STATE OF FLORIDA
DEPARTMENT OF NATURAL RESOURCES

BUREAU OF GEOLOGY
Robert O. Vernon, Chief

REPORT OF INVESTIGATION NO. 55

GROUND-WATER RESOURCES OF THE LOWER HILLSBORO CANAL AREA, SOUTHEASTERN FLORIDA

By

H. J. McCoy and Jack Hardee
U. S. Geological Survey

Prepared by the
U. S. GEOLOGICAL SURVEY
in cooperation with the
BUREAU OF GEOLOGY
DIVISION OF INTERIOR RESOURCES
FLORIDA DEPARTMENT OF NATURAL RESOURCES
and the cities of
BOCA RATON and DEERFIELD BEACH

Tallahassee, Florida
1970

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LETTER OF TRANSMITTAL

Bureau of Geology
Tallahassee
April 14, 1970

The Honorable Claude R. Kirk
Governor of Florida
Tallahassee, Florida

Dear Governor Kirk:

The Bureau of Geology of the Department of Natural Resources is publishing as its Report of Investigation No. 55 a report on the "Ground Water Resources of the Lower Hillsboro Canal Area, Southeastern Florida". The report was prepared as part of the cooperative program between the Bureau of Geology, the U. S. Geological Survey and the cities of Boca Raton and Deerfield Beach. It is written by Messrs. H. J. McCoy and Jack Hardee of the U. S. Geological Survey and was undertaken to determine the amount and kinds of water being produced from the lower Hillsboro Canal Area in Palm Beach and Broward counties.

All of the potable ground water being produced from the Biscayne aquifer is developed from the canal through infiltration. Rainfall in the area is the ultimate source for all of the water.

Careful control and management will allow the development of large quantities of water from the canal toward Lake Okeechobee, but a fresh water head must be maintained along the contact of fresh water with sea water to prevent salt water intrusion.

Respectfully yours,

R. O. Vernon, Chief
Bureau of Geology

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CONTENTS

LIST OF ILLUSTRATIONS

TABLES

GROUND WATER RESOURCES OF THE LOWER HILLSBORO CANAL AREA

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ABSTRACT

The lower Hillsboro Canal area of this report occupies about 60 square miles of Palm Beach and Broward counties in southeastern Florida. All potable ground water in the lower Hillsboro Canal area is obtained from the Biscayne aquifer. The aquifer extends from the land surface to a depth of about 400 feet and is composed of sand, sandy limestone, shells, and indurated calcareous sand. Municipal well fields of Deerfield Beach and Boca Raton and most of the domestic, irrigation, and industrial wells obtain adequate water supplies from permeable limestone 90 to 130 feet below land surface. Rainfall in the area and induced infiltration from controlled canals provide the recharge to the aquifer.

Sea-water intrusion, although a constant threat, has not advanced inland enough to contaminate either municipal well field. Intrusion from the El Rio Canal toward the Boca Raton well field appears to be stabilized, though further intrusion is a distinct possibility if fresh water levels are further lowered in the area. Data collection stations are maintained to monitor changes of the salt-water front in the aquifer.

Large quantities of water can be withdrawn from the interior part of the area without the attendant threat of salt-water intrusion. Hydraulic characteristics of the aquifer are similar throughout the area and high year-round water levels in the interior afford a potential source of immediate and long-term recharge to the aquifer underlying the coastal ridge.

The lower Hillsboro Canal area is still experiencing rapid growth with resultant demands for larger quantities of potable water. Although potable water is abundant, continuous observation and evaluation of changes in the hydrology of the area should be maintained to protect and efficiently manage the water resources of the area.

INTRODUCTION

Water problems facing the cities of Boca Raton and Deerfield Beach are similar to those experienced by other coastal communities in southeastern Florida with rapid growth and increasing water needs.

Water supplies for Boca Raton and Deerfield Beach are obtained from well fields located adjacent to the Intracoastal Waterway and to tidal reaches of the Hillsboro and El Rio Canals, all of which are normally salty. Recognizing that rapid population growth would mean large water demands and that increased well field pumping could cause sea-water intrusion, in 1963 officials of both cities requested the U.S. Geological Survey to study water resources of the area to provide information for the future development of water supplies.

PURPOSE AND SCOPE

The purpose of this report is to present an evaluation of the ground-water resources of the lower Hillsboro Canal area and pertinent supporting data to the officials of Boca Raton and Deerfield Beach, Fla. The evaluation is the result of determining the following: (1) the location, availability, and quality of potable ground water in the Biscayne aquifer; (2) the occurrence and extent of sea-water intrusion into the aquifer in the vicinity of the well fields; (3) the hydraulic characteristics of the aquifer; and (4) the degree of interconnection between the canals and the aquifer.

This report was prepared by the U.S. Geological Survey in cooperation with the cities of Boca Raton and Deerfield Beach, and as part of the statewide program with the Bureau of Geology, Florida Department of Natural Resources. The field work and report preparation were under the immediate supervision of C. B. Sherwood, Projects Engineer, and H. Klein, Subdistrict Chief, Miami, Fla., and under the general supervision of C. S. Conover, District Chief, Tallahassee, Fla., all of the U.S. Geological Survey.

PREVIOUS INVESTIGATIONS

This report results from the first detailed ground-water resources study of the lower Hillsboro Canal area. General information on the hydrology and geology of the area has been published by the Florida Geological Survey in reports by Cooke (1945), Black and Brown (1951), and Schroeder and others (1958). Some additional information on the area is included in a report resulting from a comprehensive investigation of the water resources of southeastern Florida by Parker and others (1955).

ACKNOWLEDGMENTS

Well-field and water-supply information given by William Eddinger, Water Superintendent of Boca Raton, and Arthur Strock, former City Engineer of Deerfield Beach is appreciated. Special acknowledgment is expressed to Drs. F. A. Eidsness, J. I. Garcia-Bengochea and Mr. Emmett Waite, of Black, Crow and Eidsness, Inc., Gainesville, Fla., consulting engineers for the cities of Boca Raton and Deerfield Beach.

GENERAL FEATURES

The area of study comprises about 60 square miles of Palm Beach and Broward counties in southeastern Florida as shown in figure 1. The area is bounded on the east by the Atlantic Ocean and on the west by an extensive agricultural area and the Everglades; it extends about 6 miles north and 4 miles south of the Hillsboro Canal. The county lines and the city limits of Boca Raton and Deefield Beach coincide with the Hillsboro Canal except near the mouth of the canal. The area is divided into three physiographic sub-areas (Fig. 1): (1) coastal lowlands-barrier island; (2) coastal ridge; and (3) interior flatlands and the Everglades.

The barrier islands parallel the mainland and are separated from it by the Intracoastal Waterway. Barrier islands extend intermittently along most of Florida's east coast. Relic sand dunes form the island in the study area and reach heights of more than 25 feet above msl (mean sea level) in some locations. The white, sandy beach on the ocean side of the island is one of the main tourist attractions in the area. The coastal lowland on the mainland is characterized by mangrove swamps adjacent to the Intracoastal Waterway and is generally less than 5 feet above msl except where dredging and filling has taken place for housing developments.

Paralleling the coastal lowland is the coastal ridge. In Deerfield Beach the ridge is relatively wide and flat, reaching a maximum elevation of about 25 feet above msl. However, in Boca Raton it is narrower, dissected, relatively steep-sided, and reaches a maximum elevation of nearly 40 feet above msl. The ridge is composed of white sand containing varying amounts of shelly material. Westward from the crest of the ridge the land surface slopes to the interior flatlands; in Deerfield Beach the slope is gentle but in Boca Raton it is steep, especially in the vicinity of the El Rio Canal along the west flank of the ridge.

The interior flatland extends westward from the coastal ridge to the Everglades. It is characterized by a relatively flat surface and supports a natural growth of palmettos, pine trees, and a variety of palm trees. The average elevation of the interior flatland is about 15 feet above msl.

CLIMATE

The climate of the lower Hillsboro Canal area is humid subtropical. The nearness of the Atlantic Ocean accounts for the high humidity

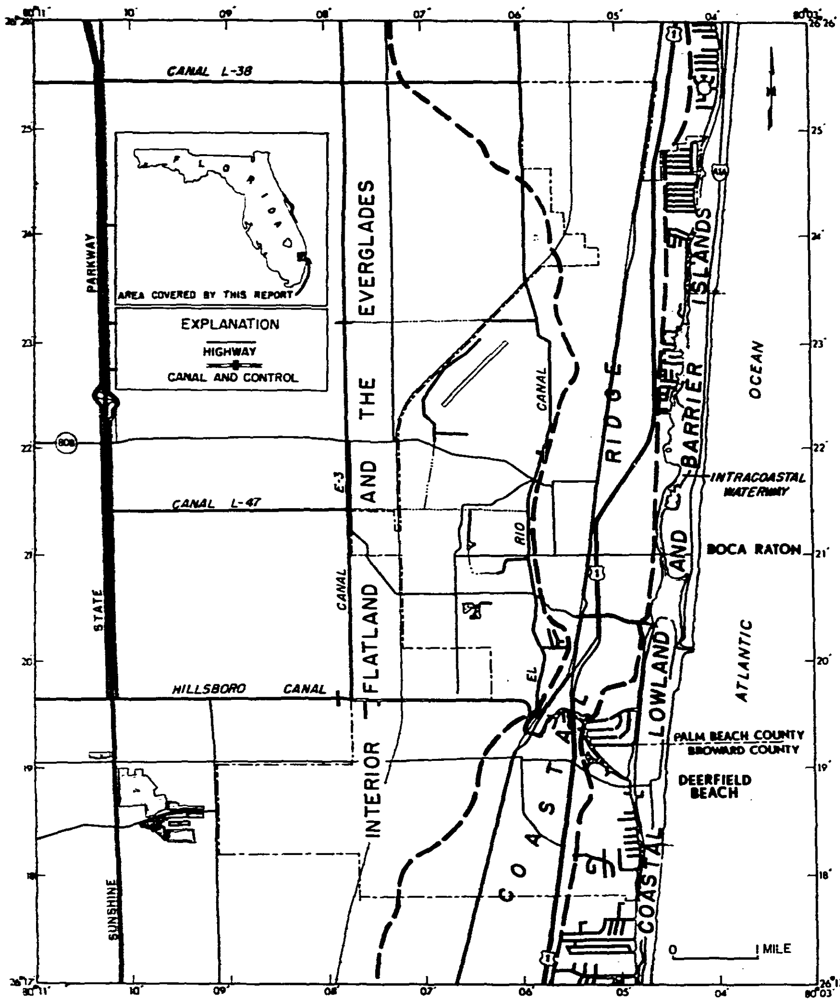


Figure 1. Location of lower Hillsboro Canal area, Florida showing physiographic subdivisions.

but the Gulf Stream moderates the temperature. The average monthly temperatures for January and August during the period 1946 through 1967 were 68° F. and 82° F. The average annual temperature for that period was 75° F. (U.S. Weather Bureau).

Rainfall in the area is unevenly distributed with time and location. The average annual rainfall for the long-term period 1951-1967 is nearly 60 inches. During this period five years were above average, five years were below average, three years were approximately average, and four years were not totaled because of incomplete data.

TABLE 1 – MONTHLY RAINFALL AT BOCA RATON, FLA.[1]

(inches)

	1961	1962	1963	1964	1965	1966	1967
January	8.56	0.47	2.93	1.85	0.73	3.27	2.41
February	.85	.69	6.18	3.82	5.25	5.79	2.34
March	1.09	3.41	4.73	3.20	.97	1.85	3.57
April	.67	6.51	.93	4.36	.71	1.66	0.00
May	6.47	1.91	13.01	6.20	1.22	4.93	2.07
June	2.80	5.20	7.47	7.93	10.91	16.51	11.86
July	1.22	10.42	2.02	5.31	11.01	7.63	3.71
August	5.06	6.08	5.43	7.89	3.44	6.18	6.83
September	4.50	7.59	12.51	6.31	4.24	8.32	7.41
October	6.93	1.98	7.11	11.13	29.64	6.95	5.42
November	1.09	1.63	2.42	.63	3.94	1.06	3.71
December	.16	.88	3.74	1.93	1.01	1.00	1.72
TOTALS	39.40	46.77	68.48	60.56	73.07	65.15	51.05

[1] Record from U.S. Weather Bureau's Climatological Data.

Table 1 shows the monthly rainfall recorded at Boca Raton for the period 1961 through 1967. This period was chosen for presentation because it includes the two dry years preceding the beginning of the study. The average for this period is 58 inches, or two inches below the long-term average. Abnormally heavy rainfall was recorded during October 1965. Most of the rain occurred during the middle and at the end of the month. At Pompano Beach, shown in figure 2, 24 inches of rainfall was recorded in 24 hours on October 31 and November 1.

POPULATION AND INDUSTRY

The lower Hillsboro Canal area has been strongly affected by the population boom of southeastern Florida. The area has grown in population from about 3,000 in 1950 to more than 36,000 in 1966. The predicted population for 1970 exceeds 50,000.

Although Boca Raton and Deerfield Beach are primarily tourist and retirement communities, both cities have planned for the expansion of light, clean industries. The largest employers are the private and chain sales and service stores. Agriculture contributes significantly to the economy of the area. Several private and state-owned educational institutions also play a part in the overall economic structure.

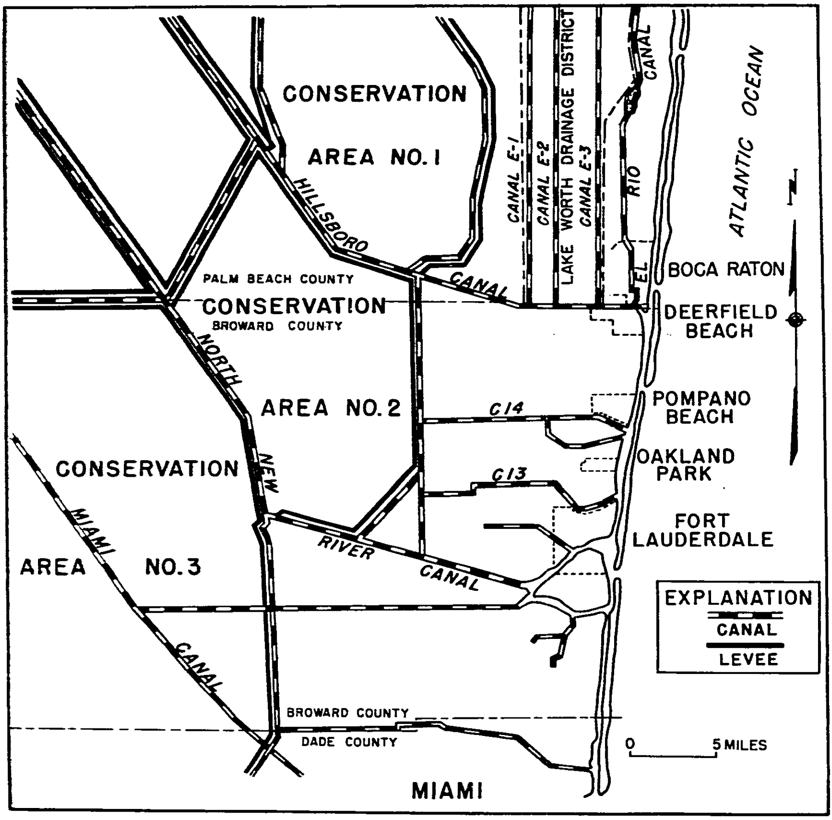


Figure 2. Parts of Broward and Palm Beach counties showing canals and levees of the Central and Southern Florida Flood Control Project and the Lake Worth Drainage District.

HYDROLOGIC SETTING

The lower Hillsboro Canal area abounds in water: the Atlantic Ocean is to the east and the vast water control works of the Central and Southern Florida Flood Control District (FCD) is to the far west and south (Fig. 2). A latticework of controlled canals of the Lake Worth Drainage District (LWDD) is immediately adjacent to the north and west sides of Boca Raton; the canals of the FCD and the LWDD were constructed primarily to improve drainage during periods of high rainfall. The canals cut across the top of permeable shallow sediments called the Biscayne aquifer. During periods of low rainfall, the canals convey water from inland areas and replenish the aquifer by induced infiltration. Because rainfall is the primary source of replenishment to the Biscayne aquifer, water levels are highest during the wet part of the year and lowest during the dry.

BISCAYNE AQUIFER

All fresh ground-water supplies in the lower Hillsboro Canal area are obtained from the Biscayne aquifer. The aquifer extends from land surface to a depth of about 400 feet (Tarver, 1964). Eight test wells were drilled in the area to augment available data in determining the lithologic composition of the upper part of the aquifer. Figure 3 shows locations. The wells ranged in depth from 127 to 208 feet below the land surface. Data from these wells were used in preparing the geologic sections in Figures 4 and 5.

The Pamlico Sand of Pleistocene age blankets most of the lower Hillsboro Canal area and is the uppermost unit of the Biscayne aquifer. It is composed of very fine to coarse quartz sand, white to black or red, depending upon the staining materials. The Anastasia Formation of Pleistocene age underlies the Pamlico Sand and is composed of coquina, sand, indurated calcarcous sand, and sandy limestone. The Anastasia Formation is the principal source of water from the Biscayne aquifer in the lower Hillsboro Canal area.

The Tamiami Formation of late Miocene age underlies the Anastasia Formation. Permeable limestone beds in the upper part of the Tamiami Formation constitute the basal part of the Biscayne aquifer. The formation is tapped by few wells in the lower Hillsboro Canal area because equally good water and comparable yields can be obtained from wells that are bottomed in shallower limestones in the Anastasia Formation.

Rock materials penetrated by the test wells are shown by Figure 4. Test-well data plus data from a few existing wells were used to draw Figure 5. Both Figures show that sand covers the lower Hillsboro Canal area to depths as much as 60 feet below the land surface. The Pamlico Sand accounts for about 20 feet of this section in the Deerfield Beach area and as much as 50 feet in the Boca Raton area. The geologic sections show that the limestone beds are discontinuous vertically and horizontally. Additional information from drillers in the area indicates that limestone beds are more persistent in the Deerfield Beach area than in the Boca Raton area.

Beds of indurated calcareous sand, or sandy limestone are widespread enough through the lower Hillsboro Canal area that wells can usually be finished with open holes below the casing. However, irrigation and municipal wells subject to heavy withdrawals are usually screened and gravel packed. In the western part of the area private

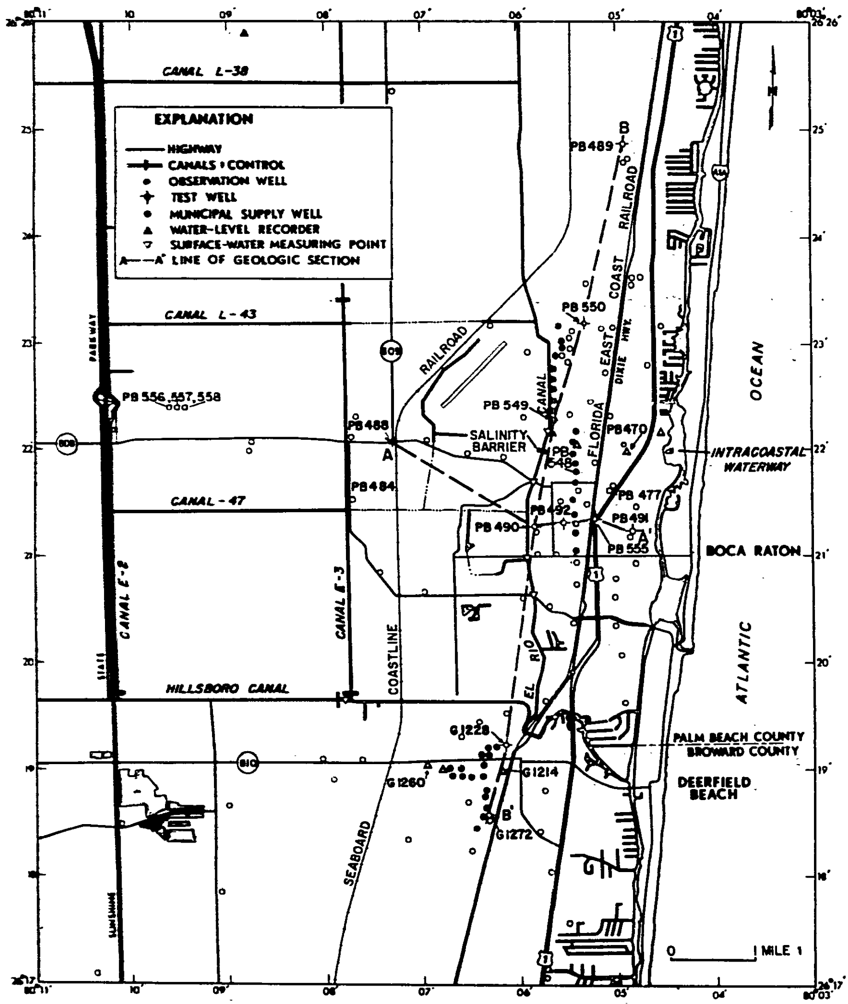


Figure 3. Map of lower Hillsboro Canal area showing location of wells and lines of geologic sections.

supply wells penetrate permeable material at depths ranging from 60 to 90 feet. This permeable material could be the same limestone as that penetrated at 70 feet in well PB488 or the shelly, friable limestone penetrated at 89 feet in wells PB-556, 557, and 558 (see Fig. 3 for locations).

The Boca Raton well field obtains water from the limestone shown by well PB 548 in Figure 5. The limestone is discontinuous and becomes increasingly sandy to the north. This is indicated by the

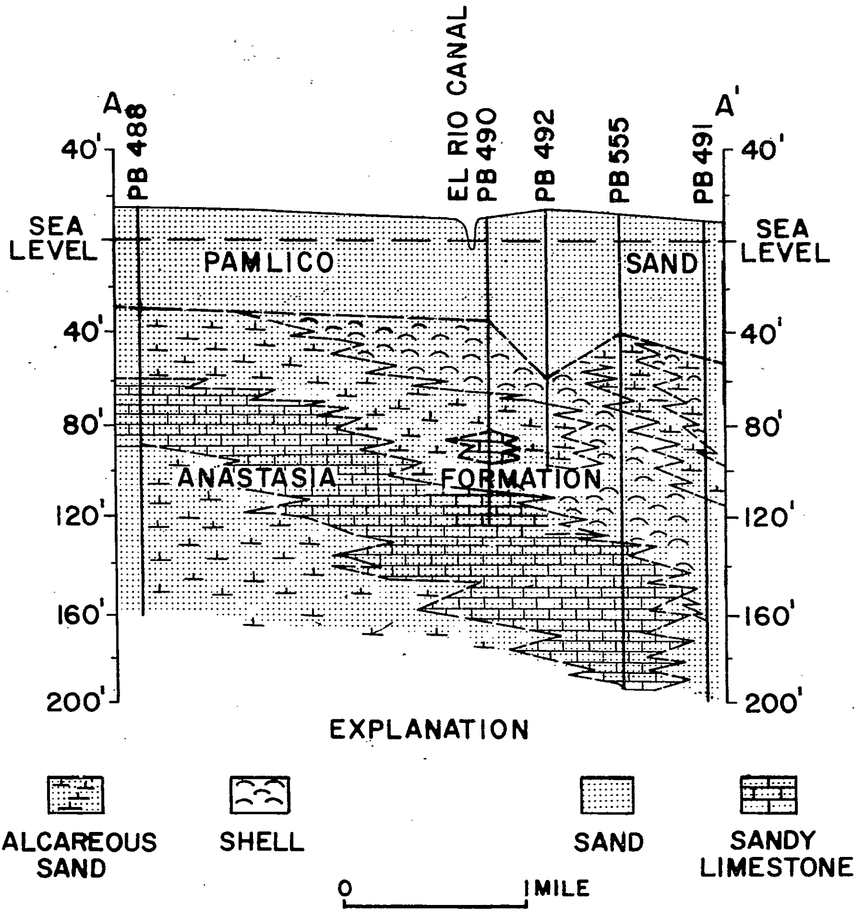


Figure 4. Geologic section of the Biscayne aquifer in the lower Hillsboro Canal area along line A-A' in figure 3.

absence of dense limestone in wells PB489, PB549 and PB550. Wells in the original Deerfield Beach well field and the southern extension are obtaining water from the limestone shown in wells G-1228 and G-1272 in Figure 5.

FLORIDAN AQUIFER

The Floridan aquifer is a thick sequence of highly permeable limestone underlying most of Florida. In the central and western parts of the Florida peninsula the aquifer is exposed or covered by relatively thin layers of sand, but in the southeastern part of the state the aquifer

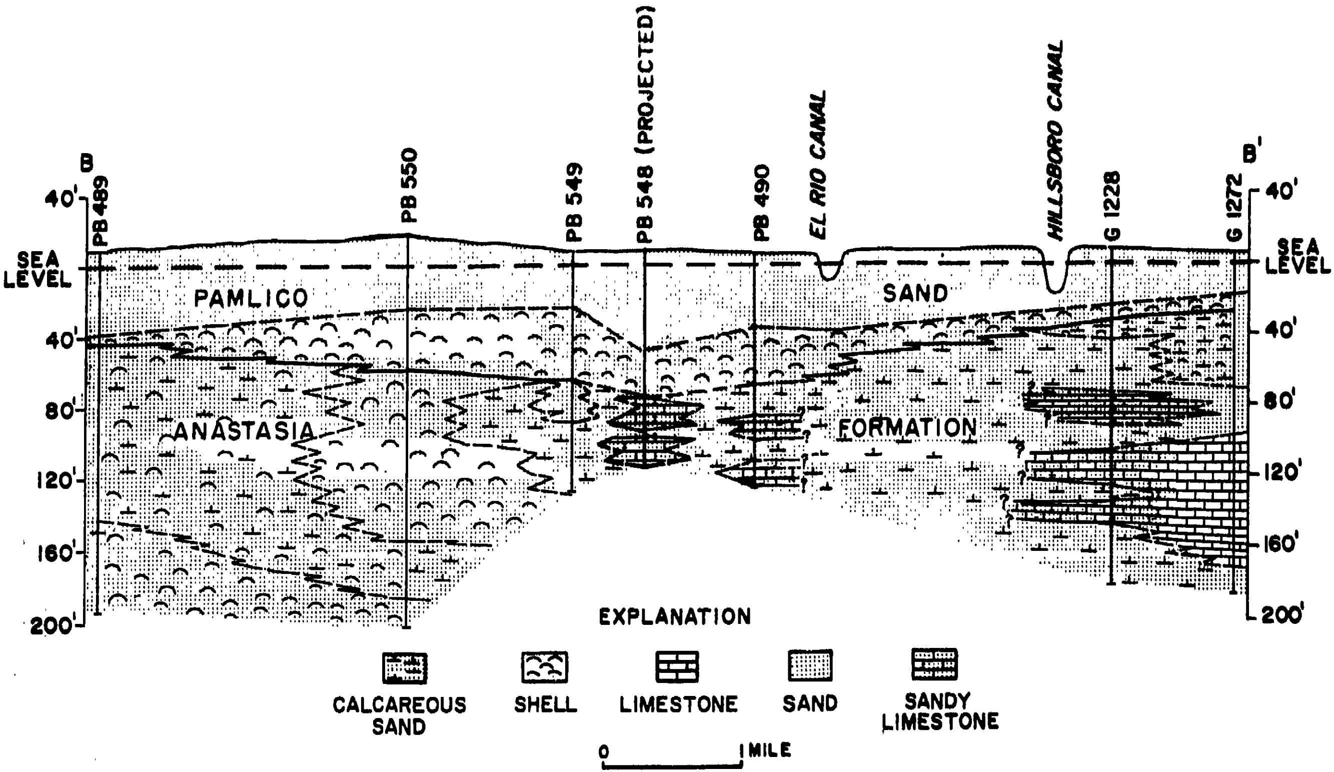


Figure 5. Geologic section of the Biscayne aquifer in the lower Hillsboro Canal area along line B-B' in figure 3.

is about 1,000 feet below the land surface and the water is under greater than atmospheric pressure. The water level in a well penetrating this aquifer in the lower Hillsboro Canal area will rise more than 25 feet above msl. Such a well may yield as much as 2,000 gpm (gallons per minute) by natural flow. However, in the study area, as in most of south Florida, water from the Floridan aquifer is too mineralized for most uses. Because of the tremendous quantities of water available, the upper, less mineralized part of the aquifer, may be considered as a potential source of supplemental water. However, the deeper, more mineralized part of the aquifer is already being used as a reservoir for discharge of chemical wastes near Lake Okeechobee, and sewage wastes for a municipality near Pompano Beach.

SURFACE FLOW SYSTEM

The Hillsboro Canal is one of the primary canals of the controlled network of the regional Central and Southern Florida Flood Control District (FCD) as shown in Figure 2. The Hillsboro Canal extends eastward from Lake Okeechobee between water Conservation Areas 1 and 2, where excess water is stored, to the Intracoastal Waterway. The canal not only provides gravity drainage for flood control, but also conveys water from the conservation areas eastward for replenishment of the aquifer near the coast during droughts. This is accomplished by keeping the control structure near the coast closed during the dry season, thereby maintaining water levels in the canal higher than the adjacent ground-water levels. During wet periods when ground-water levels begin to rise higher than the canal levels the control structure is opened to prevent flooding and the canal level and ground-water levels are lowered.

Water levels in Boca Raton are affected more by operations of the Lake Worth Drainage District than by the Hillsboro Canal. The Lake Worth Drainage District is immediately west of Boca Raton (Fig. 2) and consists of a system of controlled canals. The primary (equalizing) canals flow southward bringing water during wet periods from areas north of Boca Raton and discharge excess waters into the Hillsboro Canal several hundred feet east of the control structure. The secondary (lateral) canals are oriented east-west and connect to primary canals.

In September 1965 a salinity barrier was constructed on the El Rio Canal about 1,600 feet north of State Road 808 bridge to prevent sea-water intrusion into the Boca Raton well field. The barrier was placed as far downstream as economically feasible.

GROUND WATER

Ground water occurs beneath the land surface in the zone of saturation where it fills the interstices, joints, crevices, fissures, solution holes, and any or all other voids and is the supply for springs and wells (Meinzer, 1923, p. 38-39). The subsurface formations containing ground water, and from which this water is collectible for use, are called aquifers.

The upper surface of the zone of saturation, which is under atmospheric pressure and free to rise and fall, is called the water table. Where ground water is confined in a permeable bed overlain by a relatively impermeable bed its surface is not free to rise and fall and the water is under greater than atmospheric pressure. Water thus confined under pressure is called artesian. Direction of ground-water movement is from areas of high water levels to areas of low water levels.

The Biscayne aquifer is essentially a nonartesian (or water-table) aquifer, but in most locations in the lower Hillsboro Canal area the permeable limestone beds are partly confined by discontinuous overlying layers or lenses of less permeable materials.

RECHARGE AND DISCHARGE

The amount of fresh water potentially available in the lower Hillsboro Canal area is determined by the recharge to and discharge from the Biscayne aquifer and the quantity available from storage in the aquifer. Infiltration of rainfall through surface materials and seepage from controlled canals are the means of recharge. Recharge by rainfall is greatest, naturally, during the rainy season of June to November. Recharge from canals is greatest during the dry season, December to May, when canal levels are higher than adjacent water levels in the aquifer.

Discharge from the aquifer is by evapotranspiration, by ground-water flow to canals and by pumping from wells. Discharge by ground-water and surface-water flow and losses by evapotranspiration are greatest during and after periods of rainfall when water levels are high; discharge by pumping from wells is greatest during the dry periods, at the peak of the tourist season. Discharge by wells constitutes only a small part of the total discharge from the area.

The average annual rainfall of 60 inches evenly distributed over the lower Hillsboro Canal area would be equivalent to about 170 mgd (million gallons per day). Probably as much as 100 mgd would be lost by evapotranspiration and discharge to the ocean. The remaining 70 mgd would be available to recharge the aquifer.

WATER-LEVEL FLUCTATIONS

Ground water in the Biscayne aquifer moves from areas where water levels are high to areas where water levels are low. Water levels are highest in recharge areas or in areas that are the greatest distance from points of discharge; water levels are lowest in discharge areas along the coast, along uncontrolled drainage canals, or in the vicinity of heavy pumping.

Fluctuations of the water levels reflect the effects of recharge to and discharge from the aquifer. Water levels in the lower Hillsboro Canal area fluctuate in response to rainfall in the immediate area; therefore water levels generally are high during the rainy season (June-November) and low during the dry season (December-May). A rise in water levels does not register the total replenishment to the aquifer, but the rise is an indication of the excess of the recharge over the discharge. Fluctuations are determined by water-level measurements in a network of observation stations in canals and on wells; some stations are equipped with automatic recording instruments which provide continuous, detailed records. The network is shown in Figure 3.

Water level changes in selected wells in Boca Raton and Deerfield Beach for the period 1963-67 are shown by hydrographs on Figures 6 and 7. Monthly rainfall at Boca Raton is shown for the purpose of correlation. The hydrographs show both the day-to-day changes and the long-term trends. Well PB 470 (Fig. 6) is on the coastal ridge about a half mile east of the Boca Raton municipal well field, and the water level in the well is mildly influenced by well-field withdrawals. During extended dry periods, such as the spring of 1964 and 1965, water levels there approached one foot above msl. On the other hand, water levels in the vicinity of well PB 488 (Fig. 6) about 2 miles west of the well field are not affected by well-field withdrawals and remain high throughout most of the year. During 1967, levels near well PB 488 were 5 feet or more higher than levels east of the well field. Also, the magnitude of fluctuations at well PB 470 is greater than it is at well PB 488 because well PB 470 is influenced by well field pumping and is located near the coast where ground water is being discharged into the Intracoastal Waterway.

The hydrographs of both wells show that the response to rainfall is rapid, indicating that infiltration to the water table takes place quickly.

The hydrograph of well G-1260 (Fig, 7) in Deerfield Beach, 1500 feet west of the municipal well field, is similar to that of well PB-470 in Boca Raton. Levels in the Deerfield Beach well are generally higher than those in the Boca Raton well because the Deerfield Beach well is

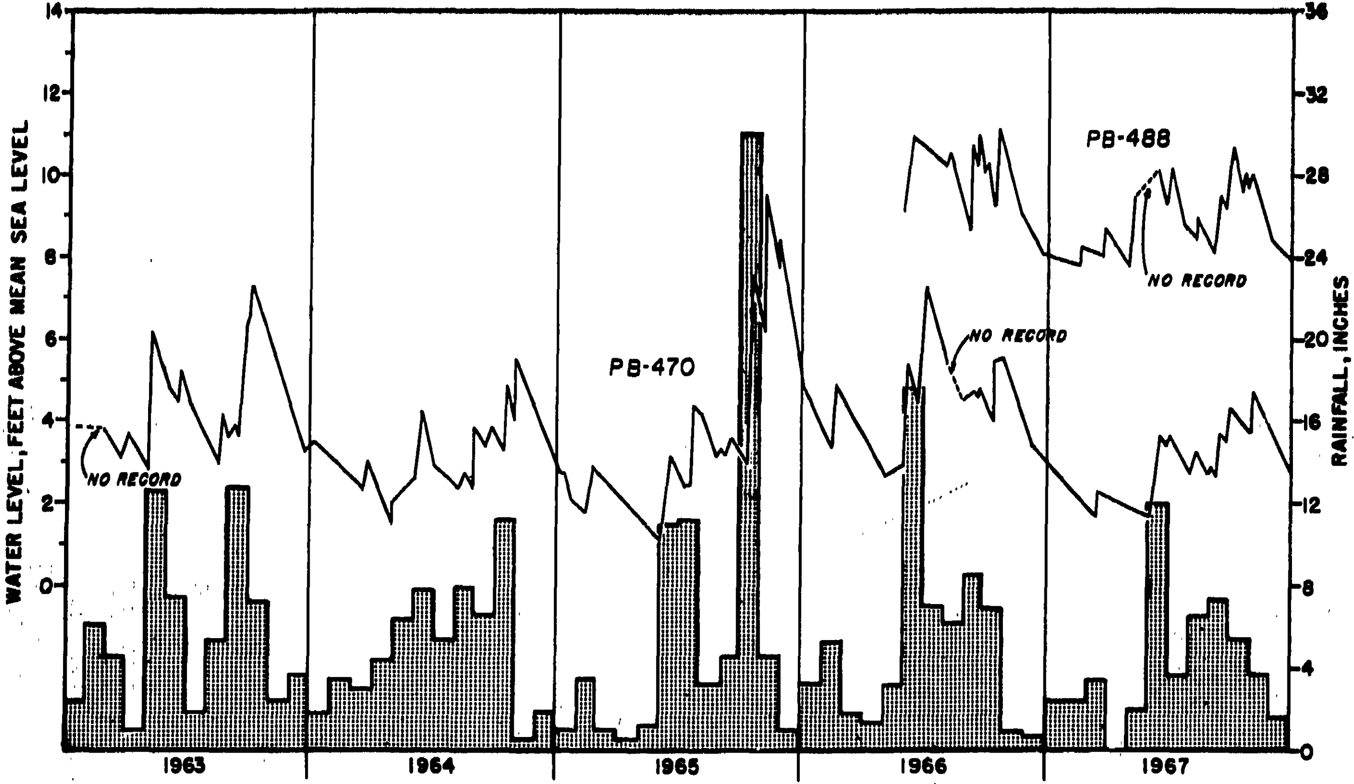


Figure 6. Hydrographs of wells PB 470 and PB 488 and monthly rainfall at Boca Raton, 1963-1967.

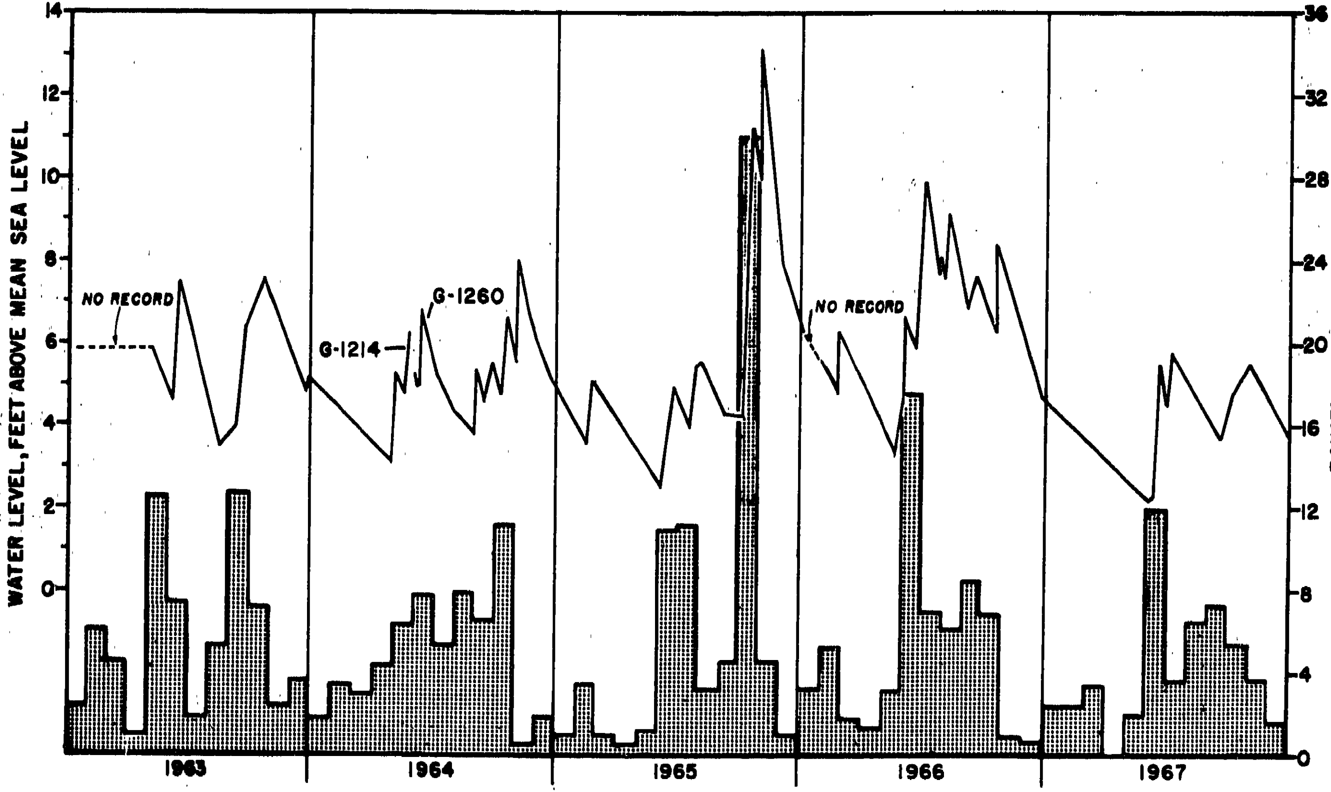


Figure 7. Hydrographs of wells G 1214 and G 1260 at Deerfield Beach and monthly rainfall at Boca Raton, 1963-1967.

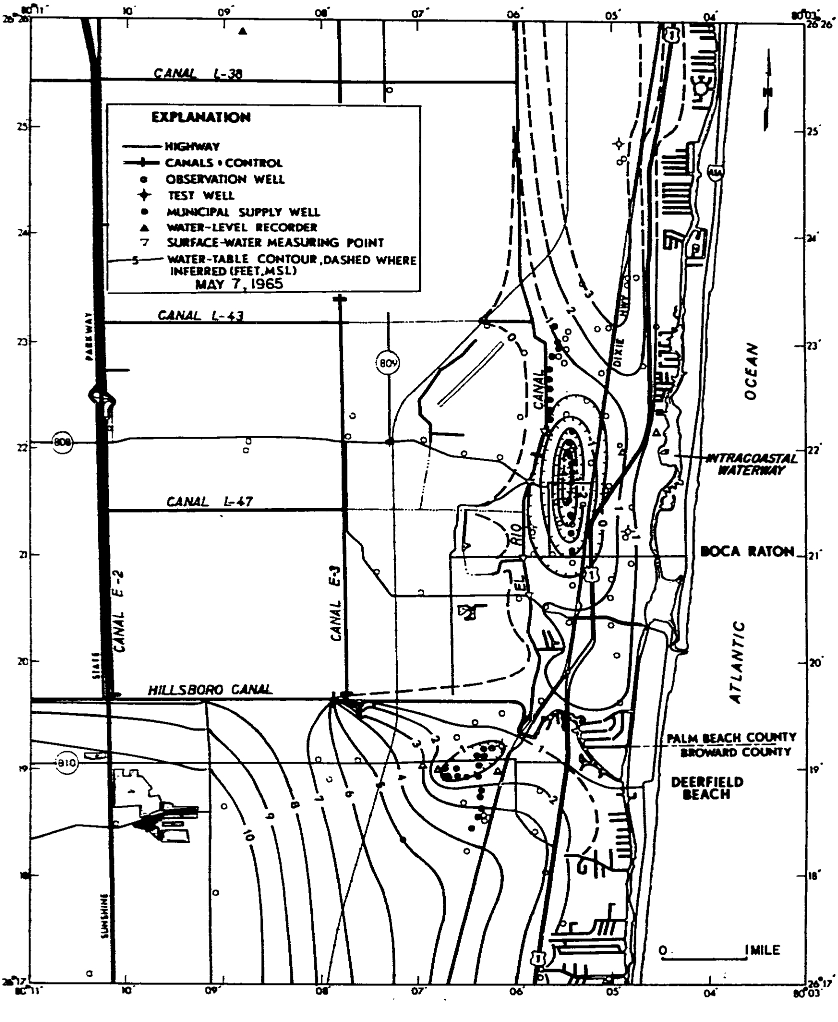


Figure 8. Water-table contour map of the lower Hillsboro Canal area, May 7, 1965, during low-water conditions.

farther from an area of natural discharge (Hillsboro Canal), and because the significantly lower pumping rate at the Deerfield Beach well field causes less drawdown of water level.

Water-level contour maps are representations of the three-dimensional configuration of the water surface for a specific time. Figure 8 shows the configuration of the water table on May 7, 1965 – the record low-water levels for the period 1963-1967. For the time this map was made, rainfall had been deficient for about seven months, and pumpage from the two municipal well fields was record high as shown in figures 9 and 10. The irrigation system west of Deerfield Beach was continuously pumping water from the Hillsboro Canal into a network of irrigation canals (not shown in Fig. 8) thus maintaining relatively high water levels in the west during the drought.

The configuration of the contours north of the Boca Raton well field shows that ground water was discharging into the El Rio Canal, but adjacent to and for some distance southward of the well field, water from the El Rio Canal was recharging the well field by induced infiltration. This was because heavy withdrawals of water had lowered the water table to four feet below msl in the well field. In addition, these withdrawals lowered the water-table mound between the well field and the Intracoastal Waterway to one foot above msl. Water levels north of Boca Raton remained relatively high due to very little pumping and the fact that less permeable sandy materials retarded the lateral movement of the ground water.

In the Deerfield Beach area, hydrologic conditions contrast rather sharply with those in Boca Raton. Water from the recharge area west of the well field, and outseepage of water from the controlled reach of the Hillsboro Canal maintained relatively high water levels in the vicinity of the well field. Pumping lowered water levels in the Deerfield Beach well field only to about one foot above msl, which was considerably higher than the pumping levels in the Boca Raton field. However, the water-table mound between the Deerfield Beach well field and the tidal reach of the Hillsboro Canal was still only one foot above msl.

Figure 11 represents the configuration of the water table on November 1, 1965 – the highest water levels for the period 1963-67. The absence of depression contour lines in the well fields indicates that municipal pumping was not significantly affecting the configuration of the water table at that time.

A salinity barrier was constructed in the El Rio Canal in September 1965 about one-half mile north of the State Road 808 bridge. The top of the barrier is two feet above msl and is designed to limit tidal flow in the canal and to impound fresh water upstream of the barrier for recharge to the well field. The water level in the canal was above the top of the salinity barrier at the time the map in figure 11 was compiled; therefore the effect of the barrier can not be seen.

The coastal ridge is delineated by the high water-level contours paralleling the coast. The saddle in the contour lines east of the Boca Raton well field corresponds to a natural depression in the land surface. The distorted contour lines in and northeast of the Deerfield Beach well field conform to a natural drainageway.

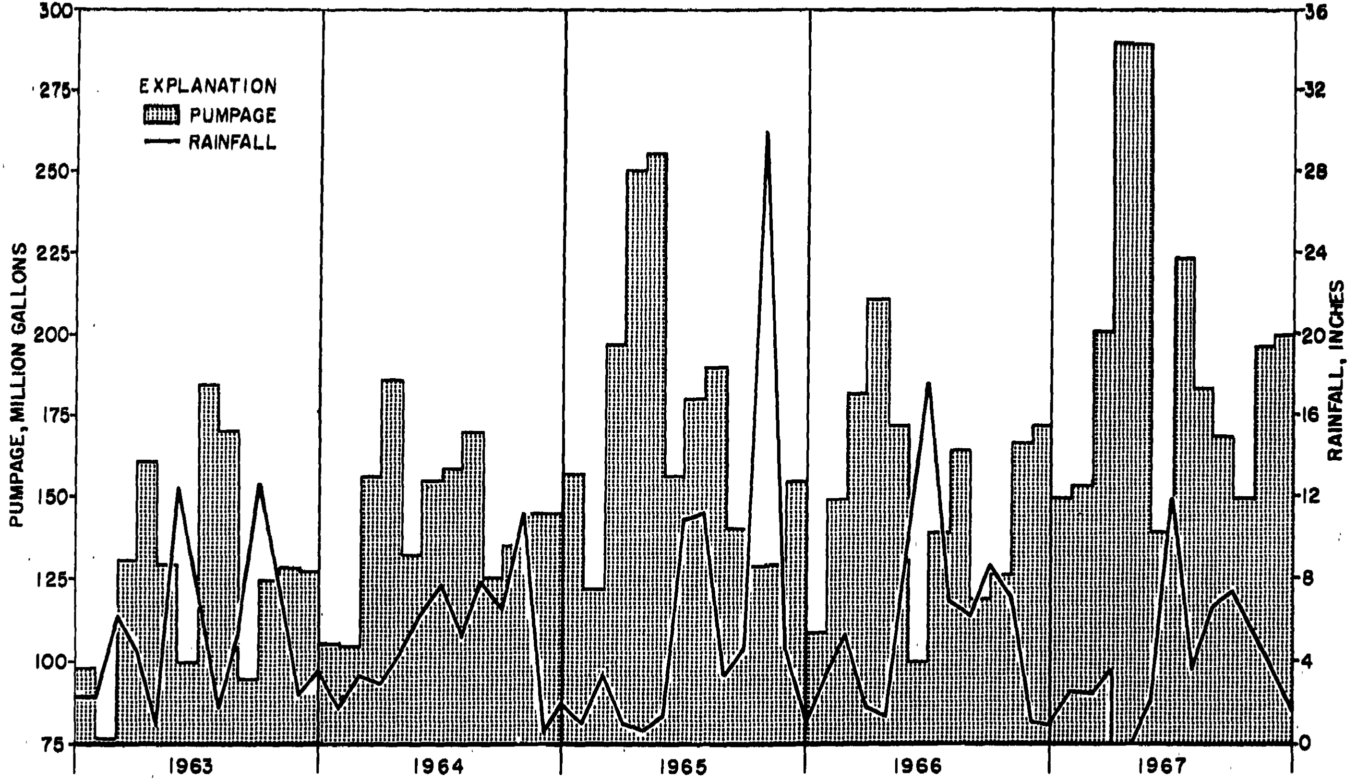


Figure 9. Graph showing monthly municipal pumpage and rainfall at Boca Raton, 1963-67

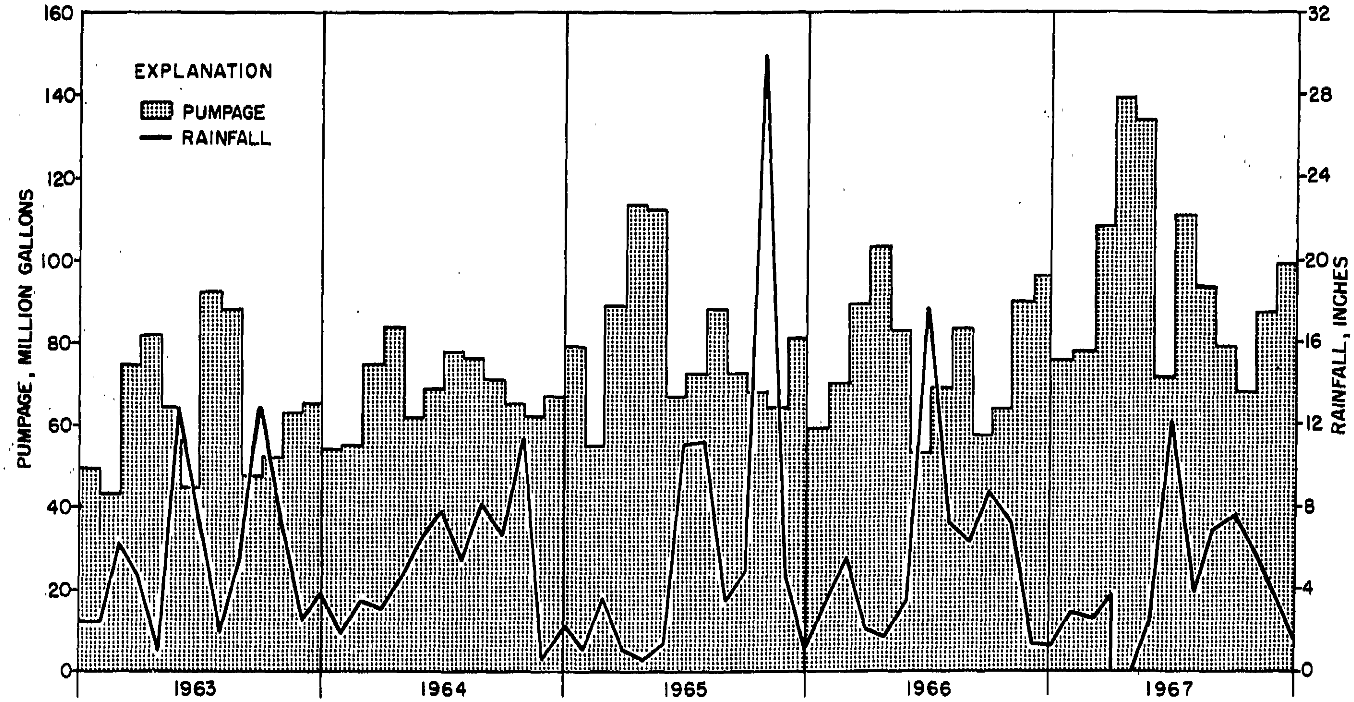


Figure 10. Graph showing monthly municipal pumpage at Deerfield Beach and monthly rainfall at Boca Raton, 1963-67.

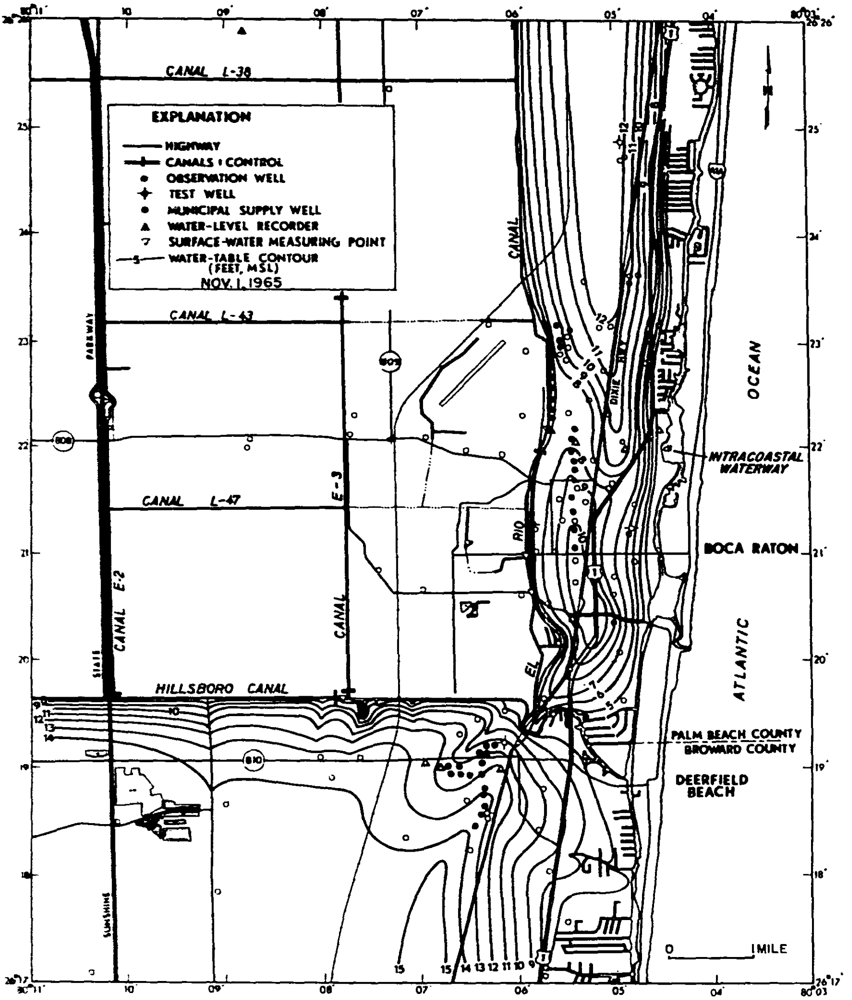


Figure 11. Water-table contour map of the lower Hillsboro Canal area, November 1, 1965, during high-water conditions.

The net increase in storage in the aquifer from May 7 to November 1, 1965, is shown by the rise in water level on Figure 12. The average rise in water levels from the low period to the high period was about six feet for the area contoured, and the average estimated rise in the remainder of the area was about two feet. If an average porosity of 25 percent is assumed for the Biscayne aquifer in the area, then the rise in levels during the period represents an increase in storage of about 10.2

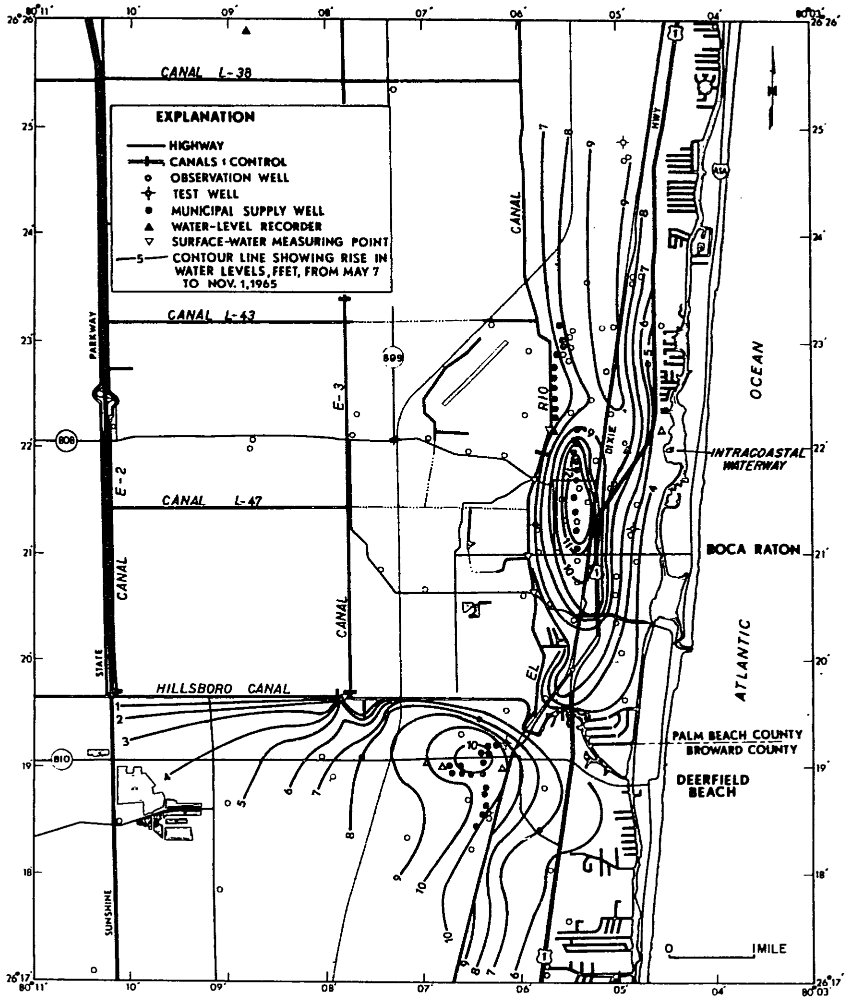


Figure 12. Contour map showing rise in water levels from May 7 to November 1, 1965, in the lower Hillsboro Canal area.

billion gallons or 60 mgd. This large increase in net storage was possible because over 60 inches of rainfall was recorded at Boca Raton during this six-month period – nearly 30 inches of it during October (see Table 1), resulting in this substantial recharging of the aquifer.

Figures 13 and 14 reflect high and low water level conditions on October 27, 1966 and April 12, 1967. Additional shallow observation wells were installed in the inland area between the El Rio Canal and

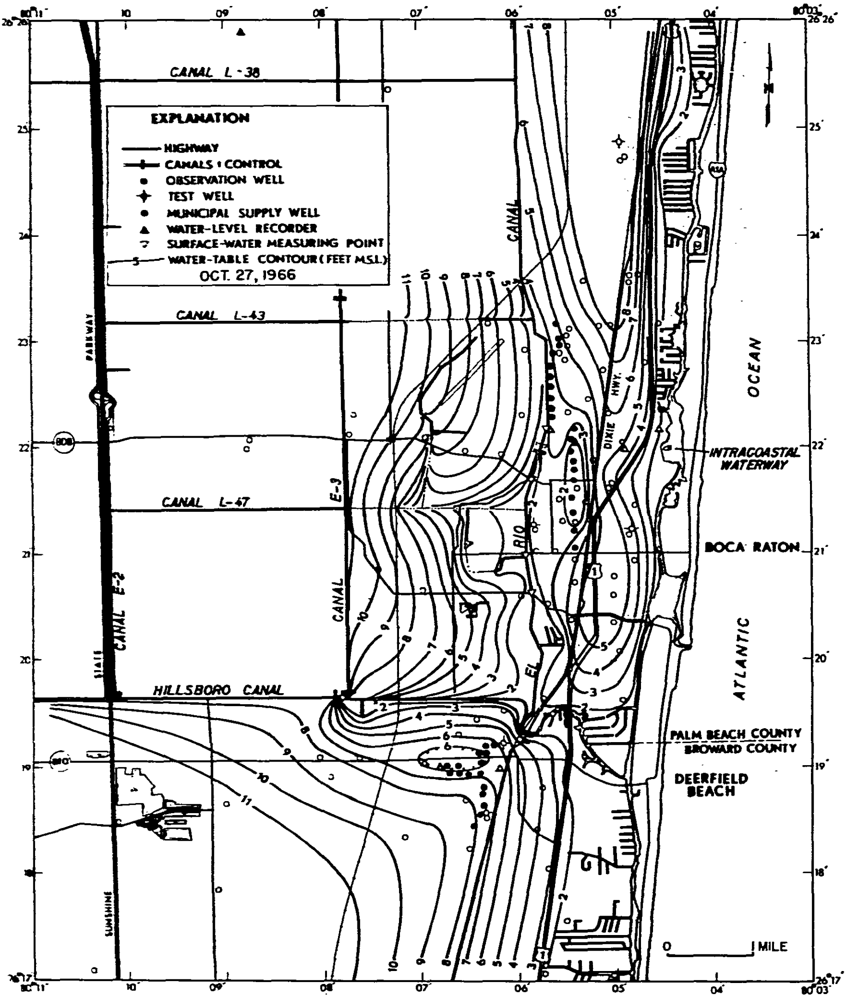


Figure 13. Water-table contour map of the lower Hillsboro Canal area, October 27, 1966, during high-water conditions.

Canal E-3 in the Boca Raton area and around the Deerfield Beach well field to allow monitoring of the effects of the salinity barrier on the El Rio Canal, the extension of the configuration of the water table west of the El Rio Canal, and more accurate delineation of the pumping levels in the Deerfield Beach well field.

The top of the control structure on Canal E-3 just north of L-43 is about 16 feet above msl, and the top of the structure near the Hillsboro

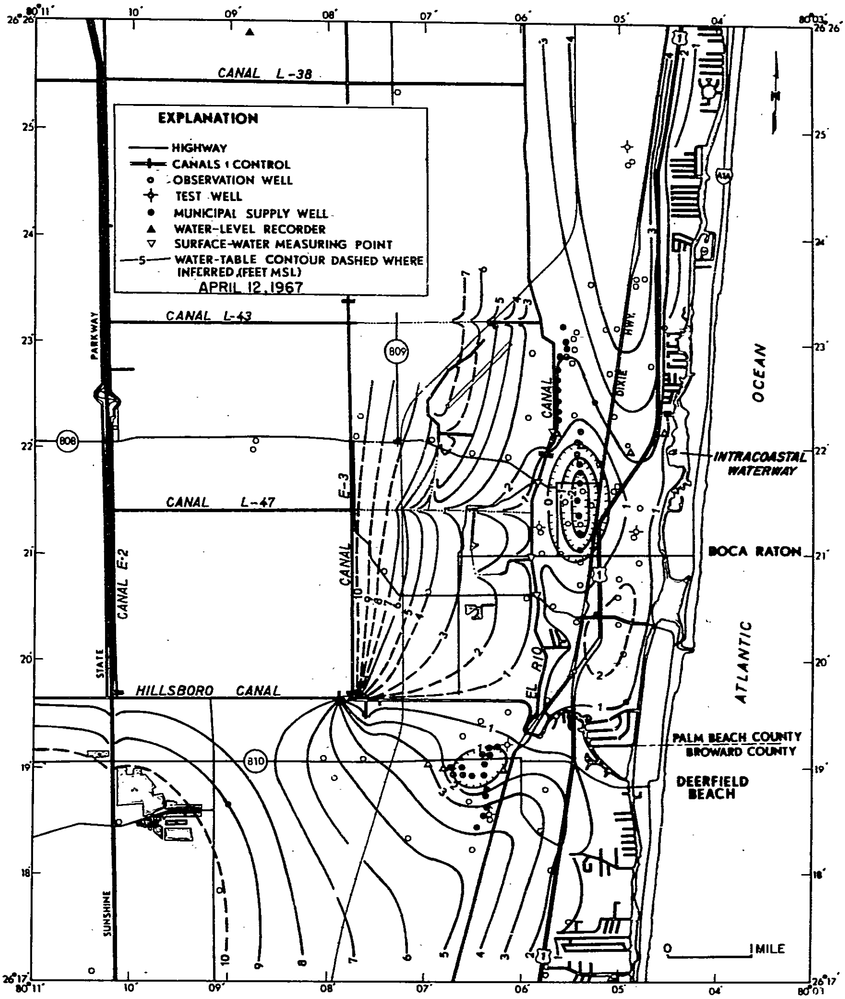


Figure 14. Water-table contour map of the lower Hillsboro Canal area, April 12, 1967, during low-water conditions.

Canal is set at about 12 feet above msl. Thus when canal levels in the northern reach of Canal E-3 exceed 16 feet msl, the excess water is discharged southward where it is impounded until it reaches a level about 12 feet msl. When levels exceed 12 feet at the lower structure, water is discharged into the uncontrolled reach of the Hillsboro Canal.

The contours in Figure 13 represent high water levels of October 27, 1966, and show that the water table west of the El Rio Canal was approximately the same level as the water table west of Deerfield Beach. The similar water table levels are due primarily to Canal E-3 replenishing the aquifer west of the El Rio in the same manner as the irrigation district west of Deerfield Beach replenishes the aquifer there. Small drainage canals have reduced water levels in the highly urbanized area adjacent to the west side of the El Rio Canal. The drawdown in the Boca Raton well field is small because of the reduction in pumping (see Fig. 9). The depression contours have extended west of the Deerfield Beach well field, probably as a result of large withdrawals for irrigation at the municipal golf course. The control structure on the Hillsboro Canal was closed and was maintaining a canal level more than seven feet above msl on the upstream side. The level in Canal E-2 upstream of the control at the Hillsboro Canal was more than 10 feet above msl.

Figure 14 depicts the low water conditions of April 12, 1967 and shows the effects of the pumping in the well-field extensions of the two cities. Although withdrawals from each well field are at record high, the pumping levels do not exceed the record low levels in either well field (Fig. 8). Instead, the pumping level in the Boca Raton well field was two feet higher than on May 7, 1965 (Fig. 8). This higher level is due in part to the recharge contributed to the Boca Raton well field extension from the controlled reach of the El Rio Canal. The position of the zero contour line in figure 14 is more than a quarter of a mile farther from the canal than it was in Figure 8. The additional pumping in the well field extension in Deerfield Beach made the pumping level depression more circular and displaced it farther inland from the tidal reach of the Hillsboro Canal.

HYDRAULIC PROPERTIES

The hydraulic properties of the Biscayne aquifer must be known in order to determine the ground-water potential of the area and to plan properly for large-scale withdrawals of ground water. The principal properties of an aquifer are its capacities to transmit and store water, which are generally expressed as transmissivity and the storage coefficient. Transmissivity (T) is the quantity of water in gallons per day that will flow through a vertical section of the aquifer one foot wide and extending the full saturated height, under unit hydraulic gradient, at the prevailing temperature of water (Theis, 1938, p. 892). The storage coefficient (S) is defined as the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. The most commonly used method for determining these properties is by an aquifer test, whereby a well penetrating the aquifer is pumped and the resultant lowering of the water table in nearby nonpumped wells is observed to relate the lowering of the water level to distance and time.

Aquifer tests were made on wells in the Deerfield Beach well field in August 1961 and on test wells west of Boca Raton (Fig. 3) in August 1967. In both areas the water is pumped from permeable limestone that is overlain by thick sections of less permeable sand, silt, shells, and marl. In the test west of Boca Raton, well PB-556 was pumped and water levels were observed in well PB-558 200 feet to the east. Both wells are 92 feet deep with 89 feet of casing. In Deerfield Beach, municipal well number 9, which is 90 feet deep with 80 feet of casing was pumped and water levels were recorded in an observation well 95 feet deep with 80 feet of casing and 100 feet to the east.

The data collected from the aquifer tests were analyzed by the leaky-aquifer method described by Hantush (1956, p. 702) which assumes, among other things, that the aquifer is artesian, is overlain by a leaky confining bed, and that the pumped well is open to the full thickness of the aquifer. None of these assumptions were completely satisfied in either of the two tests. Although under long-term conditions water levels in the Biscayne aquifer respond as if the aquifer were a water-table aquifer, the presence of less permeable sands overlying the highly permeable pumped zone causes the aquifer to react as a leaky artesian system when subjected to short-term conditions such as heavy pumping. Also, none of the wells in the lower Hillsboro Canal area are open to the full thickness of the Biscayne aquifer.

The water level drawdowns, in feet, were plotted (on logarithmic paper) against the quantity t/r^2, where t is time, in minutes, since pumping started, and r is the distance, in feet, between the pumping well and the observation well. The resulting curve was matched to a family of leaky-aquifer type curves (Cooper, 1963 p. C-48-55). By superposition, match points were established for the best fit of the observed data to the type curves, and the T and S were calculated from the match points. For the test west of Boca Raton the T was 380,000 gpd/ft (gallons per day per foot) and at the test in Deerfield Beach, the T was 400,000 gpd/ft. The value for S at the test site west of Boca Raton was 0.04. At the Deerfield Beach test site the value for S was 0.0004.

Values obtained from specific capacity tests of wells indicate to some extent the hydraulic properties of the aquifer and in some cases are of more immediate benefit than T and S values. The specific capacity is the amount of water in gpm discharged from a pumping well per foot of drawdown in the pumping well.

Specific capacity tests were made on several wells in the north extension of the Boca Raton well field. Well PB 550 had a drawdown of about three feet after being pumped for 8 hours at 1130 gpm or a specific capacity of 377 gpm per foot. This figure conforms with the data from the test wells west of Boca Raton and is similar to figures furnished by Dr. J. I. Garcia-Bengochea (personal communication) for wells in the Boca Raton and Deerfield Beach well fields. This indicates that the hydraulic properties of the aquifer in both well fields and the test area west of Boca Raton are similar.

The wells in the Boca Raton field range in depth from 115 to 120 feet with about 25 to 35 feet of open hole. The fact that the aquifer yields about the same amount of water to wells with 10-15 feet of open hole in the Deerfield Beach well field and 3 feet in the test area west of Boca Raton, and 25-35 feet in the Boca Raton well field, indicates that the aquifer is somewhat less permeable in the Boca Raton well field area than it is in the other areas.

WATER QUALITY

Major influences on the quality of fresh ground water in the lower Hillsboro Canal area are the quality of precipitation that reaches the water table and the infiltration, from canals draining inland areas, of highly colored water that is moderately mineralized. The chemical characteristics of the ground water also depend upon composition of the earth material through which the water moves and length of time the water is in contact with the materials.

Ground-water samples for chemical analyses were collected throughout the area from 26 private wells and 8 test wells. Depth of the wells ranged from 40 to 206 feet below land surface; samples were collected at different depths during drilling of each test well. Chemical analyses of water samples are shown in Table 2. The concentration of dissolved constituents is expressed as mg/l (milligrams per liter).

Iron, the most objectionable constituent found in solution in the ground water of this area, is derived from iron-bearing minerals within the aquifer. In samples analyzed, iron ranged from 0.03 to 1.83 mg/l and the average was about 0.45 mg/l. For public supply iron concentrations in excess of 0.3 mg/l are objectionable and impart a noticeable taste if the concentration exceeds 0.5 mg/l. When used for lawn irrigation, water containing iron in excess of 0.3 mg/l may cause staining on houses, sidewalks, and vegetation. The concentration of dissolved iron in ground water in the lower Hillsboro Canal area cannot be accurately predicted with reference to location or depth. Removal of iron from large volumes of water can be accomplished economically by aeration and filtration.

Hardness of water results from the solution of alkaline-earth minerals (such as the carbonate compounds) from soil and rocks, or from direct pollution by wastes. Calcium carbonate (limestone) is prevalent in the Hillsboro Canal area but is only sparingly soluble in pure water. Water that contains carbon dioxide or other acidic constituents will dissolve carbonate minerals readily; in the presence of carbon dioxide the carbonates are converted to the more soluble bicarbonates:

$$CaCO_3 + CO_2 + H_2O \longrightarrow Ca(HCO_3)_2$$

Hard water is generally believed to be harmless to man although urinary concretions may result from the consistent drinking of hard water (Rainwater, 1960, p. 173). Water having $CaCO_3$ concentration in excess of 120 mg/l is considered hard. The $CaCO_3$ concentration of water sampled in the study area ranged from 126 to 368 mg/l and averaged about 235 mg/l. Hardness increases with depth and with distance inland.

Acidity or alkalinity of water is measured by the hydrogen ion concentration (pH). Water that is neither acid nor alkaline has a pH value of 7.0. Values smaller than 7.0 denote acidity and usually indicate a corrosive water; values greater than 7.0 denote alkalinity. The pH values of the water analyzed ranged from 7.4 to 8.2 and averaged about 7.7, which is slightly alkaline and would be expected to be noncorrosive.

Color in water is expressed in terms of platinum-cobalt or Hazen units starting at zero and increasing with added color. Visible coloration of drinking water is aesthetically undesirable and concentrations in excess of 15 units is considered by U.S. Public Health Service (1962) to be unsuitable for use on interstate carriers. The range of concentration in the Hillsboro Canal area is from 0 to 50 units, the higher concentrations occurring in the western areas. Color in water is usually caused by decomposition of organic matter such as peat and muck which are common in the western part of the area and in buried mangrove swamps along the coast. Discoloration of water in the study area is also due partially to iron in solution. Material that causes high coloration in water can sometimes be recognized by its odor.

The odor of hydrogen sulfide gas (H_2S) was noted in water samples from some wells. This gas is derived from decomposition of organic matter, and it imparts an undesirable "sulphur water" odor which is easily removed by aeration. Hydrogen sulfide is not usually shown in standard complete analyses because of special techniques involved in obtaining samples.

TABLE 2 – CHEMICALS ANALYSES OF WATER FROM SELECTED WELLS IN THE LOWER HILLSBORO CANAL AREA (chemical constituents are expressed in milligrams per liter).

Well number[1]	Date of Collection	Depth of well (feet)	Depth of casing (feet)	Depth of sample (feet)	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)
G-1228	12-06-63	22	22	22	79	3.2	0.48	50	0.2	2.6	0.2	146
G-1228	01-06-64	195	195	195	79	9.8	.03	61	1.5	8.5	.6	176
G-1239	11-19-63	56	56	56	--	3.3	.07	30	29	15	1.0	206
G-1239	11-25-63	102	102	102	73	14	.07	96	20	210	7.2	310
G-1272	02-01-65	62	61	62	71	6.0	--	64	1.1	7.1	.6	204
G-1272	02-03-65	173	168	173	--	8.9	--	62	1.3	8.0	.7	196
G-1298	03-12-64	165	--	165	74	11	.12	138	5.7	22	1.2	293
G-1299	04-14-64	145	--	145	75	15	1.38	138	5.7	23	1.0	388
G-1300	03-12-64	106	--	106	77	13	.42	123	1.6	17	1.3	384
G-1301	04-14-64	62	--	62	77	7.3	1.03	98	3.8	8.4	.4	288
G-1302	03-12-64	100	--	100	77	16	.82	135	3.6	29	1.1	364
G-1303	04-14-64	104	--	104	75	19	.10	175	23	298	8.0	522
G-1304	04-05-62	83	--	83	78	6.9	.70	66	.9	8.7	.5	194
G-1314	03-12-64	--	--	--	82	13	.98	139	4.1	15	1.0	422
PB-220	03-11-64	174	--	174	77	7.3	.78	86	2.8	12	.6	220
PB-251	04-14-64	150	--	150	75	17	.30	82	3.3	13	1.4	250
PB-472	01-24-64	97	--	97	76	11	1.83	104	4.0	22	1.2	312
PB-473	01-24-64	105	--	105	76	12	.27	136	3.5	14	.6	404
PB-474	03-10-64	56	54	56	78	7.4	.20	59	3.2	15	1.2	178
PB-475	03-10-64	--	--	--	78	9.1	.25	66	2.8	12	.6	204
PB-476	03-13-64	95	--	95	76	18	.31	84	1.6	13	1.2	250
PB-477	03-11-64	120	--	120	78	5.5	.33	50	2.2	8.3	1.6	140
PB-478	03-11-64	97	--	97	77	8.9	.85	106	3.8	17	.5	236
PB-479	03-11-64	121	--	121	77	13	.32	78	2.8	12	1.1	240
PB-480	03-11-64	40	--	40	77	7.1	.39	104	15	115	3.9	200
PB-481	03-13-64	112	--	112	76	13	.32	133	1.9	16	1.1	396
PB-482	03-13-64	75	--	75	76	5.5	.11	110	3.8	22	1.4	328
PB-483	04-14-64	100	--	100	77	14	.18	83	4.6	21	1.2	264
PB-484	04-14-64	120	--	120	78	15	.05	90	3.3	14	1.0	274
PB-485	12-02-64	40	--	40	--	5.9	1.30	94	1.3	10	1.4	260
PB-486	12-02-64	30	--	30	78	6.2	1.20	76	.6	8.3	1.3	228
PB-487	12-03-64	80	--	80	73	6.1	.12	100	4.5	65	3.0	194
PB-488	01-18-65	83	82	83	68	20	--	69	1.0	6.8	1.0	210
PB-488	01-20-65	163	158	163	69	10	--	64	2.1	5.3	.6	194
PB-489	01-21-65	60	55	60	69	10	--	48	2.4	7.0	.8	140
PB-489	01-25-65	208	204	208	69	11	--	125	1.9	21	1.6	356
PB-490	01-26-65	65	61	65	72	7.6	--	75	3.2	22	.8	220
PB-490	01-27-65	135	131	135	70	16	--	220	61	700	7.0	282
PB-491	01-28-65	66	61	66	71	5.5	--	82	4.7	17	3.4	218
PB-491	01-30-65	205	202	205	68	9.6	--	1420	148	4850	30	261
PB-492	02-04-65	81	79	81	71	7.8	--	72	.1	18	1.0	212
PB-492	02-05-65	163	161	163	70	11	--	78	1.3	12	.8	248

1 G wells are in Broward County
PB wells are in Palm Beach County

2 Sampled while drilling
3 Dissolved solids (Sum)

Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	pH	Color	Remarks
					Calcium, magnesium	Noncarbonate				
4.8	5.0	0.5	0.0	144	126	6	232	7.9	70	[2]
3.6	16	.3	.3	180	158	14	312	8.0	20	[2]
15	28	.1	.4	262	194	25	429	7.8	20	[2]
32	340	.4	.1	872	320	66	1520	7.6	20	[2]
.0	8.0	.2	.1	187[3]	164	0	317	7.9	10	[2]
.0	13	.1	.0	191[3]	160	0	322	7.8	5	[2]
32	36	.2	.1	494	368	47	740	7.6	25	Pumping
31	36	.2	.2	482	368	50	741	7.6	15	Pumping
.0	25	.3	.1	386	326	12	650	7.5	15	
4.4	14	.3	.0	336	260	24	485	7.7	90	Pumped sample
17	63	.3	.0	492	352	54	755	7.7	20	
120	518	.4	.6	1458	530	102	2700	7.7	10	
7.2	15	.0	.0	204	168	9	360	7.9	25	
.0	24	.3	.3	420	364	18	690	7.6	15	
33	19	.2	.0	264	226	46	460	7.8	5	
2.4	18	.3	1.3	294	218	13	435	7.6	20	Pumped sample
2.4	39	.3	.0	346	276	20	585	7.5	25	
4.0	28	.4	.0	406	354	23	659	7.9	40	
5.6	22	.1	.0	208	160	14	361	7.9	5	
1.6	18	.1	.0	200	176	9	370	7.5	5	
2.4	21	.3	.0	264	216	11	440	7.5	20	
16	12	.2	.0	160	134	20	290	7.5	5	Pumped
68	30	.1	.0	406	280	86	585	7.4	25	
.0	18	.1	.1	270	206	10	415	7.4	5	
48	232	.1	16	748	320	156	1100	7.5	5	
3.2	26	.7	.0	408	340	16	645	7.6	50	
1.6	38	.3	.0	358	290	21	600	7.6	40	
2.4	26	.2	.4	310	226	10	485	7.5	25	
.0	24	.2	.1	310	238	14	491	7.4	15	
20	17	.2	.1	278[3]	240	27	468	8.0	40	
10	11	.3	.2	229[3]	192	2	390	8.2	50	Pumping
44	141	.1	16	475[3]	268	109	840	7.9	0	Golf Course
.0	12	.1	.0	213[3]	176	4	339	8.1	3	[2]
.0	7.0	.2	.1	185[3]	168	9	315	8.0	15	[2]
2.0	9.0	.3	.0	148[3]	130	16	248	7.6	120	[2]
16	32	.2	11	395[3]	320	28	632	7.9	45	[2]
8.0	34	.1	.1	259[3]	200	20	440	8.0	20	[2]
136	1290	.2	1.4	2570[3]	800	569	4400	8.0	20	[2]
41	25	.1	1.5	287[3]	224	46	478	7.9	5	[2]
974	9410	.2	4.0	17000[3]	4150	3940	23900	7.6	15	[2]
17	22	.2	.1	242[3]	180	6	400	7.7	5	[2]
.8	19	.1	.0	245[3]	200	0	408	8.1	10	[2]

Dissolved solids content of water represents the degree of mineralization of water and is determined by either of two methods: (1) evaporation of a measured amount of sample to dryness and weighing the residue; and (2) the sum of amounts of individually determined cations and anions. Cations are constituents which have positive electrical charges whereas anions have negative charges.

Chemical analyses in Table 2 are expressed in mg/l by weight of the constituent. However, most of the chemical characteristics of water can be better understood and more accurately represented from analyses expressed in epm (equivalents per million). Equivalents per million takes into account not only the weight of each constituent, but also the chemical reacting properties of the constituents. Therefore an analyses expressed in epm can be used more effectively in comparison of waters.

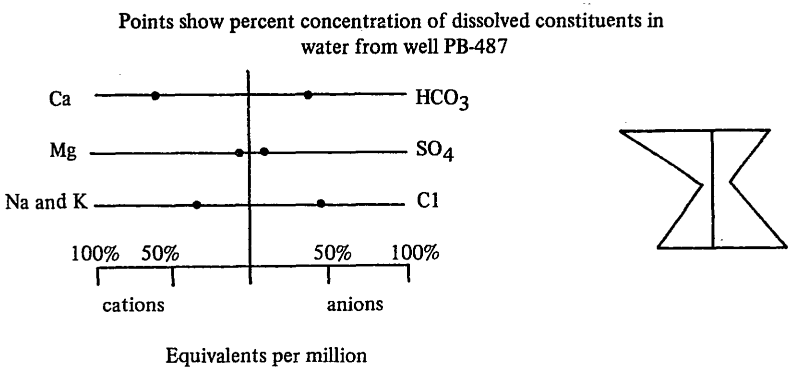
Chemical type of water is commonly classified according to the concentration of seven principal chemical constituents or ions. Difficulty in comparing seven constituents simultaneously can be overcome by using geometric figures or polygons (Stiff, 1951) to represent the type of water.

The preparation of a polygon that represents a specific chemical analysis can be shown with the analysis of water from well PB-487, in Table 2. The principal constituents are converted from mg/l to epm by using conversion factors found in most chemical handbooks. Equivalents per million of each constituent is then converted to a percentage of the total cation of anion. The results of the conversions are shown in Table 3. Percentage values are then used to construct the polygon, figure 15.

TABLE 3 – SELECTED CONSTITUENTS IN WATER FROM WELL PB-487.

Constituent	mg/l	epm	Percent
Calcium (Ca)	100	4.99	60
Magnesium (Mg)	4.5	.37	5
Sodium (Na) and Potassium (K)	68	2.91	35
Total cations	--	8.27	100
Bicarbonate (HCO_3)	194	3.18	38
Sulfate (SO_4)	44	.92	11
Chloride (Cl)	141	3.98	48
Fluoride (F)	0.1	.01	--
Nitrate (NO_3)	16	.26	3
Total anions	--	8.35	100

Dissolved solids 475 mg/1



a. Details and scale for preparing a polygon.

b. Polygon showing the general chemical type of water in well number PB-487.

Figure 15. An example of the preparation of a water-quality diagram using the percentage figures in table 3.

Figure 15a shows the basic scale with seven constituents plotted on the graph. Joining the six points by straight lines gives the polygon shown in Figure 15b. The shape of the polygon and the relative length of the "spears" show the water to be somewhat equally strong in both calcium bicarbonate type and sodium chloride type. The relatively small amounts of magnesium and sulphate are typical of shallow ground water in southeastern Florida.

Polygons showing the general type of the water from several wells distributed throughout the lower Hillsboro Canal area are shown in Figure 16. The diagrams also show the depth of the sample on the left side and the dissolved solids content on the right side. The relatively uniform shape of the polygons show that, except for a few samples, the water in the area to a depth of 200 feet is the same type (calcium bicarbonate type) containing dissolved solids generally less than 400 mg/l.

Ground water in the narrow coastal ridge area is of exceptionally good quality, but ground water of good quality in larger quantities is available for future development farther inland.

Well G-1239, located 4 miles west of State Road 7, is not in the immediate study area, figure 17, but should be considered in the overall water picture. At a depth of 56 feet the dissolved solids concentration of 226 mg/1 is normal, but the concentrations of magnesium and calcium ions are almost equal. The increase in magnesium is caused by the presence of dolomite, a carbonate rock and equal amounts of calcium and magnesium. Dissolved solids increased to 872 mg/1 at a

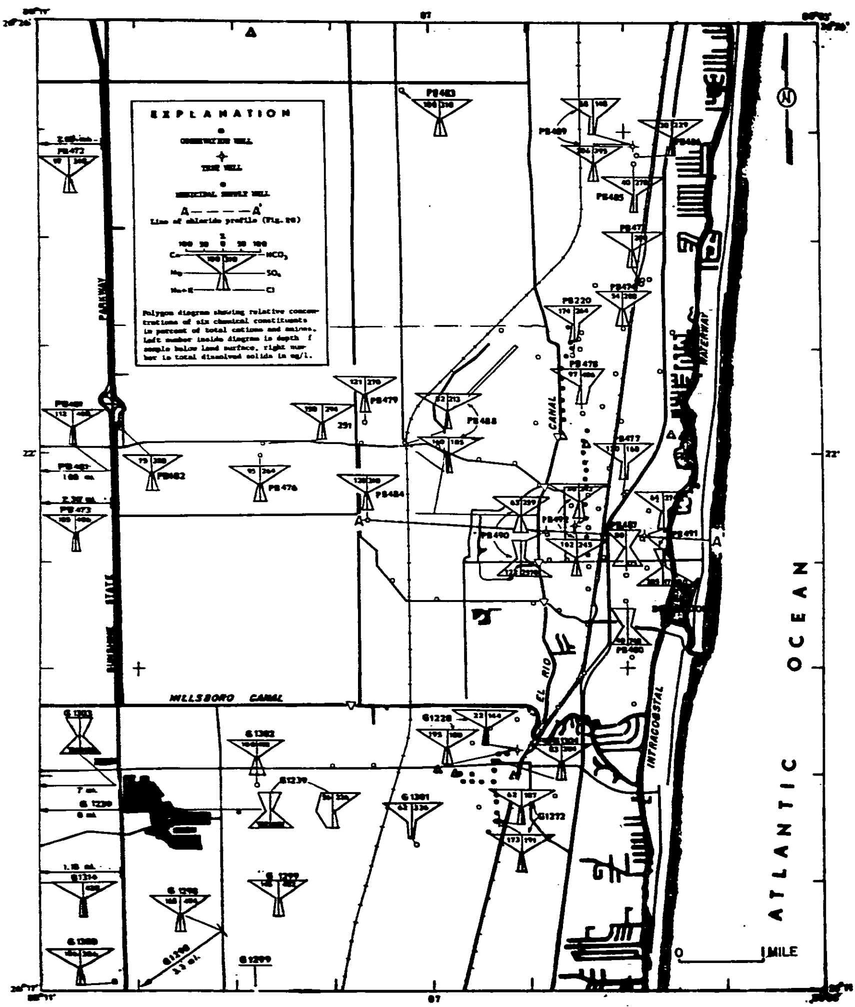


Figure 16. Map showing relative concentrations of chemical constituents in ground water of the lower Hillsboro Canal area.

depth of 102 feet, caused by the increase in sodium chloride. Saline water in shallow aquifers in inland areas of southern Florida may be residual from invasions of the sea during Pleistocene time (Sherwood and Klein, 1963).

In general the data show water in the area to be good in quality except in areas adjacent to the coast and the uncontrolled reaches of the Hillsboro and El Rio Canals where sea-water intrusion has occurred.

SEA-WATER INTRUSION

Sea-water intrusion in the Biscayne aquifer usually occurs from: (1) direct intrusion of sea water into the coastal parts of the aquifer and along uncontrolled canals; and (2) sea water that remained in the sediments after deposition during Pleistocene interglacial, when the ocean inundated most of south Florida. Present day intrusion of sea water is the only source of salt-water contamination in the lower Hillsboro Canal area. Farther west, the chloride content of the water increases with depth, indicating that residual sea water is present in the aquifer. However, part of the salty water comes from materials of lower permeability that lie below the Biscayne aquifer.

Sea-water intrusion in the lower Hillsboro Canal area of the Biscayne aquifer is governed by the relationship of ground-water levels to mean sea level. If a specific gravity of 1.025 is assumed for sea water, each foot of fresh water above mean sea level should indicate 40 feet of fresh water below mean sea level as described by the Ghyben-Herzberg principle (Brown, 1925, p. 16-17). However, in southeast Florida, geologic and hydrologic conditions are such that the depth to salt water is generally more than 40 feet for each foot of fresh water head, but the relationship is sufficiently valid to the extent that intrusion would be expected in areas where ground-water levels were persistently low.

The uncontrolled canals and waterways are connected to the ocean, which facilitates sea-water intrusion in two ways: (1) drainage is allowed which lowers adjacent ground-water levels and reduces fresh-water head that normally would oppose the inland movement of sea water; and (2) sea water is conveyed inland during dry periods, providing a source of intrusion by infiltration of the sea water into the aquifer.

Because about 91 percent of the dissolved constituents in sea water are chloride salts, analyses of the chloride content of water samples can be used reliably to determine the extent of sea-water intrusion. Figures 17 and 18 show the results of chloride traverses of the uncontrolled reaches of the El Rio and Hillsboro Canals. Water samples taken during these traverses were from the bottom of the canal at each station. Although the chloride content of the canals has a wide range, the figures illustrate that the chloride content decreases with increasing distance inland from the sea-water source. Decreased chloride content in the upper reaches also results from increased ground-water flow to the canals due to higher ground-water levels there than in the area adjacent to the lower reaches of the canals.

The El Rio Canal is relatively shallow throughout most of its reach in the vicinity of Boca Raton – the depth decreases northward from

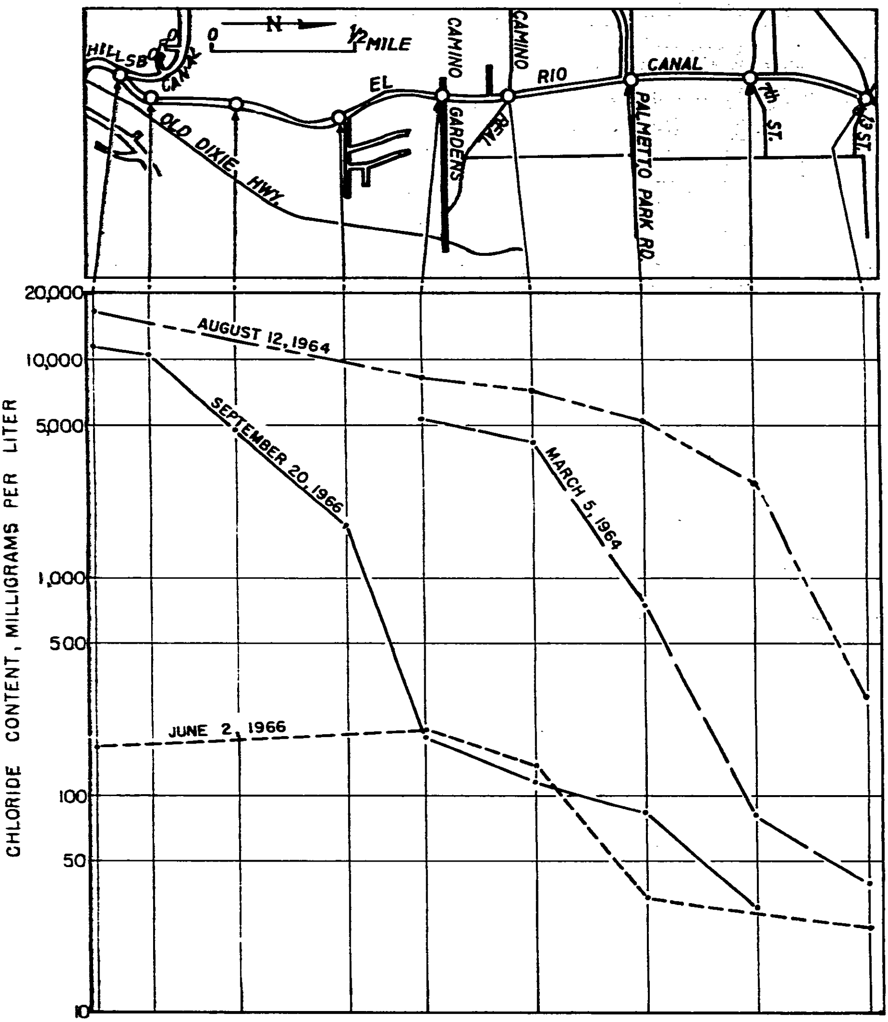


Figure 17. Chloride content of water at nine points in the El Rio Canal between the Hillsboro Canal and 13th Street.

about seven feet at the confluence with the Hillsboro Canal to about two or three feet at the N.W. 7th Street bridge (Fig. 17). The Hillsboro Canal conveys salt water to the El Rio Canal; therefore the chloride content of the water at the confluence of the two canals will determine to some degree the chloride content of the upper reaches of the El Rio Canal. The chloride content at the confluence depends largely on the combination of tidal stage and discharges at the Hillsboro Canal and E-3 Canal control structures. In Figure 17, the sample taken at the

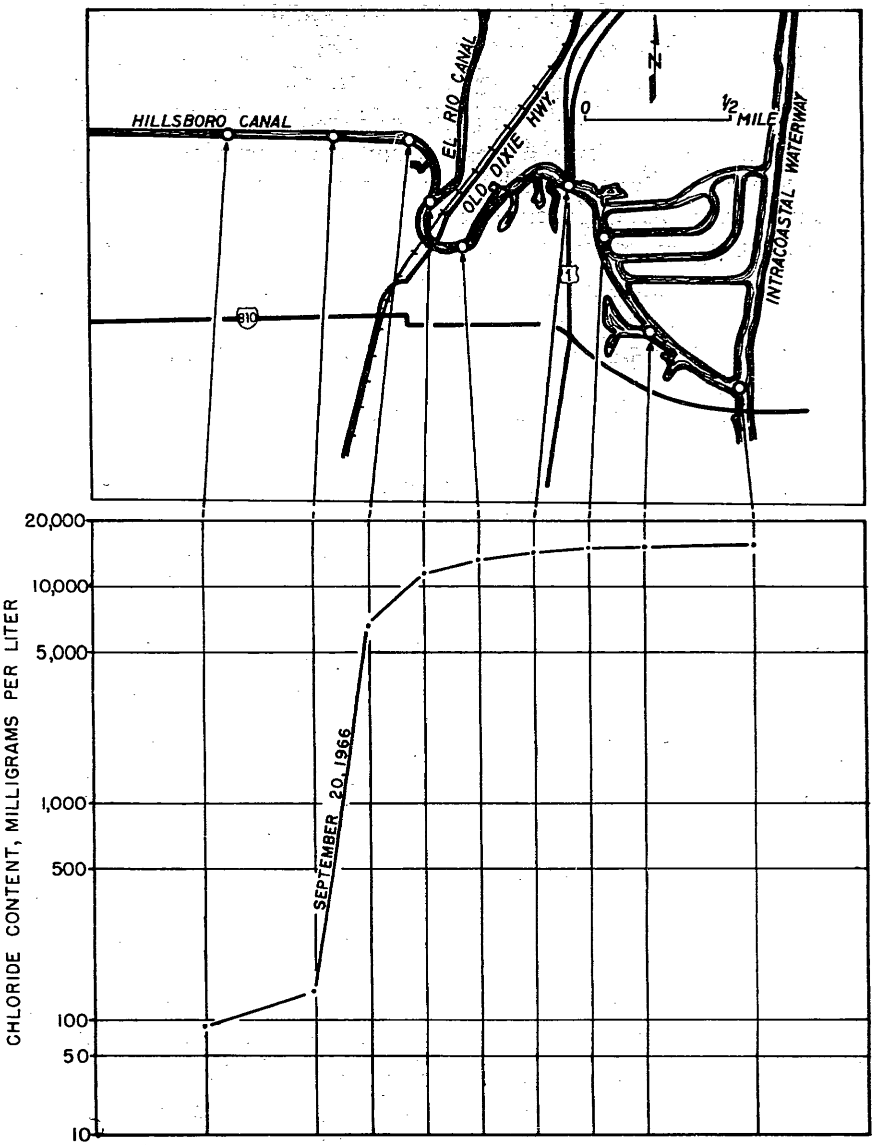


Figure 18. Chloride content of water at nine points in the Hillsboro Canal upstream from the Intracoastal Waterway, September 20, 1966.

confluence on August 12, 1964 was during high tide. On the same day discharge at the structure in the Hillsboro Canal was 37 cfs (cubic feet per second) and had been low for several days prior to the sampling. The September 20, 1966 sample was taken on a falling tide and the discharge was 198 cfs. The June 2, 1966 sample was taken on a falling tide also, but discharge at the control was 485 cfs.

Figure 18 shows that on September 20, 1966, during a falling tide, the chloride content of the Hillsboro Canal from the Intracoastal Waterway to the El Rio Canal was about the same as that of sea water. West of the confluence of the El Rio and Hillsboro Canals discharge through the controls of the Hillsboro and E-3 Canals into the lower Hillsboro Canal have freshened the water in the Hillsboro Canal.

Figure 19 shows isochlors in a subsurface section extending from the barrier islands westward through the Boca Raton well field and into the interior flatlands along line A — A' in Figure 16. The dashed lines (isochlors) connect points in the subsurface where the chloride content of the ground water is equal to the value of the line. Examination of Figure 19 indicates that sea water has intruded into the Biscayne aquifer, at depth, from both the Intracoastal Waterway and the El Rio Canal. The continuous pumping and the resultant lowering of water levels in the Boca Raton well field has caused the most intrusion from the El Rio Canal; this is indicated by the more gentle slope of the isochlors on the west side of the ridge area than on the east side of the ridge.

Sea-water intrusion from the Intracoastal Waterway into the Biscayne aquifer in the Boca Raton area is indicated by the high concentrations of sodium and chloride in the polygon diagrams of wells PB 478 and PB 489 (Fig. 16). The wells are used for irrigation of a golf course in south Boca Raton. The Diagrams in Figure 16 show that although well PB 487 is twice as deep as PB 480 the dissolved solids content of its water is only about half that of PB 480. This is probably because well PB 487 is slightly farther from the major source of sea water, Lake Boca Raton, and that well PB 480 has been in use 24 years longer than well PB 487 and has had more time to induce a tongue of sea water to move toward it.

Although some sea water has entered the Biscayne aquifer in the Boca Raton area, fresh water levels have been sufficiently high between the well field and the El Rio Canal to prevent the intrusion of a harmful amount. This is indicated by the low chloride content of water in well PB 492 to a depth of 162 feet below land surface (Fig. 16 and 19). However, several consecutive dry years might change the situation drastically, especially if pumping levels in the well field are lowered and the El Rio Canal is deepened.

Figure 20 shows the fluctuations of the chloride content of the water in the El Rio Canal at the 7th Street bridge. The relatively small volume of water in the El Rio Canal allows the chloride content to

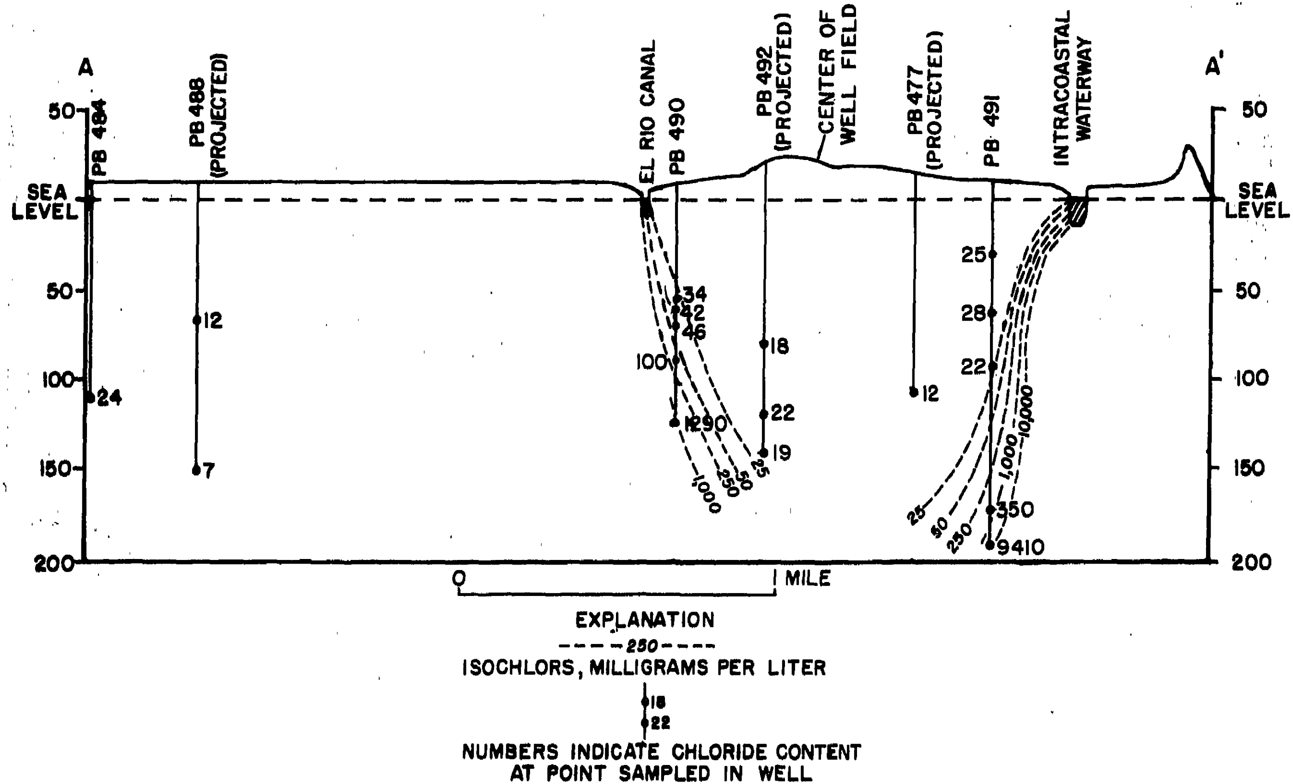


Figure 19. Section along line A-A' (figure 16) showing lines of equal chloride content (isochlors) of ground water.

change rapidly. These changes are in response to: (1) tidal action; (2) ground-water inflow from adjacent areas where ground-water levels are sufficiently high; and (3) discharge from the Hillsboro Canal and E-3 Canal. Discharge in excess of 500 cfs from the Hillsboro Canal with attendant discharge from the E-3 Canal and ground-water inflow along the uncontrolled reach of the Hillsboro Canal appears to be sufficient to maintain fresh water in the Hillsboro Canal downstream of the mouth of the El Rio Canal.

Sea-water intrusion into the Biscayne aquifer was not detected in the Deerfield Beach area except in wells adjacent to finger canals off the Intracoastal Waterway. Well G-1228 is located between the Hillsboro Canal and the Deerfield Beach well field (Fig. 3 and 16), in an area that would be most vulnerable to the threat of sea-water intrusion. Water levels in the vicinity of the well G-1228 are affected by continuous drainage to the uncontrolled reach of the Hillsboro Canal and by the pumping in the well field. Therefore, if sea water were to move inland in the aquifer, sampling of well G-1228 would give an early indication of the movement. No indication of movement has been observed in the analysis of samples from this well.

WATER USE AND POTENTIAL SUPPLY

The Biscayne aquifer is the source for all municipal water supplies in the lower Hillsboro Canal area. The rapidly increasing population of the area will require larger quantities of water from the aquifer to meet future needs. This is substantiated by past pumpage records shown in Figures 9 and 10 for the period 1963-67. The capacities of the water plants of Boca Raton and Deerfield Beach were both doubled in 1965, Boca Raton to 23 mgd and Deerfield Beach to 16 mgd, to meet the increased demands for treated water. The predicted population figure of more than 50,000 for the area by 1970 will require further expansion of the well fields or the establishment of new well fields. This is partly due to the fact that the per capita use of water increases with time: the per capita use in American cities in 1920 was 115 gallons per day; in 1960 the average use had increased to 150 gallons per day, a 30 percent rise in 40 years; in 1966, the average per capita use of water in the lower Hillsboro Canal area was about 180 gallons per day.

The potential supply available from the Biscayne aquifer in the lower Hillsboro Canal area depends upon the factors which balance recharge and discharge in accordance with the following equation:

Recharge =Discharge (surface-water discharge + ground-water discharge + evapotranspiration + pumpage) + change in storage.

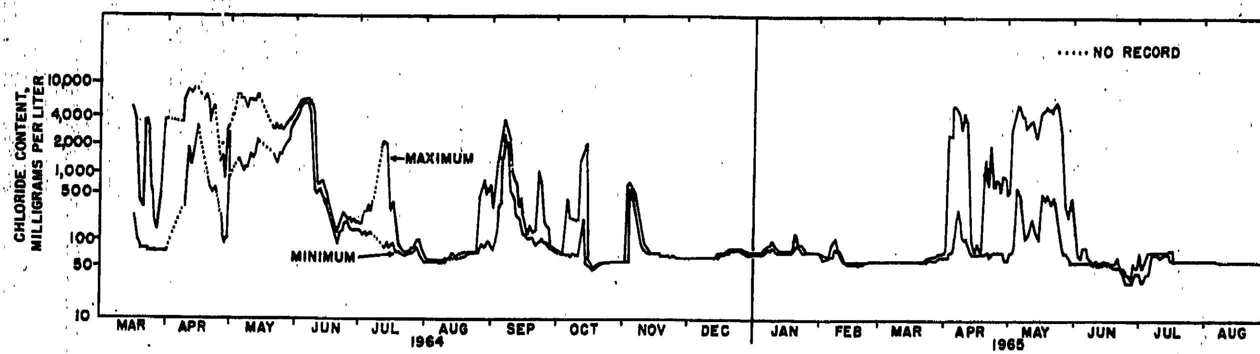


Figure 20. Approximate daily maximum and minimum chloride content of water in the El Rio Canal at 7th Street, Boca Raton, Florida, for the period March 1964 through August 1965.

Replenishment by rainfall can be assumed as constant, evapotranspiration and ground-water discharge rates will not change in magnitude, and pumping will increase with time. Water levels have not changed significantly during the period 1964-1967 indicating that the net aquifer storage has remained unchanged. The total potential supply of the area therefore represents the quantity of water discharged through the Hillsboro Canal to the ocean, plus the amounts that can be withdrawn from aquifer storage each year without lowering water levels to the detriment of quality. Lowering of water levels as a result of pumping from storage will not significantly change losses by evapotranspiration in the area.

The most critical periods affecting the water resources of the lower Hillsboro Canal area are the prolonged droughts when water levels are lowest and well field pumping is heaviest. A graph of the discharge of the Hillsboro Canal at the control structure for 1965 is shown in Figure 21. Discharge is greatest during the rainy season, the maximum of more than 3,000 cfs (1,900 mgd) occurring at the end of October.

The minimum discharge during the dry season was 40 cfs (26 mgd) and the average discharge for the year was 373 cfs (240 mgd). A significant part of the flow through the Hillsboro Canal represents water that could be used in the future if facilities were made available for retention in the system – water that could be salvaged instead of being lost to the ocean.

In addition, vast quantities of ground water are available from aquifer storage, primarily in the area west of the coastal ridge where water levels are high throughout the year. Water control practices of the Lake Worth Drainage District have maintained water levels in the area west of Canal E-3 near 12 feet above msl. Because a large part moves eastward, surface water in that District can be considered a perennial source of recharge by underseepage to the aquifer between the El Rio Canal and Canal E-3. Also, the aquifer in the inland areas of Deerfield Beach is replenished during the dry season by seepage from the controlled reach of the Hillsboro Canal and by ground water inflow from the irrigation district farther west. These sources can also be depended upon as perennial sources of replenishment to the aquifer. Therefore large withdrawals of ground water can be made from the inland areas between the Sunshine State Parkway on the west and the Seaboard Coast Line Railroad on the east without seriously lowering water levels.

Furthermore, additional supplies are yet (1969) available from the coastal ridge north of Boca Raton well field but as indicated, the aquifer there decreases in permeability and well-field expansion in that

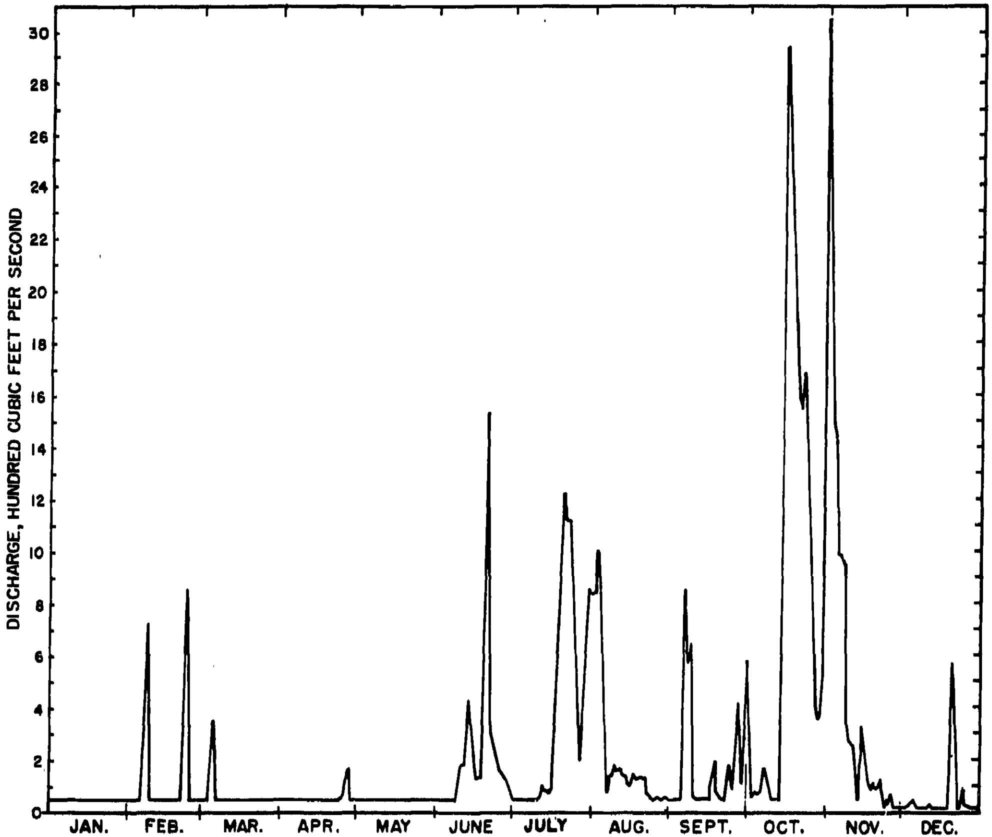


Figure 21. Graph showing the discharge of the Hillsboro Canal at the control near Deerfield Beach, 1965.

direction might not be feasible. On the other hand, the area south of the Deerfield Beach well field is underlain by materials of moderate to high permeability and possible expansion in that direction might be considered. However, withdrawals along the coastal ridge should be limited or closely monitored because of the constant threat of sea-water intrusion.

As the area continues to urbanize and water demands increase, greater reliance will have to be placed on interior water resources and possibly on importation of water from the inland water conservation system of the Central and Southern Florida Flood Control Project. Expansion of the data collection network will be necessary to monitor changes in the hydrology of the inland area for adequate management and protection of the water resources of the lower Hillsboro Canal area.

SUMMARY

The Biscayne aquifer is the only source of fresh ground water for municipal supplies in the lower Hillsboro Canal area. The aquifer extends from land surface to a depth of about 400 feet near the coast, thins to the west and decreases in permeability to the north.

The primary source of recharge to the aquifer is local rainfall, of which more than one-third reaches the water table. An additional source of recharge is infiltration from the controlled canals of the local irrigation and drainage districts and the Central and Southern Florida Flood Control District, especially the controlled reach of the Hillsboro Canal.

The ground water is of generally good chemical quality except in areas adjacent to the coast and uncontrolled reaches of the Hillsboro and El Rio Canals where sea-water intrusion has occurred.

Data indicate that the greatest potential source of water from the Biscayne aquifer is in the inland areas where water levels are high throughout the year and perennial replenishment to the aquifer is available by infiltration from the controlled canals and underseepage from the conservation areas. Large quantities of fresh ground water can be withdrawn from the Biscayne aquifer in the interior area to meet future demands without the threat of sea-water intrusion. Much of the average flow of 240 mgd through the Hillsboro Canal control represents water that could be used in the future if facilities were made available for retention in the system.

As urbanization expands to the west, the accompanying demands for water and the expansion of drainage systems for development will have a significant effect on the hydrologic system of the area. This will require that the data collection network now in existence be expanded to monitor future changes in the system so the water resources of the lower Hillsboro Canal area can be adequately managed and protected.

WELL NUMBERS

In order to coordinate data from wells on a nationwide basis, the U.S. Geological Survey has adopted a well numbering system which locates the well by a 16 character number based on latitude and longitude. The consecutive county well numbers used in this report are referenced to the nationwide system, as follows:

County No.	Latitude-Longitude No.	County No.	Latitude-Longitude No.
G-1228	261914N0800607.1	PB-479	262218N0800739.1
G-1239	261838N0801513.1	PB-480	262039N0800503.1
G-1272	261334N0800619.1	PB-481	262150N0801148.1
G-1298	261527N0801138.1	PB-482	262211N0801008.1
G-1299	261659N0800859.1	PB-483	262519N0800714.1
G-1300	261704N0801022.1	PB-484	262123N0800738.1
G-1301	261821N0800709.1	PB-485	262444N0800452.1
G-1302	261856N0800842.1	PB-486	262443N0800453.1
G-1303	261840N0801633.1	PB-487	262054N0800501.1
G-1304	261908N0800622.1	PB-488	262205N0800717.1
G-1314	261815N0801115.1	PB-489	262453N0800454.1
PB-220	262256N0800531.1	PB-490	262117N0800550.1
PB-251	262206N0800842.1	PB-491	262114N0800540.1
PB-472	262454N0801236.1	PB-492	262120N0800532.1
PB-473	262133N0801254.1	PB-548	262148N0800525.1
PB-474	262306N0800507.1	PB-549	262219N0800538.1
PB-475	262332N0800448.1	PB-550	262311N0800534.1
PB-476	262159N0800844.1	PB-555	262118N0800515.1
PB-477	262138N0800501.1	PB-556	262229N0800934.1
PB-478	262222N0800527.1	PB-557	262229N0800934.2
		PB-558	262229N0800935.1

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