassium, fluoride, and nitrate included data from both filtered (dissolved) and unfiltered (total) samples. Filtered samples consisted of native water passed through a 0.45 micrometer pore-size membrane filter, whereas unfiltered samples consisted of native water. Complete analyses were not available for major ions in 18 of 27 samples.

Statistical Procedures

Water chemistry data were grouped by land resource province, land use, well casing diameter and material, and well depth, and were compared using the Kruskal-Wallis test, a nonparametric procedure to determine whether significant differences exist among more than two groups (Gilbert, 1987; SAS Institute, Inc., 1993). The Wilcoxon rank-sum test was used to compare differences between two groups of water-quality constituents (Gilbert, 1987; SAS Institute, Inc., 1993). The Spearman rank correlation, a nonparametric regression test, was used to examine increasing or decreasing trends in data (Helsel and Hirsch, 1992; Hamilton and others, 1995). For the three statistical procedures, a p-value of 0.05 was used to determine if there were a relation or a significant difference between the variables.

Age Dating of Ground Water

Tritium is an important hydrologic tracer in age dating young (typically less than 35 year’s old) ground water (Michel, 1989). Tritium, a radioactive isotope of hydrogen (^3H) has a half-life of 12.43 years, and is naturally produced in small amounts through cosmic rays acting on atmospheric nitrogen molecules (Michel, 1989). Oxidation occurs rapidly in the atmosphere and tritiated water is produced and then enters the hydrologic cycle. Natural levels of tritium are about 0.5 tritium units (TU) in the ocean and 3 to 5 TU in rainfall (Kaufman and Libby, 1954: Robertson and Cherry, 1989), but during the 1950’s and 1960’s relatively large amounts of tritium were introduced into the atmosphere during nuclear-bomb tests in the atmosphere. Tritium concentrations in precipitation increased by up to four orders of magnitude during the 1960’s. Because of the large difference in tritium concentrations before and after bomb testing, and the constant rate of decay, tritium concentrations can be used to age date young ground water (Michel, 1989).

A worldwide network of collection stations was established in the late 1950’s and early 1960’s to estimate tritium concentrations in precipitation. A monitoring station was established in Ocala, Fla., in 1963. Volume-weighted tritium concentrations in precipitation at Ocala before 1963 were estimated using the Ottawa correlation (a linear best-fit equation based on measured tritium in precipitation at Ocala and Ottawa, Canada, $r^2 = 0.99$) (International Atomic Energy Agency, 1981a).

Estimates of tritium input from precipitation for the study area from 1953 through 1983 were obtained from a national grid established by Michel (1989). Tritium input to the study area from 1984 through 1993 was estimated by using linear regression to correlate the measured volume-weighted tritium in precipitation at Ocala, Fla., to the estimated tritium input to the grid-cells covering the study area from 1953 to 1983 (Michel, 1989). R-squared values exceeded 95 percent for these predictive equations. The amount of tritium remaining in ground water in 1993 was calculated from the estimated tritium input from 1953 to 1993. Figure 4 presents the volume-weighted tritium concentrations in precipitation collected at Ocala, the estimated tritium in precipitation in the study area, and the estimated tritium in precipitation to the study area after radioactive decay (the shaded area on figure 4 gives an estimate of the uncertainty of the tritium concentration in precipi-

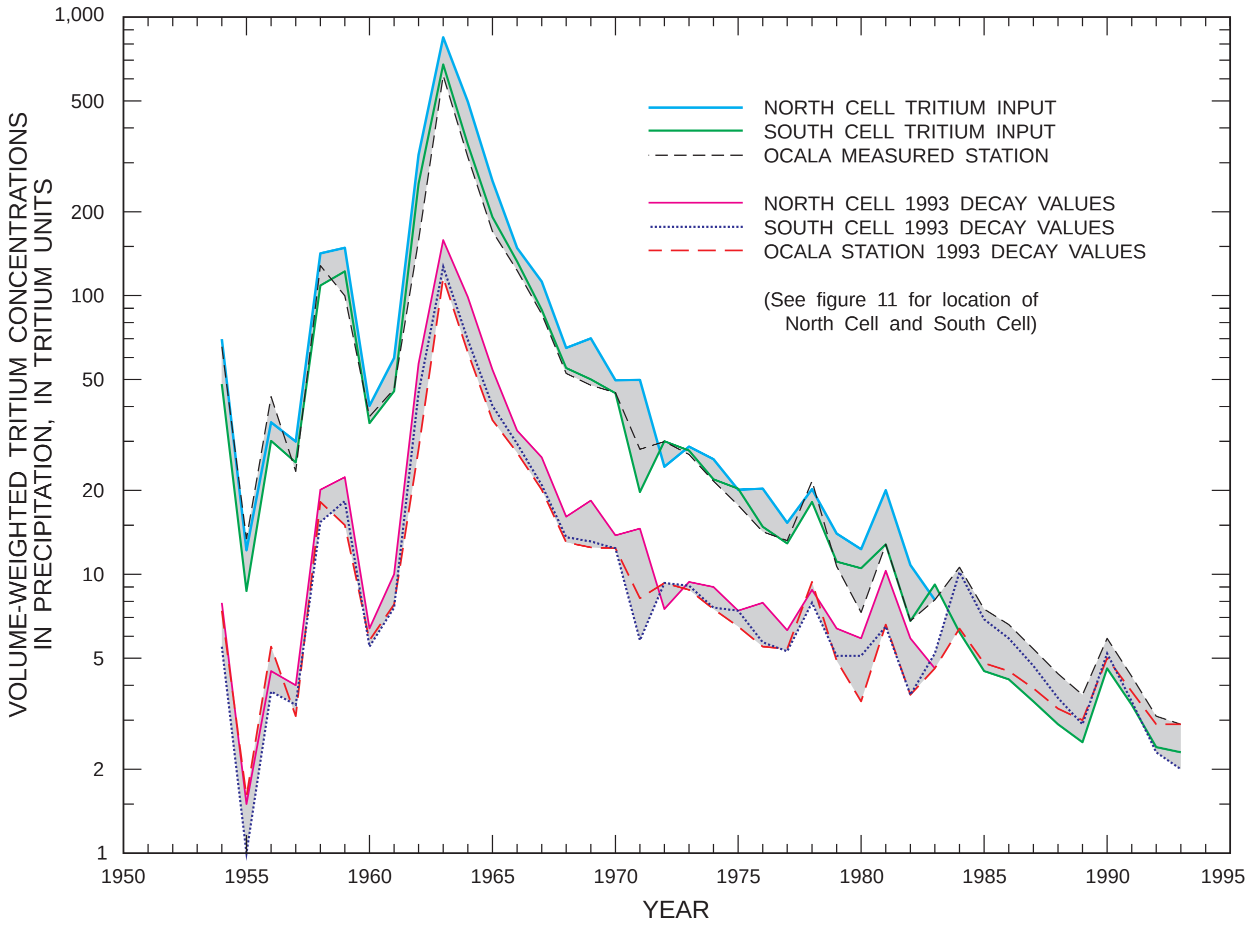


Figure 4. Volume-weighted tritium inputs in precipitation.

tation for the study area over the time period of interest). The period of high tritium concentrations from 1955 through 1970 is generally referred to as the “bomb-spike.”

WATER QUALITY OF SURFICIAL AQUIFERS

The concentrations of inorganic constituents in water from surficial aquifers are related to the quality of the recharge water. Precipitation provides most of the recharge to the surficial aquifers in the Georgia–Florida study area (Miller, 1986; Berndt and Katz, 1992). As recharge water moves through the soil zone or sediments it is chemically altered through mineral dissolution, precipitation, cation exchange, oxidation-reduction, anion exchange, and sorption of organic molecules (Snoeynik and Jenkins, 1980). In addition, evapotranspiration, plant respiration, and uptake in the root zone cause the water to become enriched in carbon dioxide (Stumm and Morgan, 1981) providing acidity and driving many of these weathering reactions (Drever, 1988). Other important factors affecting the chemistry of ground water include the residence time of the ground water that is in contact with reactive aquifer material and the proximity of a sample to the coast or a source of contamination (Berndt and Katz, 1992).

Chemical analysis of atmospheric precipitation was used to determine the quality of recharge to the aquifer. Volume-weighted means of major ions, nitrate, and dissolved solids in rainfall, collected from four National Atmospheric Deposition Program (NRSP-3) /National Trends Network (1995) sites in Florida and three in Georgia (fig. 1) from 1980 through 1993, were computed and compared to major ions, nitrate and dissolved solids in ground water by land resource province in a Durov plot (fig. 5). The Durov plot is a graphical method to compare the percentage of each major ion as a fraction of the total cations or anions and the concentrations of two additional chemical constituents. The Durov plot presents the percentage of each cation to the cation sum in milliequivalents per liter in one triangle and the percentage of each anion to the anion sum in milliequivalents per liter in the other triangle. Nitrate and dissolved-solids concentrations, in milligrams per liter, are given for each sample in the right and lower rectangles, respectively (fig. 5). The Durov plot is particularly useful for identifying chemical similarities among subgroups. Grouping occurs in precipitation data on the Durov plot, but no significant clustering was observed by land resource province in ground water samples. The Durov plot shows that precipitation is predominately composed of sulfate and chloride, sodium and calcium, and low concentrations of dissolved solids and nitrate concentrations (fig. 5). Bicarbonate concentrations in precipitation were not available, but are commonly <10 mg/L due to low pH (Hem, 1985). Although some of the ground-water samples were chemically very similar to rainfall, most ground-water samples are relatively higher in concentrations of dissolved solids, have proportionately less sodium and sulfate, and proportionately more chloride, calcium, and bicarbonate than rainfall, probably because of cation exchange, evapoconcentration, and dissolution of minerals in the aquifer matrix.

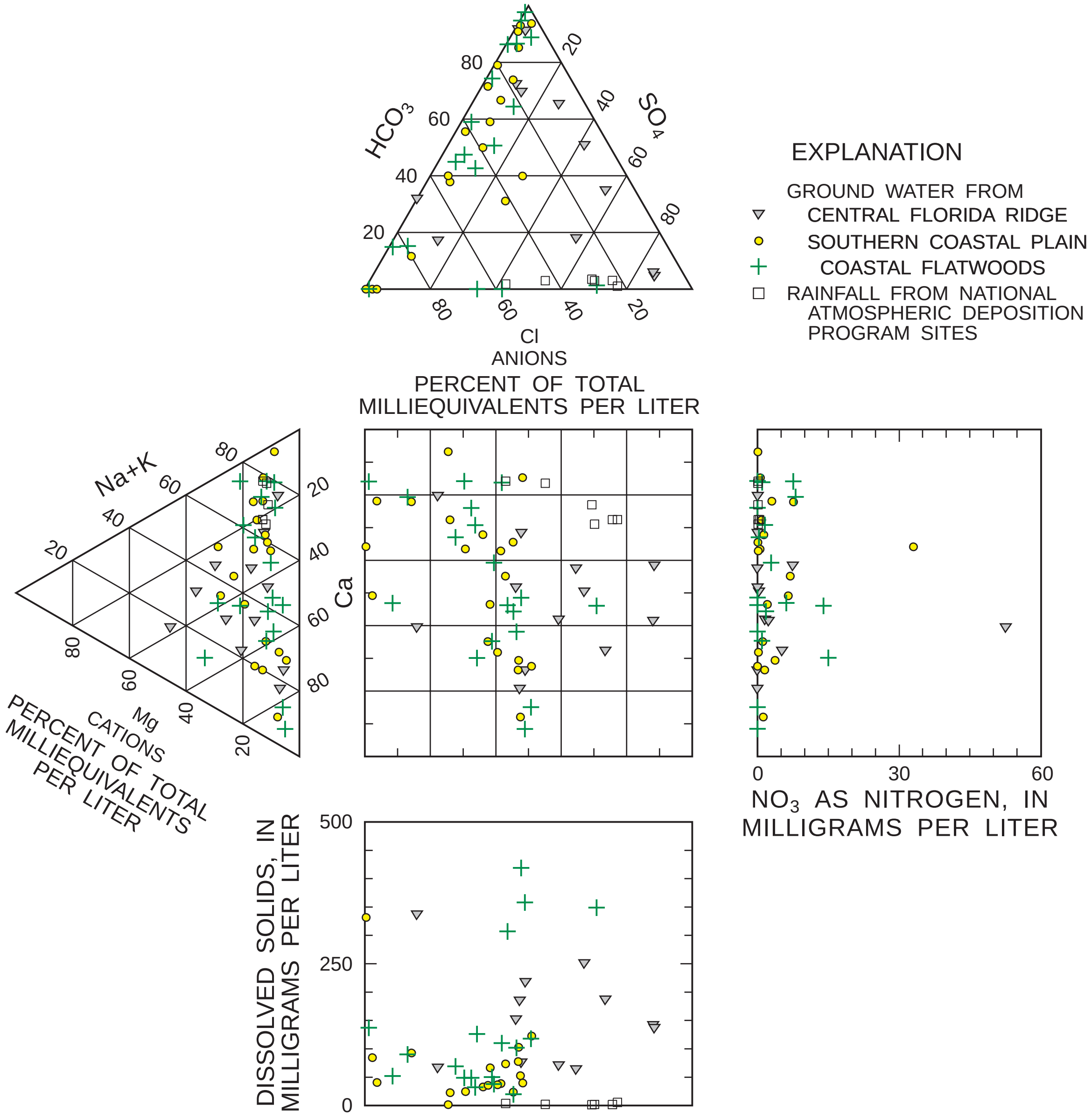


Figure 5. Major ions in ground water and precipitation by land resource province.

Land Resource Provinces

Median concentrations and ranges of major inorganic constituent concentrations were compared by land resource province (table 3). In addition, dissolved solids, nitrate, iron, manganese, and radon concentrations were compared to the U.S. Environmental Protection Agency (USEPA) primary maximum contaminant levels (MCL) and secondary MCL in drinking water. Major nutrient concentrations were also compared by land resource province. Organic compounds detected in ground water were compared by land resource province, land use near the well, well characteristics, and to USEPA MCL and secondary MCLs.

Major Ions

Most ground water samples from the study area were classified as a “mixed” water-type—meaning that no one or two cations or anions were dominant in ground water from each land resource province. No significant differences (p-value >0.05) in concentrations of inorganic constituents were noted by land resource province for magnesium, potassium, manganese, silica, sodium, chloride, fluoride, nitrate, dissolved organic carbon, organic nitrogen, radon, uranium, and hydrogen sulfide (table 3). Statistically significant differences by land resource province (p-value <0.05) were noted for temperature, pH, and specific conductance, and concentrations of bicarbonate, dissolved oxygen, calcium, iron, bromide, sulfate, phosphorus, orthophosphate and dissolved solids (table 3). Dissolved oxygen, silica, bromide, ammonium plus organic nitrogen and dissolved organic carbon were not analyzed in ground water from surficial aquifers of the Central Florida Ridge, restricting statistical comparisons to the Southern Coastal Plain and Coastal Flatwoods land resource provinces for these constituents.

Ground-water samples from the Central Florida Ridge had significantly higher median pH and specific conductance and concentrations of bicarbonate, calcium, dissolved solids, and magnesium than samples from the Coastal Flatwoods or Southern Coastal Plain

Table 3. Comparison of values of field parameters and concentrations of major ions in ground water samples from the study-unit survey by land resources province

[Constituents in milligrams per liter except where noted; µg/L, micrograms per liter; µS/cm, microsiemens per centimeters; pCi/L, picocuries per liter; p-value <0.05; significant for Kruskal-Wallis test except where only 2 land resource provinces were compared then Wilcoxon rank-sum test was used; n, number of observations]

Constituent	Central Florida Ridge			Coastal Flatwoods			Southern Coastal Plain			p-value
	n	Median	Range	n	Median	Range	n	Median	Range	
Depth of well (ft)	27	**37**	10–83	18	**34**	11–100	19	**28**	17–75	0.56
Temperature (degrees C)	17	**24**	20–26	18	**24**	21–25	19	**22**	20–32	<0.01
pH (pH units)	20	**6.0**	4.6–9.9	17	**5.2**	4.1–8.0	19	**5.2**	4.1–7.4	0.04
Specific conductance (µS/cm)	20	**200**	40–650	18	**123**	35–681	19	**58**	26–542	0.01
Dissolved solids	21	**146**	23–336	18	**96**	20–419	19	**41**	2.0–332	<0.01
Bicarbonate [a]	20	**91.2**	<1.0–240	18	**<1.0**	<1.0–17.2	19	**4.0**	<1.0–124	<0.01
Dissolved oxygen	--	**--**	--	18	**1.4**	0.05–8.0	19	**4.8**	0.20–7.9	0.03
Calcium	24	**19.5**	1.0–50	18	**5.4**	0.75–110	19	**5.1**	0.11–20	0.02
Magnesium	20	**2.4**	0.20–23	18	**2.1**	0.34–18	19	**0.84**	0.17–18	0.10
Sodium	21	**4.5**	1.4–30	18	**7.0**	1.4–63	19	**3.6**	1.3–27	0.06
Potassium	20	**1.5**	<0.10–8	18	**1.5**	<0.10–18	19	**1.0**	<0.10–8.9	0.52
Chloride	16	**13**	4.0–84	18	**9.3**	3.2–53	19	**5.3**	2.8–71	0.10
Sulfate	15	**13**	<0.10–148	18	**1.7**	<0.10–130	19	**0.80**	0.20–5.8	<0.01
Hydrogen sulfide [b]	5	**0.013**	0.005–0.1	7	**0.01**	0.001–0.66	3	**0.1**	0.007–0.219	0.81
Fluoride	18	**0.10**	<0.01–0.10	18	**<0.10**	<0.10–0.50	19	**0.10**	<0.10–0.40	0.52
Dissolved organic carbon	--	**--**	--	18	**6.9**	0.8–53	19	**3.5**	0.4–21	0.24
Iron, µg/L	8	**20**	10–1820	18	**300**	7.0–2600	19	**10**	3.0–3700	0.03
Manganese, µg/L	7	**19**	10–260	18	**15**	2.0–410	19	**9.0**	1.0–370	0.14
Silica as SiO_2	--	**--**	--	18	**8.3**	4.4–36	19	**6.7**	3.7–24	0.20
Bromide	--	**--**	--	18	**0.035**	<0.01–0.11	19	**0.02**	<0.01–0.22	0.05
Nitrate + Nitrite as N	21	**0.19**	<0.004–53	18	**1.0**	<0.05–15	19	**1.2**	<0.05–33	0.24
Ammonia as N	1	[c] **0.27**	--	18	**0.06**	<0.01–0.81	19	**0.02**	<0.01–1.0	0.14
Organic nitrogen as N	--	**--**	--	18	**<0.20**	<0.20–0.33	19	**<0.20**	<0.20–0.20	0.59
Phosphorus as P	3	**0.025**	0.016–0.30	18	**0.025**	<0.01–1.3	19	**<0.01**	<0.01–0.15	0.01
Orthophosphate as P	8	**0.061**	<0.01–0.09	18	**0.015**	<0.01–1.2	19	**0.01**	<0.01–0.13	0.02
Radon in pCi/L	--	**--**	--	17	**500**	230–13000	19	**690**	89–7900	0.38
Total uranium in µg/L	--	**--**	--	10	**<1**	<1	19	**<1**	<1–1.3	0.47

[a] Bicarbonate concentrations were not measured and concentrations were presumed to be less than 1.0 mg/L, when pH was less than 4.8.
[b] Hydrogen sulfide concentrations were not measured when dissolved oxygen was greater than 0.50 mg/L.
[c] This is not a median value, because there is only one sample.

(table 3)—probably because of the presence of carbonate minerals in surficial aquifers of the Central Florida Ridge. The median pH of water from surficial aquifers in the Central Florida Ridge was 6.0 whereas the median pH was 5.2 in the Coastal Flatwoods and Southern Coastal Plain land resource provinces (table 3). The median dissolved solids concentration was 146 mg/L for surficial aquifers of the Central Florida Ridge, 96 mg/L for surficial aquifers of the Coastal Flatwoods and 41 mg/L for surficial aquifers of the Southern Coastal Plain, respectively. The maximum dissolved solids concentration of 419 mg/L occurred in a sample from the Coastal Flatwoods. Most dissolved solids concentrations were <100 mg/L, well below the USEPA secondary MCL for dissolved solids in drinking water—500 mg/L (U.S. Environmental Protection Agency, 1990; U.S. Environmental Protection Agency, 1993).

Reducing conditions were more common in water from surficial aquifers of the Coastal Flatwoods than in the Southern Coastal Plain. Hydrogen sulfide concentrations ranged from 0.001 to 0.66 mg/L in surficial aquifers of the Coastal Flatwoods (hydrogen sulfide concentrations were measured in USGS water samples when dissolved oxygen concentrations were <0.5 mg/L). Hydrogen sulfide was found in samples from seven wells in the Coastal Flatwoods land resource province indicating strongly reducing conditions. Hydrogen sulfide was measured in samples from three wells in the Southern Coastal Plain and concentrations ranged from 0.007 to 0.219 mg/L. Median dissolved oxygen concentrations were higher in samples from the Southern Coastal Plain than in the Coastal Flatwoods—4.8 mg/L compared to 1.4 mg/L, respectively. Dissolved oxygen was not measured in the Central Florida Ridge.

Iron concentrations were much higher in samples from the Coastal Flatwoods land resource province than in samples from the Southern Coastal Plain and Central Florida Ridge. Median concentrations of iron in the Southern Coastal Plain and the Central Florida Ridge were 10 and 20 μg/L, respectively and 300 mg/L in the Coastal Flatwoods (table 3). The USEPA secondary MCL for iron in drinking water of 300 μg/L was exceeded in 15 of 45 wells. Lower pH probably mobilized iron in surficial aquifer materials of the Coastal Flatwoods.

Manganese concentrations were generally low and did not differ by land resource province. The USEPA's secondary MCL of 50 μg/L of manganese was exceeded in samples from 8 of 44 wells. Values of manganese showed no significant difference in concentrations at the 95 percent confidence level among land resource provinces. Manganese concentrations ranged from 1.0 to 410 μg/L overall.

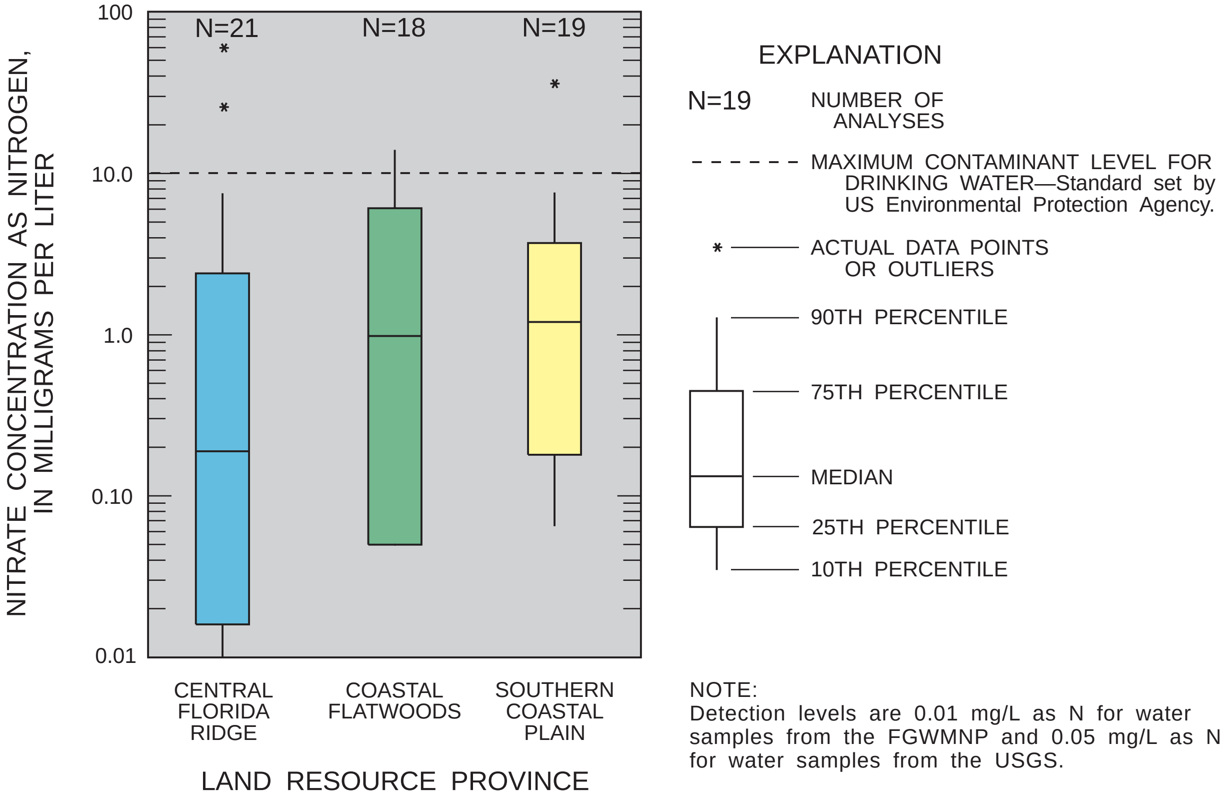
Sulfate concentrations were significantly higher in the Central Florida Ridge than in the other two land resource provinces. This could be related to differences in laboratory procedures.

Nitrogen and Phosphorus

Nitrogen and phosphorus are essential elements in the life processes of plants and animals; however, when present in elevated concentrations in water supplies, contamination to the resource results (Madison and Brunett, 1985). Contamination of drinking-water supplies due to nitrate causes the abandonment of significantly more drinking-water supplies annually than does toxic-chemical contamination (Spalding and Exner, 1991). A brief discussion of nitrogen sources is included in the factors affecting nitrate concentrations section.

Concentrations of nitrate in samples from surficial aquifers were generally not >10 mg/L, the USEPA MCL, and did not differ significantly by land resource province (fig. 6, table 3). Nitrate was analyzed in 21 samples from the Central Florida Ridge and all samples from the Coastal Flatwoods and Southern Coastal Plain land resource provinces. Median nitrate concentrations were 0.19, 1.0, and 1.2 mg/L in surficial aquifers from the Central Florida Ridge, Coastal Flatwoods and Southern Coastal Plain, respectively (table 3, fig. 6). No significant difference was found in nitrate concentrations as a function of land resource province. The concentration of nitrate exceeded the USEPA MCL in only five samples; two from the Central Florida Ridge, two from the Coastal Flatwoods, and one from the Southern Coastal Plain (fig. 7). The maximum concentration of nitrate, of 53 mg/L, was measured in a sample from the Central Florida Ridge. The concentration of nitrate was positively correlated with dissolved oxygen (p-value < 0.01) indicating that samples with higher dissolved oxygen concentrations also tended to have higher nitrate concentrations.

Ammonia (as nitrogen) concentrations in samples from surficial aquifers of the study area were, for the most part, at or near the detection level. Median concentrations of ammonium (as nitrogen) were 0.06 mg/L in the Coastal Flatwoods and 0.02 mg/L in the Southern



NOTE:
Detection levels are 0.01 mg/L as N for water samples from the FGWMNP and 0.05 mg/L as N for water samples from the USGS.

Figure 6. Nitrate concentrations in ground water by land resource province.

Coastal Plain, (table 3) (only one sample was collected in the Central Florida Ridge). No significant difference was detected between concentrations of ammonium by land resource province. A significant negative correlation was found between dissolved oxygen and ammonium ($p\text{-value} < 0.01$, $\rho = -0.67$) indicating ammonium concentrations were greater in samples with low dissolved oxygen concentrations.

The median concentration of organic nitrogen in samples from the Coastal Flatwoods and Southern Coastal Plain was <0.20 mg/L as nitrogen (the detection level) and concentrations ranged from <0.20 mg/L (the detection level) to 0.33 mg/L. No significant difference (p-value = 0.59) was found between organic nitrogen concentrations in samples collected in the Southern Coastal Plain and Coastal Flatwoods. Organic nitrogen was not measured in samples from the Central Florida Ridge.

Concentrations of orthophosphate and dissolved phosphorus in surficial aquifers were generally at or near detection levels in samples from surficial aquifers. Orthophosphate was only measured in eight samples from the Central Florida Ridge. Concentrations of orthophosphate ranged from <0.01 mg/L, the detection level, to 1.2 mg/L as phosphorus. Median concentrations of orthophosphate were 0.06, 0.015, and 0.01 mg/L in the Central Florida Ridge, Coastal Flatwoods, and Southern Coastal Plain, respectively (table 3). Low concentrations of orthophosphate are common in ground water because orthophosphate is usually bound tightly to iron oxides and organic matter in the soil zone or taken up by biota (Hem, 1985). Concentrations of orthophosphate in ground water differed significantly (p-value = 0.02) among samples from the Central Florida Ridge and Coastal Flatwoods, and Southern Coastal Plain with higher median orthophosphate concentrations in samples from the Central Florida Ridge. Concentrations of total phosphorus were low and ranged from below the detection level of 0.01 to 1.3 mg/L (table 3). Results showed a significant difference (p-value = 0.01) in concentrations of phosphorus among samples from the three land resource provinces. Higher concentrations of phosphorus were detected in samples from the Central Florida Ridge and Coastal Flatwoods.

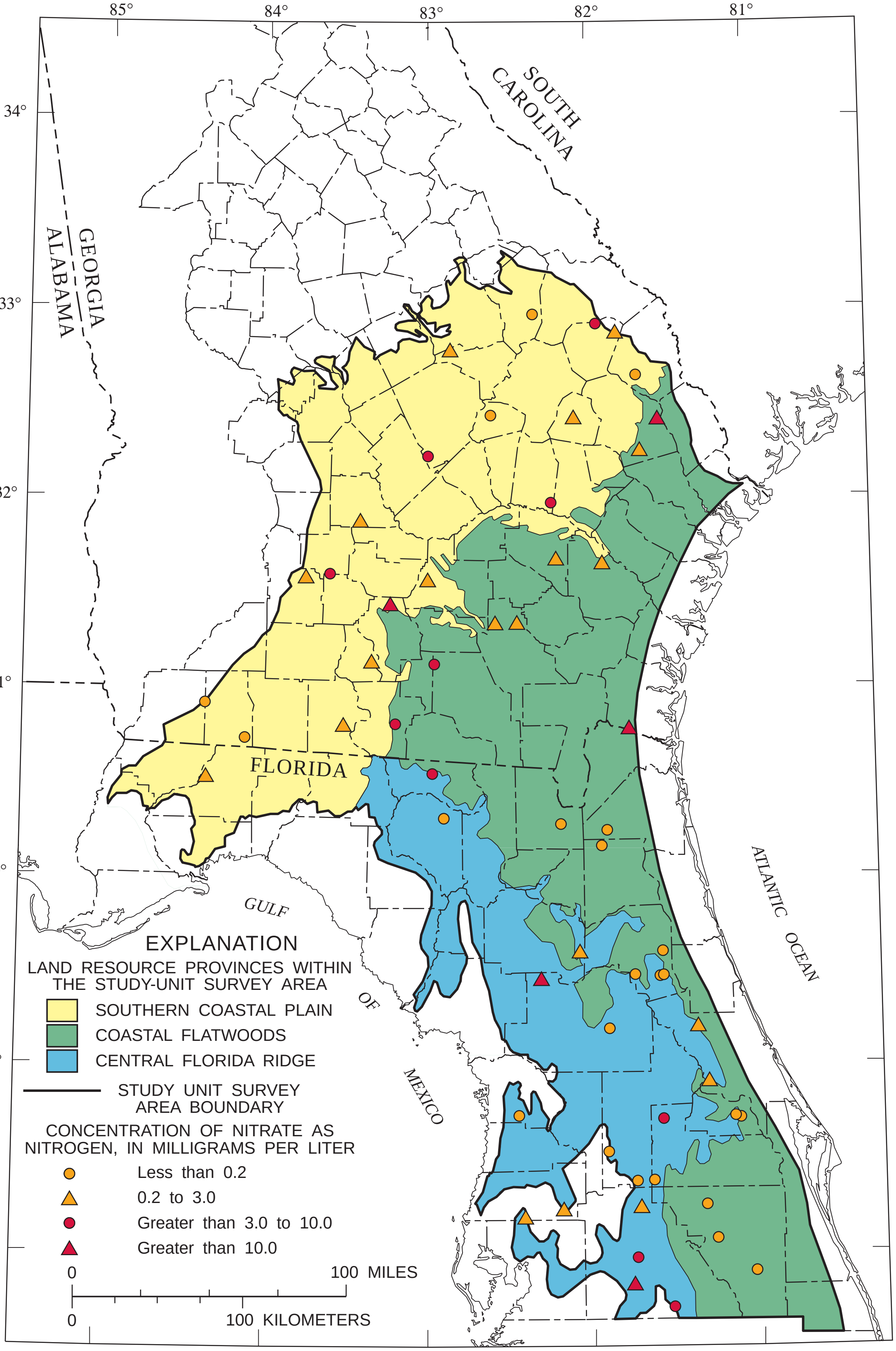


Figure 7. Nitrate concentrations in ground water over the study area.

Organic Compounds

VOCs and pesticides, detected in samples from 13 wells, were primarily in samples from the Southern Coastal Plain and Coastal Flatwoods and generally, concentrations were very low. Of those VOCs and pesticides detected above laboratory reporting levels, all were below USEPA MCLs. Generally, laboratory reporting levels are concentrations several times the actual detection limits of a compound. Two organic compounds were detected in a sample from only one well in the Central Florida Ridge—methylene chloride and tetrachloroethane. Organic compounds were detected in samples from six wells on the Southern Coastal Plain and five wells on the Coastal Flatwoods most at concentrations <1 µg/L (table 4). VOCs detected in ground-water samples at concentrations <1 µg/L included: tetrachloroethene, bromomethane, toluene, methylene chloride and methyl tert-butyl ether (MTBE), an additive for gasoline (Squillace and others, 1995) (table 4). VOCs detected in samples at concentrations >1 µg/L included: 21 µg/L of chloromethane, 8.77 µg/L of tetrachloroethane, and two samples of more than 20 µg/L of toluene.

The pesticides atrazine, desethyl-atrazine, and metolachlor were detected in samples from four wells, three on the Southern Coastal Plain and one on the Coastal Flatwoods. Extremely low concentrations of atrazine (0.02 µg/L) and desethyl-atrazine (a degradation product of atrazine) were reported in a water sample from the same well on the Coastal Flatwoods. Concentrations of 0.01 and 2.5 µg/L of metolachlor were reported in samples from two wells, both in the Southern Coastal Plain.

Organic compounds were detected in samples from wells in agricultural settings more than other land use settings; although localized sources near the well were the most likely factor in determining whether organic compounds were detected. Generally, organic compounds were detected in wells near active local sources such as heavily used driveways, highways, currently farmed fields, or sprayed yards. Organic compounds detected in samples from wells located in agricultural areas included: atrazine, desethyl-atrazine, metolachlor, toluene, tetrachloroethylene, bromomethane and chloromethane. Of the three wells where pesticides were detected, two wells are located in heavily farmed peanuts, corn, and wheat areas. The third well is located in the middle of a highly manicured lawn.

Table 4. Volatile organic compounds and pesticides detected in ground-water samples from the study-unit survey

[USEPA; U.S. Environmental Protection Agency; MCL; Maximum Contaminant Level; Southern Coastal Plain, SCP; Coastal Flatwoods, CFW; and Central Florida Ridge, CFR; N/A, not available; Well numbers where contaminant occurred are shown in figure 1]

Constituent name	Laboratory minimum reporting level (µg/L)	Maximum concentration detected (µg/L)	Number of wells with detection	USEPA MCL (µg/L)	Land use near well	Well number(s) where contaminant occurs	Land resource province(s)
VOLATILE ORGANIC COMPOUNDS							
1,1,2,2-Tetrachloroethane	0.5 1.0	8.77	1	N/A	Urban	19	CFR
Toluene	0.2	23	3	1000	Agriculture/range	41, 55, 28	CFW, SCP
Tetrachloroethylene (PCE)	0.2	0.7	1	5.00	Agriculture	45	CFW
Bromomethane	0.2	0.5	1	[a/]10	Agriculture	64	SCP
Chloromethane	0.2	21	1	[a/]3.00	Agriculture	64	SCP
Methyl tert-butyl ether (MTBE)	0.2	0.9	1	[a/]20	Forest	58	SCP
Methylene Chloride (dichloromethane)	0.2	0.56	1	5.00	Urban	19	CFR
PESTICIDES							
Atrazine	0.006	0.019	2	3.00	Agriculture	37, 56	CFW, SCP
Metolachlor	0.009	2.50	2	[a/]100	Agriculture	54, 55	SCP
Desethyl-Atrazine	0.020	0.024	1	N/A	Agriculture	37	CFW

[a/] Lifetime health advisory level for a 70 kg adult (U.S. EPA, 1993).

Compounds detected in samples from wells in forested areas included: atrazine, toluene, and MTBE. MTBE was found in a sample from a well near a forested area, but the well is located <10 ft from a residential driveway. Organic compounds detected in urban areas were methylene chloride and tetrachloroethane. Toluene was the only organic compound detected in a sample from a well located in rangeland. Toluene was also detected in one of the same wells as metolachlor and was present in a sample from a well approximately 100 ft from a major highway. Bromomethane and chloromethane were reported in the sample from a well situated in an agricultural area.

Organic compounds were detected more commonly in shallow wells (<25 ft in depth) than in deeper wells. Eight of thirteen wells where organic compounds were detected were 25 ft deep or less. Of the remaining wells, three samples were from wells that were <50 ft deep. Organic compounds were detected in only two wells >50 ft deep. Organic compounds were detected in wells of all types of construction—uncased, as well as tile, PVC, concrete, and stainless steel cased.

Radon and Uranium

Radon, a naturally occurring radionuclide with a half-life of 3.8 days and a daughter product of the decay of uranium-238, undergoes several alpha decays in a relatively rapid period of time, and so, typically presents health problems primarily when it is breathed into the lungs (Gundersen and Szabo, 1995). Generally, the concentration of radon in ground water is elevated above background levels when the ground water is directly in contact with uranium-rich rocks or sediments. Radionuclides are ubiquitous in rocks and soil throughout the southeastern United States (Gundersen and Szabo, 1995). Uranium, the parent of radon, is highly soluble in oxidizing waters, and can travel for great distances along the shallow ground-water flow paths (Gundersen and Szabo, 1995) until strongly sorbed by clays, organic humic material, or iron oxide (Gundersen and Peake, 1992) where it then becomes a continuous source of radon. The highest concentrations of radon (and adsorbed uranium) are usually measured from glauconitic, phosphatic, and carbonaceous materials (Gundersen and Peake, 1992).

Radon concentrations ranged from 89 to 13,000 picocuries per liter (pCi/L) in ground water of the Southern Coastal Plain and Coastal Flatwoods land resource provinces. Radon was not measured by the FGWQMNP in samples from the Central Florida Ridge. Radon concentrations exceeded the proposed USEPA MCL of 300 pCi/L (U.S. Environmental Protection Agency, 1993) in water from 33 of 36 wells (fig. 8). Median values of radon were 500 and 690 pCi/L in the Coastal Flatwoods and Southern Coastal Plain, respectively (table 3). No significant difference was found in radon concentrations in samples from the two land resource provinces. The two highest radon concentrations of 12,000 and 13,000 pCi/L, occurred in ground water samples from north-central Florida in the Coastal Flatwoods. The Alachua County well was completed in the Hawthorn formation, the first water-bearing zone in that area (D. Boniol, St. Johns River Water Management District, oral commun., 1995), and is associated with phosphatic deposits that contain uranium. Elevated levels of radon observed throughout the northern and central study area could be associated with uranium that has adsorbed to iron oxides or clays in the iron rich sandy-clay sediments of Georgia (Z. Szabo, U.S. Geological Survey, oral commun., 1995).

Although radon was not analyzed by FGWQMNP, other data indicate that localized radon concentrations may be high in water from some surficial aquifers of the Central Florida Ridge. A radon study was done in a small area of northern Alachua and south-central Hillsborough Counties for the Florida Institute of Phosphate Research from 1988 through 1990 (Burnett and Cowart, 1991). Mean concentrations of radon in ground water samples from surficial wells in northern Alachua County were 20, 886 pCi/L, and the concentrations ranged from 282 to 66,150 pCi/L (wells were 15 to 25 ft deep). Likewise, the mean concentration from water samples in Hillsborough County was 13,453 pCi/L and the concentrations ranged from 818 to 38, 206 pCi/L (wells were 15 to 30 ft deep) (Burnett and Cowart, 1991). Samples of aquifer material from a core taken at a site in Hillsborough County showed uranium-rich phosphate material at about 25 ft below land surface (Burnett and Cowart, 1991).

Unfiltered water samples were also analyzed for total uranium concentrations in 10 wells from the Coastal Flatwoods and 19 wells from the Southern Coastal Plain. Uranium was not measured in samples from the Central Florida Ridge. Uranium concentrations were less than the detection level of 1.0 μg/L in all samples from the Coastal Flatwoods and in 18 of 19 samples from the Southern Coastal Plain. A concentration of 1.3 μg/L was detected from one water sample collected in the Southern Coastal Plain. Concentrations

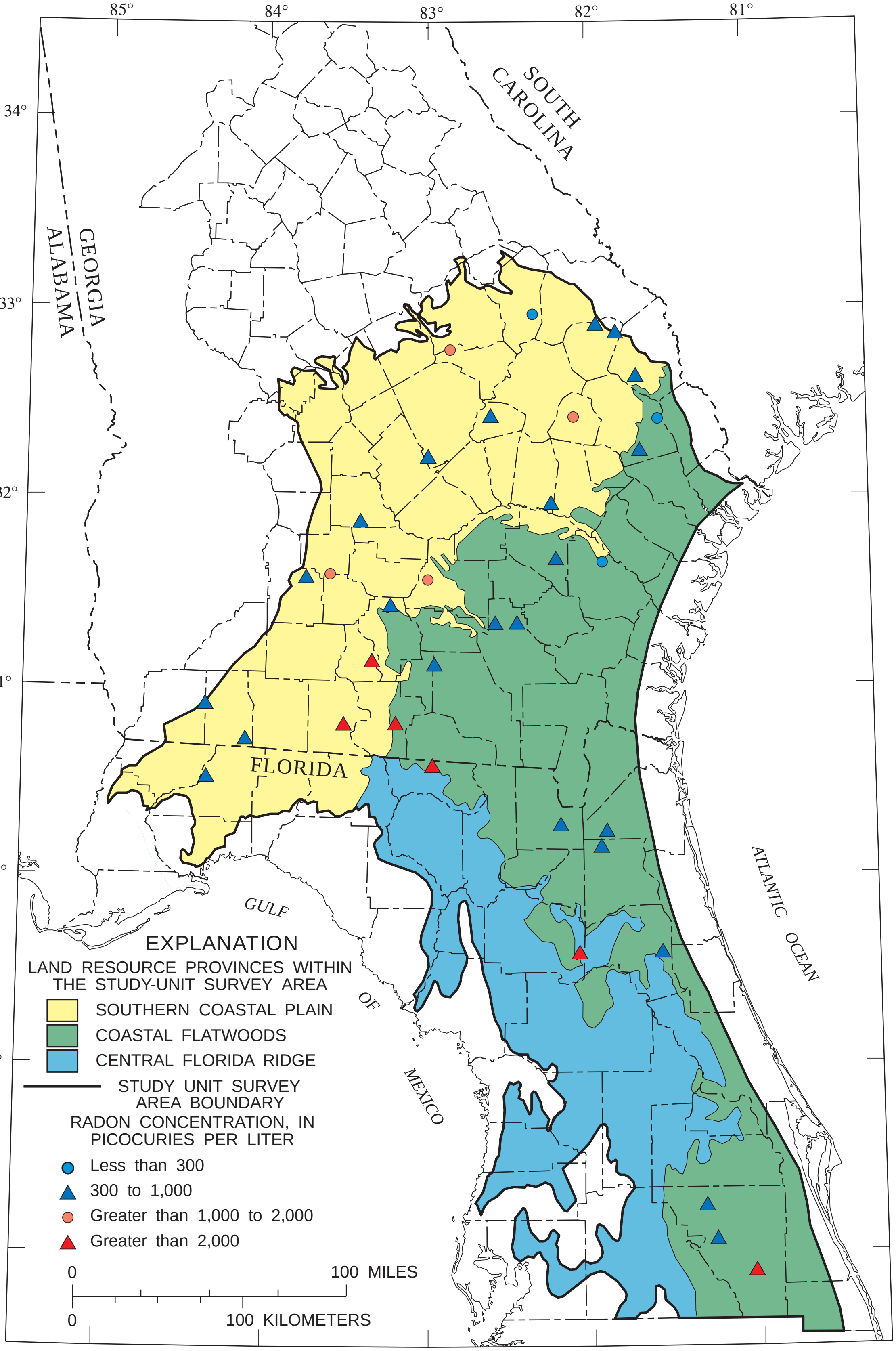


Figure 8. Radon concentrations in ground water.

of uranium are low and concentrations of radon are high in samples of ground water from the Coastal Flatwoods and Southern Coastal Plain, indicating that uranium is present but adsorbed onto aquifer materials, thereby providing a source of radon to ground water.

Factors Affecting Nitrate Concentrations

Water quality in surficial aquifers can be affected by land use upgradient from the well as well as other factors such as well construction and depth. Concentrations of nitrate were compared by land use near well, well construction, and depth of sample. Nitrate and tritium concentrations were compared by well depth. Age of water was determined.

Some of the major factors controlling nitrate concentration in ground water include:

- Land use near well—Animal corrals near poorly constructed wells (Exner, 1985) or over-fertilization and over-watering in agricultural areas can elevate nitrate concentrations in ground water (Spalding and Exner, 1991).
- Poor well construction techniques—Nitrate concentrations are usually greater in wells with poor construction (large diameter wells without a water-tight casing are vulnerable to surface contamination because they act like sumps collecting infiltrate) (Spalding and Exner, 1993).
- Depth of sample collection—Nitrate concentrations usually decrease with depth below land surface.
- Soil type and geology—Sandy soils and karst regions where fertilizer usage is high usually show elevated nitrate concentrations (due to the low water- and nutrient-holding capacities of the soils) (Spalding and Exner, 1991).

Land Use

To assess the effect of land use (human activities) on ground-water quality, four ranges of nitrate concentrations (all nitrate concentrations reported in milligrams per liter as nitrogen) were established (Madison and Brunett, 1984):

- Less than 0.2 mg/L—Assumed to represent background concentrations with little human influence.
- 0.21 to 3.0 mg/L—Transitional; concentrations may or may not represent influence from human activities.
- 3.01 to 10 mg/L—May indicate elevated concentrations resulting from human activities.
- More than 10 mg/L—Concentration exceeds MCL (U.S. Environmental Protection Agency, 1993) for nitrate as nitrogen in drinking water as a result of human activities.

Nitrate concentrations in 23 of 58 (40 percent) ground-water samples were below background levels of 0.2 mg/L (fig. 7). Samples from 20 wells (34 percent) had nitrate concentrations between 0.21 to 3.0 mg/L indicating possible influence from human activities. Ten samples (17 percent) had nitrate concentrations of between 3.01 to 10 mg/L indicating probable human influence (Madison and Brunett, 1984)—five samples from forested areas, four samples from agricultural areas and one sample from an urban area (fig. 7). The concentration of nitrate as nitrogen exceeded the USEPA MCL of 10 mg/L (U.S. Environmental Protection Agency, 1993) in five samples (9 percent). Of these five samples, three samples came from forested areas, one from an agricultural area and the highest value, 53 mg/L, came from an area near a phosphate mine and citrus grove.

Nitrate concentrations in ground water were compared by land use near the well. Results indicated no significant difference in nitrate concentrations in ground water when compared between samples from agricultural areas (n = 19) and forest (n = 26) near the well (p-value = 0.72) (the low number of samples (<10) from wells in other land use categories prevented direct statistical comparison). The median concentration of nitrate in ground water in agricultural areas was 1.35 mg/L and concentrations ranged from 0.005 to 15 mg/L. The median concentration of nitrate in ground water in samples collected near forested areas was 0.77 mg/L, whereas the median nitrate concentration in urban areas was 1.6 mg/L and concentrations ranged from 0.004 to 5.2 mg/L (n = 7).

Age of Ground Water

Tritium concentrations can be used to estimate age of recharge and, by inference, assess the how land use affected water quality at the time of recharge. Tritium concentrations in ground water ranged from less than the detection level of 0.31 to over 100 tritium units (fig. 9) and generally decreased from north to south in the study area. All water samples were most likely from recharge water younger than 1953. Samples from 27 wells had tritium concentrations below the detection

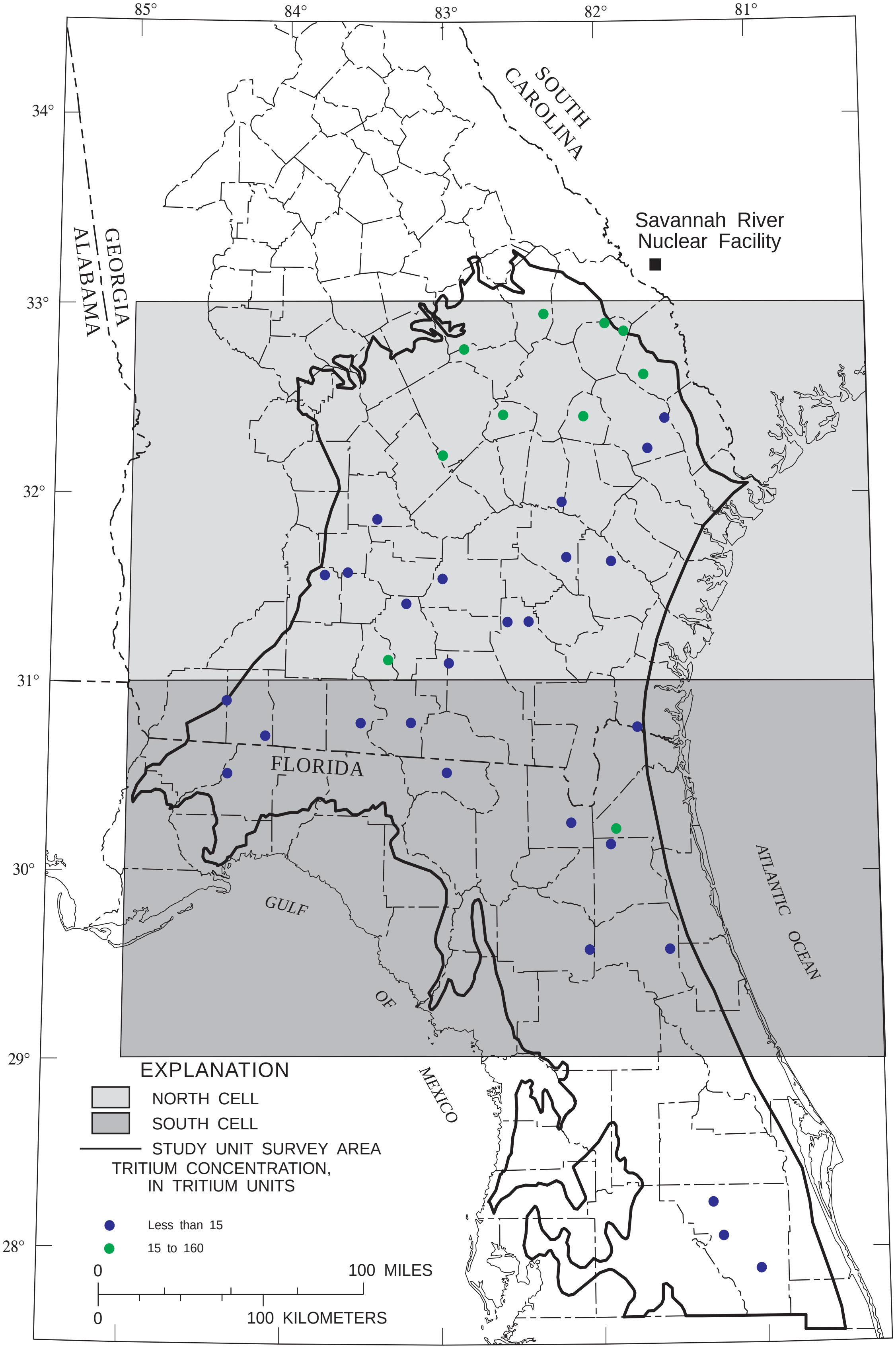


Figure 9. Tritium in ground water in the study area.

level of 0.31 to <15 TU, indicating that water was recharged during the last 25 years (fig. 9). Tritium concentrations in ground water samples from 10 wells, mostly in central Georgia, were between 15 and 160 TU and most likely originated from precipitation which fell and recharged ground water during 1959–72, or (in the extreme northern study area) may be affected by the Savannah River Nuclear Facility (fig. 9) (Summerour and others, 1994). Concentrations in all samples were well below the USEPA MCL for tritium in drinking-water of 6,173 TU (U.S. Environmental Protection Agency, 1993).

Nitrate and tritium concentrations were compared for ground water samples collected from four depth intervals to determine if nitrate concentrations were related to the age of water. It is suspected that shallow wells contain younger water (as indicated by tritium concentrations) and higher nitrate concentrations than older water in deeper wells because of recent agricultural land uses. Well depths were categorized using four ranges—0 to <25 ft, 25 to <50 ft, 50 to <75 ft, and 75 ft and greater. Nitrate concentrations did not differ significantly (p-value = 0.08) with depth of well sampled; however, the median nitrate concentration in samples from wells <25 ft deep was greater than the median nitrate concentrations in samples from deeper wells (fig. 10). The median nitrate concentration in water samples from wells <25 ft deep was 1.8 mg/L (n = 17) compared to 0.81 mg/L in wells 25 ft to <50 ft deep (n=24). Tritium concentrations were found to vary significantly with depth of well (p-value = 0.03). The greatest median tritium concentration occurred in samples from wells with depths between 25 to <50 ft deep (11.7 TU), followed by the median tritium concentration of the shallowest well group, 0 to <25 ft deep (10.2 TU). Generally, tritium concentrations and nitrate concentrations decreased with well depth. A positive monotonic correlation (rho = 0.25) was found between tritium and nitrate concentrations, although the p-value was not statistically significant (p-value = 0.13).

Well Characteristics

Nitrate concentrations in ground water were compared by casing material, and diameter of well to test for relations between nitrate concentrations and well construction factors. Nitrate concentrations were lower in PVC monitoring wells with smaller diameters

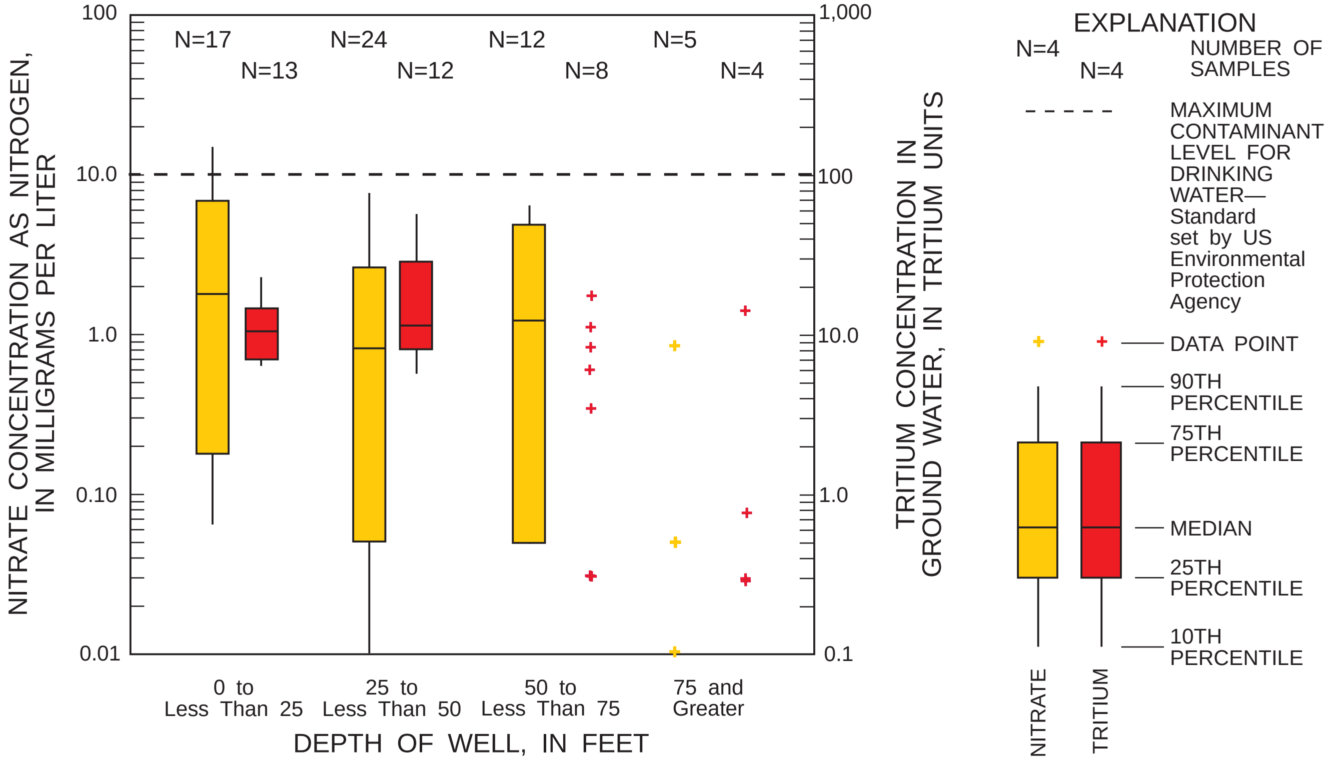


Figure 10. Nitrate and tritium concentrations as a function of well depth.

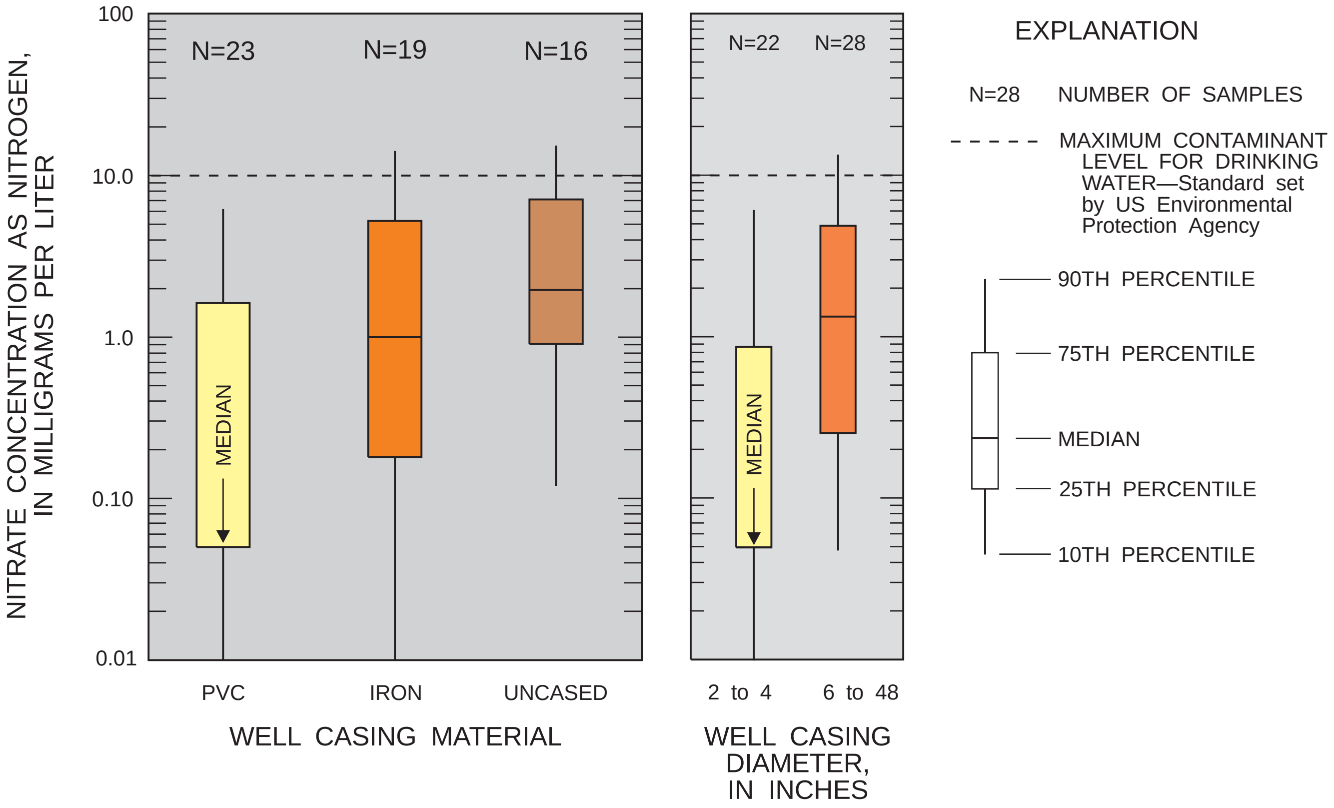


Figure 11. Nitrate distributions as a function of well casing material and nitrate distributions as a function of well diameter.

(<6 in.) than in other types of wells. The median concentration of nitrate was 0.05 mg/L in PVC monitoring wells, whereas the median nitrate concentration was 1.0 and 2.0 mg/L, respectively, in iron and uncased wells (fig. 11). The median nitrate concentration in samples from 2.0 to 4.0-in. diameter wells (mostly monitoring wells) was 0.05 mg/L as N (fig. 11). The median nitrate concentration in samples from 6.0 in. or greater diameter wells was 1.4 mg/L (fig. 11). Wells with diameters greater than or equal to 6.0 in. (there were no wells between 4.0 and 6.0 in. in diameter) generally tended to be uncased or have iron, cement, or terra cotta casings, whereas those with a smaller diameter tended to be PVC wells constructed solely for monitoring purposes. Large diameter uncased wells, because of their vulnerability to surface contamination, are unsuitable for the collection of representative water-quality samples. In samples from the FGWQMNP where 17 of the 21 wells were cased with PVC, the median nitrate concentration was 0.2 mg/L.

and nitrate distribution as a function of well diameter.

SUMMARY AND CONCLUSIONS

A ground-water study-unit survey, part of the Georgia–Florida Coastal Plain National Water Quality Assessment program, was undertaken to characterize general water quality in surficial aquifers from July through October 1993. The study area was subdivided into three land resource provinces based on general soils: the Southern Coastal Plain, the Central Florida Ridge and the Coastal Flatwoods. Eighteen wells were selected in the Coastal Flatwoods and 19 wells were selected in the Southern Coastal Plain using a stratified, aerially weighted, random selection program. Existing data from 27 wells on the Central Florida Ridge were obtained from the Florida Department of Environmental Protection’s Ground Water Quality Monitoring Network Program. Major land uses in the study area are forest (46.5 percent), agriculture (29.4 percent), wetland (13.8 percent), urban (4.9 percent), and rangeland (2.6 percent). Sampled wells were mostly located in forest, agricultural and urban areas.

Concentrations of field parameters, major ions, nutrients, radon, and uranium in ground-water samples and precipitation were compared by land resource province. Concentrations of most major ions, nutrients and dissolved solids were higher in ground water than in precipitation and were quite variable among samples of ground water from the three major land resource provinces. Statistical comparisons of concentrations by land resource provinces showed significant differences in temperature, pH, specific conductance, dissolved solids, dissolved oxygen, bicarbonate, calcium, iron, sulfate, bromide, total phosphorus and orthophosphate phosphorus. Differences in values of pH, and specific conductance, and concentrations of dissolved solids, bicarbonate, calcium, iron, and sulfate may be because more carbonate minerals comprise surficial aquifers of Central Florida Ridge than in the other land resource provinces. Concentrations of magnesium, potassium, sodium, chloride, fluoride, nitrate, dissolved organic carbon, and hydrogen sulfide showed no significant differences among land resource provinces. Iron concentrations in many samples in the Coastal Flatwoods exceeded the U.S. Environmental Protection Agency's secondary MCL of 300 µg/L.

Nitrate as nitrogen concentrations were generally low in ground water in surficial aquifers, although 5 out of 48 samples had concentrations that exceeded U.S. Environmental Protection Agency's MCL of 10 mg/L. No significant difference was found in nitrate concentrations by land resource province. The median concentration of nitrate in the Central Florida Ridge was <0.2 mg/L, whereas the median nitrate concentrations in samples from the Coastal Flatwoods and Southern Coastal Plain were 1.0 and 1.2 mg/L, respectively. The lower median nitrate concentration in the Central Florida Ridge was related, in part, to well diameter and casing material. Nitrate concentrations in ground water were significantly lower in PVC wells and wells with a casing diameter of <6 in. The highest median nitrate concentration occurred in wells <25 ft deep. Concentrations of phosphorus, orthophosphate, ammonium and organic nitrogen were very low in all samples.

Tritium was measured in ground-water from the Southern Coastal Plain and Coastal Flatwoods to determine age of recharge water. All samples indicated that ground water was less than 40 year's old. Concentrations of tritium in ground water ranged from below the detection level (0.31) to 102 tritium units, and generally increased form south to north. An area of elevated tritium concentrations, in the northern study area, may be the related to the presence of a nearby nuclear facility. A weak monotonic correlation was found between nitrate and tritium concentrations.

Organic compounds were detected in 13 wells and concentrations were mostly <1 µg/L. Sixty volatile organic compounds and 47 commonly used pesticides were analyzed in samples from the Southern Coastal Plain and Coastal Flatwoods and 30 volatile organic compounds and 2 pesticides were analyzed in data from 14 wells on the Central Florida Ridge. Only 3 volatile organic compounds and 1 pesticide were detected at concentrations >1 µg/L: toluene, chloromethane, tetrachloroethane and metolachlor. Other volatile organic compounds detected at concentrations <1 µg/L included: tetra-chloroethylene, methylene chloride, bromomethane, chloroform, and methyl tertbutyl ether. Only three pesticides were detected, atrazine, desethyl -atrazine, and metolachlor. Concentrations were near 0.02 µg/L in most cases. One sample had a metolachlor concentration of 2.5 µg/L. Organic compounds were detected most often in wells <25 ft deep in agricultural settings. However, whether or not organic compounds were detected, was more closely related to local sources near the well, such as residential driveways, highways, and currently used agricultural fields rather than general land use near the well.

Radon concentrations did not vary by land resource province and ranged from 89 to 13,000 pCi/L. Radon concentrations exceeded the proposed USEPA MCL of 300 pCi/L for radon in drinking water in 33 of 36 samples. Uranium concentrations were below detection in all but one sample which had a concentration of 1.3 µg/L.

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