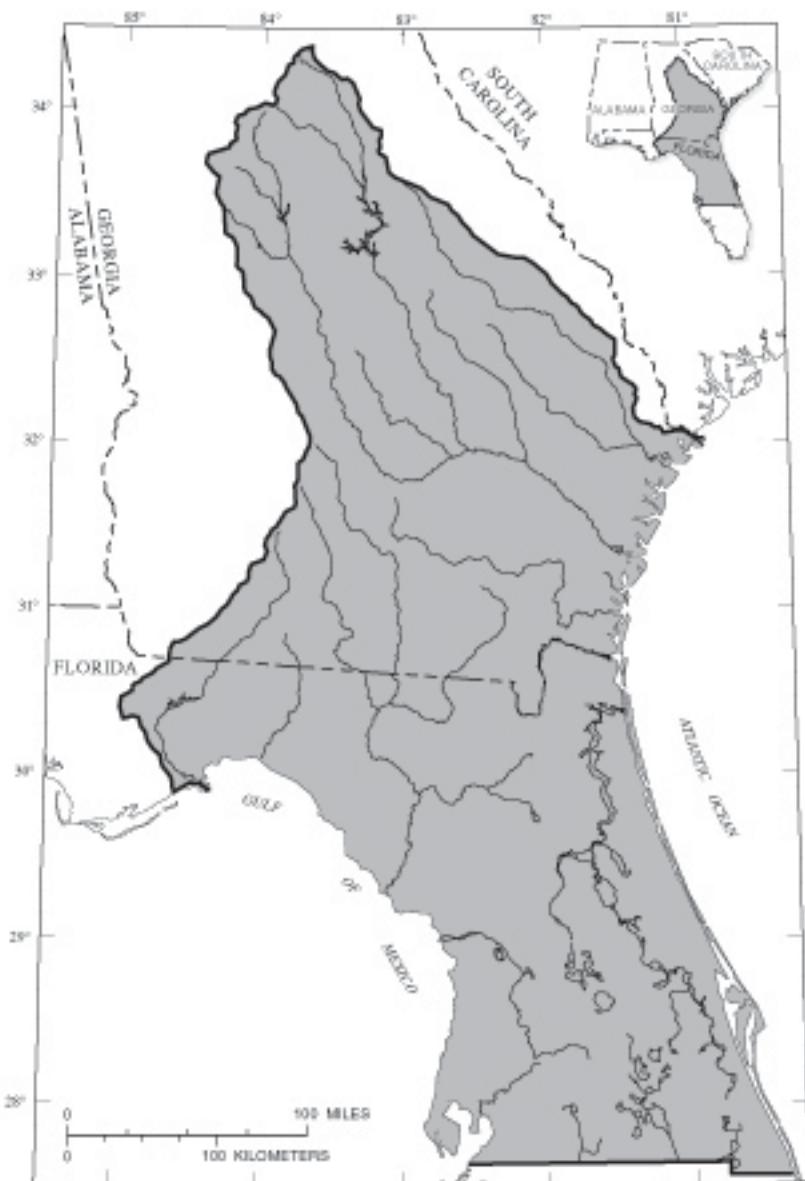


Shallow Ground-Water Quality in Selected Agricultural Areas of South-Central Georgia, 1994



U.S. Geological Survey
National Water-Quality Assessment Program
Georgia-Florida Coastal Plain Study Unit
Water-Resources Investigations Report 96-4083



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By Christy A. Crandall

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National Water-Quality Assessment Program

Tallahassee, Florida
1996



**U.S. DEPARTMENT OF THE INTERIOR
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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
inch per hour (in/hr)	2.54	centimeter per hour
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 ($^{\circ}$ F) may be converted to degrees Celsius ($^{\circ}$ C) as follows:

$$^{\circ}\text{C} = (^{\circ}\text{F}-32)/1.8$$

$$^{\circ}\text{F} = (1.8 \ ^{\circ}\text{C}) + 32$$

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
$\mu\text{g}/\text{L}$	=	micrograms per liter
pCi/L	=	picocuries per liter
<	=	less than
>	=	greater than
\geq	=	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

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

By Christy A. Crandall

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

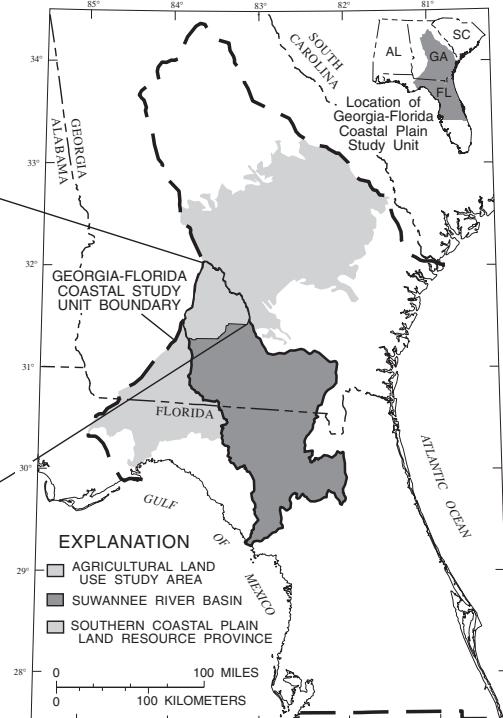
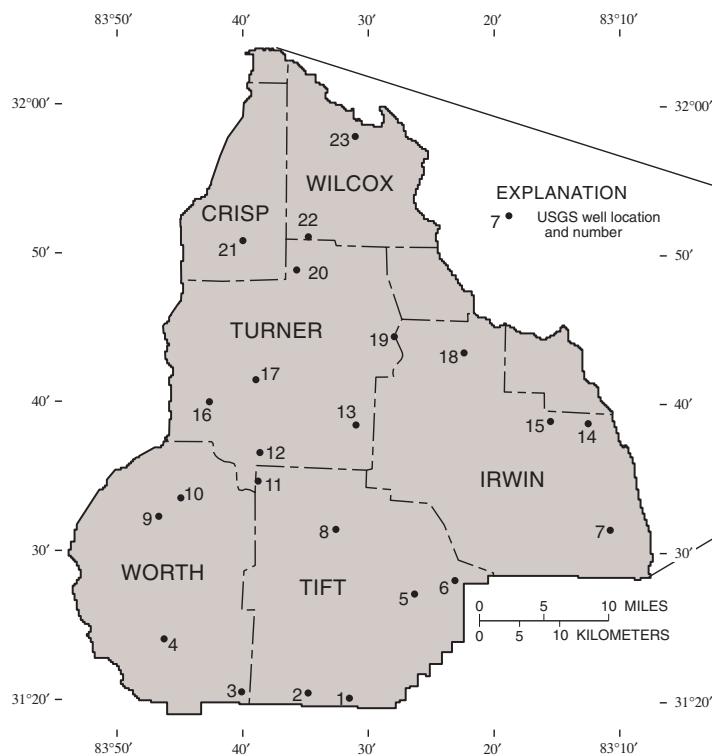


Figure 1. The Georgia-Florida Coastal Plain study unit and the agricultural land-use study area showing wells and well numbers.

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 mi² (fig. 1). The GAFL agricultural land-use ground-water study area (hereafter known as the study area) encompasses about 1,335 mi² 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; 1983; 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).

Principal sources of moisture are from continental depressions or subtropical air masses originating in the Gulf of Mexico or the Atlantic Ocean. Rainfall amounts peak during the summer months due to convective storms. A secondary peak occurs in late winter due to frontal system movement (Golden and Hess, 1991). In the study area, average annual rainfall ranges from about 45 to 48 in/yr (Owenby and Ezell, 1992) and the average evapotranspiration loss is roughly 33 in/yr (Carter and Hopkins, 1986).

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

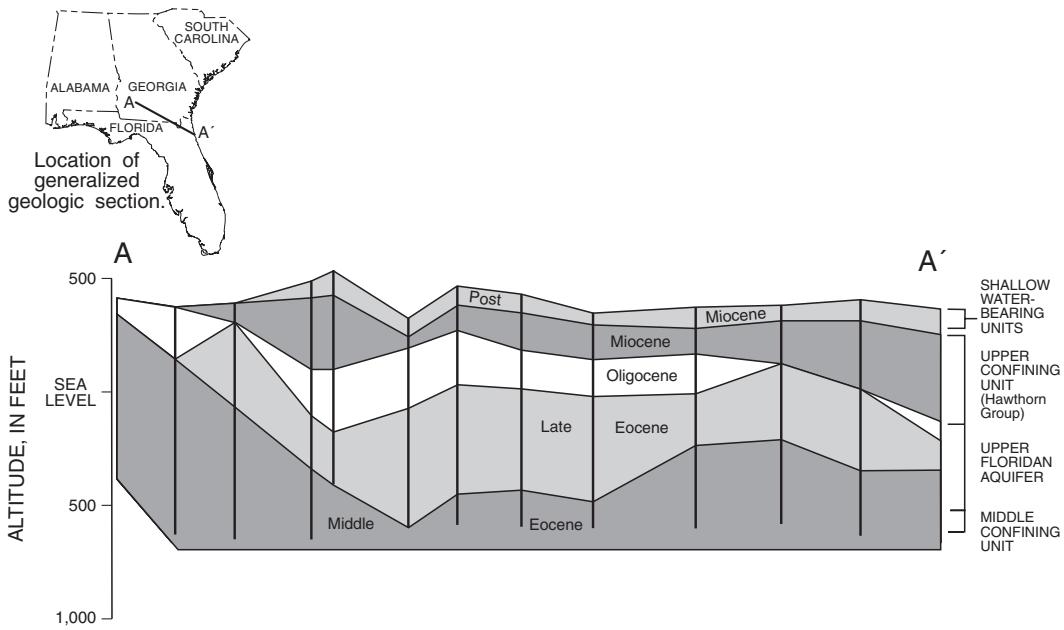


Figure 2. Generalized geologic cross section in the vicinity of the agricultural land-use study area.

from 0.06 to 0.27 ft/d in Tifton loamy soils (Hubbard and others, 1985). Within the study area, vertical hydraulic conductivities of 3.2×10^{-3} and 1.5×10^{-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.

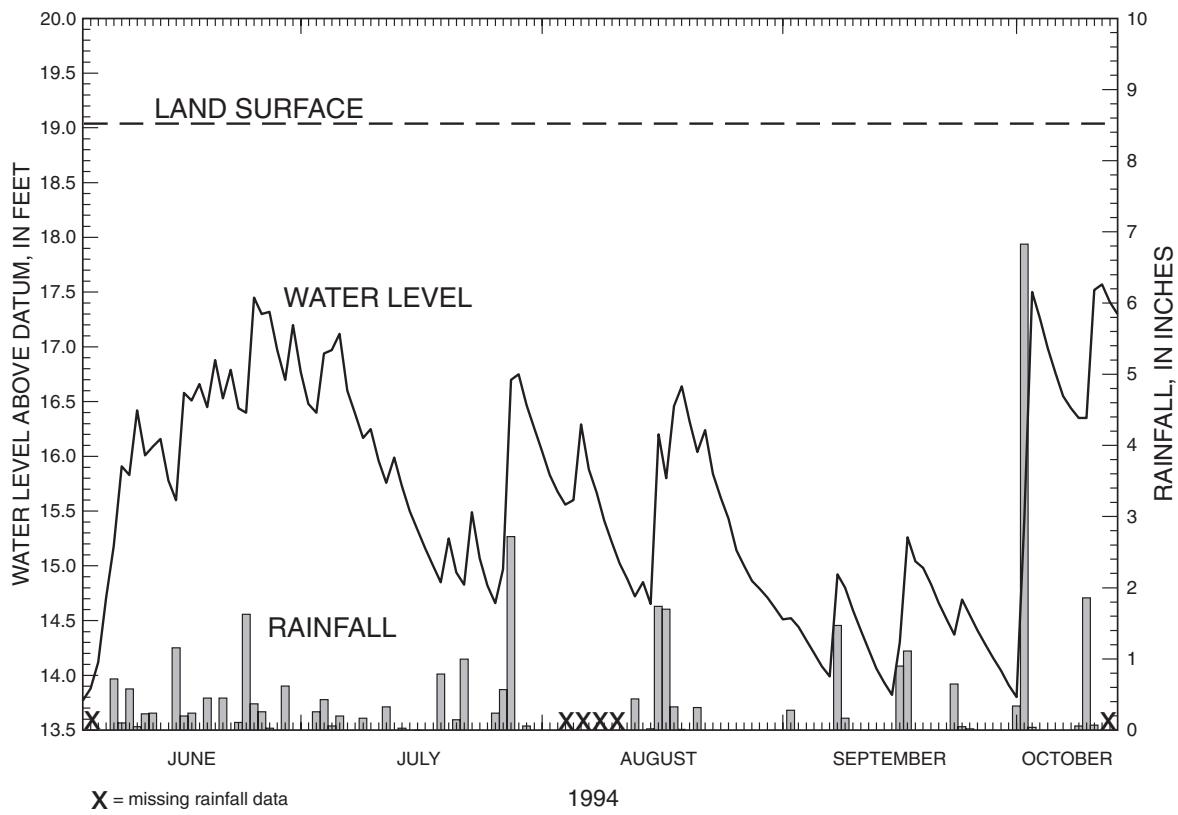


Figure 3. Water levels and daily rainfall near well 8, 1994.

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 P_2O_5) 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.

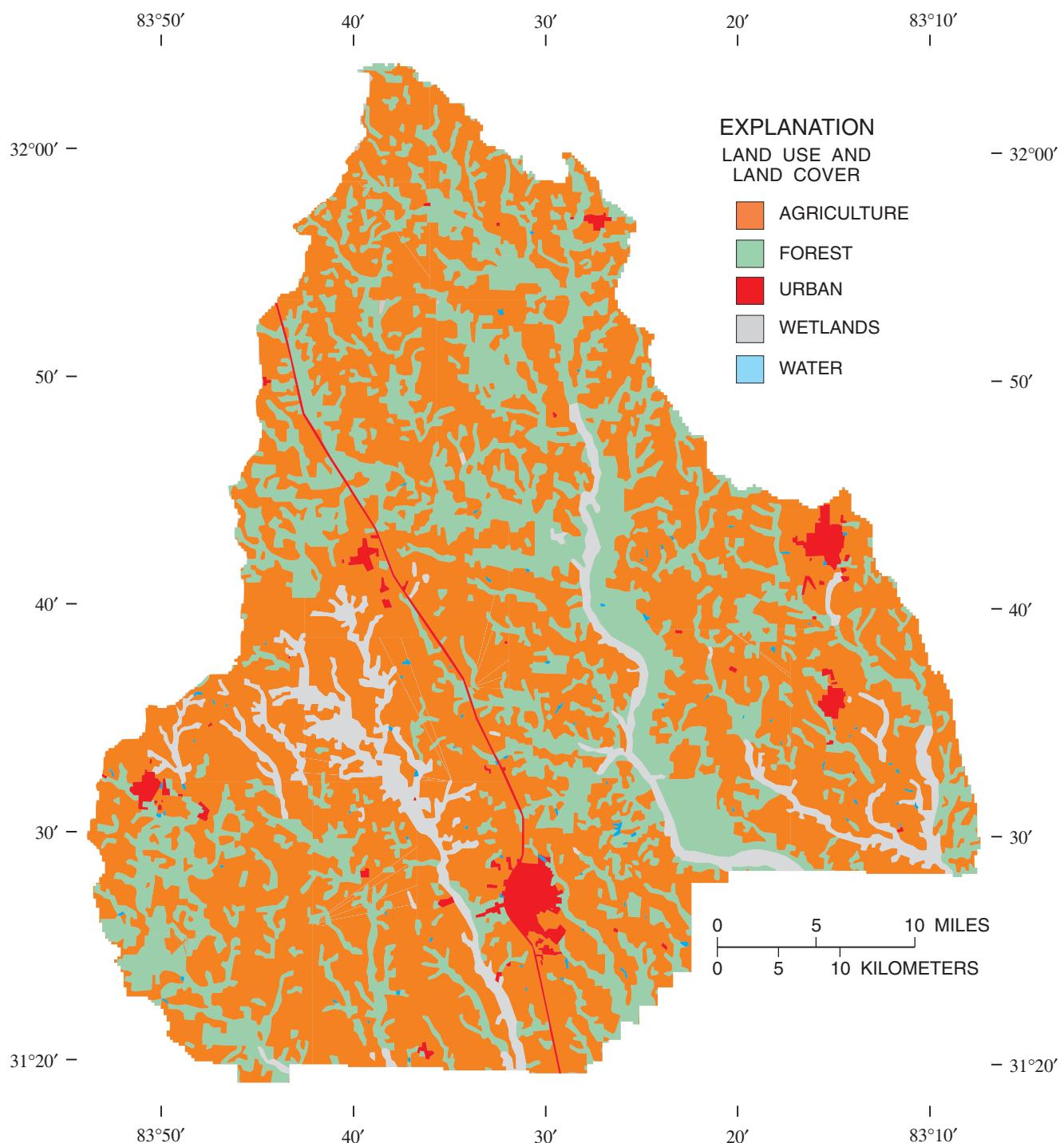


Figure 4. Land use and land cover in the study area.

Table 1. Record of wells and crops grown in upgradient fields in 1993 and 1994
[All wells were constructed of threaded polyvinyl chloride; see fig. 1 for well number locations]

Well number	Station identification number	Georgia grid number	Depth of well (feet)	Screened interval (feet)	Depth of water below land surface (spring 1994) (feet)	Crop grown in upgradient field, 1993	Crop grown in upgradient field, 1994
01	312003083314401	17J022	22.0	12-22	3.01	peanuts	millet
02	312021083350101	17J023	31.0	21-31	2.50	cotton	peanuts
03	312025083401101	16J032	17.0	7-17	3.10	corn	peanuts
04	312356083462001	15K012	24.0	14-24	6.90	peanuts	cotton
05	312703083263601	18K051	30.0	20-30	4.55	corn	peanuts
06	312758083232401	18K052	70.0	40-70	32.99	peanuts	cotton
07	313122083110901	20L006	41.0	26-36	4.08	peanuts	corn
08	313122083325101	17L026	21.0	11-21	1.61	corn	cotton
09	313209083464801	15L030	23.0	13-23	5.60	cotton	peanuts
10	313324083450601	15L031	17.0	7-17	1.70	peanuts	cotton
11	313435083390101	16L021	20.0	10-20	16.10	cotton	peanuts
12	313630083385001	16L022	65.0	35-65	9.20	peanuts	corn
13	313822083311901	17M010	45.0	30-40	17.43	peanuts	corn
14	313832083125501	20M009	27.0	17-27	11.05	corn	corn
15	313841083155401	19M004	37.0	27-37	9.60	corn	peanuts
16	313950083425401	16M015	20.0	10-20	6.35	corn	peanuts
17	314123083391301	16M016	40.0	20-40	3.80	soybeans	peanuts
18	314315083224601	18M004	25.0	15-25	7.27	corn	peanuts
19	314421083281601	18M003	20.0	5-15	0.72	corn	corn
20	314847083360301	17N002	51.0	26-46	11.60	peanuts	beans
21	315043083401901	16N006	20.0	5-15	6.21	peanuts	soybeans
22	315059083350901	17N003	30.4	20-30	8.75	peanuts	cotton
23	315747083312901	17P005	45.0	30-40	14.14	cotton	peanuts

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 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

EXPLANATION

GROUND WATER COLLECTED
IN THE

- SPRING
- △ SUMMER
- RAINFALL FROM
NATIONAL
ATMOSPHERIC
DEPOSITION
PROGRAM SITE

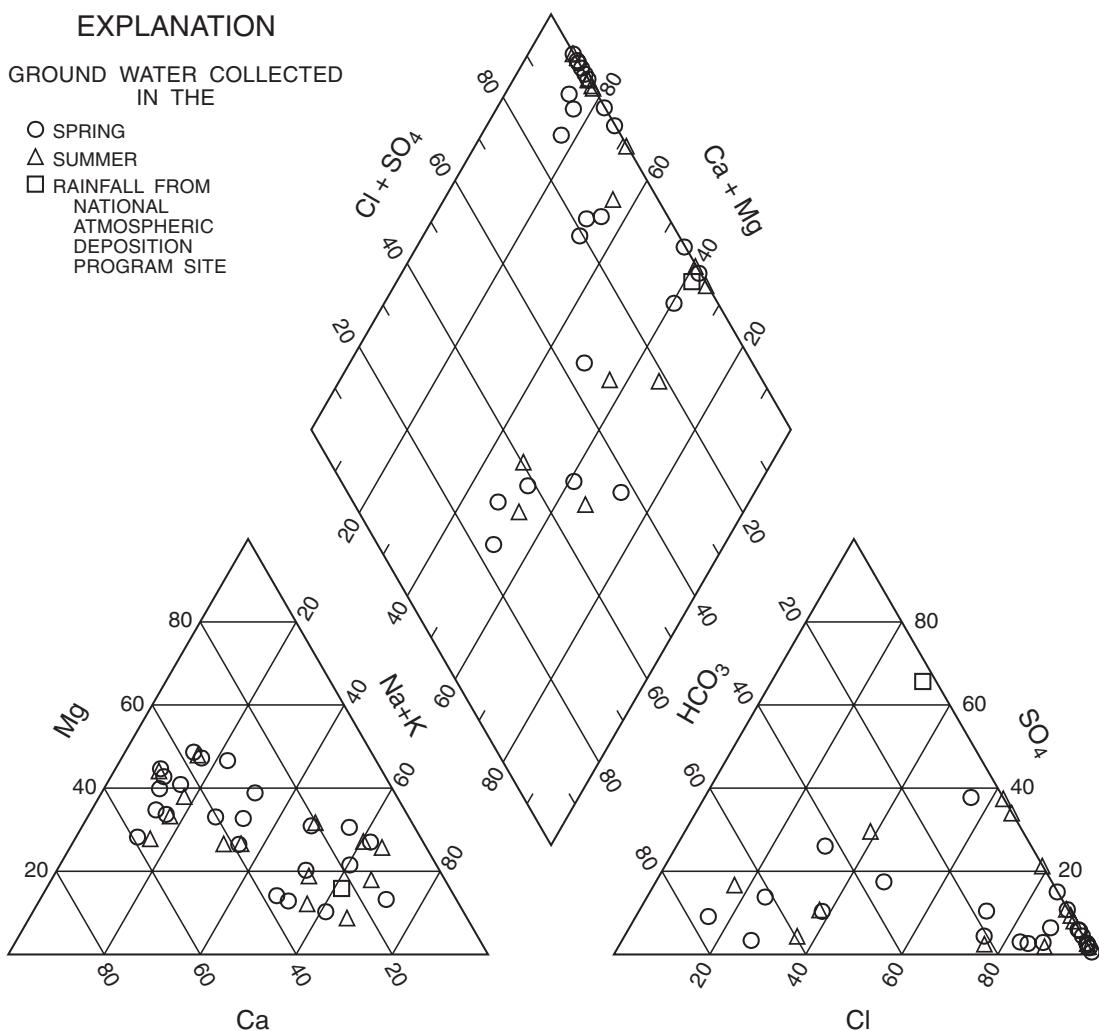


Figure 5. Piper diagram of the chemistry of rainfall and ground-water samples in the study area, spring and summer, 1994.

anion or cation concentration in milliequivalents 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 similar chemical composition to rainfall (fig. 6), most were higher in concentrations of dissolved solids, had proportionately less sodium and sulfate, and proportionately 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 fertilizer 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 dominant 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

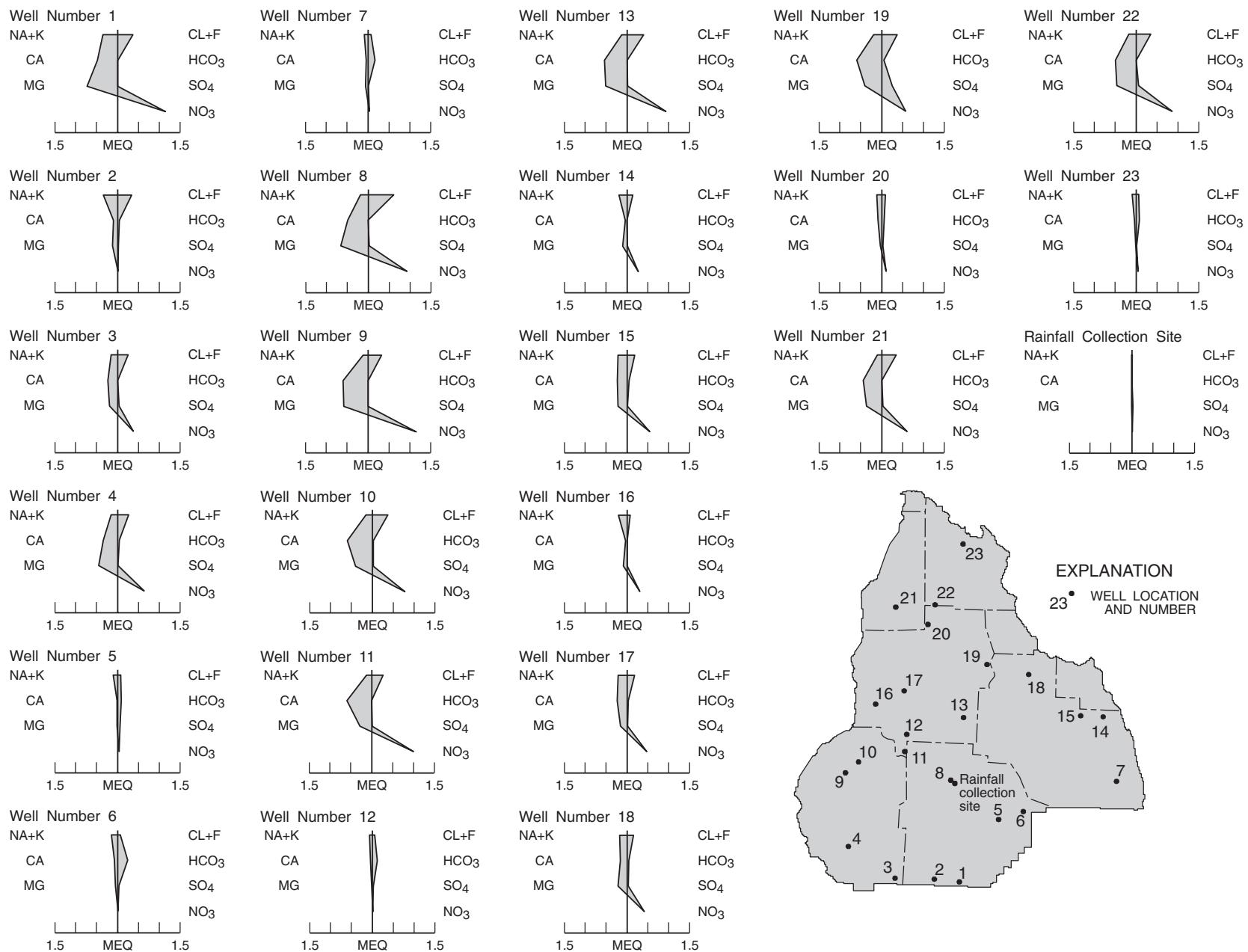


Figure 6. Stiff diagrams of the chemistry of rainfall and ground-water samples in the study area, spring, 1994.

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; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $\mu\text{g}/\text{L}$, micrograms per liter; pCi/L , picocuries per liter; --, missing or not available; <, less than; *, significant differences]

Constituent	SMCLs	Study area wells sampled spring 1994 n = 23		Background data from wells in the southern coastal plain n = 19		Wilcoxon p-value
		Median	Range	Median	Range	
Water level below land surface (feet)	--	6.35	0.7 - 33.0	20.0	4.3 - 47.4	<0.01*
Temperature (degrees Celsius)	--	18.9	14 - 24	22	20 - 32	<0.01*
pH (standard units)	6.5 - 8.5	4.7	4.1 - 5.4	5.2	4.1 - 7.4	<0.01
Specific conductance ($\mu\text{S}/\text{cm}$)	--	92	17.7 - 202	58	26 - 542	0.59
Dissolved solids	500	86	10 - 138	41	2.0 - 332	0.09
Bicarbonate ¹	--	1.7	<1.0 - 14.6	4.0	<1.0 - 124	<0.01*
Dissolved oxygen	--	6.4	3.0 - 7.4	4.8	0.20 - 7.9	0.15
Calcium	--	4.7	0.47 - 12	5.1	0.11 - 20	0.69
Magnesium	--	2.6	0.21 - 8.9	0.84	0.17 - 18	0.08
Sodium	--	2.5	1.0 - 8.0	3.6	1.3 - 27	0.06
Potassium	--	1.0	0.1 - 4.1	1.0	<0.10 - 8.9	0.91
Chloride	250	8.5	1.7 - 21	5.3	2.8 - 71	0.77
Sulfate	250	0.7	0.1 - 12	0.80	0.20 - 5.8	0.42
Fluoride	2.0	<0.1	<0.1 - 0.2	0.10	<0.10 - 0.40	0.47
Dissolved organic carbon	--	0.4	0.2 - 13	3.5	0.4 - 21	<0.01*
Iron ($\mu\text{g}/\text{L}$)	300	26	3 - 71	10	3.0 - 3,700	0.69
Manganese ($\mu\text{g}/\text{L}$)	50	12	1.0 - 87	9.0	1.0 - 370	0.41
Silica (as SiO_2)	--	8.0	3.9 - 90	6.7	3.7 - 24	0.18
Bromide	--	0.03	0.01 - 0.16	0.02	<0.01 - .22	0.06
Nitrate + nitrite (as N) ²	210	6.7	<0.05 - 16	1.2	<0.05 - 33	0.03*
Ammonia (as N) ³	33	0.02	<0.01 - 0.03	0.02	<0.01 - 1.0	<0.01*
Organic nitrogen plus ammonia (as N)	--	<0.2	<0.20 - 0.2	<0.20	<0.20 - 0.20	0.11
Phosphorus (as P)	--	<0.01	<0.01 - 0.37	<0.01	<0.01 - 0.15	0.55
Orthophosphate (as P)	--	<0.01	<0.01 - 0.39	0.01	<0.01 - 0.13	0.13
Radon (pCi/L) ⁴	300	1,000	530 - 1400	690	89 - 7,900	--
Uranium ($\mu\text{g}/\text{L}$)	--	<1.0	<1.0 - <1.0	<1.0	<1.0 - 1.3	--

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).

⁴ Proposed MCL (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

Table 3. Selected water-quality data for samples collected from 14 wells in the spring and summer for the agricultural land-use study area

[Constituents in milligrams per liter except where noted, ug/L, micrograms per liter, $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; bicarbonate not measured in samples with pH less than 4.8; <, less than; N/A, not available; --, not available or unable to compute; *, statistically significant]

Constituent	Spring 1994		Summer 1994		Number of paired samples	Wilcoxon signed rank p-value	T-test signed ranks p-value
	Median	Range	Median	Range			
Water level below land surface (feet)	7.6	0.72 - 32.99	14.01	1.61 - 33.09	14	<0.01	<0.01*
Temperature (degrees Celsius)	19.3	14 - 24	23.7	21.6 - 26.6	14	<0.01	<0.01*
pH (standard units)	4.5	4.1 - 5.4	4.4	4.1 - 6.1	14	0.58	0.57
Specific conductance ($\mu\text{S}/\text{cm}$)	87	22 - 198	100	20 - 227	14	0.57	0.57
Dissolved solids	86	10 - 138	100	28 - 167	12	<0.01	<0.01*
Bicarbonate ¹	1.5	<1.0 - 11.6	1.2	<1.0 - 11.6	11	0.47	0.30
Dissolved oxygen	6.5	3.0 - 7.4	5.9	4.3 - 8.0	11	0.52	0.50
Calcium	3.4	0.73 - 12	3.4	0.58 - 13	14	0.05	0.03*
Magnesium	2.0	0.21 - 8.0	1.7	0.15 - 7.6	14	<0.01	<0.01*
Sodium	2.4	1.0 - 8.0	3.2	1.1 - 8.8	14	0.01	0.02*
Potassium	1.0	0.1 - 4.1	1.1	0.2 - 4.1	14	0.75	0.74
Chloride	8.9	1.7 - 21	6.9	1.7 - 19	14	0.02	<0.01*
Sulfate	0.6	0.1 - 12	0.7	0.2 - 8.4		0.40	0.49
Fluoride	<0.1	<0.1 - 0.2	<0.1	<0.1 - 0.2	14	N/A	N/A
Dissolved organic carbon	0.4	0.2 - 13	N/A	N/A	N/A	N/A	N/A
Iron ($\mu\text{g}/\text{L}$)	26.5	3 - 69	7	3 - 62	14	<0.01	<0.01*
Manganese ($\mu\text{g}/\text{L}$)	11	3.0 - 87	6.5	1 - 130	14	0.04	0.03*
Silica (as SiO_2)	7.6	3.9 - 90	8.1	4.4 - 88	14	0.51	0.55
Bromide	0.03	0.01 - 0.16	0.03	<0.01 - 0.11	14	0.75	0.61
Nitrate + nitrite (as N)	4.75	<0.05 - 16	4.7	0.13 - 20	14	0.74	0.66
Ammonia (as N)	0.01	<0.01 - 0.03	<0.01	<0.01 - 0.03	14	0.65	0.95
Organic nitrogen plus ammonia (as N)	<0.2	<0.2 - <0.2	<0.2	0.2 - 0.2	14	N/A	N/A
Phosphorus (as P)	<0.01	<0.01 - 0.37	0.02	<0.01 - 0.46	14	0.30	0.38
Orthophosphate (as P)	<0.01	<0.01 - 0.39	<0.01	<0.01 - 0.41	14	1.00	N/A
$^{15}\text{N}/^{14}\text{N}$ (per mil)	N/A	N/A	3.0	2.4 - 9.1	13	N/A	N/A

water was 20.0 ft in the background data from the Southern Coastal Plain, whereas the median depth to water was 6.35 ft in the study area in the spring of 1994 (table 2). This water-level difference may be because 1993 (when the study-unit survey was conducted) was a much drier year than 1994. A significant positive correlation was detected between water level and pH, and water levels and bicarbonate concentrations in samples collected in the summer (p-value 0.04, 0.03, respectively) (pH and bicarbonate concentrations increased as depth to water increased; Miller, 1986). The amount of carbonate minerals in the aquifer material probably increases with depth. A significant negative correlation was noted between water level and temperature (p-value <0.01), specific conductance (0.04), chloride (<0.01), and magnesium (0.05) in samples collected in the summer (as depth to water increased, temperature, specific conductance, and concentrations of chloride and magnesium decreased). Water levels showed significant negative correlation with concentrations of chloride and specific conductance in samples collected in the spring (p-value 0.02, 0.04, respectively).

Fertilizer leachate may be the source of higher chloride 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 nitrite 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 summer than in the spring. 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

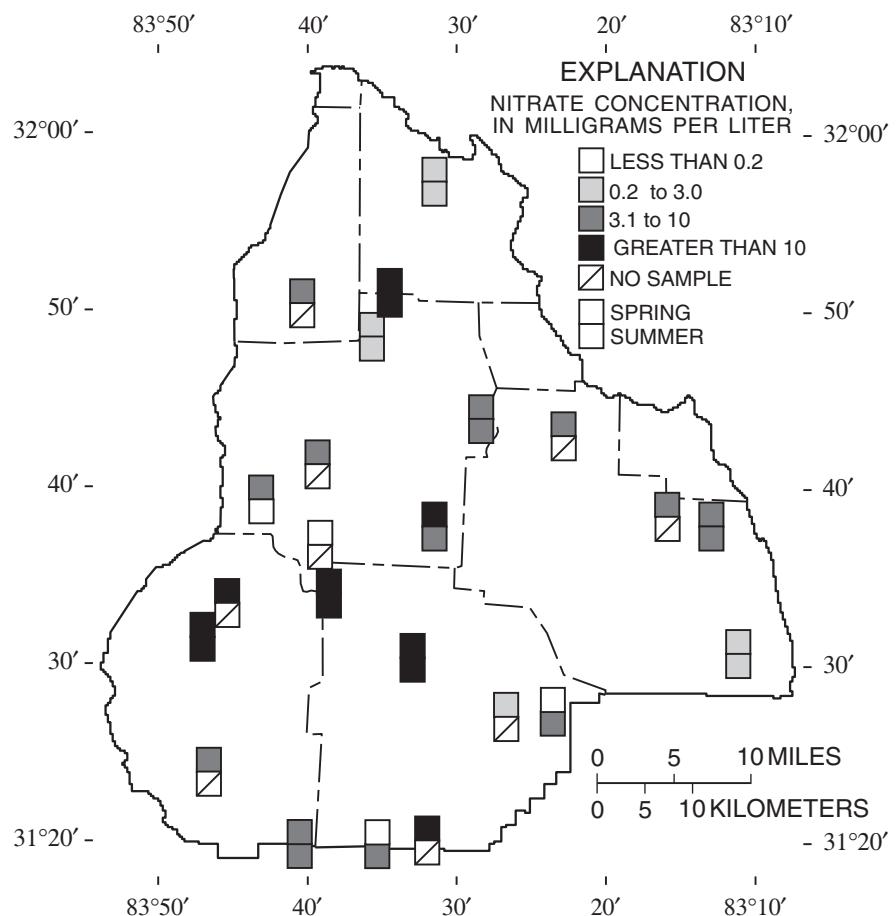


Figure 7. Nitrate concentrations in ground-water samples in the study area, 1994.

Table 4. Nitrate concentrations and water levels, 1994
[n, number of samples; p-value is a group comparison; <, less than]

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

depth; however, nitrate concentrations were negatively correlated to the depth of screened interval below the water table (p-value 0.02). Nitrate concentrations were higher when the screened interval was closer to the water table and lower as the distance between the screened interval and water table increased. This indicates that denitrification may be occurring as the water moves deeper into the aquifer or that ground water may be preferentially moving laterally rather than downward in these soils.

Nitrate concentrations in ground water were compared based on crop grown in the upgradient field near the well in 1993 and 1994. Three crop categories were assigned based on recommended fertilizer application rates for corn, cotton, soybeans, peanuts, millet, and beans. The three categories were (1) corn, (2) cotton, and (3) soybeans, peanuts, beans, and millet. Results indicate that there were no significant differences in nitrate concentrations in ground water based on crop type in the upgradient field (p-value > 0.05) (table 5).

Table 5. Nitrate concentrations and crops grown in upgradient field during 1993 and 1994
[mg/L, milligrams per liter; n, number of samples; p-value is a group comparison; <, less than]

Crop Type	Nitrate in ground water in spring, 1994; and crop grown in upgradient field				Nitrate in ground water in summer, 1994; and crop grown in upgradient field			
	Median (mg/L)	Range (mg/L)	n	p-value	Median (mg/L)	Range (mg/L)	n	p-value
<i>1993</i>								
Corn	5.5	0.36 - 13	8		5.1	0.13 - 12	5	
Cotton	7.3	<0.05 - 16	4	0.89	7.6	0.51 - 20	4	0.80
Peanuts, soybeans, millet, or beans	8.4	0.05 - 16	11		4.2	0.36 - 12	5	
<i>1994</i>								
Corn	3.8	0.08 - 13	5		4.9	0.36 - 9.9	4	
Cotton	11	0.05 - 13	5	0.56	12	4.2 - 12	3	0.37
Peanuts, soybeans, millet, or beans	5.8	<0.05 - 16	13		4.2	0.13 - 20	7	

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 ground-water 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.

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

[MRL, minimum reporting level; MCL, Maximum Contaminant Level; VOCs, volatile organic compounds; µg/L, micrograms per liter]

Compound name	Maximum and range in concentration (µg/L)	MRL (µg/L)	MCL (µg/L)	Well number where detected ¹
Pesticides				
Alachlor	0.012	0.009	2.0	11
Metolachlor	10.00 (0.011 - 1.00)	0.009	² 70	5, 11, 13, 16, 19, 21, 22
Metribuzin	0.037	0.012	² 100	1
VOCs				
Benzene	0.70	0.2	5.0	5
Toluene	1.0 (0.4 - 1.0)	0.2	1,000	2, 13
Methyl Chloride	0.2 (0.2 - 0.2)	0.2	² 30	18, 20

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).

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).

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 $\mu\text{g}/\text{L}$ 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

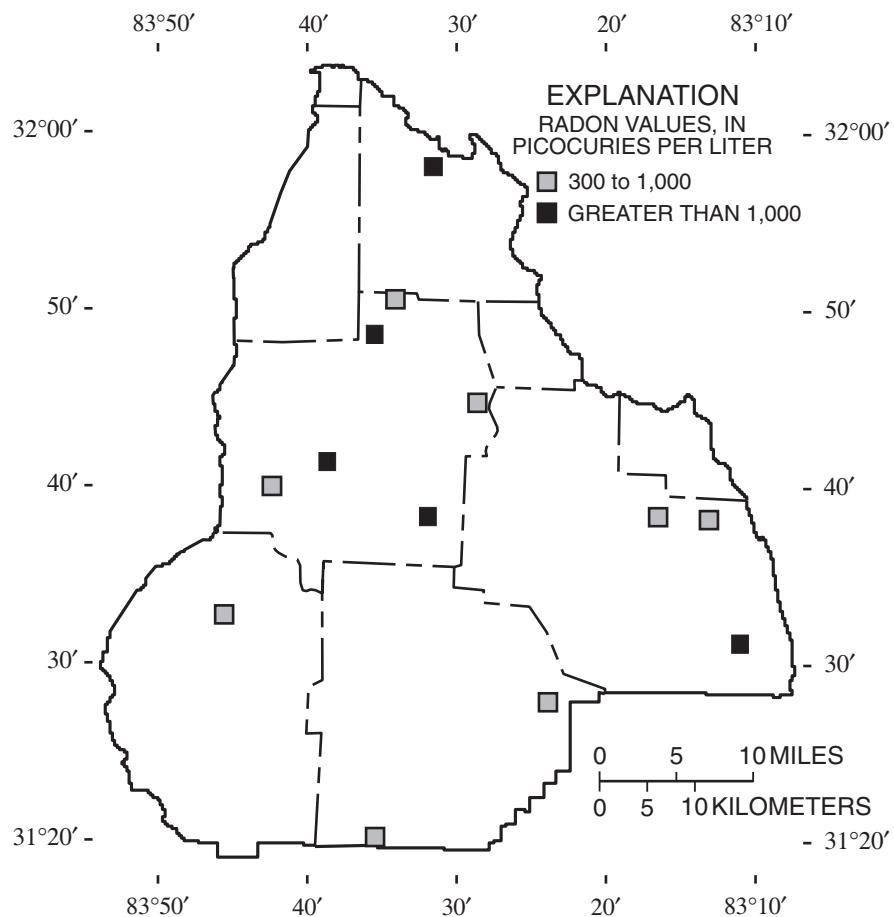


Figure 8. Radon values in ground-water samples in the study area, 1994.

Table 7. Spearman's rho (correlation) of nitrate concentrations with other major inorganic constituents in fertilizer in spring samples

	Potassium	Calcium	Magnesium	Manganese	Chloride	Iron	Specific conductance
Spearman's rho (p-value)	0.62 (<0.01)	0.85 (<0.01)	0.91 (<0.01)	0.81 (<0.01)	0.78 (<0.01)	-0.60 (<0.01)	0.86 (<0.01)

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 ($\delta^{15}\text{N}$) 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, $\delta^{15}\text{N}$ 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 $\delta^{15}\text{N}$ are expressed in parts per thousand relative to the standard of atmospheric nitrogen of 0 ppt). Values of $\delta^{15}\text{N}$ ranging from 10 to 22 ppt indicate that animal manure is the probable source of nitrogen (Kreitler, 1975). Values of $\delta^{15}\text{N}$ 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.

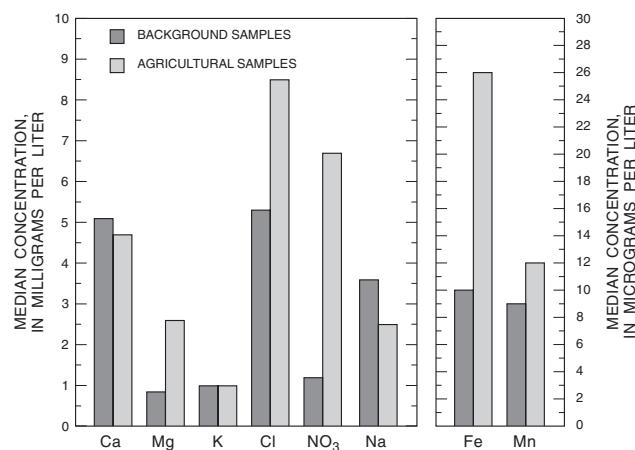


Figure 9. Median concentrations of inorganic constituents in background and in agricultural samples in the study area, spring, 1994.

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 concen-

tration 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 toluene). 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.

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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

Volatile organic compound	USEPA Code	Minimum reporting level, in µg/L	Volatile organic compound	USEPA Code	Minimum reporting level, in µg/L
Benzene	34030	0.2	Ethane, Trichlorotrifluoro-	77652	0.2
Benzene, 1,2,3-Trichloro-	77613	0.2	Ethene, 1,1-Dichloro-	34501	0.2
Benzene, 1,2,4-Trichloro-	34551	0.2	Ethene, Chloro-(Vinyl Chloride)	39175	0.2
Benzene, 1,2,4-Trimethyl-	77222	0.2	Ethene, cis-1,2-Dichloro-	77093	0.2
Benzene, 1,2-Dichloro-	34536	0.2	Ethene, Tetrachloro-	34475	0.2
Benzene, 1,3,5-Trimethyl-	77226	0.2	Ethene, trans-1,2-Dichloro-	34546	0.2
Benzene, 1,3-Dichloro-	34566	0.2	Ethene, Trichloro-	39180	0.2
Benzene, 1,4-Dichloro-	34571	0.2	Hexachlorobutadiene	39702	0.2
Benzene, 1-Chloro-2-methyl- (2-Chlorotoluene)	77275	0.2	Methane, Bromo-	34413	0.2
Benzene, 1-Chloro-4-methyl- (4-Chlorotoluene)	77277	0.2	Methane, Bromochloro-	77297	0.2
Benzene, 1-Methylethyl-(Isopropylbenzene)	77223	0.2	Methane, Bromodichloro-	32101	0.2
Benzene, Bromo-	81555	0.2	Methane, Chloro-	34418	0.2
Benzene, Chloro-	34301	0.2	Methane, Dibromo-	30217	0.2
Benzene, Dimethyl-(Xylenes, Total)	81551	0.2	Methane, Dibromochloro-	32105	0.2
Benzene, Ethyl-	34371	0.2	Methane, Dichloro-(Methylene Chloride)	34423	0.2
Benzene, 1-Methyl-4-(1-methylethyl)-(p-cymene) (p-Isopro-pyltoluene)	77356	0.2	Methane, Dichlorodifluoro-	34668	0.2
Benzene, methyl-(Toluene)	34010	0.2	Methane, Tetrachloro-(Carbon tetrachloride)	32102	0.2
Benzene, n-Butyl-	77342	0.2	Methane, Tribromo-(Bromoform)	32104	0.2
Benzene, n-Propyl-	77224	0.2	Methane, Trichloro-(Chloroform)	32106	0.2
Benzene, sec-Butyl-	77350	0.2	Methane, Trichlorofluoro-	34488	0.2
Benzene, tert-Butyl-	77353	0.2	Methyl tertbutyl ether (MTBE)	78032	0.2
Ethane, 1,1,1,2-Tetrachloro-	77562	0.2	Naphthalene	34696	0.2
Ethane, 1,1,1-Trichloro-	34506	0.2	Propane, 1,2,3-Trichloro-	77443	0.2
Ethane, 1,1,2,2-Tetrachloro-	34516	0.2	Propane, 1,2-Dibromo-3-chloro-(DBCP)	82625	1.0
Ethane, 1,1,2-Trichloro-	34511	0.2	Propane, 1,2-Dichloro-	34541	0.2
Ethane, 1,1-Dichloro-	34496	0.2	Propane, 1,3-Dichloro-	77173	0.2
Ethane, 1,2-Dibromo-(EDB)	77651	0.2	Propane, 2,2-Dichloro-	77170	0.2
Ethane, 1,2-Dichloro-	32103	0.2	Propene, 1,1-Dichloro-	77168	0.2
Ethane, Chloro-	34311	0.2	Propene, cis-1,3-Dichloro-	34704	0.2
			Propene, trans-1,3-Dichloro-	34699	0.2
			Styrene	77128	0.2

B. Pesticides Analyzed in Ground-Water Samples by the U.S. Geological Survey

Pesticide name	USEPA Code	Method detection limit, in µg/L	Pesticide name	USEPA Code	Method detection limit, in µg/L
Atrazine, Desethyl-	04040	0.003	Linuron	82666	0.039
Alachlor	46342	0.009	Malathion	39532	0.014
Atrazine	39632	0.017	Metolachlor	39415	0.009
Azinphos,Methyl-	82686	0.038	Metribuzin	82630	0.012
Benfluralin	82673	0.013	Molinate	82671	0.007
Butylate	04028	0.008	Napropamide	82684	0.010
Carbaryl(Sevin)	82680	0.046	Parathion, Ethyl	39542	0.022
Carbofuran	82674	0.013	Parathion, Methyl	82667	0.035
Chlorpyrifos	38933	0.005	Pebulate	82669	0.009
Cyanazine	04041	0.013	Pendimethalin	82683	0.018
DCPA(Dacthal)	82682	0.004	Permethrin,cis-	82687	0.016
DDE,p,p-	34653	0.010	Phorate	82664	0.011
Diazinon	39572	0.008	Pronamide	82676	0.009
Dieldrin	39381	0.008	Prometon	04037	0.008
Diethylalanine	82660	0.006	Propachlor	04024	0.015
Dimethoate	82662	0.024	Propanil	82679	0.016
Disulfoton	82677	0.008	Propargite	82685	0.006
EPTC(Eptam)	82668	0.005	Simazine	04035	0.008
Ethalfluralin	82663	0.013	Tebuthiuron	82670	0.015
Ethoprop	82672	0.012	Terbacil	82665	0.030
Fonofos	04095	0.008	Terbufos	82675	0.012
HCH, alpha-	34253	0.007	Thiobencarb	82681	0.008
HCH, gamma-(Lindane)	39341	0.011	Triallate	82678	0.008
			Trifluralin	82661	0.012