WATER RESOURCES OF SOUTHEASTERN FLORIDA WITH SPECIAL REFERENCE TO THE GEOLOGY AND GROUND WATER OF THE MIAMI AREA

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ABSTRACT

The circulation of water, in any form, from the surface of the earth to the atmosphere and back again is called the hydrologic cycle. A comprehensive study of the water resources of any area must, therefore, include data on the climate of the area.

The humid subtropical climate of southeastern Florida is characterized by relatively high temperatures, alternating semi-annual wet and dry seasons, and usually light but persistent winds.

The recurrence of drought in an area having relatively large rainfall such as southeastern Florida indicates that the agencies that remove water are especially effective. Two of the most important of the agencies associated with climate are evaporation and transpiration, or "evapotranspiration". Evaporation losses from permanent water areas are believed to average between about 40 and 45 inches per year. Over land areas indirect methods must be used to determine losses by evapotranspiration; necessarily, these values are not precise.

Because of their importance in the occurrence and movement of both surface and ground waters, detailed studies were made of the geology and geomorphology of southern Florida.

As a result of widespread crustal movements, southern Florida emerged from the sea in late Pliocene time and probably was slightly tilted to the west. At the beginning of the Pleistocene the continent emerged still farther as a result of the lowering of sea level attending the first widespread glaciation. During this epoch, southern Florida may have stood several hundred feet above sea level.

During the interglacial ages the sea repeatedly flooded southern Florida. The marine members of the Fort Thompson formation in the Lake Okeechobee-Everglades depression and the Caloosahatchee River Valley apparently are the deposits of these interglacial invasions by the sea. The fresh-water marls, sands, and organic deposits of the Fort Thompson formation appear to have accumulated during glacial ages when sea level was low and the area was a land surface partly occupied by fresh-water lakes and marshes. Elsewhere in southern Florida the deposits are mainly marine limestones and sandy terrace deposits.

The Pliocene surface upon which these Pleistocene sediments were deposited was highest to the north and west of the present Everglades and Kissimmee River basin, and it sloped gently to the south, southeast, and east. On this slightly sloping floor, alternately submerged and emerged, the later materials were built; these materials, modified by wind, rain, and surface and ground waters, have largely determined the present topographic and ecologic character of southern Florida.

The most important aquifer in southern Florida, and the one in which most of the wells are developed, is the Biscayne aquifer. It is composed of parts of the Tamiami formation (Miocene), Caloosahatchee marl (Pliocene), Fort Thompson formation, Anastasia formation, Key Largo limestone, Miami oolite, and Pamlico sand (Pleistocene). In some parts of southern Florida, the Pamlico sand and the Anastasia formation are not a part of the Biscayne aquifer; however, they are utilized in the development of small water supplies. Most of the Caloosahatchee marl and the Fort Thompson formation in the Lake Okeechobee area is of very low permeability. In the northern Everglades their less permeable

parts contain highly mineralized waters, which appear to have been trapped since the invasions by the Pleistocene seas. These waters have been modified by dilution with fresh ground water and by chemical reactions with surrounding materials.

Sea-level fluctuations, starting at the close of the Pliocene with highest levels and progressing toward the Recent with successively lower levels, have built a series of nearly flat marine terraces abutting against one another much like a series of broad stairsteps. Erosion and solution have defaced and, in places, have obliterated the original surficial forms of these old sea bottoms, shores, and shoreline features, but their remnants today are widespread and, in some places, are easily recognizable.

Ice-age terraces higher than 100 feet above present sea level are not present in southeastern Florida. The terraces recognized and their approximate shoreline elevations are as follows: Wicomico, 100 feet; Penholoway, 70 feet; Talbot, 42 feet; Pamlico, 25 feet; and Silver Bluff, 5 feet.

Southeastern Florida contains few major streams; the two largest are the Kissimmee, which empties into Lake Okeechobee, and the Caloosahatchee, which empties into the Gulf of Mexico. The flow in these streams is maintained largely by ground-water seepage from the aquifers underlying the higher terrace lands. Most of the rainfall in southeastern Florida evaporates or is utilized by plant transpiration; most of the remainder enters the permeable soils and percolates downward to the water table where it joins in a slow seaward or streamward underground flow.

The action of downward and laterally moving ground water has modified land forms and has produced sinkholes, vertical solution pipes (natural wells), and innumerable small rounded ponds aligned with the trend of underground solution channels. Intermingling channels and honeycomb-like holes in the underlying rocks cause extremely high permeabilities in some of the limestone aquifers and produce conditions favorable for the development of wells with exceptionally high yields and extremely low drawdowns.

Ground water occurs under both artesian and nonartesian conditions in southeastern Florida. Nonartesian water is by far the most important because it occurs at shallow depths and is therefore more economical to develop; also, except in the upper Everglades, the quality of this water is the best obtainable for domestic use.

The Biscayne aquifer is composed mainly of sandy limestone and calcareous sandstone with beds and pockets of quartz sand. The aquifer is riddled with solution holes generally filled with the sand, but numerous cavities of considerable size and extent occur. It is one of the most permeable aquifers ever investigated by the U. S. Geological Survey, and ranks with clean, well-sorted gravel in its capacity to transmit water. North of Dania, in Broward County, the aquifer contains considerable amounts of fine sand; this causes a lower coefficient of transmissibility. In the Fort Lauderdale well-field area the transmissibility is about 1,200,000 gpd per ft, but nearer the coast it is probably higher.

The Biscayne aquifer underlies eastern Dade County to depths ranging from about 70 to 125 feet, but it becomes thinner to the west, and is of lower transmissibility beginning about 15 miles west of Biscayne Bay. In the Everglades, in the latitude of Fort Lauderdale, and along the coastal ridge near Delray Beach, the Fort Thompson formation is finally displaced as the major unit of the aquifer by the Anastasia formation and the Caloosahatchee marl.

Wells developed in the Biscayne aquifer are usually of open-hole, rock-wall construction, having from 1 foot to about 15 feet of open hole below the bottom of the casing. An average well, 6 inches in diameter and 50 feet deep, will yield 1,000 to 1,500 gpm with a drawdown of less than 4 feet, and it will recover almost immediately. Small wells, 10 to 30 feet deep, are commonly obtained by manually driving a pipe 1¼ to 2½ inches in diameter into the ground and developing either an open-hole, a rock-wall, or a sand-point well.

The principal artesian aquifer of Florida is here named the Floridan aquifer. It includes most or all of the middle Eocene (Avon Park limestone), upper Eocene (Ocala limestone), Oligocene (Suwannee limestone), and Miocene (Tampa limestone, but only a minor part of the Hawthorn formation). It is found at depths of 800 to 1,200 feet in the southern part of the State where it yields water that is sulfurous, saline, hard, and corrosive. The water in wells penetrating the Floridan aquifer will rise as much as 40 feet above sea level. The typical well yields about 750 gpm by natural flow.

In the past, water from the Floridan aquifer has had very limited use in southern Florida. It is expensive to develop, and it generally is of poorer quality than shallow ground water. Recently a few artesian wells have been used for cooling purposes; the water is circulated through special corrosion-resistant systems. Also, some wells have been used for irrigation.

In addition to the Floridan aquifer, there are several shallow artesian aquifers in some areas of southern Florida. Chief among these are the Miocene aquifer at Everglades, Collier County, and the Miocene and Pliocene aquifers at Fort Pierce, St. Lucie County, in the Kissimmee River valley. Locally, these are very important aquifers and have not been fully explored and evaluated.

Detailed quantitative studies of the Biscayne aquifer have resulted in the following conclusions:

1. In the Miami area, the aquifer averages about 100 to 125 feet in thickness and is wedge shaped with the blade inland. Around Miami and to the south under the Atlantic Coastal Ridge, the coefficient of transmissibility ranges from about 3,000,000 to 20,000,000 gpd per ft and has a median value of about 5,000,000 gpd per ft. The transmissibility becomes smaller to the north and to the west of Miami because of larger quantities of fine sand in the aquifer. The storage coefficient of the aquifer ranges from about 0.10 to 0.35 and averages about 0.20.

2. Recharge to the aquifer is chiefly from rainfall, which at times is so localized that ephemeral ground-water mounds often build up under the Atlantic Coastal Ridge to heights considerably above the water level in the Everglades. Under these conditions, ground water flows outward in all directions from the mounds and large quantities of water flow westward into the Everglades as well as eastward into Biscayne Bay.

Studies in the coastal ridge south of Miami indicate that of the average annual rainfall (approximately 60 inches) about 38 inches reach the water table directly, and about 22 inches is lost through evapotranspiration; direct runoff is quite small in relation to these quantities. In general, the canal system in southeastern Florida is not effective in recharging the aquifer; instead, it is highly effective in draining away ground water stored in the aquifer. Only in areas of localized lowering of the water table adjacent to a canal (as in a cone of depression around a well field) do canals contribute a large amount of recharge to the aquifer. In such places recharge from canals may account for a considerable portion of the total amount pumped from the well field.

3. Discharge from the aquifer is by ground-water flow into drainage canals and Biscayne Bay, evapotranspiration loss to the atmosphere, and pumpage. Of these, discharge into canals and the bay account for about 15 to 25 inches of the rainfall, and the total evapotranspiration loss accounts for about 35 inches. Total pumpage from wells in Dade County is very difficult to estimate, but in 1945 it amounted to about 58.4 mgd or 21,300 million gallons a year.

The limits of the southeastern Florida drainage unit are not clearly definable because the land is so nearly flat, but the total area drained covers about 9,000 square miles. The physical features and flow characteristics of the drainage system from the Kissimmee River basin to the Miami area are described in detail from north to south. Records of stage and discharge for the period 1940-1946 are presented in tabular and graphical form.

The northernmost drainage basin in the area is the Kissimmee River valley. Many lakes occupy the northern and western parts of the basin, but generally it is characterized by low undulating hills and flat, wide, swampy valleys. The altitude varies from about 16 to 325 feet, although most of the basin is below 100 feet.

Lake Okeechobee, south of the Kissimmee River basin, receives natural runoff from the north and northwest and also functions as a disposal reservoir for natural and artificial drainage of excess water from the farm lands to the south and east. Prior to development of the Everglades, Lake Okeechobee overflowed its south shores at high stages, and water moved overland across the Everglades in broad sheets. At present, runoff from the Everglades is largely through the canal system, which serves generally both for irrigation and drainage.

During the period 1940-1946, rainfall over the entire southeastern Florida drainage unit averaged about 50 inches. Runoff, as measured in the canals draining to the sea, was equivalent to 7.5 inches over the area. The difference between rainfall and runoff averaged 42.6 inches; this loss was caused by evapotranspiration and changes in storage. There is also an unknown amount of subsurface percolation (ground-water flow) out of the Everglades. However, evapotranspiration is by far the most important factor in the removal of water from the area.

Effective drainage of the coastal ridge, which started about 1909, lowered the fresh-water head of the Biscayne aquifer in the Miami area and permitted a wedge of salt water to move inland at depth in the aquifer. It advanced on a broad front all along the shore zone, with tongue-like extensions pushing inland from the wedge under and along each of the tidal drainage canals. The most extensive and most rapid movement occurred in the Silver Bluff area because of the more effective drainage provided by the Miami, Tamiami, and Coral Gables Canals, which surround it on the landward side. This salt wedge may continue to move slowly inland, interrupted by periods of high water conditions, and it may gradually contaminate new areas. If the Ghyben-Herzberg principle is the governing factor, the inland movement may be expected to continue until the wedge reaches a place, determined by the average height of the water table, where the weight of fresh water above mean sea level will prevent the salt water from rising above the bottom of the Biscayne aquifer. This limiting height of the water table will probably be about 2½ feet above the average level of Biscayne Bay or about 3 feet above U. S. Coast and Geodetic Survey mean sea level datum. Salt-water encroachment via the canals can be rather effectively controlled by installing lock-and-dam structures as far downstream as is feasible.

In the coastal areas near Miami and Fort Lauderdale it is possible to map the approximate extent of subsurface salt-water encroachment by making surface electrical resistivity surveys. However, in urban areas some difficulty is caused by interference from power lines, buried pipes, and cables.

The surface waters that discharge into Lake Okeechobee from the north and west are soft, low in dissolved mineral matter, and rather highly colored. The surface waters to the south and east of Lake Okeechobee, which usually flow away from the lake, are variable in chemical character but are usually hard, contain moderate to large amounts of dissolved mineral matter, and are rather highly colored. The amount of dissolved matter in Lake Okeechobee is intermediate between the soft inflowing waters of the north and west and the hard water flowing seaward to the south and east.

Nonartesian waters along the Atlantic Coastal Ridge in Dade and Broward Counties are generally moderately hard, the dissolved mineral matter consisting largely of calcium and bicarbonate. Hardness ranges from about 150 to 300 ppm. Usually, the waters are colored by organic materials. Iron is frequently present in objectionable amounts and, when in combination with organic substances, contributes to the color of the water. The temperature averages 76° F. Shallow ground water in the Everglades is generally harder and more concentrated than the ground water along the coast because of the presence of saline residues left from former invasions of the sea. The high concentrations of bicarbonate found in some of the shallow ground water may be explained by the phenomenon of cation exchange, largely through the medium of organic matter, which colors practically all the waters in the area.

Artesian water in southeastern Florida is brackish, and generally it is unfit for domestic use and most other purposes. The average temperature is 72° to 73° F.

Of 32 public water supplies sampled, 26 had a hardness of less than 201 ppm and 13 had a hardness of less than 121 ppm.