Geochemistry of the Floridan Aquifer System in Florida and in Parts of Georgia, South Carolina, and Alabama

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REGIONAL AQUIFER-SYSTEM ANALYSIS—FLORIDAN AQUIFER SYSTEM

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ane. Measurements of dissolved gases in water samples indicate that methane is present in the aquifer system in Georgia and Florida (table 4; Ehrlich and others, 1979). The methane produced in the anaerobic parts of the aquifer system is not confined there and could migrate upward into more oxidizing environments. In an oxidizing zone, the methane is converted by bacteria to CO_2, which could have a very low ^{13}C content ($\delta^{13}C$ ranging from −65 to −85 o/oo (Hoefs, 1980, fig. 47)).

The significance of reduced carbon sources and their isotopic contents in developing geochemical reaction models of the Upper Floridan aquifer in southwestern Florida is discussed in detail by Plummer and others (1983). Their calculations using $\delta^{13}C$ and $\delta^{34}S$ showed that where the aquifer system is confined (such as in southwestern Florida), input of reduced carbon was affecting the carbon isotope chemistry. As a result of the work by Plummer and others (1983), the methodology is available for quantitative interpretation of redox reactions involving carbon in regional aquifer systems. However, application of their methods to other parts of the Floridan aquifer system must await availability of data on environmental isotopes, dissolved gases, and aquifer mineralogy.

HYDROLOGY

The Floridan aquifer system generally consists of an Upper and Lower Floridan aquifer separated by a less permeable confining unit of highly variable properties (Miller, 1986). The upper and lower aquifers were defined on the basis of permeability; thus, aquifer boundaries in many places do not coincide with boundaries for either time-stratigraphic or rock-stratigraphic units. The Upper Floridan aquifer is present throughout the region and contains units ranging in age from middle Eocene to early Miocene (Miller, 1982a, 1982c, 1986). Several formations are included in the Upper Floridan aquifer, primarily the Tampa, Suwannee, and Ocala Limestones and the Avon Park Formation. The Lower Floridan aquifer is not present in parts of northwestern Florida and in Georgia inland from the coast (fig. 9; Miller, 1986). In these areas, there is little permeability contrast within the aquifer system. Where present, the Lower Floridan aquifer may consist of Paleocene to middle Eocene formations, but consists primarily of the Oldsmar and Cedar Keys Formations.

The major features of the regional flow system of the Floridan can be seen on potentiometric surface maps. An estimated potentiometric surface map of the Upper Floridan aquifer prior to development was made by Johnston and others (1980); a modified version of the map is shown in figure 10. The potentiometric surface shown in figure 10 represents an average, undeveloped condition of the Upper Floridan made from the best information and estimates available (Johnston and others, 1980). Several important hydraulic features of the flow system are evident. Depressions in the potentiometric surface indicate areas of natural discharge that occur along stream channels or near springs; simulation of the aquifer system indicates that almost 90 percent of natural discharge is to rivers and springs (Bush and Johnston, 1988). Along the coast of Florida, low heads generally indicate nearshore springs or seepage from submarine outcrops; simulation of predevelopment conditions indicates that less than 5 percent of the total discharge is directly into the sea. The high heads along the Georgia coast result from thick confinement by the Hawthorn Formation, and freshwater flow extends as far as 50 miles (mi) offshore (Johnston and others, 1982) in that area. The potentiometric high areas shown in figure 10 are areas of potential recharge to the aquifer system. The amounts of actual recharge can vary widely, however, owing to varying thicknesses of aquifer confinement and magnitude of local downward hydraulic gradients (Bush, 1982).

The Floridan aquifer system is remarkably productive. The exceptionally high permeability of some units within the aquifer system are the result of solutional enhancement of high primary permeabilities of the coquinas and fossiliferous limestones. As a result of the wide variation in hydrogeologic conditions in the Upper Floridan aquifer, transmissivity varies by more than three orders of magnitude (Bush and Johnston, 1988, pl. 2). Transmissivities of more than 1,000,000 square feet per day (ft^2/d) occur in the karst areas of west-central and northwestern Florida. The variability of depositional environments when the limestones were formed has also produced low-permeability units that are areally extensive—for example, in the Gadsden County area of northern Florida. In this area, transmissivities are less than 1,000 ft^2/d and vertical head gradients as large as 40 ft are maintained by low-permeability limestones in the Upper Floridan (Rosenau and Milner, 1981). Extending in a northeasterly direction from Gadsden County toward Candler County, Ga., is a series of grabens which markedly affect the transmissivity of the aquifer system. These geologic structures, collectively referred to as the Gulf Trough (fig. 8; Herrick and Vorhis, 1963; Gelbaum, 1978), have the principal effects of locally reducing the thickness of the limestone section, placing low-permeability clastics adjacent to highly permeable limestones, and creating steep hydraulic gradients in the vicinity of the grabens (fig. 10; Pascale and Wagner, 1981; Krause and Randolph, 1989). The Gulf Trough feature has created a damming effect on the southeasterly flow of ground water in the Floridan aquifer system,

TABLE 4.—*Dissolved gases and bacterial organisms measured in water samples from wells in the Floridan aquifer system*

[Do., ditto]

Well location	Well depth (feet)	Sample depth (feet)	Water temperature (degrees Celsius)	Dissolved gases (pressure in atmospheres at indicated temperature)[1]							MPN[2] (organisms per 100 milliliters)			
				N_2	O_2	Ar	CH_4	CO_2	He	H_2	Total anaerobes	Total aerobes	Denitrifiers	Sulfate reducers
Waycross, Ga.	1,970	600–1,900	26.0	1.26	<0.001	0.017	0.002	0.0046	N.D.[3]	N.D.	—[4]	—	—	—
Do.	1,970	1,900–1,970	22.5	.99	<.001	.015	.001	.0024	0.003	0.26	10^3	10^4	10^3	10^2
Do.	1,970	1,100–1,900	—	—	—	—	—	—	—	—	10^4	10^4	10^4	10^2
Do.	1,970	900–1,100	—	—	—	—	—	—	—	—	10^7	10^3	10^5	10
Everglades test well (Broward County, Fla.)	2,810	811–816	24.3	1.23	.0007	.016	.0017	.0017	—	—	—	—	—	—
Do.	2,810	970–1,030	24.3	1.22	.0032	.015	.0014	.0010	—	—	—	—	—	—
Do.	2,810	2,500	24.7	[5]2.09	.076	.007	N.D.	.0022	—	—	—	—	—	—
Do.	2,810	895–1,124	26.2	1.22	.004	.018	.0014	.0017	—	—	10	10^3	10^4	1
Do.	2,810	895–1,249	26.2	1.20	.002	.015	.0012	.0017	—	—	10	10^5	10^4	10^2
Do.	2,810	1,428–1,618	25.8	1.16	.029	.013	.0008	.0009	—	—	10	10^7	10^3	10^2
Do.	2,810	2,457–2,810	24.7	.98	.002	.015	N.D.	.0027	—	—	10^2	10^6	10^4	10^2
South Miami, Fla.	2,960	1,005–1,037	23.0	1.02	.0026	.013	.0027	.0022	—	—	—	—	—	—
Do.	2,960	2,689–2,960	19.0	.96	.0033	.013	Trace	.0015	—	—	—	—	—	—
Plugged oil test well west of Jacksonville, Fla.	2,200	1,130–1,665	20.8	1.03	.0013	.0137	.038	.0095	—	—	—	—	—	—
Do.	2,200	1,665–1,935	20.5	.81	<.0003	.0108	.039	.0084	—	—	—	—	—	—
Do.	2,200	1,935–2,200	20.5	.88	.0008	.0147	.032	.0092	—	—	—	—	—	—
Grand Ridge city well, Jackson County, Fla.	200	[6]?–200	23.0	1.11	.14	.014	N.D.	.0017	—	—	—	—	—	—
Altha city well, Calhoun County, Fla.	282	?–282	23.0	1.10	.026	.014	N.D.	.0019	—	—	—	—	—	—
Well near Otter Creek, Levy County, Fla.	679	?–679	22.6	1.16	<.0003	.014	.0007	.013	—	—	—	—	—	—
Well near Dalkeith, Gulf County, Fla.	505	?–505	27.0	1.31	.0005	.017	.0017	.0093	—	—	—	—	—	—
Well near Dakfield, Worth County, Ga.	120	?–120	20.6	1.17	.12	.013	N.D.	.0026	—	—	—	—	—	—
Well near Leesburg, Lee County, Fla.	190	?–190	20.1	1.00	.11	.012	<.0002	.0019	—	—	—	—	—	—
Well near Leary, Calhoun County, Fla.	142	?–142	20.4	1.06	.044	.013	N.D.	.0027	—	—	—	—	—	—
Well, eastern Early County, Ga.	125	?–125	20.3	1.19	<.002	.013	N.D.	.0051	—	—	—	—	—	—
Well, east of Newton, Ga.	225	?–225	20.3	1.04	.16	.012	N.D.	.0021	—	—	—	—	—	—
Well near Jakin, Early County, Ga.	125	?–125	21.1	1.09	.19	.013	N.D.	.0029	—	—	—	—	—	—
Well near Brinson, Decatur County, Ga.	185	?–185	20.5	1.13	.088	.013	<.0002	.0024	—	—	—	—	—	—
Well in southwest Seminole County, Ga.	150	?–150	20.8	1.22	.15	.014	N.D.	.0045	—	—	—	—	—	—
Camp Henderson, northern Santa Rosa County, Fla.[7]	815	702–815	22.0	—	—	—	.003	.0008	—	—	—	—	—	—
Shallow monitor at American Cyanamid Company, Santa Rosa County, Fla. (sampled 6/12/79)[7]	1,108	1,096–1,108	26.0	1.32	<.0003	.017	.098	.0015	—	—	460	—	3	—
Shallow monitor at Monsanto Company, Escambia County, Fla. (gases sampled 3/8/79; bacteria sampled 8/17/76)[7]	1,140	972–1,140	29.0	1.13	.0003	.014	.143	.0017	—	—	—	—	N.D.	—

[1] No corrections have been made for salting-out effects.
[2] MPN, most probable number.
[3] N.D., gas not detected.
[4] ----, gas or bacterial organism not measured.
[5] Sample collected from an N_2-flushed thief sampler.
[6] ?, well-casing depth not known.
[7] Data from Hull and Martin, 1982, tables 24, 26, 28, 29, 30.

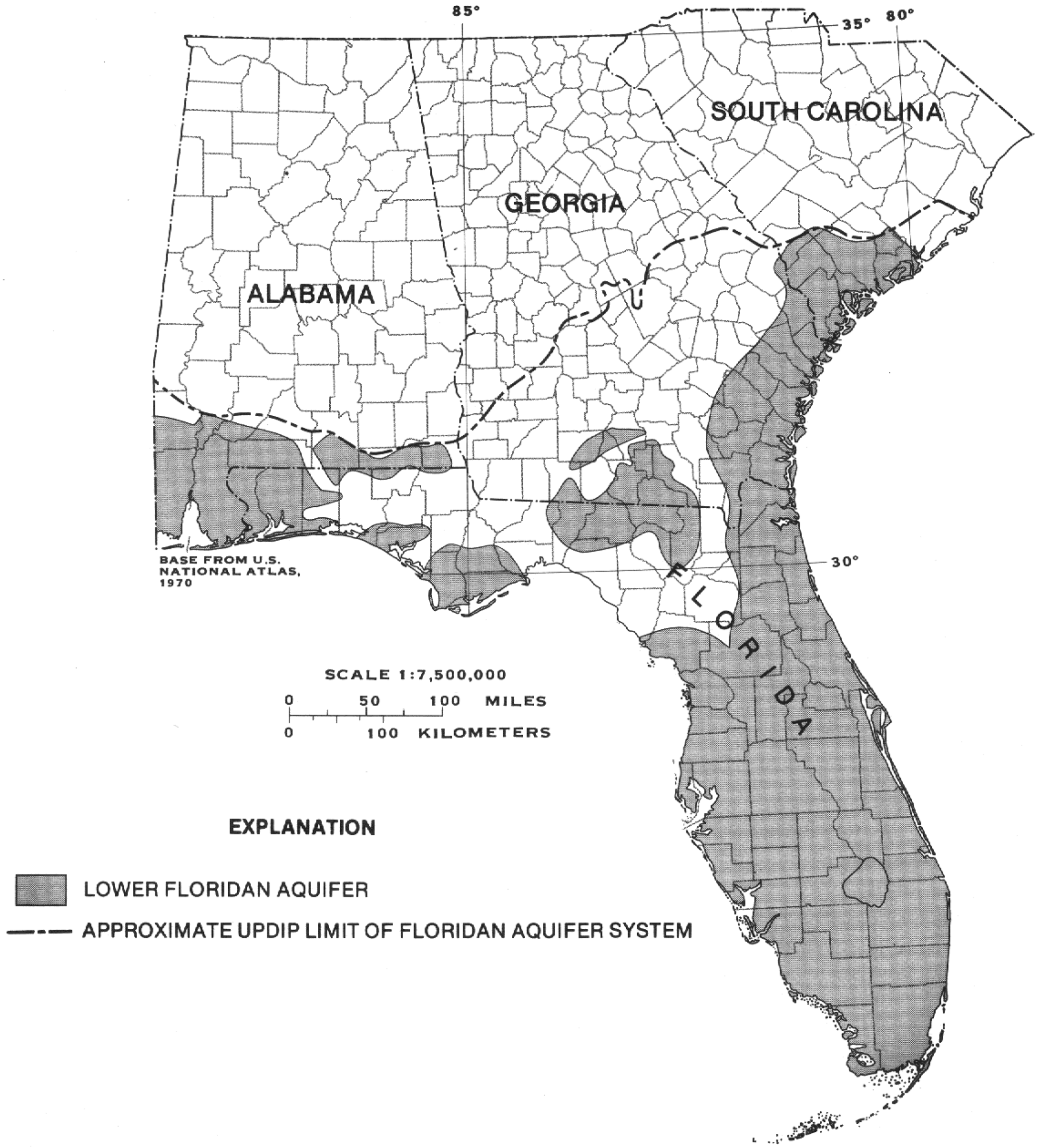

FIGURE 9.—Approximate areal extent of the Lower Floridan aquifer. (After Miller, 1986.)

thereby reducing the flow rates from outcrop areas toward the Georgia coast (Bush and Johnston, 1988).

Ground-water flow conditions in the Floridan aquifer system are directly related to the thickness and integrity of the overlying confining unit(s). Where the confining unit is thick (fig. 11), recharge and discharge rates are substantially less than in areas where the confining unit is thin or absent. Confinement retards development of secondary permeability by reducing the rates of circulation of freshwater which is undersaturated with calcite or dolomite. In some areas, high heads sustained by confinement prevent recharge from surficial sand aquifers. However, high heads sustained by confinement in coastal areas reduce encroachment of seawater, making the aquifer system a potentially more usable resource. In contrast, where the aquifer system is unconfined, recharge is rapid and plentiful, ground-water circulation and discharge rates are high, and secondary permeability can develop quickly.

Some effects of confinement on the chemistry of water in the Floridan aquifer system have been discussed by Back and Hanshaw (1970), Plummer (1977), and Plummer and others (1983). A major effect is that where the overlying confining unit is thick, the carbonate chemistry of the ground water evolves in isolation from atmospheric or soil-zone CO_2 gas (closed-system evolu-

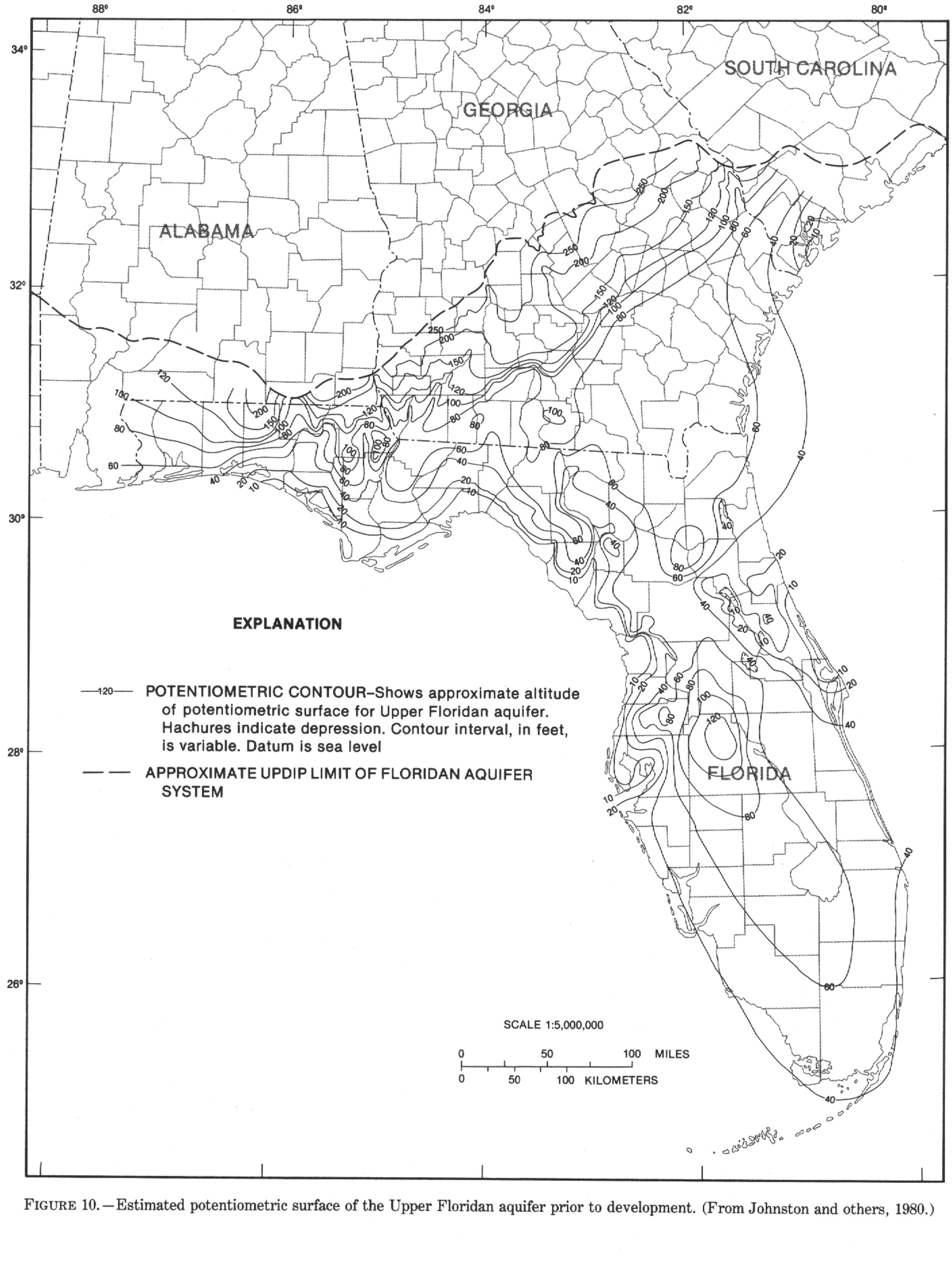

FIGURE 10.—Estimated potentiometric surface of the Upper Floridan aquifer prior to development. (From Johnston and others, 1980.)

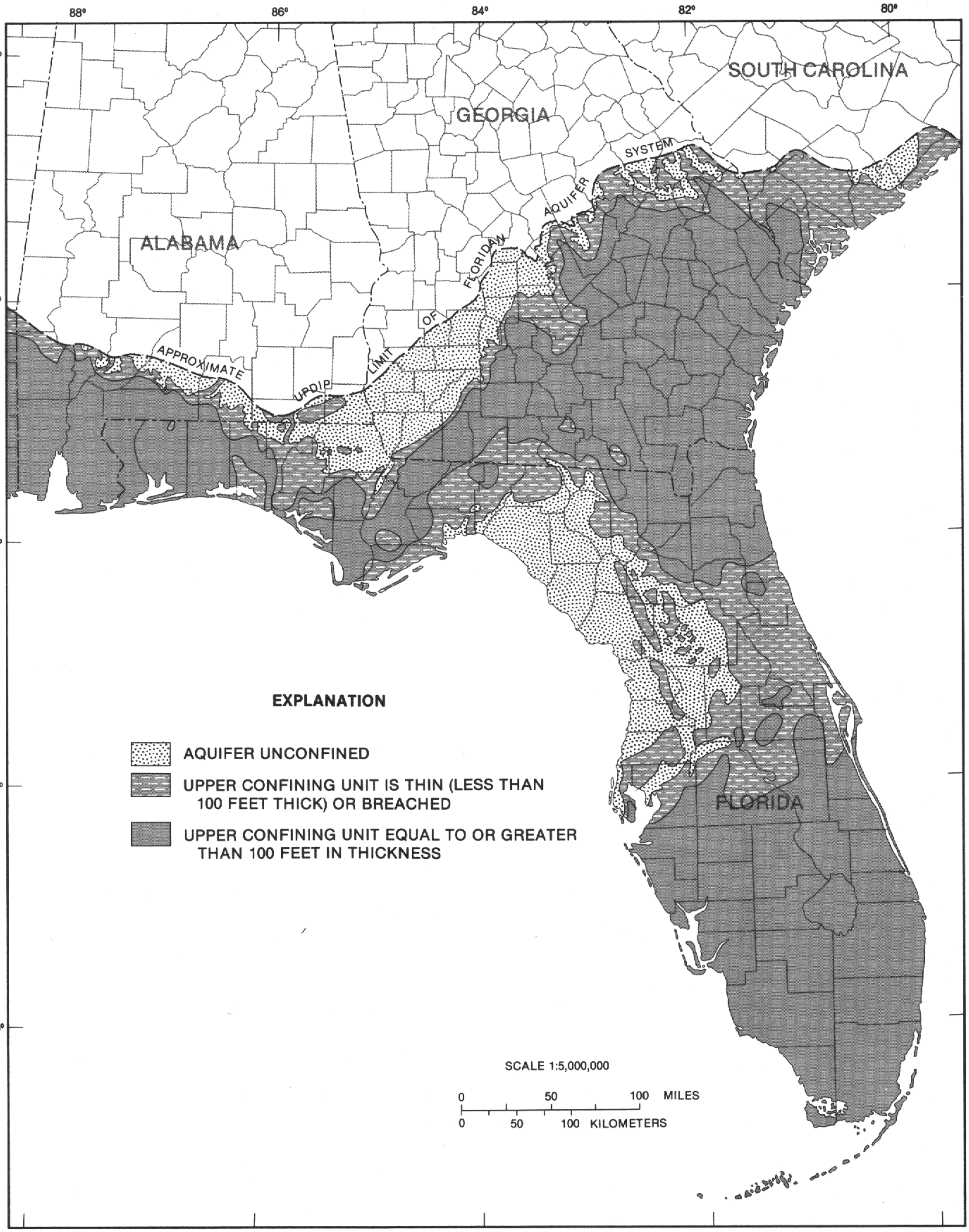

FIGURE 11.—Confined and unconfined areas of the Floridan aquifer system. (From Miller, 1986, pl. 25.)

tion). As discussed in a number of hydrology texts (for example, Freeze and Cherry, 1979, p. 109–111), dissolution of limestone (and development of secondary permeability) is enhanced in ground-water systems open to a large (infinite) source of CO_2 gas. A secondary effect of confinement is reduction in the rate of flushing of salty water from the system. Confinement may also allow changes in oxidation-reduction potential to develop owing to isolation of the ground water from atmospheric oxygen. Confinement can also protect the ground-water resource by reducing the amount of surface contaminants that reach the system.

The hydraulic effects of confinement on the system are clearly seen when areas of confinement (fig. 11) are compared with principal areas of recharge and discharge. A map of recharge and discharge areas of the Upper Floridan was developed (Bush and Johnston, 1988, pl. 11) from simulation of the steady-state predevelopment flow system; the map is reproduced in figure 12. Thick confinement in southeastern Georgia and in southern Florida extend the discharge zone (area of diffuse upward leakage, fig. 12) over thousands of square miles; in contrast, discharge zones in unconfined areas along the Gulf Coast of Florida are narrow, extending over a few hundreds of square miles. More dramatic effects of confinement are seen when ground-water fluxes are compared between confined and unconfined areas. Bush and Johnston (1988, fig. 22) subdivided the aquifer system into major ground-water areas bounded by flow lines, so that within each area, ground-water discharge equals recharge in the steady-state condition. The total simulated discharge from the Floridan aquifer system prior to development was approximately 21,700 cubic feet per second (ft^3/s) (fig. 13). Simulation showed that approximately 90 percent of this discharge occurred as springflow or discharge to streams in areas where the upper confining unit is thin or absent. By comparing figures 11 and 13, the effects of confinement on ground-water flow activity in different ground-water areas may be seen. For example, areas II, III, and IV are mostly unconfined, occupy about one-fifth of the land area where the Floridan aquifer system is present, and together account for about 63 percent of the total predevelopment discharge. Areas V and VII are mostly confined and occupy about half of the area underlain by the Floridan, yet they contribute only about 13 percent of the total predevelopment discharge from the system. Pumpage from the Floridan aquifer system of about 3 billion gallons per day (gal/d) (early 1980's) represents about 17 percent of total discharge (Bush and Johnston, 1988). This pumpage has resulted in water-level declines of more than 10 ft in three large areas—western panhandle Florida, west-central Florida, and along the Atlantic Coast from Jacksonville to north of Savannah (Bush and Johnston, 1988, pl. 6). Nonetheless, ground-water development has not greatly altered the fact that most of the discharge from the Upper Floridan aquifer is to springs and streams.

This brief characterization of the flow system is sufficient for the following discussion of aquifer geochemistry; for more detailed descriptions of both the aquifer system and models developed to simulate its ground-water flow, the reader is referred to Bush (1982), Krause (1982), Ryder (1982), Tibbals (1981), and chapters C, D, E, F, and H of Professional Paper 1403 (Bush and Johnston, 1988; Krause and Randolph, 1989; Tibbals, in press; Ryder, 1986; Maslia and Hayes, 1988).

DESCRIPTION OF GROUND-WATER CHEMISTRY

METHODOLOGY

The majority of the data used in this investigation are from previous analyses of water samples from wells and springs in the Floridan aquifer system. These data were obtained during the period 1950 to 1982 as part of areal hydrologic studies by the U.S. Geological Survey in cooperation with Federal, State, and local governmental agencies and are currently available in computer files maintained by the Geological Survey (U.S. Geological Survey, 1974, 1975). Chemical data from springs were used primarily to obtain a better understanding of the hydrogeochemistry of the Upper Floridan where it is unconfined. Chemical data from springs were also used to supplement the well data to obtain a better regional description of selected constituents. Wells with chemical data were selected on the basis of (1) depth of well penetration into the Upper or Lower Floridan aquifer, (2) areal coverage of the entire Floridan aquifer system, and (3) relatively complete chemical data in computer storage. After a preliminary review of about 52,000 water analyses from more than 7,000 wells and about 250 springs in Alabama, Florida, Georgia, and South Carolina, a subset of 601 analyses (representing 601 wells) was chosen to characterize the major ion chemistry of the Upper Floridan aquifer. Of these 601 wells, 404 are open to more than half the total thickness of the Upper Floridan at the well and none penetrate below the base of the aquifer. Very few chemical data from wells in the Lower Floridan aquifer were available for this study. Owing to the scarcity of chemical and hydrologic data from the Lower Floridan, this report emphasizes geochemical properties and processes in the Upper Floridan aquifer. Discussion of the hydrogeochemistry of the Lower Floridan aquifer is limited to maps showing distribution of chloride and concentrations of dissolved solids.