

Hydrochemistry of the Surficial and Intermediate Aquifer Systems in Florida

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Conversion Factors, Vertical Datum, Abbreviated Water-Quality Units, and Acronyms

Multiply	By	To obtain
cubic foot (ft ³)	0.00283	cubic meter
cubic foot per day (ft ³ /d)	0.00283	cubic meter per day
cubic foot per day per square foot times foot of aquifer thickness [(ft ³ /d)/ft ²]ft	0.0929	cubic meter per day per square meter times meter of aquifer thickness
foot (ft)	0.3048	meter
million gallons per day (Mgal/d)	0.0438	cubic meter per second
square foot (ft ²)	0.0929	square meter
inch per year (in/yr)	25.4	millimeter per year

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
 $^{\circ}\text{C} = \frac{5}{9} \times (^{\circ}\text{F} - 32)$.

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

Abbreviated water-quality units:

mg/L milligrams per liter
 meq/L milliequivalents per liter

Acronyms:

CBE Charge-balance error
 FGWMN Florida Ground Water Quality Monitoring Network
 IAP Ion activity product
 Log ^PCO₂ Logarithm of partial pressure of carbon dioxide
 WATSTORE National Water-Data Storage and Retrieval System
 SI Saturation index
 K_T Thermodynamic equilibrium constant

Hydrochemistry of the Surficial and Intermediate Aquifer Systems in Florida

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ABSTRACT

Hydrochemistry of the surficial and intermediate aquifer systems in Florida reflects the lithology and mineralogy of units within each aquifer and sources of water to each aquifer. The surficial aquifer system consists of sand, sandstone, clay, limestone, and shell units that are recharged primarily by precipitation. Calcium bicarbonate was the major-ion water type for 53 percent of the surficial aquifer determinations; a mixed water type (no dominant ions) accounted for 37 percent of the determinations. The median dissolved-solids concentration for the surficial aquifer system was 341 milligrams per liter.

The intermediate aquifer system consists of limestone, dolomite, sand, and sandstone, and sources of water include downward leakage from the surficial aquifer system and, in some areas, upward leakage from the Upper Floridan aquifer. In northeastern and panhandle areas of Florida, water from the intermediate aquifer system had major-ion and dissolved-solids concentrations similar to water from the surficial aquifer system. In southwestern Florida, the water type in 67 percent of analyses was mixed, and the median dissolved-solids concentration was 642 milligrams per liter. In a northern area of southwestern Florida, hydrochemistry in the limestone aquifer of the intermediate aquifer system is similar to downward leakage from the surficial aquifer system. In a southern area, downward leakage from the surficial aquifer system has calcium and bicarbonate concentrations five times higher than in the northern area, and upward leakage from the Upper Floridan aquifer contains sodium chloride type water from mixing with seawater. In southern southwest Florida, both the limestone aquifer and the overlying sandstone aquifer within the intermediate aquifer system had higher calcium, sodium, chloride, and bicarbonate concentrations than the limestone aquifer in northern southwest Florida.

INTRODUCTION

The surficial and intermediate aquifer systems in Florida are the primary sources of ground-water supplies in areas where the underlying Floridan aquifer system contains nonpotable water or is too deep for affordable use. The Floridan aquifer system underlies the entire State and

supplies most of the ground water used. The surficial and intermediate aquifer systems supplied 12 percent of the ground water withdrawn for public-supply use in Florida in 1985 (Marella, 1988, p. 16). In addition, domestic self-supplied users throughout the State also rely on aquifer systems overlying the Floridan aquifer system because sufficient quantities of water can be obtained without the cost of installing deep wells. Public-supply water represents water supplied by utilities for domestic and other uses and domestic self-supplied water represents water from individual domestic wells or supplied by utilities serving fewer than 400 people; both are sources of drinking water.

The surficial aquifer system is predominantly used for public supply in southwestern and eastern Florida. Some counties in southwestern Florida rely on the surficial aquifer system as a primary water-supply source. The aquifer system contains highly permeable sediments in some areas and is up to 400 feet thick in parts of the State. Because this aquifer system is contiguous with the land surface and its water is generally unconfined or semiconfined, it is particularly vulnerable to local contamination from surface sources. In coastal areas, the surficial aquifer system is also affected by saltwater intrusion.

The area of principal use of the intermediate aquifer system is in southwestern Florida. Charlotte, Collier, Glades, Hendry, and Lee Counties withdraw most of their public-supply water from this aquifer system because the underlying Floridan aquifer system in these areas contains nonpotable water. In other parts of southwestern Florida, water-supply wells are commonly open to both the intermediate and the Floridan aquifer systems (Lewelling, 1988). Several other adjacent counties also rely on the intermediate aquifer system, mostly for agricultural irrigation. Recent population growth in coastal areas and increased agricultural activity in rural areas have increased ground-water withdrawals in southwestern Florida. Sometimes this water is unsuitable for most uses; some communities in coastal, southwestern Florida treat water withdrawn from this aquifer system for public supply (Dykes and Conlon, 1989; Marella, 1990).

Deterioration in water quality may occur in the intermediate aquifer system in coastal areas from saltwater intrusion and where there is upward leakage of nonpotable

water from the underlying Upper Floridan aquifer. Many wells in southwestern Floridan have been installed with open intervals that span both the intermediate and Floridan aquifer systems (Duerr and others, 1988); higher heads in the Floridan aquifer system in this area (Healy, 1975) favor the upward movement of the nonpotable water from the Floridan aquifer system through these open intervals to the intermediate aquifer system. Detailed comparison of the hydrochemistry in the two aquifer systems may help to identify areas where this has occurred.

Concerns about water quality in the major aquifer systems in Florida led to the passage of the Water Quality Assurance Act in 1983 by the State of Florida and the establishment of the Florida Ground Water Quality Monitoring Network (FGWQMN). The FGWQMN was established by the Florida Department of Environmental Regulation (FDER) in cooperation with the water management districts and other State and county agencies to monitor water quality and establish baseline conditions in each of the major aquifer systems (Florida Department of Environmental Regulation, 1990). This study was undertaken by the U.S. Geological Survey in cooperation with the FDER to describe the hydrogeology and the baseline hydrochemistry in the surficial and intermediate aquifer systems in Florida.

Purpose and Scope

The baseline hydrochemistry in the surficial and intermediate aquifer systems in Florida is described as well as variations in hydrochemistry of the intermediate aquifer system in two areas of southwestern Florida where sufficient data were available to compare the effects of leakage from the overlying surficial aquifer system and the underlying Upper Floridan aquifer.

The analysis of the baseline hydrochemistry of the surficial and intermediate aquifer systems is based on samples collected by the FDER and other State agencies, including the five water management districts. Additional data were obtained from samples collected for various studies done by the U.S. Geological Survey (USGS) on the water resources and water quality of the intermediate aquifer system. Additional USGS data were not used from the surficial aquifer system because wells installed in the surficial aquifer system in past studies usually were installed to monitor specific sources of contamination and, therefore, would not be suitable for evaluating baseline conditions. The study area includes all of Florida, but more detail was given to those areas of principal use of each of the aquifer systems and to the areas where the monitoring wells were located. The sand-and-gravel aquifer of the surficial aquifer system and the Biscayne aquifer have been described in previous publications (Katz and Choquette, 1991; Radell and Katz, 1991).

Previous Investigations

Many investigations have described the hydrogeology and water quality of the surficial and intermediate aquifer systems in Florida. The most comprehensive study was done by Healy (1982) which included descriptions of both of these aquifer systems statewide. Many other publications have focused on these aquifer systems in limited geographic areas. Wolansky and others (1979) mapped the thickness of deposits overlying the Floridan aquifer system in part of southwestern Florida. Investigations of the water resources of Alachua, Bradford, Clay, and Union Counties by Clark and others (1964), Glades and Hendry Counties by Klein and others (1964), parts of Sarasota and Charlotte Counties by Joyner and Sutcliffe (1976), and De Soto and Hardee Counties by Wilson (1977) included descriptions of the two aquifer systems.

Many other reports include descriptions of the surficial and intermediate aquifer systems in investigations of the water resources of individual counties. These include investigations done by Sutcliffe (1975) in Charlotte County; McCoy (1962), Klein (1980), and Knapp and others (1986) in Collier County; Smith and Adams (1988) in Hendry County; Sproul and others (1972), Wedderburn and others (1982), and Sutcliffe and Thompson (1983) in Lee County; Peek (1958) and Brown (1983) in Manatee County; Stewart (1966) in Polk County; and Wolansky (1983), Hutchinson (1984), and Duerr and Wolansky (1986) in Sarasota County. Previous reports about the surficial aquifer system have focused on those geographical areas where the aquifer system is used as a water supply. Boggess and Watkins (1986) described the surficial aquifer system in eastern Lee County. Klein (1972) studied the surficial aquifer system in an area including Collier County and parts of Hendry and Lee Counties. Klein and Causaras (1982) described the surficial aquifer contiguous with the Biscayne aquifer in Palm Beach, Martin and St. Lucie Counties and additional studies were done in Palm Beach County (Miller, 1987) and in Martin and St. Lucie Counties (Miller, 1980). Other studies have been done in Indian River County (Schiner and others, 1988), Pinellas County (Causseaux, 1985), Duval County (Causey and Phelps, 1978), and St. Johns County (Hayes, 1981; Spechler and Stone, 1983).

The intermediate aquifer system has been referred to by a variety of names in previous reports. A partial listing of these names have been included in a report by Corral and Wolansky (1984) and will be summarized here, along with additional references. The intermediate aquifer system has been called: the secondary artesian aquifer by Peek (1958) in Manatee County, by Stewart (1966) in Polk County, and by Clark and others (1964) in Alachua, Bradford, Clay, and Union Counties; the upper unit of the Floridan aquifer by Pascale and Wagner (1982) in parts of Gadsden, Leon,

Liberty, and Wakulla Counties and by Wilson (1977) in De Soto and Hardee Counties; zones 2 and 3 by Joyner and Sutcliffe (1976) in parts of Sarasota and Charlotte Counties; the upper and lower aquifers by Sproul and others (1972) in Lee County; and zones 1, 2, and 3 by Sutcliffe and Thompson (1983), also in Lee County. New nomenclature was adopted for the major aquifer systems in Florida in 1986 (Southeastern Geological Society, 1986) and these earlier names were replaced by the "intermediate aquifer system." In the rest of this report the intermediate aquifer system will be substituted for these earlier aquifer names.

To date, Duerr and others (1988) have provided the most comprehensive study of the intermediate aquifer system in a report that described the geohydrology of the aquifer system in the Southwest Florida Water Management District. This area includes approximately the northern half of the area of principal use of the intermediate aquifer system. Ryder (1985) included descriptions of the confining units and permeable deposits of the intermediate aquifer system in his discussion of the Floridan aquifer system in approximately the same area. Duerr and Enos (1991) reported on the intermediate aquifer system in De Soto and Hardee Counties. To the south, descriptions of the intermediate aquifer system can be found in reports by Wedderburn and others (1982) in Lee County, Knapp and others (1986) in Collier County, and Smith and Adams (1988) in Hendry County. In addition, several studies have addressed the effects of upward movement of saline water from the Upper Floridan aquifer on ground-water quality of the intermediate aquifer system in Lee County (Boggess and others, 1977; Fitzpatrick, 1986; La Rose, 1990).

Methods

The data used in this report consist of information collected and compiled as part of the FGWQMN, a statewide program designed to study the hydrogeology and water chemistry of the aquifer systems in Florida. Wells selected for the FGWQMN by the water management districts and the Alachua County Department of Environmental Services were designated specifically to characterize baseline water-quality conditions in the aquifer systems; that is, these wells were chosen to avoid areas of known ground-water contamination. Analyses of water from 328 wells in the surficial aquifer system and 195 wells in the intermediate aquifer system were provided in the FGWQMN data. These data are currently available in computer files maintained by the FDER (T. Glover, Florida Department of Environmental Regulation, written commun., 1990). The criteria for selection of wells in the FGWQMN were based in part on site history and information on exact well location and well construction (Humphreys, 1986). New wells were installed if these criteria were not met. Water samples were collected from 1984 through 1988.

Detailed methods for collection and analysis of water samples for the FGWQMN program are included in Quality Assurance Project Plans on file with FDER (S. Labbie, Florida Department of Environmental Regulation, written commun., 1990). In general, FDER water sample collection and analysis procedures were very similar to standard USGS methods for sampling (Wood, 1976) and analysis (Fishman and Friedman, 1985). Contract and water-management district laboratories followed a rigorous set of quality assurance measures that included the analysis of duplicate samples, laboratory and equipment blanks, and field blanks. As an additional screening method for the accuracy of the analysis of major ions in a water sample, any analysis whose charge-balance error (CBE) exceeded ± 10 percent was not used for this study. FGWQMN analyses of water from 186 wells tapping the surficial aquifer system, mostly in eastern and peninsular Florida, and from 97 wells tapping the intermediate aquifer system passed this CBE criterion. If multiple water samples existed for a given well, the median value for each major ion was computed from the analyses that passed the CBE criterion.

The sparsity of data (58 wells) from the FGWQMN in the area of principal use of the intermediate aquifer system led to the addition of data in this area from USGS data sources. Additional data for the intermediate aquifer system in southwestern Florida were obtained from the National Water Data Storage and Retrieval System (WATSTORE) data base maintained by the USGS (U.S. Geological Survey, 1974, 1975). Most of these data were collected from October 1975 through September 1989 as part of numerous hydrologic investigations conducted by the USGS. Only analyses containing values for all of the following constituents were included: calcium, magnesium, sodium, potassium, bicarbonate, chloride, and sulfate. Most of these data were from hydrologic investigations that describe the water quality of a certain area or county, not from ground-water contamination studies. The data were edited to eliminate samples from wells that were not within the extent of the intermediate aquifer system in southwestern Florida as outlined by the location of wells in the FGWQMN data set. Also, analyses were eliminated if information concerning the aquifer tapped did not indicate deposits considered to be in the intermediate aquifer system (Wedderburn and others, 1982; Knapp and others, 1986; Duerr and others, 1988; Smith and Adams, 1988; Duerr and Enos, 1991).

The combined data set for the intermediate aquifer system in southwestern Florida contained samples from 58 wells from the FGWQMN data set and 158 wells from the WATSTORE files (after eliminating analyses with CBE greater than 10 percent). Eleven wells were common to both data sets and the combined data set for southwestern Florida contained 469 analyses from 205 wells. The data for the intermediate aquifer system contained a total of 244 wells; 16 wells in northeastern Florida, 23 wells in the panhandle area, and 205 wells in southwestern Florida.

Analyses of water from wells in the Upper Floridan aquifer in southwestern Florida were obtained from existing data bases from previous studies on that aquifer. Katz (1992) studied the hydrochemistry of the Upper Floridan aquifer using the FGWQMN data and USGS data. Data for major ions in water from the Upper Floridan aquifer used in this report (127 wells), were selected from a subset of data analyzed by Katz (1992). The Upper Floridan aquifer wells are located in the same area of southwestern Florida as the FGWQMN wells in the intermediate aquifer system. The data set is in computer files maintained by the USGS.

Geochemical and statistical techniques are used in this report to characterize the hydrochemistry of major ions in the surficial and intermediate aquifer systems and the Upper Floridan aquifer. A widely accepted method for interpreting chemical analyses of ground water in the framework of natural ground-water geochemistry is to assume that the concentrations of all dissolved species are at equilibrium. This assumption allows the use of computer-based thermodynamic models to calculate the distribution and activities of dissolved species (Nordstrom and others, 1979). The computer program WATEQF (Plummer and others, 1976) was used to calculate the activities of actual species for each major ion in solution and the departure from equilibrium (saturation index or SI) for solid phases (minerals) that may be reacting in the system. The SI of a particular mineral is defined as:

$$SI = \log (IAP/K_T),$$

where IAP is the ion activity product of the mineral-water reaction, and K_T is the thermodynamic equilibrium constant adjusted to the temperature of the given sample. When SI is equal to 0, the mineral is in equilibrium with the aqueous phase. When SI is less than 0, the water is undersaturated with respect to a particular mineral; that is, the mineral has thermodynamic potential to dissolve, although the rates of dissolution may be extremely slow. When the SI is greater than 0, the water is supersaturated with respect to a mineral and the mineral has the potential to precipitate out of solution. However, other factors will determine if a mineral will form and grow, such as nucleation energy, surface poisoning, and mineral surface topography (Drever, 1982).

Descriptive statistics are used in this report to summarize concentration data for all major ions (Ca, Mg, Na, K, HCO_3 , Cl, and SO_4), pH, NO_3 , and PO_4 , and values for dissolved solids, and temperature for aquifers or for areal groupings of wells in the various aquifers. The distributions of selected constituents are presented in graphical summaries, which are used to compare the 25th, 50th (median), and 75th percentiles, and the minimum and maximum values for these constituents or properties within the aquifers. Where data for a constituent contained values less than analytical detection limits, methods described by Helsel and Cohn (1988) were used. These methods were devised to compute descriptive statistics for data with multiple detection limits.

SURFICIAL AQUIFER SYSTEM

The surficial aquifer system is the primary source of public-supply water in many counties in western and eastern Florida. In 1985, nearly 9 percent of the total ground water withdrawn in Florida was from the surficial aquifer system and some water was withdrawn in nearly every county in the State for domestic self-supplied use (Marella, 1988). Collier, Flagler, Hendry, Indian River, Martin, Palm Beach, St. Johns, and St. Lucie Counties rely on the surficial aquifer system as a primary source of public-supply water (more than 50 percent of water used) (fig. 1), with the largest withdrawals in Palm Beach (97 Mgal/d), Collier (17 Mgal/d), and St. Lucie (12 Mgal/d) Counties (table 1) (Marella, 1990). Counties that rely on this aquifer system for domestic self-supplied use are Brevard, Duval, Flagler, Indian River, Martin, Nassau, Palm Beach, St. Johns, and St. Lucie Counties (fig. 1; table 1) (R.L. Marella, U.S. Geological Survey, written commun., 1990).

In areas where the surficial aquifer system is used almost exclusively as a source of water supply and has been extensively studied, surficial aquifers have been individually named. The baseline water quality of these aquifers, the sand-and-gravel aquifer in northwest Florida and the Biscayne aquifer in Broward, Dade, and part of Palm Beach Counties, have been the focus of previous studies by Katz and Choquette (1991) and Radell and Katz (1991), respectively, and will not be discussed in this report.

Hydrogeology

The surficial aquifer system consists of deposits ranging in age from late Miocene to Holocene whose upper surface is contiguous with the land surface, except in those places where the Floridan aquifer system is at or near land surface (Southeastern Geological Society, 1986). Water in the surficial aquifer system is generally unconfined, but locally may be semi-confined or confined where beds of low permeability that retard circulation between water-bearing units are present (Klein, 1972; Wolansky and others, 1979; Schiner and others, 1988).

Deposits in the surficial aquifer system throughout the State include sand, sandstone, sandy clay, silt, clay, limestone, shell and shelly marl (Wolansky and others, 1979; Miller, 1980; Healy, 1982). In Brevard and Indian River Counties the aquifer system consists of fine- to medium-fine-grained sand (Skipp, 1988) and in Martin and St. Lucie Counties, the aquifer system consists of sand, clay, silt, shell, and limestone (Miller, 1980). The surficial aquifer system in Palm Beach County is composed of sand, sandstone, shell, silt, calcareous clay (marl), and limestone (Miller, 1987). In the Southwest Florida Water Management District, the surficial aquifer system includes deposits of sand, clayey sand, shell and shelly marl (Wolansky and others, 1979). In Collier,

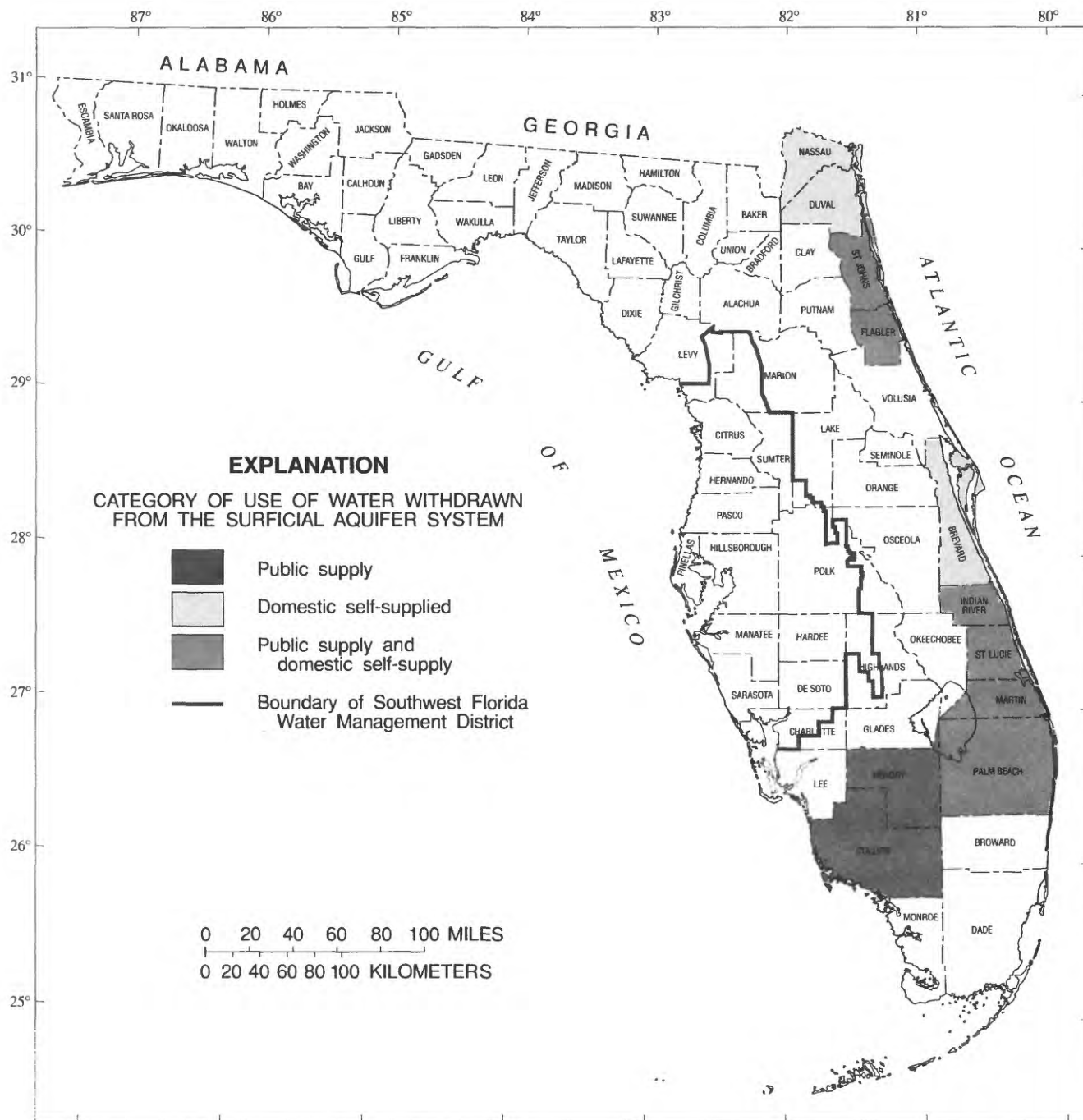


Figure 1. Locations of principal counties using water from the surficial aquifer system for public supply and domestic self-supplied use. (Data from R.L. Marella, U.S. Geological Survey, written commun., 1990; and Marella, 1990.)

Hendry, and Lee Counties, Klein (1972) described units of sand and sandy clay and a highly permeable unit of solution riddled limestone. Detailed descriptions of formations in the surficial aquifer system may be found in Klein (1972), Wedderburn and others (1982), Knapp and others (1986), Healy (1982), Miller (1987), and Smith and Adams (1988). Geologic and hydrogeologic units for the surficial aquifer system in southwestern Florida are listed in table 2.

The surficial aquifer system in Florida ranges in thickness from tens of feet to approximately 400 feet. The thickness of the surficial aquifer system is approximately 100 to 200 ft in Indian River County (Schiner and others, 1988). In Martin and St. Lucie Counties, the surficial aquifer ranges in thickness from approximately 80 to 200 ft (Miller, 1980). In Palm Beach County, the thickness of the surficial aquifer system ranges from approximately 140 to 350 ft, with greater thicknesses

Table 1. Water withdrawals in 1987 from the surficial aquifer system for public supply and for domestic self-supplied use in counties of major use

[Data from R.L. Marella, U.S. Geological Survey, written commun., 1990; and Marella, 1990; units are million gallons per day, except as noted]

County	Public supply		Domestic, self-supplied	
	Quantity withdrawn from surficial aquifer system	Percent of total public-supply use	Quantity withdrawn from surficial aquifer system	Percent of total domestic self-supplied use
Brevard	4.26	9	5.52	90
Collier	17.43	59	0	0
Duval	0	0	15.53	90
Flagler	1.74	68	.13	52
Hendry	2.98	94	0	0
Indian River	8.59	72	8.29	99
Martin	9.87	98	3.60	50
Nassau	0	0	3.18	80
Palm Beach	96.75	57	3.62	55
St. Johns	4.49	59	1.76	80
St. Lucie	12.18	99	4.79	68

toward the coast (Miller, 1987). The surficial aquifer system ranges in thickness from 25 to 250 ft, with thicknesses between 25 to 75 ft predominating, in the Southwest Florida Water Management District (Wolansky and others, 1979). Farther south, in Collier, Lee, and Hendry Counties, the surficial aquifer system has a maximum thickness of about 130 ft (Klein, 1972).

Transmissivity values for the surficial aquifer system indicate much variability due to the various hydrogeologic units present in the aquifer system and the heterogeneity within the units. Schiner and others (1988) reported transmissivity values ranging from 1,500 to 11,000 [(ft³/d)/ft²]ft in Indian River County, with lower values in the "shallow rock zone" than in the deeper clastic zone. Farther south, in Palm Beach County, Miller (1988) presented transmissivity values for two zones, one zone with a transmissivity range of 1,000 to 100,000 [(ft³/d)/ft²]ft, and another zone where the transmissivity was approximately 5,400 [(ft³/d)/ft²]ft. In the Sarasota-Port Charlotte area, Wolansky (1983) reported transmissivity ranging from 600 to 8,000 [(ft³/d)/ft²]ft in the surficial aquifer deposits. Duerr and Wolansky (1986) reported transmissivity values in eastern Lee County ranging from 1,700 to 7,750 [(ft³/d)/ft²]ft.

The water table of the surficial aquifer system is generally a subdued replica of the topography with steeper gradients near streams and lakes (Healy, 1982). The configuration of the water table may also reflect seasonal changes in precipitation, evapotranspiration, and pumping (Schiner and others, 1988). A map showing the elevation of the water table of the surficial aquifer system in areas of principal use was prepared by Healy (1982).

Recharge to the surficial aquifer system is primarily from precipitation, and most of the State receives precipitation exceeding 50 in/yr (1951-80 average) (Vecchioli and Foose, 1985). Recharge to ground water in Florida varies from near zero to as much as 20 in/yr (Vecchioli and Foose, 1985). Other sources of recharge are return flow of irrigation water and upward leakage from underlying deposits (Duerr and Wolansky, 1986). Discharge from the surficial aquifer system is through losses to evapotranspiration, downward leakage to underlying aquifers, flow to local streams, lakes, canals, and swamps, plus pumping (Vecchioli and Foose, 1985; Duerr and Wolansky, 1986; Schiner and others, 1988).

The base of the surficial aquifer system has been designated as "the top of laterally extensive and vertically persistent beds of much lower permeability" (Southeastern Geological Society, 1986, p. 4). The surficial aquifer system is underlain by confining units of the Tamiami Formation or the Hawthorn Formation of the intermediate aquifer system or the intermediate confining unit in most of the State. The Floridan aquifer system underlies the surficial aquifer system where the intermediate aquifer system or confining unit is absent.

Hydrochemistry

Concentrations of major ions in the surficial aquifer system reflect quality of recharge water, lithology and mineralogy of deposits making up the aquifer system, residence time of water, and proximity to coastal areas and other possible contamination sources. Precipitation provides most of the recharge, with minor recharge coming from irrigation return flow and leakage from underlying deposits. Major-ion, nitrogen, and phosphate concentrations in precipitation collected for several years prior to 1980 from six sites in Florida (two sites in Alachua County, and one each in Bradford, Hillsborough, Orange, and Palm Beach Counties) are listed in table 3 (Sprinkle, 1989). Bicarbonate concentrations are not included in table 3, but are commonly less than 10 mg/L in precipitation (Hem, 1985).

When precipitation enters the ground, the water comes in contact with soils and sediments, and chemical reactions occur causing the chemical composition of the water to change (Snoeyink and Jenkins, 1980). Reactions in the soil commonly cause water to become enriched in carbon dioxide (Stumm and Morgan, 1981), which provides acidity for many weathering reactions (Drever, 1982). Reactions in ground water depend on lithology of sediments. In the surficial aquifer system, sediments range from unconsolidated sand, silt, clay, and shelly units to limestone.

The most frequently occurring water types in the surficial aquifer system, calcium bicarbonate and mixed (no dominant ions) (fig. 2), reflect both the dissolution of shelly and limestone units and the variety of other sediments in the surficial aquifer system, which include sand, silt, and clay. Water

Table 2. Geologic and hydrogeologic units in southwestern Florida

Lee County ¹				Southwest Florida Water Management District ²		
Series	Hydrogeologic unit			Series	Formation	Hydrogeologic unit
	Formation	Regional unit	Local unit			
Holocene	Undifferentiated deposits	Surficial aquifer system	Surficial aquifer	Holocene	Surficial sand, terrace sand phosphorite	Surficial aquifer system
Pleistocene				Pleistocene		
Pliocene	Tamiami Formation					Pliocene
Miocene	Hawthorn Formation	Intermediate aquifer system	Confining unit	Miocene	Hawthorn Formation	
			Sandstone aquifer			
			Confining unit			
			Mid-Hawthorn or Limestone aquifer			
			Confining unit			
			Lower Hawthorn aquifer			
	Tampa Formation		Confining unit		Tampa Formation	
Oligocene	Suwannee Limestone	Floridan aquifer system	Suwannee aquifer	Oligocene	Suwannee Limestone	Floridan aquifer system

¹Modified from La Rose, 1990.²Modified from Duerr and others, 1988.³Includes all or parts of Caloosahatchee Marl and Bone Valley Formation.

types shown in figure 2 are based on milliequivalents per liter. A cation or anion is considered a dominant ion when its percent of the sum of cations or anions is greater than or equal to 60 percent, and two cations or anions are considered dominant when their combined percent of the sum of cations or anions are greater than or equal to 80 percent (Davis and DeWiest, 1966). Ground water is designated as "mixed" water type when any one cation or anion is not more than 60 percent of total equivalence of cations or anions, or any two cations or anions constitute less than 80 percent of the total equivalence of cations or anions. Calcium bicarbonate and mixed water types, represent 53 and 37 percent of analyses of water, respectively, from the 186 wells in the surficial aquifer system used for this study.

Other types of water from the surficial aquifer system include sodium chloride, calcium magnesium bicarbonate,

calcium sulfate, and calcium magnesium sulfate. Sodium chloride type water represents about 5 percent of analyses, and with one exception, these samples were from wells less than 50 ft deep (fig. 3). Of the sites with sodium chloride type water, only 4 out of 10 could be attributed to saltwater intrusion. The four sites were located on the coast and had dissolved-solids concentrations greater than 1,000 mg/L. The rest of the sites showing sodium chloride type water had dissolved-solids concentrations less than 200 mg/L and were located inland from the coast (fig. 2). Possible sources of the sodium chloride type water are contamination from septic tanks or agricultural activities. Other water types, calcium magnesium bicarbonate, calcium sulfate, and calcium magnesium sulfate, accounted for less than 6 percent of the analyses and occurred only in samples from wells less than 50 ft deep.

Table 3. Ranges in concentration of selected constituents in precipitation from six sites in Florida

[Data modified from Sprinkle, 1989; two sites in Alachua County, and one each in Bradford, Hillsborough, Orange, and Palm Beach Counties; mg/L, milligrams per liter]

Constituent	Concentration range (mg/L)
Calcium	0.32 to 3.4
Magnesium	.12 to .6
Sodium	.44 to 2.3
Potassium	.12 to .5
Chloride	.98 to 3.9
Sulfate	2.05 to 3.34
Nitrogen, total	.34 to 2.7
Phosphate	.01 to .02 ^a

^arepresents only 2 sites.

The variability in water types in the most shallow part (less than 50 ft) of the aquifer system (fig. 3) suggests that these samples are affected by surface conditions, probably localized, as well as by variations in lithology. In deeper parts of the aquifer system, differences in lithology or mixing with seawater probably account for the two principal water types, calcium bicarbonate and mixed (fig. 3).

Median concentration and distribution of selected constituents in water from wells tapping the surficial aquifer system are shown in figure 4. Calcium and bicarbonate, the dominant ions, had median concentrations of 86 and 252 mg/L, respectively. Concentrations of dissolved solids ranged from 26 to approximately 10,000 mg/L with a median of 341 mg/L, with 78 percent of analyses having dissolved-solids concentrations between 100 and 1,000 mg/L. Most of the analyses with concentrations outside this range were in samples from shallow wells (less than 50 ft deep) and had mixed or sodium chloride type water (fig. 3). Median pH was 6.8 and median temperature was 24.4°C. The wells sampled had depths ranging from 6 to 240 ft, with a median depth of 30 ft.

Nitrate and phosphate concentrations in the surficial aquifer system were low. Almost 39 percent of the nitrate and 19 percent of the phosphate determinations were less than analytical detection limits. Detection limits ranged from 0.001 to 0.22 mg/L for nitrate as NO₃, and from 0.004 to 0.31 for phosphate as PO₄. Median nitrate and phosphate concentrations were determined using the method by Helsel and Cohn (1988). Median nitrate concentration, as NO₃, was 0.035 mg/L, with a maximum concentration of 52.5 mg/L. Median phosphate concentrations, as PO₄, was 0.031 mg/L, with a maximum concentration of 4.3 mg/L.

The major-ion and nutrient concentrations reflect the relatively low dissolved-solids concentration of water in the surficial aquifer system. Most of the areas of primary use of

the surficial aquifer system have numerous monitoring wells, but some areas have very few. For example, some drinking water is withdrawn from the surficial aquifer system in Brevard, Duval, St. Johns, and Volusia Counties; however, only one or two wells for each of these counties are available and included in the data set.

INTERMEDIATE AQUIFER SYSTEM

The area of principal use of the intermediate aquifer system in southwestern Florida, based on previous investigations and the locations of monitoring wells in the FGWQMN data base, is the primary focus of the discussion of the intermediate aquifer system in this report. De Soto, Glades, Lee, and Sarasota Counties rely on water from the intermediate aquifer system as their primary source of public-supply water, whereas Charlotte, Collier, and Hendry Counties withdraw water from this aquifer system as a supplemental public-supply source (Marella, 1990). Charlotte, Collier, Glades, and Hendry Counties rely on the intermediate aquifer system as a primary source of water for agricultural irrigation and domestic self-supplied water. In addition, counties along the east coast, such as Brevard, Duval, Flagler, Indian River, Martin, St. Lucie, and Volusia use the intermediate aquifer system as a secondary source of water for domestic self-supplied use and agricultural irrigation (R.L. Marella, U.S. Geological Survey, written commun., 1990).

Hydrogeology

The intermediate aquifer system consists of those units between the underlying Floridan aquifer system and the overlying surficial aquifer system and consists of one or more water-bearing units separated by confining units. The intermediate aquifer system also acts as a confining unit for the underlying Floridan aquifer system (Miller, 1986) due to the lower permeability of the units within it compared to units within the Floridan aquifer system.

The Floridan aquifer system underlies the intermediate aquifer system throughout the study area. Transmissivity values in the Upper Floridan aquifer are much higher than those in the overlying aquifers in this area and range from 70,000 to 850,000 [(ft³/d)ft²]ft (Ryder, 1985). Discharge occurs in some areas as upward leakage through confining units (Aucott, 1988), particularly where open intervals of wells allow movement of water to overlying units.

In eastern Florida, Schiner and others (1988) described the intermediate aquifer system in Indian River County as ranging in thickness from 70 to 520 ft. In Volusia County, Knochenmus and Beard (1971) described a shell layer of the intermediate aquifer system that is approximately 0 to 50 ft thick. Farther north, in Alachua, Bradford, Clay, and Union Counties, the intermediate aquifer system is approximately

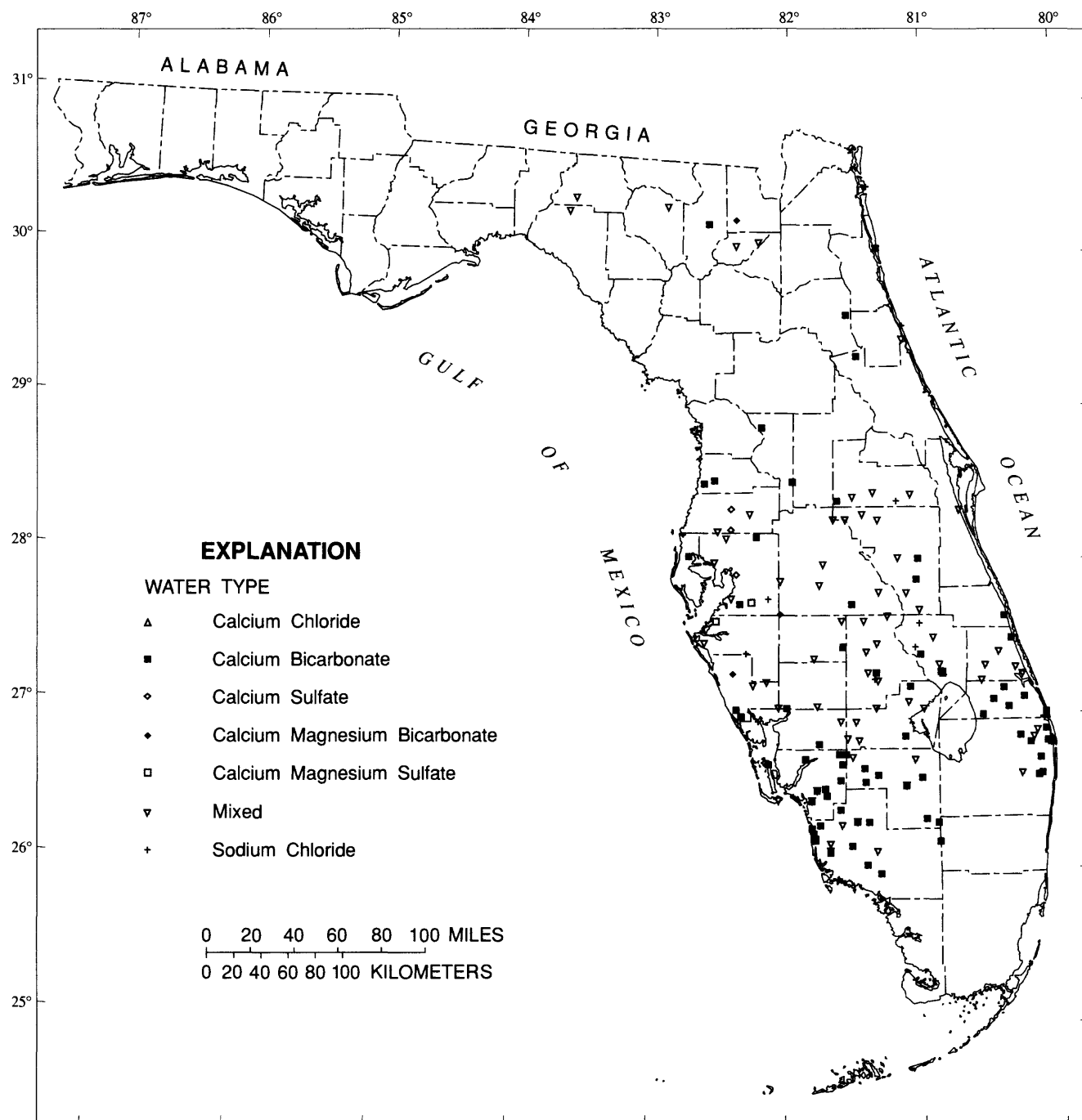


Figure 2. Locations of monitoring wells and dominant-ion water types in samples from wells tapping the surficial aquifer system.

250 ft thick (Clark and others, 1964). Causey and Phelps (1978) reported deposits of the intermediate aquifer system to be generally about 400 ft thick in Duval County.

In the panhandle area of Florida, along the eastern borders of Gadsden and Liberty Counties, and western borders of Leon and Wakulla Counties, Pascale and Wagner (1982) described the units of the intermediate aquifer system as ranging in thickness from approximately 10 to 325 ft. These deposits of the Hawthorn Formation include clay, sand, phosphorite,

and a sandy limestone that is a water-bearing zone with a maximum thickness of 200 ft. The formation has been used as source of water in northern and western Leon County (Hendry and Sproul, 1966) and becomes discontinuous to the south (Pascale and Wagner, 1982).

Duerr and others (1988) described the characteristics of the intermediate aquifer system within the Southwest Florida Water Management District. The intermediate aquifer system contains the Tamiami and Hawthorn Formations and the

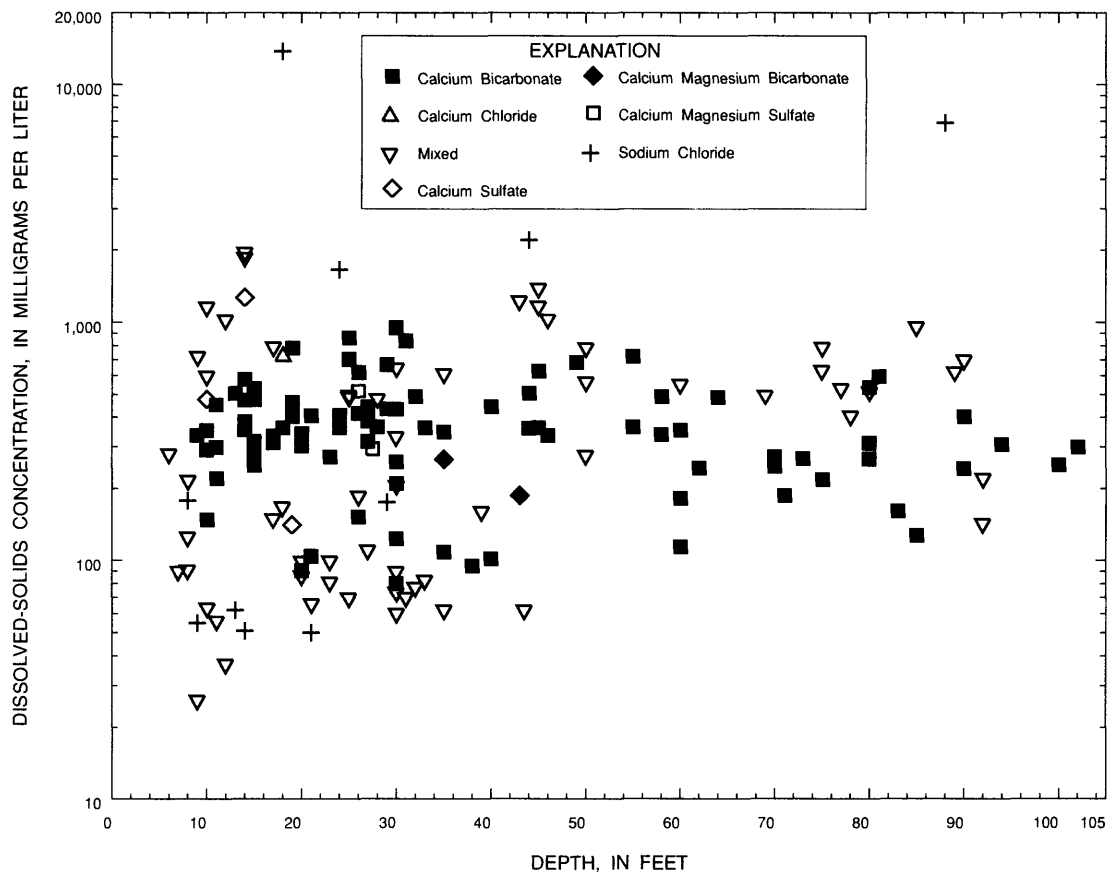


Figure 3. Distribution of dominant-ion water types in the surficial aquifer system and dissolved-solids concentration in ground-water samples as a function of depth of well.

Tampa Limestone (table 2) (Duerr and others, 1988). The Hawthorn Formation comprises most of the intermediate aquifer system sediments and consists of interbedded and intermixed carbonate and siliclastic sediments with varying amounts of phosphate grains (Scott, 1988). The water-bearing units of these deposits contain sand, gravel, shell, limestone, and dolomite, and the confining units consist of sandy clay, clay, and marl (Corral and Wolansky, 1984). In the Sarasota-Port Charlotte area, Wolansky (1983) described an upper and a lower intermediate aquifer, consisting of the Tamiami-Upper Hawthorn and the lower Hawthorn-Upper Tampa Limestone, respectively.

In Collier, Hendry, and Lee Counties, the Tamiami Formation occurs above the beds of lower permeability designated as the base of the surficial aquifer system, so this unit, which is included in the intermediate aquifer system to the north, is not included in the intermediate aquifer system to the south (Wedderburn and others, 1982; Knapp and others, 1986; Smith and Adams, 1988). The top of the Hawthorn Formation is considered the top of the intermediate aquifer system in this area, and the intermediate aquifer system consists of an upper clastic aquifer containing a sandstone unit, a mid-Hawthorn limestone aquifer and a lower Hawthorn aquifer (Knapp and others, 1986; Smith and Adams, 1988) that are separated from one another by confining units.

The sandstone and the mid-Hawthorn limestone aquifers are the principal aquifers in Collier, Hendry, and Lee Counties. The sandstone aquifer is composed of "sandy limestone, sandstone, sandy dolomite and calcareous sands" in Collier County (Knapp and others, 1986) and "very sandy phosphatic limestones and dolomites and may include sandstone or sand with a carbonate matrix" in Lee County (Wedderburn and others, 1982). The mid-Hawthorn is also referred to as the limestone aquifer and is composed of sandy and phosphatic limestones and dolomites in this area (table 2) (Wedderburn and others, 1982; Knapp and others, 1986; La Rose, 1990).

The top of the intermediate aquifer system ranges from more than 100 ft above sea level in Polk County to more than 200 ft below sea level in parts of Collier County (Wedderburn and others, 1982; Knapp and others, 1986; Duerr and others, 1988; and Smith and Adams, 1988). The thickness of the intermediate aquifer system has been mapped only in the area included in the Southwest Florida Water Management District by Duerr and others (1988). The thickness ranges from less than 100 ft in parts of Hillsborough and Polk Counties to more than 800 ft in southern Charlotte County. Individual aquifers within the aquifer system have been mapped in other areas, including Collier, Hendry, and Lee Counties. The thickness of the sandstone aquifer varies from approximately 0 ft in central Lee and

eastern Hendry Counties to approximately 100 ft in eastern Lee and central Collier Counties.

Hydraulic properties of the intermediate aquifer system vary because of the different hydrogeologic units present and heterogeneity within the units. Duerr and others (1988) reported transmissivity values ranging from approximately 200 to 13,300 [(ft³/d)/ft²]ft from Hillsborough County to Charlotte County. In the Sarasota-Port Charlotte area, Wolansky (1983) reported transmissivity values for the upper unit of the intermediate aquifer system of 800 [(ft³/d)/ft²]ft and values of 2,500 and 9,000 [(ft³/d)/ft²]ft for the lower unit, with a value of 2,740 [(ft³/d)/ft²]ft from a well open to both units. Model-derived values of transmissivity for the intermediate aquifer system range from 300 to 10,000 [(ft³/d)/ft²]ft for an area from Polk to Charlotte Counties (Ryder, 1985).

Maps of the potentiometric surface of the intermediate aquifer system are prepared twice annually in the Southwest Florida Water Management District by the USGS. The map prepared for May 1987 (Lewelling, 1988), was examined for this study. Healy (1982) and Duerr and others (1988) also have prepared potentiometric surface maps for the intermediate aquifer system in parts of southwestern Florida. Local (county) maps of the potentiometric surface in this aquifer system have also been compiled for Collier (Knapp and others, 1986), Hendry (Smith and Adams, 1988), Lee (Wedderburn and others, 1982), and Sarasota Counties (Wolansky, 1983). Flow directions are variable, but are generally toward the southwest.

Major sources of recharge to the intermediate aquifer system are downward leakage from the overlying surficial aquifer system (Duerr and others, 1988) and upward leakage in some areas from the Upper Floridan aquifer (Wolansky, 1983). Leakage from the Upper Floridan aquifer occurs in those areas where the potentiometric surface of the Upper Floridan aquifer is higher than that of the intermediate aquifer system, especially at locations where wells have been installed with open intervals to both aquifers. Water discharges from the intermediate aquifer system to the underlying Upper Floridan aquifer where the latter has a lower potentiometric surface, to the surficial aquifer by upward leakage where the potentiometric surface of the intermediate aquifer system is higher than the water table, to the Gulf of Mexico, and to springs and wells (Brown, 1983). In Charlotte and Sarasota Counties, discharge occurs to Charlotte Harbor and along the Myakka and Peace Rivers where the potentiometric surface in the aquifer system is higher than the water table (Wolansky, 1983).

Hydrochemistry

The hydrochemistry of the intermediate aquifer system reflects the different sources of water recharging the aquifer system, the residence time of water, and the mineralogy and lithology of deposits comprising the aquifer system. Sources of water include recharge from the overlying surficial aquifer system and upward leakage from the underlying Upper

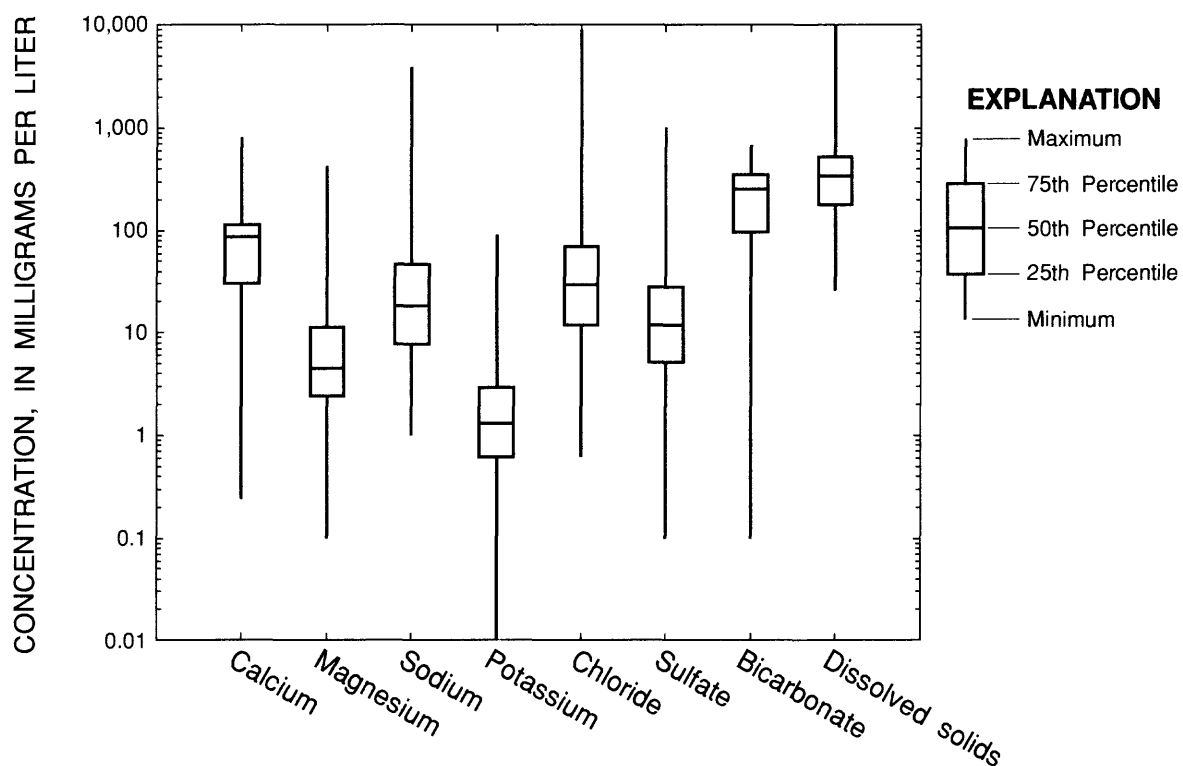


Figure 4. Concentrations of selected constituents in the surficial aquifer system.

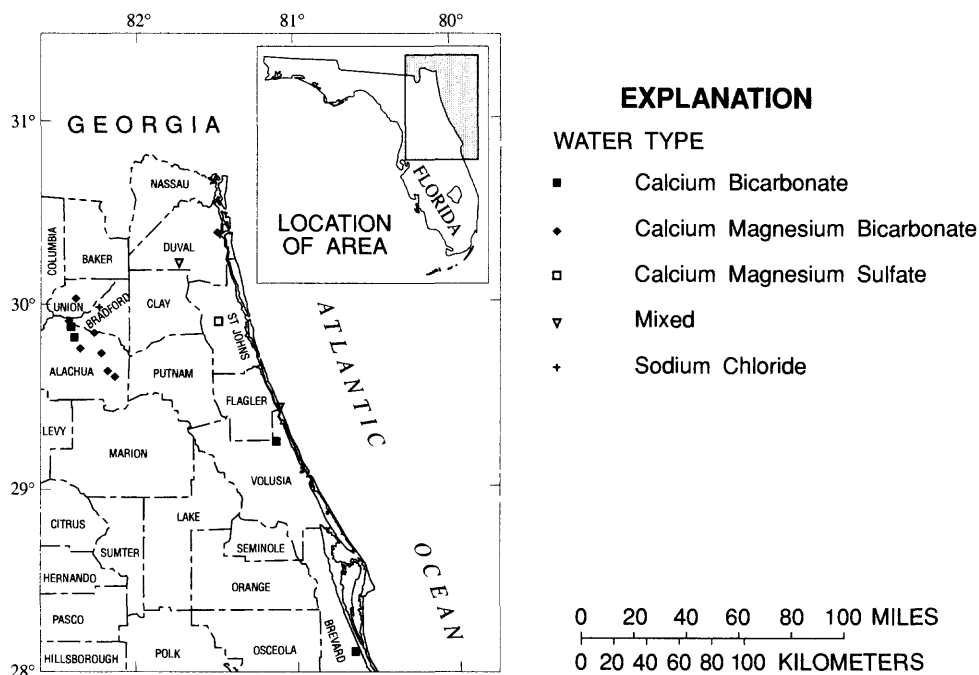


Figure 5. Locations of monitoring wells and dominant-ion water types in samples from wells tapping the intermediate aquifer system in northeastern Florida.

Floridan aquifer. The lithology of the intermediate aquifer system is variable, both vertically and laterally, consisting largely of a mixture of sand, sandstone, limestone, and dolomite. The hydrochemistry of the intermediate aquifer system will be discussed separately for each of three areas of the State: two areas where there is minor use of the intermediate aquifer system, in northeastern Florida and the panhandle area; and the area of principal use of the intermediate aquifer system in southwestern Florida. Ground water is not withdrawn from the intermediate aquifer in most other parts of the State and comprehensive hydrogeologic and water-quality data are lacking for many other parts of the State.

Northeastern Florida

Only 16 wells were included in the data set for the northeastern and eastern coastal area of Florida (fig. 5) because the Floridan aquifer system is the primary source of public-supply water for most of the counties in this area. The median dissolved-solids concentration in the intermediate aquifer system in northeastern Florida was 272 mg/L. Calcium and bicarbonate were the dominant ions with median concentrations of 42 mg/L and 171 mg/L, respectively (fig. 6). Many analyses in this area were missing sulfate concentrations, but because several analyses had a CBE less than ± 10 percent, it was assumed that sulfate was a relatively minor constituent. Nitrate analyses contained 11 values less than analytical detection limits. Detection limits for nitrate as NO_3 ranged from 0.022 to 0.05 mg/L and nitrate concentrations as NO_3 ranged from below detection limits to

0.53 mg/L, with a median of 0.025 mg/L. Phosphate analyses contained three missing values, and four values less than detection limits. Detection limits for phosphate, as PO_4 , ranged from 0.01 to 0.15 mg/L. The median phosphate concentration was 0.307 mg/L and the maximum was 6.1 mg/L.

Panhandle Area of Florida

The data set for the intermediate aquifer system in the panhandle area of Florida included analyses of water from 23 wells (fig. 7). The median concentration of dissolved solids was 160 mg/L (fig. 8). Calcium and bicarbonate were the dominant ions, with median concentrations of 38 mg/L and 134 mg/L, respectively. Other major ions had median concentrations less than 5 mg/L (fig. 8). Nitrate analyses contained four values below the analytical detection limit of 0.22 mg/L as NO_3 . The median nitrate concentration was 3.3 mg/L and the maximum, 12.4 mg/L. Phosphate analyses contained 15 values below the detection limit of 0.03 mg/L as PO_4 . The median phosphate concentration was 0.015 mg/L and the maximum was 0.31 mg/L.

Southwestern Florida

Locations of the 205 wells in the intermediate aquifer system and dominant-ion water types of ground water at each site in southwestern Florida are shown in figure 9. The water type for 67 percent of the analyses was mixed, which most likely indicates a transitional type of ground water between

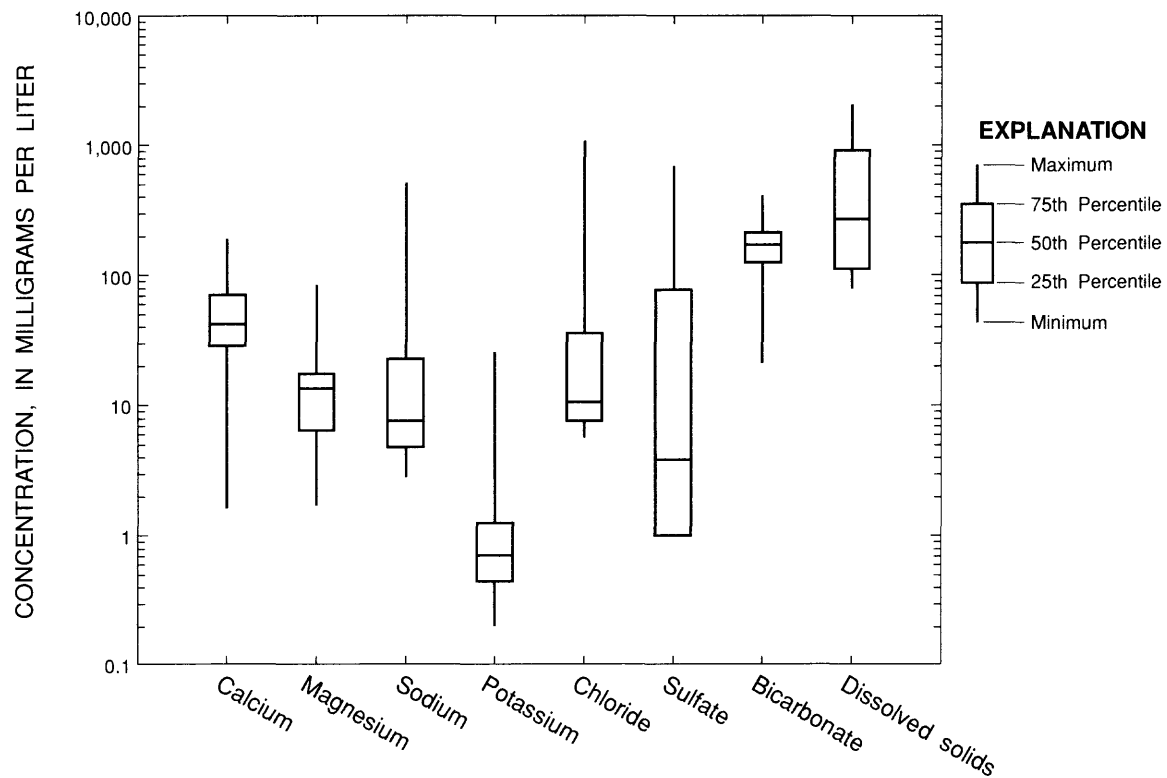


Figure 6. Concentrations of selected constituents in the intermediate aquifer system in northeastern Florida.

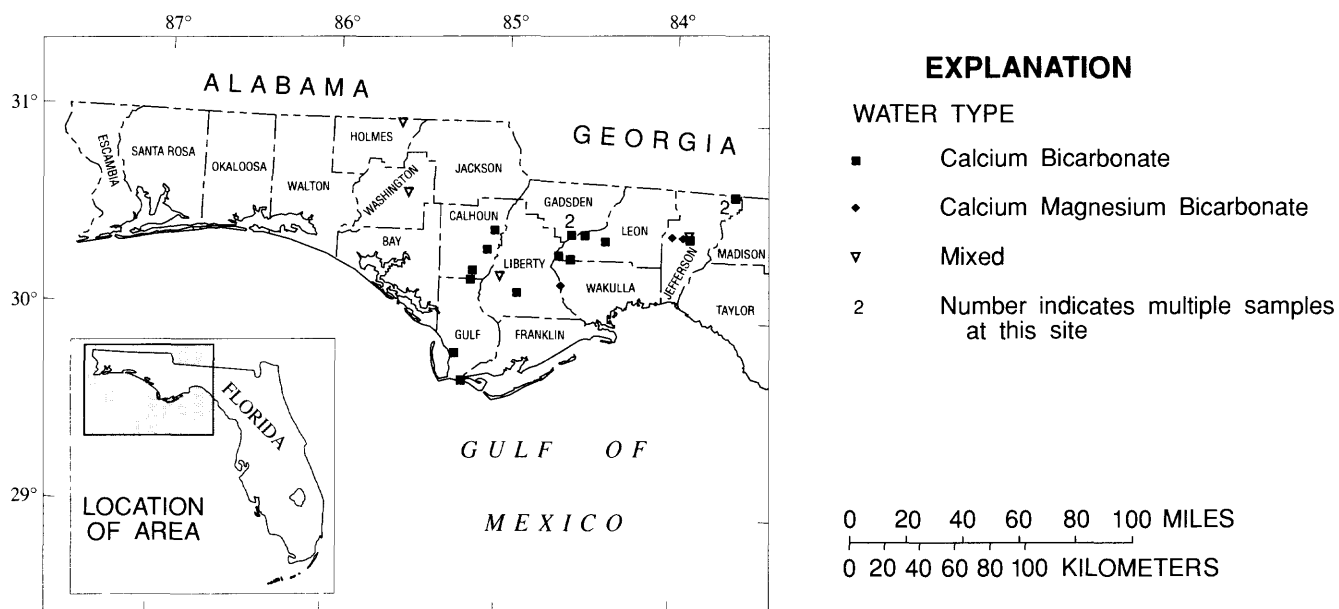


Figure 7. Locations of monitoring wells and dominant-ion water types in samples from wells tapping the intermediate aquifer system in the panhandle area of Florida.

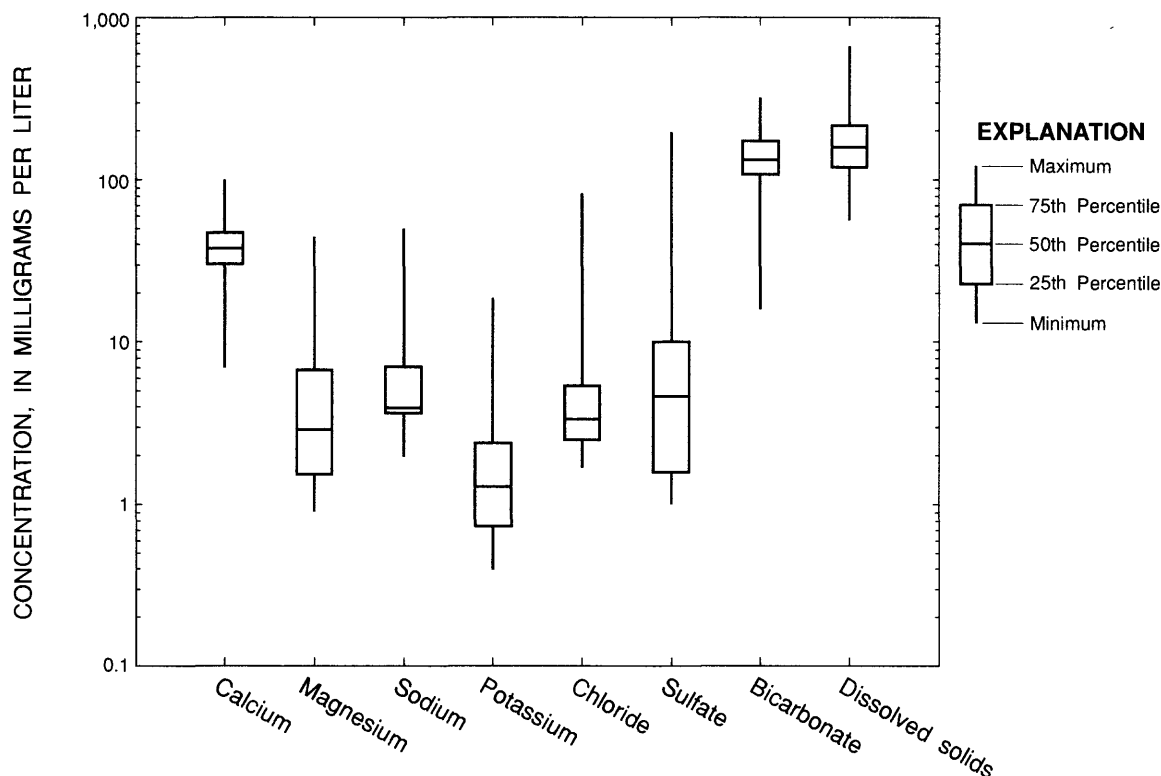


Figure 8. Concentrations of selected constituents in the intermediate aquifer system in the panhandle area of Florida.

the two sources of water moving into the aquifer, the calcium bicarbonate type common in the surficial aquifer system, and sodium chloride, the prevalent water type in the Upper Floridan aquifer system in southern Florida (Katz, 1992). The median dissolved-solids concentration, 624 mg/L, in the intermediate aquifer system also indicates water transitional between the median in southwestern Florida for the surficial aquifer system, 351 mg/L, and the median for the Upper Floridan aquifer, 710 mg/L. The median dissolved solids for the Upper Floridan aquifer was calculated from the data from this aquifer (127 wells) (Katz, 1992). Other water types common in the intermediate aquifer system include calcium magnesium bicarbonate (water type in 10 percent of analyses) and sodium chloride (11 percent of the analyses). All other water types occurred in less than 5 percent of the analyses.

Distributions of concentrations of selected constituents in the intermediate aquifer system are shown in figure 10. Dissolved-solids concentration ranged from 40 to 6,330 mg/L with a median of 624 mg/L, much higher than the range and median in the overlying surficial aquifer system (fig. 4). Sodium, chloride, and bicarbonate show slightly higher concentration ranges than the other constituents, but no ions were dominant. Median pH was 7.5 and the median temperature was 26°C.

Nitrate and phosphate concentrations for the intermediate aquifer system were low. Analyses were available only from the FGWQMN data files. Of the 58 analyses, about 40 percent and 17 percent were less than analytical detection

limits for nitrate and phosphate, respectively. Detection limits ranged from 0.01 to 0.22 mg/L for nitrate as NO_3 , and from 0.04 to 0.31 for phosphate as PO_4 . Median nitrate and phosphate concentrations were determined using the method by Helsel and Cohn (1988). The median nitrate concentration was 0.01 mg/L and the maximum was 0.50 mg/L. The median phosphate concentration was 0.06 mg/L and the maximum concentration was 3.0 mg/L.

FACTORS AFFECTING HYDROCHEMISTRY OF THE INTERMEDIATE AQUIFER SYSTEM

The chemistry of water in the intermediate aquifer system in southwestern Florida is affected by hydrochemical and physical factors, including the ground-water flow system, chemistry of recharge water, lithology and mineralogy of aquifer materials, precipitation and dissolution of minerals, seawater mixing with ground water, and leakage between aquifers through confining units. The effects of most of these factors are determined by assessing the differences between chemistry in samples from the intermediate aquifer system and the overlying and underlying aquifer systems in two areas in southwestern Florida.

Maps prepared by Healy (1975) and Stewart (1980) depicting areas of artesian conditions in the Upper Floridan aquifer and areas of recharge to the Upper Floridan aquifer

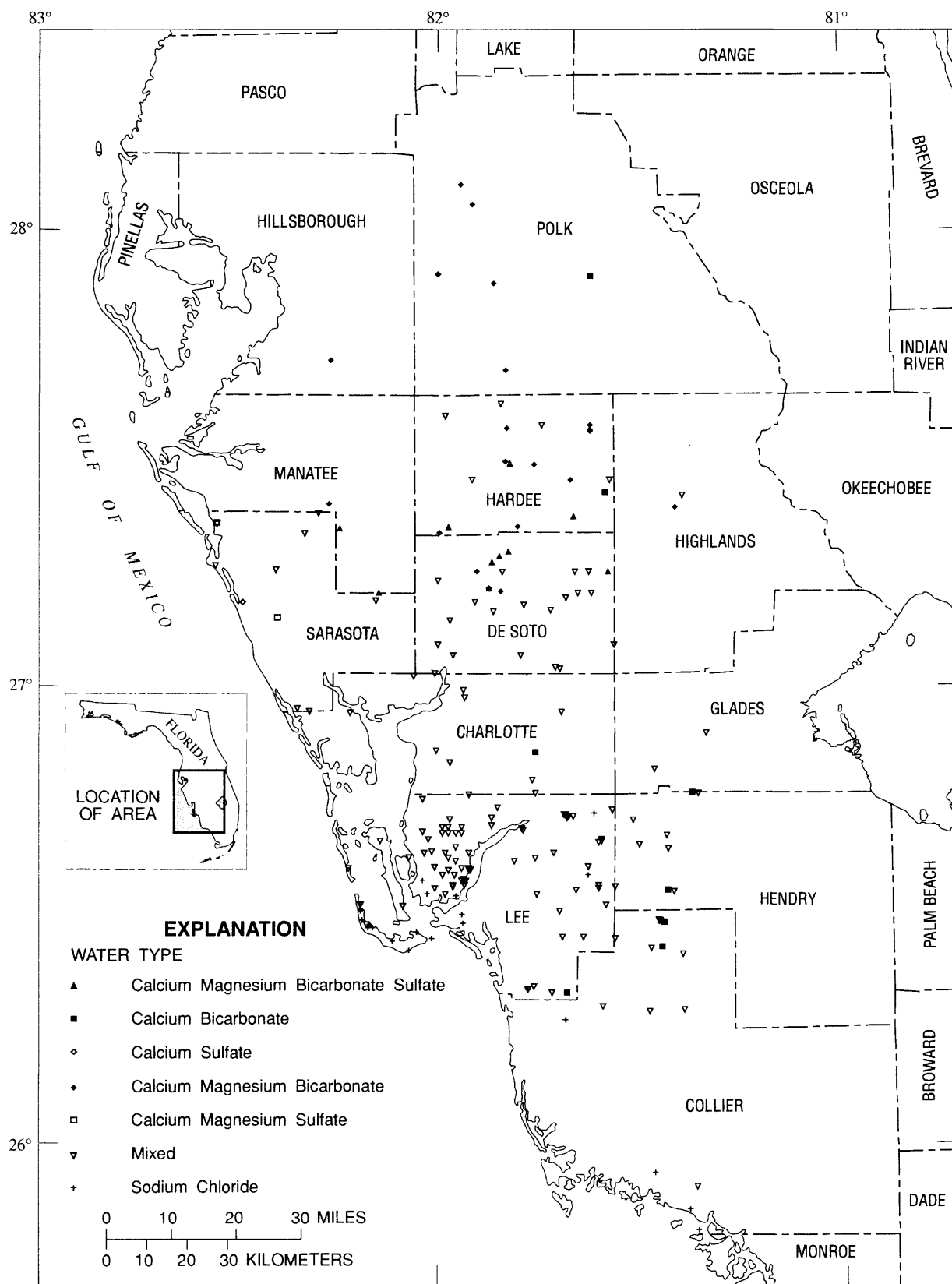


Figure 9. Locations of monitoring wells and dominant-ion water types in samples from wells tapping the intermediate aquifer system in southwestern Florida.

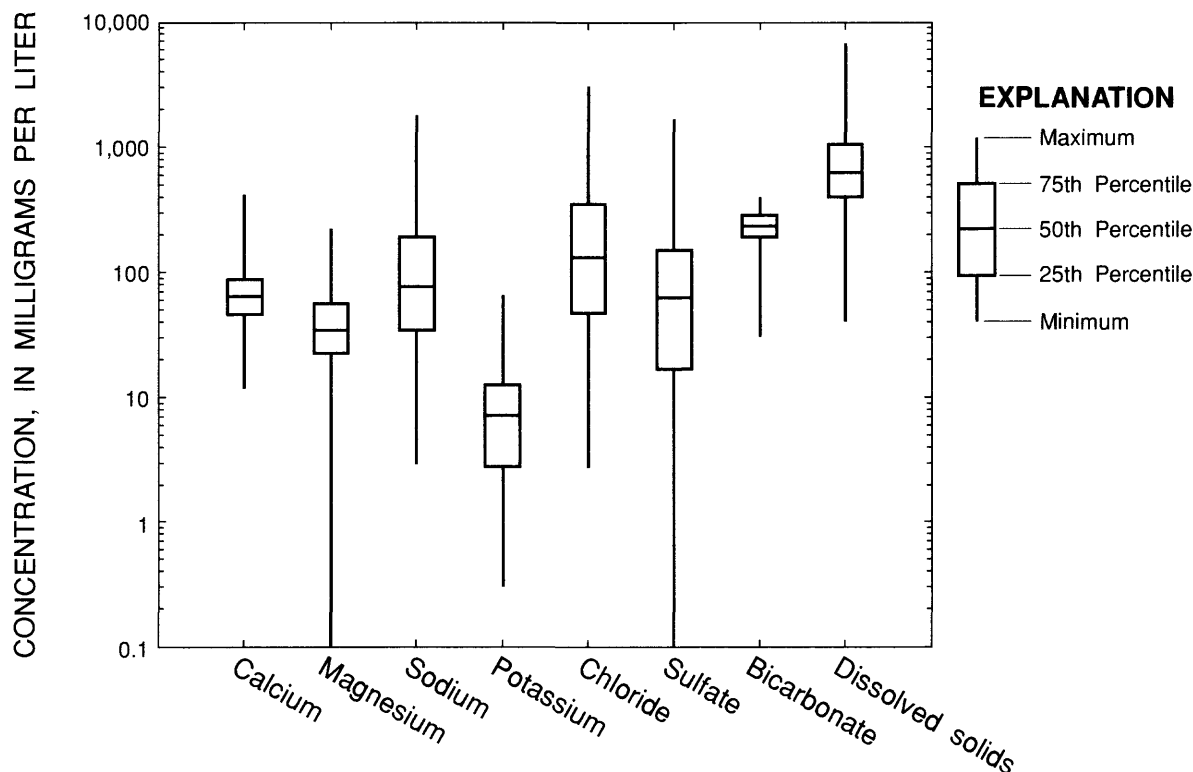


Figure 10. Concentrations of selected constituents in the intermediate aquifer system in southwestern Florida.

were used to differentiate two areas in southwestern Florida for which the above mentioned factors will be considered: Areas I and II (fig. 11).

Area I is an area of low recharge to the Upper Floridan aquifer (Stewart, 1980) and upward leakage from the Upper Floridan aquifer to overlying aquifer systems apparently does not occur. Differences in lithology in the surficial and intermediate aquifer systems also occur in this area. The surficial aquifer system contains a variety of unconsolidated deposits, and the intermediate aquifer system consists of unconsolidated deposits and a limestone aquifer (also known as the mid-Hawthorn aquifer; Wedderburn and others (1982)).

Area II is an area of artesian flow in the Upper Floridan aquifer (Healy, 1975), upward leakage from the Upper Floridan aquifer occurs, and the intermediate aquifer system contains an additional sandstone aquifer overlying the limestone (mid-Hawthorn) aquifer. Area II also roughly coincides with an area where the Upper Floridan aquifer is affected by seawater mixing (Sprinkle, 1989).

Lithologic information in USGS WATSTORE files indicated a sandstone aquifer and a limestone aquifer are present in the intermediate aquifer system in southwestern Florida. Lithologic information was available for approximately 75 percent of the 205 wells in southwestern Florida. Only samples from wells in the intermediate aquifer system for which lithologic information was available were included in this analysis of Areas I and II, so that chemical composition of water from an aquifer in Area I could be compared to water

from the same aquifer in Area II. In Area I, the sandstone aquifer was not present and the intermediate aquifer system is represented by a limestone aquifer. Previous descriptions of the intermediate aquifer system in this area have not mentioned a sandstone aquifer (Duerr and others, 1988).

Differences in lithology within the limestone aquifer of the intermediate aquifer system in Areas I and II are not evident. Therefore, differences in the chemical composition of water in the limestone aquifer from the two areas may be due to differences in amounts and chemical composition of downward leakage of water from the surficial aquifer system and upward leakage of water from the Upper Floridan aquifer, as well as other factors, such as thickness of the aquifer and variations in hydraulic properties.

Chemical composition of water from the aquifer systems in Areas I and II was compared by determining dominant-ion water types for each aquifer; plotting the median composition for each major ion for each water type in milliequivalents per liter on trilinear diagrams; calculating median values of major ions, pH, and temperature for each of the aquifer systems; and preparing graphical summaries of the distribution of selected constituents in each of the aquifers in Areas I and II. Concentrations of major ions, pH, and temperature for each analysis were used to calculate approximate partial pressures of carbon dioxide and saturation indices of calcite, dolomite, and gypsum with the computer program WATEQF (Plummer and others, 1976). Median values of the partial pressure of carbon dioxide and saturation indices were then computed for each aquifer in Areas I and II.

Downward Leakage from the Surficial Aquifer System

A major source of recharge to the intermediate aquifer system is the overlying surficial aquifer system, which has lithology and mineralogy that differs from Area I to Area II. Although some upward leakage from the intermediate to the surficial aquifer system is possible in localized, coastal areas (Healy, 1982; Duerr and Wolansky, 1986), in most of southwestern Florida, the water table of the surficial aquifer system is higher than the potentiometric surface of the intermediate aquifer system (Fitzpatrick, 1982; Healy, 1982; Wedderburn and others, 1982; Boggess and Watkins, 1986; Knapp and others, 1986; Duerr and others, 1988; Smith and Adams, 1988). In Area I, the surficial aquifer system includes deposits of sand, clayey sand, silt, clay, shell, and shelly marl (Wolansky and others, 1979). In Area II, the surficial aquifer system consists predominantly of highly permeable limestone of the Tamiami Formation (Klein and others, 1964). The effect of the downward leakage from the surficial aquifer system on the underlying intermediate aquifer system will be studied by comparing the chemical composition of water in the two aquifers in Areas I and II.

In Area I, water in the surficial aquifer system and in the limestone aquifer of the intermediate aquifer system have similar chemical composition, although water in the limestone aquifer of the intermediate aquifer system has higher concentrations of major ions and higher pH and is saturated

with respect to calcite and dolomite (table 4). In the surficial aquifer system, several water types are present (fig. 12), concentrations of most constituents are less than 50 mg/L, and water is undersaturated with respect to calcite (table 4). The sodium chloride water type in the surficial aquifer in Area I represents three samples that have a median dissolved-solids concentration of 51 mg/L. Water in the limestone aquifer in Area I has concentrations of major ions two to four times higher than concentrations in the water in the overlying surficial aquifer (table 4). The increase in concentrations of major ions, the higher pH, and the saturation of water with respect to calcite and dolomite in the limestone aquifer, indicates that processes occurring within the limestone aquifer or in confining units have modified the recharge water from the surficial aquifer system.

Water in the surficial aquifer system generally has similar chemical composition to the sandstone and limestone aquifers of the intermediate aquifer system in Area II. The chemical composition of the surficial aquifer system and the sandstone, limestone, and Upper Floridan aquifers is portrayed in figure 13. The notable sodium chloride water type in the surficial aquifer represents a single sample with dissolved-solids concentration of approximately 14,600 mg/L. This sample with a high dissolved-solids concentration was from a well located along the Gulf Coast and probably represents seawater intrusion or mixing. The distribution of water types is similar in the surficial aquifer system and the sandstone and limestone aquifers (fig. 13).

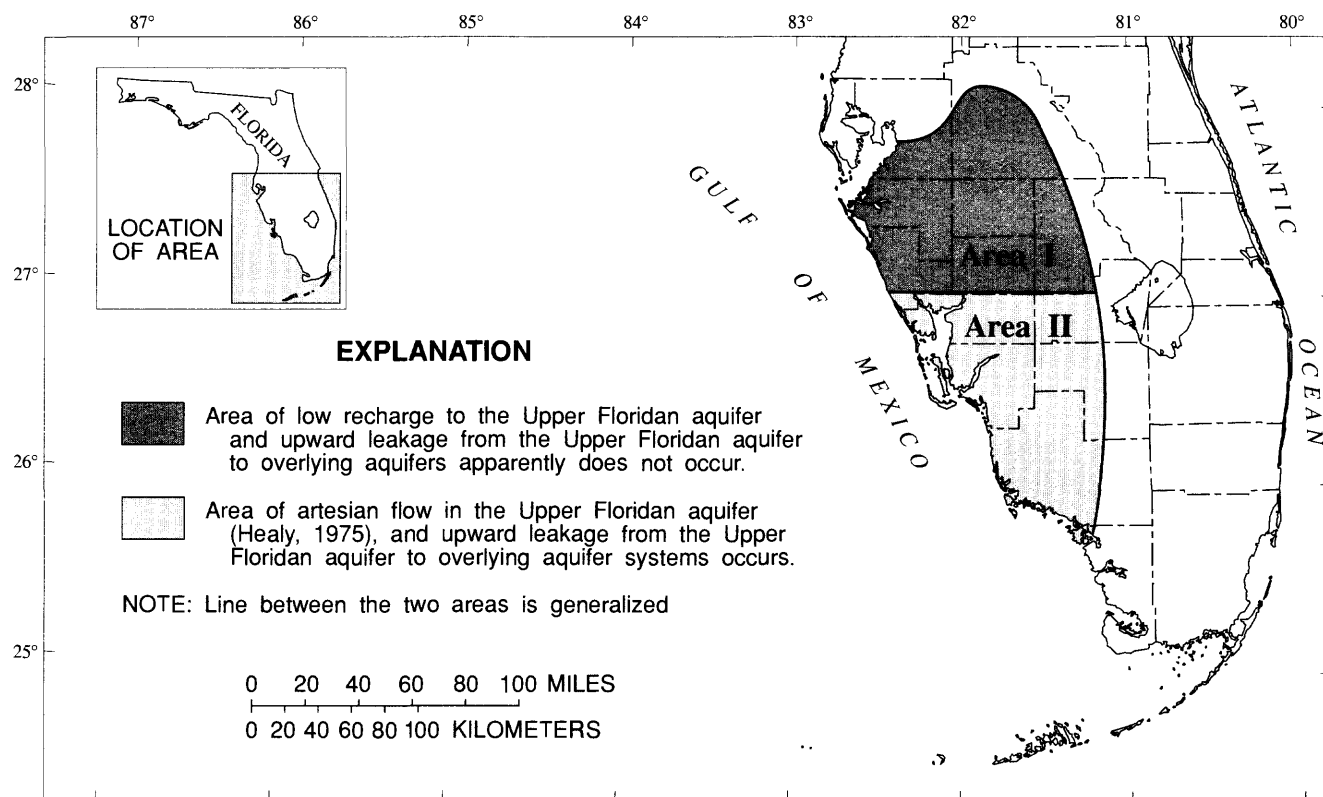


Figure 11. Locations of Areas I and II in southwestern Florida.

Table 4. Median values or concentrations for major ions, pH, and temperature, logarithm of the partial pressure of carbon dioxide, and saturation indices of selected minerals in the major aquifer systems in Areas I and II in southwestern Florida

[Area I indicates areas where heads in the intermediate aquifer system are higher than the Upper Floridan aquifer, and Area II indicates areas where heads in the intermediate aquifer system are lower than the Upper Floridan aquifer. Log P_{CO_2} = logarithm of partial pressure of carbon dioxide. Partial pressure of carbon dioxide and saturation indices were computed for each analysis using WATEQF (Plummer and others, 1976) and median values were determined for each aquifer in each area]

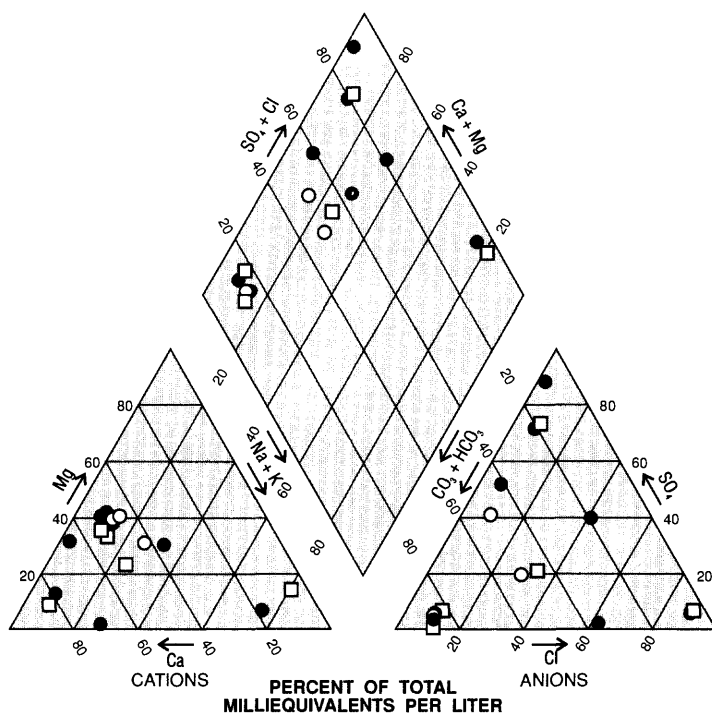
Constituent, property, or characteristic	Median value or concentration for indicated area and aquifer						
	AREA I			AREA II			
	Surficial aquifer system	Intermediate aquifer system		Surficial aquifer system	Intermediate aquifer system		Upper Floridan aquifer
		Limestone aquifer	Upper Floridan aquifer		Sandstone aquifer	Limestone aquifer	
Number of analyses	31	43	107	40	40	70	20
Calcium	23.3	52.6	80.7	103.2	73.5	65.5	126.6
Magnesium	3.7	25.0	30.7	6.1	31.8	52.	106.6
Sodium	7.2	26.0	15.0	24.9	91.1	190	612
Potassium	.94	2.3	2.4	1.1	6.8	14	23.8
Chloride	13.0	35.0	17.0	43	155	365	730
Bicarbonate	52.4	193	148	308	310	237	157
Sulfate	10.6	58.0	124	12.6	59.5	68.5	400
pH, standard units	6.8	7.5	7.5	6.9	7.5	7.6	7.4
Temperature, in degrees Celsius	24.5	26.0	26.0	24.6	25.5	26.0	27.1
Log P_{CO_2}	-1.77	-2.23	-2.37	-1.40	-2.03	-2.24	-2.21
Saturation indices ¹							
Calcite	-1.33	.05	.03	- .10	.35	.22	- .02
Dolomite	-3.25	.16	- .02	-1.16	.58	.67	.31
Gypsum	-3.13	-2.09	-1.60	-2.36	-1.91	-1.98	-1.17

¹When SI is equal to 0, the mineral is in equilibrium with the aqueous phase. When SI is less than 0, the water is undersaturated with respect to the mineral; that is, the mineral has thermodynamic potential to dissolve, although the rates of dissolution may be extremely slow. When the SI is greater than 0, the water is supersaturated with respect to the mineral and the mineral has the potential to precipitate out of solution.

In Area II, concentrations of most ions, including magnesium, sodium, potassium, chloride, and sulfate, and pH values are higher in the underlying sandstone and limestone aquifers than in water from the surficial aquifer system (table 4). Median calcium concentrations in water in the sandstone and limestone aquifers, however, are lower than in water in the surficial aquifer system. Similarly, median bicarbonate concentrations are nearly the same or lower in the sandstone and limestone aquifers than in the surficial aquifer system. Water in the surficial aquifer system and in the sandstone and limestone aquifers are saturated with respect to calcite in Area II (table 4), assuming an uncertainty of ± 0.50 in the SI (Plummer and others, 1990).

Differences between the chemical composition of water in aquifers in Areas I and II indicates that effects of recharge from the surficial aquifer system on the underlying intermediate aquifer system are different in the two areas. In Area II the

surficial aquifer system has higher median concentrations of most constituents, including calcium, sodium, chloride, and bicarbonate than in Area I. Calcium and bicarbonate concentrations are approximately five times higher in Area II than in Area I (table 4), and are probably related to the limestone lithology in the surficial aquifer system in Area II. Similarly, the upper unit of the intermediate aquifer system in Area II, the sandstone aquifer, contains higher calcium and bicarbonate concentrations than the limestone aquifer in Area I (table 4), probably reflecting the effect of recharge from the overlying surficial aquifer system. Water in the sandstone and limestone aquifers in Area II reflect the chemical composition of the recharge water from the surficial aquifer system, as well as another source of water containing elevated sodium, potassium, and chloride concentrations. The other source of water to the sandstone and limestone aquifers in Area II is upward leakage from the Upper Floridan aquifer.



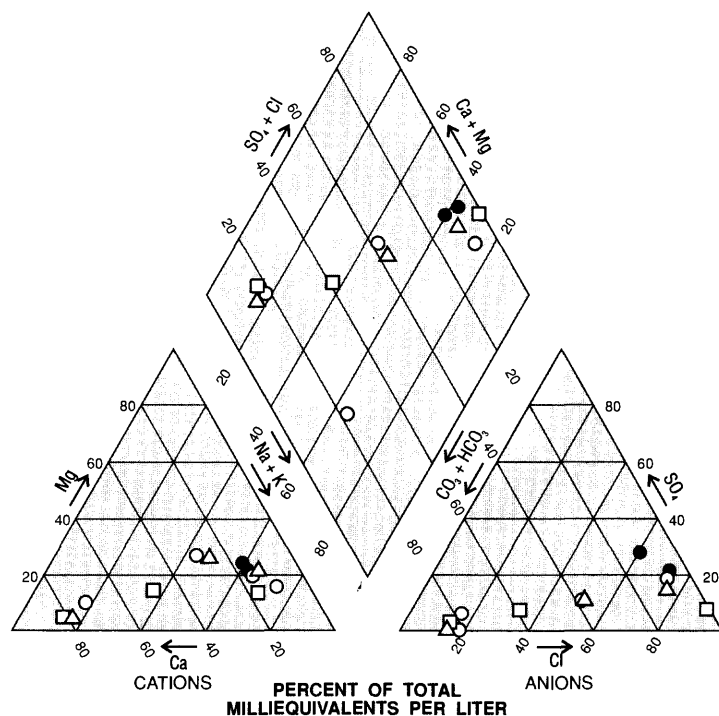
EXPLANATION

- SURFICIAL AQUIFER
- INTERMEDIATE AQUIFER SYSTEM—
Limestone aquifer
- UPPER FLORIDAN AQUIFER

NOTE: Only those sites in the Intermediate Aquifer System that had lithologic information included in this plot.

AQUIFER	WATER TYPE	NUMBER OF SAMPLES
Surficial	Calcium magnesium bicarbonate	2
	Calcium magnesium sulfate	2
	Calcium bicarbonate	6
	Mixed	18
	Sodium chloride	3
Limestone	Calcium magnesium bicarbonate sulfate	7
	Calcium magnesium bicarbonate	14
	Mixed	22
Upper Floridan	Calcium magnesium bicarbonate sulfate	10
	Calcium magnesium bicarbonate	16
	Calcium magnesium sulfate	21
	Calcium chloride	1
	Calcium bicarbonate	19
	Calcium sulfate	4
	Mixed	23
	Sodium chloride	10

Figure 12. Median-ion composition for water types in the aquifers in Area I.



EXPLANATION

- SURFICIAL AQUIFER
- △ INTERMEDIATE AQUIFER SYSTEM—
Sandstone aquifer
- Limestone aquifer
- UPPER FLORIDAN AQUIFER

NOTE: Only those sites in the Intermediate Aquifer System that had lithologic information included in this plot.

AQUIFER	WATER TYPE	NUMBER OF SAMPLES
Surficial	Calcium bicarbonate	27
	Mixed	12
Sandstone	Calcium bicarbonate	5
	Mixed	34
	Sodium chloride	1
Limestone	Calcium bicarbonate	1
	Mixed	52
	Sodium chloride	17
Upper Floridan	Mixed	6
	Sodium chloride	13

Figure 13. Median-ion composition for water types in the aquifers in Area II.

Upward Leakage from the Upper Floridan Aquifer

Upward leakage of water from the Upper Floridan aquifer to overlying aquifers has been previously documented in southwestern Florida (Bogges and others, 1977; Fitzpatrick, 1986; La Rose, 1990) and is affecting the chemical composition of the overlying intermediate aquifer system, particularly the limestone aquifer, in Area II. The chemical composition of water in the Upper Floridan aquifer in Area II has been affected by seawater mixing (Steinkampf, 1982; Sprinkle, 1989). The effect of upward leakage from the Upper Floridan aquifer on the chemical composition of the overlying intermediate aquifer system will be evaluated by comparing the chemical composition in the intermediate aquifer system to the Upper Floridan aquifer in Area II.

In Area II, water from the surficial and intermediate aquifer systems had lower concentrations of most constituents (magnesium, sodium, potassium, chloride, and sulfate) than water from the Upper Floridan aquifer. Trilinear diagrams showing major-ion composition of water from the aquifers in Area II (fig. 13) indicate a change from the uppermost surficial aquifer system to the underlying intermediate aquifer system and Upper Floridan aquifer. Water types vary from calcium bicarbonate in the surficial aquifer system, to calcium bicarbonate and mixed (no dominant ions) in the sandstone aquifer of the intermediate aquifer system, to mixed and sodium chloride in the limestone aquifer of the intermediate aquifer system, to sodium chloride in the Upper Floridan aquifer. Sulfate is present in high concentrations (about 400 mg/L) in water in the Upper Floridan aquifer in this area due to dissolution of gypsum (Sprinkle, 1989), but probably is not a dominant anion because of the even higher concentrations of chloride.

The chemical composition of water in the limestone aquifer of the intermediate aquifer system in Area II is affected by seawater mixing in the Upper Floridan aquifer. The water type in many samples from the limestone aquifer and from the Upper Floridan aquifer in Area II is sodium chloride (fig. 13). This is in contrast to the distribution of major ions in these two aquifers in Area I, where mixed (no dominant ions) is the most common water type in the limestone aquifer and the Upper Floridan aquifer shows a range of water types (fig. 12). The mixing of seawater with freshwater in the Upper Floridan aquifer in Area II has caused concentrations of magnesium, sodium, potassium, and chloride to be much higher than in Area I (table 4). Upward leakage of water from the Upper Floridan aquifer to the limestone aquifer in Area II also has probably caused the concentrations of these ions in the limestone aquifer to be higher than in the overlying sandstone aquifer (table 4).

Both calcium and bicarbonate concentrations in the sandstone and limestone aquifers, are lower or nearly equal to, concentrations in the overlying surficial aquifer system in Area II (figs. 14 and 15). The surficial aquifer system consists of highly permeable limestone of the Tamiami Formation in this

area (Klein, 1972) and this aquifer system had higher partial pressure of carbon dioxide ($\text{Log } P_{\text{CO}_2} = -1.40$, table 4) than the underlying aquifers. Carbon dioxide-enriched waters can dissolve calcite (Stumm and Morgan, 1981, p. 260), producing dissolved calcium and bicarbonate. Water from the intermediate aquifer system in Area II, is saturated with respect to calcite and dolomite, and has less carbon dioxide than the overlying surficial aquifer system, thus water in the intermediate aquifer system is less likely to dissolve calcite and dolomite and produce any more calcium and bicarbonate. Median concentrations of calcium in water from both the sandstone and limestone aquifers of the intermediate aquifer system in Area II were also lower than in water from the underlying Upper Floridan aquifer (fig. 14). In the Upper Floridan aquifer, gypsum is present and water is undersaturated with respect to gypsum (table 4), so dissolution of gypsum probably contributes calcium to ground water. Calcium and bicarbonate concentrations in aquifers in Area I are included in figures 14 and 15 for comparison with concentrations in Area II.

Bicarbonate concentrations in Area II decreased from the sandstone aquifer to the underlying limestone aquifer of the intermediate aquifer system (fig. 15). The higher median concentration of bicarbonate in the sandstone aquifer relative to the limestone aquifer may be explained by reactions occurring in the Upper Floridan aquifer upgradient from Area II, prior to upward leakage to the limestone aquifer. Plummer and Back (1980) hypothesized gypsum and dolomite dissolution and calcite precipitation in the Upper Floridan aquifer upgradient from this area, causing ground water to be enriched in calcium, magnesium, and sulfate, and depleted in bicarbonate. Within the Upper Floridan aquifer Sprinkle (1989) noted a decrease in bicarbonate concentration from 180 mg/L in a sample from De Soto County to 135 mg/L in a sample downgradient in Charlotte County, whereas other major ions had large increases in concentration. The decrease in bicarbonate concentration along the flow path within the Upper Floridan aquifer and the upward leakage of this bicarbonate-depleted water to the limestone aquifer may explain the lower bicarbonate concentration in the limestone aquifer relative to the overlying sandstone aquifer (table 4). As stated previously, water in the limestone aquifer is saturated with respect to calcite; consequently, the precipitation of calcite may also remove calcium and bicarbonate from solution.

The chemical composition of water in the Upper Floridan aquifer has also been affected by seawater mixing in this area (Steinkampf, 1982; Sprinkle, 1989; Katz, 1992). Bicarbonate concentration in seawater is approximately 145 mg/L (Nordstrom and others, 1979), which is considerably lower than the median concentrations in the overlying aquifers (310 and 237 mg/L, respectively, in the sandstone and limestone aquifers). Thus, mixing with seawater may have caused an additional slight decrease in bicarbonate concentration in Upper Floridan aquifer water prior to upward leakage to the limestone aquifer.

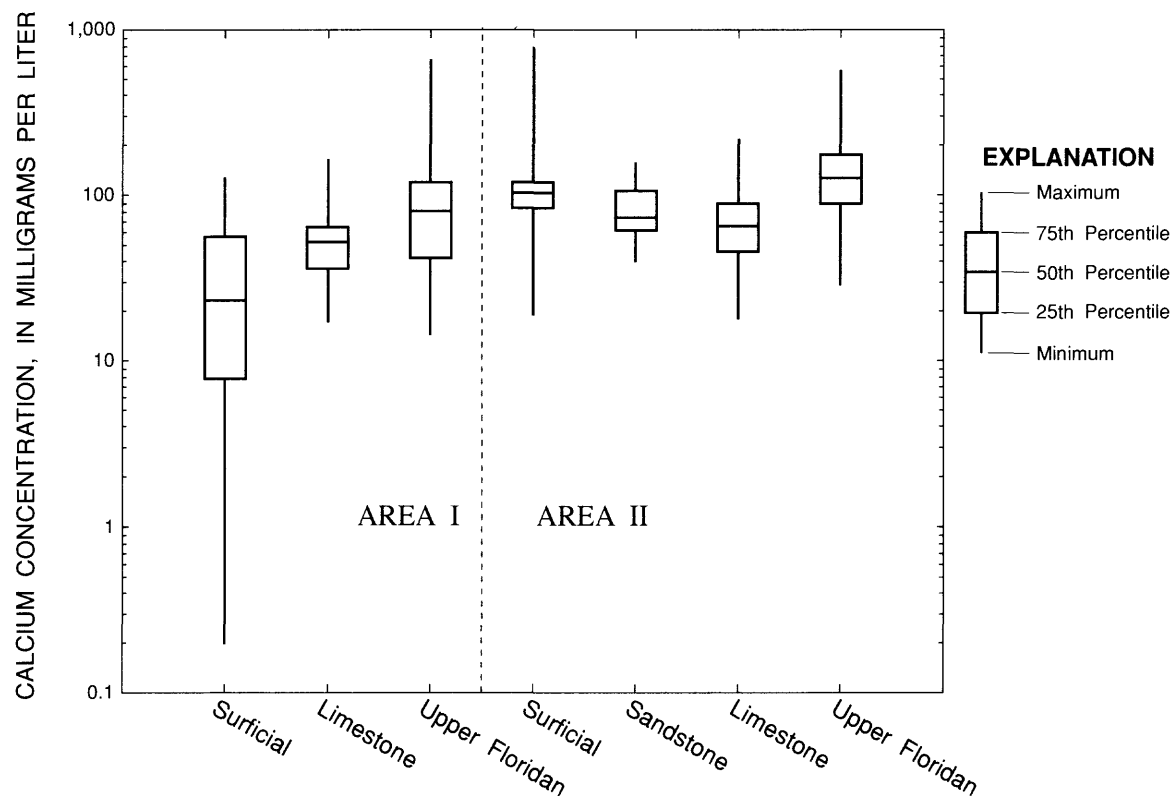


Figure 14. Calcium concentrations in water from aquifers in Areas I and II in southwestern Florida.

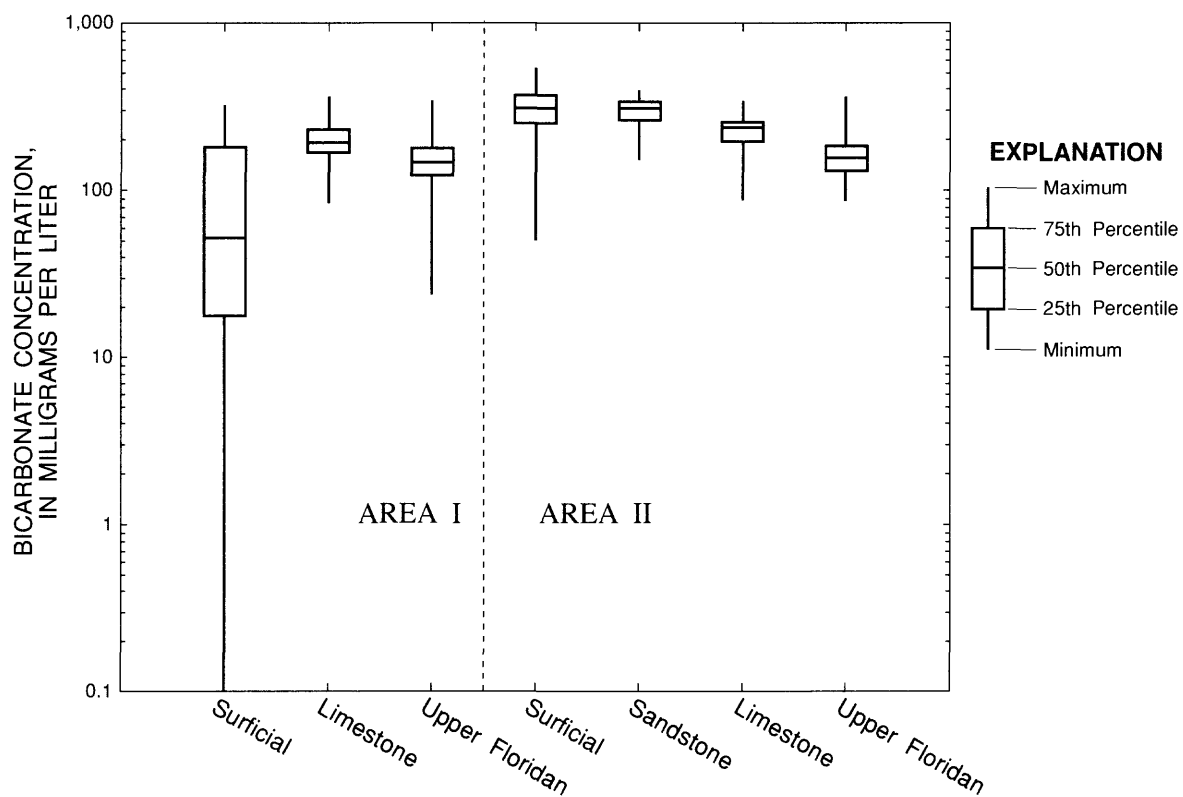


Figure 15. Bicarbonate concentrations in water from aquifers in Areas I and II in southwestern Florida.

SUMMARY AND CONCLUSIONS

The surficial aquifer system is a primary source of public-supply water in Collier, Flagler, Hendry, Indian River, Martin, Palm Beach, St. Johns, and St. Lucie Counties. Other counties in eastern Florida rely on the surficial aquifer system for sources of drinking water. The aquifer system consists of sand, sandstone, silt, clay, limestone, and shell units, and its upper surface is contiguous with land surface. Recharge is primarily from precipitation. The hydrochemistry of this aquifer system reflects the low ion concentrations of recharge water and the lithology of the aquifer deposits; the most commonly occurring water types are calcium bicarbonate and mixed (53 and 37 percent of samples, respectively), the median dissolved-solids concentration was 341 mg/L, and median pH was 6.8.

The intermediate aquifer system is the principal aquifer in Charlotte, Collier, De Soto, Glades, Hendry, Lee, and Sarasota Counties. This aquifer system consists of units between the surficial and Floridan aquifer systems and includes deposits of limestone, dolomite, sand, and sandstone, separated by confining units of sandy clay, clay, and marl. Major sources of water to this aquifer system are recharge from the overlying surficial aquifer system and upward leakage from the underlying Upper Floridan aquifer. Major-ion chemistry is variable in southwestern Florida, with dissolved-solids concentrations ranging from 40 mg/L to more than 6,000 mg/L, with a median of 642 mg/L. The water type in 67 percent of analyses was mixed, indicating transitional type water influenced by the two different sources of water and the variable lithology of the sediments. In the northeastern and panhandle areas of Florida, major-ion chemistry and dissolved-solids concentrations of water from the intermediate aquifer system are similar to that of water from the surficial aquifer system. The dominant ions were calcium and bicarbonate, and median dissolved-solids concentrations were 272 mg/L in northeastern Florida, and 160 mg/L in the panhandle area.

Differences in the chemical compositions in limestone and sandstone aquifers of the intermediate aquifer system between two areas of southwestern Florida were affected by chemical composition of downward leakage water from the surficial aquifer system and upward leakage from the Upper Floridan aquifer. In the northern area, Area I, chemical composition of water in the limestone aquifer is similar to the downward leakage from the surficial aquifer system, with concentrations of most ions higher in the limestone aquifer than in the surficial aquifer system. In the southern area, Area II, upward leakage from the Upper Floridan aquifer, as well as downward leakage from the surficial aquifer system, affect the chemical composition of the sandstone and limestone aquifers. Water from the surficial aquifer system in Area II has calcium and bicarbonate concentrations approximately five times higher than in Area I.

The Upper Floridan aquifer has been affected by processes including dissolution of gypsum and dolomite, calcite precipitation, and seawater mixing. Both the limestone and sandstone aquifers in Area II have higher concentrations of calcium, sodium, potassium, chloride, and bicarbonate than the limestone aquifer in Area I. In Area II, upward leakage of water from the Upper Floridan aquifer and possible precipitation of calcite in the limestone aquifer cause the limestone aquifer to have lower concentrations of calcium and bicarbonate and higher concentrations of magnesium, sodium, potassium, and chloride than the overlying sandstone aquifer.

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