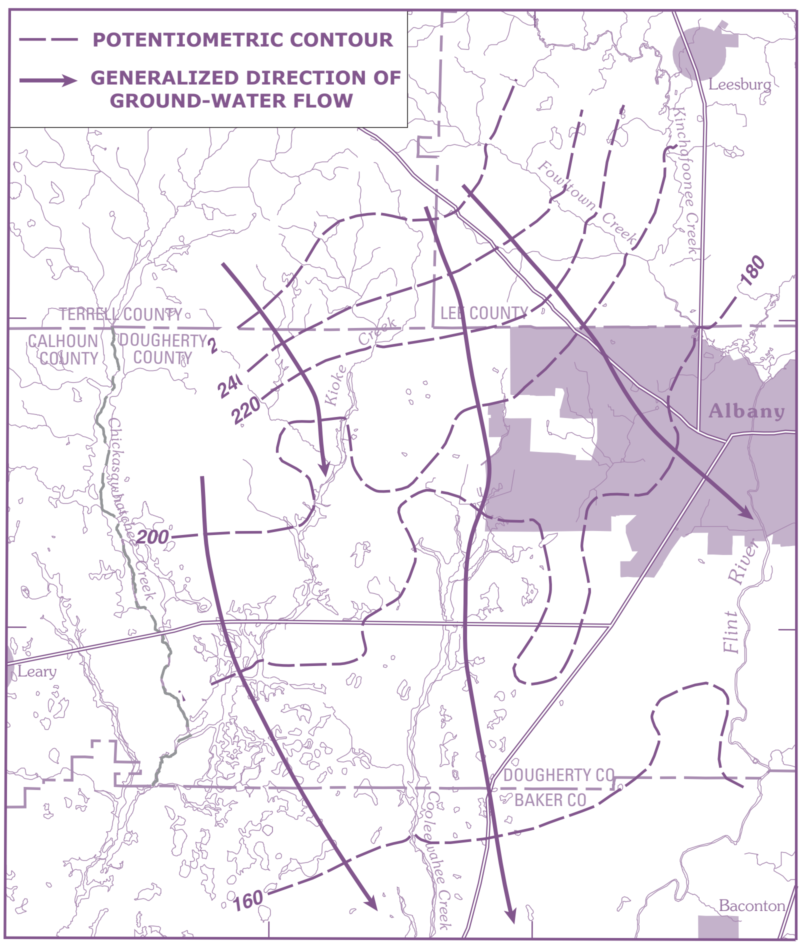
Hydrogeology and water quality of the Upper Floridan aquifer, western Albany area, Georgia

Water-Resources Investigations Report 99-4140



Prepared in cooperation with
Albany Water, Gas, and Light Commission

U.S. Department of the Interior
U.S. Geological Survey

HYDROGEOLOGY AND WATER QUALITY OF THE UPPER FLORIDAN AQUIFER, WESTERN ALBANY AREA, GEORGIA

By Lisa M. Stewart, Debbie Warner, and Barbara J. Dawson

U.S. GEOLOGICAL SURVEY

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Atlanta, Georgia
1999

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VERTICAL DATUM

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 both the United States and Canada, formerly called “Sea Level Datum of 1929.”

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ABSTRACT

Geologic, hydrologic, and water-quality data were collected to refine the hydrogeologic framework conceptual model of the Upper Floridan aquifer, and to qualitatively evaluate the potential of human activities to impact water quality in the Upper Floridan aquifer in the western Albany area, Georgia. Ground-water age dating was conducted by using chlorofluorocarbons (CFC) and tritium concentrations in water from the Upper Floridan aquifer to determine if recharge and possible contaminant migration to the aquifer is recent or occurred prior to the introduction of CFCs and tritium in the early 1950's into the global natural water system. Data were collected from core holes and wells installed during this study and previously existing wells in the Albany area.

Hydrogeologic data collected during this study compare well to the regional hydrogeologic conceptual model developed during previous studies. However, the greater data density available from this study shows the dynamic and local variability in the hydrologic character of the Upper Floridan aquifer in more detail. The occurrence of sediment sizes from clay to gravel in the overburden, the absence of overburden because of erosion or sinkhole collapse, and large areas lacking surface drainage west of the Flint River provide potential areas for recharge and contaminant migration from the surface to the Upper Floridan aquifer throughout the study area. Ground-water ages generally range from 9 to 34 years, indicating that recharge consisting of "modern" water (post early-1950's) is present in the aquifer. Ground-water ages and hydraulic heads in the Upper Floridan aquifer have an irregular distribution, indicating that localized areas of recharge to the aquifer are present in the study area.

Generally, water in the Upper Floridan aquifer is calcium-bicarbonate rich, having low concentrations of magnesium, potassium, sodium, chloride, and sulfate. Water in the Upper Floridan aquifer is oxygenated, having dissolved-oxygen concentrations greater than 2 milligrams per liter. Nitrite-plus-nitrate as nitrogen, is present in the aquifer at concentrations ranging from less than 0.02 to 5.5 milligrams per liter. Areas of higher nitrate concentrations in the aquifer, coupled with widely distributed localized recharge to the aquifer indicates that suburban residential and agricultural land use in the western Albany area may affect water quality in the Upper Floridan aquifer. However, concentrations exceeding drinking water criteria were not detected in the study area.

INTRODUCTION

The Upper Floridan aquifer underlies parts of Georgia, Alabama, South Carolina, and all of Florida—the aquifer is one of the most productive aquifers in the United States (Hicks and others, 1987). The Claiborne, Clayton, and Providence aquifers underlie the Upper Floridan aquifer, and increased pumpage from these deeper aquifers has caused water-level declines in these aquifers in the Albany, Ga., area (Hicks and others, 1987). Water-level declines raise concerns over the ability of the deeper aquifers to meet increasing water demands in the Albany area (Hicks and others, 1987). To address these concerns, the U.S. Geological Survey (USGS), in cooperation with the Albany Water, Gas, and Light Commission, began an investigation of the Upper Floridan aquifer as an alternative municipal ground-water source in 1992. However, pumpage from the Upper Floridan aquifer also may induce surface contamination into the aquifer from urban run off and agricultural practices, or other surface sources.

Previous studies conducted in the Albany area indicate that properly located, large-diameter wells tapping the lower water-bearing zone of the Upper Floridan aquifer could sustain yields of 800 to 1,200 gallons per minute (gal/min) (Hicks and others, 1987). Computer simulations of pumping in the proposed development area southwest of Albany indicate that withdrawals of 1,200 gal/min or greater would have negligible effects on hydrologic conditions (such as direction and rate of ground-water flow, vertical leakage of water from the undifferentiated overburden, and leakage of water from the Flint River) that control water quality in the Upper Floridan aquifer (Torak and others, 1993). However, the evaluations of Torak and others (1993) were conducted at a regional scale having limited detailed hydrogeologic information. Hydrologic conditions in the Upper Floridan aquifer can vary greatly over short distances.

Purpose and Scope

The purposes of this report are to (1) describe and compare the local hydrogeologic framework developed for the study area to the regional hydrologic framework developed during previous studies; and (2) describe the areal distribution of water-quality constituents and characteristics in the Upper Floridan aquifer in the western Albany area. The scope of this work includes a well, a spring, and water-filled cave inventory; test drilling of two core holes; examination of cores from the test holes; and installation of six observation wells. Ground-water-level, geophysical, well-construction, hydraulic, ground-water-quality, and environmental tracer and isotope data also were collected and analyzed.

Description of Study Area

The study area is located in the western Albany area, and covers approximately 280 square miles (mi^2) in parts of Dougherty, Terrell, Lee, and Baker Counties (fig. 1) and lies within the Dougherty Plain and Fall Line Hills Districts (Clark and Zisa, 1976) of the Coastal Plain physiographic province. Average annual precipitation is about 50 inches (Carter and Stiles, 1983), although precipitation varies greatly from year to year and can be twice as much in wet years as in dry years (National Oceanic and Atmospheric Administration, 1974).

Topography in the study area is flat to gently sloping and is characterized by numerous closed depressions (sinkholes) that are the result of chemical dissolution of the Ocala Limestone by ground water and subsequent collapse of the surficial materials. Surface drainages include the Flint River and its tributaries—including Chickasawhatchee, Kiokee, Cooleewahee, Fowltown, and Kinchafoonee Creeks. Drainage within the western part of the study area is dendritic. However, surface drainage generally does not exist east of the topographic divide between Cooleewahee Creek and the Flint River. Springs occur along the Flint River, its tributaries, and also in upland areas between drainages. Caves are present in the shallow limestone in the northwestern part of the study area.

Land use in the study area is predominantly residential and agricultural. Septic systems with leaching fields is the main method of organic waste disposal for residences in this area. Agricultural areas include row crop agriculture, pecan orchards, and pasture land. Frequent application of agrichemicals and animal wastes to the land surface has a potential impact on water quality of the Upper Floridan aquifer. Light to heavy industries generally are present in and around the Albany city limit.

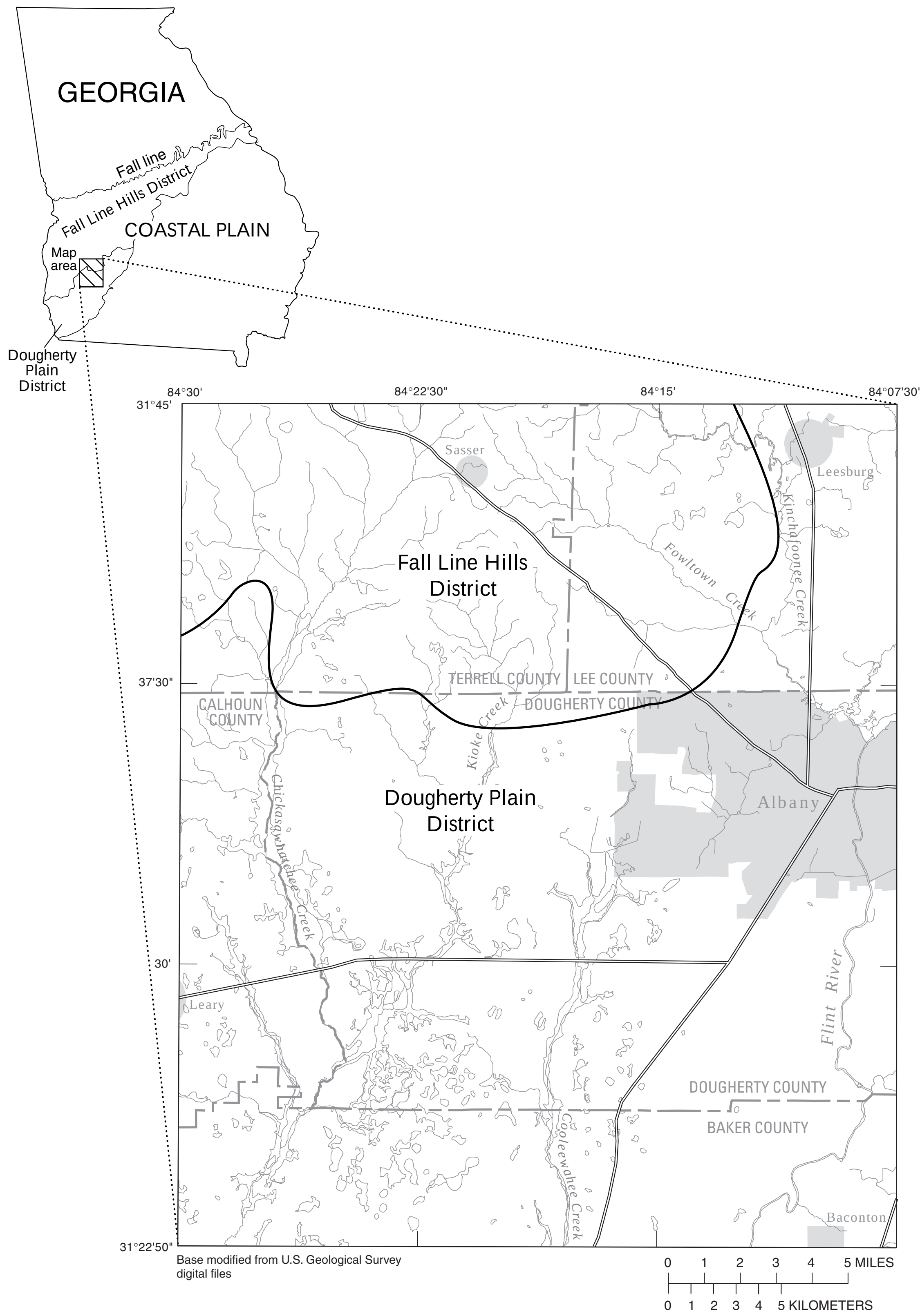


Figure 1. Location of study area and selected physiographic features in Georgia (modified from Clark and Zisa, 1976).

Previous Investigations and Regional Conceptual Model of the Upper Floridan Aquifer

Ground-water resources of the study area have been the subject of several previous investigations. A conceptual model of the regional hydrogeologic framework was developed prior to the investigation described in this report, based on interpretation of available hydrologic data collected during previous studies (Hayes and others, 1983; Hicks and others, 1987; Torak and others, 1993; and Warner, 1997). The conceptual model based on previous studies describes the lithology, hydraulic properties, ground-water levels, direction of ground-water flow, recharge and discharge, and water quality of the Upper Floridan aquifer on a regional scale.

Hicks and others (1981) discussed the hydrogeology of major aquifers of the study area and included previously unpublished data on aquifer characteristics, and the potentiometric surface of the Upper Floridan aquifer (formerly Ocala aquifer). Hayes and others (1983) developed a ground-water flow model of the Upper Floridan aquifer (formerly described as the principal artesian aquifer) in the Dougherty Plain physiographic district to simulate regional water-level changes that may result from actual or hypothetical pumpage increases and from climatic variations. Hayes and others (1983) also included data on the hydrogeology and hydraulic characteristics of the Upper Floridan aquifer. Hicks and others (1987) conducted an investigation in the study area to evaluate the development potential of the Upper Floridan aquifer as an alternative source of ground water for public supply, and the chemical quality of water in the Upper Floridan aquifer. Torak and others (1993) assessed the effects of increased ground-water withdrawal from the Upper Floridan aquifer in a 12 mi^2 area by using computer simulations of the regional ground-water-flow system. Warner (1997) described the hydrogeology of the Upper Floridan aquifer in the southwestern Albany area, and the results of an aquifer test used to quantify the hydraulic properties of the Upper Floridan aquifer.

Geologic Units

The study area is underlain by Coastal Plain sediments and sedimentary rocks of pre-Cretaceous to Quaternary age that consist of alternating units of sand, clay, sandstone, dolomite, and limestone that dip gently to the southeast and generally thicken in that direction (Hicks and others, 1987). Only those geologic units pertinent to the Upper Floridan aquifer are included in this study. Those units include, in ascending order, middle Eocene Lisbon Formation, late Eocene Ocala Limestone, and undifferentiated overburden of Quaternary age.

The Ocala Limestone is underlain by the Lisbon Formation, which consists of brownish-gray, clayey, glauconitic, dense limestone (Hicks and others, 1987). The Lisbon Formation ranges in thickness from 10 to 100 feet (ft) in the regional area (Hicks and others, 1987). Because of its distinctly lower water-yielding capability compared to the Ocala Limestone, the Lisbon Formation is considered to be the base of the Upper Floridan aquifer in the regional area (Hayes and others, 1983).

The Ocala Limestone has three distinct lithologic units—lower, middle, and upper units (Hicks and others, 1987). The lower unit of the Ocala Limestone, as described by Hicks and others (1987), consists of interlayered gray to dark-brown, recrystallized, glauconitic, dolomitic limestone. The lower unit of the Ocala Limestone also has well-developed secondary permeability along solution-enlarged joints, fractures, and bedding planes (Torak and others, 1993), and ranges in thickness from 46 to 85 ft (Hicks and others, 1987). The middle unit of the Ocala Limestone consists of relatively impermeable white to brown, clayey, dense chalky limestone interlayered with noncalcareous clay and silt layers that are not areally extensive (Hicks and others, 1987). The upper unit of the Ocala Limestone is described as a fossiliferous, very fine-grained, recrystallized, chalky limestone (Hicks and others, 1987). The combined thickness of the middle and upper units varies greatly in the regional area, ranging from 2 to 77 ft with an average thickness of 40 ft (Torak and others, 1993). In the southeastern part of the regional area, the upper unit consists of fossiliferous, white to pinkish, fine to oolitic, dolomitic limestone (Hicks and others, 1987); the middle unit is missing in this part of the regional area (Hicks and others, 1987).

The undifferentiated overburden consists of 20 to 40 ft of interlayered sediments composed of fine-to-coarse quartz sand and noncalcareous clay (Hicks and others, 1987). Overburden consisting mainly of sand probably is alluvium deposited by area streams. Overburden consisting of mainly clay probably is residuum derived from weathering of the Ocala Limestone. Generally, individual layers in the overburden are discontinuous and can be traced only for short distances. The overburden ranges in thickness from 100 to 400 ft in isolated areas where colluvial material has filled ancient sinkholes (Hicks and others, 1987).

Hydrology

Regionally, a surficial aquifer contained in the undifferentiated overburden (Hayes and others, 1983) overlies the Upper Floridan aquifer. The hydraulic conductivity and transmissivity of the surficial aquifer were estimated from sieve-size analyses of drill cuttings collected at 5-ft intervals, geophysical logs, and aquifer tests (Hayes and others, 1983). Estimated vertical hydraulic conductivity ranges from 0.0001 to 9 feet per day (ft/d) with a median value of 0.003 ft/d; estimated horizontal conductivity ranges from 0.0004 to 30 ft/d, with a median value of 0.02 ft/d (Hayes and others, 1983). Transmissivity values were estimated by using an average saturated thickness of the overburden (Hayes and others, 1983); transmissivity values ranges from 0.002 to 1,000 feet squared per day (ft^2/d), with a median value of 0.3 ft^2/d. A complete description of well locations, well construction, and aquifer-test methods and analyses used to estimate the hydraulic conductivity and transmissivity of the overburden is given in Hayes and others (1983, p. 34-41).

The relative amounts of sand to clay in the saturated zone of the overburden is the predominant lithologic characteristic that determines hydraulic conductivity and transmissivity of the surficial aquifer (Hicks and others, 1987). Test drilling by Hayes and others (1983) indicates that sand lenses occur more commonly in the upper half of the overburden than in the lower half. Therefore, transmissivities may increase greatly during periods of high ground-water levels (increased precipitation) as the permeable sand lenses in the upper half of the overburden become saturated.

Regional water levels in the surficial aquifer respond to precipitation in a subdued manner and are highest during March-April, then decline to their lowest levels during November-January (Hayes and others, 1983). Late spring and summer rains have little to no effect on water levels in the surficial aquifer because most of this precipitation is lost to evapotranspiration before the water percolates through the sandy-clayey overburden to the saturated zone (Hayes and others, 1983). Water levels in the surficial aquifer respond positively (rise) to rainfall and respond negatively (decline) to discharge (Hicks and others, 1987). The rate and amount of rise in response to rainfall is not easily predicted and varies areally (Hicks and others, 1987). Water levels in wells tapping the surficial aquifer ranged from 1 to 38 ft below land surface from January 1980 to September 1981 (Hayes and others, 1983), and from 1 to 22 ft below land surface from April 1982 to December 1984 (Hicks and others, 1987). Water-level fluctuations in the surficial aquifer ranged from 2 to 16 ft for the same time periods (Hayes and others, 1983; Hicks and others, 1987).

Regionally, the Upper Floridan aquifer is contained in the Ocala Limestone (Hayes and others, 1983), is confined below by the Lisbon Formation, and generally is confined above by the undifferentiated overburden and low permeability zones within the aquifer (Hicks and others, 1987). Clay within the undifferentiated overburden provides varying degrees of vertical confinement to the Upper Floridan aquifer except in areas where the overburden has been breached by erosion or sinkhole collapse. In the Albany area, the Upper Floridan aquifer is divided into upper and lower water-bearing zones. The lower water-bearing zone corresponds to the lower unit of the Ocala Limestone and has more developed secondary permeability; and the upper water-bearing zone corresponds to the upper and middle units of the Ocala Limestone and has relatively low permeability (Torak and others, 1993). The permeability differences in the water-bearing zones are attributed to differences in lithology and chemical dissolution of the Ocala Limestone (Hayes and others, 1983). The Upper Floridan aquifer functions mainly as a conduit-flow system, in which lateral flow in the aquifer occurs in the more permeable lower water-bearing zone because of the well-developed secondary permeability (Hicks and others, 1987).

Previous studies describe the hydraulic properties of the Upper Floridan aquifer in terms of ground-water flow, hydraulic conductivity, and transmissivity. Water flow in the Upper Floridan aquifer can be classified generally as (1) diffuse, where flow is analogous to conditions in a homogenous aquifer, and can be described by using basic Darcian equations (Hayes and others, 1983); and (2) conduit, where water flows in distinct conduits and surrounding rock has comparatively low porosity and low permeability (Hicks and others, 1987). Water flow in the conduits may be rapid and turbulent (Hicks and others, 1987).

The upper water-bearing zone has a relatively low permeability because of the fine grained, dense nature of the limestone and the lack of secondary porosity (Torak and others, 1993). The relatively low permeability in the upper water-bearing zone greatly reduces its ability to transmit large quantities of water. Aquifer-test data are not available to estimate transmissivity and hydraulic conductivity; however, yields from domestic wells completed in the upper water-bearing zone generally are low (Torak and others, 1993).

Areal differences in hydraulic conductivity and in saturated thickness result in a variable distribution of transmissivity in the lower water-bearing zone (Torak and others, 1993). Transmissivities of 90,000 to 178,000 feet square per day (ft^2/d), and hydraulic conductivity of 1,500 and 2,000 feet per day (ft/d) were estimated by conducting aquifer tests in two wells that are open only to the lower water-bearing zone (Torak and others, 1993). Warner (1997) demonstrated even greater variability in transmissivity in the Upper Floridan aquifer with aquifer tests that resulted in estimated transmissivities as high as 506,000 ft^2/d.

Regionally, water levels in the Upper Floridan aquifer rise with rainfall (recharge) and decline with drought during periods of no precipitation or pumping (discharge) (Torak and others, 1993). Response time of water-level changes resulting from precipitation in the Upper Floridan aquifer are not easily predicted; the water-level change varies areally and can range from instantaneous to very slow. The magnitude of water-level change resulting from precipitation or drought in the Upper Floridan aquifer can be either large or barely perceptible (Torak and others, 1993). Water levels in the Upper Floridan aquifer generally are at a maximum during February through April, decline through summer, and are at a minimum during November and December (Torak and others, 1993). During years of typical precipitation in the Albany area, seasonal fluctuations in water levels in the Upper Floridan aquifer range from 2 to 30 ft below land surface; and near major agricultural and industrial pumping centers, may exceed 30 ft below land surface (Torak and others, 1993). Water-level declines from pumping do not result in the formation of distinct cones of depression in the potentiometric surface of the Upper Floridan aquifer (Hicks and others, 1987). By comparing water levels measured prior to 1957 to water levels measured in November 1985, Hicks and others (1987) determined that 28 years of ground-water withdrawal (averaging 66 million gallons per day (Mgal/d) in 1983) has not resulted in a long-term decline in ground-water levels in the Upper Floridan aquifer.

Potentiometric data for the Upper Floridan aquifer were used to determine general ground-water flow directions and gradients. Regionally, potentiometric data reported by Hayes and others (1983) indicate that ground-water flow is from northwest to southeast. Ground-water discharge to the Flint River is the most important hydrologic characteristic that controls the regional potentiometric surface. However, some ground-water flow beneath the Flint River occurs (Torak and others, 1993).

Recharge to and discharge from the Upper Floridan aquifer are in dynamic equilibrium; thus, recharge from typical annual rainfall is equal to the combined effects of natural and man-induced discharge (Torak and others, 1993). Hayes and others (1983, p. 51) described the process of recharge to the water table in the overburden and to the Upper Floridan aquifer in the following manner:

> Recharge to the residuum (undifferentiated overburden) occurs chiefly from rainfall during January to May. Rainfall that is not evaporated, transpired, retained as soil moisture in the unsaturated zone, or is discharged to streams, moves downward through the overburden to recharge the principal artesian aquifer (Upper Floridan aquifer). Most rainfall occurring during the summer months is lost to evapotranspiration or is retained as soil moisture in the unsaturated zone of the residuum (overburden). Consequently, little, if any, summer precipitation percolates to the water table or the principal artesian aquifer (Upper Floridan aquifer).

Recharge to the Upper Floridan aquifer varies spatially because of the variable permeability of the overburden (Hayes and others, 1983). Vertical conductivity of the overburden decreases where clay layers are common, consequently recharge is reduced to the Upper Floridan aquifer. The Upper Floridan aquifer transmits water from interstream areas of recharge to natural areas of discharge and to wells (Hayes and others, 1983). Natural areas of discharge include springs, streams, and the overburden or the underlying Lisbon Formation. Ninety percent of the annual ground-water discharge from the Upper Floridan aquifer occurs as discharge to streams and springs, as determined by using base-runoff analyses and digital modeling (Hayes and others, 1983).

Flow directions in the Upper Floridan aquifer were simulated by using a finite-element model and ground-water-level data from November 1985 (Torak and others, 1993). The model simulations show the general regional ground-water flow direction is from northwest to southeast. However, the simulations also show many areas of localized discharge and recharge, which most likely correspond to areas of natural recharge and discharge such as springs, streams, where the overburden is breached by erosion and sink holes, and discharge from wells.

Ground-water quality is affected by inorganic, and in some areas, organic constituents in solution. The type and concentration of dissolved constituents depend on the sources of recharge, recharge mechanisms, and subsurface conditions. Excess concentration of dissolved constituents may affect the suitability of water for potable, industrial, or agricultural uses. However, in the Albany area, water in the surficial aquifer and the Upper Floridan aquifer is of good quality and acceptable for most uses. Constituent concentrations do not exceed the maximum contaminant levels (MCL's) established for drinking water by the Georgia Department of Natural Resources (1993). Ground-water samples indicate that the volatile organic compounds benzene, trichloroethylene, and toluene, and the herbicide atrazine, and the insecticide carbofuran are not present in the Upper Floridan aquifer west of the Albany city limits (James B. McConnell, U.S. Geological Survey, oral commun., 1995).

Acknowledgments

Appreciation is extended to Robert Bruner for allowing installation of monitoring wells on his property and for his continued cooperation throughout the study. Sincere gratitude is extended to L. Niel Plummer, Eurybiades Busenberg, and Julian Wayland, of the USGS, for the onsite help provided in applying the chlorofluorocarbon age-dating technique. Appreciation is extended to the staff of the low-level tritium USGS laboratory in Menlo Park, Calif. Courtesies and help extended by Harold Bryan of the Albany Water, Gas, and Light Commission, and by the Dougherty County Health Department also are sincerely appreciated. Gratitude is extended to all the landowners and plantation managers who allowed access to wells and springs to collect water-resources data.

METHODS OF INVESTIGATION

Several interdisciplinary methods were used during this investigation to (1) describe the qualitative evaluation of the potential for contamination of the Upper Floridan aquifer; and (2) describe the local hydrogeologic framework for comparison with the regional hydrogeologic framework described in previous studies. The study methods included a well, spring, and water-filled cave inventory; observation-well drilling; water-quality sampling; and ground-water-age dating.

Well, Spring, and Water-Filled Cave Inventory

An inventory of wells, springs, and water-filled caves present in the study area was conducted during this study. Well-construction data and driller's logs were obtained for privately-owned wells, mainly from the Dougherty County Health Department. Well-construction, yield, and location data for wells inventoried during this study were obtained from well drillers and well owners. Well-construction, yield, location, and ownership data for wells used in previous studies (Hicks and others, 1981; Hayes and others, 1983; and Hicks and others, 1987) were obtained from the existing USGS Ground-Water Site Inventory (GWSI) data base. Ground-water levels were measured at selected sites, and remarks were noted on general ground-water quality and well/spring history. Where necessary, altitudes of wellheads/springs were measured by using a global positioning system (GPS).

Each of the 72 wells, one spring, and one water-filled cave inventoried (table 1, located in back of report) (fig. 2), was field located, plotted on a 7 1/2-minute USGS topographic map, and assigned a number according to the USGS numbering system. Of the 72 wells, one spring, and one cave—27 wells, and the spring and cave were selected to sample ground-water quality; 65 wells were selected to monitor fluctuations in ground-water levels; 6 wells were selected to record continuous ground-water levels; and 17 wells were selected to analyze geophysical data.

Observation Wells

Six observation wells were drilled during this study to collect water-quality, water-level, lithologic, and geophysical data. Two core holes—one in the northern part (11L116) and one in the southeastern part of the

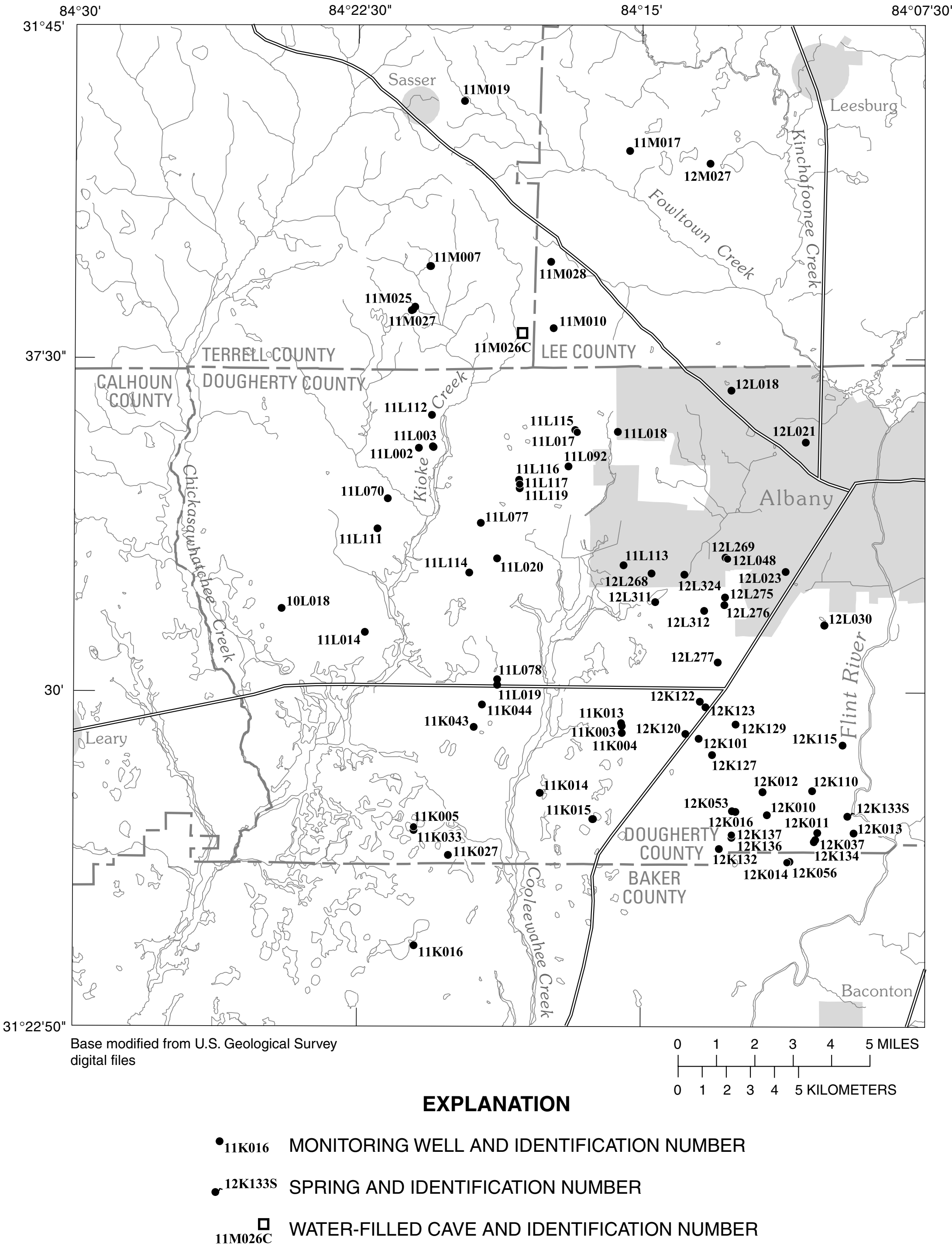


Figure 2. Well, cave, and spring sites used for water-quality and water-level monitoring, and geophysical and geologic data collection (type of site and data collected at each site given in table 1, located in back of report).

study area (12K136) (fig. 2)—were drilled during February and March 1993 to obtain lithologic and geophysical data. Continuous cores were collected for the entire thickness of the Ocala Limestone and terminated in the underlying Lisbon Formation. Observation wells subsequently were installed at each core-hole site to collect periodic water-quality and continuous water-level data. Two other observation wells were installed at each core location to form a well cluster. Each well cluster contains three observation wells—one well fully penetrates the Upper Floridan aquifer and is open only to the lower unit of the Ocala Limestone; one well partially penetrates the Upper Floridan aquifer and is open only to the middle unit of the Ocala Limestone; and one well is screened in the surficial aquifer in the undifferentiated overburden.

Well Construction and Well Distribution in the Upper Floridan Aquifer

The depth and the open (uncased) bore interval of each well in which hydraulic-head data and ground-water samples were collected must be determined to examine the vertical distribution of hydraulic head and water quality in the Upper Floridan aquifer. Generally, domestic and irrigation wells in the Upper Floridan aquifer have a well bore that is open to both low- and high-permeability zones below the bottom of a cased interval. Water-level data collected during this study reflect the average head in the open bore hole. Likewise, ground water collected during sampling under pumping conditions has migrated into the open bore hole from zones having the highest horizontal permeability, and it has mixed with water from other zones in the aquifer. As a result, a composite chemical composition of the aquifer water is represented from samples collected from these wells with multiple water-bearing zones.

For the collection of water-quality samples, the distribution of well depths included in this study consists of 8 wells open to the middle unit of the Ocala Limestone, 6 wells open to the lower unit of the Ocala Limestone, and 16 wells open to both the middle and lower units of the Ocala Limestone. The number of wells was insufficient to determine if water from each zone has statistically different quality and age. Therefore, the distribution of water-quality constituents, properties, and ages of water in the Upper Floridan aquifer is discussed as if the lower and middle units of the Ocala Limestone function as one hydrologic unit in the Upper Floridan aquifer.

Lithologic and Geophysical Data

Lithologic data from two cores collected during this study and geophysical logs from the core holes and other available wells were used to identify and correlate stratigraphic and hydrologic units within the Ocala Limestone. Geophysical logs include natural gamma and caliper. Maps showing the altitude of the top of the middle and lower units of the Ocala Limestone, and stratigraphic sections through the study area were developed by using the correlation of stratigraphic and hydrologic units. The maps and sections were used to determine which unit of the Ocala Limestone contributes water to wells selected for ground-water-quality and ground-water-age sampling.

Zones of dissolution indicated by the caliper geophysical logs were used to determine the top and bottom of the middle and lower units of the Ocala Limestone. Lithologic changes indicated in gamma geophysical logs were used to identify the contact between the undifferentiated overburden and the Ocala Limestone; and between the Ocala Limestone and the Lisbon Formation.

Ground-Water Levels

Water-level data from a network of 65 privately owned and USGS observation wells in the study area (table 1, located in back of the report) (fig. 2) were used to construct maps of the generalized potentiometric surface of the Upper Floridan aquifer. Water-level data were collected semiannually from the monitoring-well network, in November 1992 (low water-level period) and April 1993 (high ground-water-level period). Water-level data for the surficial aquifer and the Upper Floridan aquifer were collected by using continuous recorders installed on seven wells in the study area. Continuous water-level data from the cluster wells at the two core locations were used to gain a better understanding of the hydraulic connection between land surface and the surficial aquifer; between the surficial aquifer and the Upper Floridan aquifer; and between the middle and lower units of the Ocala Limestone in the Upper Floridan aquifer.

Ground-Water Sampling and Quality Assurance

Collection of ground-water samples for this study included well purging, sample collection, sample filtering and preservation, shipping to the USGS National Water Quality Laboratory for laboratory analysis, and quality assurance of the samples. Water samples were collected during July 1993 from 27 wells, one spring, and one cave to determine concentrations of major and minor ions, nitrate-plus-nitrite, dissolved organic carbon, chlorofluorocarbons (CFC), and tritium.

Well purging consisted of (1) removing a minimum of three casing volumes of water from each well; and (2) monitoring pH, dissolved oxygen, specific conductance, and temperature. Samples were collected after the field parameters stabilized. During purging, field parameters were measured in a flow-through chamber connected to a faucet near the well head or to the delivery hose of the sampling pump. Wells without permanently installed pumps were purged and sampled by using a stainless-steel submersible pump equipped with a Teflon delivery line. Wells with permanently installed pumps were purged and sampled by using existing pumps. Samples were collected from Teflon tubing attached to a faucet as close to the well head as possible and before the pressure tank. Alkalinity was measured in the field at the time of sampling by using the incremental titration method.

Ground-water samples for analysis of major and minor ions, dissolved organic carbon, and nitrite-plus-nitrate were collected as filtered or unfiltered and preserved or unpreserved samples. Samples analyzed for dissolved major and minor ions were filtered through a 0.45-micron pore-size membrane filter. Major and minor nonmetal ion samples were preserved by chilling on ice. Major and minor metal ion samples were preserved by acidification with nitric acid to a pH of less than 2. Samples for the analysis of nitrite-plus-nitrate were preserved with mercuric chloride, and chilled. Dissolved organic carbon (DOC) samples were filtered through a 0.45-micron pore-size silver filter and preserved by chilling on ice.

Ground-water samples to determine CFC-11, CFC-12, and CFC-113, and tritium concentrations were collected as unfiltered, unpreserved samples. The CFCs samples were collected by using a copper sample-delivery line from a well to the sampling apparatus. Copper tubing prevents contamination of the sample by trace amounts of CFCs that can be desorbed from nonmetallic tubing. The CFC samples were collected in 62-milliliter (mL) borosilicate glass ampules and flame sealed to prevent contact of the ground-water samples with the atmosphere. The apparatus for collecting and sealing water samples in the ampules and other details of the field procedure are given in Busenberg and Plummer (1992). Ground-water samples for the analysis of tritium were collected in 1-liter glass or polyethylene bottles, capped, and sealed with tape.

Ground-water samples were submitted to the USGS Water Quality Services Unit, Ocala, Fla., and analyzed for major and minor ions, nitrite-plus-nitrate as nitrogen, and dissolved organic carbon. Samples collected for CFC concentrations were analyzed by the USGS Laboratory, Reston, Va. Samples collected for tritium concentrations were analyzed by the USGS Laboratory, Menlo Park, Calif.

Quality-assurance (QA) procedures for samples collected for major and minor ions, nitrite-plus-nitrate, and DOC consisted of submitting a field blank, replicate, and reference sample. Field blanks ensure that samples collected are not contaminated during the process of sample collection, preservation, transportation, and laboratory handling. Replicate samples are used to evaluate the precision of laboratory analytical methods. Reference samples are used to evaluate the accuracy and precision of laboratory analytical methods. Field-blank water is subjected to the same procedures used to collect environmental samples (for example, pumped through the sampling pump, filtered, and preserved with nitric acid). Replicate samples were collected at selected sites in sequence with environmental samples, by using the same procedures. Analytical results should be similar to the paired environmental sample. Reference samples are laboratory prepared samples with known concentrations of the analytes. The total number of QA samples taken was 20 percent of the total number of samples taken for major and minor ions, nitrate-plus-nitrite, and DOC. QA procedures for samples collected for CFCs consisted of collecting a minimum of five CFC samples at each well and analyzing at least three of the samples from each well. QA procedures for samples collected for tritium consisted of collecting replicate samples at selected wells.

Ground-Water Age Dating by Using Chlorofluorocarbons and Tritium

Over the past 50 years, human activities have introduced substances into the atmosphere and hydrosphere that have application to tracing and estimating the age of young ground water; that is, water recharged within the past 50 years (Plummer and others, 1993). A detailed discussion of the hydrologic application of these transient tracers is provided by Plummer and others (1993). CFCs and tritium were used as hydrologic tracers during this study to evaluate the hydraulic connection between water-bearing zones within and recharge to the Upper Floridan aquifer.

CFCs are volatile organic compounds that were first produced in the 1930's and are believed to be entirely of anthropogenic origin (Lovelock, 1971). CFCs are used as refrigerants, aerosol propellants, cleaning agents, solvents, and blowing agents in the production of plastics and foam rubber. All CFCs produced are eventually released to the atmosphere, and by gas-liquid exchange, are partitioned into the hydrosphere. The most abundant CFCs in the atmosphere, CFC-12 and CFC-11, and the lesser abundant CFC-113 indicate recent recharge in natural water and provide a useful dating tool.

The CFC age of ground water is determined by comparing CFC concentrations in ground water to concentrations measured in air from Niwot Ridge, Colo. (L.N. Plummer, U.S. Geological Survey, written commun., 1995). A reconstruction of CFC-11, CFC-12, and CFC-113 concentrations in air is shown in figure 3 (see Busenberg and others, 1993). An estimate of the temperature of water that recharges an aquifer is required in CFC-age dating to calculate the Henry's Law solubility constants that relate concentrations of CFCs in ground water (fig. 4) to concentrations in the atmosphere at time of recharge. CFC-modeled recharge ages refer to the time since the recharge water was isolated from the atmosphere. Relatively small errors in CFC dating are introduced by uncertainties in recharge temperature. An age error of 2 to 3 years results from uncertainties of ± 2 °C (degrees Celsius) for waters recharged after 1980. CFC-age uncertainties in recharge temperature are usually less than one year for waters recharged prior to 1975 (Busenberg and others, 1993). Evaluation and use of recharge temperatures in age dating ground waters by using CFCs is described in detail in Busenberg and others (1993) and in Busenberg and Plummer (1992). A recharge temperature of 19 °C was estimated for the study area. Samples collected for CFC-age dating during this study were analyzed by using a purge-and-trap gas chromatography procedure with an electron-capture detector (Busenberg and others, 1993).

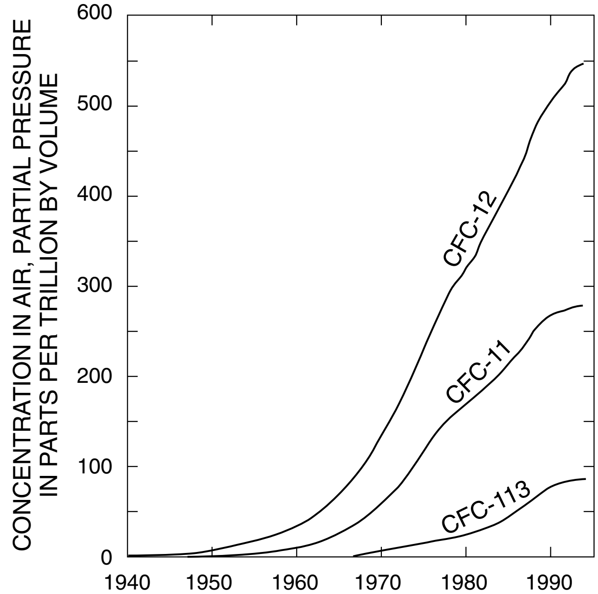


Figure 3. Concentrations of chlorofluorocarbons CFC-11, CFC-12, and CFC-113 in the atmosphere, from 1940 to 1993 (from Busenburg and others, 1993).

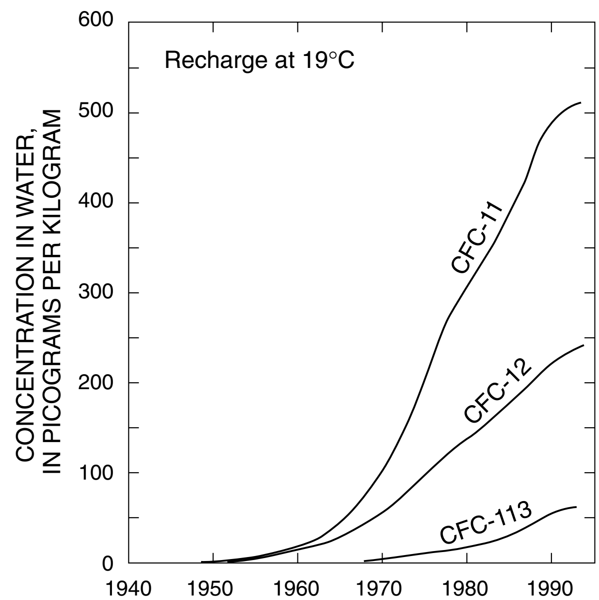


Figure 4. Concentrations of chlorofluorocarbons CFC-11, CFC-12, and CFC-113 in water, from 1940 to 1993 (from Busenburg and others, 1993).

Tritium (half-life of 12.4 years (Solomon and others, 1992)) is a useful tracer of water that entered a ground-water system after 1952. Tritium input into ground water has occurred in a series of spikes following periods of atmospheric testing of nuclear devices that began in 1952 and reached a maximum in 1963-64 (fig. 5). Tritium concentrations are reported in tritium units (TU), which are equivalent to one tritium atom in 10^{18} hydrogen atoms. Concentrations of tritium in precipitation have decreased since the mid-1960's bomb peak, except for some small increases from French and Chinese tests in the late 1970's (Solomon and others, 1992). Tritium concentrations in ground water can provide residence time ranges of (1) pre-thermonuclear bomb testing (tritium not detected in ground water, indicating a recharge prior to 1952); and (2) post-bomb (tritium detected in ground water, recharge after 1952) (Solomon and others, 1992). Samples collected for tritium concentrations were analyzed by using electrolytical enrichment and liquid scintillation counting.

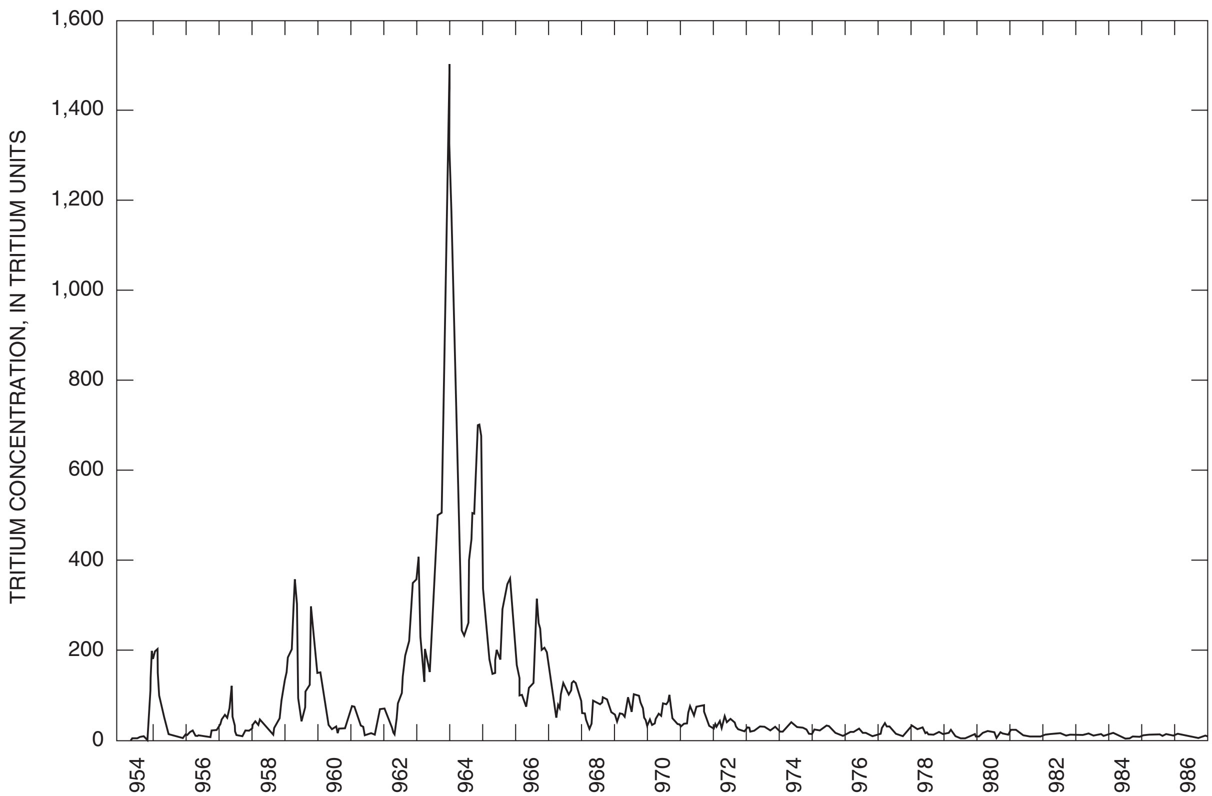


Figure 5. Tritium concentrations in precipitation at latitude 30° N, from 1954 to 1986 (modified from N. L. Plummer, U.S. Geological Survey, written commun., 1995).

HYDROGEOLOGY

Hydrogeologic features and properties controlling downward migration of surface water, and possible contaminants leached from the surface, include the composition and thickness of the undifferentiated overburden and Ocala Limestone, direction of ground-water gradient, and surface drainage. The distribution of these features and factors aid in identifying areas of potential migration of agrichemicals and other anthropogenic contaminants from the surface to the Upper Floridan aquifer.

Geologic and hydrologic data were used to develop a detailed description of hydrogeologic sections A-A' and B-B' (figs. 6, 7, and 8), the hydrogeologic framework, and a conceptual model of the study area. Altitudes of geologic contacts and thicknesses of the upper and middle units of the Ocala Limestone based on geophysical logs from 15 wells from previous studies and 4 wells from this study are listed in table 2. Geologic descriptions of the core holes from this study are presented in table 3.

Geologic Units

Geophysical logs collected during previous studies from 15 wells, and 2 core samples, and geophysical logs collected from 4 wells installed during this study were used to determine the lithology of the Lisbon Formation; thickness and lithology of the undifferentiated overburden; and thickness, lithology, and structural and water-bearing characteristics of the Ocala Limestone. The geologic units are discussed in ascending order.

Lisbon Formation

The Lisbon Formation is an easily recognizable unit consisting of tan to green, glauconitic, clayey limestone in the core samples collected for this study (table 3). The surface of the Lisbon Formation is irregular because of erosion from weathering (fig. 7). Two cores collected during this study only partially penetrated the Lisbon Formation; therefore, the total thickness of the Lisbon Formation could not be determined during this study.

Table 2. Altitude and thickness of middle and lower units of the Ocala Limestone in selected wells, western Albany area, Georgia

[—, no data]

Well number	Altitude of land surface (feet above sea level)	Ocala Limestone: Altitude of top of middle unit of Ocala Limestone (feet above sea level)	Thickness of middle unit of Ocala Limestone (feet)	Altitude of bottom of lower unit of Ocala Limestone (feet above sea level)	Thickness of lower unit of Ocala Limestone (feet)	Altitude of contact between middle and lower units of Ocala Limestone (feet above sea level)
11K003	195	155	54	—	—	101
11K005	181	135	78	-91	148	57
11K015	175	122	51	-37	108	71
11L002	222	197	—	124	—	—
11L017	230	189	61	—	—	128
11L16/11L117	210	182	42	63	77	140
12K016	195	115	40	—	—	75
12K123	201	153	37	7.0	109	116
12K127	180	88	4	—	—	84
12K129	193	143	38	13	92	105
12K136/12K137	194	124	59	-16	81	65
12L018	231	191	49	47	95	142
12L021	195	159	—	13	112	—
12L023	192	141	48	11	82	93
12L030	180	148	53	25	70	95
12L048	200	164	76	30	58	88
12L277	192	145	36	62	47	109

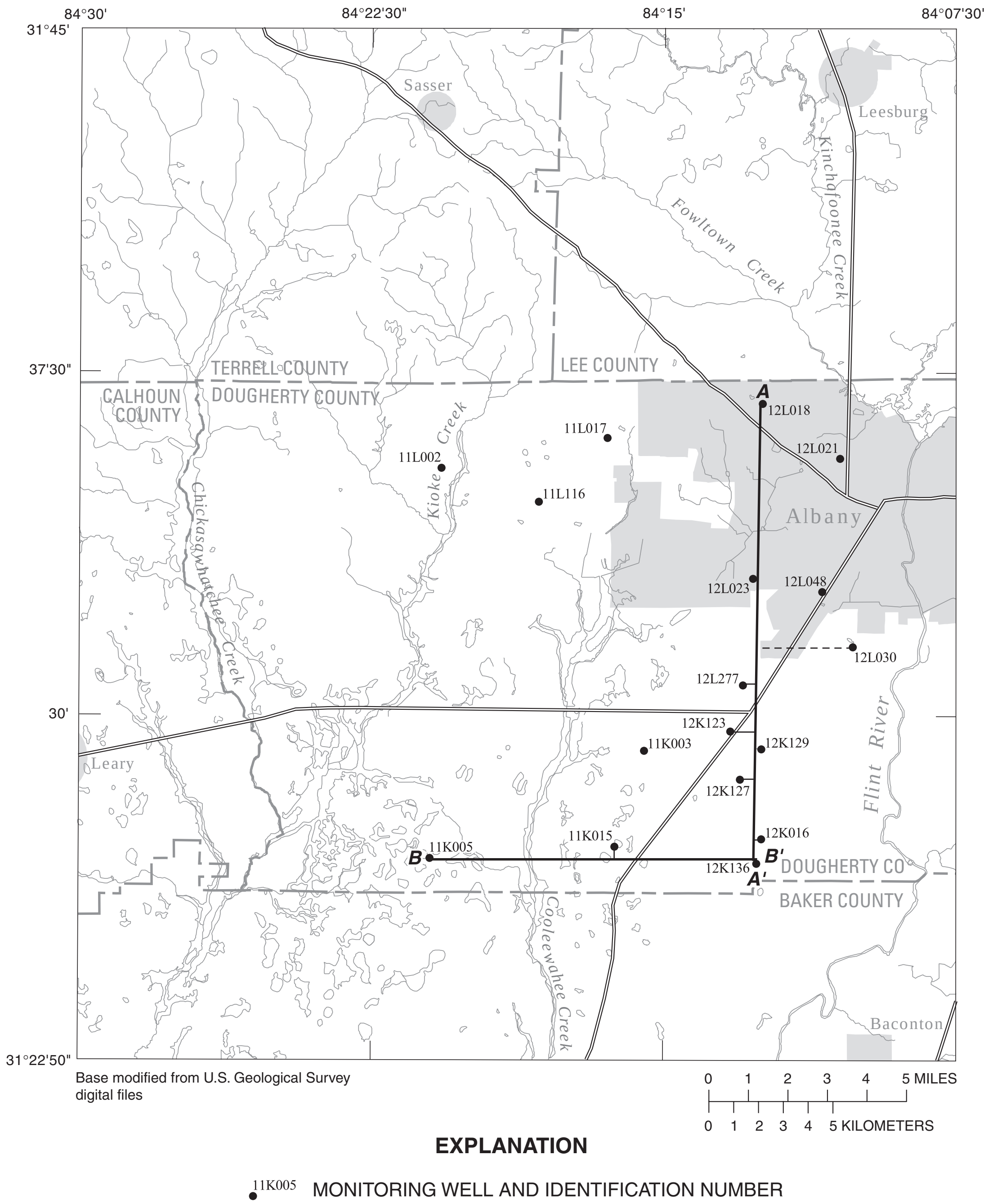


Figure 6. Monitoring wells used to describe the lithology of the Ocala Limestone and locations of hydrogeologic sections *A-A'* and *B-B'*.

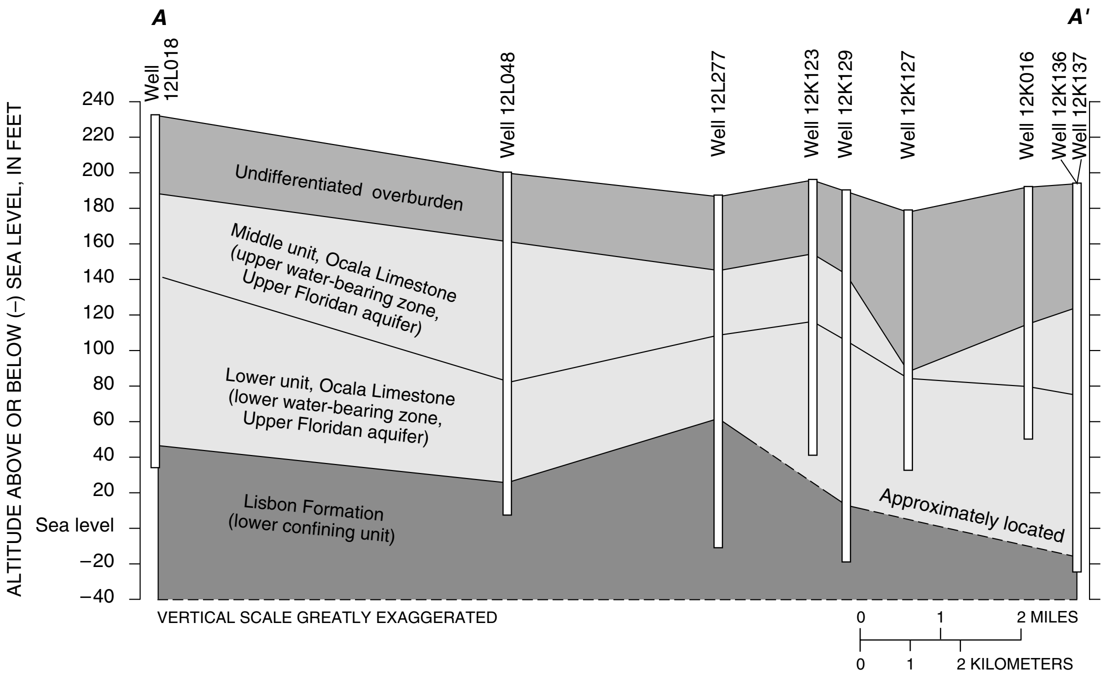


Figure 7. Hydrogeologic section *A–A′* showing the geologic sequence and Upper Floridan aquifer in the Albany area (see fig. 6 for line of section).

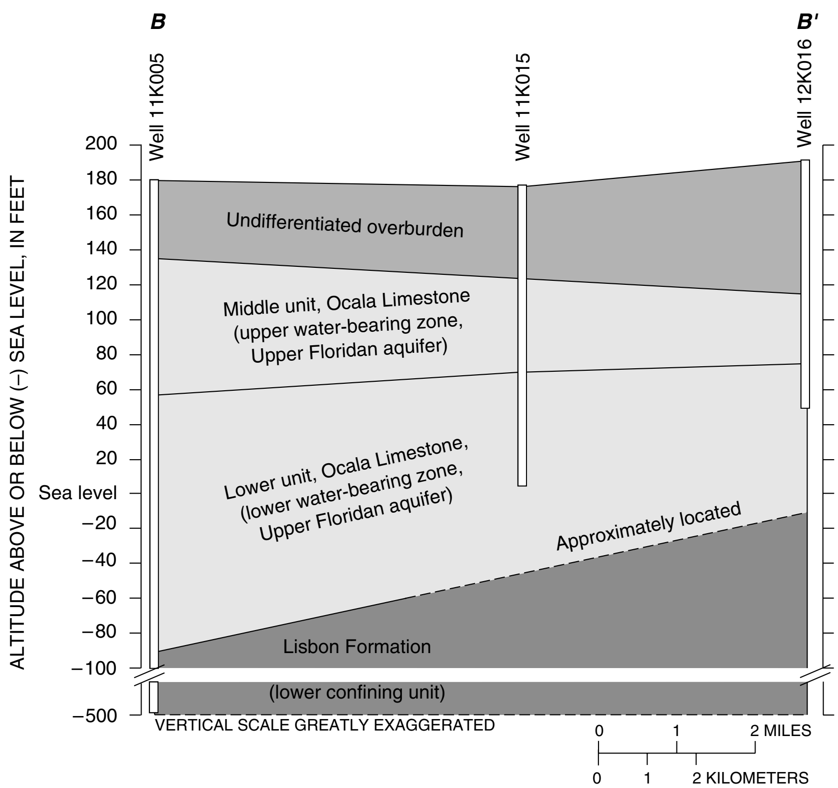


Figure 8. Hydrogeologic section *B–B′* showing the geologic sequence and Upper Floridan aquifer in the Albany area (see fig. 6 for line of section).

Table 3. Lithologic descriptions of U.S. Geological Survey observation wells 11L116 and 12K136 in the western Albany area, Georgia

[do., ditto]

Well number	Depth (feet below land surface)	Lithologic unit	Description of lithology
11L116	0-28	undifferentiated overburden	clay with varying sand-gravel content, texture varies from soft, sticky clay to hard plastic clay, color varies from gray to tan, in some areas mottled tan-gray-red-purple-black; sand mostly quartz, also some ironstone/lithic fragments; limestone fragments occur throughout section
	28-50	Ocala Limestone	cream-white limestone fossiliferous, molds; varying amounts of clay or sand, some orange staining in more porous zones and along fractures
	50-65	do.	friable, sandy, fossiliferous zone, minor orange staining
	65-76	do.	same as 50-65 ft, changing to arenaceous limestone, very few fossils, some zones of higher clay content
	76-120	do.	same as 65-76 ft, gradually changing to white-cream-tan limestone, in places very porous/fossiliferous, molds lined with drusy calcite, some calcite rhombs in matrix, orange-dark brown staining in molds and along some fractures
	120-126	do.	same as 76-120 ft, changing to glauconite which occurs in molds
	126-147	do.	glauconite occurs throughout core; lithology varies from white-tan fossiliferous limestone to green calcareous clay; some zones friable, some spar with drusy calcite in molds
	147-150	Lisbon Formation	green calcareous clay with some white fossiliferous limestone zones
12K136	0-32	undifferentiated overburden	clay with varying sand-gravel content, in some places clayey sand; color varies from tan-orange-gray-white, in some places mottled with black-purple-red; limestone fragments occur throughout section
	32-34	do.	white clay layer
	34-37	do.	clay with varying sand-gravel content, in some places clayey sand; color varies from tan-orange-gray-white, in some places mottled with black-purple-red; limestone fragments occur throughout section
	37-38	do.	white, silicified, fossiliferous “limestone” (chert) layer
	38-70	do.	clay with varying sand-gravel content, in some places clayey sand; color varies from tan-orange-gray-white, in some places mottled with black-purple-red; limestone fragments occur throughout section
	70-95	Ocala Limestone	yellow-tan-cream fossiliferous clayey limestone, clay non-calcareous, orange-brown staining in molds and friable zones
	95-129	do.	brown-orange kaolinitic clay, texture varies from gel-like to sticky to soupy to stiff; in some places very sandy; rare zones of cream clayey limestone, sometimes as fragments, sometimes in sharp contact with brown clay
	129-197	do.	brownish, tan-cream-white limestone, very fossiliferous in zones, drusy calcite in molds and matrix, orange-dark brown-black staining in porous zones, molds and fractures.
	197-211	do.	glauconite infilling molds
	211-215	Lisbon Formation	green glauconitic clayey limestone

Ocala Limestone

The lower unit of the Ocala Limestone, as observed in the core samples and geophysical logs, consists of a white to tan, fossiliferous, recrystallized, glauconitic, dolomitic limestone (table 3) with well-developed permeability along solution-enlarged joints, fractures, and bedding planes (figs. 9-11). The thickness of the lower unit in the study area ranges from about 36 to 112 ft (table 2). The contact between the middle and lower units of the Ocala Limestone is irregular and dips to the southeast at about 7 ft/mi (fig. 12).

The middle unit of the Ocala Limestone, as described regionally by Hicks and others (1987), is actually the upper part of the Ocala Limestone in the study area. Core samples show that the middle unit is a light tan, friable, clayey, fossiliferous, weathered, dense limestone (table 3). Voids filled with clay- to gravel-size sediments in the core samples are thought to be collapse features or infilled solution caverns. These filled-in voids do not appear to be laterally extensive. The thickness of the middle unit ranges from about 4 to 78 ft (table 2). The top of the middle unit is coincident with the weathered top of the Ocala Limestone in the study area, and has a very irregular surface that generally dips to the southeast at about 5 to 7 feet per mile (ft/mi) (fig. 13). A 32-ft deep, 2 1/2-mi wide surface depression exists in the weathered top of the Ocala Limestone in the southeastern part of the study area (fig. 13). This depression may represent either a relic stream channel or a large collapse feature in the limestone surface.

Undifferentiated Overburden

The undifferentiated overburden consists of interlayered clay, silty clay, clayey sand, and gravel deposits (table 3) that are distributed areally and vertically. Natural gamma radiation logs and core samples (table 3) (figs. 9-11) indicate that the undifferentiated overburden contains a large amount of clay, except where breached by erosion or sinkhole collapse of the underlying Ocala Limestone. Because of the limited number of core samples collected during this and previous studies, the composition of the overburden cannot be mapped in detail. Thickness of the overburden ranges from 25 ft in the northern part of the study area to about 92 ft in the southeastern part of the study area (fig. 14). The thickest overburden occurs in the area of the depression identified in the top of the Ocala Limestone (fig.14). Erosion, sink-hole collapse, and minimal clay content in the overburden provides pathways for migration of recharge and potential contamination from the surface to the Upper Floridan aquifer.

Hydrology

Ground-water-level data were used to determine the thickness and extent of the surficial aquifer, connection between the surficial aquifer and the Upper Floridan aquifer, and vertical and lateral hydraulic-head gradients in the Upper Floridan aquifer.

Surficial Aquifer

In the study area, a surficial aquifer consisting of discontinuous, mostly perched, and/or seasonal water tables is contained in the undifferentiated overburden. Water levels in the surficial aquifer respond positively to recharge (increase) and negatively to discharge (decrease), and fluctuate seasonally and areally throughout the study area. An increase in water level results in an increase in thickness of the surficial aquifer, and a decrease in water level results in a decrease in thickness. Water levels in the surficial aquifer ranged from about 10 to 35 ft below land surface (September 1993 through December 1994). Fluctuations in ground-water levels in the surficial aquifer are seasonal—highest water levels occur from February through April; water levels decline during the summer and fall, and minimum levels occur from November through January (figs. 15, 16). Although precipitation generally is heavy from April through September, water lost to evapotranspiration is greatest during the growing season, and consequently, recharge to the surficial aquifer is greatly reduced during that period.

Upper Floridan Aquifer

In the study area, the Upper Floridan aquifer consists of the Ocala Limestone (figs. 7-11). The overlying undifferentiated overburden locally confines the Upper Floridan aquifer where large amounts of clayey deposits are present in the overburden. The Upper Floridan aquifer is unconfined where clayey deposits are lacking in the overburden, or where the overburden has been breached by erosion or sinkhole collapse of the Ocala Limestone.

Ground-Water Levels

Water levels in the Upper Floridan aquifer respond positively to recharge (increase) and negatively to discharge (decrease), and fluctuate seasonally and

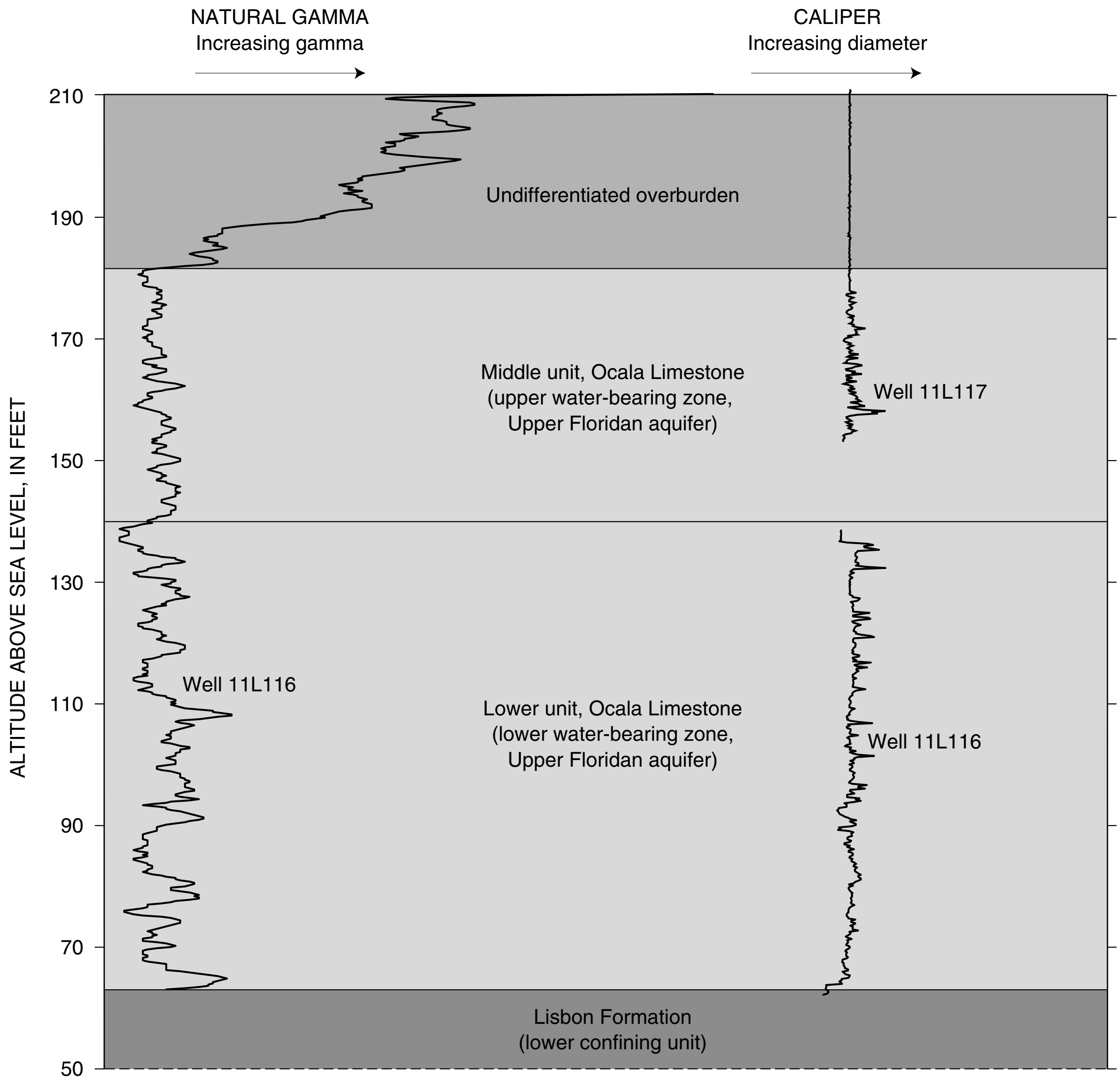


Figure 9. Geophysical logs and generalized hydrogeologic sequence at wells 11L116 and 11L117.

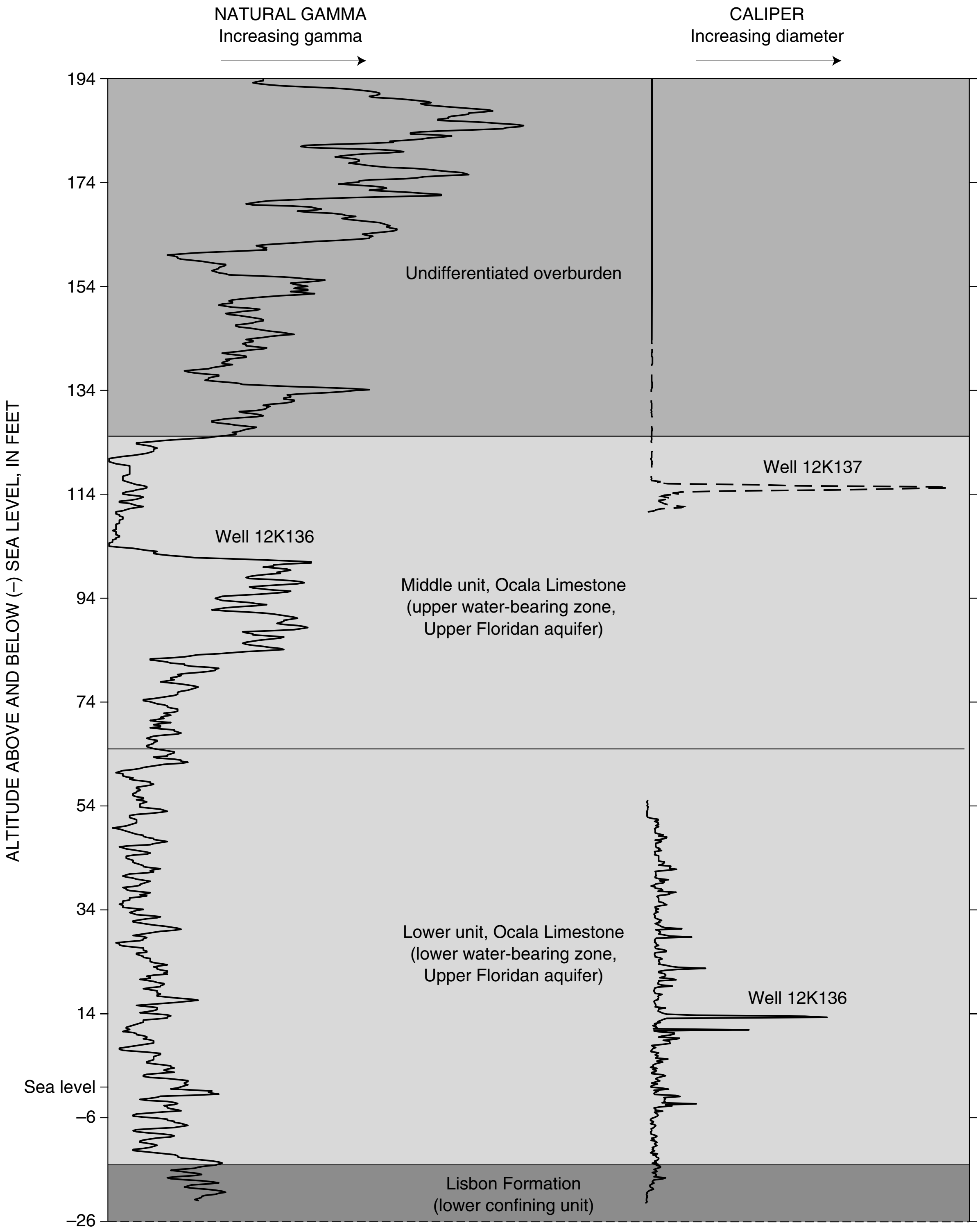


Figure 10. Geophysical logs and generalized hydrogeologic sequence at wells 12K136 and 12K137.

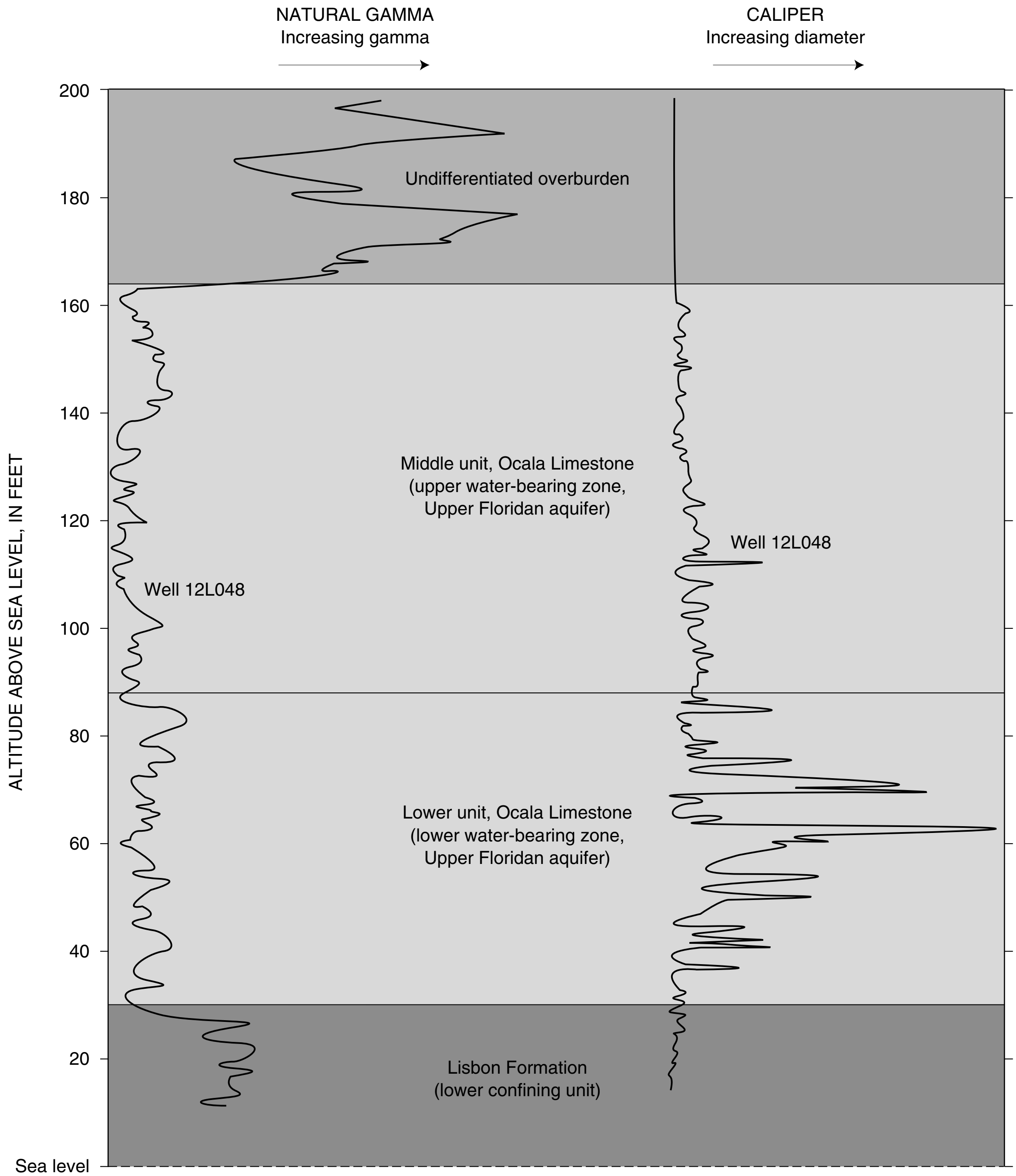
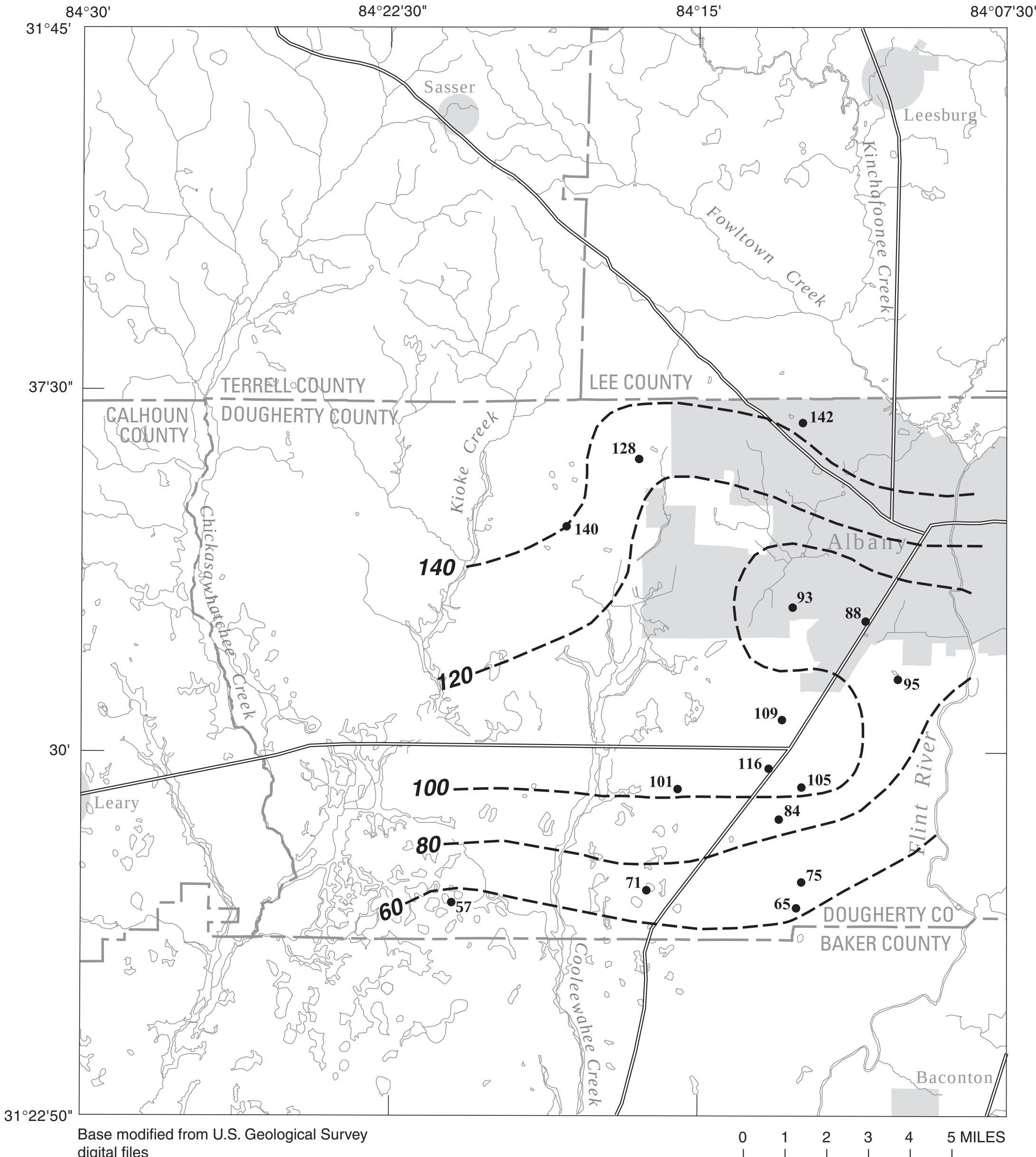


Figure 11. Geophysical logs and generalized hydrogeologic sequence at well 12L048.

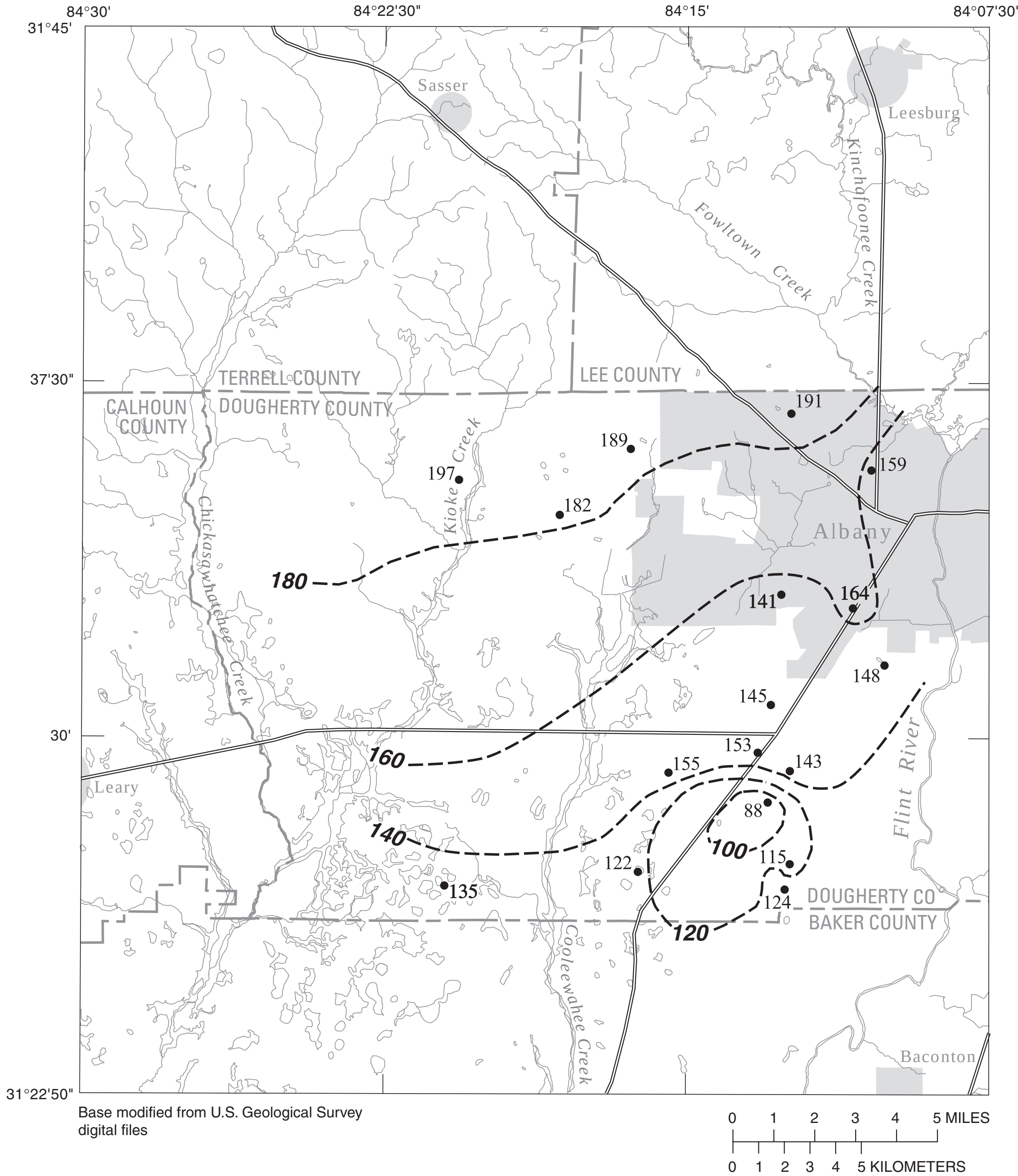


EXPLANATION

60 – – – CONTOUR OF APPROXIMATE EQUAL ALTITUDE OF CONTACT BETWEEN MIDDLE AND LOWER UNITS OF OCALA LIMESTONE—Contour interval 20 feet. Datum is sea level

•57 MONITORING WELL AND ALTITUDE OF CONTACT BETWEEN MIDDLE AND LOWER UNITS OF THE OCALA LIMESTONE—In feet above sea level

Figure 12. Approximate altitude of the contact between the middle and lower units of the Ocala Limestone.

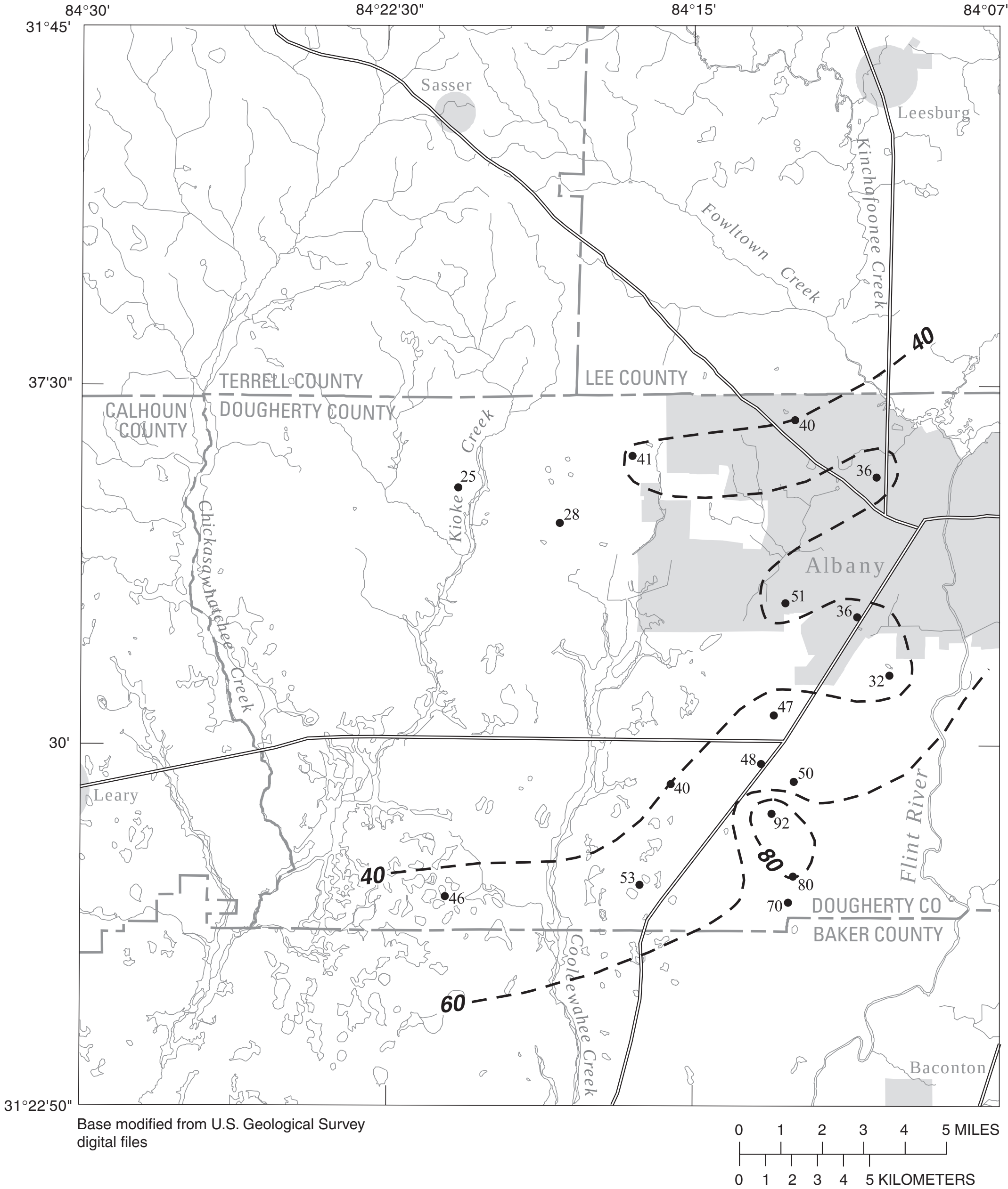


EXPLANATION

160 – – – CONTOUR OF APPROXIMATE EQUAL ALTITUDE OF TOP OF OCALA LIMESTONE—Contour interval 20 feet. Datum is sea level

•135 MONITORING WELL AND ALTITUDE OF TOP OF OCALA LIMESTONE—In feet above sea level

Figure 13. Approximate altitude of the top of the Ocala Limestone.



EXPLANATION

60 — — — LINES OF APPROXIMATE EQUAL THICKNESS OF OVERBURDEN—Interval 20 feet

•46 MONITORING WELL COMPLETED IN UNDIFFERENTIATED OVERBURDEN—Number is thickness, in feet

Figure 14. Approximate thickness of the undifferentiated overburden.

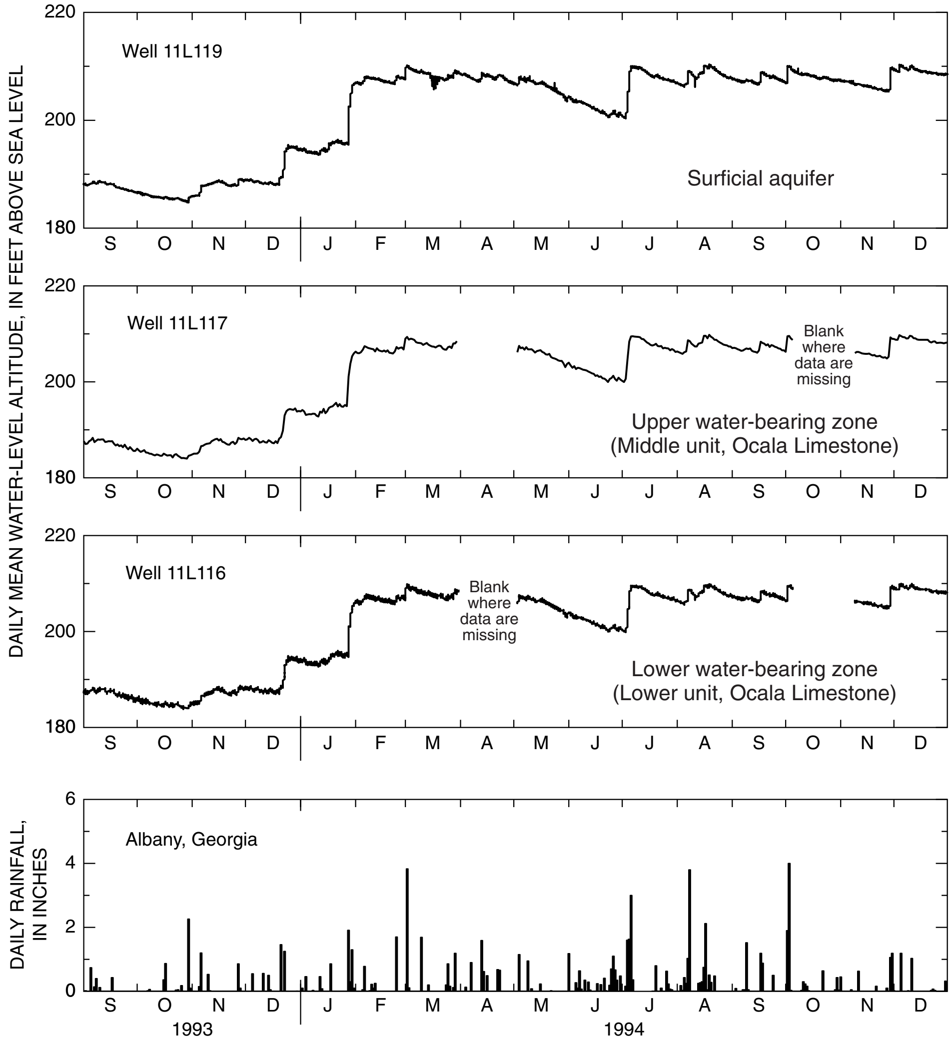


Figure 15. Daily rainfall at Albany, Georgia, and daily mean water-level altitudes in surficial aquifer well 11L119; Upper Floridan aquifer, upper water-bearing zone well 11L117; and Upper Floridan aquifer, lower water-bearing zone well 11L116, September 1993–December 1994.

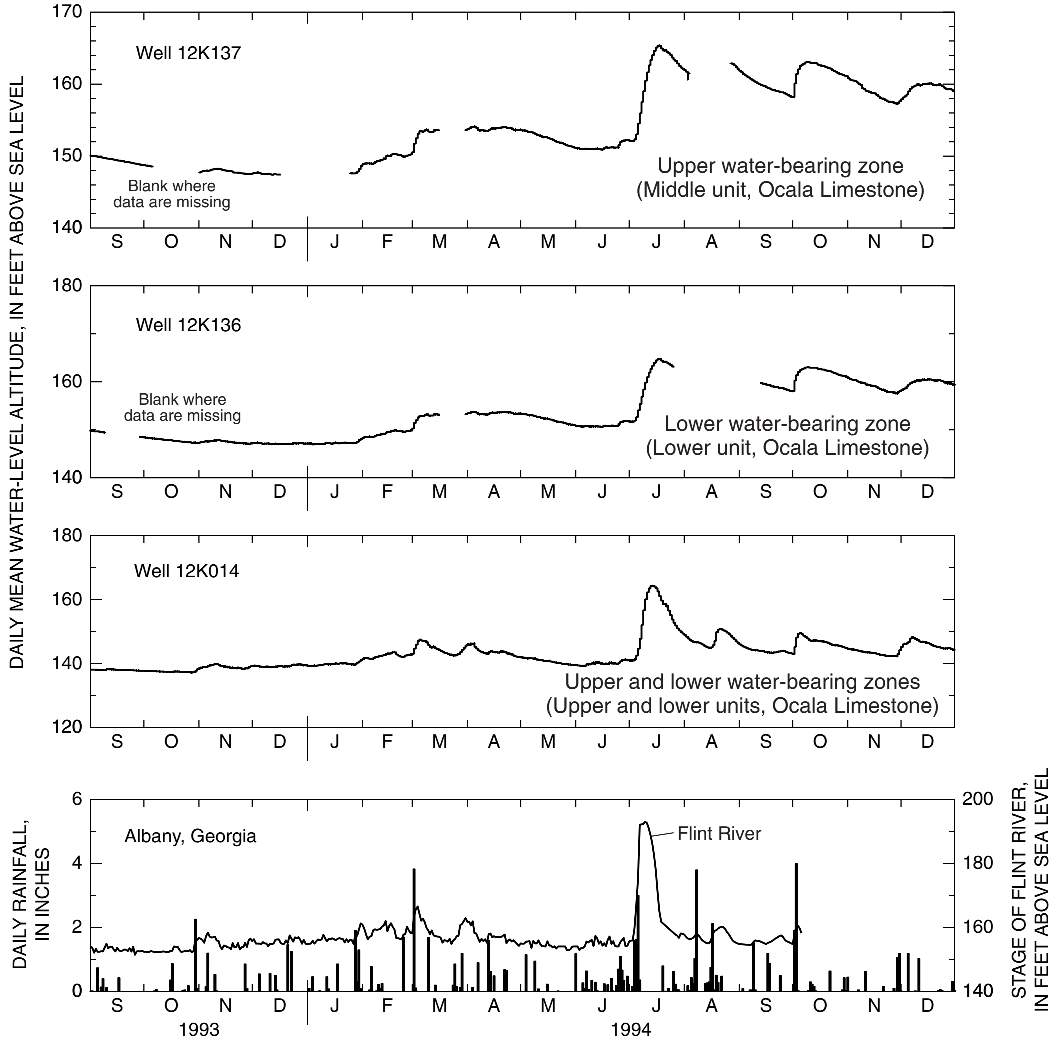


Figure 16. Daily rainfall and stage of the Flint River at Albany, Georgia, and daily mean water-level altitudes in the Upper Floridan aquifer; upper water-bearing zone well 12K137; Upper Floridan aquifer, lower water-bearing zone well 12K136; and upper and lower water-bearing zones well 12K014, September 1993–December 1994.

areally throughout the study area. In the Upper Floridan aquifer, an increase in water level is the result of an increase in hydrostatic pressure in the aquifer and a corresponding increase in storage. Water levels in the Upper Floridan aquifer range from 210 ft above sea level (nearly land surface) in the northwestern area (wells 11L116 and 11L117) to 135 ft above sea level (nearly 60 ft below land surface) in well 12K014 near the Flint River (September 1993 through December 1994).

Water levels in the study area respond quickly to recharge from precipitation. Hydrographs from wells in the northwestern part of the study area (fig. 15) show that water levels in the Upper Floridan aquifer change as rapidly and at the same magnitude as water levels in the surficial aquifer. The magnitude of change for a given rainfall is unpredictable. For example, rainfall of about 4 inches results in ground-water level increases from about 2 to 10 ft over the study area (fig. 15) and is a function of antecedent soil moisture and ground-water conditions. Ground-water levels in the southeastern part of the study area respond to stage fluctuations of the Flint River as well as precipitation (fig. 16). In this area, the magnitude of change for a given rainfall or change in river stage also is unpredictable and ranges from near 0 to 15 ft.

Water levels in wells open only to the middle unit or the lower unit of the Ocala Limestone respond similarly to precipitation or stage fluctuations of the Flint River (figs. 15 and 16). This relation was observed in the northwestern and southeastern parts of the study area, indicating that the water-bearing zones of the Ocala Limestone respond to recharge as a single hydraulic unit throughout the study area.

Seasonal fluctuations in water levels in the Upper Floridan aquifer generally are at a maximum from February through April, decline through summer, and are at a minimum from November through January (figs. 15 and 16). However, water levels in the Upper Floridan and surficial aquifers were elevated in late-summer 1994 to mid-winter 1995 because of increased rainfall from Tropical Storm Alberto in July 1994 (figs. 15 and 16). Annual ground-water-level fluctuations ranged from about 10 ft in the extreme northwestern part of the study area near cave 12M026C to about 25 ft throughout much of the remainder of the study area.

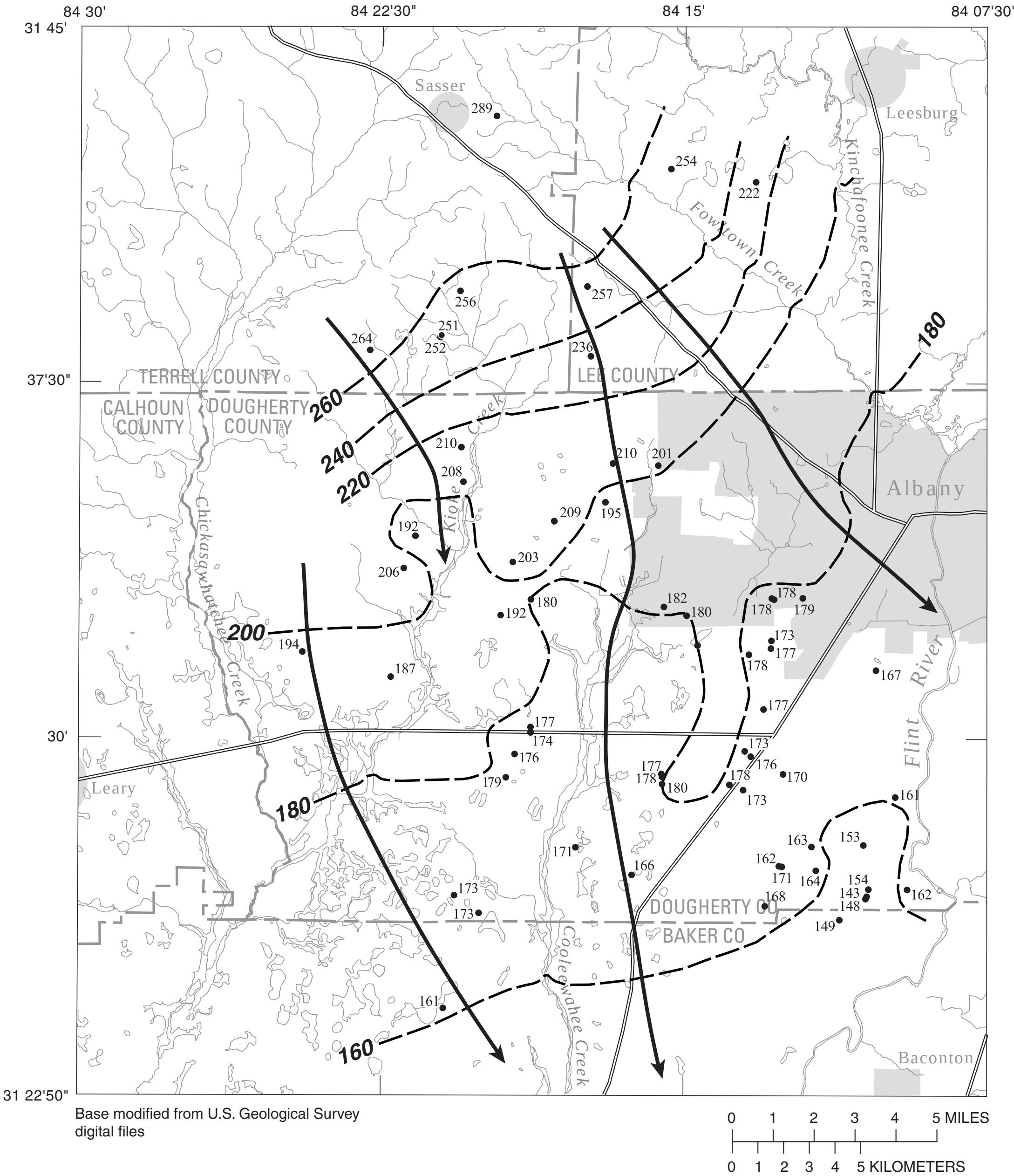
Potentiometric Surface and Directions of Ground-Water Flow

Potentiometric-surface maps were constructed and approximate directions of ground-water flow evaluated by using water-level altitudes for the Upper Floridan aquifer. Ground-water flow generally is from northwest to southeast with a gradient that ranges from about 10 ft/mi in the northwest to about 3 ft/mi in the southeast where the Upper Floridan aquifer thickens (figs. 17, 18). Ground-water-flow directions and flow gradients remain consistent during high ground-water-level months (February through April) compared with low ground-water-level months (November through January) with the exception of a possible ground-water ridge in the central part of the study area during high ground-water-level months (fig. 17).

Recharge and Discharge

The direction of vertical hydraulic gradient between a surficial aquifer and a lower aquifer; and within an aquifer, controls the potential movement of ground water to and from the aquifer. For example, an upward hydraulic gradient indicates the potential for discharge from the aquifer to occur. A downward hydraulic gradient indicates the potential for recharge to the aquifer. Water-level data collected from clusters of wells open only to the middle or lower unit of the Ocala Limestone in the Upper Floridan aquifer or to the surficial aquifer were used to evaluate recharge to—or discharge from—the Upper Floridan aquifer.

Recharge to the Upper Floridan aquifer is seasonal and typically occurs from December through March. In the northwestern part of the study area, the potential for recharge to the Upper Floridan aquifer from the surficial aquifer is indicated by water levels in the surficial aquifer (well 11L119) that are 0.5 to 1.0 ft higher than in the middle unit of the Ocala Limestone (well 11L117) (fig.15), indicating a slight downward hydraulic gradient. Water levels in the lower unit of the Ocala Limestone (well 11L116) are roughly equivalent to water levels in the middle unit (well 11L117) indicating that there is virtually no hydraulic gradient between the middle and lower units in this area (fig.15). Therefore, the middle and lower units of the Ocala Limestone act as one hydraulic unit with mostly horizontal flow in the Upper Floridan aquifer in the northwestern part of the study area.



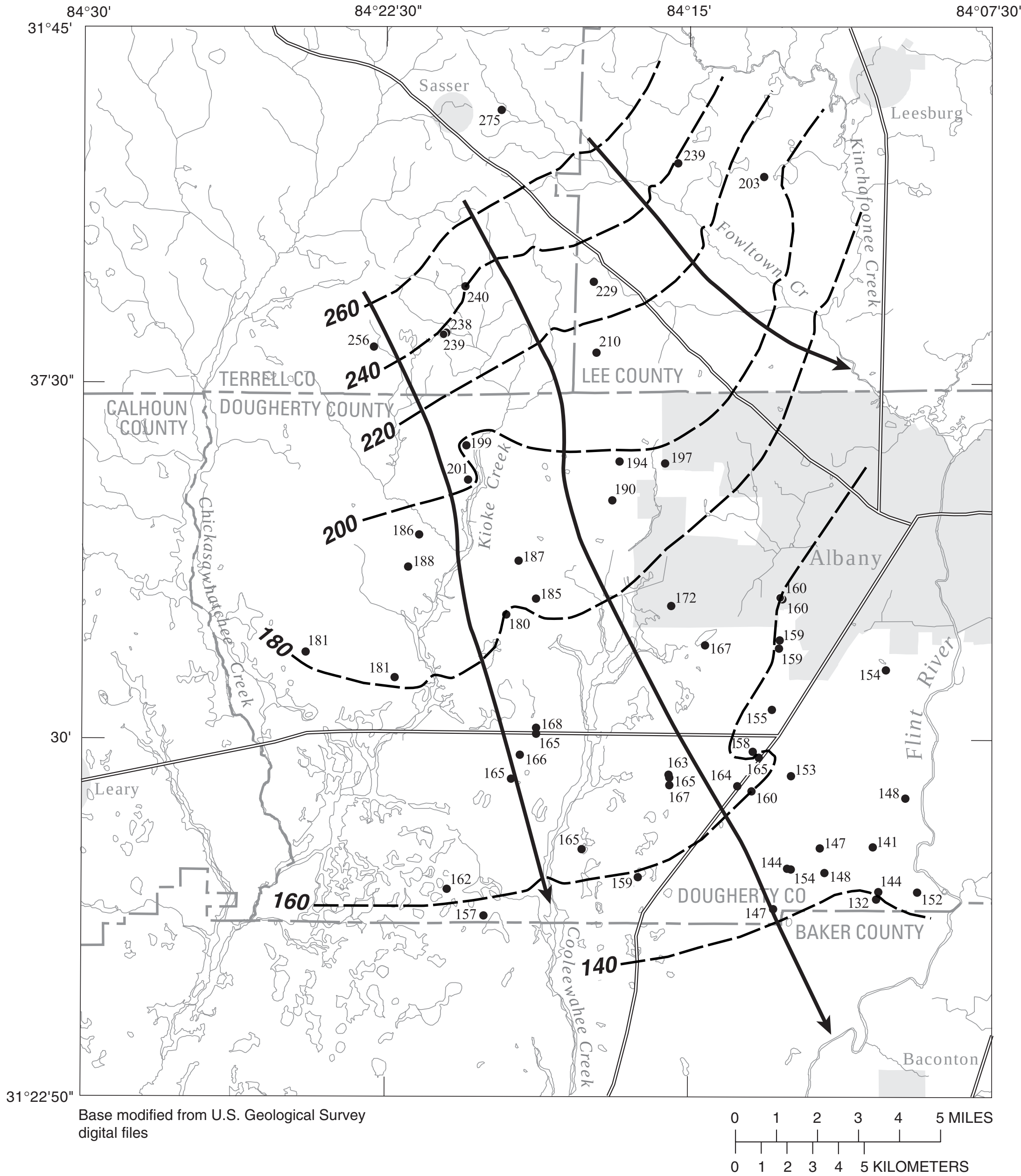
EXPLANATION

160 — — — POTENTIOMETRIC CONTOUR—Shows approximate altitude at which water level would have stood in tightly cased wells completed in the Upper Floridan aquifer during April 1993. Contour interval 20 feet. Datum is sea level

⟶ GENERALIZED DIRECTION OF GROUND-WATER FLOW

161• MONITORING WELL AND ALTITUDE OF WATER LEVEL IN UPPER FLORIDAN AQUIFER

Figure 17. Generalized potentiometric surface and ground-water flow direction in the Upper Floridan aquifer, April 1993.



EXPLANATION

140 — — — POTENTIOMETRIC CONTOUR—Shows approximate altitude at which water level would have stood in tightly cased wells completed in the Upper Floridan aquifer during November 1993. Contour interval 20 feet. Datum is sea level

⟶ GENERALIZED DIRECTION OF GROUND-WATER FLOW

•162 MONITORING WELL AND ALTITUDE OF WATER LEVEL IN UPPER FLORIDAN AQUIFER

Figure 18. Generalized potentiometric surface and ground-water flow direction in the Upper Floridan aquifer, November 1993.

The potential for recharge to the Upper Floridan aquifer also is indicated in the southeastern part of the study area. Typically, water levels in the middle unit of the Ocala Limestone at well 12K137 are 1.0 ft higher than water levels in the lower unit at well 12K136, suggesting that a slight downward hydraulic gradient exists in the Upper Floridan aquifer in this area (fig. 16). The surficial aquifer is not present at this location. Recharge to the Upper Floridan aquifer in this area may occur as a result of a nearby breach in the overburden from erosion or sinkhole collapse, or the lack of clayey sediments in the overburden allowing rainfall to percolate through the overburden to the aquifer. Water levels in the well open to the lower unit of the Ocala Limestone were higher than those in the well open to the middle unit during November and December 1994. The reversed vertical hydraulic gradient was attributed to increased recharge to the lower unit of the Ocala Limestone from Tropical Storm Alberto; which occurred in July 1994. Localized recharge also is indicated by the ground-water ridge in the east-central part of the study area present during April 1993 (fig. 17). Although the distribution of vertical hydraulic gradient was determined at only two areas in the study area, the presence of downward hydraulic gradients in those two areas suggests that downward hydraulic gradients likely are present in other areas along the general direction of ground-water flow, allowing for areally distributed recharge to the Upper Floridan aquifer.

The degree of surface drainage in an area is an indicator of the connection of surface water to the subsurface in recharge areas. The presence of well-defined surface drainage indicates that part of precipitation runs overland to streams, and the other part percolates downward to the shallowest aquifer. The lack of well-defined surface drainage in an area indicates that a large part of precipitation percolates downward to the shallowest aquifer. Evapotranspiration also accounts for a part of the precipitation in either area. The presence of well-defined surface drainage (dendritic in this case) west of the divide between Cooleewahee Creek and the Flint River (fig. 1) suggests that significant amounts of precipitation run overland to local streams in this area. Precipitation has the potential to migrate to the Upper Floridan aquifer, as demonstrated by the downward hydraulic head measured in this area, and partially discharges from the aquifer to these streams as well. The lack of surface drainage east of the divide between Cooleewahee Creek and the Flint River (fig. 1) and a downward hydraulic gradient suggest that precipitation may migrate from the land surface to the Upper Floridan aquifer in this area. The migration of precipitation from the land surface to the surficial aquifer and then to the Upper Floridan aquifer provides a means for contamination from the land surface, such as agricultural chemicals, sewage treatment, and other anthropogenic contaminants to reach these aquifers.

Discharge from the Upper Floridan aquifer occurs at the Flint River and other streams that breach the aquifer, at pumping wells, and as lateral flow (regional flow) from the study area. Ground-water-level data collected during this study indicate that the Flint River is the most important hydrologic feature shaping the potentiometric surface of the Upper Floridan aquifer.

Chlorofluorocarbon and Tritium Calculated Ground-Water Ages

Ground-water age-dating was conducted by using chlorofluorocarbon and tritium concentrations in water from the Upper Floridan aquifer to determine if recharge and possible contaminant migration to the aquifer is recent or occurred prior to the introduction of CFCs and tritium in the early 1950’s into the global natural water system. Ground-water ages in the study area generally range from 9 to 34 years with one age calculated at greater than 50 years (table 4; fig 19), indicating that recharge consisting of “modern” water (post early-1950’s) is present in the aquifer. Areal distribution of ground-water ages calculated during this study varies from the truly confined aquifer model, in which ground water typically is the youngest in the area where the aquifer is recharged with ground-water ages increasing along flow paths to discharge areas (Nir, 1964). A natural system that varies from this model indicates that recharge may enter the aquifer through breeches in confinement, and mixing of differing-age waters is occurring along the ground-water-flow direction. Areas of younger ground-water ages are interspersed with areas of older water throughout the study area (fig. 19), indicating that recharge is reaching the aquifer in widely distributed localized areas which may be potential migration points for surface derived contaminants.

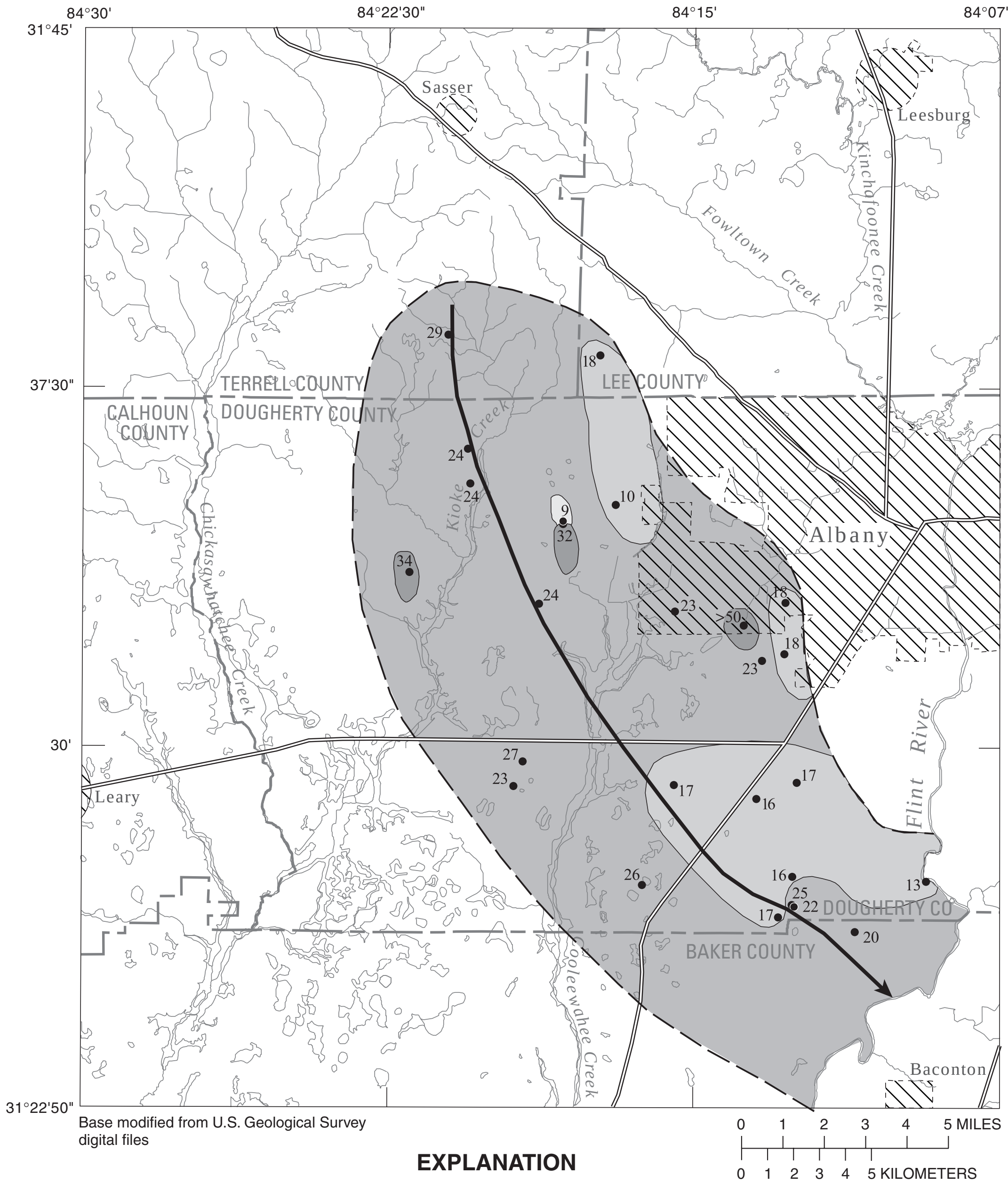
Tritium concentrations in water from the Upper Floridan aquifer range from 0.1 to 12 tritium units (table 4). The presence of tritium indicates that water in the aquifer was recharged mainly after 1963, which is consistent with the CFC-calculated age range of 9 to 34 years. CFC and tritium concentrations and calculated ground-water ages for the Upper Floridan aquifer are listed in table 4.

Table 4. Chlorofluorocarbon and tritium concentrations; computed ages of ground water; and confidence intervals from selected wells completed in the Upper Floridan aquifer, western Albany area, Georgia, July 1993

[pg/kg, picograms per kilogram; pptv, partial pressure in parts per trillion per volume; TU, tritium unit; CFC, chlorofluorocarbon]

Site number	Date of collection	Chlorofluorocarbon concentration: In solution[1] (pg/kg) CFC/11	In solution (pg/kg) CFC/12	In solution (pg/kg) CFC/113	In air (pptv) CFC/11	In air (pptv) CFC/12	In air (pptv) CFC/113	Computed age (years)	Confidence interval in computed age (± years)	Tritium concentrations (TU)	Confidence interval (± TU)
Upper Floridan aquifer—*middle unit of Ocala Limestone*											
11L113	07/13/93	2.3	68	5.3	1.3	154	7.4	23	CFC/113 only	6.5	0.4
11L117	07/14/93	1,018	225	28	555	512	38	9	CFC/113 only	11	.4
12K053	07/13/93	262	129	19	143	293	27	16	2	9.9	.5
12K133S	07/15/93	539	139	17	293	314	24	13	5	9.3	.3
12K137	07/15/93	98	51	8	53	116	11	25	2	8.6	.4
12L312	07/13/93	109	75	13	60	171	18	23	2	8.9	.4
Upper Floridan aquifer—*middle and lower units of Ocala Limestone*											
11K003	07/15/93	210	115	23	114	262	32	17	2	9.3	.9
11K015	07/16/93	74	47	12	40	106	17	26	2	8.3	.5
11K043	07/14/93	101	66	13	55	150	19	23	2	7.4	.4
11K044	07/13/93	25	37	179	14	83	248	27	CFC/113 only	6.8	.4
11L003	07/15/93	84	44	10	46	99	14	24	2	5.5	.4
11L020	07/14/93	78	52	8	43	118	11	24	2	7.9	.4
11L092	07/13/94	380	215	19	207	487	26	10	5	9.7	.3
11L112	07/13/93	96	3,001	6.0	52	6,821	8	24	2	4.0	.4
11M010	07/14/93	206	122	37	112	278	51	18	2	9.6	.4
11M025	07/14/93	46	29	0.0	25	65	0.0	29	2	10	.5
12K014	07/16/93	190	87	12	104	197	16	20	2	9.2	.5
12K123	07/16/93	251	128	10	137	290	14	17	2	7.7	.4
12K132	07/13/93	493	431	13	269	979	18	17	CFC/113 only	8.2	.4
12L276	07/16/93	238	403	18	129	914	25	18	CFC/113 only	9.5	.5
Upper Floridan aquifer—*lower unit of Ocala Limestone*											
11L111	07/13/93	18	17	8.7	10	38	12	34	2	1.1	.1
11L116	07/14/94	30	16	0	16	36	0	32	2	6.5	.3
12K101	07/14/93	6,211	925	14	3,382	2,099	20	16	CFC/113 only	11	.6
12K129	07/13/94	430	490	14	234	1,112	19	17	CFC/113 only	9.8	.5
12K136	07/15/93	133	73	11	72	165	15	22	2	8.4	.4
12L324	07/16/94	16	0.0	8	8.7	0.0	11	>50	5	0.1	.2

[1]Recharge temperature calculated at 19 ° C.



EXPLANATION

CHLOROFLUOROCARBON CALCULATED GROUND-WATER AGES, IN YEARS

- 2 to 9
- 10 to 19
- 20 to 29
- Equal to or greater than 30

APPROXIMATE BOUNDARY OF AREA IN UPPER FLORIDAN AQUIFER SAMPLED FOR CHLOROFLUOROCARBON CONCENTRATION

GENERALIZED DIRECTION OF GROUND-WATER FLOW

26 MONITORING WELL COMPLETED IN UPPER FLORIDAN AQUIFER—Number is chlorofluorocarbon calculated ground-water age, in years

Figure 19. Distribution of chlorofluorocarbon calculated ground-water ages in the Upper Floridan aquifer, July 1993.

WATER QUALITY IN THE UPPER FLORIDAN AQUIFER

Analyses of ground-water samples collected during this study were used to (1) describe the ground-water type and quality in the Upper Floridan aquifer; and (2) evaluate the potential for anthropogenic contaminants to migrate from the land surface to the Upper Floridan aquifer by using the areal distribution of dissolved oxygen and nitrogen in water from the Upper Floridan aquifer. Major and minor ions, along with selected chemical constituent concentrations and properties in the Upper Floridan aquifer are listed in tables 5 and 6.

Descriptive statistics (number of observations, mean, standard deviation, median, minimum, and maximum) were used to determine the variation of selected ground-water constituents, properties, and ages (table 7) present in the study area. Analyses of samples collected from 29 sites in July 1993 (tables 5 and 6) show that the Upper Floridan aquifer contains calcium-bicarbonate type water. The sum of dissolved solids ranges from 101 to 294 milligrams per liter (mg/L) (table 5), with a median concentration of 151 mg/L (table 7). Calcium concentrations range from 27 to 82 mg/L (table 5) with a median value of 51 mg/L (table 7). Generally, water quality in the Upper Floridan aquifer is good—concentrations of ionic constituents (chloride, sulfate, nitrite-plus-nitrate, iron, and manganese) are below Georgia Department of Natural Resources (GaDNR) Environmental Protection Division (EPD), Safe Drinking Water standards (1993).

Water from the Upper Floridan aquifer generally is oxygenated, with concentrations of dissolved oxygen greater than 2 mg/L (table 5). Widely dispersed localized areas of water in the Upper Floridan aquifer depleted in dissolved oxygen (concentrations less than 2 mg/L) occur throughout the study area. An area enriched in dissolved oxygen occurs near the Baker County and Dougherty County line, several miles along the generalized ground-water-flow path (fig. 20). In a regionally confined aquifer, dissolved oxygen would be expected to be greatest in recharge areas and decrease along flow paths because of long isolation from the atmosphere and in situ oxidation of organic matter. This area of elevated dissolved-oxygen concentrations near the county line indicates that surface water (precipitation or stream leakage) recharges the Upper Floridan aquifer in localized and areally distributed areas; these represent potential areas for migration of anthropogenic contaminants from the land surface to the Upper Floridan aquifer.

Areas of elevated (above background) nitrate concentration in water from the Upper Floridan aquifer were used as an indicator of potential effects of anthropogenic activities on ground-water resources. Nitrogen occurs most commonly in ground water as nitrite (NO_2^-) or nitrate (NO_3^-) ions; these forms are stable over time and a range of aquifer conditions (Hem, 1985). High concentrations of nitrate in ground water can be toxic to infants, some livestock, and domestic animals that drink the water. Sources of nitrite-plus-nitrate in the Upper Floridan aquifer include the leaching of fertilizers, and soil amendments applied to the soil in agricultural areas, leachate from septic systems, and animal manure. Nitrite-plus-nitrate concentrations measured during this study range from less than 0.02 mg/L to 5.5 mg/L (table 6) (fig. 21) with a median concentration of 1.09 mg/L (table 7). These nitrite-plus-nitrate concentrations are below the GaDNR, EPD drinking-water standards maximum contaminant level of 10 mg/L (1993). The lowest nitrite-plus-nitrate concentrations measured during this study were less than 0.02 mg/L at well 12L324, 0.02 mg/L at well 11L113, and 0.03 mg/L at well 11K044 (table 6) (fig. 21). Water from these wells also was depleted in dissolved-oxygen concentrations (<0.1 mg/L at wells 12K324 and 11L113, and 0.6 mg/L at well 11K044 (table 5)), suggesting that denitrification may be occurring in the aquifer at these well locations. The presence and irregular distribution of nitrogen in the Upper Floridan aquifer (fig. 21) indicate that land-use activities of row-crop agriculture, animal husbandry, and suburban housing development—which are associated with the use of nitrogen containing fertilizers, septic leachate, and animal manure—result in locally elevated nitrite-plus-nitrate concentrations in the Upper Floridan aquifer in the western Albany area.

Table 5. Field properties and major ion concentrations in water from the Upper Floridan aquifer, western Albany area, Georgia, July 1993

[° C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; —, no data; <, less than]

Site number	Date of collection	Temperature (° C)	Specific conductance (µS/cm)	pH	Dissolved oxygen (mg/L)	HCO_3 (mg/L)	Alkalinity as $CaCO_3$ (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Fluoride (mg/L)	Silica, as SiO_2 (mg/L)
Upper Floridan aquifer—*middle unit, Ocala Limestone*															
11L113	07-13-93	20.4	295	7.4	<0.1	177	145	42	0.4	1.9	0.1	5.8	5.2	<0.1	7.5
11L117	07-14-93	20.6	271	7.5	5.0	153	126	52	.4	2.4	.2	5.8	.6	<.1	7.2
11M026C	07-21-93	18.6	254	7.3	—	179	147	61	.3	1.8	.2	3.2	.6	<.1	7.7
12K053	07-13-93	21	175	7.4	7.9	83	68	34	.4	1.4	.3	3.1	.6	<.1	6.7
12K133S	07-15-93	20.2	182	7.7	5.2	96	79	34	.5	1.6	.2	3.4	.4	<.1	7.4
12K137	07-15-93	20.4	176	8.0	5.7	93	76	35	.5	1.3	.4	3.6	1.5	<.1	8.3
12L048	07-15-93	20.6	366	7.3	1.3	98	80	33	.3	2.0	.3	2.9	2.5	<.1	8.5
12L312	07-13-93	20.2	349	7.3	1.7	191	157	70	1.1	3.1	6	6.7	1.3	<.1	9.8
Upper Floridan aquifer—*middle and lower units, Ocala Limestone*															
11K003	07-15-93	21.7	255	7.5	5.5	154	126	49	.9	1.9	.3	5.4	.5	<.1	8.0
11K015	07-16-93	20.6	254	7.6	3.8	156	128	53	.6	1.6	.3	3.1	.5	<.1	7.9
11K043	07-14-93	20.5	267	7.5	2.7	165	135	56	.5	1.7	.1	2.9	1.2	<.1	8.8
11K044	07-13-93	20.6	266	7.5	.6	167	137	56	.9	1.8	.5	2.3	3.2	<.1	13
11L003	07-15-93	20.1	250	7.4	1.9	154	126	51	1.0	1.8	.3	3.1	.9	<.1	11
11L020	07-14-93	20.0	263	7.6	2.9	156	128	54	1.0	1.7	.3	3.2	.7	<.1	9.6
11L092	07-13-93	20.7	321	7.3	3.6	210	172	68	.7	2.0	.3	3.7	.7	<.1	8.6
11L112	07-13-93	20.1	275	7.5	3.6	177	145	56	1.4	2.2	.5	3.1	3.6	<.1	24
11M010	07-14-93	20.5	345	7.2	6.3	181	148	67	.8	2.9	.8	6.7	1.3	<.1	8.3
11M025	07-14-93	20.6	225	7.6	4.9	133	109	45	.3	1.9	<.1	5.3	.6	<.1	7.5
12K014	07-16-93	21.4	173	7.8	5.9	110	90	35	.5	1.4	.2	2.8	.4	<.1	7.5
12K132	07-13-93	20.1	227	7.4	6.0	140	115	44	.5	1.6	.2	2.9	.6	<.1	7.4
12L269	07-15-93	21.4	176	7.9	5.9	98	87	75	.7	3.0	.3	4.2	3.7	<.1	8.8
12L276	07-16-93	20.3	247	7.5	4.6	153	125	48	.7	1.7	.4	5.0	.9	<.1	8.8
12L277	07-15-93	20.8	295	7.5	7.0	137	112	56	.8	2.6	.7	7.6	.8	<.1	8.4
Upper Floridan aquifer—*lower unit, Ocala Limestone*															
11L111	07-13-93	19.4	378	7.2	4.5	245	201	82	1.0	2.0	.3	3.0	1.4	<.1	12
11L116	07-14-93	19.8	218	7.7	4.8	126	103	44	.6	1.5	.2	3.6	.5	<.1	7.0
12K101	07-14-93	20.6	185	7.9	7.8	98	80	36	.4	1.6	.3	3.7	.3	<.1	7.8
12K129	07-13-93	20.5	186	7.9	8.1	101	83	34	.4	1.7	.2	3.8	.3	<.1	7.7
12K136	07-15-93	21	141	8.0	5.6	87	71	27	1.3	1.7	.4	2.8	.8	<.1	8.4
12L324	07-16-93	20.5	390	7.3	<.1	260	213	75	4.3	2.7	1.0	3.4	.9	<.1	18

Table 6. Trace metals and nitrite-plus-nitrate concentrations in the Upper Floridan aquifer, western Albany area, Georgia, July 1993

[μg/L, micrograms per liter; mg/L, milligrams per liter; <, less than; —, no data]

Site number	Date(s) of collection	Iron (μg/L)	Manganese (μg/L)	Strontium (μg/L)	Nitrite + nitrate, as N (mg/L)
Upper Floridan aquifer—*middle unit, Ocala Limestone*					
11L113	07/13/93	560	98	29	0.02
11L117	07/14/93	15	<1	23	2.0
11M026C	07/21/93	4	<1	15	.45
12K053	07/13/93	3	<1	13	2.5
12K133S	07/15/93	3	2	17	2.5
12K137	07/15/93	9	2	15	2.0
12L048	07/15/93	3	<1	14	.6
12L312	07/13/93	3	<1	36	5.5
Upper Floridan aquifer—*middle and lower units, Ocala Limestone*					
11K003	07/15/93	9	<1	25	5.3
11K015	07/16/93	3	1	21	.38
11K043	07/14/93	11	<1	27	.29
11K044	07/13/93	280	28	75	.03
11L003	07/15/93	7	1	85	.58
11L020	07/14/93	3	<1	47	.37
11L092	07/13/93	5	<1	38	1.2
11L112	07/13/93	4	<1	170	.31
11M010	07/14/93	14	13	26	4.3
11M025	07/14/93	3	<1	14	.97
12K014	07/16/93	3	<1	16	1.6
12K132	07/13/93	5	<1	18	.5
12L269	07/15/93	23	2	34	.8
12L276	07/16/93	5	2	28	2.0
12L277	07/15/93	3	1	25	.7
Upper Floridan aquifer—*lower unit, Ocala Limestone*					
11L111	07/13/93	3	1	59	.23
11L116	07/14/93	24	<1	40	1.2
12K101	07/14/93	3	<1	14	2.0
12K129	07/13/93	4	<1	14	2.7
12K136	07/15/93	3	3	60	1.4
12L324	07/16/93	890	53	160	<.02

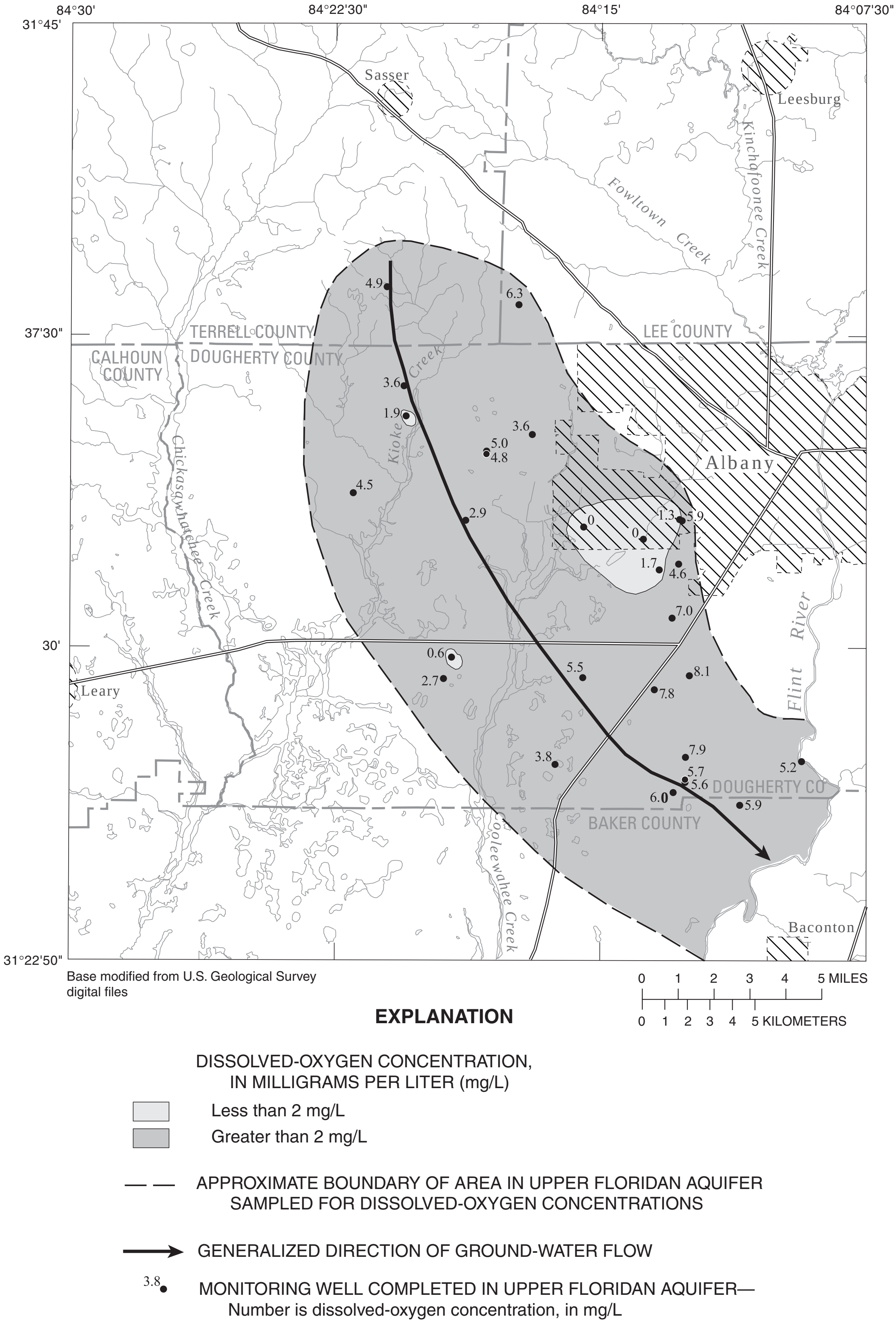
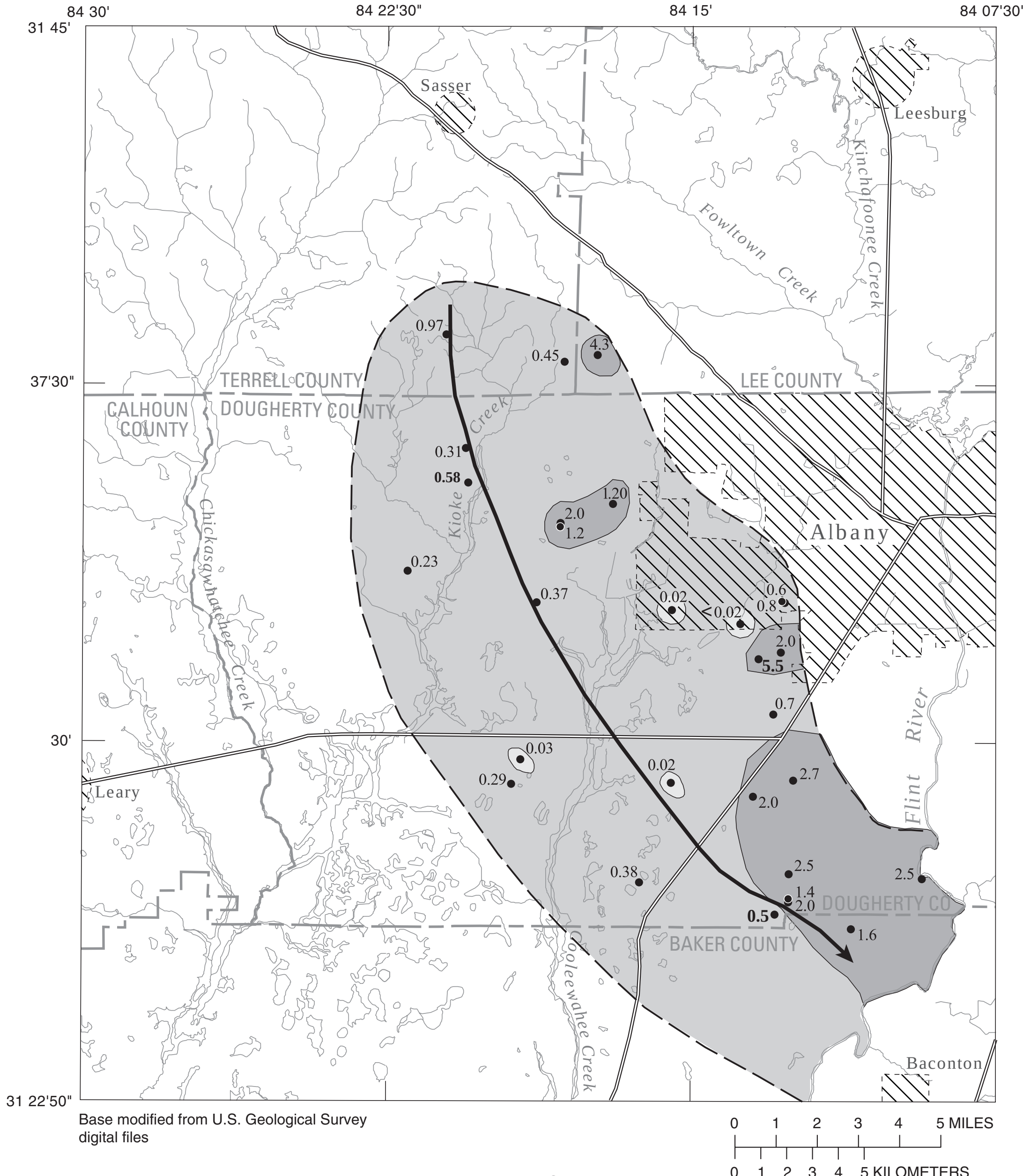


Figure 20. Distribution of dissolved-oxygen concentrations in water from the Upper Floridan aquifer, July 1993.



EXPLANATION

NITRATE CONCENTRATION AS NITRITE-PLUS-NITRATE, IN MILLIGRAMS PER LITER (mg/L)

- < 0.02 to 0.09
- 0.1 to 0.9
- 1.0 to 5.5

APPROXIMATE BOUNDARY OF AREA IN UPPER FLORIDAN AQUIFER SAMPLED FOR WATER-QUALITY CONSTITUENTS AND PROPERTIES

GENERALIZED DIRECTION OF GROUND-WATER FLOW

0.38 MONITORING WELL COMPLETED IN UPPER FLORIDAN AQUIFER—Number is nitrogen concentration as nitrite-plus-nitrate, in mg/L

Figure 21. Distribution of nitrogen concentrations as nitrite-plus-nitrate in water from the Upper Floridan aquifer, July 1993.

Table 7. Summary statistics for field properties, major ion constituents, trace metals, other constituents, and ground-water age in the western Albany area, Georgia, July 1993

[mg/L, milligrams per liter; $^\circ$C, degrees Celsius; μs/cm, microsiemens per centimeter at 25 $^\circ$ Celsius; <, less than; >, greater than]

Variable	Number of observations	Mean	Standard deviation	Median	Minimum	Maximum
Properties						
pH (standard units)	29	7.5	0.23	7.5	7.2	8.0
specific conductance at 25 $^\circ$C (μS/cm)	29	255	67.6	254	141	390
Major constituents						
Bicarbonate, dissolved (mg/L)	29	144	47	140	83	260
Calcium, dissolved (mg/L)	29	50.8	14.6	51	27	82
Chloride, dissolved (mg/L)	29	4.7	1.4	3.6	2.3	7.6
Dissolved solids (mg/L)	29	166	48.8	151	101	294
Magnesium, dissolved (mg/L)	29	0.8	0.62	0.6	0.3	4.3
Potassium, dissolved (mg/L)	29	.35	.21	.3	.1	1.0
Sodium, dissolved (mg/L)	29	1.9	.43	1.8	1.3	3.1
Sulfate, dissolved (mg/L)	29	1.3	1.2	.8	.3	5.2
Trace elements						
Iron, total (mg/L)	29	.07	.19	.004	.003	.89
Manganese, total (mg/L)	29	.007	.02	<.001	<.001	.01
Strontium, dissolved (mg/L)	29	.04	.04	.03	.013	.17
Dissolved organic carbon (mg/L)	29	.19	.20	.10	<.01	1.1
Dissolved oxygen (mg/L)	28	4.4	2.3	4.9	<.1	8.1
Nitrite-plus-nitrate as nitrogen (mg/L)	29	1.51	1.5	1.09	<.02	5.5
Other constituents						
Tritium (tritium units)	29	8.2	2.9	9.0	.1	13
Ground-water age						
CFC age (years)	26	22	8	22	9	>50

SUMMARY AND CONCLUSIONS

Geologic and hydrologic data collected during this study compare well with the regional hydrogeologic framework conceptual model for the study area as described in previous investigations. Data from this study however, show in greater detail the dynamic and highly variable hydrologic nature of the Upper Floridan aquifer in the study area. Data also demonstrate that human activity in the Albany area may affect the water quality of the Upper Floridan aquifer.

The additional detail developed for the local geologic framework includes (1) only the middle and lower units of the Ocala Limestone are present in the study area; (2) altitudes of the tops of the middle and lower units were determined for the study area; (3) a large depression in the middle unit forms a measurable structural feature in the Ocala Limestone that may represent a relic stream channel or solution feature; and (4) the composition of the overburden is areally and vertically distributed and ranges from clay- to gravel-size sediments, with a thickness that ranges from 25 to 92 ft.

Hydrologic information added to the conceptual model of the Upper Floridan aquifer includes (1) the undifferentiated overburden contains a surficial aquifer that consists of discontinuous, perched, and, or seasonal water tables; (2) local zones of confinement occur in the Upper Floridan aquifer in the northwestern and southeastern parts of the study area; (3) although differences in permeability resulting from different degrees of weathering and differences in lithology exist, the middle and lower units of the Ocala Limestone respond to hydraulic stress as a single unit in the Upper Floridan aquifer; (4) the surficial aquifer potentially provides recharge to the Upper Floridan aquifer in the northwestern part of the study area; (5) in the southeastern part of the study area, the surficial aquifer is absent, and rainfall percolating downward through the overburden, or the absence of the overburden due to erosion or sinkhole collapse, results in recharge to the Upper Floridan aquifer; (6) ground-water ages in the Upper Floridan aquifer are indicative of “modern” water and generally range in age from 9 to 34 years; and (7) the irregular distribution of ground-water ages in the aquifer indicate that widely distributed areas of recharge to the Upper Floridan aquifer occur in the study area.

Water quality in the Upper Floridan aquifer in the study area was determined from water samples collected in 27 wells, one spring, and one water-filled cave during July 1993. Descriptive statistics were developed to describe the distribution of selected water-quality constituents and properties, including major and minor ion concentrations, nitrogen as nitrite-plus-nitrate concentrations, dissolved-oxygen concentrations, dissolved solids concentrations, pH, dissolved organic carbon concentrations, and specific conductance. Generally, the Upper Floridan is calcium rich, having low concentrations of magnesium, potassium, sodium, chloride, sulfate, and carbonate. The Upper Floridan aquifer also is oxygen rich, having concentrations greater than 2 mg/L. Nitrogen as nitrite-plus-nitrate occurs in the aquifer at concentrations ranging from less than 0.02 to 5.5 mg/L.

In conclusion, suburban residential and agricultural land use in the western Albany area may affect water quality in the Upper Floridan aquifer. Occurrence of sediment sizes from clay to gravel in the overburden, the presence of downward hydraulic gradients to and in the Upper Floridan aquifer, and large land areas lacking surface drainage indicate potential areas for contaminant migration from land surface to the aquifer. Areal distribution of nitrite-plus-nitrate, and dissolved-oxygen concentrations, and ground-water ages, and a highly irregular potentiometric surface for the Upper Floridan aquifer demonstrate that widely distributed areas of localized recharge to the Upper Floridan aquifer occur in the western Albany area.

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Table 1. Well-construction data at selected ground-water monitoring sites in the western Albany area, Georgia

[—, no data; S, steel; P, polyvinylchloride (PVC); do., ditto; TW, test well]

Well number	Well name (or owner)	Latitude	Longitude	Date drilled	Aquifer	Altitude of land surface (feet above sea level)	Depth of well (feet)	Bottom of casing (feet)	Casing type	Type of data collected
10L018	Magnolia Plantation Headquarters	31°31'53"	84°24'32"	—	Upper Floridan	207	—	—	S	water level
10M003	M.L. Shiver	31°38'18"	84°22'52"	01-01-77	do.	268	176	65	—	water level
11K003	Nilo Plantation U.S. Geological Survey TW north	31°29'14"	84°15'31"	12-21-78	do.	195	150	63	S	water level, water quality, and geophysical log(s)
11K004	Nilo Plantation U.S. Geological Survey TW south	31°29'05"	84°15'31"	12-22-78	do.	203	150	60	S	water level, water quality
11K005	U.S. Geological Survey TW 12	31°26'54"	84°21'01"	03-29-79	do.	181	646	—	—	geophysical log(s)
11K013	Nilo-Howell	31°29'18"	84°15'32"	01-01-75	do.	191	—	50	—	water level
11K014	Nilo lake well	31°27'44"	84°17'41"	03-01-56	do.	181	—	79	—	water level
11K015	Nilo Plantation U.S.Geological Survey TW 14	31°27'09"	84°16'17"	01-01-82	do.	183	177	74	S	water level, water quality, and geophysical log(s)
11K016	Pinebloom swamp house	31°24'18"	84°21'00"	—	do.	170	—	—	—	water level
11K027	Tarva Plantation	31°26'20"	84°20'06"	11-10-72	do.	178	100	63	S	water level
11K033	St. Joe Sealy, Ocala well	31°26'54"	84°21'01"	1980	do.	183	77	43	S	water level
11K043	Wynfield Place pond well	31°29'13"	84°19'26"	—	do.	194	170	58	S	water level, water quality
11K044	Dr. Clayton Wood	31°29'43"	84°19'13"	—	do.	195	200	97	S	water level, water quality
11L002	Georgia Department of Natural Resources, Albany Nursery	31°35'32"	84°20'32"	01-01-73	Clayton	222	542	—	—	geophysical log(s)
11L003	Ocala Game and Fish	31°35'30"	84°20'31"	—	Upper Floridan	220	86	—	—	water level, water quality
11L013	Georgia Department of Natural Resources, Game & Fish Commission observation well	31°35'31"	84°20'32"	10-07-82	surficial	220	15	5	P	water level
11L014	H. Goodyear, Jr.	31°31'21"	84°22'19"	01-01-76	Upper Floridan	210	145	40	—	water level
11L017	U.S. Geological Survey TW 20	31°36'04"	84°16'28"	01-01-83	do.	230	144	41	—	geophysical log(s)
11L018	Doublegate utility 1	31°35'51"	84°15'38"	02-23-76	do.	215	125	70	—	water level
11L019	St Joe 3-in. well	31°30'10"	84°18'49"	—	do.	180	—	—	—	water level
11L020	Doug Pope	31°33'00"	84°18'49"	1973	do.	208	150	63	S	water level, water quality
11L070	Fowler Farms, pond well	31°34'21"	84°21'43"	01-15-73	do.	210	135	44	S	water level
11L077	John Meyers	31°33'48"	84°19'16"	01-14-74	do.	211	130	60	S	water level
11L078	Joseph Bateman	31°30'17"	84°18'49"	03-12-74	do.	181	100	63	S	water level
11L092	Dr. James Lee	31°35'04"	84°16'57"	08-25-80	do.	222	125	63	S	water level, water quality
11L111	Fowler Farms, llama well	31°33'40"	84°22'00"	—	do.	220	125	96	S	water level, water quality
11L112	Winston Hooks	31°36'14"	84°20'34"	1990	do.	232	180	83	S	water level, water quality

Table 1. Well-construction data at selected ground-water monitoring sites in the western Albany area, Georgia—Continued

[—, no data; S, steel; P, polyvinylchloride (PVC); do., ditto; TW, test well]

Well number	Well name (or owner)	Latitude	Longitude	Date drilled	Aquifer	Altitude of land surface (feet above sea level)	Depth of well (feet)	Bottom of casing (feet)	Casing type	Type of data collected
11L113	Westbrook catfish well	31°32'51"	84°15'29"	1988	Upper Floridan	193	99	84	—	water level, water quality
11L114	W. J. and Sherry Jackson	31°32'41"	84°19'34"	1987	do.	217	180	—	S	water level
11L115	John and Sarah Phillips	31°35'54"	84°16'46"	1987	do.	220	150	84	S	water level
11L116	U.S. Geological Survey deep TW	31°34'40"	84°18'14"	03-30-93	do.	210	150	72	S	water level, water quality, geophysical log(s), and core
11L117	U.S. Geological Survey shallow TW	31°34'40"	84°18'14"	03-31-93	do.	210	64	35	S	water level, water quality
11L119	U.S. Geological Survey residium TW	31°34'40"	84°18'14"	04-01-93	surficial	210	27	22	P	water level, water quality
11M007	Alvin Vann	31°39'34"	84°20'36"	01-01-76	Upper Floridan	260	95	63	S	water level
11M010	Holly Plantation	31°38'11"	84°17'20"	01-01-52	do.	263	120	40	—	water level, water quality
11M017	Jan Clay 6-in. well	31°42'10"	84°15'19"	—	do.	264	—	—	—	water level
11M019	Jon Daniels 3-in. well	31°43'17"	84°19'42"	—	do.	305	—	—	—	water level
11M025	Stan Cumbie	31°38'36"	84°21'04"	05- -92	do.	260	120	67	S	water level, water quality
11M026C	Dr. T. Gray Fountain, cave	31°38'04"	84°18'09"	—	do.	239	—	—	—	water quality
11M027	Teresa Kregl	31°38'35"	84°21'06"	—	do.	259	—	—	S	water level
11M028	Glen Green	31°39'40"	84°17'25"	04-16-92	do.	280	—	—	S	water level
12K010	Blue Springs Plantation 1	31°27'14"	84°11'40"	—	do.	198	—	—	—	water level
12K011	Blue Springs Plantation 2	31°26'50"	84°10'21"	—	do.	185	—	—	—	water level
12K012	Blue Springs Plantation 5	31°27'45"	84°11'47"	—	do.	192	—	—	—	water level
12K013	Blue Springs Plantation 6	31°26'50"	84°09'23"	—	do.	185	—	—	—	water level
12K014	Blue Springs Plantation U.S. Geological Survey TW	31°26'11"	84°11'05"	—	do.	183	137	69	—	water level, water quality
12K016	Cecil Avant	31°27'19"	84°12'31"	—	do.	195	131	84	—	water level, geophysical log(s)
12K037	Blue Springs shop well	31°26'41"	84°10'24"	08-06-66	do.	178	200	69	S	water level
12K053	Lee R. Jenkins	31°27'20"	84°12'36"	05-22-70	do.	189	85	48	S	water level, water quality
12K056	Blue Springs Plantation U.S. Geological Survey (TW) observation well	31°26'11"	84°11'07"	—	surficial	178	30	—	P	water level
12K101	E. Mitchell	31°28'57"	84°13'29"	02-12-85	Upper Floridan	204	120	105	S	water level, water quality
12K110	Nonami Plantation 7	31°27'47"	84°10'29"	—	do.	182	—	—	—	water level
12K115	Nonami duck pond well	31°28'48"	84°09'41"	—	do.	172	—	—	—	water level
12K120	Second Bethesda Baptist Church	31°29'04"	84°13'50"	—	do.	193	—	—	—	water level
12K122	S.M. Goode	31°29'47"	84°13'27"	—	do.	190	—	—	—	water level
12K123	Albany Water, Gas, and Light Commission TW 2	31°29'40"	84°13'18"	—	Upper Floridan	201	242	55	—	water level, geophysical log(s)
12K127	Albany Water, Gas, and Light Commission TW 5	31°28'37"	84°13'03"	01- -88	do.	180	142	—	S	water level, geophysical log(s)

Table 1. Well-construction data at selected ground-water monitoring sites in the western Albany area, Georgia—Continued

[—, no data; S, steel; P, polyvinylchloride (PVC); do., ditto; TW, test well]

Well number	Well name (or owner)	Latitude	Longitude	Date drilled	Aquifer	Altitude of land surface (feet above sea level)	Depth of well (feet)	Bottom of casing (feet)	Casing type	Type of data collected
12K129	Albany Water, Gas, and Light Commission TW 3	31°29'17"	84°12'30"	02- -88	do.	193	211	122	S	water level, water quality, and geophysical log(s)
12K132	Robert Brunner	31°26'29"	84°12'57"	1975	do.	184	110	—	S	water level, water quality
12K133S	Wilson Blue Spring	31°27'15"	84°09'23"	—	do.	155	—	—	P	water quality
12K134	Blue Springs ivy well	31°26'38"	84°10'26"	1930	do.	185	—	—	S	water level
12K136	U.S. Geological Survey Bruner deep well	31°26'44"	84°12'37"	04-21-93	do.	194	215	135	S	water level, water quality, geophysical log(s), and core
12K137	U.S. Geological Survey Bruner shallow well	31°26'45"	84°12'37"	04-21-93	do.	195	85	75	S	water level, water quality
12L018	Albany 27	31°36'49"	84°12'29"	01-20-76	—	231	830	300		geophysical log(s)
12L021	U.S. Geological Survey TW 10	31°35'37"	84°10'29"	11-21-78	—	195	846	810	S	geophysical log(s)
12L023	Herty Nursery 4	31°32'43"	84°10'57"	01-01-54	—	192	—		—	geophysical log(s)
12L030	Hubert Johnson, U.S. Geological Survey TW 16	31°31'30"	84°10'10"	01-01-82	Upper Floridan	180	180	84	—	water level, geophysical log(s)
12L048	U.S. Geological Survey TW 21	31°33'00"	84°12'43"	1984	do.	200	85	40	S	water level, water quality, and geophysical log(s)
12L269	U.S. Geological Survey TW 22	31°33'02"	84°12'47"	09-24-86	do.	200	164	57	S	water level, water quality
12L275	Pretoria Acres north well	31°32'08"	84°12'47"	—	do.	197	—	—	—	water level
12L276	Pretoria Acres south well	31°31'58"	84°12'48"	—	do.	187	—	—	—	water level, water quality
12L277	Albany Water, Gas, and Light Commission TW 1	31°30'40"	84°12'59"	1988	do.	192	203	—	S	water level, water quality, and geophysical log(s)
12L311	Chip Hall, lakehouse	31°32'02"	84°14'38"	1983	do.	184	100	—	S	water level
12L312	Chip Hall, barn	31°31'50"	84°13'21"	1985	do.	198	110	—	S	water level, water quality
12L324	U.S.Geological Survey LS-1	31°32'34"	84°13'48"	03-09-93	do.	193	154	101	S	water quality
12M027	Haley-Byne	31°41'53"	84°13'11"	—	do.	243	—	—	—	water level