Chemical and Isotopic Composition and Potential for Contamination of Water in the Upper Floridan Aquifer, West-Central Florida, 1986–89

United States
Geological
Survey
Water-Supply
Paper 2409

Prepared in cooperation
with the Southwest Florida
Water Management District

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

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By AMY SWANCAR and C.B. HUTCHINSON

Prepared in cooperation with the
Southwest Florida Water Management District

U.S. GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2409

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
GORDON P. EATON, Director

MARCH 3, 1849

UNITED STATES GOVERNMENT PRINTING OFFICE: 1995

For sale by the
U.S. Geological Survey, Information Services
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Library of Congress Cataloging in Publication Data

Swancar, Amy.
Chemical and isotopic composition and potential for contamination
of water in the Upper Floridan aquifer, west-central Florida,
1986-89 / by Amy Swancar and C.B. Hutchinson.
p. cm. — (U.S. Geological Survey water-supply paper ; 2409)
"Prepared in cooperation with the Southwest Florida Water
Management District."
Includes bibliographical references.
Supt. of Docs. no.: I 19.13:2409
1. Water—Pollution potential—Florida. 2. Water—Pollution
potential—Floridan Aquifer. 3. Water—Composition—Florida.
4. Water—Composition—Floridan Aquifer. I. Hutchinson, C. B.
II. Southwest Florida Water Management District. III. Title.
IV. Series.
TD224.F6S93 1995
363.73'942'09759—dc20 93–12401
CIP

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CONVERSION FACTORS, VERTICAL DATUM, AND ADDITIONAL ABBREVIATIONS

Multiply	By	To obtain
inch (in.)	25.4	millimeter
inch per year (in/yr)	2.54	centimeter per year
foot (ft)	0.3048	meter
foot per day per foot [(ft/d)/ft]	1.000	meter per day per meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
million gallons per day (Mgal/d)	0.04381	cubic meter per second
gallons per day per foot squared [$(gal/d)/ft^2$]	0.04073	meter per day

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

$$°C=5/9\bullet(°F-32)$$

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

Additional Abbreviations

atmosphere (atm)
dissolved oxygen (DO)
Florida Department of Health
and Rehabilitative Services (HRS)
milligrams per liter (mg/L)
parts per thousand (permil)
saturation index (SI)
Standard Mean Ocean Water (SMOW)

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Abstract

The Upper Floridan aquifer is the major source of ground-water supplies in west-central Florida. The aquifer crops out in the northern part of west-central Florida and is encountered at depths between 200 and 700 feet below land surface in the southern part. Because the aquifer is unconfined in large areas of northern west-central Florida, there is concern about contamination of the aquifer from surface sources.

Major ions, unstable field constituents, and the environmental isotopes tritium, deuterium, and oxygen–18 were measured in water samples from 112 wells that are open to the upper half or less of the aquifer. Sampling was done between February 1986 and May 1989. Calcium and bicarbonate were the dominant ions in nearly all ground-water samples. Saltwater mixing occurs near the gulf coast and upwelling of deep calcium magnesium sulfate ground water occurs in confined discharge areas.

In the northern parts of the study area where the Upper Floridan aquifer is unconfined, tritium analyses indicate that the aquifer contains relatively young water that has entered the aquifer since 1953, whereas water in the confined aquifer in southern areas is older. The potential for contamination is greater in those areas where the ground water is relatively young because of high rates of recharge to the aquifer and high aquifer transmissivity. Within the areas where the aquifer is unconfined and tritium concentrations indicate young water throughout the flow system, dissolved oxygen and carbon dioxide are useful indicators of relative potential for contamination. Concentrations of dissolved oxygen in water are greater than 3 milligrams per liter in the northern part of the study area along the Brooksville Ridge and in Marion and Levy Counties. Recharge to the aquifer in these areas ranges from 15 to 20 inches per year. Partial pressures of dissolved carbon dioxide in water are greater than 10^{-2} atmospheres in northern areas where wetlands exist at the land surface. These are areas of low recharge to or discharge from the aquifer.

Water in the Upper Floridan aquifer that has a high tritium concentration (greater than 5 tritium units) and a high dissolved-oxygen concentration (greater than 3 milligrams per liter) is considered to have a very high potential for contamination. Ground water with a high tritium concentration and low dissolved oxygen is considered to have a high potential for contamination. Ground water with concentrations from 1 to 5 tritium units occurs in areas where sinkholes allow mixing between younger and older water and is considered to have a moderate potential for contamination. Ground water having tritium concentrations of less than 1 tritium unit is considered to have a low potential for contamination. Ground water having tritium concentrations less than detection limits that is present in areas where the aquifer is overlain by more than 300 feet of strata of varying permeability is considered to have a very low potential for contamination.

Potential for contamination is high or very high in nearly all areas where the confining unit is less than 50 feet thick or breached by sinkholes; the Green Swamp is an exception. Even though the aquifer is unconfined within the swamp, recharge is

low, as is the potential for contamination. In areas where the aquifer is confined, the potential for contamination is low or very low. In both confined and unconfined areas of the aquifer, the potential for contamination is highest in areas of high recharge. Areas where the aquifer had previously been defined as semiconfined could not be distinguished either chemically or isotopically from areas where the aquifer is unconfined. Compared to the chemical indicators of potential for contamination, the DRASTIC index, a method for evaluating the potential for ground-water contamination developed by the U.S. Environmental Protection Agency, overestimates potential for contamination in wetlands and in the Green Swamp and underestimates it in the Brooksville Ridge.

INTRODUCTION

West-central Florida is one of the fastest growing areas in the United States. Along with this growth, there is an increased demand for water and an increased threat of water contamination. Consequently, the environment and the hydrologic system are under stress.

The Upper Floridan aquifer supplies 90 percent of the freshwater used in west-central Florida. Although the aquifer is a large and productive resource, it is not inexhaustible. Ground-water recharge is primarily derived from rainfall. Increased ground-water withdrawals can lead to declines in ground-water and surface-water levels and induce leakage of nonpotable waters from overlying and underlying aquifers.

Areas that are most vulnerable to contamination from the surface are assumed to occur where the Upper Floridan aquifer is at or near land surface and where recharge to the aquifer is relatively rapid. In 1986, the U.S. Geological Survey began a 4-year cooperative study with the Southwest Florida Water Management District to assess the potential for contamination of the Upper Floridan aquifer in west-central Florida. Principal objectives of the study were to (1) evaluate existing chemical, radiochemical, and stable isotope methods used to indicate relatively recent recharge water; (2) collect and analyze ground-water samples to supplement existing analyses of radioactive and stable isotopes in the Southwest Florida Water Management District; and (3) use hydrogeologic and chemical data to map the relative potential for contamination of the Upper Floridan aquifer from land surface.

To assess the potential for contamination of the Upper Floridan aquifer, 112 wells open to the uppermost producing zones of the aquifer were sampled for water-quality constituents that may be indicators of the relative age of ground water. Areas underlain by old, intermediate-age, and young waters were considered to have respective low, moderate, and high potentials for contamination. Age determinations were based on the radioactive isotope tritium (^3H), which can be used to date ground water less than 30 years old (Coplen, 1993). Tritium has a half-life of 12.43 years, making it an even more suitable age indicator in active ground-water flow systems like west-central Florida.

In this report, the phrase "potential for contamination" refers to the processes affecting the flow of water into the aquifer from land surface at a given location. It is a hypothetical measure used to describe the study area. A distinction is made between this hypothetical measure and a threat posed by an actual contaminant source, such as a landfill. Human activity adds many contaminants to the environment from sewage, fertilizers, pesticides, and domestic and industrial wastes. The fate of such contaminants depends on how we choose to use and dispose of them, and how the environment reacts to them. A threat of contamination to ground water depends on the existence of a contaminant source and the ability of the overburden to reduce contamination. It is the ability of the overburden to inhibit migration of contaminants that this report considers when defining potential for contamination.

Purpose and Scope

This report describes the water quality in the Upper Floridan aquifer of west-central Florida in terms of major ion and environmental isotope concentrations, and assesses the potential for contamination of the aquifer. It also contains calculated mineral saturation indices of ground water and a statistical analysis of ground-water chemistry data. Information and results are presented in maps showing the distribution of physical aspects of the hydrogeologic setting, chemical constituents, and potential for contamination of the Upper Floridan aquifer in west-central Florida. Details of how the study was conducted appear in the section entitled "Sampling Methods."

Previous Studies

Potential for contamination is related to the physical setting in terms of depth to the top of the aquifer below land surface, thickness of the confining unit, lithology, and geomorphology. Much of this information is available in published reports.

The altitude of the top of the Upper Floridan aquifer was mapped by Buono and Rutledge (1979) and by Miller (1986). Thickness of the confining unit overlying the Upper Floridan aquifer was mapped by Buono and others (1979). Geologic cross sections by Gilboy (1982) and Scott (1988) describe regional stratigraphy. Locations and types of sinkholes were mapped by Sinclair and others (1985).

Recharge rates to the Upper Floridan aquifer have been reported in several studies. Stewart (1980) was the first to map the relative recharge rates to the Upper Floridan aquifer. Ryder (1982) used recharge rates as input to a numerical model of the Upper Floridan aquifer. Aucott (1988) mapped the areal variation in recharge to and discharge from the Upper Floridan aquifer. Because the potential for contamination is directly related to recharge, the results of these earlier studies are pertinent to one of the principal objectives of the study described in this report.

Several studies have used water quality to define areas of high recharge. Within west-central Florida, this has been done by Trommer (1987) for five sinkholes and an internally drained basin and by G.L. Barr (U.S. Geological Survey, written commun., 1989) for Polk County. Faulkner (1973) measured tritium in ground water from wells and springs in the Cross Florida Barge Canal area within Citrus and Marion Counties. Lawrence and Upchurch (1980) used geochemical factor analysis to identify ground-water recharge areas in north Florida. Osmond and others (1971) measured tritium in ground water near Tallahassee, Fla. Tritium concentrations also have been used by Knott and Olimpio (1986), Darling and Bath (1988), and Robertson and Cherry (1989) to estimate ground-water recharge rates in other areas.

DRASTIC, a method for assessing potential for contamination (Aller and others, 1985), has recently been applied to the study area by the Southwest Florida Water Management District. This method utilizes previously published information on physical aspects of the hydrologic system in west-central Florida.

Acknowledgments

The assistance of the staff of the Ambient Ground-Water Quality Monitoring Program, Southwest Florida Water Management District, during various phases of the study is greatly appreciated. They provided a thorough well inventory and requested permission from well owners to sample their wells. They also provided DRASTIC maps and data. We would also like to thank well owners for allowing their wells to be sampled and for their interest and hospitality. The first author would like to acknowledge the guidance of Samuel B. Upchurch of the University of South Florida, in Tampa, during this study.

DESCRIPTION OF THE STUDY AREA

Location, Physiography, and Climate

The study area encompasses about 10,000 square miles (mi^2) in west-central Florida. It includes all of Citrus, Sumter, Hernando, Pasco, Pinellas, Hillsborough, Manatee, Hardee, De Soto, and Sarasota Counties and parts of Levy, Marion, Lake, Polk, Highlands, and Charlotte Counties (fig. 1). Elevations range from sea level along the coast of the Gulf of Mexico to about 300 feet (ft) above sea level in Polk County.

The effect that surface contaminants have on the aquifer is determined largely by the nature of the materials lying between the surface and the aquifer. These materials may either impede or facilitate flow from a surface contaminant source. The thickness and composition of the sediments overlying the aquifer are a result of past and present geologic processes. These processes are reflected in both the surface landforms (physiography) and the subsurface structure (geology).

Physiographic features of the area have been described by White (1970) and are shown on figure 2. The most prominent features are the elongated Brooksville and Lake Wales Ridges and the smaller Cotton Plant, Lakeland, Winter Haven, and Lake Henry Ridges. Orientation of the ridges is parallel to existing and residual Atlantic Coast beaches, and they are believed to be remnants of low-relief beach ridges formed during higher sea levels in the late Miocene or early Pliocene (White, 1970; Scott, 1988). Broader positive physiographic features are the Polk and Sumter Uplands and the De Soto Plain. Coastal lowlands, swamps, lagoons, barrier islands, and estuaries are features of the western part of the study area.

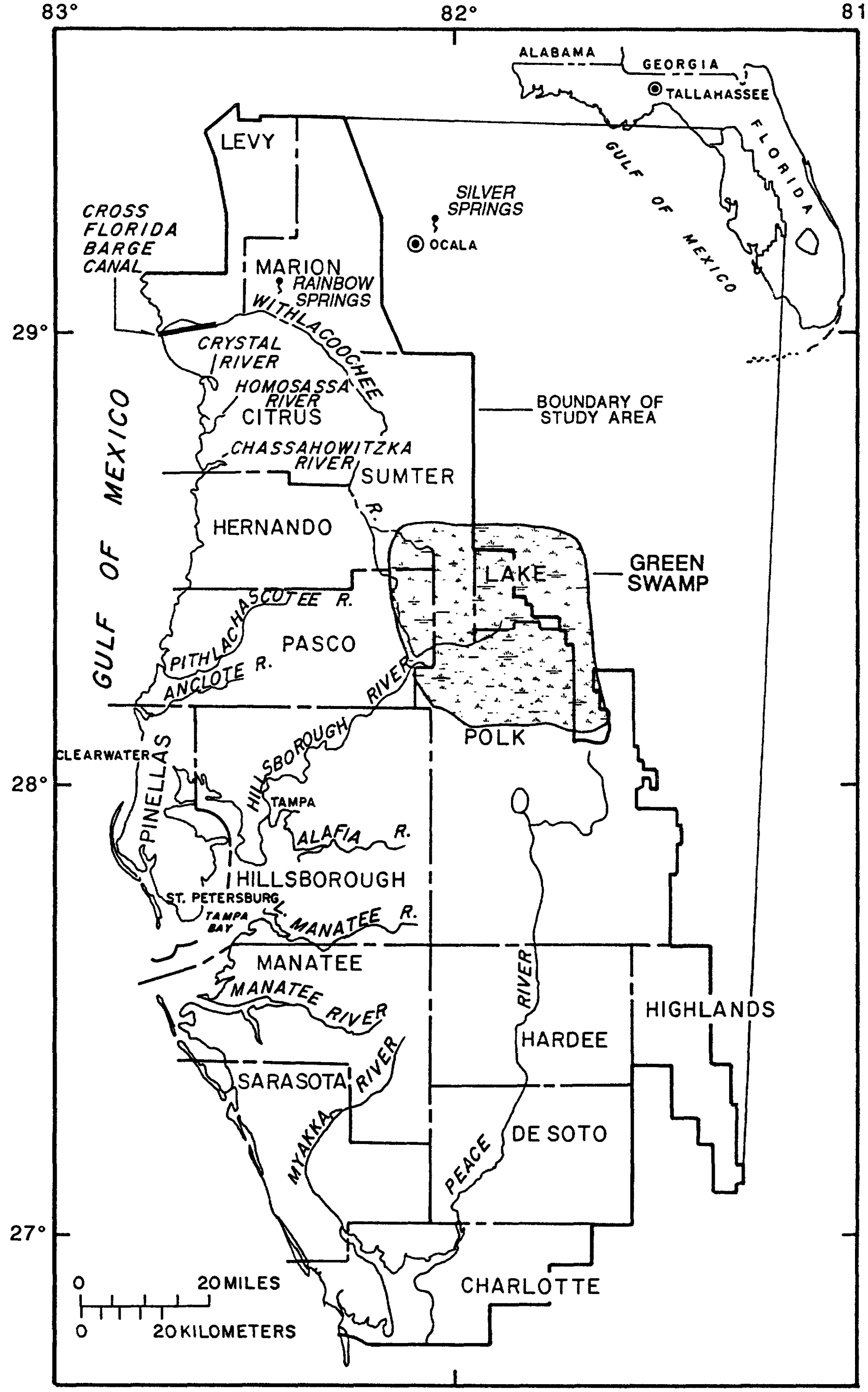

Figure 1. Location of study area.

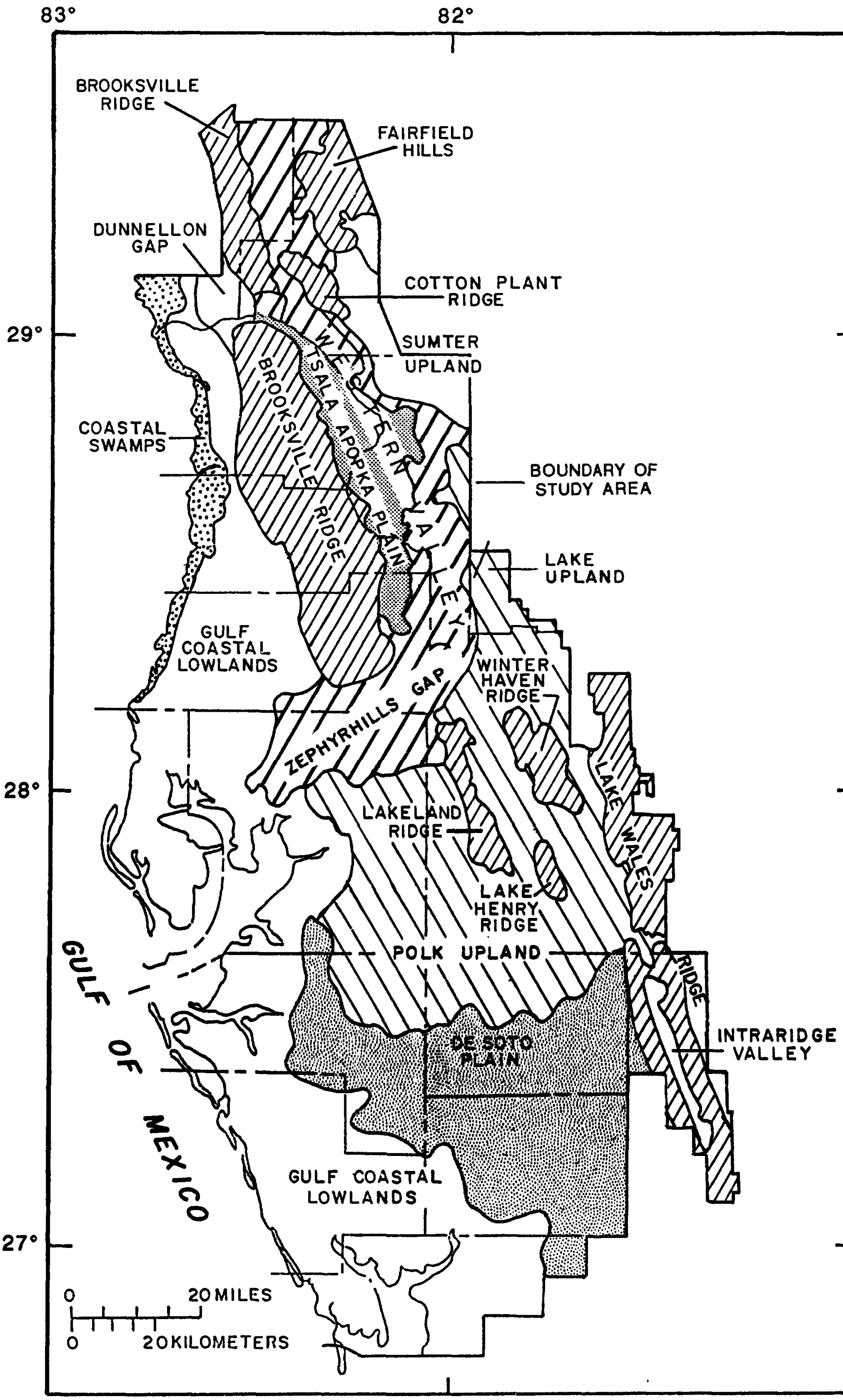

Figure 2. Physiographic features of study area (from White, 1970).

Major rivers in the study area are the Withlacoochee, Homosassa, Pithlachascotee, Anclote, Hillsborough, Alafia, Manatee, Myakka, and Peace (fig. 1). Coastal and inland springs discharge up to 2,300 million gallons per day (Mgal/d) from the Upper Floridan aquifer into rivers that flow into the Gulf of Mexico (Ryder, 1985). Surface-water drainage in the northern and eastern parts of the study area is predominantly into lakes or swampy lowlands rather than rivers.

The climate is humid subtropical. Rainfall averages 52 inches per year (in/yr) over most of the study area, 50 percent of which falls in the summer (June through September) during local, intense thunderstorms (Fernald and Patton, 1984). The average annual temperature in Tampa is 72 °F (National Oceanic and Atmospheric Administration, 1989). Summers are typically hot and wet, and winters are mild and dry.

Hydrogeology

Peninsular Florida is a thick shallow-water carbonate platform overlying igneous basement rocks. The formations underlying west-central Florida generally thicken to the south and west, away from the axis of the Peninsular arch, a northwest trending feature uplifted between Middle Jurassic and Late Cretaceous time (180–70 million years before present) (Miller, 1986). Southwest of and parallel to the Peninsular arch is the Ocala "uplift," a positive feature produced by either anomalous deposition (Winston, 1976) or differential compaction (Miller, 1986) during the Eocene Epoch.

The Floridan aquifer system incorporates highly permeable carbonate rocks of Paleocene to Miocene age. The aquifer is underlain by relatively impermeable beds of Paleocene anhydrite in the study area (Miller, 1986). The upper 1,500 ft of the carbonate deposits make up the freshwater aquifer system (Steinkampf, 1982). The freshwater "lens," which is thinnest at the coast and thickens toward the center of the State, is underlain by saltwater. Regional confining units divide the Floridan aquifer system into the Upper and Lower Floridan aquifers. In west-central Florida, the middle confining unit is a gypsum-containing dolomite of middle Eocene age (Miller, 1986).

This report will describe rocks of the Upper Floridan aquifer and overlying units. The uppermost producing zone of the Upper Floridan aquifer is considered to be the top of the aquifer for this study, as most existing wells are open to this zone. Concern exists over contamination of this productive aquifer because of its proximity to surface contaminant sources and the dependence on water from the aquifer for public, domestic, irrigation, and industrial supplies.

The stratigraphy and hydrogeology of the study area are presented in table 1 and shown in figures 3 through 5. Overlying the Upper Floridan aquifer are Miocene through Holocene clastic deposits. In Miocene time, the complex lithologies of the Hawthorn Group (Scott, 1988)[1] were deposited in the study area during several periods of high sea level. In Scott's (1988) classification, the previously named Tampa Limestone is redefined as the Tampa Member of the Arcadia Formation in the lower part of the Hawthorn Group. The Hawthorn Group in the study area consists of carbonates (limestone and dolomite), siliciclastics (sand and clay), and phosphate. The lower Miocene Tampa Member, a sandy limestone, is included in the Floridan aquifer system in areas where it is hydraulically connected to the underlying limestones of the Upper Floridan aquifer. This occurs near the city of Tampa (Miller, 1986). Farther south and east, the Nocatee Member, a sand and clay unit at the base of the Tampa Member, separates it from the underlying Upper Floridan aquifer.

In southern Hillsborough and Polk Counties and all counties generally south and east of Tampa Bay, permeable carbonate rocks within the Hawthorn Group constitute one or two aquifers within the intermediate aquifer system (Duerr and others, 1987). Less permeable siliciclastics and carbonates within the Hawthorn Group constitute confining or semiconfining units that separate intermediate aquifers from one another. Upper and lower confining units separate the surficial and Floridan aquifer systems from the intermediate aquifer system.

As the Hawthorn Group thins north of Tampa Bay, the Upper Floridan aquifer becomes less confined. In the north, poor water-yielding strata dominate the Miocene section, and the term intermediate confining unit is used rather than intermediate aquifer system to describe the hydrogeologic properties of these deposits (Southeastern Geological Society, 1986). The Upper

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[1] Stratigraphic nomenclature used in this report was compiled mainly from the U.S. Geological Survey and the Florida Geological Survey. Any other references used are given in table 1.

Table 1. Relation of geologic and hydrogeologic units
[Modified from Wilson and Gerhart, 1982; Ryder, 1985]

System	Series	Stratigraphic unit		Hydrogeologic unit			
				System	North of Tampa Bay	East of Tampa Bay	South of Tampa Bay
Quaternary	Holocene and Pleistocene	Terrace deposits		Surficial aquifer system	Absent or surficial aquifer	Surficial aquifer	Surficial aquifer
Tertiary	Pliocene	Caloosahatchee Marl and Tamiami Formation		Intermediate aquifer system or intermediate confining unit[2]	Absent or confining unit[2]	Upper confining unit[2]	Semiconfining unit[4]
	Miocene	Hawthorn Group[1]	Peace River Formation			Intermediate aquifer[2]	Tamiami-Upper Hawthorn aquifer[5]
							Semiconfining unit[4]
			Arcadia Formation				Lower Hawthorn-Upper Tampa aquifer[5]
			Tampa Member Nocatee Member			Lower confining unit[2]	Lower Tampa semiconfining unit[4]
	Oligocene	Suwannee Limestone		Floridan aquifer system[3]	Upper Floridan aquifer[3]	Upper Floridan aquifer[3]	Suwannee permeable zone[4]
	Eocene	Ocala Limestone					Lower Suwannee-Ocala semiconfining unit[4]
		Avon Park Formation[3]					Ocala-Avon Park moderately permeable zone[4]
							Avon Park highly permeable zone[4]
					Middle confining unit[3]	Middle confining unit[3]	Middle confining unit[3]
	Paleocene	Oldsmar and Cedar Keys Formations			Lower Floridan aquifer[3]	Lower Floridan aquifer[3]	Lower Floridan aquifer[3]

[1] Based on nonmenclature of Scott (1988).
[2] Based on nonmenclature of Southeastern Geological Society (1986).
[3] Based on nonmenclature of Miller (1986).
[4] Based on nonmenclature of Hutchinson (1992).
[5] Based on nonmenclature of Wolansky (1983).

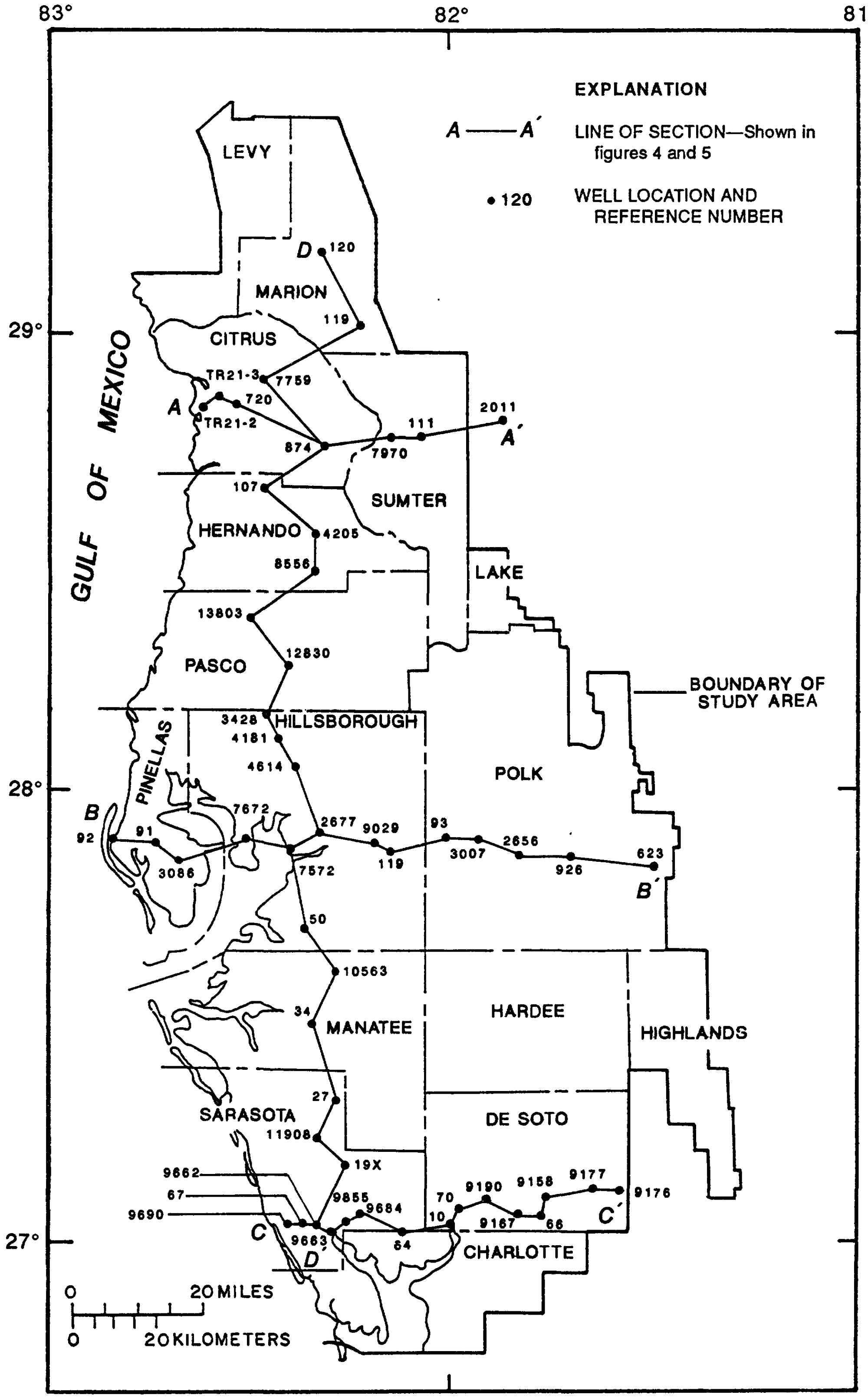

Figure 3. Locations of geologic sections (modified from Gilboy, 1982).

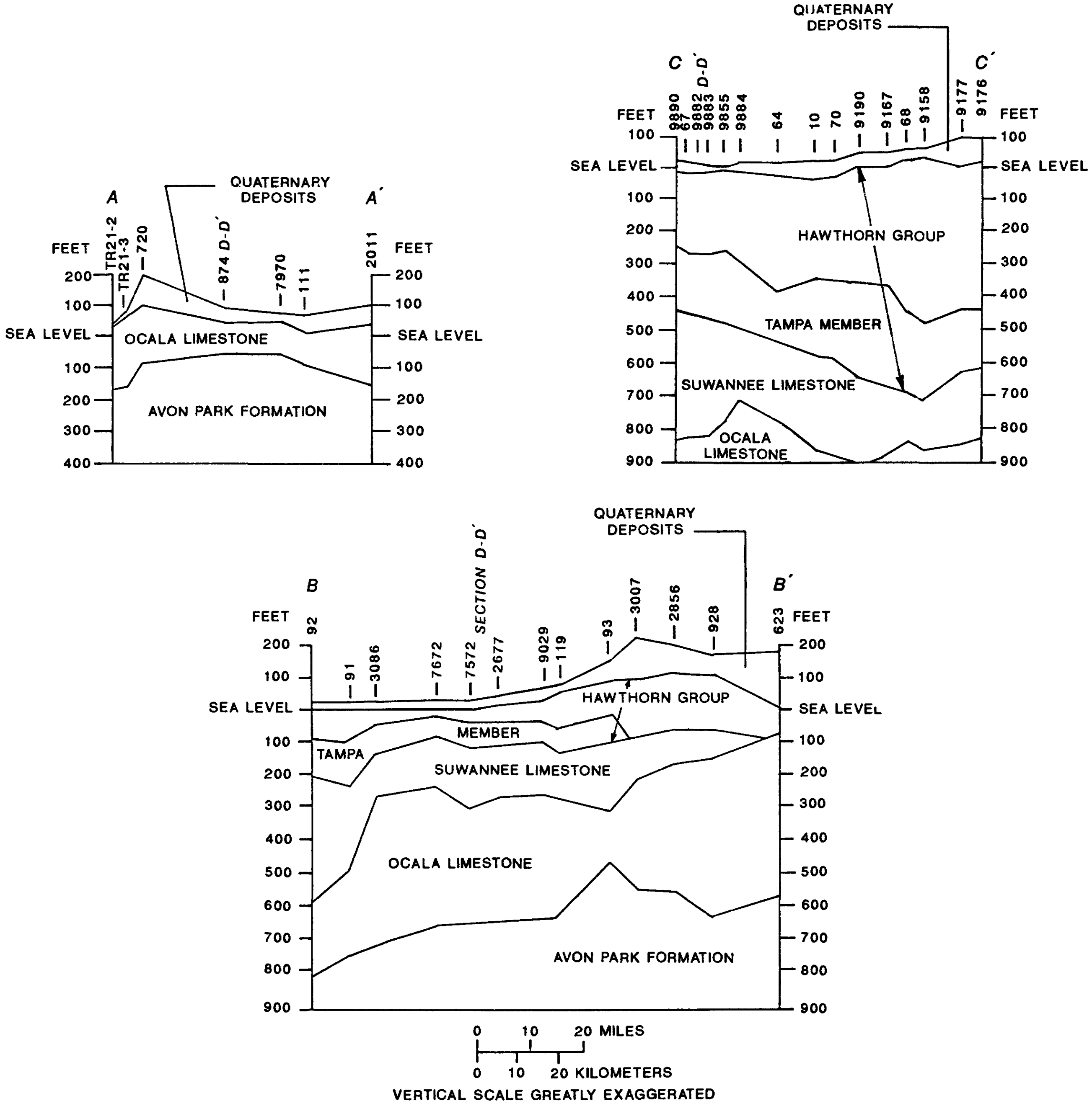

Figure 4. Geologic sections *A–A'*, *B–B'*, and *C–C'*. Locations of sections are shown in figure 3 (modified from Gilboy, 1982).

Floridan aquifer crops out and is unconfined in northeast Hillsborough, northwest Polk, and parts of all other counties in the northern study area.

Sands, clayey sands, shells, and soils of Quaternary age overlie nearly all of the study area and are greater than 100 ft thick on ridges. These Quaternary deposits make up the surficial aquifer system, which overlies the intermediate aquifer system south and east of Tampa Bay, and the Upper Floridan aquifer in the north. Where the surficial aquifer system consists of a single unconfined layer of sand, it becomes the surficial aquifer and contains a water table.

Degree of Confinement of Aquifer

An aquifer is considered to be confined if it is bounded stratigraphically between units of significantly

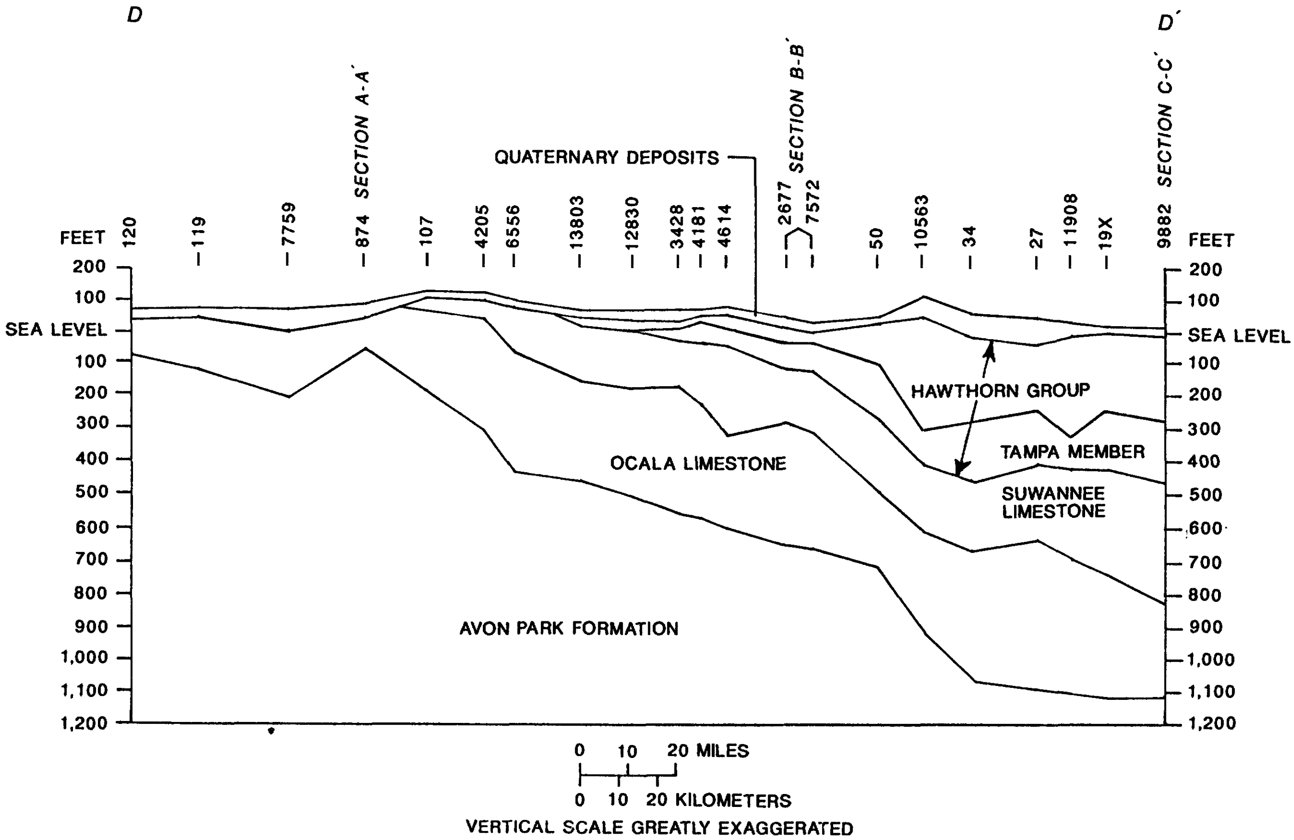

Figure 5. Geologic section *D–D′*. Location of section is shown in figure 3 (modified from Gilboy, 1982).

lower permeability, known as confining units. Water levels in wells open to confined aquifers commonly rise above the top of the aquifer. Because a confining unit impedes downward flow of water, it is an important factor in determining the potential for contamination of an aquifer. The degree of confinement of the Upper Floridan aquifer in the study area is determined by the continuity and thickness of low-permeability beds of the Hawthorn Group called the intermediate confining unit (fig. 6). These beds consist of sandy clay, clay, or fine-grained weathered limestone.

In the southern part of the study area, the Upper Floridan aquifer is confined by 100 to 700 ft of the intermediate aquifer system, which contains one or more aquifers of low to moderate yield, interlayered with confining units (Southeastern Geological Society, 1986). In the southern part of the study area, the potential for contamination of the Upper Floridan aquifer from the surface is expected to be low, and any contamination that does occur probably will be through breaks in the confining units of the intermediate aquifer system made by sinkholes or wells.

North of central Hillsborough and Polk Counties, where the intermediate confining unit is less than 100 ft thick, the Upper Floridan aquifer is unconfined or semiconfined (fig. 6). In the north, the confining unit consists of low-permeability beds; these beds do not alternate with more permeable ones as they do in the south. For this report, semiconfined areas are considered to be the areas with leakance values of the intermediate confining unit greater than 10^{-4} feet per day per foot [(ft/d)/ft] (Ryder, 1985). North of Hillsborough and Polk Counties, the thickness of the intermediate confining unit ranges from 0 to 50 ft. The intermediate confining unit thickens under the Brooksville Ridge (east-central Pasco County and central Citrus County) and under the Cotton Plant Ridge in western Marion County (fig. 2). Although a thin confining unit exists along the ridges and elsewhere in the northern part of the study area, these less permeable deposits are limited in extent. The Upper Floridan aquifer is unconfined in most of Citrus and

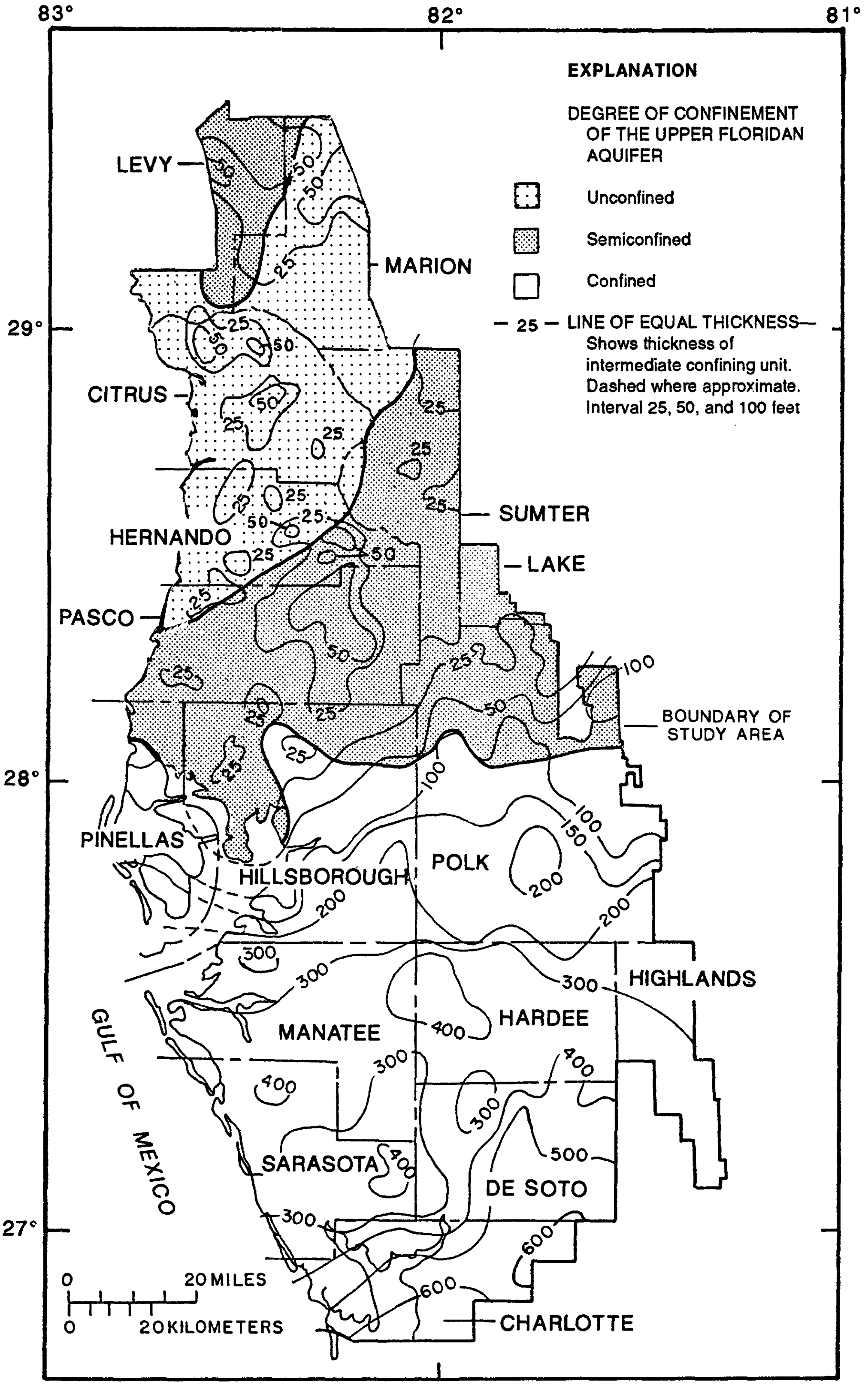

Figure 6. Thickness of the intermediate confining unit or intermediate aquifer system (from Buono and others, 1979) and degree of confinement of the Upper Floridan aquifer (modified from Ryder, 1985).

Hernando Counties and parts of Pasco, Sumter, Marion, and Levy Counties (Ryder, 1985; Miller, 1986).

Sinkholes and Drainage Wells

Sinkholes are a common topographic feature in the study area. They provide a more direct path for water flowing into the Upper Floridan aquifer from the surface because the confining unit and surficial materials have been disturbed. Sinclair and others (1985) mapped the types, features, and occurrence of sinkholes in the study area (fig. 7).

Sinkholes are formed as the limestone units that underlie west-central Florida are gradually dissolved by infiltrating acidic rain and soil water. Four types of sinkholes have been described: limestone solution, limestone collapse, cover subsidence, and cover collapse (Sinclair and others, 1985). The first two types occur in areas where the limestone is near land surface, and the last two types occur where there is a thick (30–200 ft) clastic unit overlying the limestone. Limestone-solution and cover-subsidence sinkholes develop gradually, whereas limestone-collapse and cover-collapse sinkholes develop suddenly and can be catastrophic.

Limestone-solution and limestone-collapse sinkholes occur in the coastal lowlands, valleys, and northern ridges. Cover-collapse and cover-subsidence sinkholes become more common as the confining unit thickens to the south, as occurs in northwest Hillsborough, Pinellas, southwest Pasco, central Polk, and Highlands Counties. To the south, the confining unit becomes thick enough that it can support the overburden and neutralize the acidity in the recharging water before it reaches the aquifer. Areas where sinkholes are common have a higher potential for contamination than areas with an equivalent thickness of unbreached confining unit.

In addition to sinkholes, the confining unit in west-central Florida is breached by human activities, particularly mining and well drilling. The middle confining unit contains a phosphate ore in parts of the study area, and its removal during mining increases the potential for contamination of the Upper Floridan aquifer.

The confining unit also is breached by two types of wells. The first type, a drainage well, is used to rapidly drain surface-water runoff or to dispose of waste. Most of the drainage wells are outside the study area, but there are 26 of these wells in Citrus, Hernando, Hillsborough, Polk, and Hardee Counties (Kimrey and Fayard, 1984). The second type is an interaquifer connection well that is constructed with a screened section in the surficial aquifer system, a closed part in the intermediate aquifer system, and an open section in the Upper Floridan aquifer. Interaquifer connection wells have two purposes for the phosphate-mining industry: (1) they lower water levels in the surficial aquifer system, making mining operations easier; and (2) they provide recharge to the Upper Floridan aquifer, offsetting the large quantities of water that are withdrawn (Hutchinson, 1977). There are 167 interaquifer connection wells used by the phosphate-mining industry in Hillsborough, Manatee, and Polk Counties (Kimrey and Fayard, 1984). Because a downward head gradient exists between the surficial aquifer system and Upper Floridan aquifer in this area, the wells provide a direct path for water to flow from the surficial aquifer into the Upper Floridan aquifer.

Drainage and interaquifer connection wells allow surface water or water from the surficial aquifer system to enter the Upper Floridan aquifer directly, bypassing all or much of the natural filtration through the overburden. Therefore, the potential for contamination of the Upper Floridan aquifer in localized areas near such wells is high.

Ground-Water Flow Paths

Ground-water flow paths into and through the Upper Floridan aquifer also describe the path that will probably be taken by contaminants traveling with the water. Ground-water flow paths are determined by interrelated factors, including the degree of confinement of the aquifer, hydraulic gradients, and applied stresses from pumpage and injection. Where downward flow is impeded by less permeable sediments, the potential for contamination is expected to be lower than where these sediments do not occur. In areas where recharge to the aquifer is greatest, potential for contamination from the surface is expected to be higher than in areas of low recharge or discharge.

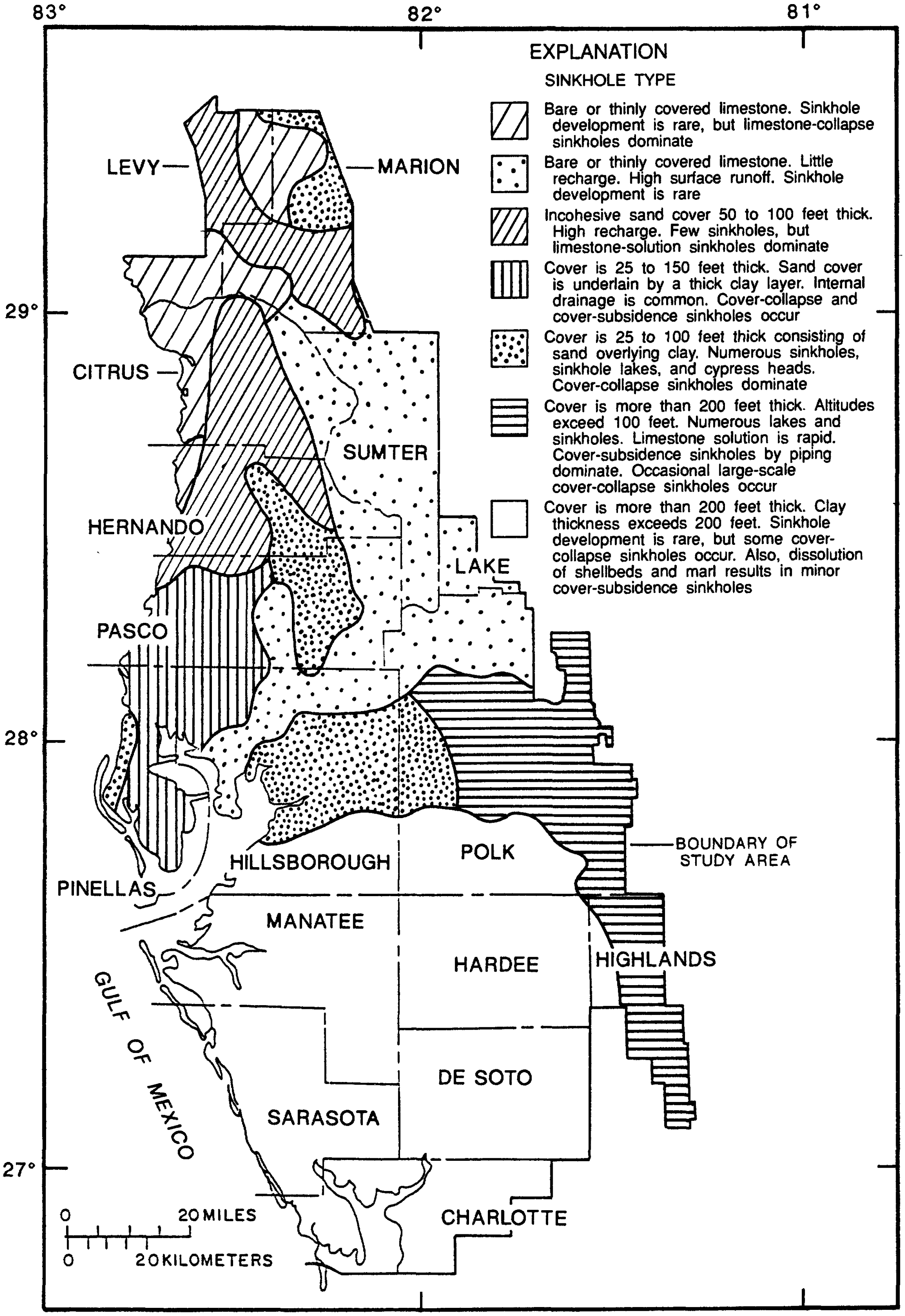

Figure 7. Zones of sinkhole types (modified from Sinclair and others, 1985).

Water levels in wells open to the Upper Floridan aquifer of west-central Florida have been monitored for the past 25 years and can be used to determine approximate ground-water flow paths. The potentiometric surface of the Upper Floridan aquifer in September 1988 (Barr, 1988) is shown in figure 8. The potentiometric surface is an imaginary surface that represents the level to which water would rise in a tightly cased well open to the Upper Floridan aquifer. Ground water flows downgradient from an area of higher potential to one of lower potential in a continuous effort to stabilize the energy of the system. Potentiometric surface highs correspond roughly to topographic highs in peninsular Florida and occur in northern Polk County, along the Lake Wales Ridge, and in east-central Pasco County.

In areas where the Upper Floridan aquifer is recharged from the surface (fig. 9), water levels in wells open to the surficial aquifer are higher than water levels in wells open to the Upper Floridan aquifer. Water levels in wells open to the intermediate aquifer system are between those of the surficial aquifer system and Upper Floridan aquifer. A downward gradient between the surficial aquifer system and Upper Floridan aquifer exists in the eastern and central parts of the study area. Areas of highest recharge occur where the aquifer is unconfined and overlain by permeable sand units that can store significant volumes of infiltrating water (Grubb, 1977). Recharge also is high in areas where the confining unit is thicker but is breached by cover-subsidence or cover-collapse sinkholes (Sinclair and others, 1985). Areas of high recharge to the aquifer typically are internally drained. Many sinkholes are expressed in the topography as lakes, and these, rather than streams, are the converging points of surface-water drainage.

Along the western coast, water levels in wells open to the Upper Floridan aquifer and the intermediate aquifer system are higher than those in the surficial aquifer system and often are higher than land surface, resulting in flowing wells. Ground water flows upward, or discharges, from the underlying aquifers in these areas. The large coastal springs common to west-central Florida are discharge points for the Upper Floridan aquifer. According to Ryder (1985), springs accounted for about 84 percent of the water discharged from the Upper Floridan aquifer in west-central Florida under predevelopment conditions. Parts of many riverbeds also are typically discharge areas.

Areas where the Upper Floridan aquifer is discharging have a lower potential for contamination because water is flowing out of, rather than into, the aquifer, but recharge and discharge relations have limited use for determining potential for contamination because the recharge and discharge zones are not fixed. Ryder (1982) shows that areas of discharge are changed into areas of recharge when the potentiometric surface is permanently lowered by pumping. Recharge to the aquifer also can be increased when the downward head gradient is increased because of large ground-water withdrawals.

CHEMICAL AND ISOTOPIC COMPOSITION OF WATER IN THE UPPER FLORIDAN AQUIFER

One objective of this study was to determine how the chemistry of the ground water reflects its history. Age relations between water in different parts of the Upper Floridan aquifer can be estimated by analysis of the chemical composition of the water. If the age of water in the Upper Floridan aquifer can be estimated by geochemical methods, then the aquifer's potential for contamination can be evaluated.

Sampling Methods

During the initial phase of the study, two pilot sites were chosen, one in an area where the Upper Floridan aquifer was expected to have low potential for contamination and the other in an area of high potential. The low-potential area was in the southern part of west-central Florida where the intermediate aquifer system exceeds 300 ft in thickness (fig. 6). This area is either one of low recharge to the aquifer (less than 1 in/yr) or of low discharge from the aquifer (less than 1 in/yr) (Aucott, 1988). Within the low-potential region, the areas of recharge to the aquifer are inland and to the north, and the areas of discharge are toward the coast. The area where the aquifer was assumed to have a high potential for contamination was in central Hernando County where the confining unit is less than 25 ft thick. This is also one of the areas of highest recharge to the aquifer (more than 15 in/yr) (Stewart, 1980; Ryder, 1985; Aucott, 1988).

An extensive sampling program was designed for 28 wells in the two pilot sites selected for the initial phase of the study. Major ions, environmental

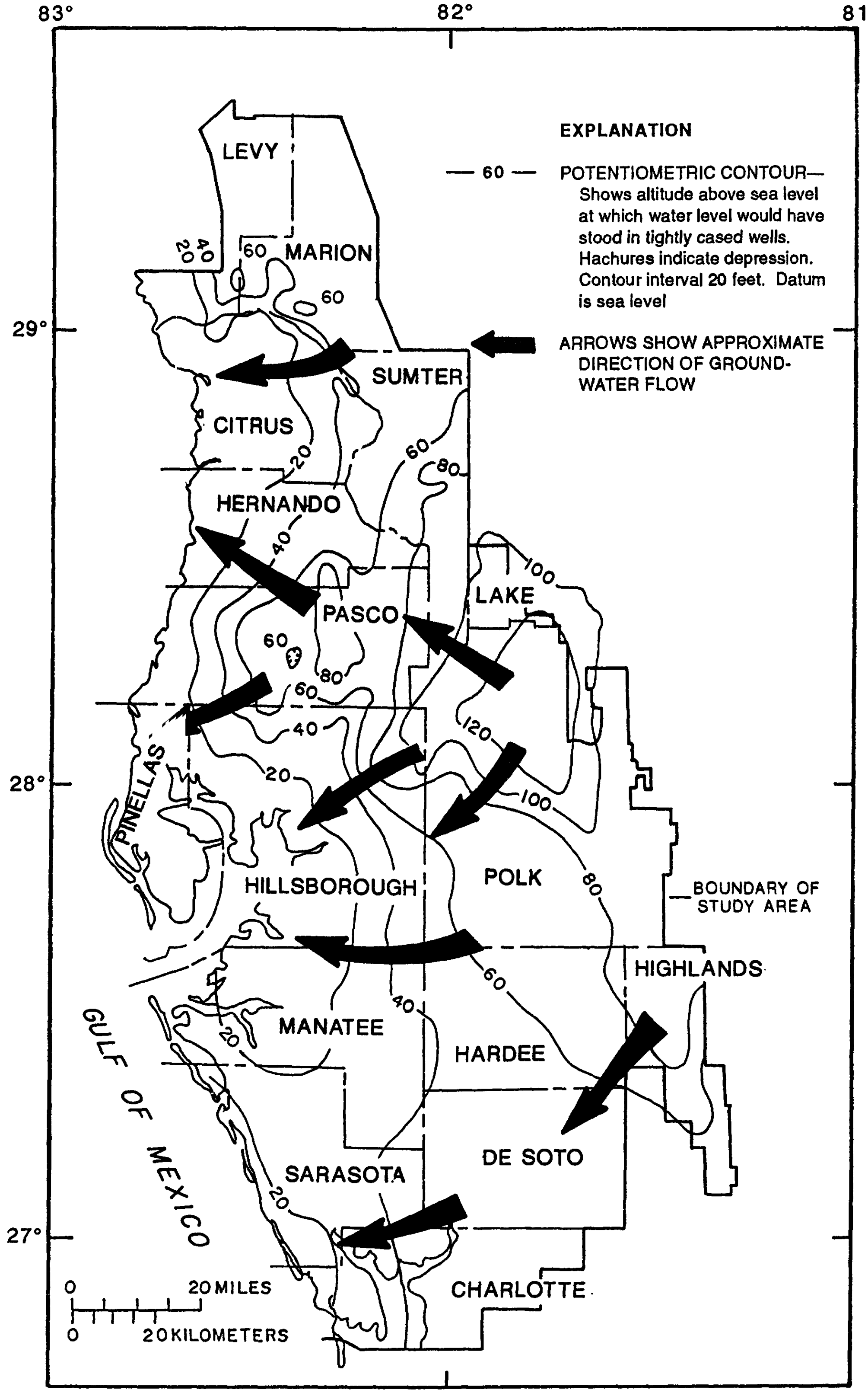

Figure 8. Potentiometric surface of the Upper Floridan aquifer, September 1988 (modified from Barr, 1988).

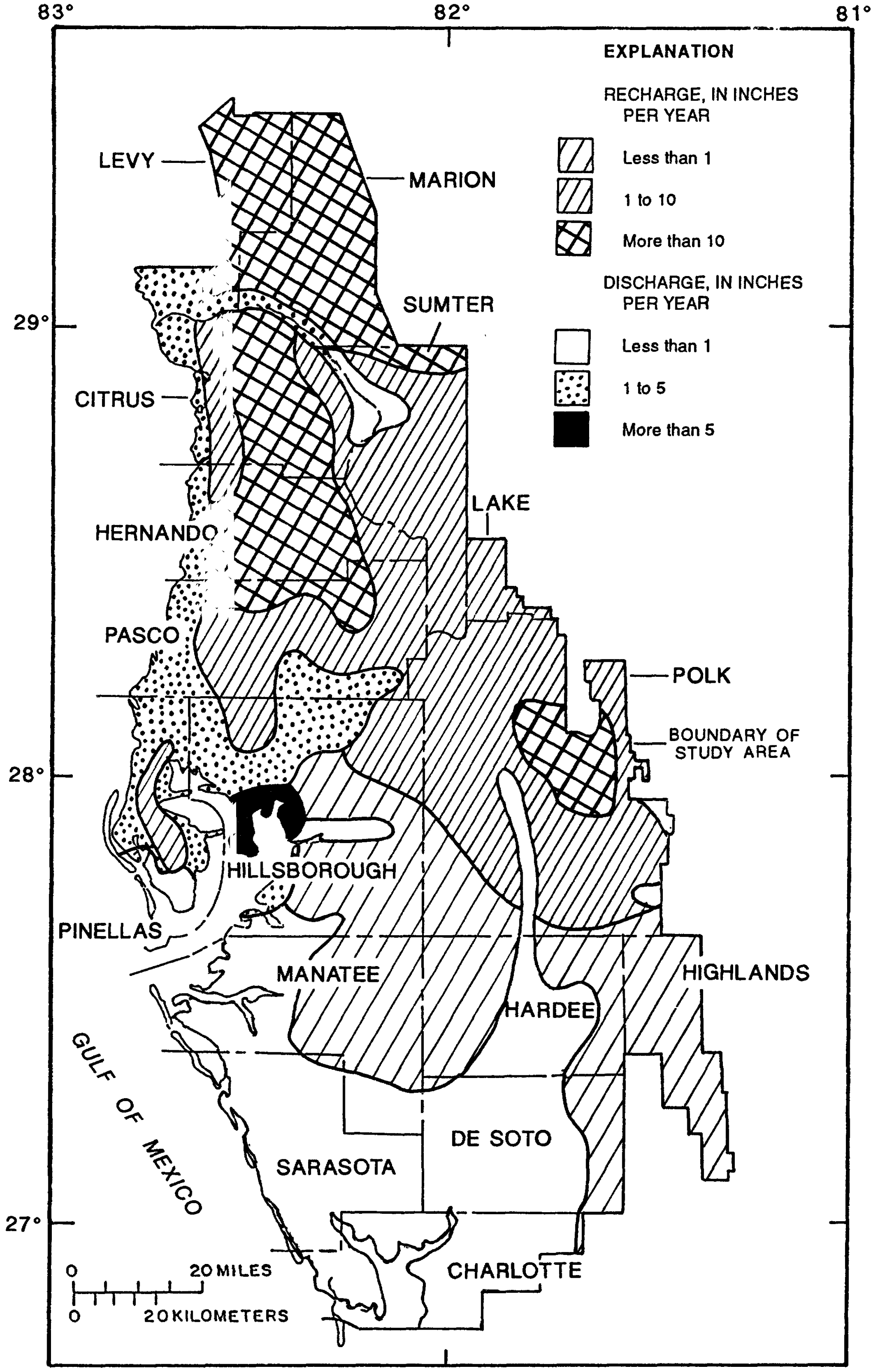

Figure 9. Recharge to and discharge from the Upper Floridan aquifer (modified from Aucott, 1988).

isotopes, volatile organic compounds, pesticides, freon, methylene-blue active substances (detergent brighteners), and unstable field constituents such as pH, dissolved oxygen, Eh, and temperature were analyzed. On the basis of sample analyses from the pilot sites, decisions were made on which constituents would be suitable for the regional sampling.

The manmade compounds sampled in the initial phase were eliminated from the regional sampling because insignificant quantities were found. These compounds (volatile organic compounds, pesticides, detergent brighteners, and freon) have been introduced to the environment in Florida within the past 50 years. Trace amounts of these compounds in ground water should indicate that recharge is recent and the water is relatively young. However, the presence of these compounds in ground water is dependent on their application in the recharge area, and their absence does not necessarily eliminate the possibility that the water is young.

Sampling for all other constituents was continued during the regional sampling in the second phase of the study. Locations of wells sampled for the study are shown in figure 10. Wells were selected on the basis of the following criteria: wells should be cased into the top of the Upper Floridan aquifer, they should have a limited open-hole interval, and they should be distributed throughout the study area. Well completion reports were used in conjunction with existing maps of the top of the aquifer (Buono and Rutledge, 1979; Miller, 1986; G.L. Barr, U.S. Geological Survey, written commun., 1989) to determine whether wells were cased into the Upper Floridan aquifer.

The criterion of a limited open hole is more easily met in the northern part of the study area than in the southern part. Small-diameter domestic wells are the main source of drinking water in sparsely populated Hernando, Citrus, Sumter, Marion, and Levy Counties. In the southern part of the study area, wells open to the Upper Floridan are usually high-volume irrigation wells, which by design have a large open-hole interval. Domestic-supply wells in the southern part generally are finished in the shallower intermediate aquifers.

Sampling was concentrated in the central and northern parts of the study area. The thickness of material overlying the Upper Floridan aquifer in the southern counties (Manatee, Hardee, De Soto, Sarasota, and Charlotte) ranges from 200 to 600 ft (Buono and others, 1979). This material provides a significant barrier to contamination of the aquifer from the surface. Analyses and carbon–14 dating described by Plummer (1977) and Hanshaw and Back (1979) indicate that Upper Floridan aquifer water in these areas is much older than in the northern area.

More than 120 wells were sampled for this study. Wells were selected either from U.S. Geological Survey files or from a well inventory completed for the Florida Department of Health and Rehabilitative Services (HRS). Wells selected from the U.S. Geological Survey files were generally water-level observation wells. The inventory of domestic wells for HRS was completed by the Southwest Florida Water Management District Ambient Ground-Water Quality Monitoring Program. In addition, seven wells that were sampled in 1986 by the U.S. Geological Survey Branch of Regional Research, Reston, Va., are used in the analysis. These seven wells are in the southern part of the study area and were selected along regional flow paths in the Upper Floridan aquifer. Appendix A lists information about wells used in this study as well as the type of pump used to sample each well. Samples from domestic wells were obtained using available centrifugal or submersible pumps. Water-level observation wells were sampled using either a centrifugal, submersible, or bladder pump. The type of pump used was dependent on the well yield, diameter of well, and depth to water.

The seven analyses obtained by the Branch of Regional Research were used in this study because they contained tritium, deuterium, and oxygen–18, in addition to other unstable field constituents such as pH, alkalinity, and dissolved oxygen. These samples, along with others collected during the Cross Florida Barge Canal investigation by Faulkner (1973), make up all of the available data on these isotopes that could be located for the Upper Floridan aquifer in the study area.

Wells were sampled for the constituents listed in appendix B. Temperature, dissolved oxygen, pH, Eh, alkalinity, and specific conductance were measured at each site using methods described by Wood (1981). Except for specific conductance and alkalinity, all field constituents were measured using probes submerged in a flow-through chamber to eliminate atmospheric contamination. All meters were calibrated at each well. The results of lab analyses are listed in appendix B. The following sections describe the chemical and isotopic composition of water in the Upper Floridan aquifer and discuss specific constituents that were found to be useful indicators of the age of water.

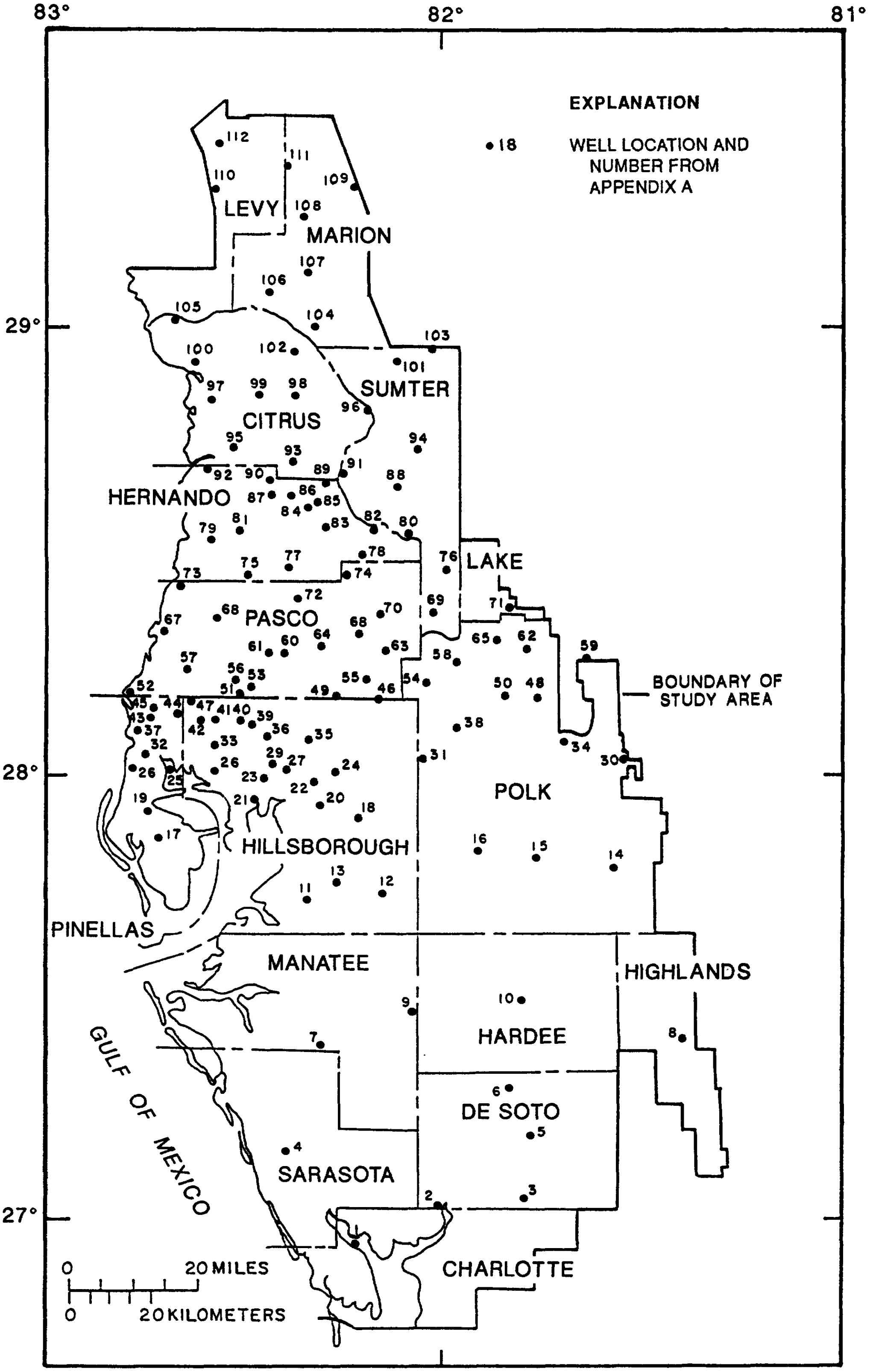

Figure 10. Locations of sampled wells.

Chemical Composition

Ground water can be classified by its dominant major ions (Kaufman and Dion, 1967). The ionic composition of water samples from the Upper Floridan aquifer is shown in figure 11. Nearly all of the water in the uppermost producing zones of the Upper Floridan aquifer is a calcium bicarbonate ($CaHCO_3$) or calcium magnesium bicarbonate ($CaMgHCO_3$) water type. Calcium magnesium sulfate ($CaMgSO_4$) waters occur in the southern part of the study area, and water with greater proportions of sodium chloride (NaCl) occurs near the gulf coast.

The evolution of ground water in carbonate aquifers has been described by Hanshaw and Back (1979). In the southern part of the study area, where the aquifer is confined, water in the Upper Floridan aquifer follows the theoretical evolutionary trend from $CaHCO_3$ water in the recharge areas to $CaMgSO_4$ water in the middle of the regional flow path, to NaCl water near the end of the flow path (fig. 12).

The increase in sulfate to the south is due to upwelling of water from the gypsum-anhydrite units of the Avon Park Formation (Wilson, 1977). Upwelling increases to the south and toward the gulf coast as the regional flow system changes from recharging to discharging conditions. The increase in sulfate toward the coast also is due to the proximity of the freshwater-saltwater interface.

In the northern areas where the aquifer is unconfined or semiconfined, flow paths are too short for regional ground-water evolution to be evident. In these areas, the Upper Floridan aquifer is an open system, meaning that it is open to recharge and in contact with the atmosphere. The confining units are limited in extent and are commonly breached by sinkholes (Sinclair and others, 1985). Mixed freshwater and saltwater was found in six of the westernmost wells, and saltwater dominated in two.

Dissolved-solids concentrations in water from the Upper Floridan aquifer are high in the south and west, as shown in figure 13. Ground water farther along the flow path has higher dissolved solids, as does water in areas where the aquifer is affected by saltwater intrusion. Localized areas where the aquifer discharges around rivers also have slightly higher dissolved-solids concentrations.

Saturation Indices

Ground water reacts with rocks and minerals in the aquifer, and the extent of the reaction is partly dependent on the length of time the water has been in contact with these materials. The reactions between ground water and aquifer minerals can be used as an index of the relative age of ground water. The equilibrium state of a water with respect to a mineral phase can be expressed by calculating a saturation index (SI) using analytical data. SI is defined as the logarithm of the ratio of the ion activity product to the mineral equilibrium constant at a given temperature.

The variation in mineral SI can be related to lithology and residence time. Oversaturation (SI greater than zero) can indicate a long period of contact between ground water and the mineral or the thermodynamic potential for precipitation of the mineral. An SI of zero indicates the potential for equilibrium, or saturated, conditions between the dissolved mineral species in ground water and the mineral in the rock. Undersaturation (SI less than zero) indicates that the mineral is not present along the flow path, that it is being dissolved, or that the water has not yet reached equilibrium with the mineral. Because of uncertainties in analytical and thermodynamic data, a water with an SI between -0.1 and 0.1 is considered saturated or in equilibrium with respect to the mineral phase.

Saturation indices for calcite, dolomite, quartz, and gypsum were calculated for each water sample using the computer program WATEQF (Plummer and others, 1976). All ground-water samples were undersaturated with respect to gypsum. Gypsum is found at the base of the Upper Floridan aquifer, so low gypsum SI was expected in wells open only to the top section of the aquifer. All samples were saturated or oversaturated with respect to quartz and undersaturated with respect to amorphous silica. Both of these situations are typical of natural waters because silica solubility is probably controlled by other forms of silica, such as clay minerals or other weathering products of silicate rocks (Hem, 1985).

Ground water is saturated with respect to calcite and dolomite in the southern part of the study area where the Upper Floridan aquifer is confined (fig. 14 and appendix B). Ground water in areas to the north where the aquifer is unconfined and semiconfined is saturated or undersaturated with respect to these two minerals. Although calcite SI exhibits some regional trends, generally being higher in the

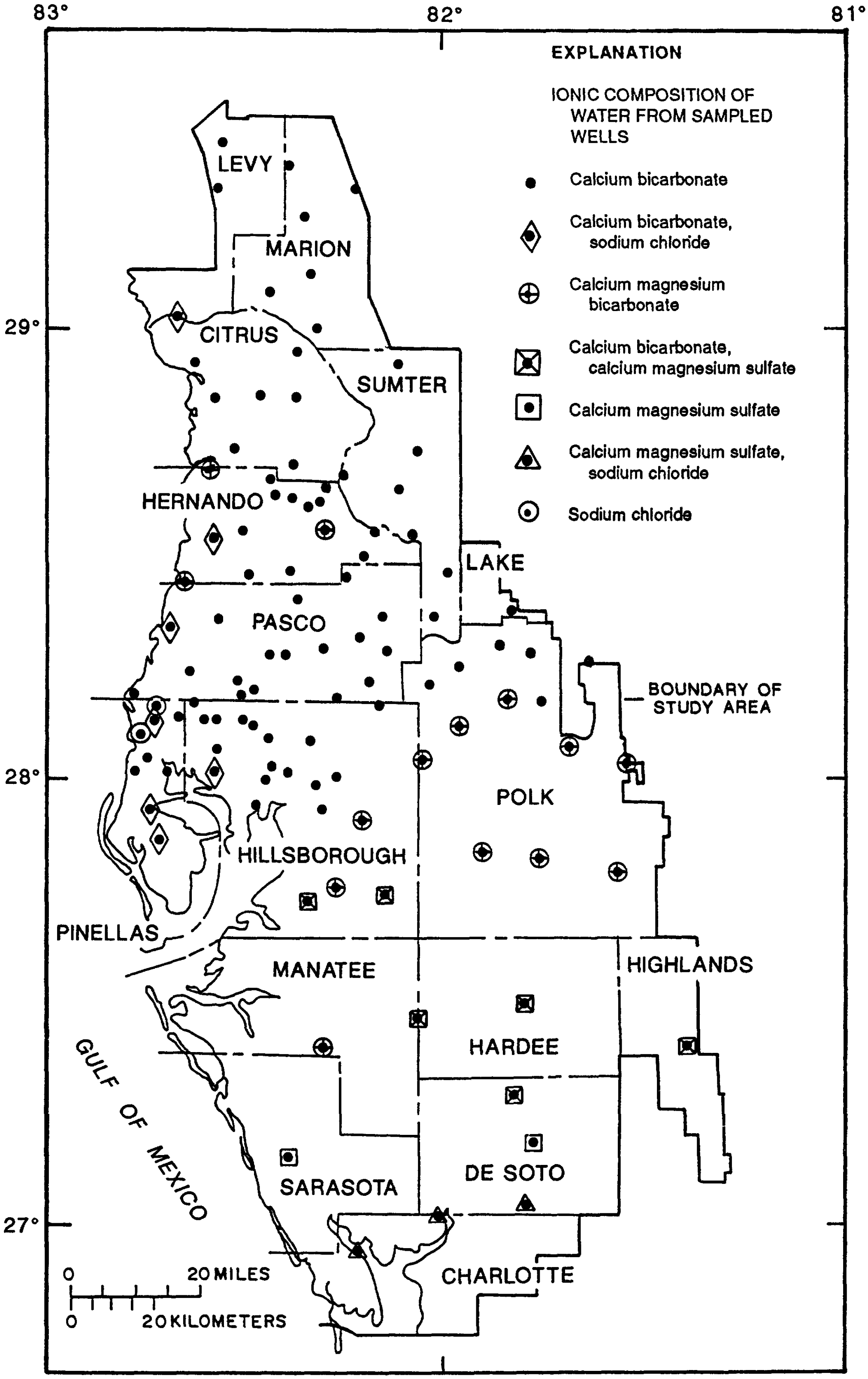

Figure 11. Ionic composition of water in wells that are open to the uppermost zone of the Upper Floridan aquifer.

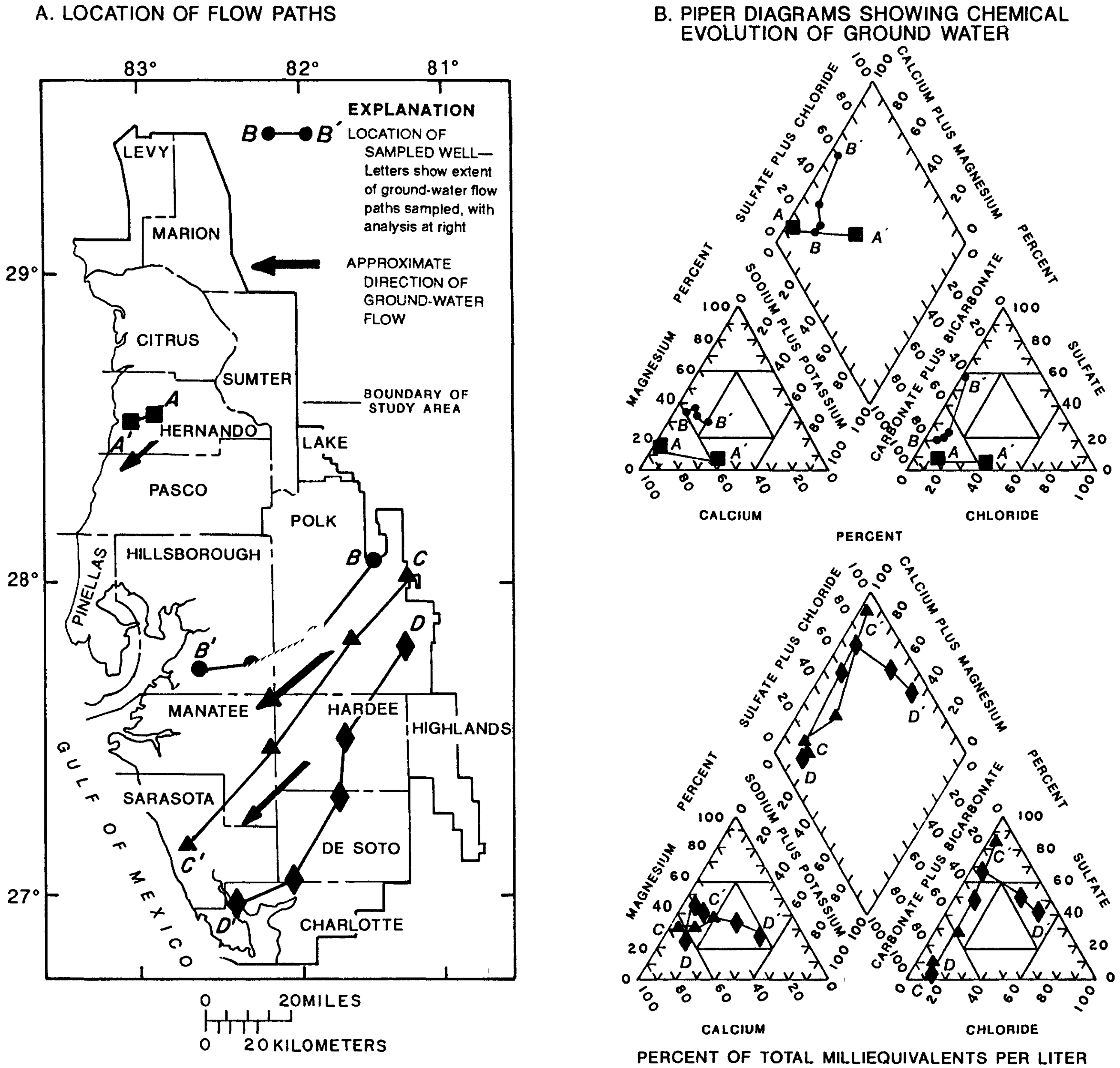

Figure 12. Chemical evolution of water along selected flow paths in the Upper Floridan aquifer.

south and lower in the north, it is typically close to zero throughout the study area, only a small number of analyses exceeding positive or negative 0.5. Dolomite SI has a wider range of values in the Upper Floridan aquifer than does calcite SI. In a large area that includes Sumter County and eastern parts of Citrus, Hernando, and Pasco Counties, ground water is undersaturated with respect to dolomite.

Dissolved Carbon Dioxide

WATEQF was also used to calculate the partial pressure of carbon dioxide gas (P_{CO_2}) for each sample. Atmospheric P_{CO_2} is approximately $10^{-3.5}$ atmospheres (atm). Partial pressure of carbon dioxide in ground water is usually higher than atmospheric pressure because decay of organics and respiration by plants and microorganisms produce CO_2 in the soil zone.

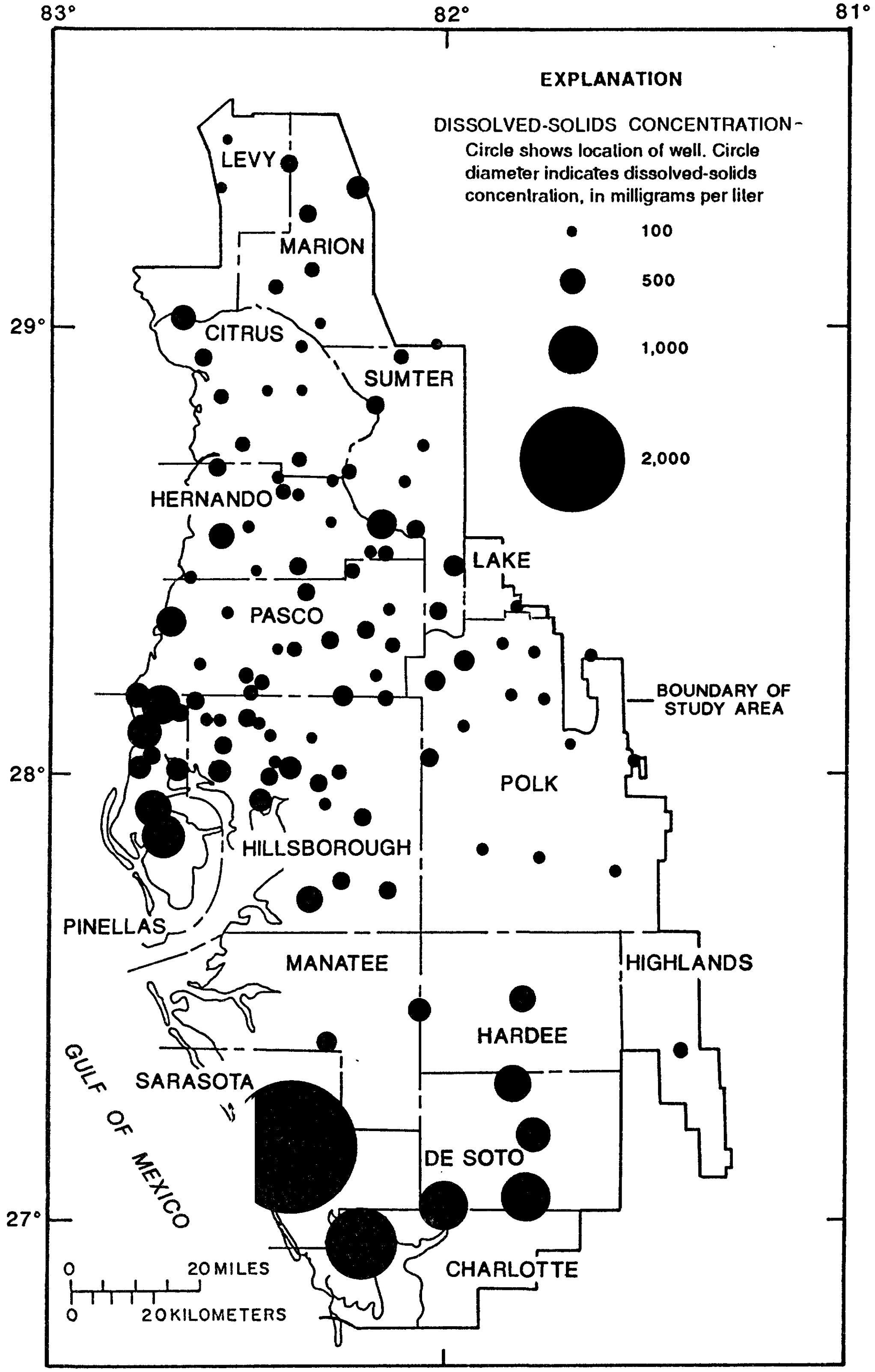

Figure 13. Concentrations of dissolved solids in water from the Upper Floridan aquifer.

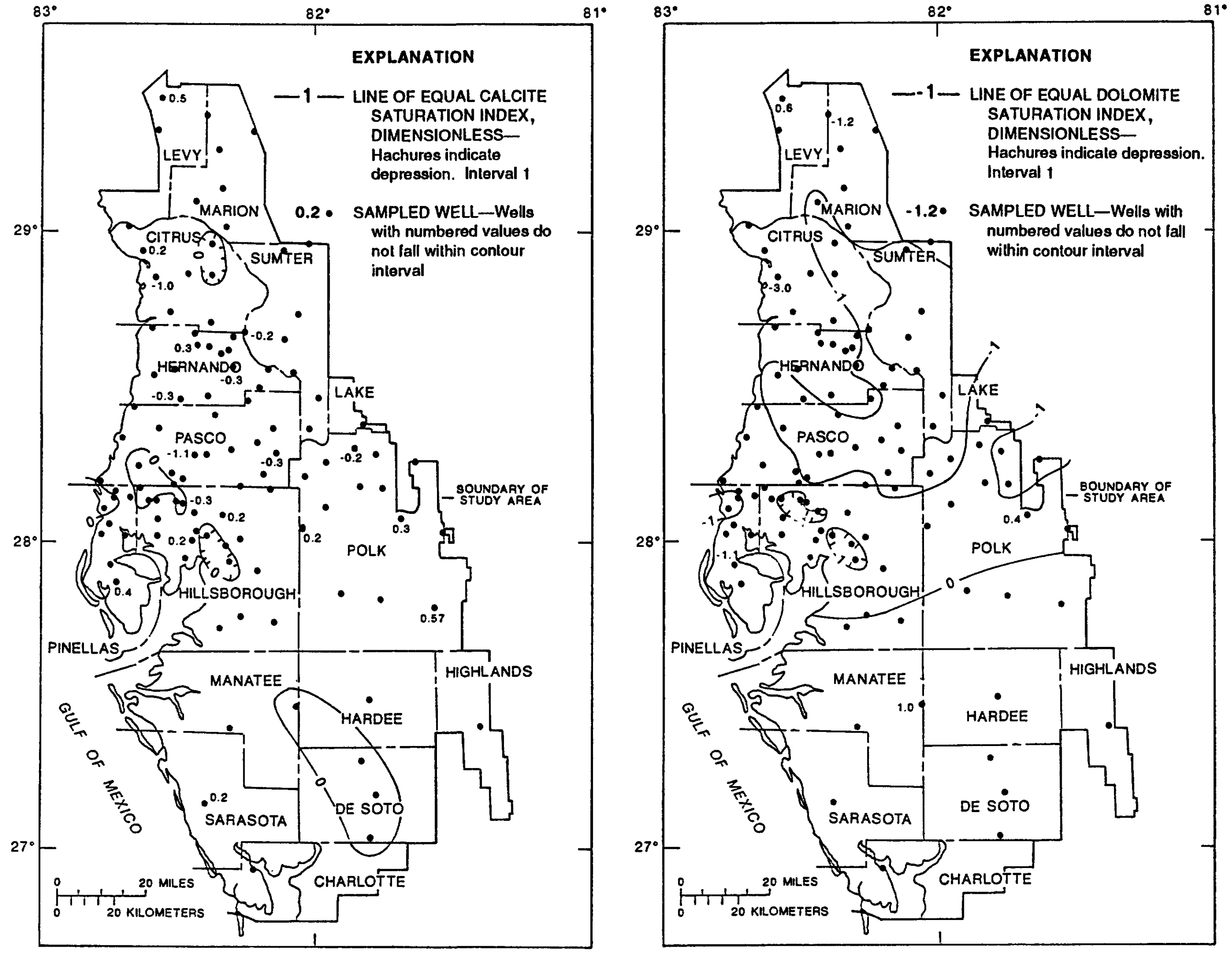

Figure 14. Saturation indices of calcite and dolomite in water from the Upper Floridan aquifer.

Dissolved carbon dioxide is the source of acidity for most weathering reactions, including limestone dissolution (Drever, 1982).

The P_{CO_2} in water from the Upper Floridan aquifer ranged from $10^{-3.7}$ to $10^{-1.1}$ atm (fig. 15). Values of P_{CO_2} were highest in unconfined or semiconfined areas of the Upper Floridan aquifer that also are wetlands. These areas typically have well-developed soils and denser vegetation. Many of the wetlands in west-central Florida occur in river valleys and at the gulf coast. A detailed map of wetland areas in Florida has been published by the U.S. Fish and Wildlife Service (1985).

Fine-grained soil particles that impede downward flow of water and an active microbial community that is capable of degrading many pollutants (Freeze and Cherry, 1979) occur in wetland areas. Because high P_{CO_2} also occurs in wetland areas in west-central Florida, it is assumed to indicate an area of relatively lower potential for contamination of the aquifer from the surface.

Dissolved Oxygen

Dissolved oxygen (DO) was measured at each well using a DO meter in a flow-through chamber to reduce contact with the atmosphere. Although DO measurements were made at all sites, some of the measurements were discarded to eliminate any confusion as to the source of DO in the water. Specifically, seven samples were obtained using centrifugal pumps in which significant DO concentrations were measured. The DO measurements for these samples

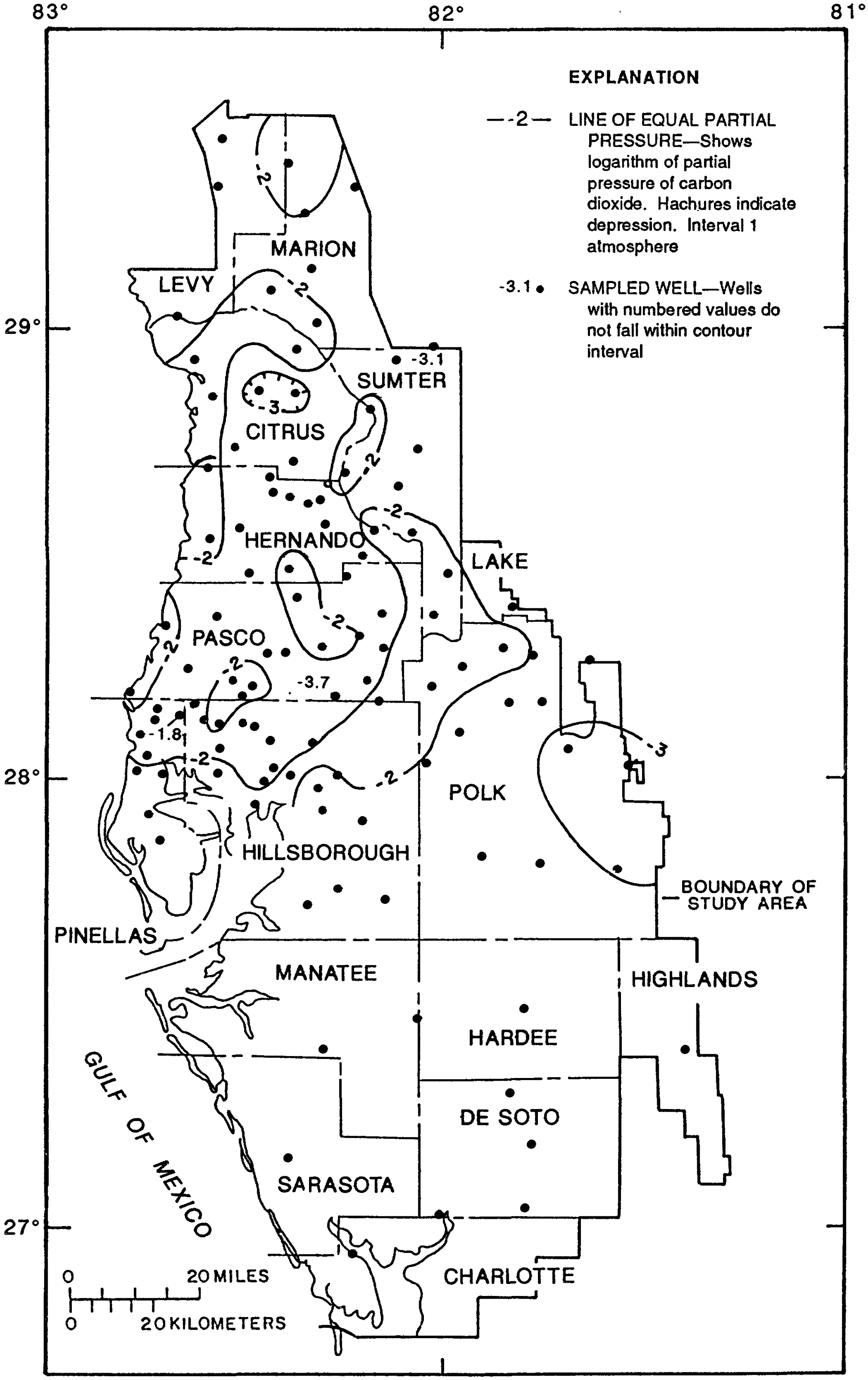

Figure 15. Partial pressures of dissolved carbon dioxide in water from the Upper Floridan aquifer.

were discounted because of the possibility that the pump might be mixing air with the water while the water was pumped to the surface. The mechanism for DO contamination by centrifugal pumps is not consistent (Rose and Long, 1988), however, as many other wells with centrifugal pumps had DO concentrations of zero.

Concentrations of DO in the Upper Floridan aquifer ranged from 0 to 6.2 milligrams per liter (mg/L) (fig. 16). Concentrations were insignificant for most of the study area. High DO concentrations were found under the Brooksville Ridge in Hernando and Citrus Counties, in Levy and Marion Counties north of the Withlacoochee River, and in two wells in central Hillsborough County, just east of Tampa. Under the Brooksville Ridge and in Marion and Levy Counties, Hawthorn Group deposits, which act as a confining unit farther south, do not impede recharge because deep sinkholes allow water to flow more directly into the aquifer. In central Hillsborough County, sinkholes are also responsible for the rapid infiltration of oxygenated water. The two sampled wells in Hillsborough County that had high DO concentrations are in the "Brandon internally drained basin" described by Trommer (1987).

Isotopic Composition

One or more different types of atoms can exist for a chemical element. When only the number of neutrons and the atomic mass are different, these types of atoms are called isotopes of the element. There are two types of isotopes: stable and radioactive. Stable isotopes, such as deuterium and oxygen–18, are used in hydrologic studies to identify sources of water and to learn more about hydrologic processes. Radioactive isotopes, such as carbon–14 and tritium, generally are used for age dating.

Tritium

Tritium (^3H) is a radioactive isotope of hydrogen that is produced naturally in small amounts by the interaction of cosmic rays with the Earth's atmosphere. Tritium enters the hydrosphere in rain at a concentration of approximately 3 to 5 tritium units (Kaufman and Libby, 1954; Robertson and Cherry, 1989). One tritium unit represents 1 tritium atom in 10^{18} hydrogen atoms. With the onset of atmospheric testing of high-yield thermonuclear devices in 1953, tritium concentrations in rainfall increased by up to four orders of magnitude. Because of the difference in tritium concentrations before and after 1953, tritium has been used as a hydrologic tracer in many studies (Coplen, 1993). The time required for the tritium concentration to decay to half of the original concentration (half-life) is 12.43 years.

A global network of stations that monitor tritium in rainfall has been in existence for about 30 years (International Atomic Energy Agency, 1981). The concentration of tritium in rainfall at Ocala, Fla., is shown in figure 17. Ocala is a few miles outside of the study area, in central Marion County (fig. 1). Tritium concentrations in rain at Ocala from 1954 to 1961 are predicted by a regression of concentrations at Ocala with concentrations at Ottawa, Ontario, Canada, from 1962 to 1976 (International Atomic Energy Agency, 1981). Figure 17 also shows the tritium concentration that rain falling in a certain year would have in 1988 after radioactive decay. There is a distinct peak in the tritium concentration of rain that fell during the early 1960's, even after decay.

Assuming a conservative pre-1953 input concentration of 5 tritium units (Robertson and Cherry, 1989) and a half-life of 12.43 years, the concentrations that infiltrating rainwater from selected years would have in 1988 are as follows:

Year	Tritium units
1910	0.06
1920	0.11
1930	0.20
1940	0.34
1950	0.60

For the gas counting method used for these tritium analyses, the detection limit is 0.1 tritium unit and the error is approximately 3 percent. When the tritium concentration is less than the lab detection limit, the water is assumed to be more than 70 years old. Between 1953 and 1963, the tritium input concentration was much larger and more variable than before 1953. After 1963, when above-ground nuclear tests were banned, the tritium input concentration declined with time. The amount of tritium in rain at Ocala as of 1988 was not significantly different from the estimated pre-1953 concentration.

Some constraints can be applied to the analysis of tritium because of its short half-life and the artificially high concentrations caused by atmospheric weapons testing. A ground water must be more than 70 years old to contain no measureable tritium within the analytical

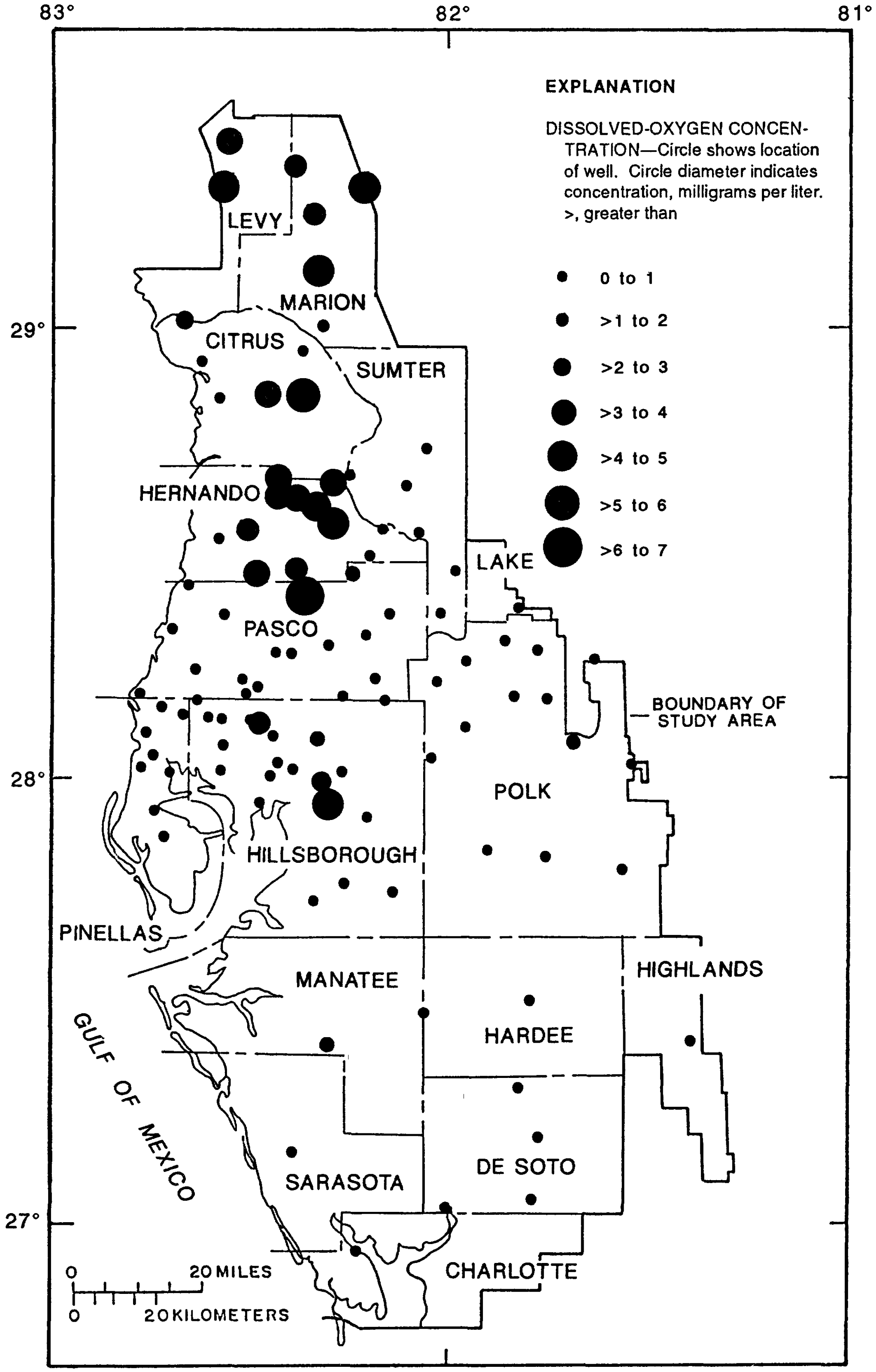

Figure 16. Concentrations of dissolved oxygen in water from the Upper Floridan aquifer.

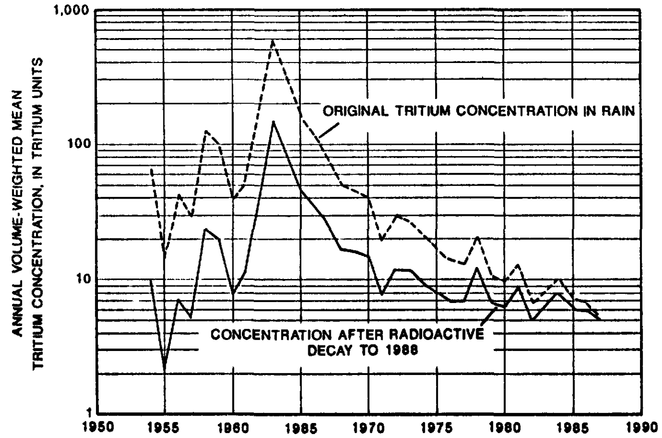

Figure 17. Annual volume-weighted mean tritium concentration of rainfall at Ocala, 1954–87. Pre-1962 data are estimated from a regression equation with data from Ottawa, Ontario, Canada.

detection limit of 0.1 tritium unit, assuming a pre-1953 concentration of 5 tritium units. Ground water recharging between 1962 and 1970 is expected to have concentrations of more than 15 tritium units. A ground water in west-central Florida with a concentration greater than 50 tritium units would have to contain a large proportion of water that fell as precipitation between 1962 and 1965.

Tritium concentrations in rainfall vary seasonally; spring and summer concentrations are 3 to 10 times greater than fall and winter concentrations. This variation is due to increased atmospheric mixing in the spring. The seasonal variation was greatest in the years when tritium concentrations were highest. During this period, summer concentrations were 10 times greater than winter concentrations. Current seasonal variation is much lower; summer concentrations are now about three times greater than winter concentrations. It is assumed that the input tritium concentration to the Upper Floridan aquifer is accurately represented by an annual weighted mean concentration (the tritium concentration is weighted by the amount of rainfall). The weighted mean concentration is calculated by summing each rainfall amount multiplied by its tritium concentration and then dividing the sum by the total rainfall for the year.

Tritium concentrations in water from the top part of the aquifer are shown in figure 18, and a histogram of the tritium concentrations is shown in figure 19. The low tritium distribution (less than 1 tritium unit) on the histogram probably indicates pre-1953 water, or relatively "old" water, and the high tritium distribution (greater than 5 tritium units) indicates relatively "young" (post-1953) water. Water that contains greater than 15 tritium units after decay, which is assumed to have recharged between 1962 and 1970, was not found in any of the wells open to the Upper Floridan aquifer.

In samples from all wells in areas where the confining unit is thicker than 100 ft, the water contained no detectable tritium and thus was presumed to be more than 70 years old. Ground water more than 70 years old also was found in southern Pinellas County, northern Polk County, southern Sumter County, and in isolated wells in Hillsborough and Pasco Counties.

Of particular interest is the area of northern Polk County and southern Sumter County known as the Green Swamp (fig. 18). Wells in the southern part of the Green Swamp have the highest water levels in the Upper Floridan aquifer in south Florida (see fig. 8), and therefore, the Green Swamp is a point of origin for regional ground-water flow. Because it is the origin of regional flow paths, the Green Swamp is a recharge area to the Upper Floridan aquifer. The water in the top part of the Upper Floridan aquifer in the Green Swamp, however, is presumed to be older than 70 years because it contains no tritium. Therefore, despite its importance as the origin of regional flow paths, the Green Swamp appears to be an area of low recharge compared with other parts of west-central Florida. These results agree with previous work in the Green Swamp by Pride and others (1966), who calculated a recharge rate of 3 to 5 in/yr, and Grubb (1977), who states that almost one-half of the Green Swamp has low potential for downward leakage to the Upper Floridan aquifer. The areas of low potential for downward leakage are on the west side of the Green Swamp and include most of the swamp within the study area. In addition to the low rate of recharge in the Green Swamp, aquifer transmissivity is also relatively low (Ryder, 1985), so the water that does recharge the aquifer does not move away from the swamp as rapidly as in areas to the north and west.

Tritium concentrations in the Upper Floridan aquifer in northwest Hillsborough, northern Pinellas, and southwest Pasco Counties varied widely over short distances. Water from the top part of the aquifer in 7 public-supply well fields and 11 domestic-supply wells in this area was collected and analyzed for tritium. Tritium concentrations ranged from 0.13 tritium units in northeast Pinellas County to 10.94 tritium units in south-central Pasco County. There was no systematic variation in tritium concentrations in this area; wells within 1 mi of each other with similar depths and confining-unit thicknesses had widely varying tritium concentrations. The clay confining unit in this area ranges from 0 to 25 ft

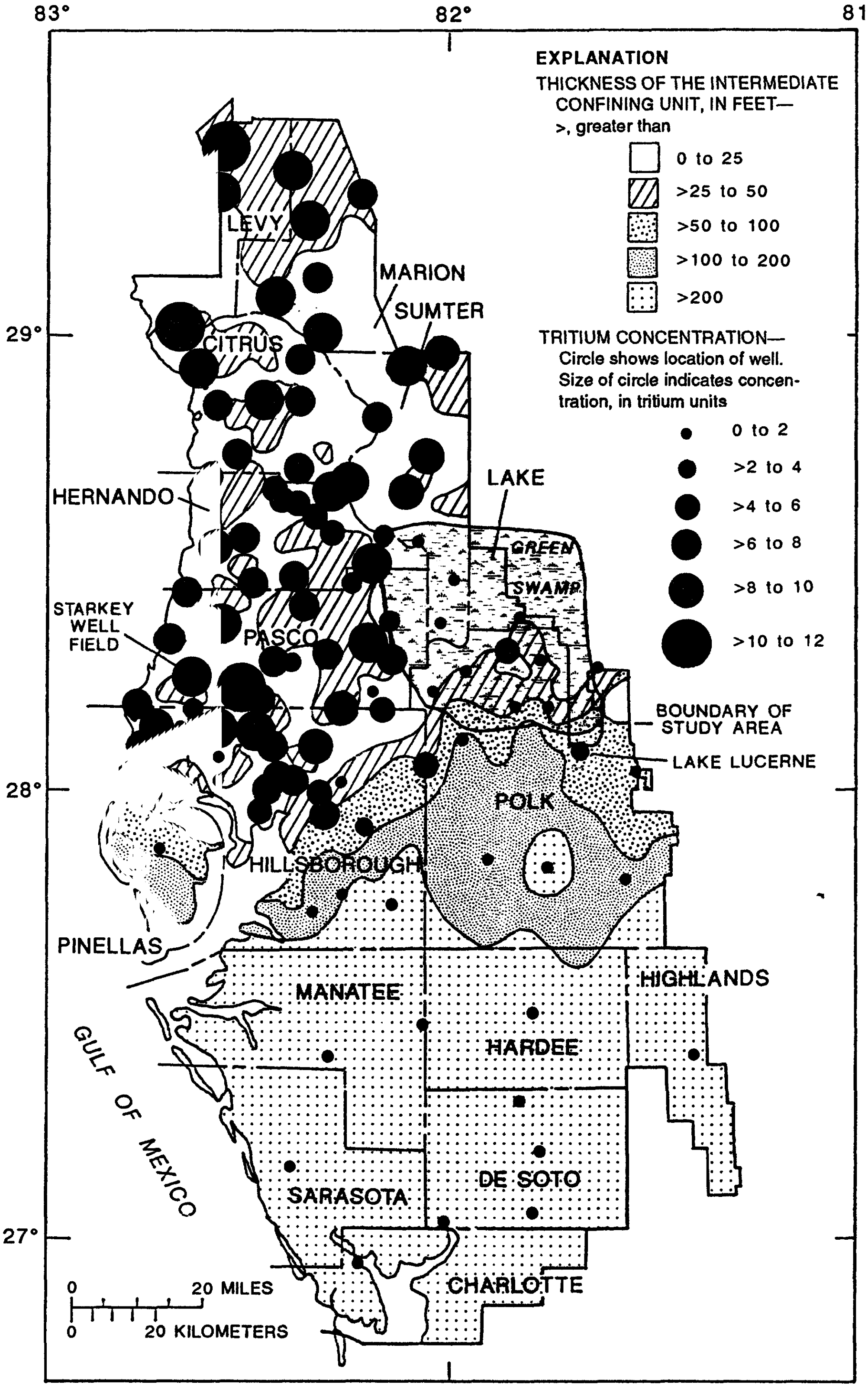

Figure 18. Tritium concentrations in water from the Upper Floridan aquifer and thickness of the intermediate confining unit (from Buono and others, 1979).

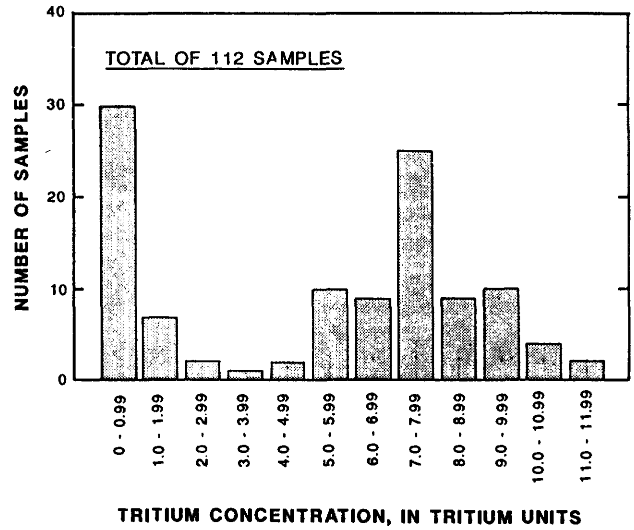

Figure 19. Distribution of tritium concentrations in water samples from the upper part of the Upper Floridan aquifer.

in thickness, and cover-collapse sinkholes are common (Sinclair and others, 1985).

Several explanations are possible for the variation in tritium concentration in northwest Hillsborough, Pinellas, and Pasco Counties: (1) natural variability due to local flow systems, (2) induced recharge of "young" water due to pumping, and (3) upconing of "old" water due to pumping. Prior to development, this area was a zone of regional discharge from the Upper Floridan aquifer (Ryder, 1985). Currently, large well fields pump an average of 90 Mgal/d from the aquifer in this area (Moore and others, 1986). At least some of the variability in tritium concentrations is undoubtedly due to induced recharge or upconing resulting from large withdrawals from the Upper Floridan aquifer.

Because ground-water flow has both lateral and vertical components, tritium concentration also varies with depth, and the distribution of tritium in a depth profile can be used to calculate dispersion and recharge rates (Knott and Olimpio, 1986; Robertson and Cherry, 1989). Tritium concentrations were measured along profiles at two sets of nested observation wells with screened intervals from the surficial aquifer system to the Upper Floridan aquifer in an area of high recharge (Lake Lucerne in Polk County) and an area of moderate recharge (Starkey well field in Pasco County) (fig. 18).

Vertical flow velocities of ground water can be estimated using tritium because concentrations greater than 15 tritium units are restricted to the years 1962–70. However, tritium concentrations did not exceed 15 tritium units in either profile. Peaks in tritium concentration occurred at about 60 ft below the water table at Lake Lucerne (11.7 tritium units) and at about 25 ft below the water table at Starkey well field (11.9 tritium units) (fig. 20). If these peaks are assumed to represent the high tritium years, 1962–70, and the effective porosity of both profiles is assumed to be 30 percent, the calculated downward velocity is approximately 9 in/yr at Lake Lucerne and 4 in/yr at Starkey well field. These estimates are consistent with earlier values based on hydrogeologic and numerical modeling studies (Ryder, 1985; Aucott, 1988).

Tritium concentrations in water from the Upper Floridan aquifer at both sites were less than in the overlying strata. At Lake Lucerne, the water in the Upper Floridan aquifer is a mixture of young and old water and has a tritium concentration of 2.4 tritium units. At Starkey well field, the water in the aquifer is young and has a tritium concentration of 8.1 tritium units. The tritium concentrations at both sites are representative of those in ground water in the surrounding areas. Even though the calculated vertical flow rate is higher at Lake Lucerne than at Starkey well field, tritium concentrations at Lake Lucerne are reduced by decay before they reach the aquifer. Young water found in the Upper Floridan aquifer at Starkey well field could have moved laterally from areas of high recharge to the east rather than vertically. Vertical head gradients between the surficial and the Upper Floridan aquifer at Lake Lucerne average 8 ft (Lee and others, 1991), compared with 2 ft at Starkey well field.

In addition to the tritium profiles, six other samples were collected from aquifers above the Upper Floridan aquifer. Four samples were taken from the intermediate aquifer system: one in Pinellas County, two in Hillsborough County, and one in Polk County. Three of these samples had higher tritium concentrations than the nearest sample from the Upper Floridan aquifer, and one sample had a tritium concentration equal to a nearby Upper Floridan aquifer well (Pinellas County). Two samples from wells screened into saturated sands overlying the Upper Floridan aquifer in Hernando County had the highest tritium concentrations encountered, 15.3 and 17.4 tritium units. These two samples had a pH near 5, dissolved-oxygen saturation, and low alkalinity, indicating a composition more similar to rainwater than ground water. The high tritium concentration of water in sands overlying the Upper Floridan aquifer can indicate water from the period 1962 to 1970, or it can be water from a seasonal period of rainfall having high tritium concentrations. As discussed earlier, concentrations of tritium in rainfall

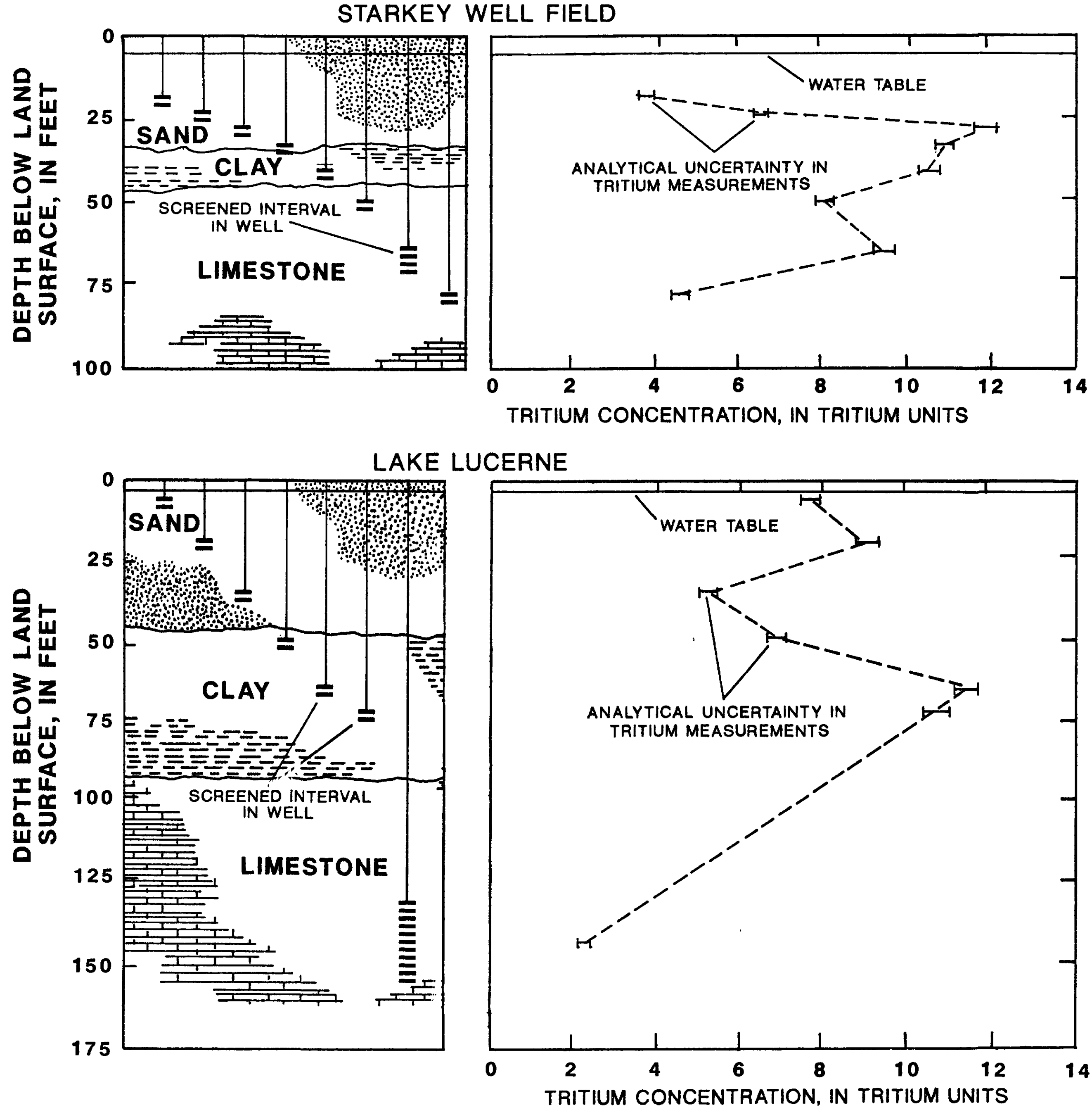

Figure 20. Depth profiles of tritium concentration in ground water at Starkey well field (December 14, 1988) and near Lake Lucerne (August 28, 1987).

vary with season. Although it was assumed that the input of tritium to the Upper Floridan aquifer was adequately represented by an annual mean of tritium concentration weighted by the amount of rainfall, this assumption might not be valid for the overlying deposits.

The vertical tritium distribution in the Upper Floridan aquifer and overlying units is more complex than the horizontal distribution within the uppermost producing zones of the Upper Floridan aquifer. The highest tritium concentrations were found in units overlying the aquifer, and it is probable that even higher tritium concentrations from water infiltrating during the mid-1960's also could be found here. Flow through large fractures in the Upper Floridan aquifer might produce a more homogeneous tritium distribution than flow through pores in the overlying aquifers and confining units.

Tritium analyses of ground water in the northern part of the study area are available for 1966–68 in a report by Faulkner (1973). Samples were collected from wells and springs in the area of the proposed Cross Florida Barge Canal (Citrus, Levy, and Marion Counties, fig. 1) at bimonthly or greater intervals during the 2-year period. Faulkner (1973) reported tritium concentrations in ground water ranging from 13 to 174 tritium units between 1966 and 1968, when rainfall concentrations ranged from 20 to 158 tritium units. Concentrations in Rainbow Springs and Silver Springs during this period ranged from 38 to 85 tritium units and 25 to 150 tritium units, respectively. A 1- to 2-month lag existed between the tritium concentration peak in annual rainfall and the tritium concentration peak in ground water.

It can be assumed that water from the period 1962–70 has entered the aquifer because Faulkner (1973) found high tritium concentrations in samples from the aquifer during this period. Water containing detectable tritium had not discharged completely from the system by 1987 because flow velocities are not high enough for water to have traveled the length of most flow paths in 35 years. Dispersion and diffusion could reduce the tritium concentration in the aquifer, and mixing of recent (high tritium) water with older (low tritium) water in the open-hole section of the aquifer during pumping is also a possibility. Because the 9 years (1962–70) when the highest tritium concentrations entered the ground-water system represent a short period of time and a small amount of recharge relative to the total aquifer storage, this zone of water could easily be obscured during sampling. In the southern part of the study area, water having high tritium concentrations would not be expected to have reached the Upper Floridan aquifer, but probably could be found in the intermediate aquifer system or other overlying units.

Deuterium and Oxygen–18

Deuterium (^2H) and oxygen–18 (^{18}O) are two stable isotopes commonly used in hydrologic studies. These stable isotopes do not undergo radioactive decay, but because of the difference in mass between them and the more common isotopes of their respective elements, protium (^1H) and oxygen–16 (^{16}O), they react differently with other atoms and molecules as they move through the hydrologic system. The higher mass of deuterium and oxygen–18 causes them to bond more tightly in molecules (including water), thus requiring more energy to break the bonds when these molecules participate in chemical reactions. Consequently, these two isotopes become enriched in the reactants of chemical reactions requiring energy.

One of the most important reactions in the hydrologic cycle is the evaporation of water into the atmosphere; the evaporated water eventually forms into clouds and rain. Deuterium and oxygen–18 do not evaporate as readily as the lighter isotopes and, therefore, are concentrated in seawater relative to atmospheric or cloud water vapor. When it rains, the same mechanism works in reverse, and deuterium and oxygen–18 are concentrated in rain relative to clouds because they bond more readily than protium and oxygen–16.

Deuterium and oxygen–18 ratios are reported as delta values in units of parts per thousand, or permil (o/oo), relative to an arbitrary standard called Standard Mean Ocean Water (SMOW) (Craig, 1961). This ratio is calculated as follows:

$$\text{delta } X\,(\text{o/oo}) = \left(\frac{R_X}{R_{\text{standard}}} - 1\right)1000,$$

where R_X and R_{standard} are $^2H/^1H$ or $^{18}O/^{16}O$ of the sample and standard, respectively. Delta deuterium and delta oxygen–18 values used in hydrogeologic studies are usually negative because of the initial isotopic depletion on evaporation from the ocean. For example, an oxygen sample that is -50 o/oo is depleted in oxygen–18 by 5 percent, or 50 o/oo, relative to the standard; the sample is isotopically "light" relative to the standard. The process in which the heavier isotopes are separated from the lighter ones during chemical reactions is called fractionation. Oxygen and hydrogen isotopes fractionate at approximately the same rate in the same reaction, and delta deuterium and delta oxygen–18 values usually are highly correlated within a system.

A high correlation exists between delta deuterium and delta oxygen–18 in the Upper Floridan aquifer (fig. 21). Seven rain samples also were collected and analyzed for these isotopes. They show a much greater variability than the ground water (Gat, 1971). The line formed by delta deuterium as a function of delta oxygen–18 values in ground water also passes close to the origin, which is the value of SMOW. This can be explained by the proximity of the study area to the Gulf of Mexico. Most rain that falls in the study area originates as evaporation from the gulf. Because it has

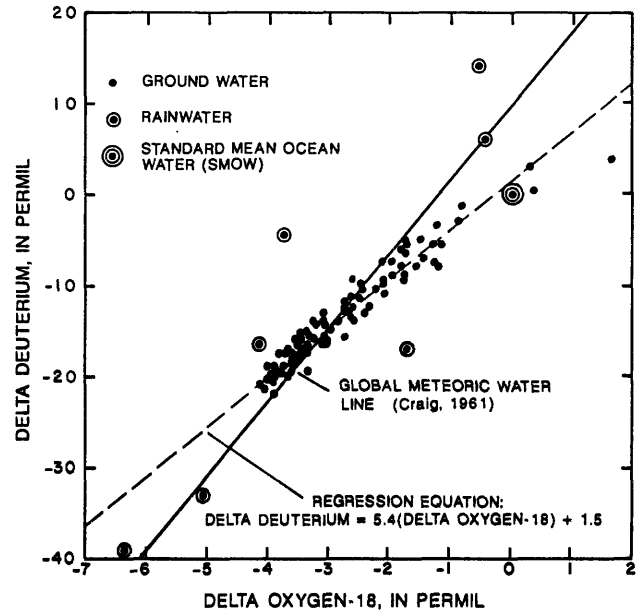

Figure 21. Relation of delta deuterium and delta oxygen–18 for ground water and rain samples.

been through only one evaporation-condensation cycle, it is only slightly depleted compared to seawater. The global meteoric water line shown in figure 21 is an average of delta deuterium and delta oxygen–18 values in global precipitation and freshwater.

The distribution of delta deuterium in the Upper Floridan aquifer is shown in figure 22. Because delta deuterium and delta oxygen–18 are highly correlated, the distribution of delta oxygen–18 is very similar to that of delta deuterium. A regional trend is apparent; ground water in the southern part of the study area is enriched in deuterium and oxygen–18 relative to ground water in the northern part. Ground water with enriched delta deuterium and delta oxygen–18 values corresponds to water with little or no tritium.

Delta deuterium and delta oxygen–18 have been used to date waters between 1,000 and 40,000 years old because long-term climatic changes are reflected in delta deuterium and delta oxygen–18 values (Buchardt and Fritz, 1980). The utility of isotopic dating with deuterium and oxygen–18 for younger water samples has not been determined. There are no widely used isotopic dating methods for ground water between 100 and 1,000 years old (Coplen, 1993). In the seven ground-water samples that included carbon–14 analysis, the more depleted deuterium ratios corresponded to a greater percent modern carbon. Unfortunately, carbon is not a conservative constituent in a carbonate aquifer, and carbon–14 analysis is beyond the scope of this study.

Statistical Relations Among Chemical Constituents

Statistical methods were used to investigate the relations between water-quality constituents, particularly between isotopes and more widely available analyses. Isotope analyses are relatively expensive, and it was hoped that other types of data could provide the same information if other constituents were highly correlated with the isotopes.

Most statistical methods assume that the data follow a normal distribution. Prior to statistical analysis, the distributions of the concentrations of chemical constituents were investigated to determine which constituents had normally distributed concentrations and which might require transformations of the data to normalize the distribution. Graphical methods used to describe the data were box plots and stem and leaf diagrams (Kleiner and Graedel, 1980). Both of these methods provide a quick estimation of the distribution of a data set and the efficiency of a transformation.

The distributions of calcium, pH, alkalinity, deuterium, and oxygen–18 in the Upper Floridan aquifer were normal. The distributions of nitrate plus nitrite, orthophosphate, magnesium, sulfate, silica, iron, and specific conductance were log normal. The best transformation for sodium, chloride, and strontium was a reciprocal root transform (-1/2 power). Tritium (fig. 19), dissolved oxygen, and Eh had bimodal distributions.

Correlation and Regression

The highest correlations among chemical constituents were between sodium and chloride (correlation coefficient, r=0.95) and delta deuterium and delta oxygen–18 (r=0.97; see fig. 21). Sodium and chloride would be expected to be highly correlated because they are both conservative in a carbonate aquifer and their ratio is derived from seawater. Delta deuterium and delta oxygen–18 are usually correlated because of the fractionation process.

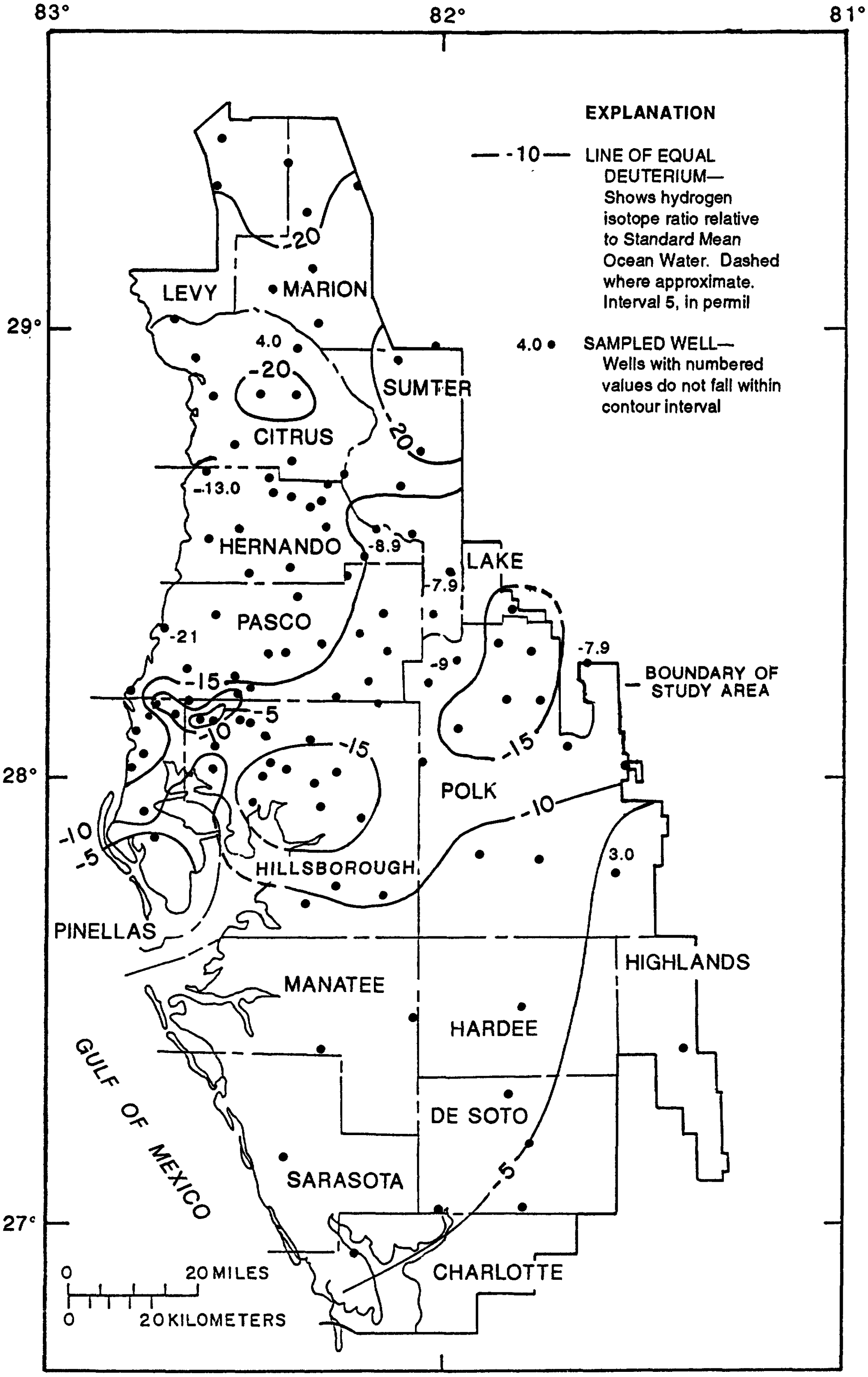

Figure 22. Delta deuterium in water from the Upper Floridan aquifer.

The regression equation describing the relation between delta deuterium and delta oxygen–18 is of interest because it can be compared to the global meteoric water line (Craig, 1961). The global meteoric water line represents an average of deuterium and oxygen–18 ratios in rain from around the world. The equation for the global meteoric water line is

delta deuterium=8(delta oxygen–18)+10.

The equation for water in the Upper Floridan aquifer is

delta deuterium=5.4(delta oxygen–18)+1.5.

The lower slope of the regression line representing the relation between delta deuterium and delta oxygen–18 in water from the Upper Floridan aquifer probably reflects the effects of evaporation (Gat, 1971). Evaporation, either directly from rain or from surface water, causes preferential enrichment of delta oxygen–18 relative to delta deuterium. The delta deuterium intercept of the relation representing water from the Upper Floridan aquifer also is lower than that of the global meteoric water line (fig. 21). Because the source of most rain in west-central Florida is the Gulf of Mexico, the delta values of deuterium and oxygen–18 in rain in the study area are closer to SMOW than the values in rain farther inland.

The sources of variability for tritium are distinctly different from other chemical constituents. Tritium concentrations in rain have changed through time because of the onset and cessation of atmospheric nuclear weapons tests. Other chemical constituents vary within the hydrologic system because of chemical and biological reactions and climate changes. The tritium concentrations provided unique information about the age of water in the Upper Floridan aquifer, but because the distribution of tritium is bimodal, regression analysis is not appropriate.

An alternative way to examine the variation of chemical constituents in relation to tritium was facilitated by the bimodality of the data set. Dividing the samples into two groups of high (>5 tritium units) and low (<5 tritium units) tritium concentrations, a T-test was done to see if significant differences existed between the means of chemical constituents in the two groups. Significant differences were found for the following variables at an alpha level of 0.05 (95-percent probability that there is a significant difference between the means of the two groups): dissolved oxygen, silica, nitrite plus nitrate, potassium, delta oxygen–18, delta deuterium, magnesium, and Eh. High tritium in the Upper Floridan aquifer corresponded to higher dissolved oxygen, nitrate plus nitrite, and Eh and lower silica, potassium, magnesium, delta deuterium, and delta oxygen–18.

Factor Analysis

Factor analysis is a multivariate statistical technique used to interpret large data sets by analyzing linear combinations of correlated variables that are mapped onto new, uncorrelated variables called factors. The factors are independent orthogonal axes in *n*-dimensional space, where *n* is the number of variables. When analyzing geochemical data, the factors are assumed to represent hydrogeologic and geochemical processes that control the distribution of chemical constituents within a system (Lawrence and Upchurch, 1980). To clarify the explanation of factor analysis, we can use an example in which a hypothetical factor A represents the process of saltwater intrusion into the Upper Floridan aquifer in coastal areas.

Each variable in the data set is related to each factor by a coefficient called the factor loading. The higher the factor loading, the more important the variable is in the process represented by the factor. For factor A, sodium and chloride are variables that would have high loadings because the concentration of these constituents is directly related to the presence of saltwater in the aquifer. The sum of squares of the factor loadings for an individual factor is the eigenvalue for that factor. The eigenvalue of a factor is a measure of the amount of variability of the whole data set that is explained by the factor.

In an area where saltwater intrusion is the dominant process affecting ground-water chemistry, the eigenvalues for other factors would be low or insignificant. When the loadings are combined with the original data set, factor scores can be calculated for each observation. These scores indicate the intensity of the process represented by the factor for that observation. In the example being considered, areas where saltwater intrusion was greatest would have the highest scores on factor A. For this study, each observation is a well, so the intensity of the processes represented by factors can be mapped using the factor scores.

The mathematical derivation of factor analysis has been described by Koch and Link (1971), Klovan (1975), and Davis (1986). The method used for this study was R-mode principal factor analysis that included varimax rotation. The rotation either maximizes or minimizes factor loadings, which simplifies the interpretation. Factors were extracted from a normalized data set. Constituents whose concentrations had log normal or other distributions were transformed before the factor analysis. Factors with eigenvalues greater than 1 were considered significant (Davis, 1986), but an additional factor with a lower eigenvalue was subsequently included because the system was more accurately represented by adding the additional factor.

Four factors explained 99 percent of the variance in the data set containing the variables listed in table 2. The amount of variability in the data set that is explained by each factor is listed in table 2 as "percent of total variability." The percent of total variability is the sum of squares of the factor loadings for each factor (columns). Similarly, the amount of variability of each variable, or constituent, that is explained by the factor analysis is listed as the communality. The communality is the sum of squares of the factor loadings of each variable (rows). Variables are repeated in the table if they load significantly on more than one factor. A variable such as specific conductance reflects more than one process, and therefore, it loads on more than one factor.

Table 2. Variables and factor loadings for chemical constituents after varimax rotation

Variable	Percent communality	Factor loadings			
		I	II	III	IV
Factor I					
Sodium[1]	94.7	0.88	0.20	0.21	0.30
Chloride[1]	94.7	.85	.19	.11	.37
Potassium[2]	71.8	.72	.31	.27	-.08
Magnesium[2]	70.7	.59	.57	.28	.02
Specific conductance[2]	81.5	.58	.54	.17	.49
Silica[2]	61.8	.43	.20	.40	.03
Factor II					
Fluoride	70.5	.28	.78	.25	-.07
Calcium	68.2	.08	.69	.08	.46
Sulfate[2]	59.3	.41	.62	-.11	-.24
Magnesium[2]	70.7	.59	.57	.28	.02
Specific conductance[2]	81.5	.58	.54	.17	.49
Factor III					
Oxygen–18	96.9	.15	.05	.95	.08
Deuterium	96.9	.23	.13	.94	.05
Factor IV					
pH	73.5	-.05	-.01	.00	-.85
Alkalinity	73.5	.21	-.04	.09	.84
Specific conductance[2]	81.5	.58	.54	.17	.49
Calcium	68.2	.08	.69	.08	.46
Eigenvalues before rotation		5.82	1.87	1.55	0.80
Percent of total variability		57.4	18.5	15.2	7.9
Cumulative percent of total		57.4	75.9	91.1	99.0

[1] Reciprocal root transform. [2] Log transform.

Factor I is interpreted as a mixing of water in the Upper Floridan aquifer with saltwater. Variables with high loadings on factor I are sodium, chloride, potassium, specific conductance, and to a lesser degree, silica. A map of the distribution of factor scores for factor I is shown in figure 23. High factor I scores generally reflect both the proximity to the coast and ground-water discharge areas. Low factor I scores occur in areas of high recharge to the aquifer.

Factor II represents the chemical changes in the water, independent of saltwater mixing at the coast, that occur in the Upper Floridan aquifer along confined flow paths. Factor II has high loadings on the variables fluoride, calcium, sulfate, magnesium, and specific conductance. The distribution of factor II scores is shown in figure 24. Highest factor II scores occur near the ends of regional confined flow paths in the southern part of the study area.

Factor III represents the recent age of the ground water. This factor has high loadings on the variables delta deuterium and delta oxygen–18. Relatively young waters have low scores on factor III, and older waters have high scores. The distribution of factor III scores is shown in figure 25. Areas where delta deuterium and delta oxygen–18 are high (enriched) have high scores on this factor. These areas also typically have low tritium values (less than 1 tritium unit), indicating waters at least 35 to 70 years old. Areas where the Upper Floridan aquifer is fully confined have higher factor III scores. The Green Swamp also has moderately high scores on this factor.

Factor IV is comparable to the first factor described by Lawrence and Upchurch (1980), which represents ground-water flow rates and limestone dissolution. This factor accounts for the variability of pH and alkalinity and half of the variability of calcium. Specific conductance loads onto this factor, as well as factors I and II, because all these factors reflect ionic strength. Areas of low factor IV scores correlate with zones of rapid ground-water movement along karst conduits. In these areas, limestone dissolution would be less than maximum. High scores on this factor occur in areas of higher alkalinity where flow is slower and ground water is closer to equilibrium with respect to calcite. The distribution of factor IV is shown in figure 26. Transmissivity values used by Ryder (1985) to model the Floridan aquifer system are lowest in most of the high factor IV areas. Low transmissivity values also indicate relatively low rates of ground-water flow.

POTENTIAL FOR CONTAMINATION OF THE UPPER FLORIDAN AQUIFER

At each location in the Upper Floridan aquifer there exists a slightly different combination of physical factors, such as depth to water, confining-unit thickness, and overburden lithology. If an estimate of potential for contamination is based on physical controls on ground-water flow, the assessment relies on assumptions about how these controls affect recharge to the aquifer. Each of these controls has a different and typically interrelated effect on the recharge rate.

The variation in ground-water chemistry within an aquifer can be a more direct measure of potential for contamination than methods based on physical aspects of the hydrologic system. Ground-water chemistry also is influenced by physical processes that affect the length of time water is in contact with aquifer and overburden materials. The changes in water chemistry that occur as water moves through the unsaturated zone and into the aquifer are a result of the reactions occurring along the recharge path. Assuming that samples are representative, the type and concentration of chemical constituents in the sample reflect conditions that exist in the aquifer. We can gain insight into the mechanics of the flow system by looking at the end result of the physical processes controlling recharge, rather than trying to define these processes and their effect on water quality independently.

Indicators of Potential for Contamination

A useful chemical indicator of potential for aquifer contamination is one that is sensitive to changes in the age of ground water, recharge rates, or aquifer residence times. Water that has entered the aquifer most recently is the youngest in age and is considered to have the highest potential for contamination. Aquifer recharge rates also are directly related to potential for aquifer contamination. A constituent that has high concentrations in an area of high aquifer recharge, and also has low concentrations in an area of low recharge, is assumed to be a good indicator of potential for contamination. Constituents that reflect aquifer residence times can reflect potential for contamination because longer aquifer residence times indicate lower flows in the aquifer and, therefore, reduced movement of contaminants. Constituents that reflect other processes, such as saltwater mixing and changes in aquifer mineralogy, are not useful indicators of potential for contamination because these processes are not related to rates of flow into or through the aquifer.

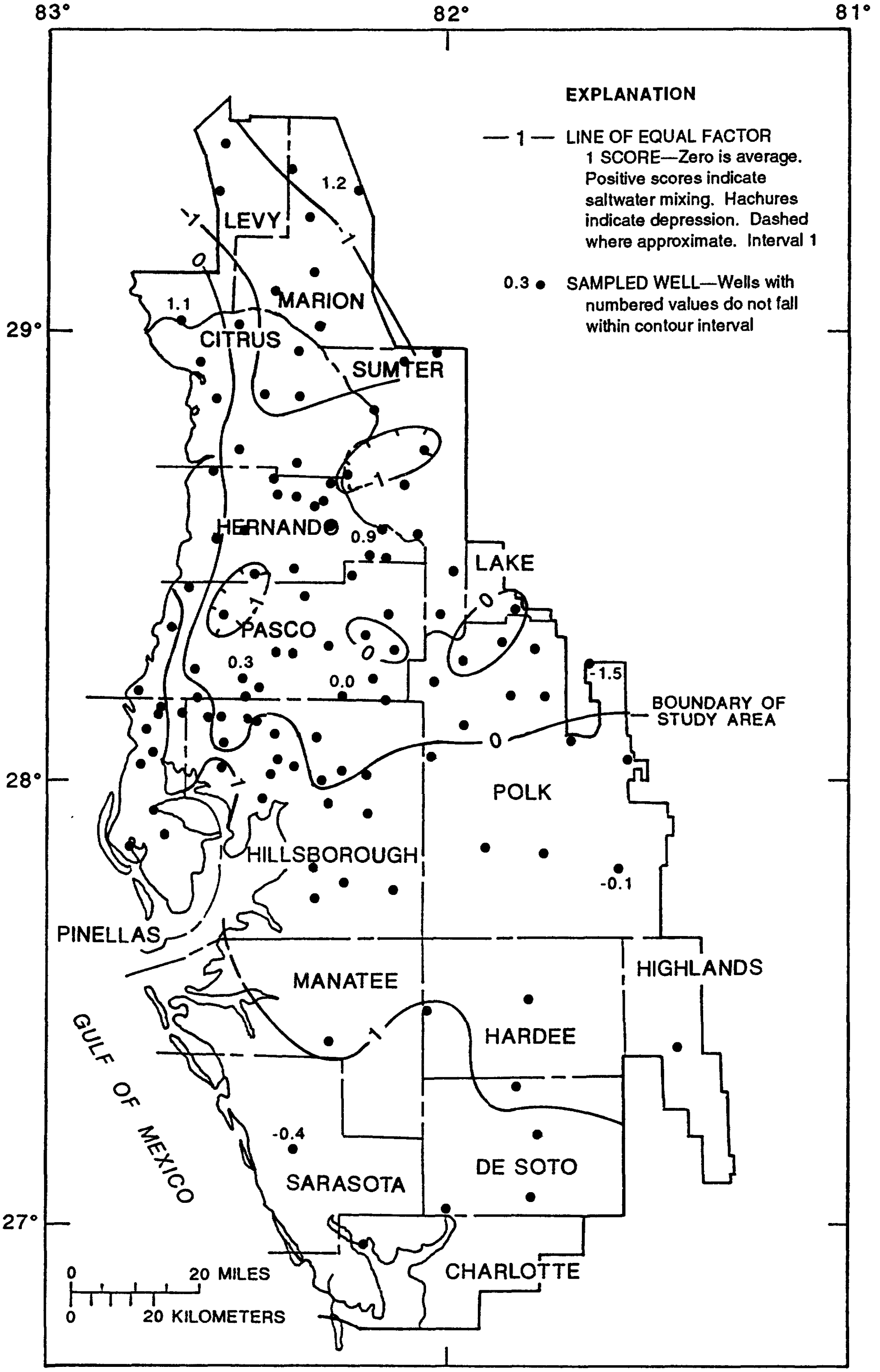

Figure 23. Distribution of factor I scores representing saltwater mixing.

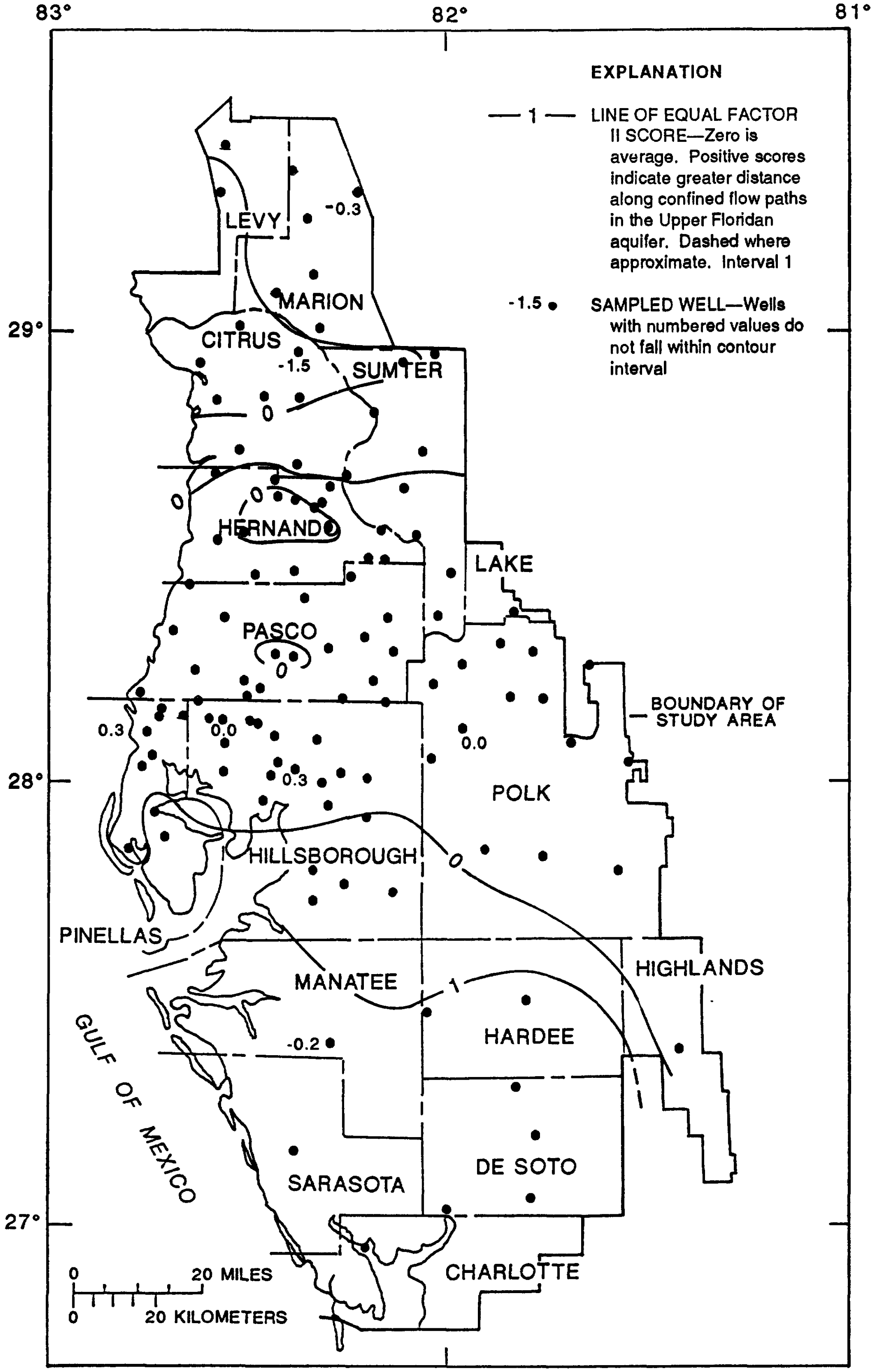

Figure 24. Distribution of factor II scores representing ground-water evolution along flow paths.

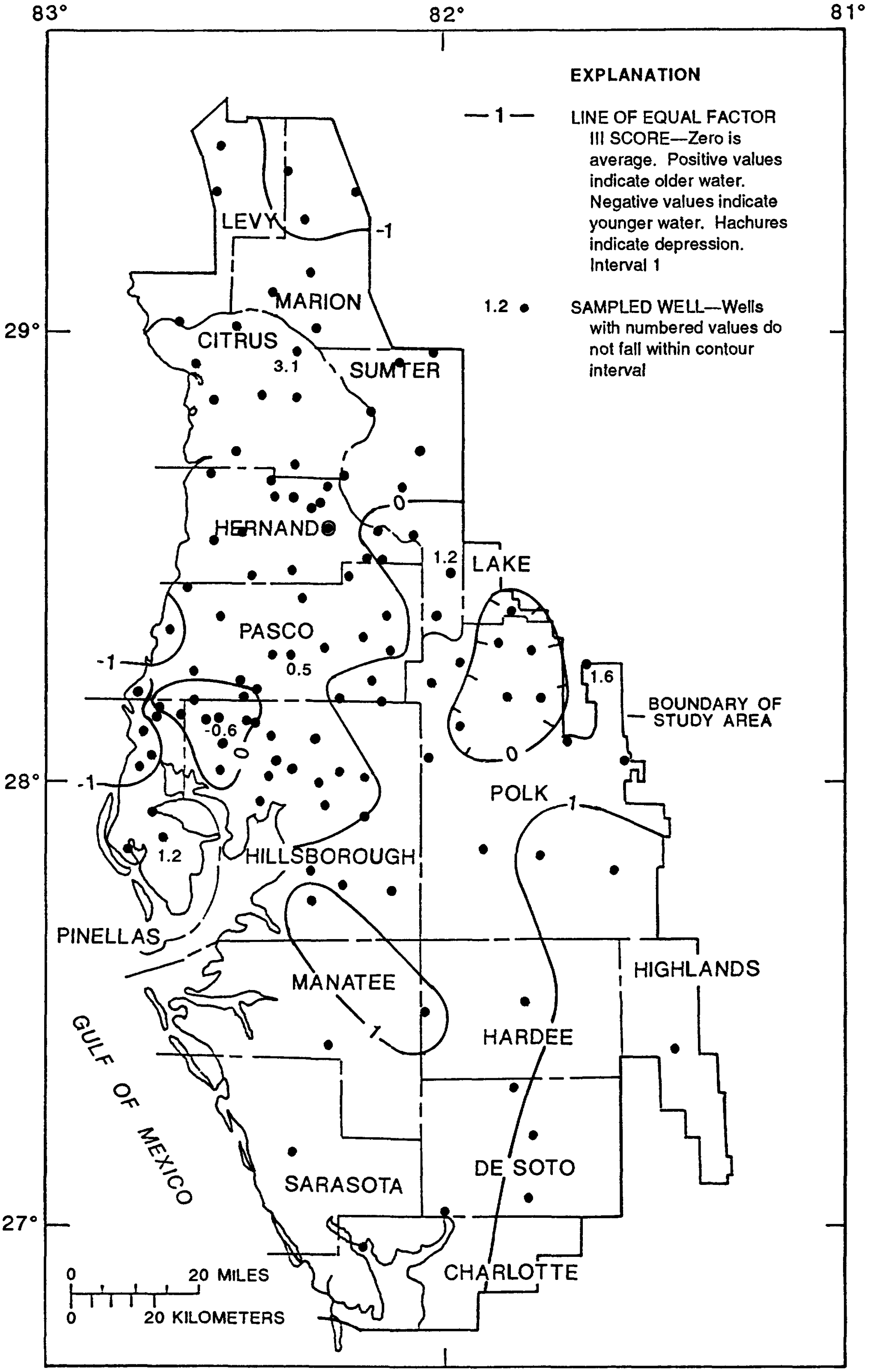

Figure 25. Distribution of factor III scores representing ground-water age.

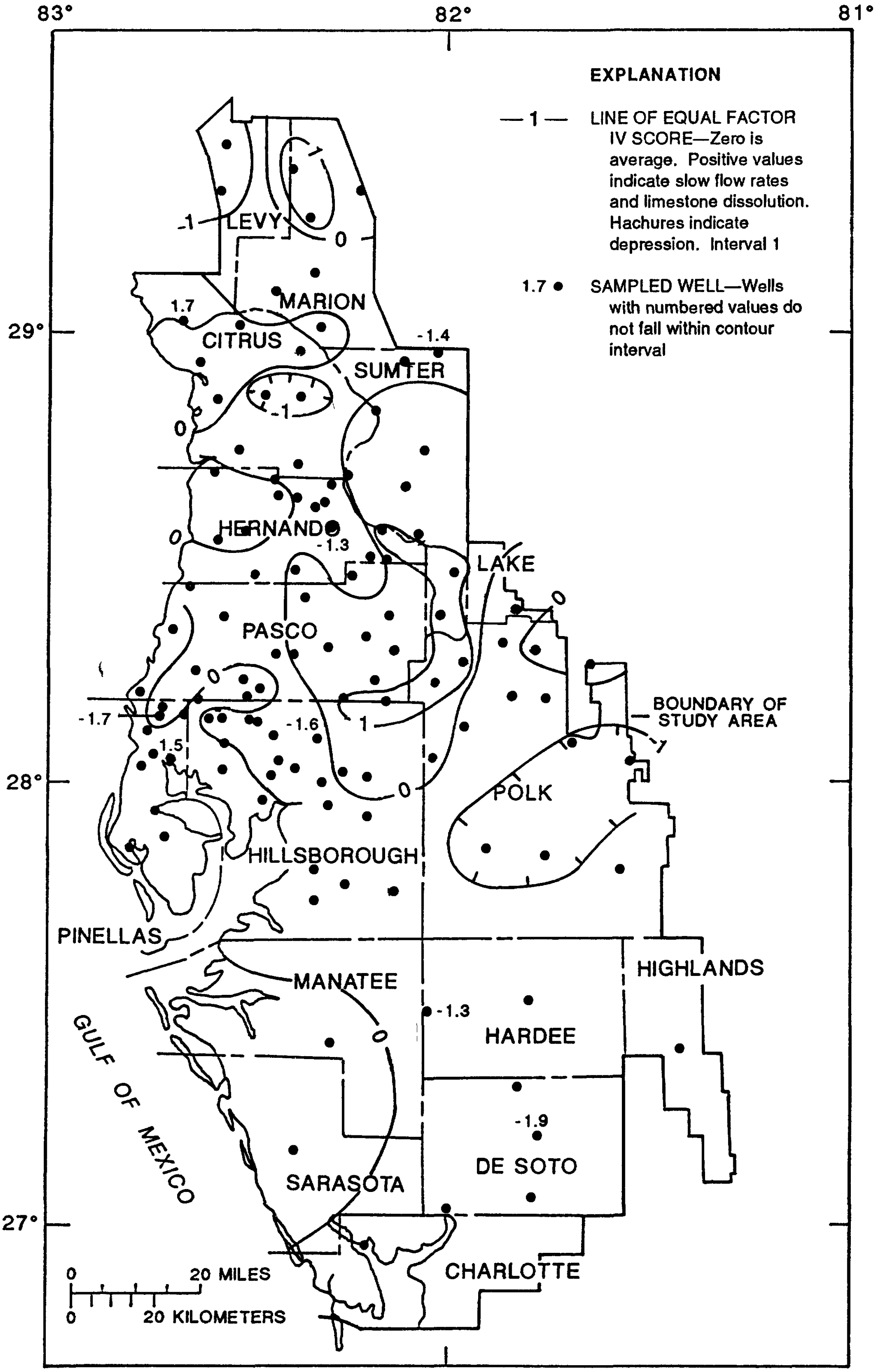

Figure 26. Distribution of factor IV scores representing ground-water flow rates and limestone dissolution.

Tritium

Isotopes are uniquely useful for determining the age of ground water because they provide a reference point in time. Tritium is a good indicator of ground-water age in the Upper Floridan aquifer. High tritium concentrations in water from the top part of the Upper Floridan aquifer indicate relatively young water and a high potential for contamination. Water that fell as rain before 1953 had low background tritium concentrations, which are currently even lower because of radioactive decay. Water that infiltrated into the ground-water system after 1953 has measurable tritium (concentrations greater than 5 tritium units), even after radioactive decay. Ground water with tritium concentrations between 1 and 5 tritium units are mixtures of pre-1953 and post-1953 water.

Pre-1953 tritium concentrations are present in confined parts of the Upper Floridan aquifer, in parts of the Green Swamp, and in central Polk County (fig. 18). Post-1953 tritium concentrations were found in unconfined and semiconfined parts of the aquifer, except for those areas of the Green Swamp already mentioned. Ground water containing a mixture of pre-1953 and post-1953 water was uncommon, but is present in west-central Polk County and at the approximate boundary between confined and semiconfined parts of the aquifer.

Deuterium and Oxygen–18

Water in the Upper Floridan aquifer that has low tritium concentrations also was found to be enriched in deuterium and oxygen–18. Ground water that has high concentrations of tritium (greater than 5 tritium units) typically is depleted in deuterium and oxygen–18. Because of the relation between the stable isotopes and tritium, which is known to be an indicator of the age of ground water, delta deuterium and delta oxygen–18 variations may be a good index of potential for contamination. However, the mechanisms controlling the distribution of deuterium and oxygen–18 in the aquifer are not well understood. Unlike tritium, the historical input of these isotopes from rain is not available for this area. Climate, latitude, elevation, and evaporation, among other processes, control the fractionation of stable isotopes. Before deuterium and oxygen–18 ratios can be effectively interpreted, the variation in these processes with time must be known, along with their effect on isotope fractionation. It is also possible that the distribution of the stable isotopes is unrelated to the age of ground water and that the correlation with tritium is due to geography or other factors.

Despite these limitations, the proportions of deuterium and oxygen–18 in the Upper Floridan aquifer may be a potential method for dating ground water. A limitation to the use of tritium is the maximum age limit of 70 years. Additional study of the relation of stable isotopes to radioactive ones, especially carbon–14, would be enlightening.

Dissolved Oxygen

Dissolved oxygen (DO) exists in an aquifer because there is little oxidizable material coming in contact with the water as it infiltrates. This is typical of arid regions (Rose and Long, 1988) but unusual for the humid climate that exists in west-central Florida, where the combination of heat and humidity produces an active plant and animal community capable of rapid oxygen uptake. Dissolved oxygen is also a reactant in many inorganic oxidation reactions involving polyvalent species such as iron, sulfur, and other metals.

In the study area, DO would be expected to be removed before infiltrating water reached the aquifer because of the processes just described. This is true for most of west-central Florida, with the exception of some areas of high recharge to the aquifer or areas internally drained through sinkholes (Trommer, 1987). Ground water containing DO occurs in the areas of high recharge in Pasco, Hernando, Citrus, and Marion Counties (see figs. 9 and 16). This water also typically has low dissolved solids, low alkalinity, and low P_{CO_2} making it closer in composition to rainwater than other water sampled in the Upper Floridan aquifer. High concentrations of DO in water from the top part of the Upper Floridan aquifer are a useful indicator of recently recharged water and a high potential for contamination from the surface. Within an area already described as having a high potential for contamination, the appearance of DO in ground water indicates an even greater susceptibility of the aquifer to contamination.

Dissolved Carbon Dioxide

Carbon dioxide is produced by respiration of soil microorganisms and roots. Well-developed soils in wetland areas of northern west-central Florida contribute P_{CO_2} to water as it flows downward into the aquifer. High P_{CO_2} was found in areas of low recharge

Table 3. DRASTIC parameters, weights, ranges, and ratings for the Upper Floridan aquifer

[in/yr, inch per year; [(gal/d)/ft^2], gallon per day per foot squared; <, less than; >, greater than. From E. DeHaven, Southwest Florida Water Management District, written commun., 1988]

Parameter	Weight	Range	Rating
D, Depth to water (feet)	5	0–5	10
		5–15	9
		15–30	7
		30–50	5
		50–75	3
		75–100	2
		100+	1
R, Net recharge (in/yr)	4	0–2	1
		2–4	3
		4–7	6
		7–10	8
		10+	9
A, Aquifer media	3	Karst limestone.	10
S, Soil media	2	Phosphate mines, soil thin or absent.	10
		100 percent fine sand.	9
		Fine sand and 15 percent sandy clay.	8.5
		Fine sand and <50 percent loamy fine sand.	8
		Fine sand and <50 percent swamp, marsh, and (or) muck.	7.5
		Fine sand and >50 percent loamy sand.	7
		Sandy clay and sandy clay loam.	4
		Fine sand and >50 percent swamp, marsh, and (or) muck.	2
T, Topography (percent of slope)	1	0–2	10
		2–6	9
		6–12	5
I, Impact of the vadose zone	5	Confined	1
		Unconfined—Vadose zone thin to absent.	10
		Sand and <25 feet clay.	8
		Sand and 25–50 feet clay.	6
		Sand and 50–100 feet clay.	4
		Semiconfined—Thickness of confining bed, in feet.	
		<25	8
		25–50	6
		50–100	4
		100–150	3
		150–200	2
		200+	1
C, Hydraulic conductivity [(gal/d)/ft^2]	3	1–100	1
		100–300	2
		300–700	4
		700–1,000	6
		1,000–2,000	8
		2,000+	10

and discharge of the unconfined Upper Floridan aquifer. The combination of fine-grained soil particles and a reduced downward head gradient inhibits recharge from the surface in wetlands. Because high P_{CO_2} in ground water indicates reduced recharge in the study area, areas where it occurs have relatively lower potential for contamination than surrounding areas where the ground water has equivalent tritium concentrations.

DRASTIC Index

A method that assimilates available data on physical aspects of a hydrogeologic setting to evaluate ground-water contamination potential was developed by the National Water Well Association under a cooperative agreement with the U.S. Environmental Protection Agency (Aller and others, 1985). In this method, called DRASTIC, each aspect is weighted according to its importance in defining contamination potential (called "pollution potential" in the original version), and the weighted values are summed to produce a DRASTIC index that can be mapped. The index can be used to compare the relative potentials for contamination of different areas. The aspects of the hydrogeologic setting that are used in the method are shown in table 3, along with their weights.

DRASTIC was applied to the Upper Floridan aquifer in the Ambient Ground Water Quality Monitoring Program of the Southwest Florida Water Management District. The DRASTIC maps are presented, by county, in a series of reports (Southwest Florida Water Management District, 1987). DRASTIC maps of the Upper Floridan aquifer were not published for Manatee, Hardee, Highlands, Sarasota, Charlotte, and

De Soto Counties. DRASTIC indices for these areas are very low because of the more than 200-ft thickness of the intermediate aquifer system. A DRASTIC map of Levy County had not been completed at the time of this study.

The application of the DRASTIC method to west-central Florida is described in the following paragraphs. Numerical ratings for individual DRASTIC aspects of a hydrogeologic setting were assigned so that high ratings indicate a high potential for contamination.

DRASTIC ratings vary depending on the degree of confinement of the aquifer. For the DRASTIC maps, the Upper Floridan aquifer was mapped as a confined aquifer in areas where the depth to the top of the aquifer is 100 ft or more (Miller, 1986) and as an unconfined aquifer where it is under water-table conditions (Moore and others, 1986). The remaining areas were mapped as semiconfined. These divisions are very similar to the ones shown in figure 6 of this report.

Depth to water in areas where the aquifer is unconfined was considered to be the distance from land surface to the water table (Barr, 1985). For areas where the aquifer is confined and semiconfined, the distance from land surface to the top of the Upper Floridan aquifer was used (Buono and Rutledge, 1979). Net recharge to the aquifer was taken from Ryder (1985) and Adams (1985) and regrouped according to the ranges and ratings in table 3. Areas where the Upper Floridan aquifer discharges are rated in the lowest range. There is no provision in DRASTIC for dealing with areas of aquifer discharge as such, and it is assumed that gradient reversals could change conditions of discharge to recharge. This has occurred in southwest Hillsborough and western Manatee Counties because of heavy irrigation pumping (Kaufman, 1967). Contamination potential is inversely related to depth to water and directly related to recharge.

The aquifer medium is considered to be the same throughout the study area, that is, karst limestone. Consequently, the variation in this aspect has no effect on the DRASTIC index of the Upper Floridan aquifer in west-central Florida. Variation in aquifer media would be important if the DRASTIC indices for this area were compared with another region with a different aquifer medium. Soil types and topography, in the form of percent slope estimates, are taken from the Florida General Soil Atlas and County Soil Surveys (Florida Department of Administration, 1975). As soil grain size decreases, so does contamination potential because of the ability of silts and clays to impede ground-water flow. Lower percent slopes indicate higher contamination potential in DRASTIC.

The effect of the unsaturated zone (called "impact of the vadose zone" in the original version) is an important aspect that describes the nature of the materials overlying the aquifer. In areas where the Upper Floridan aquifer is confined, the effect of the unsaturated zone is given the lowest possible value (1). In areas where the aquifer is semiconfined and unconfined, the effect of the unsaturated zone is a function of the thickness of the clay bed or confining unit (Buono and others, 1979; Wolansky and others, 1979; Fretwell, 1985, for Hernando County only). Hydraulic conductivity values were calculated by dividing Ryder's (1985) transmissivity values by the thickness of the Floridan aquifer (Wolansky and Garbade, 1981), then grouping the values according to the DRASTIC ranges. Contamination potential is directly related to hydraulic conductivity and inversely related to the effect of the unsaturated zone.

The DRASTIC indices calculated by the Ambient Ground Water Monitoring Program for the areas around the wells sampled are listed in appendix C and contoured in figure 27. County DRASTIC maps produced by the Southwest Florida Water Management District (1987) are more complex than as shown in figure 27 because they are subdivided by soil type, but figure 27 accurately shows the general trends of the DRASTIC index in each county. The DRASTIC maps in the Southwest Florida Water Management District reports appear to be very detailed because of the subdivision into areas defined by different soil types. It should be recognized, however, that the most highly weighted aspects, depth to water and effect of the unsaturated zone, are derived from regional maps with less detail than the soil maps. A regional DRASTIC map is not available because DRASTIC indices for Hernando County were calculated using a different reference for the effect of the unsaturated zone. Differences in the overall index between Hernando and surrounding counties are not apparent in figure 27, and for this study, the DRASTIC indices will be considered consistent throughout the study area.

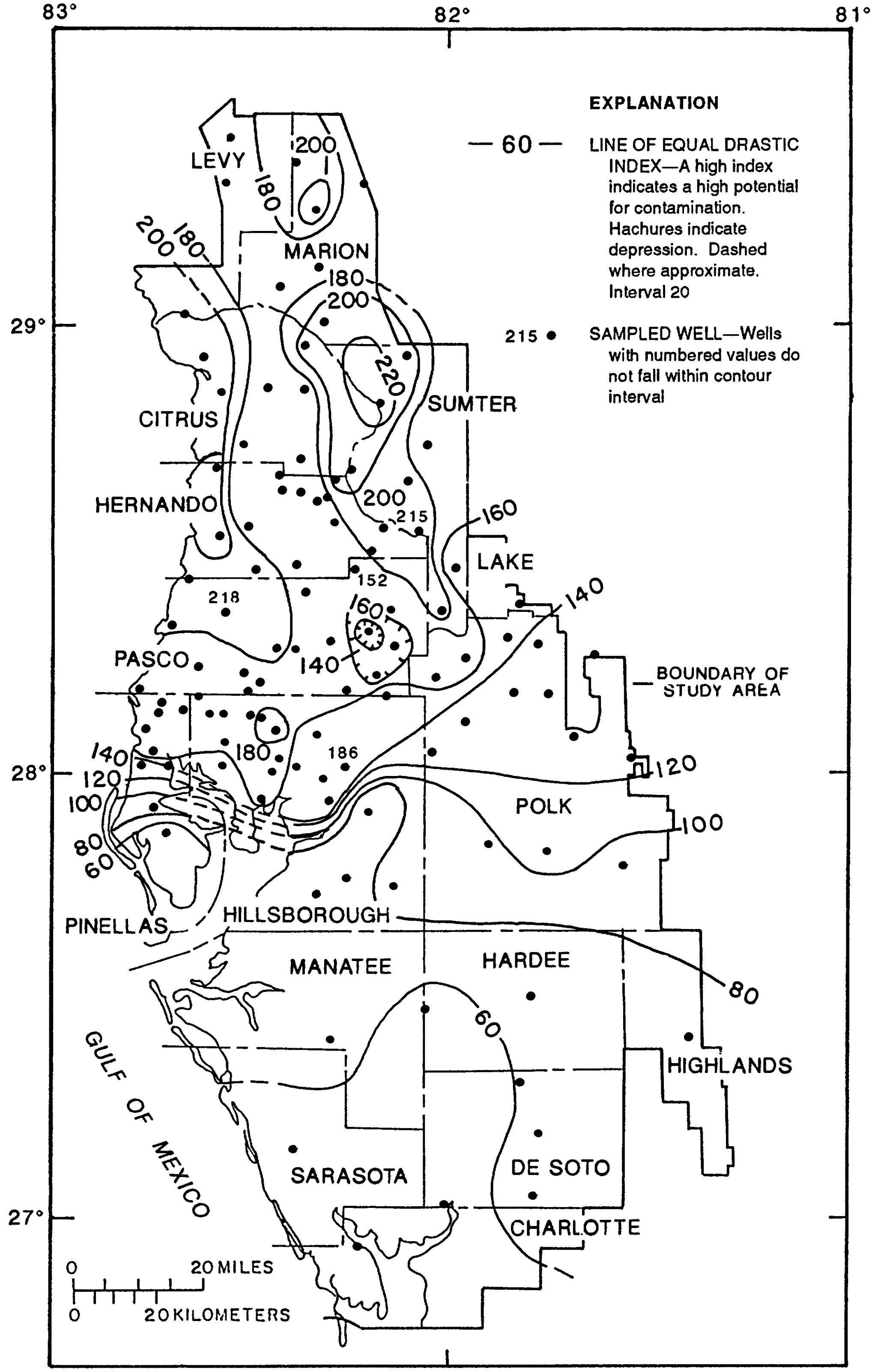

Figure 27. DRASTIC indices for areas around sampled wells (from Southwest Florida Water Management District, 1987).

Classification of Potential for Contamination From Land Surface

Very Low Potential

The potential for contamination of the Upper Floridan aquifer was classified using data on the chemical constituents tritium and dissolved oxygen, along with existing information on degree of confinement (fig. 28). In Charlotte, Sarasota, De Soto, and the southern parts of Manatee, Hardee, and Highlands Counties, the potential for contamination of the Upper Floridan aquifer is considered to be very low. In these areas, the aquifer is overlain by more than 300 ft of strata of varying, but substantially lower, permeability (the intermediate confining unit or intermediate aquifer system), which functions as an effective barrier to surface contamination (fig. 6). The Upper Floridan aquifer is confined in these areas, and at the northern boundary of the area of very low contamination potential, the flow system is in transition between recharging and discharging conditions (fig. 9).

The change from recharging to discharging conditions also is reflected in the ground-water chemistry. Ground-water types in the area of very low contamination potential are either $CaMgSO_4$ or NaCl, and dissolved-solids concentrations are typically greater than 500 mg/L. Tritium concentrations are less than detection limits. Plummer (1977) used carbon–14 to date waters along regional flow paths in the Floridan aquifer system, finding ages from 3,200 to 36,000 years for waters recharging in the Green Swamp and flowing south. Therefore, tritium concentrations less than the detection limit probably represent ground water considerably older than 70 years.

Low Potential

Pre-1953 tritium concentrations of less than 0.6 tritium units occur in the Upper Floridan aquifer where the intermediate aquifer system is greater than 100 ft thick. In areas where the intermediate aquifer system is between 100 and 300 ft thick, the potential for contamination is considered to be low. Tritium concentrations are greater than the detection limit, but less than 1, indicating that the water is between 35 and 70 years old.

Two areas where the intermediate confining unit is less than 100 ft thick also had low tritium concentrations. The first is the Green Swamp, where the potentiometric surface of the Upper Floridan aquifer is at the highest level in peninsular Florida. Water in seven wells in the Green Swamp area (Pride and others, 1966) had tritium concentrations of 0.2 tritium units or less. Most of the western side of the Green Swamp, the part that lies within the study area, has poor potential for downward leakage to the Upper Floridan aquifer (Grubb, 1977). An area of 270 mi^2 of the Green Swamp that is within the study area has less than 25 ft of unconsolidated sediments overlying the aquifer (Pride and others, 1966). "These limestone outcrop areas have poor potential for downward leakage because the thin or nonexistent unconsolidated sediments there provide little or no storage capacity" (Grubb, 1977). In addition, the potentiometric surface of the Upper Floridan aquifer is at or near land surface, so there is little or no downward head gradient. The combination of low recharge, low downward head gradient, and low aquifer transmissivity probably accounts for the sluggish ground-water flow in the Green Swamp.

The other location in the study area where low tritium values occur in unconfined or semiconfined parts of the aquifer is in northwest Hillsborough County. Low tritium concentrations in this area are probably due to two factors: (1) regional discharge of the Upper Floridan aquifer near Tampa Bay (Stewart, 1980) and (2) upconing of older water around large well fields in this area.

Moderate Potential

Tritium concentrations between 1 and 5 tritium units occurred in 11 water samples from the Upper Floridan aquifer. These waters are assumed to be mixtures of young (post-1953) and old (pre-1953) waters because none of the concentrations in rain, after correcting for radioactive decay, are in this range. Concentrations from 1 to 5 tritium units occur between areas of low and high tritium concentration. Generally, these values occur at the transition between confined and unconfined conditions in the Upper Floridan aquifer. They also occur in some of the areas where the aquifer is confined in Polk County, where numerous solution-pipe sinkholes permit more direct recharge to the aquifer (Sinclair and others, 1985). Areas where the tritium concentrations in water in the Upper Floridan aquifer are between 1 and 5 tritium units are considered to have moderate potential for contamination.

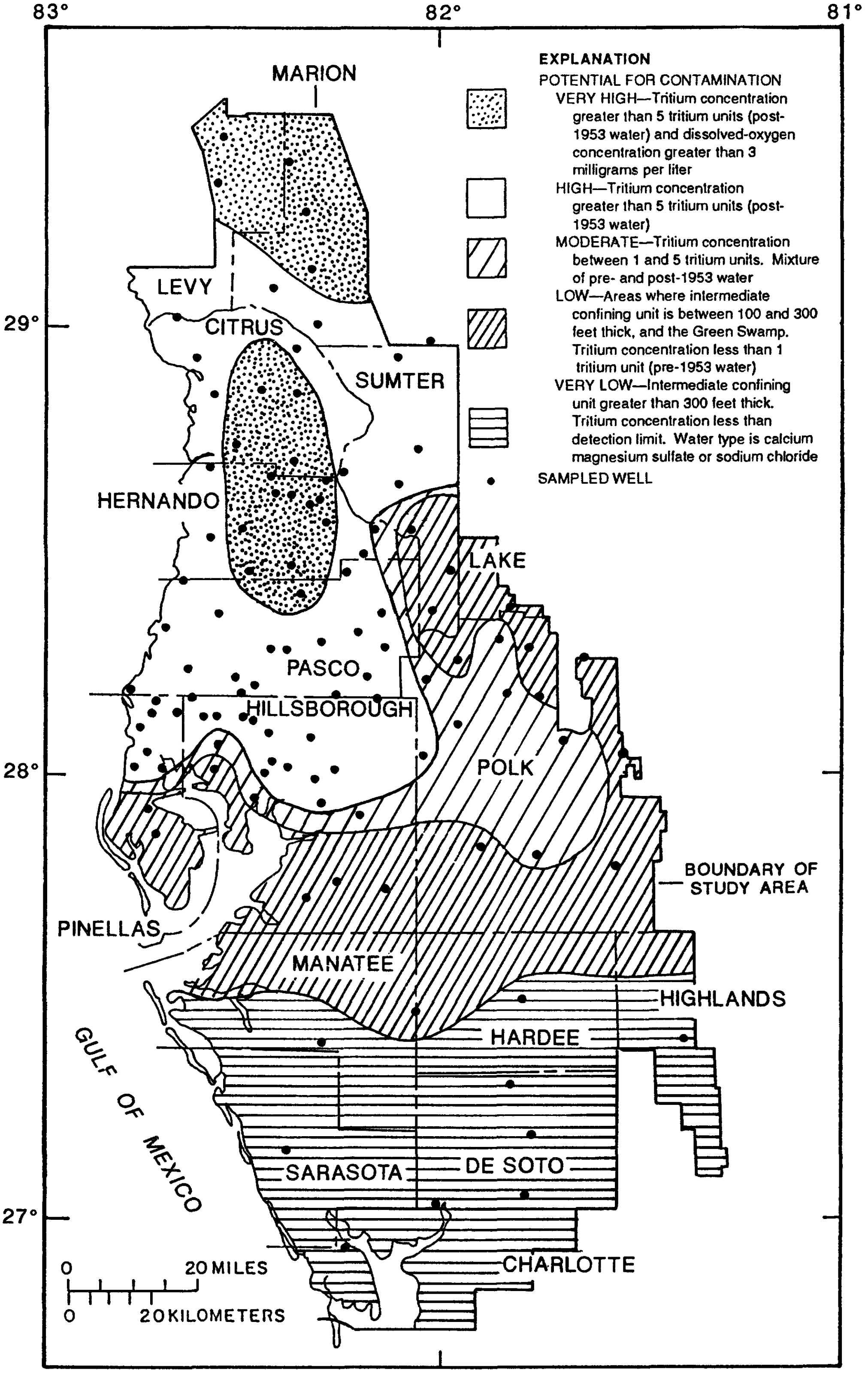

Figure 28. Potential for contamination of the Upper Floridan aquifer.

High Potential

In the northern half of the study area, tritium concentrations in water at the top of the Upper Floridan aquifer are in the range of 5 to 12 tritium units. This range corresponds to the range in annual weighted mean rainfall from 1970 to the present and also for a period in the late 1950's (fig. 17). Ground water with tritium concentrations greater than 5 tritium units can be assumed to have recharged since 1953. Water in the Upper Floridan aquifer with tritium concentrations greater than 5 tritium units is considered to have high potential for contamination.

Very High Potential

Water in the Upper Floridan aquifer along the Brooksville Ridge and in Marion and Levy Counties contains high DO (greater than 3 mg/L), as well as high tritium (greater than 5 tritium units) concentrations. The presence of DO is considered to reflect the high recharge rates of 15 to 20 in/yr in these areas. Because recharge is so high, and because the presence of DO indicates very little interaction of infiltrating water with soils or fine-grained materials that could reduce contaminant migration, the aquifer in these areas is considered to have very high potential for contamination.

Relation of Potential for Contamination to Flow Paths

In a confined system, the potential for contamination is expected to be higher at the origins of regional or local ground-water flow paths and decrease as the water travels downgradient through the aquifer. Potential for contamination decreases downgradient as the opportunities for dilution and absorption of contaminants increase. Flow paths originate in the Green Swamp, in east-central Pasco County in an area known as the "Pasco High," and in the Lake Wales Ridge (figs. 2 and 8). Potentiometric surface lows occur near the west coast. Flow lines fan out from the east-central part of the study area toward the gulf coast.

Potential for contamination does not follow the expected pattern along flow paths in the northern part of the study area where the Upper Floridan aquifer is unconfined or semiconfined. Tritium occurs in water throughout the top of the Upper Floridan aquifer in northern west-central Florida, with the exception of the Green Swamp. Therefore, recharge to the aquifer must be occurring locally west of the Green Swamp. Tritium occurs in ground water under the Pasco potentiometric surface high, an area of recharge to the aquifer west of the Green Swamp.

Flow paths trending south or southwest from the Green Swamp into confined areas of the Upper Floridan aquifer contain water with low tritium concentrations throughout their lengths. Ground water shows geochemical evolution from calcium and bicarbonate as the major ions, to calcium magnesium sulfate types, to sodium chloride sulfate types down these flow paths (Hanshaw and Back, 1979), in addition to the increase in age shown by carbon–14 dating (Plummer, 1977). Potential for contamination decreases down the flow path in confined parts of the aquifer.

The boundary between water of different ages in the Upper Floridan aquifer typically occurs at the boundary between confined and unconfined parts of the aquifer. Mixing between waters of different ages is spatially limited because regional flow through the aquifer is parallel to this boundary.

Relation of Potential for Contamination to Recharge and Discharge

Areas of recharge to an aquifer would be expected to have a higher potential for contamination from the surface than areas of discharge because of the downward flow of water into the aquifer in the former. This is generally true for the Upper Floridan aquifer. The areas of high recharge to the aquifer in the northern part of the study area also have a high potential for contamination, and the area of high recharge in central Polk County has higher potential for contamination than the surrounding areas (see fig. 9).

Areas of recharge to and areas of discharge from the unconfined Upper Floridan aquifer have a high potential for contamination because flow through the aquifer is rapid and flow paths are short. There is no distinction, either chemically or isotopically, between parts of the Upper Floridan aquifer that have previously been defined as either semiconfined or unconfined. The areas of low recharge to and discharge from the aquifer in southern west-central Florida have a low potential for contamination and so does the area of high discharge from the aquifer around Tampa Bay. In Pinellas County, the potential for contamination is related to the degree of confinement rather than recharge-discharge relations. Areas where the aquifer discharges near the Hillsborough, Withlacoochee, Alafia, and

Peace Rivers are not distinguishable by differences in tritium concentration, but some of these areas show small differences in ground-water chemistry, which will be discussed in the following section.

Comparison of Chemical Indicators With DRASTIC Index of Contamination Potential

The highest DRASTIC indices for the study area, which are among the highest possible DRASTIC indices (230 is the maximum), are at the coast in Hernando and Citrus Counties and near the Withlacoochee River in Hernando, Citrus, Sumter, and Marion Counties. DRASTIC indices are high because limestone is at or near the surface; the confining unit is either thin, discontinuous, or absent; and the aquifer water level is very close to the surface. This area also is considered to have a high potential for contamination on the basis of tritium data.

The differences among DRASTIC indices in the northern part of the study area are not consistent with other hydrologic information, however. In the areas where DRASTIC indices are highest, indicating the greatest susceptibility of the aquifer to contamination from the surface, numerous springs discharge hundreds of millions of gallons of water daily. High P_{CO_2} and low DO concentrations indicate an active soil zone capable of degrading many contaminants. Because the water level in the aquifer is at land surface, there is no downward head gradient. The lack of overburden means there is no storage of recharging water. Rain either enters the aquifer directly or flows into streams.

Conversely, the areas with lower DRASTIC indices, such as the northern Brooksville Ridge, have up to 200 ft of overburden, relatively thick confining units, and up to 100-ft depths to water. But despite these physical constraints on ground-water flow, ground water sampled under the Brooksville Ridge is less than 35 years old, has high DO concentrations, low dissolved solids, and low alkalinity. Aquifer recharge is up to 20 in/yr, partly because the overlying sands act as a reservoir for infiltrating rainwater.

In the northern part of the study area, the DRASTIC indices do not agree with the results of the ground-water chemistry analysis. The DRASTIC assumption that all areas where the aquifer discharges are potential areas of recharge does not accurately represent the existing flow system. With enough ground-water development, it is conceivable that the hydraulic gradient could be reversed, but it is unlikely that this will occur, given the present level of awareness of the adverse effects of overdeveloping the ground-water resource. The numerous large springs that discharge from the Upper Floridan aquifer on the west coast of Florida are centers for development, and any reduction in spring flow created by overuse of ground water would be a cause for immediate concern.

The DRASTIC method gives wetlands the highest rating for contamination potential. Although it is important to protect wetland areas for other ecological reasons, the chemical and hydraulic data indicate that the aquifer is relatively less susceptible under wetlands than it is under upland areas. In the Green Swamp, the Upper Floridan aquifer has a lower potential for contamination than would have been predicted by DRASTIC. This is mainly because the Green Swamp is an area of low recharge. There is very little downward head gradient in the Green Swamp and no overlying unit capable of storing potential recharge water.

SUMMARY AND CONCLUSIONS

Water in the top part of the Upper Floridan aquifer is predominantly a calcium bicarbonate type, reflecting the limestone lithology, the lack of confinement over much of the study area, and the position at the beginning of the ground-water flow path. In areas where the aquifer is confined, the water evolves to a calcium magnesium sulfate type midway along the flow path, as mixing with upwelling water containing gypsum increases. At the end of the flow path, the water in the Upper Floridan aquifer comes into contact with the freshwater-saltwater transition zone, and a sodium chloride water type results. In areas where the aquifer is unconfined or semiconfined, flow paths are short and continuously open to recharge; therefore, regional ground-water evolution is not evident. Mixing with saltwater and replacement of sodium and chloride as the dominant ions occur in some ground water near the coast in the northern part of the study area.

All the water in the top part of the Upper Floridan aquifer was undersaturated with respect to gypsum and amorphous silica and saturated or oversaturated with respect to quartz. Water was saturated with respect to calcite throughout the top of the Upper Floridan aquifer. Water generally was undersaturated with respect to dolomite in areas where the aquifer is unconfined, and saturated in areas where it is confined.

Partial pressures of carbon dioxide gas in water from the Upper Floridan aquifer ranged from 10^{-3} to $10^{-1.5}$ atm. Partial pressures were highest in the aquifer under wetlands, which are commonly in river valleys and near the gulf coast. Dissolved-oxygen concentrations in water from the Upper Floridan aquifer ranged from 0 to 6.2 mg/L. High dissolved-oxygen concentrations (greater than 3 mg/L) occurred in the north under the Brooksville Ridge in Hernando and Citrus Counties, in Marion and Levy Counties, and in central Hillsborough County.

Tritium concentrations in the Upper Floridan aquifer were bimodally distributed, with high tritium (greater than 5 tritium units) indicating water less than 35 years old, and low tritium (less than 1 tritium unit) indicating water greater than 35 years old. Tritium concentrations between 1 and 5 tritium units indicate mixtures of relatively "young" (post-1953) and "old" (pre-1953) water.

Relatively young water is present in all areas where the Upper Floridan aquifer is unconfined and in most areas where the aquifer is semiconfined. The water is older in areas where the Upper Floridan aquifer is confined and in the Green Swamp. Concentrations of more than 15 tritium units, which could be definitively dated to the period 1962–70, were not found in any water samples. Historical tritium data indicate a 1- to 2-month lag between tritium concentration in rain and the concentration in ground water in the area near Rainbow and Silver Springs. In the northern part of the study area, high tritium waters have either diffused into matrix pores, dispersed into surrounding older water, or been diluted during sampling. In areas where the aquifer is confined, vertical time of travel or flow-path length is so long that radioactive decay reduces environmental tritium concentrations to less than the analytical detection limit.

Delta deuterium and delta oxygen–18 were highly correlated in the Upper Floridan aquifer. The line representing the relation of delta deuterium to delta oxygen–18 in the aquifer has a slope of 5.4 and an intercept of 1.5. The global meteoric water line, representing the average values of delta deuterium relative to delta oxygen–18 from rain samples around the world, has a slope of 8 and an intercept of 10. The lower slope of the line for the Upper Floridan aquifer indicates evaporation during rainfall or from surface waters before recharge to the aquifer. The low intercept results from the proximity of the Gulf of Mexico; most water that falls as rain in the study area comes directly from the gulf. Because this water has not traveled far inland in the form of clouds, fractionation through rainout of enriched water has not progressed enough to cause its delta deuterium and delta oxygen–18 values to deviate from SMOW. Delta deuterium and delta oxygen–18 show a pattern similar to tritium in the Upper Floridan aquifer, in which water enriched in deuterium and oxygen–18 corresponds to older water, and depleted values correspond to younger water. Delta deuterium and delta oxygen–18 have a continuous distribution between high and low values, unlike tritium, and may be a better indicator of the age of ground water if they can be correlated to a long-term isotopic age marker such as carbon–14.

Factor analysis of the ground-water chemistry data set indicated that four factors accounted for 99 percent of the variability of the data. Factor I represents saltwater mixing, factor II represents the process of ground-water evolution or mixing with more evolved ground water, factor III accounts for the variability due to ground-water age differences indirectly represented by the delta deuterium and delta oxygen–18 concentrations, and factor IV represents the differences in rates of limestone dissolution through the variability in pH and alkalinity.

Relations among physical and chemical aspects of the system were developed by investigating how DRASTIC parameters compared with ground-water chemistries. The DRASTIC method assimilates available information on the hydrologic system, giving important aspects of the system greater weight in calculating an index of contamination potential. The DRASTIC index was highly dependent on the thickness of the confining unit. The DRASTIC parameters, depth to water and effect of the unsaturated zone, are closely related, and the high weighting of these parameters extends their influence on the final index. Compared with chemical indicators of potential for contamination, the DRASTIC method overestimates contamination potential in areas where the unconfined aquifer discharges, in wetlands, and in the Green Swamp. DRASTIC underestimates contamination potential in the northern ridge areas.

The quality of water in the Upper Floridan aquifer provides useful information for interpreting age relations of water. Isotopic data were especially helpful, both intrinsically and in illuminating how subtle differences in chemistry can reflect the age of ground water. Tritium was a useful indicator of the age of water in the Upper Floridan aquifer, and deuterium and oxygen–18 also may prove to be useful after additional study.

Water in the northern unconfined and semiconfined areas of the Upper Floridan aquifer is less than 35 years old throughout the top of the aquifer. In these areas, the potential for contamination of the Upper Floridan aquifer is considered to be high or very high. Very high potential for contamination occurs in areas where water in the aquifer has high tritium (greater than 5 tritium units) and high dissolved-oxygen (greater than 3 mg/L) concentrations. There is no distinction, either chemically or isotopically, between areas where the aquifer was previously defined as either unconfined or semiconfined. Water in the confined areas of the Upper Floridan aquifer is greater than 35 years old from the beginning to the end of the flow path, and the potential for contamination is considered to be low or very low. Very low potential for contamination occurs in confined parts of the aquifer that are also areas of aquifer discharge. Carbon–14 dating indicates that water in areas where the aquifer is confined is much older than the maximum age limit that can be estimated using tritium. There is minimal mixing of water between areas where the aquifer is confined and unconfined, as this would be perpendicular to the approximate direction of ground-water flow. Mixing of younger and older water does occur in Polk County through solution-pipe sinkholes, which provide a more direct path for recharge to the aquifer through the confining unit. In the areas of the aquifer where mixing does occur, the potential for contamination is considered to be moderate.

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APPENDIXES A–C

Appendix A. Information on sampled wells

[Sampling pump type: 1, centrifugal; 2, submersible; 3, bladder; 4, peristaltic; blank indicates unknown. All wells are open hole below the casing unless indicated by "S" after casing depth]

Well number	Name	Latitude	Longitude	Elevation (feet above sea level)	Depth (feet below land surface)	Bottom of casing (feet below land surface)	Type of pump
1	Charlotte ROMP TR3-1 Suwannee	265638	821307	7.00	620.0	600.0 S	
2	Charlotte ROMP 10 Deep Creek 917	270152	820028	20.00	917.0	595.0	
3	De Soto Hancock and Lawrence	270256	814728	35.00	900.0	700.0	2
4	Sarasota ROMP TR5-2	270919	822342	15.00	700.0	510.0	2
5	De Soto ROMP 16 Ocala	271115	814627	60.00	942.0	757.0	2
6	De Soto ROMP 26	271757	814930	75.28	1,320.0	580.0	
7	Manatee Verna deep well 1A	272356	821813	81.90	480.0	412.0	2
8	Coca Cola well Highlands	272408	812325	130.00	595.0	546.0	2
9	Manatee ROMP 32-2	272814	820348	104.00	600.0	560.0	2
10	Hardee Zolfo Springs 1	272944	814740	65.00	1,000.0	350.0	
11	Hillsborough Sun City 1	274318	822028	60.00	800.0	271.0	
12	Hillsborough ROMP 48 near Fort Lonesome	274427	820837	101.00	541.0	215.0	
13	Sweat well Hillsborough HRS34	274533	821552	125.00	220.0	156.0	2
14	Polk ROMP 55 Suwannee	274730	813338	122.00	[1]250.0	212.0	
15	Polk Lake Garfield Nurseries	274910	814522	130.50	817.0	316.0	
16	Pebbledale Road	275009	815409	167.30	303.0	288.0	2
17	Steelman well Pinellas HRS34	275150	824316	15.00	140.0	132.0	
18	Pardo well Hillsborough HRS67A	275432	821225	55.00	247.0	189.0	
19	St. Catherine deep well	275521	824443	20.00	200.0	149.0	2
20	Ward well Hillsborough HRS66	275609	821822	40.00	156.0	78.0	2
21	Pope well Hillsborough HRS65	275639	822821	15.00	136.0	63.0	1
22	Griffin well Hillsborough HRS20	275910	821715	50.00	100.0	80.0	2
23	Wilson well Hillsborough HRS61	280004	822700	30.00	110.0	63.0	
24	Fox well Hillsborough HRS62	280033	821609	40.00	153.0	53.0	1
25	Graham well Pinellas HRS26	280054	824113	25.00	100.0	80.0	2
26	Ward well Hillsborough HRS9	280056	823429	10.00	42.0	30.0	1
27	Koch well Hillsborough HRS60	280057	822327	35.00	120.0	75.0	2
28	Lambert well Pinellas HRS23	280111	824642	25.00	75.0	63.0	1
29	Armstrong well Hillsborough HRS59	280150	822550	45.00	105.0	90.0	
30	Smith well Polk HRS31	280200	813207	105.00	310.0	218.0	1
31	Kelly well Polk HRS24	280230	820240	115.00	90.0	80.0	2
32	Polaski well Pinellas HRS16	280259	824454	60.00	100.0	65.0	2
33	Palmer well Hillsborough HRS54	280407	823414	40.00	130.0	82.0	1
34	Polk Lake Lucerne well 1PN-155	280437	814102	133.29	155.0	130.0	
35	Morris Bridge area 514 deep	280508	821957	42.59	160.0	80.0	2
36	Upcavage well Hillsborough HRS5	280527	822630	50.00	120.0	48.0	1
37	Denney well Pinellas HRS10	280601	824600	20.00	85.0	65.0	1
38	Davis well Polk HRS47	280643	815730	155.00	200.0	140.0	1
39	Ziemnin well Hillsborough HRS52	280714	822853	60.00	180.0	105.0	2
40	Section 21 well field 468 deep	280740	823012	61.20	69.0	65.0 S	3
41	Cosme well field 313 deep	280744	823427	62.00	51.0	50.5 S	3
42	Burkhart well Hillsborough HRS51	280750	823626	55.00	195.0	140.0	1
43	Carlson well Pinellas HRS8	280806	824357	15.00	106.0	85.0	
44	Hejl well Pinellas HRS3	280826	824014	25.00	90.0	80.0	1
45	Carter well Pinellas HRS1	280924	824336	20.00	80.0	63.0	1

[1] Sampled during drilling. Finished depth 1,200 ft.

Appendix A. Information on sampled wells —Continued

[Sampling pump type: 1, centrifugal; 2, submersible; 3, bladder; 4, peristaltic; blank indicates unknown. All wells are open hole below the casing unless indicated by "S" after casing depth]

Well number	Name	Latitude	Longitude	Elevation (feet above sea level)	Depth (feet below land surface)	Bottom of casing (feet below land surface)	Type of pump
46	Hall well Hillsborough HRS8	281008	820937	72.00	100.0	50.0	
47	Eldridge-Wilde well field 142 deep	281017	823809	37.40	39.0	38.0 S	3
48	Royce well Polk HRS8	281032	814505	130.00	170.0	107.0	2
49	Burkam well Pasco HRS46	281039	821559	65.00	125.0	76.0	1
50	Fussell well Polk HRS7	281045	815006	150.00	200.0	126.0	
51	Pasco well field 223 deep	281056	823033	59.00	45.0	40.0 S	3
52	Mickler well Pasco HRS34	281127	824702	5.00	47.0	42.0	1
53	Barclay well Pasco HRS65	281159	822847	65.00	53.0	42.0	1
54	Wells well Polk HRS44	281240	820158	110.00	75.0	50.5	1
55	Hughes well Pasco HRS48	281257	821107	75.00	100.0	72.0	1
56	Bexley well 743 deep	281309	823113	59.81	39.0	34.0 S	3
57	Starkey well field 728-52	281427	823828	35.00	51.5	49.5 S	3
58	Wyatt well Polk HRS5	281528	815727	110.00	125.0	63.0	1
59	Goodman well Polk HRS9	281530	813800	120.00	180.0	139.0	1
60	Cypress Creek well field 829 deep	281637	822335	70.00	52.0	49.0 S	3
61	Rogers well Pasco HRS58	281637	822608	70.00	115.0	50.0	2
62	Tagge well Polk HRS4	281703	814630	130.00	160.0	105.0	1
63	Stewart well Pasco HRS63	281705	820818	87.00	110.0	77.0	1
64	Becken well Pasco HRS29	281740	821807	105.00	88.0	63.0	1
65	Dillman well Polk HRS1A	281810	815120	125.00	160.0	105.0	1
66	Bryant well Pasco HRS30	281904	821224	100.00	115.0	110.0	2
67	Lewis well Pasco HRS17	281954	824156	10.00	62.0	46.0	1
68	Swan well Pasco HRS8	282144	823402	45.00	125.0	95.0	1
69	Green Swamp well L11KD	282152	820112	93.13	35.0		4
70	Smith well Pasco HRS55	282152	820858	75.00	140.0	54.0	1
71	Lake USGS Eva deep	282245	814926	113.47	192.0	100.0	
72	Pike well Pasco HRS54	282415	822144	128.00	130.0	103.0	2
73	Magnolia Springs well	282600	823926	5.00	110.0	84.0	
74	Anderson well Pasco HRS1	282709	821428	90.00	150.0	120.0	2
75	Bridges well Hernando HRS64	282717	822921	67.00	100.0	78.0	2
76	Sumter USGS Richloam	282741	815857	96.94	175.0	90.0	
77	Hernando HRS43 Bedillion	282759	822312	90.00	95.0	76.0	2
78	Hernando HRS51 McGowlar	282929	820923	75.00	85.0	63.0	1
79	Wathen well Hernando HRS14	283159	823458	20.00	67.0	42.0	2
80	Franklin well Sumter HRS44	283245	820433	84.00	100.0	37.0	1
81	Edwards well Hernando HRS21	283308	823033	100.00	190.0	157.0	2
82	Hernando HRS31	283315	820958	62.00	80.0	34.0	2
83	Justice well Hernando HRS60	283341	821735	100.00	190.0	148.0	2
84	Hernando HRS26	283625	822003	75.00	105.0	84.0	2
85	Hernando HRS12	283658	821832	60.00	64.0	59.0	2
86	Hernando HRS7	283738	822250	80.00	133.0	79.0	2
87	Hernando HRS6	283759	822527	105.00	115.0	94.0	2
88	Staples well Sumter HRS34	283904	820622	77.00	38.0	33.0	1
89	Hernando HRS10	283924	821727	80.00	165.0	84.0	2
90	Hernando HRS4	284001	822602	75.00	120.0	63.0	2

Appendix A. Information on sampled wells —Continued

[Sampling pump type: 1, centrifugal; 2, submersible; 3, bladder; 4, peristaltic; blank indicates unknown. All wells are open hole below the casing unless indicated by "S" after casing depth]

Well number	Name	Latitude	Longitude	Elevation (feet above sea level)	Depth (feet below land surface)	Bottom of casing (feet below land surface)	Type of pump
91	Zentz well Sumter HRS32	284036	821459	50.00	50.0	44.0	1
92	Rita Maria Springs well	284113	823528	2.00	72.0		
93	Citrus Coats well	284152	822818	70.00	80.0		
94	Roberts well Sumter HRS28	284402	820324	40.00	80.0	60.0	1
95	Citrus Sugarmill Woods	284412	823130	70.00	107.0	80.0	
96	Swisshelm well Sumter HRS18	284920	821050	82.00	67.0	38.0	2
97	Dumal well Citrus HRS28	285052	823444	10.00	84.0	57.0	1
98	Byerley well Citrus HRS38	285119	822211	70.00	68.0	66.0	2
99	Garland well Citrus HRS33	285131	822732	10.00	147.0	121.0	2
100	Coon well Citrus HRS15	285554	823730	7.00	58.0	56.0	1
101	Lambert well Sumter HRS4	285603	820635	62.00	150.0	105.0	1
102	Sale well Citrus HRS21	285718	822209	40.00	35.0	20.0	2
103	Gephart well Sumter HRS52	285734	820111	72.00	70.0	40.0	1
104	Norbert well Marion HRS30	290038	821903	55.00	65.0	60.5	2
105	Weaver well Citrus HRS1	290129	824014	15.00	32.0	28.0	2
106	Biederman well Marion HRS25	290522	822547	65.00	120.0	92.0	1
107	Yonke well Marion HRS26	290755	821955	90.00	105.0	81.0	2
108	Teagle well Marion HRS13	291535	822040	75.00	70.0	57.0	2
109	Freimuth well Marion HRS10	291910	821258	170.00	186.0	126.0	2
110	Bullock-Huber well	291910	823411	92.00	91.0	68.0	2
111	Kohr well Marion HRS4	292215	822325	100.00	120.0	87.0	2
112	Sutherland well Levy	292530	823323	80.00	80.0	63.0	2

Appendix B. Water-quality data, part 1

[°C, degrees Celsius; mV, millivolts; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; TU, tritium unit; permil, part per thousand; –, no data; <, less than]

Well number	Station number	Date	Water temperature (° C)	Oxidation reduction potential (mV)	Specific-conductance, (µS/cm)		Dissolved oxygen, (mg/L)	pH, (standard units)		Alkalinity, (mg/L as $CaCO_3$)	
					Field	Lab		Field	Lab	Field	Lab
1	265638082130706	2-02-86	27.0	–	–	2,620	0	7.48	–	146	–
2	270152082002801	2-02-86	27.0	–	–	1,520	0	7.53	–	124	–
3	270256081472801	7-09-87	30.0	-90	1,710	1,710	.2	7.70	7.90	123	114
4	270919082234205	10-06-87	27.0	-365	2,720	2,740	.3	7.10	7.50	134	118
5	271115081462701	6-17-87	29.0	40	900	890	.1	–	8.20	107	94
6	271757081493002	2-05-86	31.5	–	–	975	0	7.45	–	144	–
7	272356082181302	11-02-87	25.0	-180	452	442	1.2	7.30	8.00	227	229
8	272408081232501	5-31-89	27.5	–	299	315	.4	7.79	7.60	145	140
9	272814082034802	11-02-87	27.0	-127	495	488	.9	8.00	8.00	155	145
10	272944081474001	2-05-86	30.0	–	–	703	0	7.45	–	154	–
11	274318082202801	2-04-86	26.0	–	–	593	0	7.44	–	145	–
12	274427082083701	2-03-86	24.5	–	–	372	0	7.71	–	131	–
13	274533082155202	3-01-89	24.5	49	370	378	.2	7.38	7.59	203	200
14	274730081333801	7-14-87	25.0	–	285	265	–	7.80	8.20	–	130
15	274910081452201	2-03-86	25.5	–	–	336	0	7.78	–	130	–
16	275009081540901	2-23-89	24.5	–	305	303	.2	7.94	7.78	118	111
17	275150082431601	6-16-88	–	-119	1,180	1,120	.5	7.34	7.60	227	215
18	275432082122501	3-01-89	23.0	94	350	352	.3	7.38	7.60	164	161
19	275521082444301	3-28-89	25.0	–	1,160	1,160	.4	7.24	7.49	187	180
20	275609082182201	8-23-88	26.0	313	209	205	5.4	7.40	7.70	60	59
21	275639082282101	8-16-88	25.5	118	558	555	1.5	7.16	7.80	241	239
22	275910082171501	8-17-88	25.0	333	328	321	2.3	7.38	7.90	129	121
23	280004082270001	8-16-88	27.0	348	415	393	.8	7.52	7.80	157	151
24	280033082160901	8-18-88	24.0	413	348	332	.5	7.34	7.80	171	166
25	280054082411301	6-16-88	–	109	470	578	.5	6.99	7.70	286	278
26	280056082342901	8-03-88	28.5	487	582	595	.5	7.26	7.60	192	188
27	280057082232701	8-16-88	25.0	164	630	635	.5	6.43	7.70	199	200
28	280111082464201	6-09-88	24.5	64	638	603	.5	7.14	8.00	198	187
29	280150082255001	8-17-88	25.0	265	272	265	.7	7.79	7.90	96	89
30	280200081320701	8-11-88	25.5	14	189	184	.5	8.05	8.10	–	80
31	280230082024001	3-03-89	24.0	94	410	413	.2	7.13	7.40	195	188
32	280259082445401	6-09-88	24.0	95	484	463	.5	7.50	7.70	164	166
33	280407082341401	8-17-88	25.0	108	345	340	.5	7.38	7.80	174	169
34	280437081410207	8-28-87	24.5	400	190	175	.9	8.30	8.60	71	68
35	280508082195701	1-26-89	24.0	412	140	150	1.4	8.14	4.92	58	56
36	280527082263001	8-19-88	24.5	124	290	282	.5	7.31	7.70	113	109
37	280601082460001	7-21-88	25.5	321	1,020	1,100	–	7.39	8.10	83	84
38	280643081573001	8-10-88	24.5	31	250	244	.5	7.71	7.90	120	116
39	280714082285301	8-15-88	24.5	88	323	321	3.2	–	7.70	125	122
40	280740082301201	1-26-89	26.0	195	355	357	.9	7.58	7.57	158	176
41	280744082342701	1-25-89	23.5	17	180	184	.3	7.94	7.82	–	79
42	280750082362601	8-17-88	24.5	462	300	291	.5	7.70	7.80	134	132
43	280806082435701	6-17-88	29.0	255	170	161	–	8.19	8.00	41	42
44	280826082401401	6-17-88	25.5	-7	406	401	.5	7.24	7.80	201	201
45	280924082433601	8-03-88	24.0	-67	1,410	1,480	.5	7.95	8.10	204	180

Appendix B. Water-quality data, part 1 —Continued

[°C, degrees Celsius; mV, millivolts; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; TU, tritium unit; permil, part per thousand; –, no data; <, less than]

Well number	Station number	Date	Water temperature (° C)	Oxidation reduction potential (mV)	Specific-conductance, (µS/cm)		Dissolved oxygen, (mg/L)	pH, (standard units)		Alkalinity, (mg/L as $CaCO_3$)	
					Field	Lab		Field	Lab	Field	Lab
46	281008082093701	8-18-88	23.5	408	490	479	0.5	7.07	7.50	241	237
47	281017082380901	1-25-89	25.0	72	478	462	.4	7.01	7.21	227	210
48	280132081450501	8-05-88	24.5	66	235	236	.5	7.59	7.90	113	111
49	281039082155901	3-29-89	24.5	73	550	551	.4	6.96	7.36	255	254
50	281045081500601	8-05-88	26.5	71	282	284	.5	7.62	7.90	142	136
51	281056082303301	3-08-89	23.0	124	415	412	.7	7.38	7.48	200	200
52	281127082470201	9-01-88	24.5	368	623	609	.6	7.04	7.50	214	203
53	281159082284701	8-26-88	25.0	108	437	421	.5	7.02	7.50	214	206
54	281240082015801	8-10-88	25.0	112	494	512	.5	6.90	7.40	255	248
55	281257082110701	8-26-88	25.0	211	309	296	1.0	7.47	7.80	143	140
56	281309082311301	1-24-89	25.0	122	420	416	.4	6.83	7.13	186	180
57	281427082382804	12-14-88	23.5	–	248	266	.5	7.76	7.64	–	121
58	281528081572701	8-10-88	25.5	385	525	520	.5	6.92	7.30	258	248
59	281530081380001	8-11-88	24.5	521	335	318	.5	7.41	7.60	167	157
60	281637082233501	1-24-89	23.5	114	475	472	.6	7.21	7.37	–	229
61	281637082260801	8-29-88	24.5	293	142	136	.8	7.01	7.40	60	57
62	281703081463001	8-04-88	25.5	375	390	349	.5	7.30	7.70	174	172
63	281705082081801	8-30-88	25.0	391	341	335	–	7.22	7.60	128	115
64	281740082180701	8-24-88	24.0	152	400	395	.5	7.14	7.70	207	201
65	281810081512001	3-03-89	24.0	142	295	297	.2	7.53	7.60	128	125
66	281904082122401	9-02-88	24.0	397	432	436	.6	7.30	7.60	165	160
67	281954082415601	9-01-88	24.5	97	882	903	.5	7.04	7.40	241	228
68	282144082340201	9-01-88	24.5	46	199	189	.5	7.76	7.90	91	86
69	282152082011201	3-10-89	–	117	496	492	.6	7.26	7.43	246	249
70	282152082085801	8-30-88	26.0	69	293	282	.5	7.45	7.80	141	136
71	282245081492601	9-11-87	24.0	-236	315	291	.6	7.60	7.80	145	138
72	282415082214401	8-25-88	24.5	391	401	396	6.0	7.26	7.70	203	195
73	282600082392601	7-14-88	23.0	61	332	333	.5	7.55	7.90	135	135
74	282709082142801	8-25-88	24.0	343	281	274	1.7	7.71	7.90	113	109
75	282717082292101	9-29-88	24.0	385	176	171	4.1	7.64	8.10	75	73
76	282741081585701	9-11-87	23.5	-87	630	580	.4	6.90	7.40	286	285
77	282759082231201	9-11-87	23.5	350	420	430	3.3	7.20	7.60	216	207
78	282929082092301	9-08-87	24.5	90	370	413	–	7.27	7.50	169	161
79	283159082345801	9-29-88	23.5	77	695	696	.5	7.11	7.60	200	189
80	283245082043301	9-07-88	24.5	406	400	381	.5	7.26	7.50	205	190
81	283308082303301	9-29-88	25.0	400	306	303	3.2	7.42	8.00	146	143
82	283315082095801	9-09-87	22.5	70	930	911	.9	7.03	7.40	250	236
83	283341082173501	9-30-88	23.0	391	158	151	6.2	7.85	8.20	69	69
84	283625082200301	8-31-87	24.5	–	209	–	5.6	7.95	–	93	–
85	283658082183201	8-31-87	24.0	410	169	–	5.1	8.06	–	73	–
86	283738082225001	9-04-87	23.5	380	303	–	4.1	7.47	7.80	144	146
87	283759082252701	9-02-87	25.0	430	418	420	5.2	7.50	7.70	205	203
88	283904082062201	9-07-88	23.5	191	330	320	.5	7.43	7.70	141	138
89	283924082172701	9-04-87	24.0	320	217	228	4.7	7.75	7.90	–	100
90	284001082260201	9-02-87	25.0	380	315	316	5.3	7.50	7.90	145	143

Appendix B. Water-quality data, part 1 —Continued

[°C, degrees Celsius; mV, millivolts; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; TU, tritium unit; permil, part per thousand; –, no data; <, less than]

Well number	Station number	Date	Water temperature (° C)	Oxidation reduction potential (mV)	Specific-conductance, (µS/cm)		Dissolved oxygen, (mg/L)	pH, (standard units)		Alkalinity, (mg/L as $CaCO_3$)	
					Field	Lab		Field	Lab	Field	Lab
91	284036082145901	9-07-88	24.0	398	401	393	3.8	6.97	7.50	199	195
92	284113082352801	7-14-88	21.0	52	520	514	.5	7.05	7.60	255	253
93	284152082281801	9-12-87	24.0	112	250	262	5.5	7.60	7.80	109	119
94	284402082032401	9-08-88	23.5	389	273	270	1.2	7.48	7.80	133	128
95	284412082313001	9-22-87	24.5	87	280	283	3.5	7.60	8.10	129	125
96	284920082105001	9-08-88	24.5	89	460	446	.5	7.11	7.40	231	212
97	285052082344401	1-20-89	22.5	227	247	259	2.0	7.94	7.92	106	103
98	285119082221101	1-18-89	24.5	364	94	101	5.8	8.37	7.78	47	42
99	285131082273201	1-18-89	23.5	392	151	166	4.0	8.01	7.82	78	76
100	285554082373001	1-19-89	23.5	31	408	405	.2	7.43	7.48	201	190
101	285603082063501	9-08-88	24.5	357	225	218	–	7.77	7.80	102	99
102	285718082220901	1-20-89	22.0	233	235	233	.3	6.81	6.92	102	90
103	285734082011101	9-08-88	24.5	358	175	167	–	8.06	7.90	69	67
104	290038082190301	3-15-89	24.0	197	389	376	1.2	7.27	7.60	188	186
105	290129082401401	1-19-89	23.0	133	790	792	2.4	7.15	7.46	282	277
106	290522082254701	3-15-89	23.0	298	310	302	–	7.63	7.79	128	127
107	290755082195501	3-14-89	23.5	364	330	322	5.4	7.64	7.77	95	96
108	291535082204001	3-14-89	22.0	394	500	493	3.8	7.04	7.40	250	247
109	291910082125801	3-14-89	23.0	354	543	533	5.0	7.27	7.59	165	166
110	291910082341101	3-30-89	24.0	271	123	121	5.7	8.39	7.89	43	42
111	292215082232501	3-14-89	22.5	319	511	504	3.8	7.03	7.45	254	250
112	292530082332301	3-31-89	25.0	301	120	113	4.0	8.31	7.93	53	49

Appendix B. Water-quality data, part 2

[°C, degrees Celsius; mV, millivolts; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; TU, tritium unit; permil, part per thousand; –, no data; <, less than]

Well number	Dissolved nitrogen $NO_2 + NO_3$ (mg/L as N)	Dissolved phosphorus, ortho (mg/L as P)	Total sulfide (mg/L as S)	Dissolved calcium (mg/L as Ca)	Dissolved magnesium (mg/L as Mg)	Dissolved sodium (mg/L as Na)	Dissolved potassium, (mg/L as K)	Dissolved chloride, (mg/L as Cl)	Dissolved sulfate, (mg/L as SO_4)
1	0.010	0.010	2.4	110	79	260	17	410	470
2	.010	.010	2.1	100	65	120	6.9	180	410
3	–	–	–	75	42	160	5.0	340	180
4	–	–	1.0	480	140	23	3.9	44	1,400
5	–	–	–	80	46	26	3.3	39	320
6	.010	.010	1.8	100	52	12	2.9	14	340
7	–	–	< .5	44	22	17	1.6	10	.20
8	.020	.010	–	25	17	11	1.3	16	3.4
9	–	–	1.1	42	22	20	2.8	20	77
10	.010	.010	1.4	69	33	13	1.9	17	180
11	.030	.010	2.4	80	30	9.7	1.4	11	190
12	.010	.020	.4	44	16	11	1.2	15	42
13	< .020	< .010	–	40	21	7.7	1.0	4.1	< .20
14	–	.086	–	36	7.9	7.1	2.6	8.0	7.0
15	.010	.020	1	37	12	6.6	1.5	8.3	16
16	< .020	< .010	–	31	10	13	1.2	10	28
17	–	–	2.9	130	24	52	5.6	220	37
18	< .020	< .010	–	47	14	4.7	.70	6.7	16
19	< .020	.030	–	110	21	84	2.6	230	10
20	3.20	.250	1.1	30	1.5	6.4	.60	11	13
21	< .020	.030	<1.0	97	6.3	11	1.1	27	17
22	3.80	.030	<1.0	54	3.0	4.1	.60	11	13
23	.850	.030	<1.0	66	4.6	7.5	.90	12	33
24	< .020	.040	<1.0	58	4.0	5.0	.50	6.6	.10
25	< .020	–	<1.0	93	11	11	.50	23	1.5
26	.020	.020	<1.0	79	5.1	31	1.1	69	6.6
27	2.30	.030	<1.0	100	8.2	16	1.5	32	72
28	< .020	–	< .5	91	5.3	24	1.2	58	39
29	.620	.030	<1.0	43	1.9	5.5	.60	18	15
30	< .020	< .010	–	18	8.0	5.0	1.9	5.9	4.5
31	1.80	.020	–	57	12	8.7	.90	19	2.4
32	< .020	–	< .5	65	7.4	16	1.0	36	21
33	< .020	.050	<1.0	60	3.1	4.9	.60	7.3	.10
34	< .10	< .01	–	20	4.5	6.0	2.5	9.5	6.0
35	.130	.020	–	25	.70	2.2	.40	4.5	8.4
36	.040	.030	<1.0	48	1.1	6.6	.40	16	12
37	.360	.070	<1.0	52	14	120	4.4	220	42
38	< .020	.030	–	25	13	3.6	.30	5.8	2.1
39	< .020	.030	<1.0	54	1.4	8.9	.40	13	22
40	.090	.030	–	64	3.1	4.0	1.1	7.1	< .10
41	.120	.070	–	33	.80	2.1	.20	3.1	8.6
42	< .020	.070	<1.0	48	3.7	5.5	.50	10	4.6
43	1.10	–	1.3	19	1.2	6.9	.60	15	5.6
44	< .020	–	1.0	68	5.1	5.9	.80	9.0	.80
45	.020	.150	<1.0	19	13	260	12	300	54

Appendix B. Water-quality data, part 2 —Continued

[°C, degrees Celsius; mV, millivolts; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; TU, tritium unit; permil, part per thousand; –, no data; <, less than]

Well number	Dissolved nitrogen $NO_2 + NO_3$ (mg/L as N)	Dissolved phosphorus, ortho (mg/L as P)	Total sulfide (mg/L as S)	Dissolved calcium (mg/L as Ca)	Dissolved magnesium (mg/L as Mg)	Dissolved sodium (mg/L as Na)	Dissolved potassium, (mg/L as K)	Dissolved chloride, (mg/L as Cl)	Dissolved sulfate, (mg/L as SO_4)
46	<.020	.080	<1.0	95	1.8	5.6	.10	13	.50
47	.030	.010	–	86	2.1	7.1	1.0	17	8.1
48	.020	.020	<1.0	43	1.2	2.8	1.1	5.2	2.1
49	<.020	<.010	–	100	3.8	10	.10	25	1.6
50	<.020	.030	<1.0	38	9.9	3.3	1.0	6.6	2.4
51	.020	.030	–	78	3.8	4.3	.70	12	<1.0
52	2.40	.020	<1.0	84	5.3	30	8.6	42	37
53	<.020	.030	<1.0	82	1.6	4.3	.60	7.7	4.2
54	<.020	.010	–	93	4.0	8.4	.20	14	<.10
55	.090	.020	<1.0	54	1.4	3.4	.40	6.6	5.4
56	.030	.020	–	73	3.4	5.9	2.4	16	11
57	<.020	.240	<1.0	52	1.4	3.7	.90	4.9	2.6
58	<.020	.030	–	88	4.2	15	.90	14	<.10
59	<.020	.030	–	60	1.4	2.6	.90	5.1	<.10
60	.050	.030	–	84	6.4	5.3	.80	9.7	9.2
61	.050	.080	<1.0	23	.70	1.8	.20	2.7	5.2
62	<.020	.160	<1.0	60	3.1	4.2	2.1	6.5	<.10
63	5.70	.180	<1.0	50	2.7	11	.50	16	6.0
64	<.020	.020	<1.0	75	2.9	4.5	.50	6.3	.70
65	<.020	.070	–	47	3.9	5.4	.50	12	3.9
66	4.80	.020	<1.0	74	2.3	9.1	.40	20	16
67	<.020	.020	1.4	100	8.6	73	2.9	140	28
68	<.020	.020	<1.0	34	.60	2.3	.30	5.0	2.7
69	<.021	<.010	–	91	6.3	7.2	.60	12	.10
70	.170	.010	<1.0	52	1.2	3.2	.10	7.3	1.1
71	–	–	.5	54	2.1	4.0	1.5	8.4	.40
72	.580	.040	<1.0	75	2.1	4.5	.20	8.1	.70
73	–	–	<1.0	41	12	7.0	.70	18	8.3
74	2.30	.030	<1.0	40	6.2	4.4	.20	10	11
75	1.50	.020	<1.0	30	.80	2.2	.20	4.5	2.5
76	–	–	<.5	110	2.5	6.9	.40	14	<.10
77	–	–	–	75	6.6	4.9	.20	9.2	1.6
78	–	–	.8	66	1.3	14	.30	30	.10
79	.020	.060	<1.0	78	2.3	61	.30	100	11
80	<.020	.010	<1.0	72	1.6	4.3	.20	8.3	<.10
81	.880	.020	<1.0	54	3.8	2.8	.30	5.5	6.0
82	–	–	1.1	110	4.3	63	.40	150	.30
83	.290	<.020	1.0	21	4.5	2.2	.30	3.9	2.0
84	–	–	–	–	–	–	–	–	–
85	–	–	–	–	–	–	–	–	–
86	–	–	<.5	49	6.4	3.4	.30	7.2	5.0
87	–	–	–	71	8.9	5.0	.30	11	8.0
88	1.50	.030	<1.0	60	1.0	4.1	.30	9.6	7.1
89	–	–	<.5	40	2.0	2.7	.10	6.4	3.7
90	–	–	<.5	48	7.2	4.0	.30	9.6	7.0

Appendix B. Water-quality data, part 2 —Continued

[°C, degrees Celsius; mV, millivolts; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; TU, tritium unit; permil, part per thousand; –, no data; <, less than]

Well number	Dissolved nitrogen $NO_2 + NO_3$ (mg/L as N)	Dissolved phosphorus, ortho (mg/L as P)	Total sulfide (mg/L as S)	Dissolved calcium (mg/L as Ca)	Dissolved magnesium (mg/L as Mg)	Dissolved sodium (mg/L as Na)	Dissolved potassium, (mg/L as K)	Dissolved chloride, (mg/L as Cl)	Dissolved sulfate, (mg/L as SO_4)
91	1.10	.070	<1.0	79	1.5	2.9	.40	5.5	7.7
92	–	–	<1.0	78	14	8.6	.50	13	5.6
93	–	–	.5	41	5.4	2.8	.20	6.8	8.8
94	.030	.040	<1.0	51	.80	2.7	<.10	4.5	5.2
95	–	–	<.5	45	5.8	3.5	.20	7.8	5.5
96	<.020	.030	<1.0	85	3.6	4.0	.20	7.6	10
97	.170	.020	–	34	5.9	7.6	.40	13	7.7
98	.220	.030	–	17	.50	1.8	<.10	3.1	1.0
99	.130	.030	–	27	2.5	2.1	.10	3.7	2.7
100	.020	.010	–	65	7.7	7.6	.50	11	7.5
101	.620	.060	<1.0	39	.70	3.3	.10	3.8	3.6
102	.020	.090	<1.0	35	1.5	7.1	.20	13	1.0
103	2.10	.010	<1.0	26	2.4	2.6	.30	3.5	3.7
104	.130	.010	–	79	1.2	2.5	<.10	4.9	5.6
105	<.020	<.010	–	120	4.7	39	.30	83	11
106	.680	.020	–	53	6.1	2.6	.20	6.3	21
107	.640	.020	–	55	4.9	3.3	.30	6.1	52
108	.940	.050	–	100	2.7	3.4	.10	7.8	3.9
109	2.90	.010	–	84	5.5	16	.70	57	4.2
110	2.50	.020	–	17	2.4	1.6	.20	4.0	1.5
111	1.30	.050	–	100	1.9	3.7	.10	10	3.5
112	.400	.020	–	17	2.5	1.4	<.10	2.9	1.6

Appendix B. Water-quality data, part 3

[°C, degrees Celsius; mV, millivolts; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; TU, tritium unit; permil, part per thousand; –, no data; <, less than]

Well number	Dissolved fluoride (mg/L as F)	Dissolved silica (mg/L as SiO_2)	Dissolved iron (µg/L as Fe)	Dissolved strontium (µg/L as Sr)	Total tritium (TU)	Dissolved solids residue at 180 °C (mg/L)	$^2H/^1H$ stable isotope ratio (permil)	$^{18}O/^{16}O$ stable isotope ratio (permil)	Saturation index		Log P_{CO_2} (atmospheres)
									Calcite	Dolomite (ordered)	
1	1.5	19	<3	15,000	0	1,500	-6.5	-1.75	0.098	0.437	-2.281
2	1.9	20	30	19,000	.1	987	-5.5	-1.70	.076	.349	-2.394
3	.70	17		28,000	0	954	-3.4	-1.20	.211	.580	-2.547
4	2.0	21	40	13,000	0	2,740	-7.4	-1.95	.188	.234	-1.959
5	1.1	27	–	23,000	0	686	-5.0	-1.75	–	–	–
6	1.0	21	11	24,000	0	662	-7.5	-2.10	.166	.472	-2.207
7	.70	37	270	180	0	277	-10.0	-2.45	-.067	-.084	-1.874
8	.10	25	60	2,800	0	173	-1.4	-.8	.048	.309	-2.988
9	1.5	24	10	6,700	.2	304	-5.9	-1.80	.429	.955	-2.739
10	1.0	21	5	31,000	.3	456	-9.5	-2.10	.082	.252	-2.176
11	.50	20	13	3,300	.1	418	-7.0	-1.45	.053	.050	-2.220
12	.50	21	4	1,800	.2	223	-11.5	-2.65	.096	.100	-2.524
13	.40	34	30	60	.2	233	-14.0	-3.10	-.110	-.419	-2.100
14	.19	–	220	–	.3	192	3.0	.3	.575	.845	-2.966
15	.30	21	14	2,000	1.3	175	-8.0	-1.80	.125	.118	-2.591
16	.40	24	200	460	.1	186	-9.4	-2.60	-.084	-.102	-2.000
17	.30	26	290	2,000	0	833	-5.0	-1.50	.350	.321	-1.939
18	.30	21	360	80	3.4	214	-16.0	-2.75	-.029	-.800	-2.348
19	.30	35	40	980	0	780	-13.0	-2.75	-.022	-1.119	-1.487
20	.10	6.7	<10	30	7.5	127	-16.0	-3.45	-.637	-2.213	-2.537
21	.20	19	830	270	5.0	332	-16.5	-3.50	.143	-.542	-1.709
22	.10	14	10	250	4.7	213	-17.0	-3.40	-.116	-1.135	-2.193
23	.10	14	20	190	7.5	237	-15.0	-3.00	.193	-.395	-2.243
24	.20	18	550	80	.6	189	-13.0	-2.65	-.019	-.862	-2.039
25	.30	29	3,100	190	5.9	353	-14.0	-3.15	.023	-.530	-1.468
26	.20	17	700	220	0	365	-5.4	-1.25	.108	-.583	-1.889
27	.30	18	10	790	7.5	384	-16.5	-3.35	-.682	-2.096	-1.064
28	.10	28	2,600	150	9.1	393	-18.0	-3.55	-.010	-.908	-1.781
29	.10	13	<10	280	7.8	176	-17.0	-3.40	.072	-.860	-2.738
30	.10	22	60	120	0	120	-12.5	-2.60	-.098	-.191	-3.075
31	.40	30	1,300	90	5.9	256	-10.0	-2.10	.186	-.613	-2.018
32	.20	19	580	140	6.3	272	-19.0	-3.65	.142	-.319	-2.224
33	.20	15	110	120	1.7	204	-10.5	-2.20	.055	-.826	-2.066
34	–	–	–	–	2.4	–	-13.0	-2.40	.325	.355	-3.591
35	.10	7.3	<10	80	7.8	88	-17.0	-3.65	.153	.161	-2.795
36	.10	7.3	160	60	7.8	156	-14.5	-3.05	-.292	-1.879	-2.184
37	.20	6.0	10	260	6.9	600	-16.9	-3.45	-.387	-.984	-2.414
38	.03	20	220	30	1.0	146	-18.5	-3.60	-.143	-.225	-2.560
39	.10	9.6	210	70	8.4	178	-14.0	-2.85	.173	-.894	-2.536
40	.20	13	70	130	.2	216	-2.9	-.85	-.002	-1.218	-3.299
41	.10	9.0	150	60	9.7	118	-20.0	-3.80	-.068	-1.398	-1.581
42	.20	12	10	90	7.5	173	.5	.35	.165	-.438	-2.504
43	.10	8.7	20	60	9.4	100	-19.0	-4.00	-.169	-1.144	-3.492
44	.20	14	180	210	.1	237	-5.4	-1.15	.028	-.712	-1.860
45	.20	8.3	170	240	1.8	792	-9.5	-1.75	.064	.308	-2.594

Appendix B. Water-quality data, part 3—Continued

[°C, degrees Celsius; mV, millivolts; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; TU, tritium unit; permil, part per thousand; –, no data; <, less than]

Well number	Dissolved fluoride (mg/L as F)	Dissolved silica (mg/L as SiO_2)	Dissolved iron (µg/L as Fe)	Dissolved strontium (µg/L as Sr)	Total tritium (TU)	Dissolved solids residue at 180 °C (mg/L)	$^2H/^1H$ stable isotope ratio (permil)	$^{18}O/^{16}O$ stable isotope ratio (permil)	Saturation index		Log P_{CO_2} (atmospheres)
									Calcite	Dolomite (ordered)	
46	0.10	11	3,200	140	5.9	291	-12.5	-2.75	0.035	-1.319	-1.627
47	.10	12	7,100	110	5.9	283	-13.0	-2.75	.253	- .445	-2.299
48	.10	13	260	70	.1	129	-19.0	-3.90	- .045	-1.300	-2.461
49	.30	12	1,200	110	6.9	361	-11.5	-2.50	- .041	- .594	-3.684
50	.20	19	200	60	1.3	158	-16.5	-3.10	.042	- .131	-2.382
51	.10	16	210	160	1.5	256	-7.5	-1.25	.233	- .341	-1.799
52	.10	9.5	<10	190	7.2	365	-20.5	-4.00	-.107	-1.067	-1.644
53	.10	11	440	120	7.5	249	-14.5	-3.20	- .098	-1.554	-1.616
54	.30	18	1,600	60	1.2	310	-10.5	-2.45	- .104	-1.223	-1.424
55	.10	12	20	110	.3	167	-14.0	-3.25	.026	-1.184	-2.237
56	.20	6.3	680	120	10.9	248	-19.0	-3.75	.101	- .583	-1.787
57	.20	9.6	5,500	290	8.1	149	-15.9	-3.55	.213	- .812	-2.608
58	.10	17	2,900	90	.2	506	-9.0	-1.95	- .096	-1.155	-1.435
59	.10	10	3,200	60	.7	171	-7.9	-1.20	.064	-1.159	-2.114
60	.20	18	460	170	3.0	291	-11.5	-2.50	.035	-1.213	-2.968
61	< .10	7.6	<10	40	7.5	74	-17.5	-3.80	1.132	-3.438	-2.146
62	.20	18	590	90	0	198	-15.5	-3.30	- .018	- .967	-1.980
63	.20	10	<10	170	7.2	207	-15.0	-3.45	- .307	-1.531	-2.035
64	.10	18	120	70	6.9	220	-16.0	-3.25	- .041	-1.155	-1.757
65	.10	10	50	80	5.0	174	-17.5	-3.45	- .192	- .722	-1.770
66	.10	9.8	<10	80	9.7	271	-14.0	-2.60	.011	-1.146	-2.017
67	.10	5.8	1,100	280	7.5	522	-21.0	-4.10	- .010	- .739	-1.601
68	.10	9.0	770	50	8.1	108	-17.5	-3.50	- .065	-1.538	-2.727
69	.10	12	1,400	160	0	285	-11.0	-2.10	.022	-1.357	-1.570
70	.10	12	570	100	5.0	161	-12.0	-2.75	.001	-1.272	-2.218
71	.10	15	860	110	0.2	180	-18.5	-3.55	.149	-.773	-2.367
72	.20	13	20	120	7.8	229	-15.0	-3.35	.079	-1.050	-1.883
73	.10	15	180	220	7.2	190	-15.9	-3.15	- .077	- .361	-2.359
74	.10	10	<10	140	5.6	154	-16.0	-3.20	.019	- .433	-2.590
75	.10	6.7	<10	80	7.5	92	-18.4	-3.60	- .318	-1.873	-2.692
76	.10	11	1,800	140	0	343	-7.9	-1.55	- .012	-1.333	-1.385
77	.10	13	60	150	6.3	243	-17.5	-3.35	.027	- .668	-1.802
78	< .10	5.4	880	100	8.8	256	-13.5	-2.65	.017	-1.224	-2.988
79	.10	4.3	2,900	120	9.1	414	–	–	- .106	-1.410	-1.751
80	.40	9.0	3,700	90	0	220	-12.5	-2.35	.063	-1.183	-1.878
81	.10	8.6	–	200	7.8	189	-19.5	-3.60	- .020	- .842	-2.180
82	.10	8.6	3,200	290	4.1	578	-8.9	-1.75	.021	-1.046	-1.587
83	.20	10	–	50	7.5	93	-18.5	-3.60	- .307	- .959	-2.943
84	–	–	–	–	6.4	–	-18.5	-3.50	–	–	–
85	–	–	–	–	8.3	–	-17.5	-3.60	–	–	–
86	< .10	9.7	<10	160	6.9	184	-17.5	-3.45	- .037	- .626	-2.244
87	.20	11	<10	210	5.6	238	-16.0	-3.10	.295	.039	-2.119
88	.20	5.4	40	70	8.4	185	-18.0	-3.50	- .001	-1.448	-2.214
89	.10	7.3	<10	90	10	132	-18.0	-3.60	.024	- .916	-2.679
90	.20	10	<10	180	7.3	183	-19.5	-3.35	.005	- .463	-2.263

Appendix B. Water-quality data, part 3 —Continued

[°C, degrees Celsius; mV, millivolts; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; TU, tritium unit; permil, part per thousand; –, no data; <, less than]

Well number	Dissolved fluoride (mg/L as F)	Dissolved silica (mg/L as SiO_2)	Dissolved iron (µg/L as Fe)	Dissolved strontium (µg/L as Sr)	Total tritium (TU)	Dissolved solids residue at 180 °C (mg/L)	$^2H/^1H$ stable isotope ratio (permil)	$^{18}O/^{16}O$ stable isotope ratio (permil)	Saturation index		Log P_{CO_2} (atmospheres)
									Calcite	Dolomite (ordered)	
91	.20	6.5	20	80	8.8	224	-19.5	-3.80	- .205	-1.793	-1.603
92	.30	10	900	290	5.0	294	-13.0	-3.10	- .088	- .622	-1.598
93	.20	9.1	<10	170	6.9	153	-17.5	-3.70	- .084	- .711	-2.489
94	.20	7.5	10	60	6.7	151	-20.0	-3.85	- .035	-1.543	-2.287
95	< .10	8.2	20	120	7.9	161	-18.0	-3.55	.029	- .486	-2.414
96	.40	8.3	4,300	180	7.5	265	-16.5	-3.05	.024	- .979	-1.678
97	.10	7.3	10	140	7.8	148	-17.5	-3.60	- .978	-3.012	-1.731
98	< .10	6.6	<10	30	7.8	40	-22.0	-3.90	- .584	-2.358	-3.018
99	< .10	7.9	<10	80	9.1	77	-20.0	-3.65	.018	- .666	-3.044
100	.10	6.6	2,600	140	9.4	214	-19.0	-3.60	.166	- .262	-2.062
101	.20	5.4	10	50	9.4	121	-20.5	-3.90	.051	-1.300	-2.686
102	.10	3.3	2,100	70	6.6	125	3.9	1.64	- .392	-1.766	-1.484
103	.20	10	10	80	9.1	100	-20.0	-3.95	.005	- .680	-3.150
104	.10	5.4	60	80	8.1	208	-17.0	-3.40	.120	- .127	-1.913
105	.20	3.9	560	110	11.6	481	-21.0	-3.90	.140	- .161	-2.851
106	.30	7.0	<10	330	8.8	172	-17.5	-3.65	.074	-1.330	-1.926
107	.50	7.1	<10	540	7.9	189	-19.0	-3.60	.092	- .429	-2.457
108	.20	11	10	170	9.1	283	-21.5	-4.05	.015	- .828	-1.994
109	.20	12	<10	210	7.8	347	-19.0	-3.75	- .017	- .749	-2.594
110	.10	6.2	<10	50	10.6	98	-20.0	-3.75	- .014	- .511	-3.504
111	.10	8.3	10	110	11.6	298	-20.0	-3.75	.019	-1.218	-1.590
112	< .10	5.9	10	40	10.6	86	-20.0	-3.80	.488	.612	-2.242

Appendix C. DRASTIC indices for areas around sampled wells

[D, depth to water; R, net recharge; A, aquifer media; S, soil media; T, topography; I, impact of the vadose zone; C, hydraulic conductivity. DRASTIC indices were not calculated for Levy and Lake Counties; therefore, wells 71, 110, and 112 are not included in this appendix. From E. DeHaven, Southwest Florida Water Management District, written commun., 1988]

Well number	Name	D	R	A	S	T	I	C	Index
1	Charlotte ROMP TR3-1 Suwannee	5	4	30	1	1	1	12	54
2	Charlotte ROMP 10 Deep Creek 917	5	4	30	1	1	1	12	54
3	De Soto Hancock and Lawrence	5	4	30	1	1	1	24	66
4	Sarasota ROMP TR5-2	5	4	30	1	1	1	12	54
5	De Soto ROMP 16 Ocala	5	4	30	1	1	1	24	66
6	De Soto ROMP 26	5	4	30	1	1	1	18	60
7	Manatee Verna deep well 1A	5	12	30	1	1	1	18	68
8	Coca Cola well Highlands	5	12	30	1	1	1	24	74
9	Manatee ROMP 32-2	5	12	30	1	1	1	6	56
10	Hardee Zolfo Springs 1	5	4	30	1	1	1	30	72
11	Hillsborough Sun City 1	5	4	30	2	1	5	18	65
12	Hillsborough ROMP 48 near Fort Lonesome	5	32	30	2	1	5	18	93
13	Sweat well Hillsborough HRS34	5	12	30	2	1	5	18	73
14	Polk ROMP 55 Suwannee	5	32	30	2	1	5	18	93
15	Polk Lake Garfield Nurseries	5	12	30	18	10	10	18	103
16	Pebbledale Road	5	32	30	2	1	5	18	93
17	Steelman well Pinellas HRS34	5	4	30	2	1	5	6	53
18	Pardo well Hillsborough HRS67A	10	4	30	2	1	5	12	64
19	St. Catherine deep well	10	4	30	18	10	20	6	98
20	Ward well Hillsborough HRS66	25	4	30	18	10	30	24	141
21	Pope well Hillsborough HRS65	35	4	30	18	10	40	24	161
22	Griffin well Hillsborough HRS20	25	4	30	18	10	40	24	151
23	Wilson well Hillsborough HRS61	25	24	30	18	10	40	24	171
24	Fox well Hillsborough HRS62	35	32	30	15	10	40	24	186
25	Graham well Pinellas HRS26	35	24	30	18	10	30	12	159
26	Ward well Hillsborough HRS9	45	4	30	18	10	40	12	159
27	Koch well Hillsborough HRS60	25	4	30	18	10	40	24	151
28	Lambert well Pinellas HRS23	35	4	30	18	10	20	6	123
29	Armstrong well Hillsborough HRS59	25	24	30	18	10	40	24	171
30	Smith well Polk HRS31	10	32	30	18	10	20	12	132
31	Kelly well Polk HRS24	10	32	30	15	10	20	18	135
32	Polaski well Pinellas HRS16	35	24	30	18	9	40	6	162
33	Palmer well Hillsborough HRS54	35	24	30	18	10	40	12	169
34	Polk Lake Lucerne well 1PN-155	5	32	30	18	10	20	12	127
35	Morris Bridge area 514 deep	25	4	30	4	10	40	12	125
36	Upcavage well Hillsborough HRS5	35	36	30	18	10	40	12	181
37	Denney well Pinellas HRS10	25	36	30	18	10	40	12	171
38	Davis well Polk HRS47	10	32	30	18	10	20	18	138
39	Ziemnin well Hillsborough HRS52	35	36	30	18	10	40	12	181
40	Section 21 well field 468 deep	25	36	30	18	10	40	12	171
41	Cosme well field 313 deep	25	36	30	18	10	40	12	171
42	Burkhart well Hillsborough HRS51	25	36	30	18	10	40	12	171
43	Carlson well Pinellas HRS8	45	24	30	18	10	40	12	179
44	Hejl well Pinellas HRS3	35	24	30	18	10	40	12	169
45	Carter well Pinellas HRS1	35	12	30	18	10	40	6	151

Appendix C. DRASTIC indices for areas around sampled wells —Continued

[D, depth to water; R, net recharge; A, aquifer media; S, soil media; T, topography; I, impact of the vadose zone; C, hydraulic conductivity. DRASTIC indices were not calculated for Levy and Lake Counties; therefore, wells 71, 110, and 112 are not included in this appendix. From E. DeHaven, Southwest Florida Water Management District, written commun., 1988]

Well number	Name	D	R	A	S	T	I	C	Index
46	Hall well Hillsborough HRS8	45	4	30	18	10	40	12	159
47	Eldridge-Wilde well field 142 deep	25	36	30	18	10	40	12	171
48	Royce well Polk HRS8	10	32	30	4	10	30	12	128
49	Burkam well Pasco HRS46	35	32	30	18	10	30	12	167
50	Fussell well Polk HRS7	10	24	30	18	10	30	12	134
51	Pasco well field 223 deep	25	36	30	18	10	40	12	171
52	Mickler well Pasco HRS34	50	4	30	18	10	40	6	158
53	Barclay well Pasco HRS65	35	36	30	18	10	40	12	181
54	Wells well Polk HRS44	25	32	30	18	10	40	12	167
55	Hughes well Pasco HRS48	35	4	30	18	10	40	12	149
56	Bexley well 743 deep	25	36	30	18	10	40	6	165
57	Starkey well field 728-52	45	12	30	18	10	40	6	161
58	Wyatt well Polk HRS5	45	12	30	18	10	40	12	167
59	Goodman well Polk HRS9	10	32	30	18	10	30	12	142
60	Cypress Creek well field 829 deep	35	36	30	4	10	40	6	161
61	Rogers well Pasco HRS58	45	36	30	18	10	40	6	185
62	Tagge well Polk HRS4	10	12	30	18	10	30	12	122
63	Stewart well Pasco HRS63	35	4	30	16	10	30	30	155
64	Becken well Pasco HRS29	35	32	30	18	10	30	6	161
65	Dillman well Polk HRS1A	25	12	30	18	10	40	12	147
66	Bryant well Pasco HRS30	35	4	30	16	5	20	12	122
67	Lewis well Pasco HRS17	50	4	30	18	10	50	18	180
68	Swan well Pasco HRS8	50	36	30	18	10	50	24	218
69	Green Swamp well L11KD	50	12	30	18	10	50	12	182
70	Smith well Pasco HRS55	45	4	30	18	9	40	30	176
72	Pike well Pasco HRS54	25	32	30	14	10	40	24	175
73	Magnolia Springs well	50	4	30	4	10	50	18	166
74	Anderson well Pasco HRS1	25	32	30	16	5	20	24	152
75	Bridges well Hernando HRS64	25	36	30	18	10	40	30	189
76	Sumter USGS Richloam	35	12	30	18	10	40	12	157
77	Hernando HRS43 Bedillion	25	32	30	14	10	30	30	171
78	Hernando HRS51	45	32	30	16	10	50	12	195
79	Wathen well Hernando HRS14	45	36	30	18	9	50	30	218
80	Franklin well Sumter HRS44	45	32	30	18	10	50	30	215
81	Edwards well Hernando HRS21	15	36	30	18	9	40	30	178
82	Hernando HRS31	45	32	30	16	10	50	12	195
83	Justice well Hernando HRS60	15	36	30	18	9	30	30	168
84	Hernando HRS26	25	36	30	18	9	40	30	188
85	Hernando HRS12	25	36	30	16	9	30	30	176
86	Hernando HRS7	15	36	30	16	9	30	30	166
87	Hernando HRS6	10	36	30	14	9	40	30	169
88	Staples well Sumter HRS34	45	32	30	18	10	50	12	197
89	Hernando HRS10	35	36	30	18	9	50	30	208
90	Hernando HRS4	25	36	30	14	9	20	30	164
91	Zentz well Sumter HRS32	45	36	30	16	10	50	30	217

Appendix C. DRASTIC indices for areas around sampled wells —Continued

[D, depth to water; R, net recharge; A, aquifer media; S, soil media; T, topography; I, impact of the vadose zone; C, hydraulic conductivity. DRASTIC indices were not calculated for Levy and Lake Counties; therefore, wells 71, 110, and 112 are not included in this appendix. From E. DeHaven, Southwest Florida Water Management District, written commun., 1988]

Well number	Name	D	R	A	S	T	I	C	Index
92	Rita Maria Springs well	50	36	30	4	10	50	30	210
93	Citrus Coats well	5	36	30	16	9	30	30	156
94	Roberts well Sumter HRS28	25	32	30	18	10	40	30	185
95	Citrus Sugarmill Woods	25	36	30	18	10	30	30	179
96	Swisshelm well Sumter HRS18	50	32	30	18	10	50	30	220
97	Dumal well Citrus HRS28	50	36	30	4	10	50	30	210
98	Byerley well Citrus HRS38	15	36	30	18	9	40	30	178
99	Garland well Citrus HRS33	10	36	30	18	9	30	30	163
100	Coon well Citrus HRS15	50	32	30	18	10	50	30	220
101	Lambert well Sumter HRS4	45	36	30	18	10	50	30	219
102	Sale well Citrus HRS21	45	36	30	18	10	50	30	219
103	Gephart well Sumter HRS52	25	36	30	18	10	30	30	179
104	Norbert well Marion HRS30	45	36	30	18	10	50	30	219
105	Weaver well Citrus HRS1	50	32	30	18	10	50	12	202
106	Biederman well Marion HRS25	10	36	30	18	10	30	30	164
107	Yonke well Marion HRS26	25	36	30	18	10	30	30	179
108	Teagle well Marion HRS13	35	36	30	18	10	50	30	209
109	Freimuth well Marion HRS10	15	36	30	14	10	40	30	175
111	Kohr well Marion HRS4	25	36	30	18	10	50	30	199

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