Shallow Ground-Water Quality in Selected Agricultural Areas of South-Central Georgia, 1994

By Christy A. Crandall

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CONVERSION FACTORS, VERTICAL DATUM, ABBREVIATIONS, AND ACRONYMS

<table>
<thead>
<tr>
<th>Multiply</th>
<th>By</th>
<th>To obtain</th>
</tr>
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<tbody>
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<td>inch (in.)</td>
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<td>centimeter</td>
</tr>
<tr>
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<td>2.54</td>
<td>centimeter per year</td>
</tr>
<tr>
<td>inch per hour (in/yr)</td>
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<td>centimeter per hour</td>
</tr>
<tr>
<td>gallon per minute (gal/min)</td>
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</tr>
<tr>
<td>mile (mi)</td>
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<td>kilometer</td>
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<tr>
<td>square mile (mi²)</td>
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<td>square kilometer</td>
</tr>
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<td>million gallons per day (Mgal/d)</td>
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</tr>
<tr>
<td>foot squared per day (ft²/d)</td>
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<td>meter squared per day</td>
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</tbody>
</table>

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

°C = (°F - 32)/1.8
°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
≥ = equal to or greater than
ppt = parts per thousand

**Acronyms**

DOC = dissolved organic carbon
GAFL = Georgia-Florida Coastal Plain
MCL = maximum contaminant level
NAWQA = National Water Quality Assessment
PVC = polyvinyl chloride
SMCL = secondary maximum contaminant level
USEPA = U.S. Environmental Protection Agency
USGS = U.S. Geological Survey
VOC = volatile organic compounds
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Abstract

The Georgia-Florida Coastal Plain National Water-Quality Assessment Program began an agricultural land-use study in March 1994. The study area is located in the upper Suwannee River basin in Tift, Turner, Worth, Irwin, Wilcox, and Crisp Counties, Ga. Twenty-three shallow monitoring wells were installed in a 1,335-square-mile area characterized by intensive row-crop agriculture (peanuts, corn, cotton, and soybeans). The study focused on recently recharged shallow ground water in surficial aquifers to assess the relation between land-use activities and ground-water quality. All wells were sampled in March and April (spring) 1994, and 14 of these wells were resampled in August (summer) 1994.

Shallow ground water in the study area is characterized by oxic and acidic conditions, low bicarbonate, and low dissolved-solids concentrations. The median pH of shallow ground water was 4.7 and the median bicarbonate concentration was 1.7 mg/L (milligrams per liter). Dissolved oxygen concentrations ranged from 3.0 to 8.0 mg/L. The median dissolved-solids concentration in samples collected in the spring was 86 mg/L. Major inorganic ion composition was generally mixed with no dominant cation; nitrate was the dominant anion (greater than 60 percent of the anion composition) in 14 of 23 samples. Only concentrations of bicarbonate, dissolved organic carbon, and nitrate had significant differences in concentrations between samples collected in the spring and the background samples. However, median concentrations of some of the major ingredients in fertilizer (including magnesium, chloride, nitrate, iron, and manganese) were higher in water samples from agricultural wells than in background samples.

The median concentration of dissolved solids in ground-water samples collected in the spring (86 mg/L) was more than double the median concentration (41 mg/L) of the background samples.

The median nitrate as nitrogen concentration of 6.7 mg/L in the spring samples reflects the effects of agricultural activities on ground-water quality. Samples from 30 percent of the wells exceeded the maximum contaminant level (MCL) for nitrate in drinking water (10 mg/L as N). Nitrogen isotope ratios ranged from 2.4 to 9.0 parts per thousand and indicate that most nitrogen in shallow ground water is probably from inorganic fertilizer. In addition, nitrate concentrations were positively correlated (p-values all less than 0.01) with concentrations of some of the major ingredients in fertilizer, such as potassium, calcium, magnesium, manganese, and chloride, and with values of specific conductance.

Concentrations of pesticides and volatile organic compounds, detected in samples from 11 wells, were all below the MCLs. Of these constituents, only alachlor, metolachlor, metribuzin, toluene, benzene, and methyl chloride were detected in ground water at concentrations that ranged from 0.01 to 1.0 μg/L (micrograms per liter). Maximum concentrations of 1.0 μg/L of metolachlor and toluene were detected in two wells. Radon concentrations ranged from 530 to 1,400 pCi/L (picocuries per liter), exceeding the proposed MCL of 300 pCi/L in all samples; the median concentration was 1,000 pCi/L.
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 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; evaluate variations in ground-water quality, both areally and with depth; and determine and compare the concentration and distribution of constituents in shallow ground water underlying areas of different land uses (Gilliom and others, 1995). To meet these objectives, ground-water quality is being assessed by a study-unit survey, land-use studies, and a flow-path study. The study-unit survey is designed to broadly characterize ground-water quality in the study unit, whereas the land-use and flow-path studies, conducted at the local scale, are designed to increase the understanding of causal relations and processes affecting ground-water quality (Gilliom and others, 1995). The primary objectives of land-use studies are to assess the concentrations and distribution of constituents in recently recharged ground water (generally less than 10 years old) in each study unit and to determine the human and natural factors affecting ground-water quality (Gilliom and others, 1995).

The GAFL NAWQA began an agricultural land-use study in February 1994 to assess the relation between agricultural land-use activities and ground-water quality. For this study, shallow ground water is defined as the first water-bearing zone present in the mostly unconsolidated sandy clays and clays that occur less than 100 ft below land surface.

Purpose and Scope

This report describes the concentrations and distribution of water-quality constituents in recently recharged shallow ground water in row-crop (peanuts, corn, cotton, and soybeans) agricultural areas in the upper Suwannee River basin in Crisp, Irwin, Tift, Turner, Wilcox, and Worth Counties, Ga. (fig. 1). Water samples were collected from 23 recently installed monitoring wells tapping shallow ground water in the spring and summer of 1994. Major inorganic water-quality constituent and dissolved organic carbon (DOC)
concentrations before and during the growing season were compared to background data and to the MCLs for drinking water. Concentrations of pesticides, volatile organic compounds (VOCs), radon, and uranium detected in shallow ground water were compared to the MCLs. Nitrogen isotope ratios were also determined to identify sources of nitrogen in shallow ground water.

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$^2$ (fig. 1). The GAFL agricultural land-use ground-water study area (hereafter known as the study area) encompasses about 1,335 mi$^2$ of the GAFL study unit and includes the upper Suwannee River basin in Crisp, Irwin, Tift, Turner, Wilcox, and Worth Counties, Ga. (fig. 1). The study area is situated within the Southern Coastal Plain land resource province; a physiographic subdivision of the study unit based primarily on soils (Berndt and others, 1995). This land resource province consists of broad interstream areas characterized by rolling hills and shallow to deeply incised stream valleys (Caldwell and Johnson, 1982). Altitudes in the study area range from approximately 250 to 475 ft (U.S. Geological Survey, 1979; 1981).

Upland soils in the study area (wells were located primarily in uplands of the study area) are ultisols mostly in the Tifton loam series (Soil Conservation Service, 1969; 1981; 1990; L. Busby, Soil Conservation Service, Wilcox County, written commun., 1994). Soils of this order are found throughout the southeastern United States (Brady, 1974). Soils of the Tifton series, formed in loamy fluvial sediments, are described as deep, well drained, moderately permeable, and strongly acidic in all horizons. In addition, these soils contain 5 percent or more iron by volume (Soil Conservation Service, 1983). Soils of this series are composed of finely siliceous, loamy sand, sandy loam, clayey loam, and sandy clay loam. Permeability ranges from 0.2 to 20 in/hr and water capacity ranges from 6 to 15 percent (Soil Conservation Service, 1983). Perched water tables are common in these soils and organic content ranges from about 1 to 2 percent by volume (Soil Conservation Service, 1983).

The climate of the study area is temperate to subtropical and is primarily influenced by the Gulf of Mexico or continental systems. Mean annual temperature for the study area ranges from about 46 °F in January to 80 °F in July (Owenby and Ezell, 1992).

Hydrogeology

The Southern Coastal Plain of the southeastern United States is a low, sloping, relatively flat surface which gently dips toward the Atlantic Ocean and the Gulf of Mexico (fig. 1). For the most part, relief is minimal except in river valleys. The Southern Coastal Plain is underlain by shallow fluvial and marine materials deposited during the rise and fall of sea level. The deposits consist of alternate layers of sloping, permeable and impermeable materials capable of storing large amounts of water (fig. 2) (Hubbard and Sheridan, 1989). Beneath the study area, low permeability units of the Hawthorn Group form a confining layer between the shallow aquifers and the regional Upper Floridan aquifer (Scott, 1988). Shallow aquifers are present beneath most of the study area (Miller, 1986) and are defined as permeable hydrologic units that are contiguous with land surface (Southeastern Geological Society, 1986). Shallow aquifers in the study area generally consist of unconsolidated fluvial deposits of sandy-clay that often contain iron oxides and range from late Miocene to Holocene in age (Bush and Johnston, 1988).

The thickness of these shallow water-bearing units varies over the study area but is generally less than 100 ft; however, a thickness of 325 ft southeast of the study area was recorded by Miller (1986). Shallow ground water is usually unconfined and perched, although semiconfined conditions may exist locally in the overburden where clay beds are present. Shallow aquifers include zones of confined conditions where clay lenses are present (Clarke and others, 1990).

Water enters the soil from rainfall, and, although some of the water is returned to the atmosphere through evapotranspiration, the remaining water either moves laterally and discharges to streams or percolates downward to recharge shallow aquifers and the Upper Floridan aquifer (Miller, 1986). At depths below 5 ft, saturated horizontal hydraulic conductivity ranges
from 0.06 to 0.27 ft/d in Tifton loamy soils (Hubbard and others, 1985). Within the study area, vertical hydraulic conductivities of $3.2 \times 10^{-3}$ and $1.5 \times 10^{-2}$ ft/d were recorded for the iron-rich impeding soil layer in the Tifton upland series (generally about 3 to 4 ft below land surface) and a soil layer at the top of the Hawthorn Group, respectively (Hubbard and Sheridan, 1989). These iron-rich clay and sandy-clay lenses cause perching of ground water. Saturated vertical hydraulic conductivity of the sandy clay generally ranges from 0.08 to 0.16 ft/d in Tifton soils (Hubbard and others, 1986). Well yields from shallow wells in the study area are poor and ranged from less than 1 to 3 gal/min.

Generally, the water-table surface of an unconfined aquifer is a subdued replica of the land-surface topography. Gradients are steeper between ridges and nearby streams and less steep in broad interstream areas. In the study area, the water-table surface may be very irregular with the direction of ground-water flow changing markedly within a short distance. Shallow ground water levels may fluctuate seasonally (by as much as 10 ft) and respond rapidly to rainfall (Krause and Randolph, 1989).

Water levels in the shallow ground water wells of the study area generally responded within 24 hours of a rainfall event and rose by as much as 4 ft in a 6-hour period (October 1 through 3, 1994) (fig. 3). A pressure transducer was installed in well 8 to monitor water-level fluctuations. Water levels were compared with rainfall amounts measured in a National Atmospheric Deposition Program/National Trends Network (NADP/NTN) rainfall collector, located approximately 40 ft from the well site (station GA99). Figure 3 shows water levels recorded from June through October 1994 in well 8 and nearby rainfall.

**Land Use and Agricultural Practices**

Land use can affect shallow ground-water quality in unconfined and semiconfined aquifers. Data from the USGS classification system for land use and land cover (1972-76), hereafter referred to as USGS land use (Anderson and others, 1976; Mitchell and others, 1977), were used with some modifications to identify areas of the highest percentages of agricultural land uses in the GAFL study unit. General land use and land cover in the study area includes forest (28.7 percent), agriculture (63.5 percent), wetland (5.5 percent), urban (2.0 percent), water and other (about 0.3 percent) (Anderson and others, 1976; Hitt, 1994). The category "other" includes rangeland, mines, and quarries. The geographic extent of the urban, forest, agricultural, and other land-use areas is shown in figure 4.
Figure 3. Water levels and daily rainfall near well 8, 1994.

Peanuts, corn, and cotton are the major crops grown in the study area and are generally grown on a 3-year rotation schedule in each field. Peanuts are commonly grown more frequently than once every 3 years. A nitrogen fixer, such as soybeans or peanuts, typically will be grown in the season preceding a crop that has high nitrogen needs, such as corn. The rotation is usually arranged to minimize the nitrogen needs, thereby reducing the application of fertilizer, and to reduce pest accumulation, such as nematodes. Peanuts were the most common crop in the upgradient field during the 1993 and 1994 growing seasons (table 1). Soybeans, millet, beans, rye and truck vegetables were also grown in the study area but to a much lesser extent. During the 1993 growing season, 10 upgradient fields were planted in peanuts, 8 were planted in corn, 4 were planted in cotton, and 1 was planted in soybeans (table 1). During the 1994 growing season, 10 upgradient fields were planted in peanuts, 5 were planted in cotton, 5 were planted in corn, and 1 each was planted in soybeans, millet, and beans. A significant increase in cotton production has taken place in southern Georgia since 1993 as the result of controlling the boll weevil (John Chisholm, Worth County Agricultural Extension Office, oral commun., 1994).

Generally, fertilizer application rates in the study area are moderate to heavy depending on crop rotation, soil type, and irrigation practices. Approximately 20 lb/acre of nitrogen and 40 to 60 lb/acre of phosphorus (as P₂O₅) are applied to grow soybeans and peanuts (W. Segars, Cooperative Extension Service, written commun., 1994). In well drained upland soils such as those of the study area, approximately 90 lb/acre of nitrogen and 75 lb/acre of phosphorus are applied to grow cotton (W. Segars, written commun., 1994). As much as 125 to 220 lb/acre of nitrogen and 50 lb/acre of phosphorus may be applied to grow corn (W. Segars, written commun., 1994) depending on the use of the crop (cash, silage, or grain) and irrigation practices (more nitrogen is applied to an irrigated cash crop than to a crop intended to be used for silage) (Cooperative Extension Service, 1990). Only the upgradient field near well 8 was irrigated during the 1993 and 1994 growing season. The water was pumped from a nearby storage pond.
Figure 4. Land use and cover in the study area.
Methods

Ground-water sampling sites were selected using a stratified, areally weighted, random statistical method (Scott, 1990). Potential ground-water sampling sites were identified by dividing the study area into 25 equal area cells. Within each equal area cell, five potential well sites were randomly selected. Each potential well site was investigated at the corresponding county Agricultural Stabilization and Conservation Service (ASCS) office using aerial photographs to determine current and past land uses of the closest upgradient field to the site. Acceptable well sites had grown row crops in the immediate upgradient field for the past 10 years. Once candidate sites were identified, field reconnaissance was performed to choose the best well site within each cell. Permission to drill and sample water from the well was then sought from each land owner.

Wells were drilled and installed in February and March 1994 using an 8-in. diameter hollow-stem auger. The auger flights were steam cleaned between sites. Each well was constructed of 2-in. diameter, threaded joint, polyvinyl chloride (PVC) casing and screens (no glue was used) (Lapham and others, 1995). Well depths ranged from 17 to 70 ft (table 1). Most wells were constructed with a 10-ft, 0.008-in slot-size screen; longer screens (20-30 ft) were installed in four wells drilled in low permeability material. In six wells, screens were placed 5 ft above the bottom of the well. The annulus adjacent to each screen and about 2 ft above the screen was packed with clean silica sand. A bentonite seal was placed above the sand pack to seal the annulus. Native material was used to backfill to within 2 ft of the top of the hole, where cement was poured to protect the hole from surface contamination and to secure a locking steel protector over the well. Well number and construction information are given in table 1.

Ground-water samples were collected according to the NAWQA protocols (Koterba and others, 1995) from the 23 wells in the spring (March and April, 1994) and 14 wells in the summer (August 1994). Before sampling, each well was purged by removing three well volumes of water. The pH, specific conductance, temperature, dissolved oxygen, and turbidity were measured every 10 minutes until stabilization was achieved. A 2-in diameter, submersible, stainless steel and Teflon pump was used to collect samples from 14 wells and a Teflon bailer was used to collect samples from nine wells in March and April because of poor

Table 1. Record of wells and crops grown in upgradient fields in 1993 and 1994

<table>
<thead>
<tr>
<th>Well number</th>
<th>Station identification number</th>
<th>Georgia grid number</th>
<th>Depth of well (feet)</th>
<th>Screened interval (feet)</th>
<th>Depth of water below land surface (spring 1994) (feet)</th>
<th>Crop grown in upgradient field, 1993</th>
<th>Crop grown in upgradient field, 1994</th>
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<tbody>
<tr>
<td>01</td>
<td>312003083314401</td>
<td>17O22</td>
<td>22.0</td>
<td>12-22</td>
<td>3.01 peanuts</td>
<td>millet</td>
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<tr>
<td>02</td>
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<td>17O23</td>
<td>31.0</td>
<td>21-31</td>
<td>2.50 cotton</td>
<td>peanuts</td>
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<td>14.14 cotton</td>
<td>peanut</td>
<td></td>
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</tbody>
</table>

[All wells were constructed of threaded polyvinyl chloride; see fig. 1 for well number locations]
yields. Generally, wells sampled with a bailer were evacuated by removing three casing volumes. Dissolved oxygen and turbidity were not measured in these wells because of the sampling method.

Laboratory analyses of samples included: pH, specific conductance, alkalinity, major inorganic constituents, nutrients, DOC, pesticides, VOCs, radon, and uranium (Rose and Schoeder, 1994; American Society for Testing and Materials, 1995a,b; Zaugg and others, 1995) (app. I). Because radon must be measured from water that has not been in contact with the atmosphere, bailed samples were not analyzed for radon. Additionally, samples collected in the summer were analyzed for nitrogen isotope ratios. Quality-assurance samples, including blanks, duplicates, and spikes (VOCs only) were included in samples collected in both the spring and summer.

Nonparametric statistical methods were also used to compare inorganic constituent concentrations from samples collected in the spring (before the growing season) to background data collected in the southern coastal plain as part of the NAWQA ground-water study-unit survey (Crandall and Berndt, 1996) and to samples collected in the summer (during the growing season). The Wilcoxon rank-sum test was used to compare differences between water-quality constituents collected in the spring to background samples. The Kruskal-Wallis test was used to determine if significant differences existed between nitrate concentrations at different water depths and different crop types (Gilbert, 1987; SAS Institute, Inc., 1993). A significant difference was determined between groups if the level of significance or p-value was less than or equal to 0.05. The Wilcoxon signed-rank test and the paired t-test (SAS Institute, Inc., 1993) were used to compare paired samples from the spring and summer to determine if significant differences existed in these paired populations. The Spearman rank correlation was used to examine correlation in data between two variables (Helsel and Hirsch, 1992; Hamilton and Helsel, 1995). A positive or negative correlation was considered significant at a level or p-value of less than or equal to 0.05.

**Ground-Water Quality**

Major inorganic constituent concentrations in ground water were compared to constituent concentrations in rainfall and to MCLs and Secondary Maximum Contaminant Levels (SMCLs). Ground-water quality constituent concentrations were compared to back-

Ground data from the Southern Coastal Plain collected in 1993 for the NAWQA ground-water study-unit survey (Crandall and Berndt, 1996). Concentrations of major inorganic constituents and nutrients were also compared before and during the growing season (samples collected in spring and summer). Concentrations of nitrate were compared relative to crop grown in 1993 and 1994 in the upgradient field, depth of water below land surface, and the vertical distance between the sampling point and the water table. VOCs and pesticides detected in shallow ground water are compared to the MCLs. The radon values in shallow ground water are also discussed.

**Major Inorganic Constituents**

Factors affecting the water quality of shallow ground water include the quality and quantity of the rainfall providing recharge in the study area. As recharge water moves through the soil zone and aquifer material, the water is chemically altered through mineral dissolution, precipitation of solids, cation exchange, oxidation-reduction, anion exchange, and sorption of organic molecules (Snoeyink and Jenkins, 1980). Evapotranspiration, plant respiration, and uptake in the root zone enriches the water with carbon dioxide (Stumm and Morgan, 1981) providing the acidity that drives many of the weathering reactions (Drever, 1988). Other important factors affecting the water chemistry include the residence time of the ground water in contact with reactive aquifer material and the proximity of a sample-collection site to a source of contamination (Berndt and Katz, 1992).

The volume-weighted mean concentrations of major inorganic constituents and nitrate in rainfall were compared to concentrations of major inorganic constituents and nitrate in shallow ground water. Rainfall chemistry data were available from the National Atmospheric Deposition Program/National Trends Network sites GA99 and GA50 (the collector was moved adjacent to well 8 in January 1994) from 1980 through 1994 (fig. 1) (National Atmospheric Deposition Program/National Trends Network, 1995). Piper plots and Stiff diagrams (figs. 5 and 6, respectively) were used to evaluate the relative concentrations (in milliequivalents per liter) of major ions in rainfall and ground water. The Piper plot (fig. 5) shows that sulfate was the dominant anion and that sodium and potassium were the dominant cations in rainfall. An ion is considered dominant when it composes more than 60 percent of
the total anion or cation concentration in milliequiva-
lents per liter (Davis and DeWiest, 1966). Rainfall at
the site generally had low dissolved-solids and nitrate
concentrations (fig. 5). Bicarbonate concentrations in
rainfall were not available, but are commonly less than
10 mg/L (Hem, 1989).

Although some ground-water samples had a simi-
lar chemical composition to rainfall (fig. 6), most were
higher in concentrations of dissolved solids, had pro-
portionately less sodium and sulfate, and proportion-
ately more nitrate, chloride, calcium, and bicarbonate
than rainfall. These differences may exist because of
cation exchange, evapoconcentration, dissolution of
minerals in the aquifer matrix, and movement of fertil-
izer into the soil zone. Nitrate was the dominant anion
in 14 of 23 ground-water samples collected in the
spring. The remaining ground-water samples were
mixed or dominated by chloride or bicarbonate; in
contrast, the dominant anion in rainfall was sulfate.
Most ground-water samples were mixed with respect to
cation composition (13 of 23 samples). Sodium and
potassium or calcium and magnesium were the domi-
nant cation pairs in 10 samples collected in the spring.
The major ion composition of samples collected in the
summer was similar to the composition of samples
collected in the spring.

Concentrations of fluoride, silica, and bromide
were generally low in ground-water samples collected
in the study area. The median concentration of fluoride
was less than 0.1 mg/L (the detection limit) in samples
collected in the spring and summer (tables 2 and 3).
Silica concentrations (as SiO₂) in spring samples
ranged from 3.9 to 90 mg/L and had a median value of
7.6 mg/L. Concentrations of bromide ranged from less

Figure 5. Piper diagram of the chemistry of rainfall and ground-water samples in the study area, spring and
summer, 1994.
Figure 6. Stiff diagrams of the chemistry of rainfall and ground-water samples in the study area, spring, 1994.
Table 2. Selected water-quality data for samples collected in 1994 and samples collected as part of the Georgia-Florida Coastal Plain study-unit survey

[Concentrations of constituents are in milligrams per liter, unless stated otherwise; for agricultural land-use area, 14 samples for dissolved oxygen and 13 samples for radon, uranium were measured in 18 samples; SMCL, Secondary Maximum Contaminant Levels; n, number of samples; µS/cm, microsiemens per centimeter at 25 degrees Celsius; µg/L, micrograms per liter; pCi/L, picocuries per liter; --, missing or not available; <, less than; *, significant differences]

<table>
<thead>
<tr>
<th>Constituent</th>
<th>SMCLs</th>
<th>Study area wells sampled</th>
<th>Background data from wells in the southern coastal plain</th>
<th>Wilcoxon p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>spring 1994 n = 23</td>
<td>n = 19</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Median                 Range</td>
<td>Median       Range</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td>Water level below land surface (ft)</td>
<td>--</td>
<td>6.35                   0.7 - 33.0</td>
<td>20.0          4.3 - 47.4</td>
<td></td>
</tr>
<tr>
<td>Temperature (degrees Celsius)</td>
<td>--</td>
<td>18.9                   14 - 24</td>
<td>22            20 - 32</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td>pH (standard units)</td>
<td>6.5 - 8.5</td>
<td>4.7                    4.1 - 5.4</td>
<td>5.2           4.1 - 7.4</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td>Specific conductance (µS/cm)</td>
<td>--</td>
<td>92                     17.7 - 202</td>
<td>58            26 - 542</td>
<td>0.59</td>
</tr>
<tr>
<td>Dissolved solids</td>
<td>500</td>
<td>86                     10 - 138</td>
<td>41            2.0 - 332</td>
<td>0.09</td>
</tr>
<tr>
<td>Bicarbonate¹</td>
<td>--</td>
<td>1.7                    &lt;1.0 - 14.6</td>
<td>4.0           &lt;1.0 - 124</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td>Dissolved oxygen</td>
<td>--</td>
<td>6.4                    3.0 - 7.4</td>
<td>4.8           0.20 - 7.9</td>
<td>0.15</td>
</tr>
<tr>
<td>Calcium</td>
<td>--</td>
<td>4.7                    0.47 - 12</td>
<td>0.51          0.11 - 0.20</td>
<td>0.09</td>
</tr>
<tr>
<td>Magnesium</td>
<td>--</td>
<td>2.6                    0.21 - 8.9</td>
<td>0.08          0.17 - 18</td>
<td>0.08</td>
</tr>
<tr>
<td>Sodium</td>
<td>--</td>
<td>2.5                    1.0 - 8.0</td>
<td>3.6           1.3 - 27</td>
<td>0.06</td>
</tr>
<tr>
<td>Potassium</td>
<td>--</td>
<td>1.0                    0.1 - 4.1</td>
<td>1.0           &lt;0.10 - 0.9</td>
<td>0.91</td>
</tr>
<tr>
<td>Chloride</td>
<td>250</td>
<td>8.5                    1.7 - 21</td>
<td>5.3           2.8 - 71</td>
<td>0.77</td>
</tr>
<tr>
<td>Sulfate</td>
<td>280</td>
<td>0.7                    0.1 - 12</td>
<td>0.80          0.20 - 5.8</td>
<td>0.42</td>
</tr>
<tr>
<td>Fluoride</td>
<td>2.0</td>
<td>&lt;0.1                   &lt;0.1 - 0.2</td>
<td>0.10          &lt;0.10 - 0.40</td>
<td>0.47</td>
</tr>
<tr>
<td>Dissolved organic carbon</td>
<td>--</td>
<td>0.4                    0.2 - 13</td>
<td>3.5           0.4 - 21</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td>Iron (µg/L)</td>
<td>300</td>
<td>26                     3 - 71</td>
<td>10            3.0 - 3.0</td>
<td>0.69</td>
</tr>
<tr>
<td>Manganese</td>
<td>50</td>
<td>12                     1.0 - 87</td>
<td>9.0           1.0 - 370</td>
<td>0.41</td>
</tr>
<tr>
<td>Silica (as SiO₂)</td>
<td>--</td>
<td>8.0                    3.9 - 90</td>
<td>6.7           3.7 - 24</td>
<td>0.18</td>
</tr>
<tr>
<td>Bromide</td>
<td>--</td>
<td>0.03                   0.01 - 0.16</td>
<td>0.02          &lt;0.01 - 0.22</td>
<td>0.06</td>
</tr>
<tr>
<td>Nitrate + nitrite (as N)</td>
<td>210</td>
<td>6.7                    &lt;0.05 - 0.16</td>
<td>1.2           &lt;0.05 - 0.33</td>
<td>0.03*</td>
</tr>
<tr>
<td>Ammonia (as N)</td>
<td>3</td>
<td>0.02                   &lt;0.01 - 0.03</td>
<td>0.02          &lt;0.01 - 1.0</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td>Organic nitrogen plus ammonia (as N)</td>
<td>--</td>
<td>&lt;0.2                   &lt;0.20 - 0.2</td>
<td>&lt;0.20         &lt;0.20 - 0.20</td>
<td>0.11</td>
</tr>
<tr>
<td>Phosphorus (as P)</td>
<td>--</td>
<td>&lt;0.01                  &lt;0.01 - 0.37</td>
<td>&lt;0.01         &lt;0.01 - 0.15</td>
<td>0.55</td>
</tr>
<tr>
<td>Orthophosphate (as P)</td>
<td>--</td>
<td>&lt;0.01                  &lt;0.01 - 0.39</td>
<td>0.01          &lt;0.01 - 0.13</td>
<td>0.13</td>
</tr>
<tr>
<td>Radon (pCi/L)</td>
<td>4300</td>
<td>1,000                  530 - 1400</td>
<td>690           89 - 7,900</td>
<td>--</td>
</tr>
<tr>
<td>Uranium (µg/L)</td>
<td>--</td>
<td>&lt;1.0                   &lt;1.0 - &lt;1.0</td>
<td>&lt;1.0          &lt;1.0 - 1.3</td>
<td>--</td>
</tr>
</tbody>
</table>

¹ Bicarbonate alkalinity measured on samples with pH greater than 4.8 only.
² MCLs (U.S. Environmental Protection Agency, 1990; 1995).
³ Lifetime health advisory for a 70-kilogram (154-pound) adult (U.S. Environmental Protection Agency, 1990; 1995).

than 0.01 to 0.16 mg/L in samples collected in the spring and summer. No significant differences (p-value 0.51 and 0.75) were detected in silica and bromide concentrations between samples collected in the spring and summer (table 3). Fluoride concentrations were generally below detection levels (0.1 mg/L) in samples collected in the spring and summer.

Dissolved oxygen concentrations (in water from pumped wells) were relatively high. Concentrations of dissolved oxygen in shallow ground water ranged from 3.0 to 7.4 mg/L in the spring and 4.3 to 8.0 mg/L in the summer (tables 2 and 3). The median dissolved oxygen concentrations were 6.4 mg/L and 5.9 mg/L in samples collected in the spring and summer, respectively.

Concentrations of major inorganic constituents in samples collected in the 1994 were compared to concentrations in background samples collected for the Georgia-Florida Coastal Plain ground-water study-unit survey from shallow wells in the Southern Coastal Plain land resource province (Crandall and Berndt, 1996). Although concentrations of most major inorganic constituents in the spring data were similar (p-value >0.05) to those of the background samples (table 2), concentrations of nitrate were significantly higher in the spring samples. Concentrations of ammonia, DOC, bicarbonate, and values of pH and temperature were significantly higher in background samples than in spring samples. No significant differences were detected among concentrations of fluoride, bromide, and silica and background concentrations (p-values were 0.47, 0.06, and 0.18, respectively) (table 2).

Water levels (depth below land surface) were compared to concentrations of selected inorganic constituents and to background wells. The median depth to
and magnesium concentrations and higher values of specific conductance near the top of the water table. No significant positive correlations were detected between water levels and other constituents in samples collected in the spring or summer.

Data from samples collected from the 14 wells in the spring and summer were compared using two paired-sample nonparametric tests to identify significant differences in water chemistry before and during the growing season (table 3). The median concentrations of bicarbonate, dissolved oxygen, magnesium, chloride, iron, manganese, and nitrate plus nitrate were greater in samples collected in the spring than in the summer. The median dissolved-solids, sodium, potassium, sulfate, silica, and phosphorus concentrations were greater in samples collected in the spring than in the summer. The heaviest application of fertilizer is in the spring and may account for the higher concentrations of magnesium, chloride, and nitrate in the spring samples. The median water level (below land surface) in the 14 wells sampled both in the spring and summer.
was significantly greater in the wells in the summer (14.0 ft) than in the spring (7.6 ft) (p-value < 0.01) (table 3). Dissolved solids concentrations may have been higher in the summer because of higher rates of evapotranspiration (lowering water levels).

Concentrations of most constituents were below the drinking water standards and criteria established by the U.S. Environmental Protection Agency (USEPA, 1990; 1995) to safeguard public health and welfare. The SMCL for manganese was exceeded in five samples collected in the spring and in two samples collected in the summer (tables 2 and 3). Values for pH were outside the SMCL range established for drinking water of 6.5 to 8.5.

Nitrogen and Phosphorus

Nitrogen and phosphorus are essential elements in the life processes of plants and animals; however, when these are present in elevated concentrations in water supplies, damage to the resource results (Madison and Brunett, 1985). Nutrient sources to ground water are rainfall, fertilizer, irrigation, and weathering of soil parent material. Nutrients may be removed from a watershed via overland flow, denitrification, streamflow, subsurface flow, deep seepage, through the loss of volatile gases, and/or the harvest of plant and animal crops (Lowrance and others, 1985). Ground water of the southeastern United States is at risk for elevated nitrate levels for several reasons: the sandy soils of the area require large amounts of nitrogen fertilizer to grow certain crops (corn and cotton); and the high average annual rainfall (approximately 48 in/yr in the study area) and high annual runoff (10-15 in/yr) is likely to move fertilizer into the soil zone with the infiltrating water (Hubbard and Sheridan, 1989).

Concentrations of nitrate, ammonia, organic nitrogen, phosphorus, and orthophosphate in shallow ground water in the study area before and during the growing season were compared to background concentrations. Nitrate concentrations were compared to depth to water, and to crop planted in the upgradient field from each well in 1993 and 1994.

Nitrate

Nitrate concentrations in ground water in agricultural areas reflect, among other things, the timing of the application of fertilizer and rainfall, denitrification rates, and plant growth (Hubbard and others, 1991). Nitrogen may be transported through overland flow or leached before biological uptake by plants, or before microbial activity can remove it from the soil if a heavy rainfall occurred immediately after the application of fertilizer (Hubbard and others, 1991). This latter situation would most likely occur at the beginning of the growing season when most of the nitrogen fertilizers are applied. Once infiltrated, nitrate generally moves through the soil in a pulse; an initial concentration spike is produced from macropore flow, followed by a relatively slow moving wave of nitrate through the soil matrix (Hubbard and others, 1991).

Concentrations of nitrate as nitrogen in ground water in the study area ranged from less than 0.05 to 16 mg/L in samples collected in the spring and from 0.13 to 20 mg/L in samples collected in the summer (tables 2 and 3). The median nitrate concentration in samples collected in the spring was 6.7 mg/L, which is significantly higher (p-value 0.03) than concentrations of nitrate in background samples (from study-unit survey wells in the Southern Coastal Plain) (median of 1.2 mg/L) (table 2). Background wells were generally located more than 100 ft away from an active agricultural field. Study-area wells are usually 20 ft or less from an active agricultural field growing some type of row crop. The median nitrate concentration in samples collected in the summer was 4.7 mg/L in the study area. Differences in the nitrate concentrations were insignificant, based on a paired Wilcoxon signed-rank test, in samples from 14 wells sampled before (spring) and during (summer) the growing season (p-value 0.74) (table 3).

To assess the scope of land use (human activities) on ground-water quality, four ranges of nitrate concentrations were established (Madison and Brunett; 1985):

- 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 for nitrate as nitrogen in drinking water as a result of human activities.

Nitrate concentrations in 3 of 23 (13 percent) ground-water samples collected in the spring and 1 of 14 samples (7 percent) collected in the summer were below 0.2 mg/L (fig. 7) and indicate little human influence (Madison and Brunett, 1985). Samples from four wells (17 percent) collected in the spring and three wells (21 percent) collected in the summer had nitrate
concentrations between 0.21 to 3.0 mg/L, indicating possible influence from human activities. Nine samples (39 percent) collected in the spring and six samples (43 percent) collected in the summer had nitrate concentrations between 3.0 and 10 mg/L, indicating probable human influence. The concentration of nitrate as nitrogen exceeded the MCL of 10 mg/L (USEPA, 1990, 1995) in 7 of 23 samples (30 percent) collected in the spring and 4 of 14 samples (29 percent) collected in the summer. In summary, samples from 69 percent of the wells in the spring and 72 percent of the wells in the summer show influence from human activities (concentrations >3.0 mg/L). In contrast, only 26 percent of samples from the study-unit survey in the Southern Coastal Plain had nitrate concentrations greater than 3.0 mg/L.

Nitrate concentrations were compared with depth of water (below land surface) and distance of the sampling point from the water table. Three intervals for depth to water were evaluated: 0 to less than 5.0 ft, 5.0 to 10.0 ft and 10.0 ft and greater. Nitrate concentrations in each depth category between samples collected in the spring and summer did not differ significantly (p-value 0.72 and 0.59, respectively) (table 4). However, median nitrate concentrations were greatest (8.0 mg/L and 10.1 mg/L in the spring and summer, respectively) in the interval between 5.0 and 10.0 ft below land surface (table 4). Median nitrate concentrations were lowest (2.6 mg/L and 3.8 mg/L in the spring and summer, respectively) when the water table was 10 ft or more below land surface (table 4). Nitrate concentrations were not significantly correlated to well

Figure 7. Nitrate concentrations in ground-water samples in the study area, 1994.
Table 4. Nitrate concentrations and water levels, 1994

<table>
<thead>
<tr>
<th>Depth of water below land surface, in feet</th>
<th>Median concentration (mg/L)</th>
<th>Range (mg/L)</th>
<th>n</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spring, 1994</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0–&lt;5.0</td>
<td>6.7</td>
<td>&lt;0.05–16.0</td>
<td>9</td>
<td>0.72</td>
</tr>
<tr>
<td>5.00–&lt;10.0</td>
<td>8.0</td>
<td>0.08–16.0</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>≥10.0</td>
<td>2.6</td>
<td>0.05–14.0</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td><strong>Summer, 1994</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0–&lt;5.0</td>
<td>7.5</td>
<td>4.2–12.0</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5.00–&lt;10.0</td>
<td>10.1</td>
<td>0.13–20.0</td>
<td>2</td>
<td>0.59</td>
</tr>
<tr>
<td>≥10.0</td>
<td>3.8</td>
<td>0.36–12.0</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

Nitrate concentrations and water levels, 1994

[n, number of samples; p-value is a group comparison; <, less than]

This may be because these crops are grown on a 3-year rotation cycle; nitrate concentrations may reflect the application rates averaged over the 3-year period (actual fertilizer application times and rates were unknown in relation to sampling).

Ammonia, Organic Nitrogen, Phosphorus, and Orthophosphate

Ammonia and organic nitrogen concentrations in ground-water samples collected in the spring and summer were, for the most part, at or near the detection level. Median concentrations of ammonia (as nitrogen) were 0.02 mg/L in samples collected in the spring and less than 0.01 mg/L in samples collected in the summer (tables 2 and 3). No significant differences were detected between concentrations of ammonia in the paired samples collected in the spring and summer (p-value 0.65). Ammonia concentrations in the study area were significantly lower than in the background samples collected for the study-unit survey in the Southern Coastal Plain (p-value < 0.01). Ammonia concentrations ranged from less than 0.01 to 0.03 mg/L in samples from the spring and ranged from less than 0.01 to 1.0 mg/L in background samples. This may be due to the higher dissolved oxygen concentrations in ground water in the spring study area samples. Organic nitrogen concentrations were below detection levels in samples collected in the spring and summer.

Concentrations of orthophosphate and total dissolved phosphorus in ground-water samples from the study area were also at or near the detection level. Concentrations of orthophosphate (as phosphorus) ranged from less than 0.01 (the detection level) to 0.39 mg/L in samples collected in the spring, and ranged from less than 0.01 to 0.41 mg/L in samples collected in the summer (tables 2 and 3). Low concentrations of phosphorus compounds are common in ground water, because orthophosphate is usually tightly bound to iron oxides and organic matter in the soil zone or taken up by biota (Hem, 1989).
Concentrations of orthophosphate in ground water did not differ significantly (p-value 1.00) between samples collected in the spring and summer. The median concentration of orthophosphate was less than 0.01 mg/L in samples collected in the spring and summer (tables 2 and 3). The median orthophosphate concentration in background samples from the Southern Coastal Plain was also 0.01 mg/L (table 2). Concentrations of total phosphorus were low and ranged from below the detection level of 0.01 to 0.46 mg/L (tables 2 and 3). Results showed no significant difference (p-value 0.30) in concentrations of phosphorus between samples collected in the spring and summer.

Organic Compounds

DOC concentrations were generally low in groundwater samples collected in the spring and were much lower than background samples. Concentrations of DOC ranged from 0.2 to 13 mg/L in samples collected in the spring. The median DOC was 0.4 mg/L, whereas the median concentration of DOC in background samples was 3.5 mg/L and ranged from 0.4 to 21 mg/L (table 2). Concentrations of DOC were significantly higher (p-value less than 0.01) in background samples (table 2).

Pesticides and VOCs were detected at trace concentrations in samples from only 11 wells, but at concentrations well below MCLs or lifetime health advisory levels (table 6). Organic compounds that were detected and minimum reporting levels are listed in table 6.

Although many insecticides, herbicides, and nematicides are commonly used in growing corn, cotton, peanuts, and soybeans, only alachlor, metolachlor, and metribuzin were detected in water samples from eight of the sampled wells. Metolachlor was detected in seven samples collected in the spring and in three samples collected in the summer (from three of the same wells where it was detected in the spring). These pesticides were detected in samples collected in wells downgradient from a field of peanuts three times, downgradient from a field of corn two times, and downgradient from a field of soybeans, millet, or cotton one time each in the 1994 season.

Benzene, toluene, and methyl chloride were the only VOCs detected in ground-water samples in the study area. Concentrations of VOCs in the five samples detected were below MCLs. The maximum concentration of VOCs detected was 1.0 µg/L of metolachlor in water from well 5 and 1.0 µg/L of toluene in water from well 2. Both metolachlor and toluene were detected in well 13, but at lower concentrations.

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 short period of time. As a result of the alpha decays, radon 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 in rocks or sediments. Uranium is 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 shallow ground-water flow paths (Gundersen and Szabo, 1995) until sorbed by clays, organic humic material, or iron oxides (Gundersen and Peake, 1992). Once sorbed, it becomes a continuous source of radon. The highest concentrations of radon (and adsorbed uranium) are usually detected in iron-rich, glauconitic, phosphatic, or carbonaceous materials (Gundersen and Peake, 1992).

Table 6. Volatile organic compounds and pesticides detected in ground water in water samples collected, spring and summer, 1994

<table>
<thead>
<tr>
<th>Compound name</th>
<th>Maximum and range in concentration (µg/L)</th>
<th>MRL (µg/L)</th>
<th>MCL (µg/L)</th>
<th>Well number where detected</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pesticides</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alachlor</td>
<td>0.012</td>
<td>0.009</td>
<td>2.0</td>
<td>11</td>
</tr>
<tr>
<td>Metolachlor</td>
<td>10.00 (0.011 - 1.00)</td>
<td>0.009</td>
<td>270</td>
<td>5, 11, 13, 16, 19, 21, 22</td>
</tr>
<tr>
<td>Metribuzin</td>
<td>0.037</td>
<td>0.012</td>
<td>100</td>
<td>1</td>
</tr>
<tr>
<td><strong>VOCs</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benzene</td>
<td>0.70</td>
<td>0.2</td>
<td>5.0</td>
<td>5</td>
</tr>
<tr>
<td>Toluene</td>
<td>1.0 (0.4 - 1.0)</td>
<td>0.2</td>
<td>1.000</td>
<td>2, 13</td>
</tr>
<tr>
<td>Methyl Chloride</td>
<td>0.2 (0.2 - 0.2)</td>
<td>0.2</td>
<td>0.30</td>
<td>18, 20</td>
</tr>
</tbody>
</table>

1See table 1 and figure 1 for 15-digit station identification numbers and locations.
2Lifetime Health Advisory for a 70-kg adult (U.S. Environmental Protection Agency, 1990; 1995).
Radon concentrations ranged from 530 to 1,400 picocuries per liter (pCi/L) in 14 ground-water samples collected in the spring of 1994. Radon concentrations exceeded the proposed MCL of 300 pCi/L (U.S. Environmental Protection Agency, 1990; 1995) in all samples (fig. 8) and exceeded 1,000 pCi/L in seven wells. The median concentration of radon was 1,000 pCi/L (table 2).

Eighteen samples collected in the spring of 1994 were analyzed for dissolved uranium concentrations. Uranium concentrations were below the detection level of 1.0 µg/L in all samples. Uranium is present but is sorbed onto aquifer materials, based on radon concentrations. Generally, aquifer sediments containing about 1 mg/kg of uranium would produce a radon activity greater than 800 pCi/L (Rogers, 1958); only ultramafic and basaltic rocks would have concentrations of uranium less than 1 mg/kg (Rogers and Adams, 1969). Background samples from the Southern Coastal Plain also had low concentrations of uranium (below detection level) and fairly high concentrations of radon (ranging from 89–7,900 pCi/L; see table 2).

Effects of Fertilizer Application on Water Quality

The application of fertilizer has changed the natural quality of shallow ground water throughout agricultural areas of the United States. Agricultural chemicals are a significant source of nitrate in ground water near

Figure 8. Radon values in ground-water samples in the study area, 1994.
Table 7. Spearman’s rho (correlation) of nitrate concentrations with other major inorganic constituents in fertilizer in spring samples

<table>
<thead>
<tr>
<th></th>
<th>Potassium</th>
<th>Calcium</th>
<th>Magnesium</th>
<th>Manganese</th>
<th>Chloride</th>
<th>Iron</th>
<th>Specific conductance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spearman’s rho</td>
<td>0.62</td>
<td>0.85</td>
<td>0.91</td>
<td>0.81</td>
<td>0.78</td>
<td>-0.60</td>
<td>0.86</td>
</tr>
<tr>
<td>(p-value)</td>
<td>(&lt;0.01)</td>
<td>(&lt;0.01)</td>
<td>(&lt;0.01)</td>
<td>(&lt;0.01)</td>
<td>(&lt;0.01)</td>
<td>(&lt;0.01)</td>
<td>(&lt;0.01)</td>
</tr>
</tbody>
</table>

agricultural fields and elevated nitrate concentrations have been previously associated with agricultural practices in Georgia (Hubbard and others, 1985; 1986).

On the Delmarva Peninsula, the highest concentrations of nitrate were associated with areas of intensive corn and soybean production primarily in the well drained uplands where aerobic conditions prevailed (Hamilton and others, 1991). A study in Texas showed that ground water in wells in or near agricultural fields had an average nitrate concentration of 21 mg/L, whereas domestic supply wells ranged from 6 to 14 mg/L (Kreitler and Jones, 1975).

Water samples collected in the spring and summer of 1994 from monitoring wells in the study area had significantly higher nitrate concentrations than background samples from the study-unit survey in the Southern Coastal Plain (table 2 and 3). As stated previously, nitrate was the dominant anion in 14 of 23 samples collected in the spring of 1993. Nitrate concentrations were as high as 20 mg/L (collected in the summer) and approximately 30 percent of the samples exceeded the MCL (10 mg/L as N) for drinking water.

Nitrogen isotope ratios ($\delta^{15}N$) were calculated for ground-water samples collected in the summer of 1994 to determine the probable sources of nitrogen in shallow ground water in the study area. Generally, $\delta^{15}N$ values ranging from about -3 to 2 ppt indicate that inorganic fertilizer is the most probable source of the nitrogen (Kreitler and others, 1978) (values of $\delta^{15}N$ are expressed in parts per thousand relative to the standard of atmospheric nitrogen of 0 ppt). Values of $\delta^{15}N$ ranging from 10 to 22 ppt indicate that animal manure is the probable source of nitrogen (Kreitler, 1975). Values of $\delta^{15}N$ calculated in this study ranged from 2.4 to 9.1 ppt and indicate that inorganic fertilizer is most likely the predominant source of nitrogen in shallow ground water in the study area. However the median value of 3.0 ppt indicated that some mixing with animal manure may have occurred.

Because the predominant source of nitrate in ground water in the study area was probably fertilizer, nitrate concentrations were correlated with concentrations of other components of fertilizer to determine if nitrate concentrations in ground water could be attributed to the use of fertilizer. Nitrate concentrations were positively correlated (p-values less than 0.05) with concentrations of calcium, magnesium, manganese, chloride, and potassium (table 7), indicating that concentrations of these ions increased as concentrations of nitrate increased. Nitrate concentrations were positively correlated (p-value less than 0.01) with values of specific conductance (table 7). Specific conductance has been used as a general indicator of nitrate concentrations in ground water in agricultural areas (Hamilton and others, 1991).

Median concentrations of major components in the common fertilizers (other than nitrate) from samples collected in the spring from the study area, were compared to median concentrations in background samples to determine if samples from agricultural areas showed more effects from fertilizer. Median concentrations of magnesium, chloride, nitrate, iron, and manganese were higher in the spring samples than in the background samples (figure 9, table 2). Ground-water samples collected in the spring of 1994 had significantly higher dissolved solids than background samples. The median dissolved-solids concentration was 41 mg/L in background sample and 86 and 100 mg/L in the spring and summer samples from the study area, respectively (tables 2 and 3) fig. 9.

![Figure 9. Median concentrations of inorganic constituents in background and in agricultural samples in the study area, spring, 1994.](image-url)
Summary and Conclusions

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 GAFL NAWQA began the agricultural land-use study in March 1994. The study area is situated in the southeastern United States in south-central Georgia and in the Southern Coastal Plain land resource province. The study area is located in the upper Suwannee River basin in Tift, Turner, Worth, Irwin, Wilcox, and Crisp Counties. A 1,335-mi² area was selected because of intensive row-crop agriculture; peanuts, corn, cotton, and soybean production. The study focused on recently recharged shallow ground water to assess the relation between land-use activities and water quality. For this study, shallow ground water was defined as the first water-bearing zone present in the mostly unconsolidated sand and sandy-clays less than 100 ft below land surface.

Twenty-three monitoring wells ranging in depths from 17 to 70 ft were installed adjacent to farm fields. The 23 wells were sampled in the spring (March and April 1994) and 14 of these wells were resampled in the summer (August 1994). Constituents analyzed in samples included pH, specific conductance, dissolved oxygen, temperature, turbidity, major ions, nitrogen, phosphorus, dissolved organic carbon, pesticides, volatile organic compounds, uranium, and radon. Samples collected in the summer were also analyzed for nitrogen isotope ratios. Nonparametric methods were used to analyze all water-quality data. Data from the NAWQA ground-water study-unit survey in the Southern Coastal Plain in 1993 were used to establish background water quality.

Shallow ground water in the study area is characterized by oxic and acidic conditions and low dissolved-solids concentrations. This is probably because of the relatively low concentrations of inorganic constituents and low pH (between 4 and 5) of rainfall, the composition of the aquifer material, and the effects of human activities. Dissolved oxygen concentrations in ground water ranged from 3.0 to 7.4 mg/L in the spring and 4.3 to 8.0 mg/L in the summer. The median pH of shallow ground water was 4.7 in the spring and 4.4 in the summer. Dissolved-solids concentrations were generally low and not significantly elevated above background levels. The median dissolved-solids concentration in samples collected in the spring was 86 mg/L, whereas the median dissolved-solids concentration in background samples was 41 mg/L. Bicarbonate concentrations ranged from less than 1 to 14.6 mg/L in the spring. Nitrate was the major anion in 14 of 23 samples collected in the spring and 5 of 14 samples collected in the summer.

The median nitrate as nitrogen concentration in samples collected in the spring was 6.7 mg/L. Samples from 30 percent of the wells exceeded the MCL of 10 mg/L for nitrate as nitrogen in drinking water. Samples from about 70 percent of the wells had nitrate concentrations greater than 3.0 mg/L, indicating probable influence from human activities. Nitrogen isotope ratios, calculated for samples collected in the summer, indicate that most of the nitrate present in shallow ground water is probably from inorganic fertilizer. Concentrations of ammonium, organic nitrogen, phosphorus, and orthophosphate were generally low or below the detection levels.

Nitrate concentrations were not significantly different when compared by three ranges of depth to water. However, nitrate concentrations were significantly correlated to distance between water table and screened interval. Nitrate concentrations increased with decreased distance between the water table and the screened interval. Concentrations of nitrate were not significantly different when compared by crop grown in the upgradient field during the previous season (1993) or with the crop grown in the upgradient field at the time of sampling (1994) probably because the row-crops are rotated over a 3-year cycle.

Pesticides and/or volatile organic compounds were detected in water samples from 11 wells, but concentrations were low. Alachlor, metolachlor, and metribuzin were the only pesticides detected in shallow ground water. The maximum concentration of any synthetic organic compound was 1.0 µg/L (metolachlor and tolouene). Toluene, benzene, and methyl chloride were also detected in shallow ground water. Concentrations of dissolved organic carbon ranged from 0.2 to 13 mg/L and the median was 0.4 mg/L in samples collected in the spring and summer.

Radon was analyzed in 13 samples and uranium was analyzed in 18 samples collected in the spring. Radon concentrations ranged from 530 to 1,400 picocuries per liter (pCi/L) with a median concentration of 1,000 pCi/L. Radon concentrations exceeded the proposed MCL of 300 pCi/L in all samples. Uranium concentrations were below detection levels in all 18 samples.
References Cited


Cooperative Extension Service, 1990, Growing Corn in Georgia, University of Georgia/College of Agricultural and Environmental Sciences, Athens, Georgia, Bulletin 547, 36 p.


Kreitler, C.W., 1975, Determining the source of nitrate in ground water by nitrogen isotope studies: Bureau of Economic Geology, University of Texas at Austin, 57 p.


Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986, Hydrogeological Survey Special Publication 28, 8 p.


U.S. Geological Survey, 1979, Topographic map of Moultrie, Ga.: scale 1:100,000, 1 sheet.

____ 1981, Topographic map of Cordele, Ga.: scale 1:100,000, 1 sheet.

### Appendix

[USEPA, U.S. Environmental Protection Agency; USGS, U.S. Geological Survey; μg/L, micrograms per liter]

#### A. Volatile Organic Compounds Analyzed for Ground-Water Samples for the Study-Unit Survey

<table>
<thead>
<tr>
<th>Volatile organic compound</th>
<th>USEPA Code</th>
<th>Minimum reporting level, in μg/L</th>
<th>Volatile organic compound</th>
<th>USEPA Code</th>
<th>Minimum reporting level, in μg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>34030</td>
<td>0.2</td>
<td>Ethane, Trichlorotrifluoro-</td>
<td>77652</td>
<td>0.2</td>
</tr>
<tr>
<td>Benzene, 1,2,3-Trichloro</td>
<td>77613</td>
<td>0.2</td>
<td>Ethene, 1,1-Dichloro</td>
<td>34501</td>
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</tr>
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<td>Benzene, 1,2,4-Trichloro</td>
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<td>Ethene, Chloro-(Vinyl Chloride)</td>
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</tr>
<tr>
<td>Benzene, 1,2,4-Trimethyl</td>
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<td>Ethene, cis-1,2-Dichloro</td>
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<td>Ethene, Tetrachloro</td>
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</tr>
<tr>
<td>Benzene, 1,3,5-Trimethyl</td>
<td>77226</td>
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<td>Ethene, trans-1,2-Dichloro</td>
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<tr>
<td>Benzene, 1,3-Dichloro</td>
<td>34566</td>
<td>0.2</td>
<td>Hexachlorobutadiene</td>
<td>39702</td>
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<tr>
<td>Benzene, 1,4-Dichloro</td>
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<td>Methane, Bromo</td>
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</tr>
<tr>
<td>Benzene, 1-Chloro-2-methyl-(2-Chlorotoluene)</td>
<td>77275</td>
<td>0.2</td>
<td>Methane, Bromochloro</td>
<td>77297</td>
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</tr>
<tr>
<td>Benzene, 1-Chloro-4-methyl-(4-Chlorotoluene)</td>
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<td>0.2</td>
<td>Methane, Bromodichloro</td>
<td>32101</td>
<td>0.2</td>
</tr>
<tr>
<td>Benzene, 1-Methyl- (Isopropylbenzene)</td>
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<td>0.2</td>
<td>Methane, Chloro</td>
<td>34418</td>
<td>0.2</td>
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<tr>
<td>Benzene, Chloro</td>
<td>34301</td>
<td>0.2</td>
<td>Methane, Dibromochloro</td>
<td>32105</td>
<td>0.2</td>
</tr>
<tr>
<td>Benzene, Diethyl- (Xylenes, Total)</td>
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<td>Methane, Dichlorodifluoro</td>
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<tr>
<td>Benzene, 1-Methyl-4-(1-methylthyl)-(p-cymene)</td>
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<td>Methane, Tetrachloro-(Carbon tetrachloride)</td>
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<tr>
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<td>Methane, Tribromo-(Bromoform)</td>
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<tr>
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<td>Methane, Trichloro-(Chloroform)</td>
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<tr>
<td>Benzene, Diethyl- (Xylenes, Total)</td>
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<td>Methane, Tribromo-(Bromoform)</td>
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<tr>
<td>Benzene, 1-Methyl-4-(1-methylthyl)-(p-cymene)</td>
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<td>0.2</td>
<td>Methane, Tribromo-(Bromoform)</td>
<td>34488</td>
<td>0.2</td>
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<tr>
<td>Benzene, 1-Methyl-4-(1-methylthyl)-(p-cymene)</td>
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<td>0.2</td>
<td>Methane, Tribromo-(Bromoform)</td>
<td>34488</td>
<td>0.2</td>
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<tr>
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<td>0.2</td>
<td>Methane, Tribromo-(Bromoform)</td>
<td>34488</td>
<td>0.2</td>
</tr>
<tr>
<td>Benzene, Chloro</td>
<td>34301</td>
<td>0.2</td>
<td>Methane, Tribromo-(Bromoform)</td>
<td>34488</td>
<td>0.2</td>
</tr>
<tr>
<td>Ethane, 1,1,1,2-Tetrachloro</td>
<td>77562</td>
<td>0.2</td>
<td>Propane, 1,2,3-Trichloro</td>
<td>77443</td>
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<tr>
<td>Ethane, 1,1,1-Trichloro</td>
<td>34506</td>
<td>0.2</td>
<td>Propane, 1,2-Dibromo-3-chloro-(DBCP)</td>
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<td>1.0</td>
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<td>Ethane, 1,1,2,2-Tetrachloro</td>
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<td>Propane, 1,2-Dichloro</td>
<td>34541</td>
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<td>Ethane, 1,1,2-Trichloro</td>
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<td>Propane, 1,3-Dichloro</td>
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<td>Ethane, 1,1-Dichloro</td>
<td>34466</td>
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<td>Propane, 2,2-Dichloro</td>
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#### B. Pesticides Analyzed in Ground-Water Samples by the U.S. Geological Survey

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<th>Pesticide name</th>
<th>USEPA Code</th>
<th>Method detection limit, in μg/L</th>
<th>Pesticide name</th>
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<th>Method detection limit, in μg/L</th>
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</thead>
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<tr>
<td>Atrazine, Desethyl-</td>
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<td>0.003</td>
<td>Linuron</td>
<td>82666</td>
<td>0.039</td>
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<td>Acephate</td>
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<td>0.030</td>
<td>Malathion</td>
<td>39532</td>
<td>0.014</td>
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<td>Atrazine</td>
<td>39632</td>
<td>0.017</td>
<td>Metolachlor</td>
<td>39415</td>
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<tr>
<td>Azinphos-Methyl</td>
<td>82686</td>
<td>0.030</td>
<td>Methribuzin</td>
<td>82630</td>
<td>0.012</td>
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<td>Benfuran</td>
<td>82673</td>
<td>0.013</td>
<td>Molinate</td>
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<td>Butylate</td>
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<td>Napropamide</td>
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<tr>
<td>Carbaryl(Sevin)</td>
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<td>0.046</td>
<td>Parathion, Ethyl</td>
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<td>Carbophuran</td>
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<td>Chlorpyrifos</td>
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<td>Peforate</td>
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<td>Cyanazine</td>
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<td>Permethrin, cis</td>
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<td>Fonofos</td>
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<td>0.011</td>
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