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

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REGIONAL AQUIFER-SYSTEM ANALYSIS

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1403–B

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DEPOSITIONAL ENVIRONMENTS

Pliocene rocks in southeastern Florida (Tamiami and Caloosahatchee Formations) were deposited in shallow to marginal marine environments. The Bone Valley Formation of central Florida is mostly of fluvial origin and is comprised largely of material reworked from underlying Miocene rocks (Puri and Vernon, 1964). The Citronelle Formation of southern Alabama and westernmost Florida represents a thick sequence of fluvial beds. The Raysor and Charlton Formations of South Carolina and easternmost Georgia were deposited in lagoonal to estuarine conditions. The Goose Creek Limestone was laid down in a shallow marine (inner shelf) environment.

Pleistocene rocks throughout most of the study area represent a series of constructional sandy marine terraces deposited at the shoreline of a fluctuating Pleistocene sea. The Waccamaw Formation equivalents in South Carolina and the complex series of Pleistocene units in southeastern Florida represent marginal marine depositional conditions. All Holocene materials in the study area are either of fluvial origin or derived from the weathering of older rocks.

AQUIFERS AND CONFINING UNITS

GENERAL

The ground-water system beneath the study area generally consists of two major water-bearing units; a surficial aquifer and the Floridan aquifer system. In most places, a low-permeability sequence of rocks herein called the upper confining unit of the Floridan aquifer system separates the Floridan from the surficial aquifer. The Floridan is everywhere underlain by low-permeability rocks that are called the lower confining unit of the Floridan aquifer system in this report.

The surficial aquifer consists mostly of poorly consolidated to unconsolidated clastic rocks (except for southeastern Florida, where it is composed of limestone). Most of the water within the surficial aquifer occurs under unconfined conditions. The Floridan aquifer system's upper confining unit, which lies between the Floridan and the surficial aquifer in many places, consists mostly of low-permeability clastic rocks.

The Floridan aquifer system is a more or less vertically continuous sequence of generally highly permeable carbonate rocks whose degree of vertical hydraulic connection depends largely on the texture and mineralogy of the rocks that comprise the system. The high permeability is only rarely vertically continuous. Flowmeter data from scattered wells show that the aquifer system usually consists of several very highly permeable zones, which generally conform to bedding planes and which commonly are either solution riddled or fractured. These zones, which contribute most of the water to wells, are separated by rocks whose permeability ranges from only slightly less to considerably less than that of the high-yield zones. Because the aquifer system (and its upper and lower confining beds) is defined primarily on the basis of permeability, both the top and the base of the system as mapped in this report are composite surfaces that locally cross formation and age boundaries. Accordingly, the time- and rock-stratigraphic units that make up the aquifer system and its contiguous confining beds vary widely from place to place.

Over much of southern Florida, the aquifer system consists of several relatively thin, highly permeable zones isolated from one another by relatively thick sequences of low-permeability rocks. Differences in the hydraulic heads the several highly permeable zones and differences in the quality of the water that they contain show that the zones behave essentially as separate aquifers.

The Floridan aquifer system's lower confining unit consists of either low-permeability clastic rocks or evaporite deposits. The Floridan is everywhere underlain by these relatively impermeable strata, which separate the high-permeability carbonate rocks from older, deeper aquifers that are mostly of Cretaceous age.

SURFICIAL AQUIFER

A surficial aquifer containing water under mostly unconfined or water-table conditions is present throughout all of the study area except for those places where the Floridan aquifer system or its overlying confining bed is exposed at land surface. The surficial aquifer consists predominantly of sand, but gravel, sandy limestone, and limestone are important constituents in places. Where surficial deposits are thick, highly permeable, and extensively used as sources of ground water, they have been given aquifer names, such as the Biscayne aquifer in southeastern Florida and the sand-and-gravel aquifer in westernmost panhandle Florida. Figure 6 shows the extent of the Biscayne and sand-and-gravel aquifers, which grade laterally into widespread but thin sands that are called simply a surficial aquifer.

The term surficial aquifer as used in this report refers to any permeable material (other than that which is part of the Floridan aquifer system) that is exposed at land surface and that contains water under mostly unconfined conditions. The surficial aquifer may be in direct hydraulic contact with the Floridan or be separated from it by confining beds. Rainfall easily infiltrates the permeable surficial materials and, after percolating downward to the water table, moves either laterally to points where it is discharged into surface streams or vertically downward to recharge either the Floridan or local intermediate aquifers, if the water levels in these deeper aquifers are lower than those in the surficial aquifer. Such downward leakance may be rapid or slow, depending on the presence and character of intervening confining beds (low-permeability rocks) and the head differences between the surficial aquifer and deeper aquifers. Water levels within the surficial aquifer fluctuate widely and rapidly in response to rainfall and other natural stresses such as evapotranspiration or the stages of streams. The general configuration of the water-level surface (water table) of the surficial aquifer is a subdued replica of the configuration of land surface.

The surficial aquifer is important in simulating ground-water flow in the Floridan aquifer system because it serves as a "source-sink" bed for the Floridan. Where the head at the base of the surficial aquifer is higher than the potentiometric surface of the underlying Floridan, the surficial aquifer is the "source" of water that moves downward to recharge the Floridan. Where the potentiometric surface of the Floridan is higher than the head at the base of the surficial aquifer, flow is upward from the Floridan to the surficial

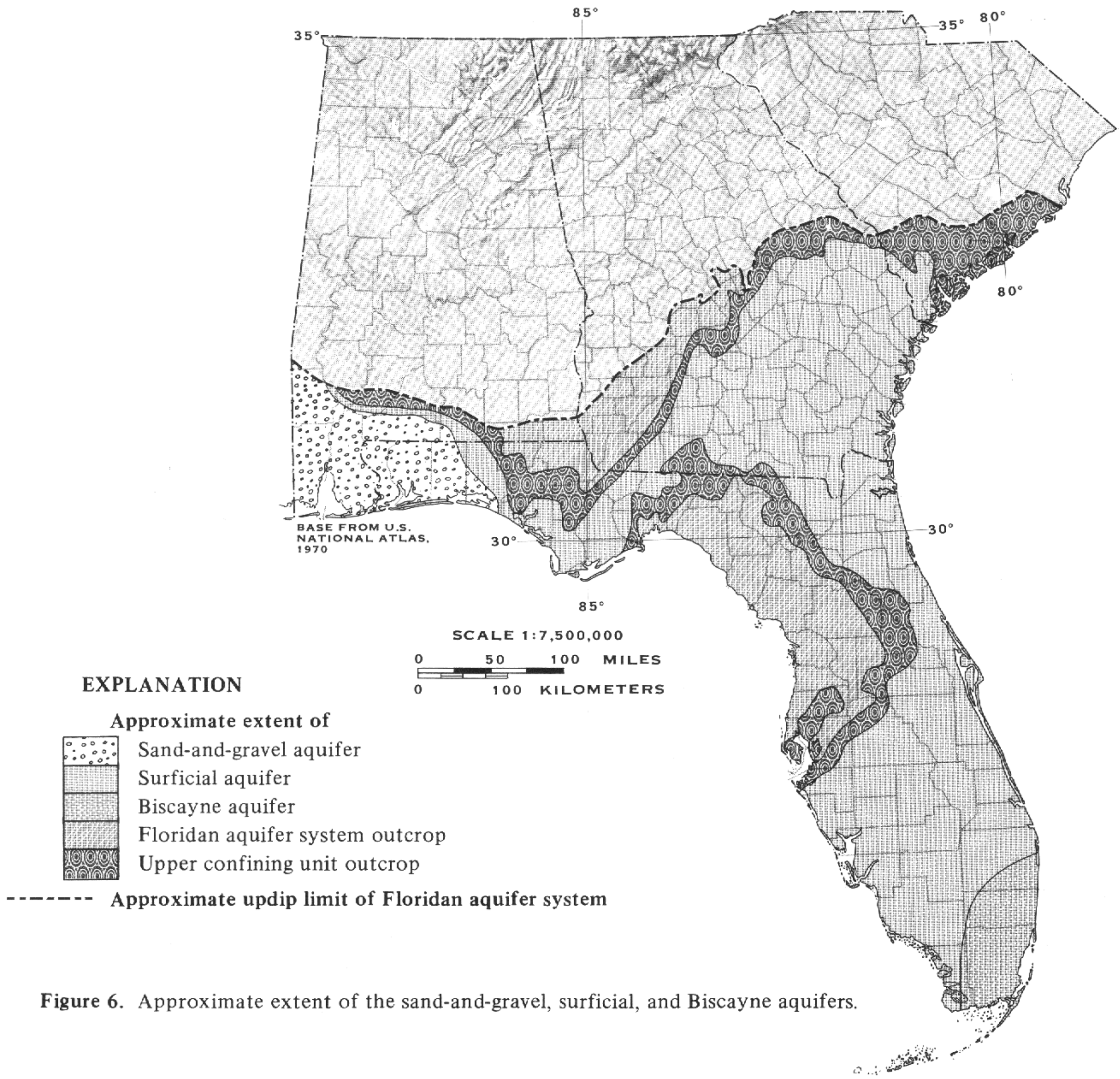

Figure 6. Approximate extent of the sand-and-gravel, surficial, and Biscayne aquifers.

aquifer. In such areas, the surficial aquifer is considered a hydraulic "sink." The thickness and lithologic character of the confining beds that separate the surficial aquifer from the Floridan aquifer system determine the degree of hydraulic interconnection between the two.

The surficial aquifer in the strict sense as mapped on figure 6 consists of all surficial strata containing water under unconfined conditions other than the Biscayne and sand-and-gravel aquifers. Given these restrictions, the surficial aquifer consists mostly of unconsolidated sand and shelly sand deposits that are predominantly of Holocene age but in places include deposits of Pleistocene and Pliocene age. For example, Pleistocene sands that are preserved as ancient beach and shoreline deposits, offshore bars, and the flows of marine terraces (Healy, 1975) are part of the surficial aquifer. Klein (1972) and Hyde (1975) included shell beds and sands of the Anastasia Formation (Pleistocene) and limestones of the Tamiami Formation (Pliocene) in southern Florida in a nonartesian aquifer that they termed the "shallow aquifer"—the equivalent of the surficial aquifer of this report. Callahan (1964) thought that the surficial "sand aquifer" in Georgia consisted of Pliocene to Holocene sands that reach a thickness of about 100 ft in southeastern Georgia. Klein (1972) recorded 130 ft of surficial aquifer in southwestern Florida. The maximum measured thickness of the surficial aquifer recorded during this study is 325 ft in well GA-COF-1 in Coffee County, Ga.

Because the sands designated surficial aquifer on figure 6 are mostly thin and discontinuous in places, water is produced from them primarily for domestic use. Where no other source of ground water exists and the surficial aquifer is sufficiently thick, the aquifer supplies water for industrial or municipal use. Highly permeable strata containing water under nonartesian conditions are the principal source of supply for large municipalities in two areas. These strata are the lateral equivalents of the surficial aquifer. In southeastern Florida, these highly permeable rocks are called the Biscayne aquifer (fig. 6); in extreme western panhandle Florida and south Alabama, they are called the sand-and-gravel aquifer.

The Biscayne aquifer is the source of supply for all municipal water systems in the Palm Beach-Miami area of Florida. Over 500 Mgal/d of water are currently pumped from the Biscayne (Klein and Hull, 1978). The Biscayne is a wedge-shaped body of highly permeable limestone, sandstone, and sand that thickens from a featheredge at its western boundary to more than 200 ft near the Atlantic coast in eastern Broward County (well FLA-BRO-1). The sand content of the aquifer is higher to the north and east; limestone and sandstone are more prominent to the south and west. Included in the Biscayne aquifer are several sand and limestone units of Pleistocene age, the Pliocene and Pleistocene Caloosahatchee Formation, and the upper part of the Pliocene Tamiami Formation (Franks, 1982). Permeability is highest in those areas where the aquifer is mostly limestone, partly because of the development of solution cavities in the limestone. In limestone-rich areas, the transmissivity of the Biscayne aquifer is greater than 1.6×10^6 ft^2/d, but decreases to about 5.4×10^4 ft^2/d where the aquifer is mostly sand (Klein and Hull, 1978). Because of its high permeability and because it is intensively used as a source of water, the Biscayne is subject to contamination by saltwater intrusion from the ocean and by infiltration from an extensive system of canals cut into it that are connected to the ocean. The Biscayne is everywhere separated from the Floridan aquifer system by a thick sequence of low-permeability argillaceous rocks that are mostly of Miocene age. More detailed discussions of the Biscayne aquifer have been given byParker and others (1955), Schroeder and others (1958), Klein and Hull (1978), and Franks (1982).

The sand-and-gravel aquifer (fig. 6) consists primarily of quartz sand that contains much gravel-sized quartz as disseminated particles and as layers. Geologic units included by Franks (1982) in the sand-and-gravel aquifer are, from oldest to youngest, (1) coarse clastics that are probably equivalent to part of the Alum Bluff Group of Miocene age, (2) the Pliocene Citronelle Formation, (3) undifferentiated Pleistocene terrace deposits, and (4) Holocene alluvium. The aquifer thickens southward and westward from a featheredge in southern Alabama and in Walton County, Fla., to a maximum measured thickness of about 1,400 ft in well ALA-MOB-17 in Mobile County, Ala. Locally, layers and lenses of clay within the aquifer form semiconfining beds and create confined conditions in the permeable materials that lie between clay beds. For the most part, however, water in the sand-and-gravel aquifer is unconfined. The aquifer is the primary source of ground water in western panhandle Florida and southwestern Alabama. In places near its updip limit, the sand-and-gravel aquifer is in direct hydraulic contact with the Floridan aquifer system. However, the two aquifers are for the most part separated by thick clay beds. The transmissivity of the sand-and-gravel aquifer is locally as high as about 2×10^4 ft^2/d (Musgrove and others, 1961). Detailed descriptions of the geology and hydrologic characteristics of the sand-and-gravel aquifer have been presented by Musgrove and others (1961), Barraclough and Marsh (1962), Marsh (1966), Trapp (1978), and Franks (1982).

UPPER CONFINING UNIT

Over much of the study area, the Floridan aquifer system is overlain by an upper confining unit that consists mostly of clastic rocks but locally contains much low-permeability limestone and dolomite in its lower parts. In places, the upper confining unit has been removed by erosion, and the Floridan either crops out or is covered by only a thin veneer of permeable sand that is part of the surficial aquifer. Because the lithology and thickness of the upper confining unit are highly variable, the unit retards the vertical movement of water between the surficial aquifer and the Floridan aquifer system in varying degrees. Where the upper confining unit is thick or where it contains much clay, leakance through the unit is much less than where it is thin or highly sandy. In these thick or clay-rich areas, therefore, water in the surficial aquifer moves mostly laterally and is discharged into surface-water bodies rather than moving downward through the upper confining unit (when the head differential is favorable) to recharge the Floridan aquifer system.

The upper confining unit may be breached locally by sinkholes and other openings that serve to connect the Floridan aquifer system directly with the surface. These sinkholes are for the most part found where the thickness of the upper confining unit is 100 ft or less. They appear to result from the collapse of a relatively thin cover of clastic materials into solution features developed in the underlying limestone of the Floridan aquifer system rather than from the solution of limestone beds within the upper confining unit itself. The upper confining unit is generally more sandy where it is less than 100 ft thick because these relatively thin areas represent upbasin depositional sites where coarser clastic rocks were laid down. Plate 25 shows the extent and thickness of the upper confining unit. The maximum measured thickness of the unit is about 1,890 ft in well ALA-BAL-30 in Baldwin County, Ala. The maximum contoured thickness is 1,900 ft. Plate 25 also shows areas where water in the Floridan aquifer system occurs under unconfined, thinly confined (thickness of upper confining unit between 0 and 100 ft), and confined conditions.

The upper confining unit includes all beds of late and middle Miocene age, where such beds are present. Locally, low-permeability beds of post-Miocene age are part of the upper confining unit. Over most of the study area, middle Miocene and younger strata consist of complexly interbedded, locally highly phosphatic sand, clay, and sandy clay beds, all of which are of low permeability in comparison with the underlying limestone of the Floridan aquifer system. Locally, low-permeability carbonate rocks that are part of the lower Miocene Tampa Limestone or of the Oligocene Suwannee Limestone are included in the upper confining unit. Very locally, in the West Palm Beach, Fla., area, the uppermost beds of rocks of late Eocene age are of low permeability and are included in the upper confining unit.

Parker and others (1955) and Stringfield (1966) included basal beds of the Hawthorn Formation in their Floridan and principal artesian aquifers where those beds are permeable. In a few isolated cases (for example, in Brevard County, Fla.), the lowermost Hawthorn strata are indeed somewhat permeable, but their permeability is considerably less than that of the underlying Floridan aquifer system, as Parker and others (1955, p. 84) recognized. Locally, in parts of southwestern Florida (Sutcliffe, 1975; Boggess and O'Donnell, 1982) and west-central peninsular Florida (Ryder, 1982), permeable zones within the Hawthorn Formation are an important source of ground water over a one- or two-county area. Although some of these permeable zones are limestones, their transmissivity is at least an order of magnitude less than that of the Floridan aquifer system, and they are separated from the main body of permeable limestone (Floridan) by thick confining beds. Because of their limited areal extent, relatively low permeability, and vertical separation from the Floridan aquifer system practically everywhere, water-bearing Hawthorn limestones are excluded from the Floridan in this report.

Where the limestone and dolomite of the Floridan crop out, a clayey residuum may form over the carbonate rocks as a result of chemical weathering that dissolves the carbonate minerals and concentrates trace amounts of clay that are in them. Such residumm is particularly well developed in the Dougherty Plain area of southwestern Georgia (Hayes and others, 1983). Although this residuum is a low-permeability material and may very locally form a semiconfining layer above the limestone, it is usually thin and laterally discontinuous. Accordingly, the clayey residuum is not included in this report as part of the upper confining unit of the Floridan aquifer system.

Because the rocks that comprise the upper confining unit vary greatly in lithology, are complexly interbedded, and for the most part are of low permeability, little is known about their hydraulic characteristics. Where clay beds are found in the Hawthorn Formation, they are usually very effective confining beds. Vertical hydraulic conductivity values for Hawthorn clays, as established from core analysis and from aquifer tests, range from 1.5×10^{-2} ft/d (Hayes, 1979) to 7.8×10^{-7} ft/d (Miller and others, 1978). Where sandy beds of the Hawthorn comprise a local aquifer, transmissivity values for the sand range as high as about 13,000 ft^2/d (Ryder, 1982). Hawthorn limestone beds that are local aquifers yield up to 750 gal/min (Boggess, 1974).

FLORIDAN AQUIFER SYSTEM

GENERAL

The Floridan aquifer system is a thick sequence of carbonate rocks generally referred to in the literature as the "Floridan aquifer" in Florida and the "principal artesian aquifer" in Georgia, Alabama, and South Carolina. As defined in this report, the Floridan aquifer system encompasses more of the geologic section and extends over a wider geographic area than either the Floridan or the principal artesian aquifer, as those aquifers have been described in the literature. Figure 7 shows the geologic formations in Florida and southeastern Georgia that were called "principal artesian formations" by Stringfield (1936), those that were included in the "Floridan aquifer" as defined by Parker and others (1955), and those placed in the "principal artesian aquifer" as defined by Stringfield (1966). Subsequent deep drilling and hydraulic testing have shown that highly permeable carbonate rocks extend to deeper stratigraphic horizons than those included in either the "Floridan" or "principal artesian" aquifers as originally described. Accordingly, this author (cited by Franks, 1982) extended the base of the Floridan aquifer downward to include part of the upper Cedar Keys Limestone (fig. 7). Limestone and dolomite beds that commonly occur at the base of the Hawthorn Formation have been included as part of the "Floridan" or "principal artesian" aquifer in most previous reports. However, data collected for the present study show that, except very locally, there are no high-permeability carbonate rocks in the lower part of the Hawthorn Formation that are in direct hydraulic contact with the main body of the Floridan aquifer system.

The Hawthorn Formation was thus excluded from the aquifer system in a report by Miller (1982a) that was one of a series of several interim reports published during the present study. In these interim reports, the aquifer system was called the "Tertiary limestone aquifer system of the Southeastern United States." This cumbersome, albeit more accurate, terminology has subsequently been abandoned, and the aquifer system is referred to in this professional paper as the "Floridan aquifer system" (see Johnston and Bush, 1985 for a more detailed history of the terminology applied to the aquifer system).

The Floridan aquifer system is defined in this report

EPOCH		Stringfield (1936) Formation	Stringfield (1936) Aquifer	Parker and others (1955) Formation	Parker and others (1955) Aquifer	Stringfield (1966) Formation	Stringfield (1966) Aquifer	Miller, in Franks (1982) Formation	Miller, in Franks (1982) Aquifer	Miller (1982 a,c) Formation	Miller (1982 a,c) Aquifer system	This Report Formation	This Report Aquifer system
MIOCENE	Middle	Hawthorn Formation		Hawthorn Formation	Where Permeable	Hawthorn Formation		Hawthorn Formation	Where Permeable	Hawthorn Formation		Hawthorn Formation	
MIOCENE	Early	Tampa Limestone	Principal artesian formations	Tampa Limestone	Floridan aquifer	Tampa Limestone	Principal artesian aquifer	Tampa Limestone		Tampa Limestone	Where Permeable	Tampa Limestone	Where Permeable
OLIGOCENE		Oligocene Limestone		Suwannee Limestone		Suwannee Limestone		Suwannee Limestone	Floridan aquifer	Suwannee Limestone	Tertiary limestone aquifer system	Suwannee Limestone	Floridan aquifer system
EOCENE	Late	Ocala Limestone		Ocala Limestone		Ocala Limestone		Ocala Limestone		Ocala Limestone		Ocala Limestone	
EOCENE	Middle			Avon Park Limestone		Avon Park Limestone		Avon Park-Lake City Limestones		Avon Park-Lake City Limestones		Avon Park Formation	
EOCENE	Middle			Lake City Limestone		Lake City Limestone							
EOCENE	Early					Oldsmar Limestone		Oldsmar Limestone		Oldsmar Limestone		Oldsmar Formation	
PALEOCENE								Cedar Keys Limestone		Cedar Keys Limestone		Cedar Keys Formation	

Figure 7. Comparison of aquifer terminologies.