

STATE OF FLORIDA
DEPARTMENT OF NATURAL RESOURCES
Harmon W. Shields, *Executive Director*

DIVISION OF INTERIOR RESOURCES
Robert O. Vernon, *Director*

BUREAU OF GEOLOGY
C. W. Hendry, Jr., *Chief*

REPORT OF INVESTIGATIONS NO. 77

**GROUND-WATER RESOURCES OF THE
HOLLYWOOD AREA, FLORIDA**

by
H. W. Bearden

Prepared by
U. S. GEOLOGICAL SURVEY
in cooperation with the
BUREAU OF GEOLOGY
FLORIDA DEPARTMENT OF NATURAL RESOURCES
and the
CITY OF HOLLYWOOD

Tallahassee, Florida
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OF
NATURAL RESOURCES**

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LETTER OF TRANSMITTAL



Bureau of Geology
Tallahassee
January 10, 1975

Honorable Reubin O'D. Askew, *Chairman*
Department of Natural Resources
Tallahassee, Florida

Dear Governor Askew:

We are pleased to make available the report "Ground-water Resources of the Hollywood Area, Florida" by H. W. Bearden. The purpose of this report is to provide hydrologic data for an area which, according to current projections, will double its fresh-water needs within the next fifteen years. The data developed from this study should prove most useful to planners in developing plans for additional water supplies and also for safeguarding the existing supplies from salt-water intrusion.

Respectfully yours,

Charles W. Hendry, Jr., *Chief*
Bureau of Geology

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Division of Interior Resources
Bureau of Geology

Tallahassee
1974

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GROUND-WATER RESOURCES OF THE HOLLYWOOD AREA, FLORIDA

By
H. W. Bearden

ABSTRACT

Population in the Hollywood area increased more than 200 percent from 1960 to 1970 (35,237 to 106,873) and the growth in population is expected to continue. This explosion in population is the source of most of the area's water problems.

Fresh water for all purposes in Hollywood is derived from the highly permeable Biscayne aquifer. The aquifer is composed chiefly of permeable beds of limestone, sandstone, and sand that extend from land surface to a depth of about 200 feet.

Water levels in the aquifer fluctuate chiefly in response to rainfall, the major source of recharge. The water table slopes gently from the west and averages about 1.0 foot higher in the western part of the city than in the eastern part. The configuration of the water table is greatly influenced by Hollywood Canal and the ocean. Because the permeability of the aquifer is high, the effect of pumping wells is dispersed over a large area and drawdowns are about 0.1 foot.

Salt-water intrusion from Hollywood Canal is the chief threat to the ground-water supply in Hollywood. When discharge is low, the chloride concentration of water in the canal has reached levels greater than 10,000 milligrams per liter. Salt water has been detected in the aquifer at depth within 0.1 mile of the municipal wells.

Results of test drilling and water quality analyses indicate that ground water of good quality is available in the western part of the Hollywood area. Because the transmissivity of the Biscayne aquifer is high, with proper planning additional quantities of water can be obtained without affecting water levels significantly in existing wells.

INTRODUCTION

Hollywood's water problems are similar to those of other major cities in southeastern Florida (fig. 1) that are experiencing explosive increases in population. Demands are being placed on the water-supply systems that far exceed projected demands for the 1970's. City and Broward County planners indicate that this growth is destined to continue, and according to current projections, fresh-water needs will almost double in 15 years.

The highly permeable Biscayne aquifer underlying the Hollywood area is an excellent source of fresh water. However, if fresh water levels in the aquifer are lowered very much below their current position, the highly permeable materials will permit the inland intrusion of salt water, as well as the infiltration of urban and industrial contaminants from land surface and canals. The areas adjacent to uncontrolled reaches of Hollywood Canal are the major areas in which salt-water intrusion is a threat to fresh water supplies. The projected water needs of the rapidly expanding population require that well-field capacity be increased; however, increasing withdrawals could cause further salt-water intrusion. The U.S. Geological Survey, in cooperation with the City of Hollywood, undertook a study of the fresh ground-water resources of the area to obtain information that will be useful to planners in developing plans for additional supplies and safeguarding the existing supplies from salt-water intrusion. The field work was started in 1970 and completed in 1973.

LOCATION OF AREA

The city of Hollywood (fig. 2) is an area of about 25 square miles in southeastern Florida. It is bounded by the ocean on the east, the cities of Hallandale and Pembroke Park on the south, the city of Pembroke Pines on the west, and the cities of Dania and Fort Lauderdale and urbanized areas of Broward County on the north. The area of investigation encompasses the city of Hollywood (with the exception of the coastal strip extending north to Fort Lauderdale) and parts of adjacent cities and urban areas of Broward County. Particular attention was given to the area of major ground-water withdrawal centered about the municipal well field in the west-central part of the city.

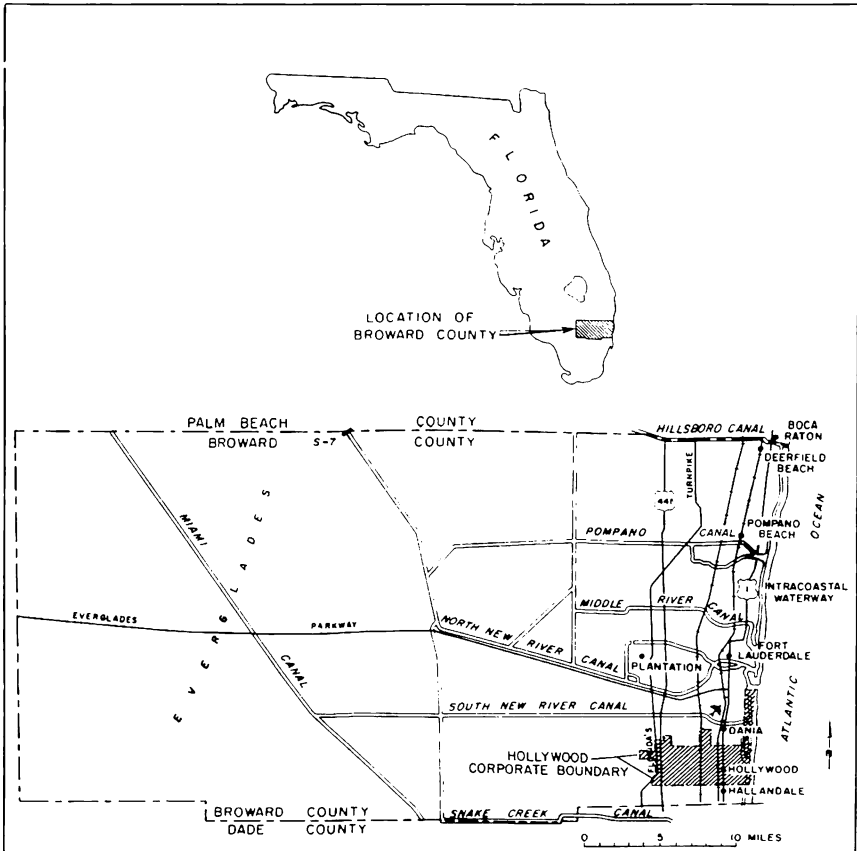


Figure 1.—Map of the State of Florida showing the location of Broward County and Hollywood.

PURPOSE AND SCOPE

The purpose of this report is (1) to describe the hydrology and water problems of the Hollywood area, (2) to summarize data on the fresh groundwater resources that will aid planners in the development of future water supplies, and (3) to provide information that they can use in developing plans

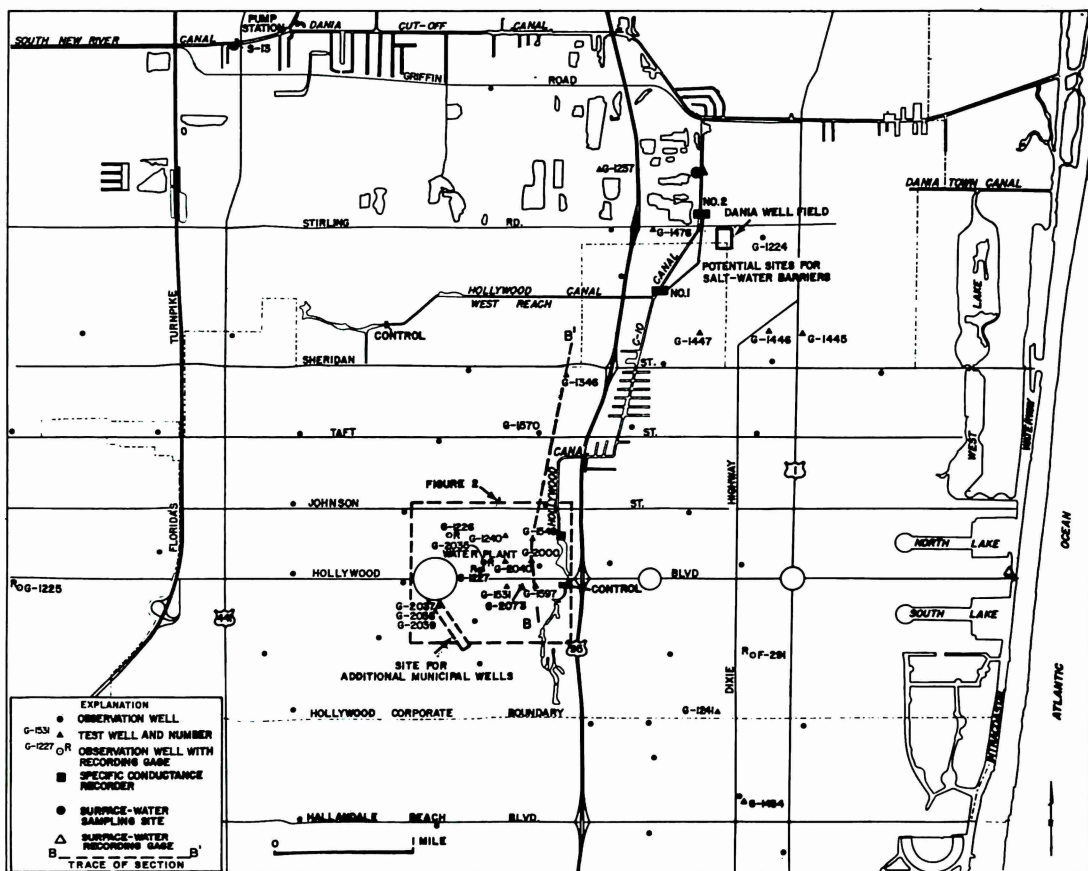


Figure 2.—Map of Hollywood showing locations of observation and test wells, surface-water gaging stations, canal sampling site, and specific conductance recording station.

for safeguarding ground-water supplies from salt-water intrusion. This information was obtained by determining: (1) the availability and chemical quality of water in the Biscayne aquifer, (2) the relation of water-level fluctuation to pumping, (3) general direction of ground-water movement, (4) the occurrence and extent of salt-water intrusion, and (5) the general geology of the Biscayne aquifer.

PREVIOUS INVESTIGATIONS

General information on the hydrology and geology of the Hollywood area is in reports by Cooke and Mossom (1929), Parker and Cooke (1944), Cooke and Parker (1945), and Parker and others (1955). Additional information on the area is included in reports from investigations in Broward County and north Dade County by Sherwood (1959), Leach and Sherwood (1963), Sherwood and Grantham (1965), Grantham and Sherwood (1968), Bearden (1972), and Sherwood and others (1973).

ACKNOWLEDGEMENTS

Special appreciation is expressed to Mr. Marshall Bergacker, City Engineer; and all the Hollywood officials for their cooperation during the investigation; to Mr. Floyd Leininger, water-treatment-plant superintendent, for information about the Hollywood water supply; and to the residents of Hollywood for supplying information about their wells.

The project was under the immediate direction of T. J. Buchanan, Sub-district Chief, Miami, and under the general supervision of C. S. Conover, District Chief, U. S. Geological Survey.

THE PROBLEM

Hollywood is one of the fastest growing major cities in Florida, the population increased 203 percent from 35,237 in 1960 to 106,873 in 1970. Tourists and winter residents probably increase Hollywood's population by as much as 25 percent.

Municipal water needs increased 312 percent from 1.6 billion gallons in 1960 to 5.0 billion gallons in 1972 (fig. 3). Using available municipal pumpage data at Hollywood from 1960-72, an arithmetic projection of municipal pumpage to 1980 (fig. 3) shows an estimated pumpage of 8.1 billion gallons in 1980, an increase of 3.1 billion gallons, 62 percent, over 1972.

Water use is greatest during December-May when the tourist season and the dry season coincide to cause maximum domestic and recreational use, along with heavy lawn irrigation. The building of apartment complexes and condominiums has increased population density and placed heavy demands on the water system. Pumpage was especially high during the 1971 dry season; water demands approached record levels in March and April (fig. 4).

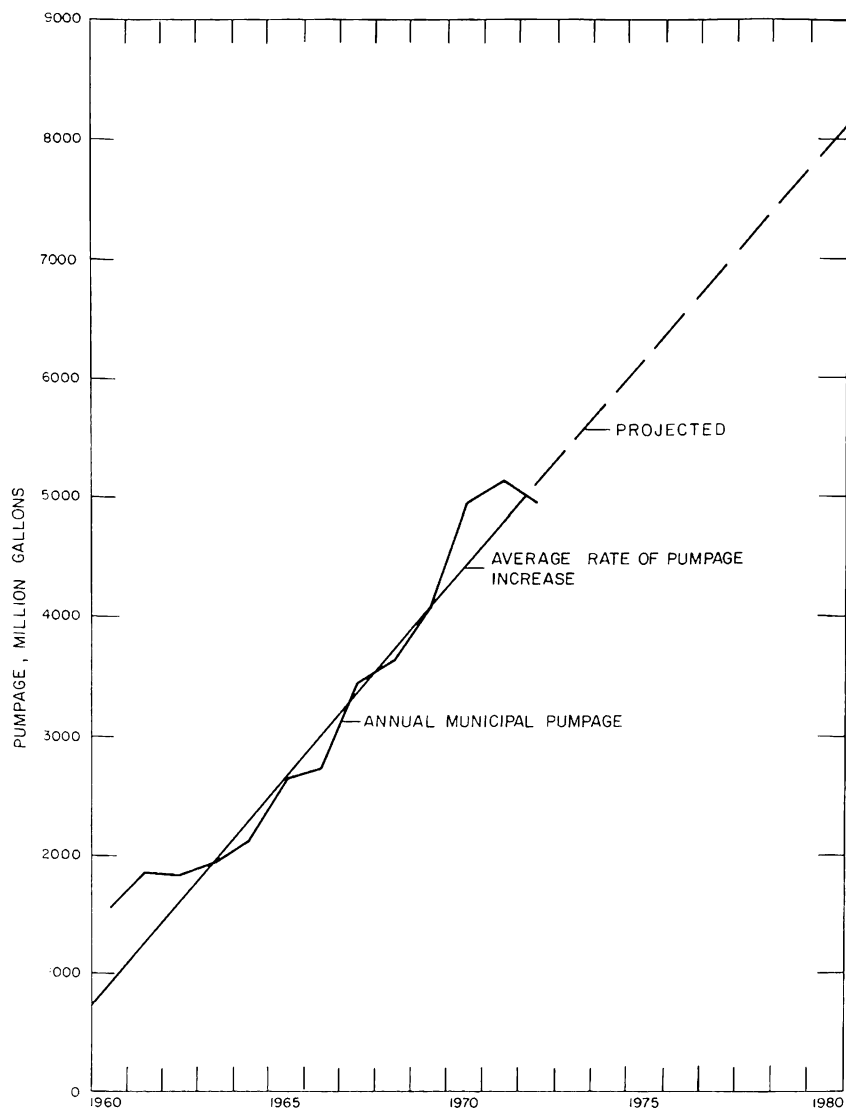


Figure 3.—Graph showing annual municipal pumpage at Hollywood for 1960-72, and projected pumpage through 1980.

Hollywood has the second largest water-supply system in Broward County and is the major municipal supplier in the southern part of the county. All public, most of the domestic and industrial, and a large part of irrigation needs in the city are provided for by municipal supply. It is connected with the Dania, Pembroke Pines, Hallandale, and Davie water systems to provide

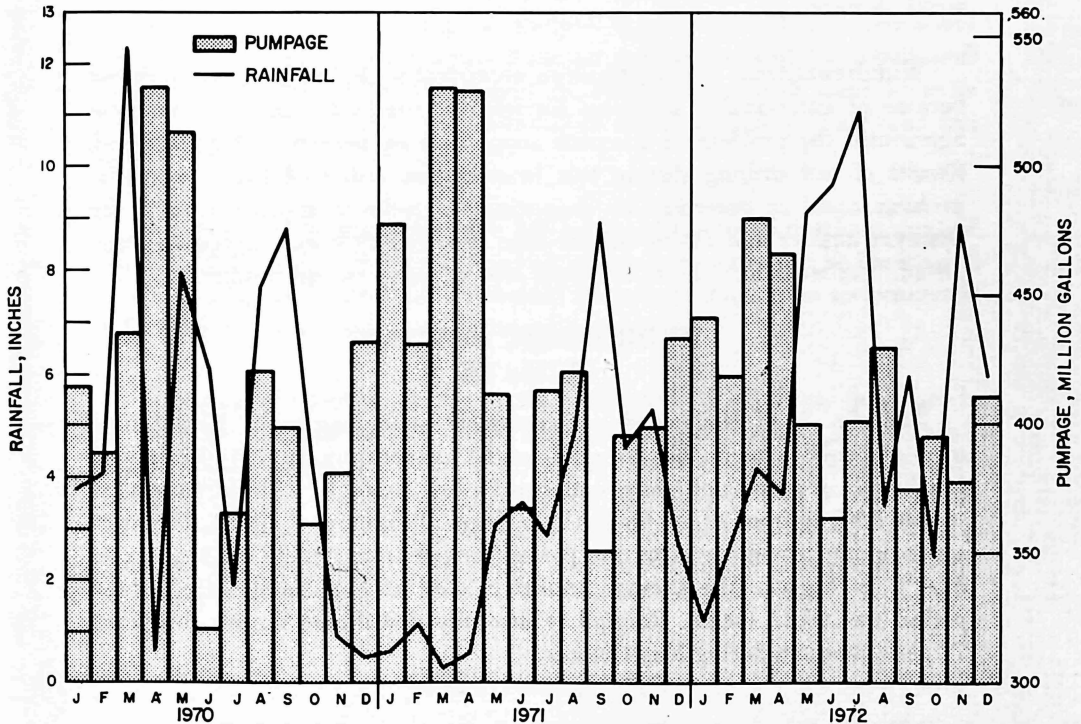


Figure 4.—Graph showing monthly municipal pumpage at Hollywood and rainfall at Fort Lauderdale, 1970-72.

water for their systems during peak demand. Some of these systems, especially Dania's, use water from the Hollywood system during much of the year.

The Biscayne aquifer is the source of all public, domestic, industrial, and irrigation water supplies in Hollywood. The Biscayne aquifer is a highly permeable aquifer and will transmit large volumes of water with only slight declines in water level.

The most immediate threat to the ground-water supply in the Hollywood area is salt-water intrusion from the Hollywood Canal. Because salt water is heavier than fresh water and the Biscayne aquifer is highly permeable, salt water will move inland into the aquifer if fresh-water levels are not maintained at an elevation higher than mean sea level.

Additional ground-water supplies must be developed to meet projected increases in water needs. What must be determined is whether the additional supplies are available in the Hollywood area; if so, will the additional withdrawals lower existing water levels to a point that will induce further salt-water intrusion.

Withdrawal from five of the city's municipal wells had been discontinued because of water-quality problems not related to salt-water intrusion and this aggravated the problem of adequate supply during periods of high demand. Results of test drilling during this investigation indicated that the quality problem could be overcome by deepening the wells to another zone in the Biscayne aquifer and casing out the zone in which they were originally completed. The wells have been deepened and returned to full production.

HYDROLOGIC SETTING CLIMATE

The climate of Hollywood is sub-tropical, with long, warm, humid summers and mild winters. The average annual temperature for 1931-72 at Fort Lauderdale, just north of Hollywood, was 75.2°F (table 1) with infrequent extremes ranging from 29° to 96°F (U. S. Dept. of Commerce, 1968). The average monthly temperature for the period ranged from 67.3°F in January to 82.6°F in August. The average annual rainfall at Fort Lauderdale for the period was 60.22 inches. Rainfall is unevenly distributed during the year; 72 percent occurs during May-October.

Table 1.—Average monthly rainfall and average monthly temperature at Fort Lauderdale, Florida, 1931-72.¹

Month	Rainfall (inches)	Temperature °F
January	2.18	67.3
February	2.34	67.9
March	2.78	70.4
April	3.58	74.3
May	5.57	77.5
June	8.34	80.4
July	5.94	82.0
August	6.77	82.6
September	8.52	81.4
October	8.48	77.7
November	3.21	72.3
December	2.51	68.6
Yearly Average	60.22	75.2

¹ Record from National Weather Service Climatological Data.

TOPOGRAPHY AND DRAINAGE

A major part of the city of Hollywood is on the coastal ridge that parallels the seacoast. The ridge is about 6 miles wide and nearly everywhere is very low and flat. The ridge crests about 2 miles inland and begins to decline 4 to 5 miles inland. The land surface in Hollywood generally is 5 to 10 feet above msl (mean sea level) except along the coast and just west of the Intracoastal Waterway. West of the coastal ridge, the Everglades extends some 40 miles inland and covers the western two-thirds of Broward county (Sherwood and others, 1973).

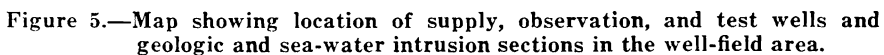
A network of levees and canals has been constructed throughout most of the Everglades area to form conservation areas where water can be impounded and stored for use during the dry season. The conservation areas are connected to the coastal canal system in the county.

Drainage is controlled chiefly by the Hollywood (C-10) Canal that extends through the heart of the city (fig. 2) and north to the Dania Cut-Off Canal, a tidal canal. Hollywood Canal is tidal from the Dania Cut-Off Canal south to the control near Hollywood Boulevard and west to the control at 16th Avenue on the western reach of the canal that parallels Sheridan Street. East of Dixie Highway the ridge area slopes to the east and drainage is eastward to the Intracoastal Waterway.

BISCAYNE AQUIFER

In the Hollywood area, fresh-water supplies for all purposes are obtained from the Biscayne aquifer. The aquifer underlies all the coastal areas and most of the Everglades in Broward County (Schroeder and others, 1958). The aquifer is thickest along the coast where it extends from land surface to a depth of about 200 feet and thins westward to a feather-edge near the Collier-Broward County line. It is underlain by marl of low permeability which extends to a depth of about 900 feet and separates the Biscayne aquifer from the underlying Floridan aquifer.

The Biscayne aquifer of southeastern Florida is a highly permeable sequence of beds of limestone, sandstone, and sand that ranges in age from late Miocene through Pleistocene. In Hollywood, the aquifer is composed of the following marine Pleistocene formations (from the oldest to youngest). Anastasia Formation, Miami Oolite, and Pamlico Sand (Tarver 1961). The thickness of the limestone section and the permeability of the aquifer generally decrease to the north.



GROUND WATER

Ground water in the Hollywood area occurs both under confined (artesian) and unconfined (nonartesian) conditions. Confined ground water as defined

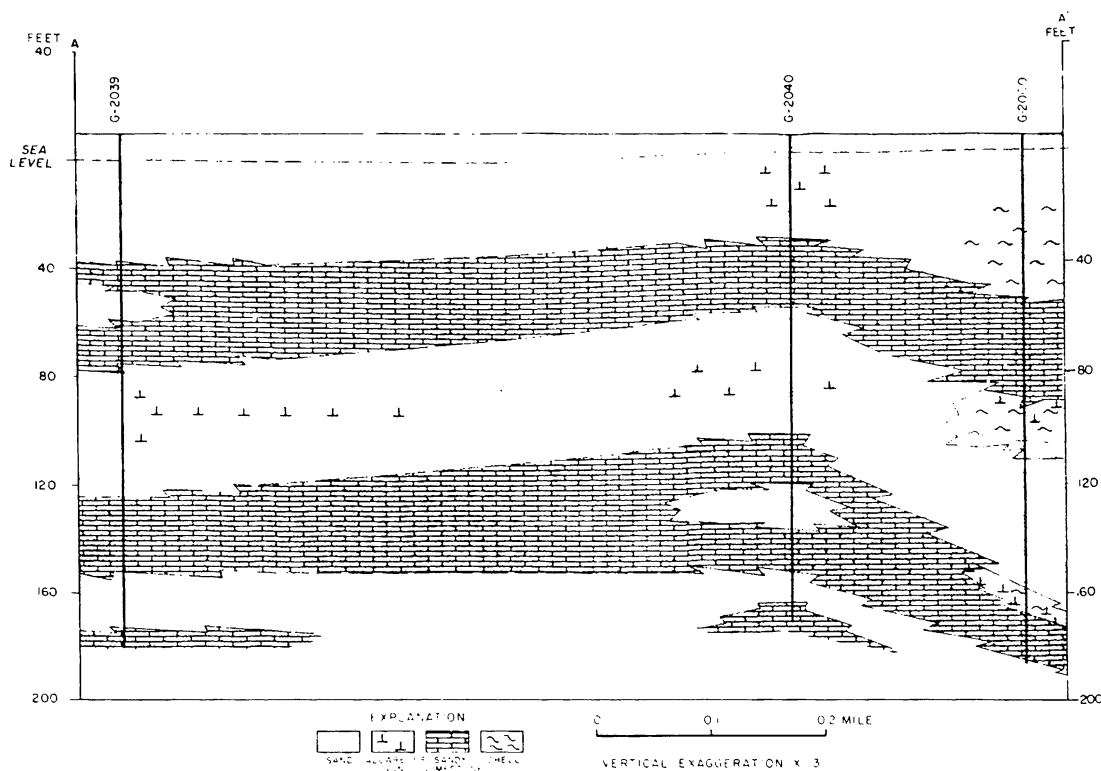


Figure 6.—Geologic section of the Biscayne aquifer along line A-A' in figure 5.

by Lohman and others (1972, p. 7) is “water under pressure significantly greater than atmospheric, and its upper limit is the bottom of a bed of distinctly lower hydraulic conductivity (coefficient of permeability) than that of the material in which the confined water occurs.” Confined highly mineralized water in the Hollywood area occurs in the Floridan aquifer which underlies the area at a depth of about 900 feet.

Unconfined ground water as described by Lohman and others (1972, p. 7) is “water in an aquifer that has a water table.” The water table is the upper surface of the water, is at atmospheric pressure, and is free to rise and fall. Unconfined water in the Hollywood area occurs in the Biscayne aquifer.

In the Hollywood area, the water table normally lies 6 to 10 feet below land surface. The water table fluctuates seasonally in response to rainfall,

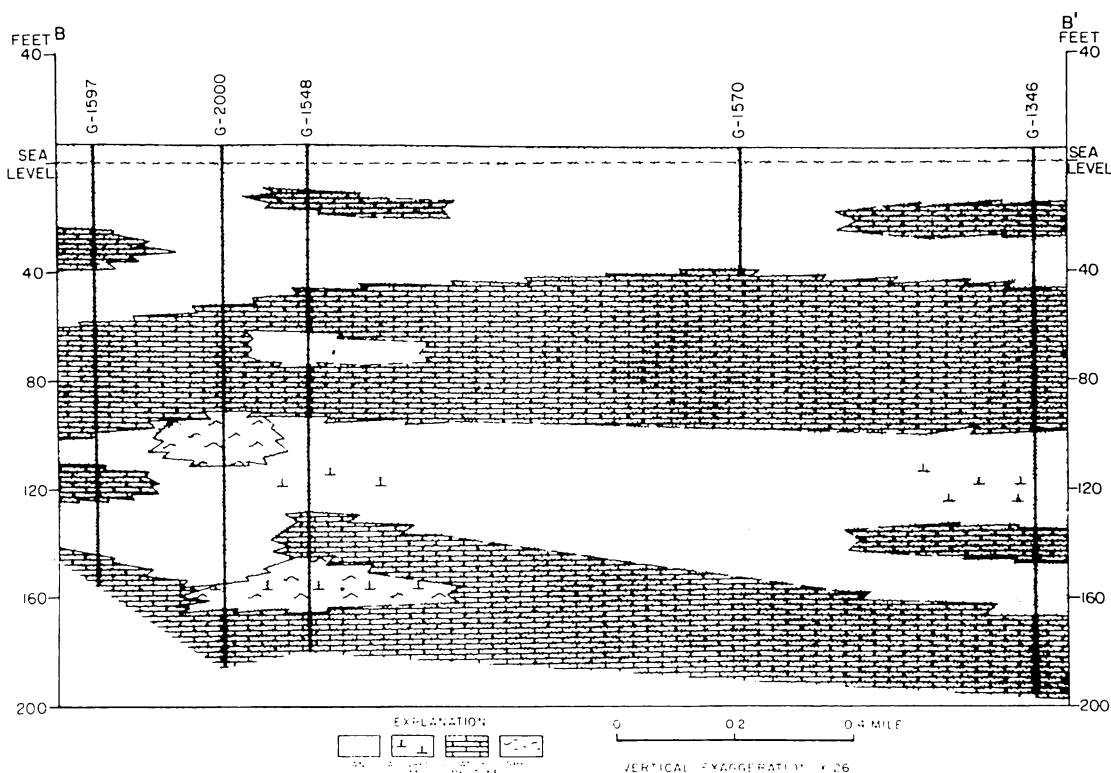


Figure 7.—Geologic section of the Biscayne aquifer along line B-B' in figure 2.

rising during periods of heavy rainfall and falling during periods of low rainfall. Other forces such as discharge to canals, evaporation, transpiration, and pumping from wells also cause the water table to fluctuate. The water table can be mapped (contoured) by determining the elevation of water-levels in a network of wells. Water-level maps show the shape and slope of the water table and the general direction that ground water moves. Ground water moves downgradient from the area of recharge (high elevation) to the areas of discharge (low elevations).

RECHARGE AND DISCHARGE

During the wet season the major source of recharge to the Biscayne aquifer in the Hollywood area is rainfall that filters through surface materials to the water table. During the dry season water in the South New River and Snake Creek Canals provides a source of recharge. The water levels in these con-

trolled canals are maintained at a higher elevation than the water table by water released from the conservation areas. Because of this elevation difference water can move from the canals into the aquifer.

Evapotranspiration, ground-water flow to canals and the sea, and pumping from wells are the means of discharge from the Biscayne aquifer in the Hollywood area. Evapotranspiration and flow to the canals and the sea are major means of discharge and are greatest when water levels in the aquifer are high. Pumping from wells is the greatest means of discharge during the dry season because of higher public water-supply demand and the need to irrigate lawns and gardens.

WATER-LEVEL FLUCTUATIONS AND GROUND WATER MOVEMENT

Water levels in the Biscayne aquifer fluctuate in response to recharge to and discharge from the aquifer. Rapid short-term fluctuations are caused by rainfall and by pumping. Fluctuations of several feet a day have occurred from heavy rainfall. Fluctuations due to pumping of wells are generally small.

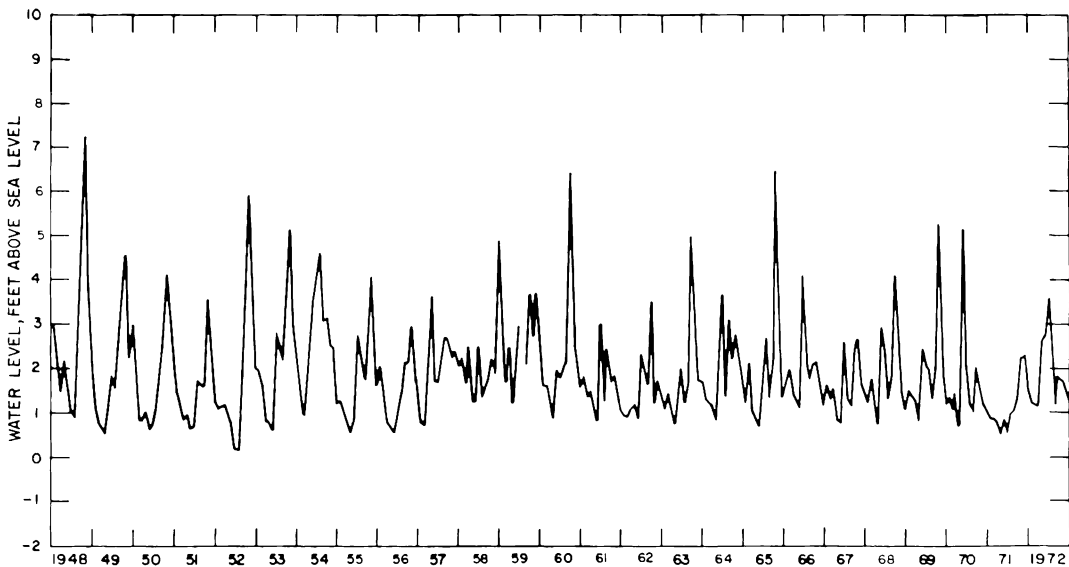


Figure 8.—Hydrograph of well F-291, 1948-72.

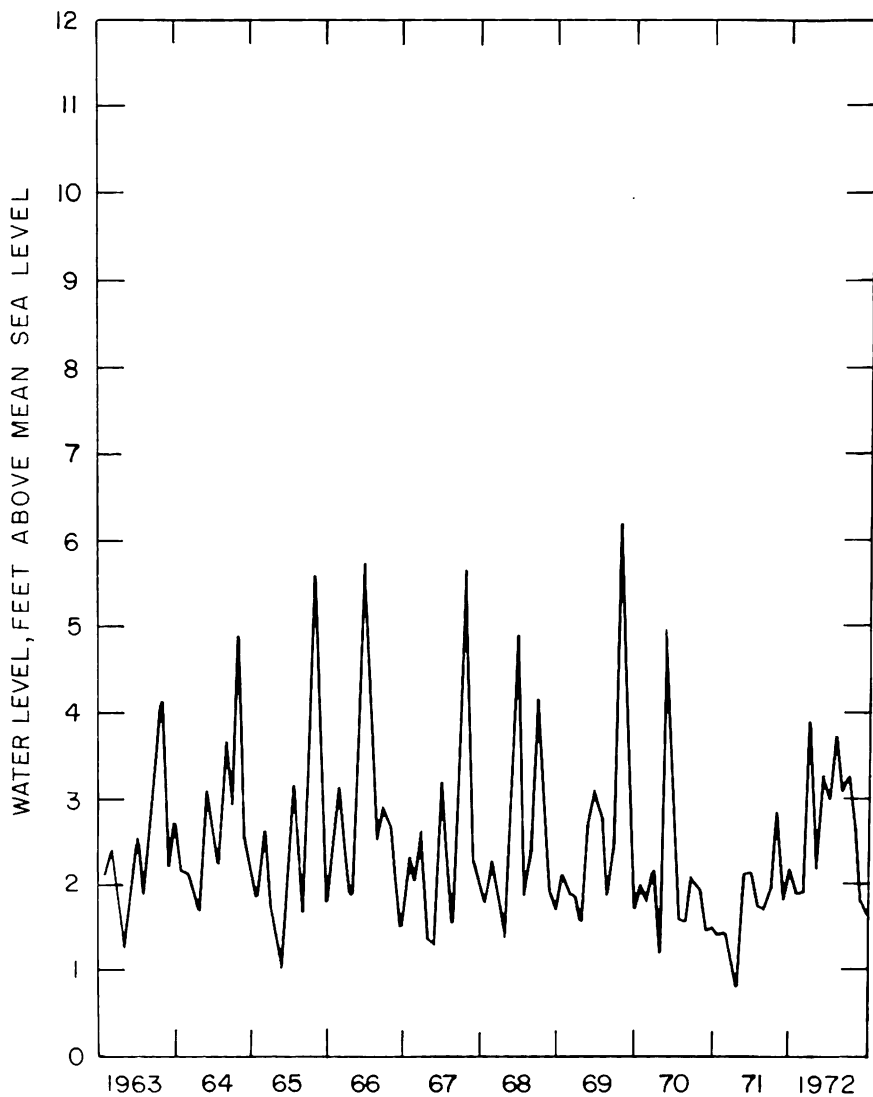


Figure 9.—Hydrograph of well G-1225, 1963-72.

Gradual changes in water levels are caused by evapotranspiration and ground-water outflow to the canals or directly to the ocean.

Water-level fluctuations in the Hollywood area were measured in 45 wells, of which 5 are equipped with automatic recording instruments (fig. 2). All the wells are finished with open hole in permeable limestone and sandy limestone formations.

The water level in the western part of the Hollywood area, on the average, is about 1.0 higher than in the eastern part as shown by comparing hydrographs of well F-291 (fig. 8), in the eastern part of the city, and well G-1225 (fig. 9), in the western part of the city. The peak water levels vary in time of occurrence each year because of the distribution of rainfall during the year. Although large seasonal fluctuations occur, the levels return quickly to about average elevation.

Because the Biscayne aquifer is highly permeable, the effects of pumping are dispersed over a large area. For example, although well G-1227 is in the midst of a cluster of pumping wells, and well G-1226 is 0.4 mile away (locations on fig. 2), the water levels are nearly identical (fig. 10). Water levels

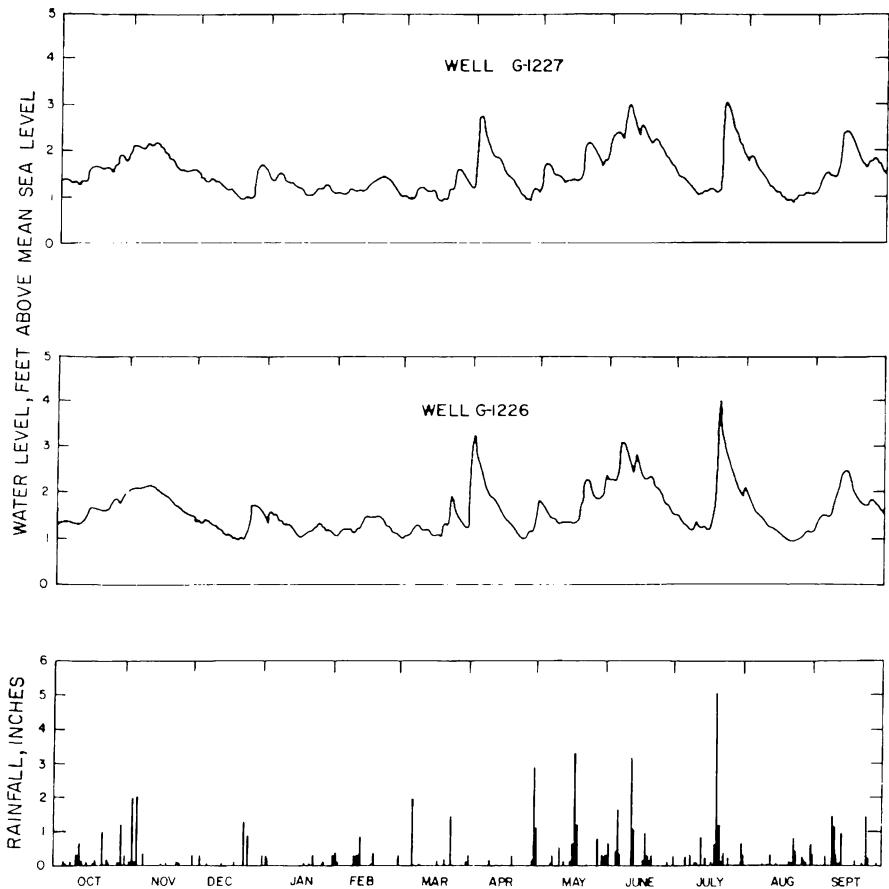


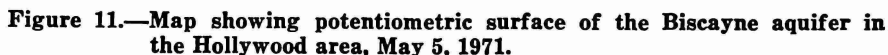
Figure 10.—Graphs showing water levels in wells G-1226 and G-1227 and daily rainfall at Fort Lauderdale, 1972 water year.

in these wells rise rapidly in response to recharge by rainfall (fig. 10). The peak water levels during the 1972 water year (October 1971 - September 1972), were 4.10 feet above mean sea level in well G-1226, and 3.15 feet above in well G-1227, and occurred on July 21 as a result of 5.12 inches of rainfall on July 20. Decline of the water level from the peak was more gradual than the rise to the peak and is caused by evapotranspiration, pumping, and discharge to the canal system and the ocean.

To prepare dry- and wet-season water-level contour maps for 1971, water-level measurements were made in the network of observation wells (fig. 2) in the Hollywood area near the end of the wet and dry seasons. For the dry season map water levels were measured on May 5, 1971 (fig. 11), near the end of an extreme drought. Rainfall at Fort Lauderdale totaled 0.89 inch for March and April 1971, 5.47 inches below average (table 1) for the 2 months and rainfall had been deficient for several months. Although the aquifer was being partly recharged by South New River and Snake Creek Canals, water levels in wells G-1225, G-1226 and G-1227 (fig. 2) reached record low levels during March and April. Levels in well G-1227 reached an extreme low of 0.2 foot above sea level, but due to 0.4 inch of rainfall on May 2 and 3, the water level had risen to 0.7 foot above sea level by May 5, 1971. Peak daily water levels in Hollywood Canal at the gaging station just south of Dania Cut-Off Canal ranged from 0.61 to 1.88 feet during high tide and averaged about 1.25 feet for the months of April and May for 1962-68. With water levels of 0.7 foot above sea level in the well field the assumption is reasonable that during high tide water levels in the tidal part of the Hollywood Canal (C-10) were higher than ground-water levels in the adjacent aquifer.

For the wet season map water levels were measured on October 19, 1971 (fig. 12) and were from 0.7 to 1.3 feet higher than on May 5, 1971. Rainfall at Fort Lauderdale was 8.98 inches in September 1971, 0.46 inch above the average rainfall for September, and 4.57 inches in October, 3.91 inches below the average rainfall for October (table 1).

The contours on both maps, figures 11 and 12, reveal virtually the same flow pattern throughout the area. The general direction that ground water moves can be inferred from the contour map because ground water generally moves downgradient perpendicular to the contours. The hydraulic gradients slope gently toward the Hollywood Canal from the northwest, west, and southwest and from the east along the ridge area near Dixie Highway. East of Dixie Highway, gradients slope gently to the ocean and north of Stirling Road, to Dania Cut-Off Canal. In the southwest part of Hollywood, water levels are maintained during the dry season by recharge from Snake Creek Canal 3 miles



The recharge and drainage system in the Hollywood area is effective in keeping ground-water levels between 1 and 2 feet above msl year around except during extreme wet and dry periods. Water levels on May 11, 1972 (fig. 13), near the end of the 1972 dry season were only slightly lower than the

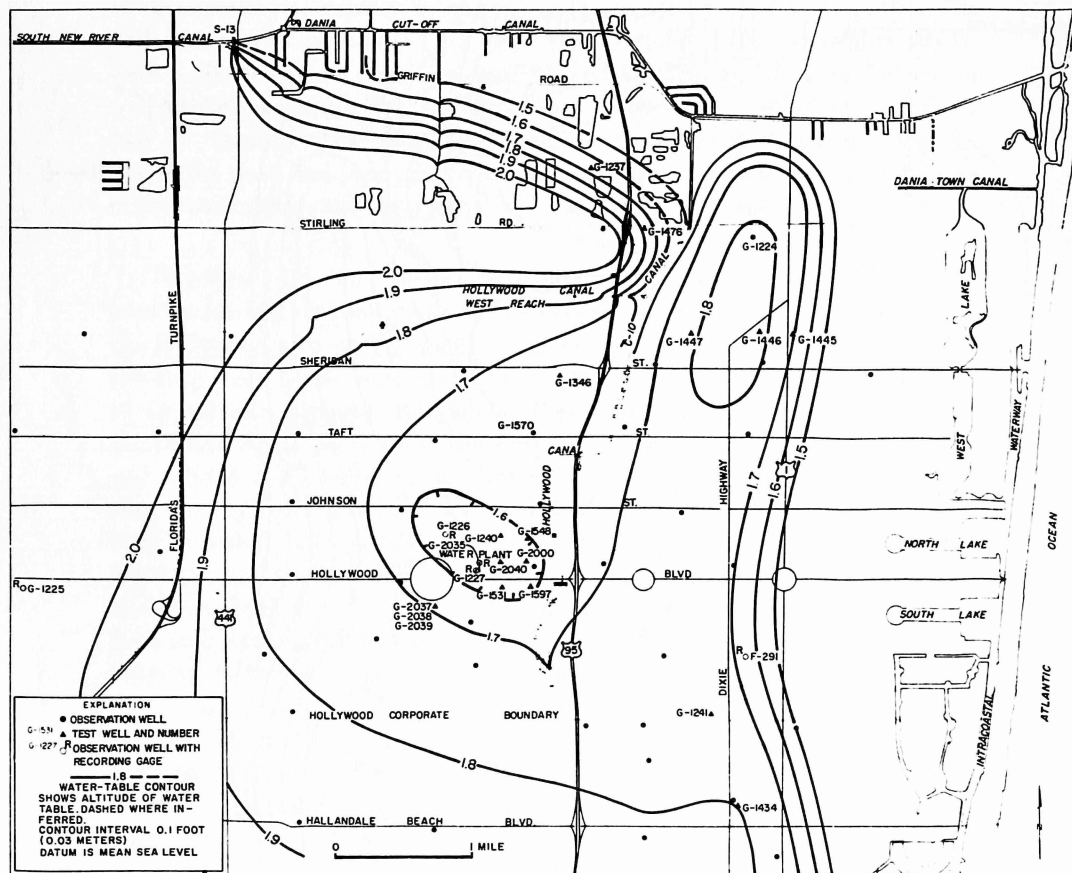


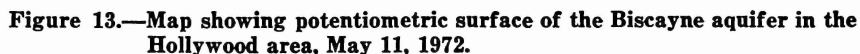
Figure 12.—Map showing potentiometric surface of the Biscayne aquifer in the Hollywood area, October 19, 1971.

water levels on October 19, 1971 (fig. 12), near the end of the 1971 wet season. Rainfall during the 1971 wet season was slightly below average, and during the 1972 dry season was slightly above average. Consequently, water levels in the aquifer were maintained at fairly stable levels.

WATER QUALITY

GROUND WATER

Ground water in the Biscayne aquifer can be easily treated to meet standards recommended by the U.S. Public Health Service (1962) for public supply. Chemical analyses listed in table 2 show that the chemical character of water in the Biscayne aquifer from 20 to 144 feet below land surface is



The U.S. Public Health Service recommends that iron in water for public supply not exceed 0.3 mg/l (milligrams per liter). Iron concentrations in excess of 0.3 mg/l begins to affect the taste and if the water is used for lawn irrigation, it will stain buildings and sidewalks. The iron concentration of the samples whose analyses are listed in table 2 ranged from 0.08 to 2.2 mg/l. Dissolved iron within that concentration range can be easily removed by aeration and filtration.

Hardness is a term applied to the soap-neutralizing power of a water (Mc-

Table 2.—Chemical analyses of water from test wells G-1531, G-2037, and G-2038.
(Chemical constituents in milligrams per liter, physical properties, in units as shown.)

Well No.	Depth (feet)	Date of Collection	Specific conductance, in microhmhos at 25°C (Kx10 ⁶)	pH	Temperature (°C)	Color (cobalt-platinum units)	Turbidity (Jackson-turbidity units)	Silica (SiO ₂)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Strontium (Sr)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO ₃)	Sulfate (SO ₄)	Chloride (Cl)	Fluoride (F)	Phosphorus as PO ₄		Alkalinity as CaCO ₃
																				Ortho	Total	
G-1531	66 128	3-29-71 4- 8-71	1,200 520	7.8 8.0	25 22	30 20	10 25	8.2 8.2	0.32 .44	0.20 .01	160 88	15 6.2	— 8.20	65 15	36 0.7	596 304	8.0 0.0	98 22	0.20 .20	0.11 .02	— .05	489 249
G-2037	20	2- 4-72 2-14-73	568 365	8.0 7.7	— —	20 20	10 50	5.4 3.4	.08 .91	.00 .01	88 68	2.5 2.9	.77 .30	23 8.5	8.8 8.2	236 220	45 12	38 8	.20 .30	.08 .01	.08 .08	194 180
G-2038	144	2- 4-72 2-14-73	561 560	8.0 7.7	— —	10 10	20 30	12.0 9.6	2.2 .50	.01 .01	82 86	6.7 6.7	.93 .92	24 24	1.2 .9	284 296	.0 .0	38 36	.20 .20	.06 .00	.06 .00	232 243
Well No.	Date	Hardness (Ca, Mg)	Non-carbonate hardness	Dissolved solids		Aluminum (Al)	Zinc (Zn)	Lead (Pb)	Copper (Cu)	Chromium (Cr ⁺⁶)	Arsenic (As)	Bromide (Br)	Iodide (I)	Baron (B)	MBAS (Detergents)	Nitrogen (N)				Total organic nitrogen as N	Oil and grease	
				Residue at 180 °C	Calculated											Ammonium NH ₄ as N	Nitrate NO ₃ as N	Nitrite NO ₂ as N				
G-1533	3-29-71 4- 8-71	460 246	0 0	708 304	685 299	0.04 .05	0.09 .06	0.000 .000	0.00 .00	0.00 .00	0.04 .00	— —	— —	— .30	— .06	22.1 1.4	0.00 .00	0.01 .00	11.26	— —		
G-2037	2- 4-72 2-14-73	230 180	38 0	340 220	328 220	— —	.08 .16	.004 .006	.00 .00	.00 .00	.00 .01	— —	— —	.70 .04	.1 .02	2.6 .02	.00 .00	.02 .00	2.2 .55	— —		
G-2038	2- 4-72 2-14-73	230 240	100 0	314 319	305 310	— —	.07 .07	.011 .004	.00 .00	.00 .00	.00 .00	— —	— —	.20 .04	.1 .01	1.9 .9	.00 .00	.11 .00	.55 .33	— —		

1. Analyzed by Hollywood Water Plant personnel.

Kee and Wolf, 1963, p. 195). It is attributable principally to calcium and magnesium and is expressed as an equivalent amount of calcium carbonate (CaCO_3). Hardness in water consumes soap in laundry operations and forms incrustations in pipes, boilers, and plumbing fixtures. Any water with hardness between 61 and 120 mg/l is moderately hard; between 121 and 180 mg/l, hard; and over 180 mg/l, very hard (Durfor and Becker, 1962, p. 27). The hardness in table 2 ranged from 180 to 460 mg/l.

The U.S. Public Health Service recommends that the color of water for public supply not exceed 15 platinum cobalt units. Color in ground water is usually caused by organic matter extracted from the soil. Water that is colored is undesirable for public use. Color in the samples in table 2 ranged from 10 to 30 units. It generally can be lowered by chlorination and lime softening.

SURFACE WATER

The Hollywood Canal is the major waterway in the Hollywood area. The canal is tidal and during periods of high tides and low fresh-water discharge, water in the canal is mostly sea water. The canal is used primarily for recreation and drainage. Therefore, the quality of the water is important chiefly for appearance and because it may be used for contact sports. Both its salinity and its level of manmade wastes are highest during low flow because of the lack of flushing.

Poor water quality in Hollywood Canal other than the high chloride concentration is generally the result of manmade contaminants. Typical contaminants are bacteria, nutrients, detergents, and pesticides. Bacteria indicative of contamination include total and fecal coliform; nutrients include the nitrogen family and phosphorous; and pesticides include all insecticides and herbicides.

Of the coliform bacteria, some live in soils and natural waters and others in the intestines of warm-blooded animals. Fecal coliform are found in the intestinal tracts of warm blooded animals and their detection in water indicates the presence of animal or human wastes.

High levels of nitrogen (nitrite, nitrate, ammonia and organic nitrogen) and phosphorous can usually be attributed to sewage effluent and/or agricultural fertilizers. Detergents, MBAS (methylene blue active substances), reflect the household and industrial cleaners introduced into the canals in waste water.

Water quality in Hollywood Canal was determined at a site half a mile south of Dania Cut-Off Canal (fig. 2). That the canal is affected by tidal in-

Table 3A.—Chemical analyses of water from Hollywood Canal half a mile south of Dania Cut-Off Canal.
(Chemical constituents, in milligrams per liter, physical properties in units as shown.)

Date of Collection	Specific conductance in micromhos at 25°C. (Kx10 ⁶)	pH	Temperature (°C)	Color (cobalt-platinum units)	Turbidity (Jackson turbidity units)	Silica SiO ₂	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Strontium (Sr)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO ₃)	Sulfate (SO ₄)	Chloride (Cl)	Fluoride (F)	Phosphorous (P)		Alkalinity as CaCO ₃
																		Ortho PO ₄ as P	Total PO ₄ as P	
9-30-70	17,500	7.8	31.0	30	3	4.6	0.10	0.02	175	212	—	3,200	123	233	809	5,550	0.6	0.05	0.06	190
1-14-71	40,000	7.7	24.0	20	4	1.6	.12	.04	340	500	7.8	7,690	300	196	2,000	14,000	1.4	.06	.06	161
4-15-71	39,000	7.7	23.0	20	5	3.5	.14	.03	340	980	5.3	8,000	330	188	2,000	14,000	1.2	.02	.04	154
7-13-71	18,000	7.3	—	40	4	3.4	.09	.03	220	450	5.0	3,000	110	252	860	5,800	.6	.01	.02	207
9-22-71	13,000	6.9	30.0	45	15	5.0	.03	.01	160	260	2.8	2,300	86	258	580	4,200	.4	.06	.09	212
1- 6-72	23,300	7.9	25.0	30	8	2.0	.05	.02	230	550	4.5	4,200	180	240	1,100	7,000	.9	.03	.05	197
4- 3-72	8,870	7.2	24.0	40	9	6.0	.35	.02	140	180	1.8	1,500	53	298	328	2,600	.5	.09	.11	244
6-15-72	4,100	7.7	28.0	50	2	6.6	—	—	—	—	—	—	—	—	—	—	—	.05	.07	—
7-27-72	13,500	7.9	29.0	40	4	5.2	.15	.01	200	300	4.2	2,500	110	252	590	4,400	.6	.04	.04	207
1-18-73	32,000	8.0	23.0	20	3	3.1	.12	.03	260	660	5.5	6,400	220	232	1,300	10,100	.9	.05	.05	190

Date	Hardness (Ca, Mg)	Non-carbonate hardness	Dissolved solids		Aluminum (Al)	Zinc (Zn)	Lead (Pb)	Copper (Cu)	Chromium (Cr+6)	Arsenic (As)	Baron (B)	MBAS (Detergents)	Nitrogen (N)				Oil and grease
			Residue at 180°C	Calculated									Ammonium NH ₄ as N	Nitrate NO ₃ as N	Nitrite NO ₂ as N	Total organic nitrogen as N	
9-30-70	1,310	1,120	—	10,200	0.16	0.12	0.000	0.020	0.020	0.020	1.5	—	0.20	0.1	0.02	0.44	0.7
1-14-71	2,900	2,800	—	25,000	.26	.05	.010	.050	.040	.000	.21	.023	.27	.1	.01	.18	.0
4-15-71	4,900	4,700	—	25,900	.08	.07	.000	.040	.000	.000	.78	.90	.18	.0	.00	.37	8.0
7-13-71	2,400	2,200	—	10,600	—	.01	.003	.020	.000	.000	1.5	.30	.36	.0	.01	.73	.0
9-22-71	1,473	1,261	—	7,720	—	.03	.002	.030	.000	.010	1.5	.25	.22	.1	.03	1.2	8.6
1- 6-72	2,800	2,600	—	13,400	—	.03	.004	.030	.000	.010	1.6	.48	.24	—	—	.69	—
4- 3-72	1,100	850	—	4,900	—	.01	.028	.010	.000	.020	.47	.38	.48	.2	.01	.66	2.7
6-15-72	—	—	—	—	—	—	—	—	—	—	—	—	.40	.2	.04	1.0	—
9-27-72	1,700	1,500	—	8,200	—	.02	.006	—	—	.010	—	—	.21	.1	.02	.83	9.7
1-18-73	3,400	3,200	—	19,100	—	.02	.005	.040	.000	.010	—	—	.24	.1	.01	1.4	8.2

flow is evident from the high hardness and high concentrations of chloride, sodium, and dissolved solids (table 3A). In general, the concentrations of principle cations and anions in Hollywood Canal (table 3A) are below limits set by the FDPC (Florida Department of Pollution Control) for pollution of surface waters to be used for contact sports. Nitrogen, phosphorous, and MBAS were also found in the water in Hollywood Canal.

Total coliform levels in Hollywood Canal ranged from 1,020 to 15,200 colonies per 100 ml (milliliters) of water and fecal coliform levels ranged from 80 to 800 colonies per 100 ml in 1970-72 (table 3B). The FDPC requires that in water to be used for body contact activities, total coliforms are not to exceed 1,000 colonies per 100 ml on a monthly average; nor to exceed this number in more than 20 percent of the samples examined during the month, no fecal

Table 3B.—Bacteria and carbon analyses of water from Hollywood Canal half a mile south of Dania Cut-Off Canal.

DATE	Coliform in colonies/100 ml		BOD (mg/l)	Total carbon (mg/l)	Organic carbon (mg/l)	Inorganic carbon (mg/l)
	Total	Fecal				
9/28/70	6,200	400	0.7	—	—	—
1/26/71	4,100	120	.7	—	—	—
4/27/71	—	—	—	37	6	31
4/29/71	1,600	80	—	—	—	—
5/19/71	1,540	120	2.1	—	—	—
6/30/71	—	—	1.3	—	—	—
7/ 7/71	1,020	—	—	—	—	—
7/13/71	—	—	—	62	16	46
9/20/71	—	—	1.6	—	—	—
10/ 5/71	7,500	160	—	—	—	—
1/ 3/72	—	—	—	63	5	58
1/ 6/72	—	—	—	56	7	49
1/11/72	—	—	1.6	—	—	—
1/18/72	5,600	360	—	—	—	—
4/ 3/72	15,200	670	2.1	—	—	—
6/15/72	9,600	800	—	—	—	—

Table 3C.—Pesticide analyses of water and sediments from Hollywood Canal half a mile south of Dania Cut-Off Canal.

Water samples in micrograms per liter (ug/l)

DATE	Aldrin	DDD	DDE	DDT	Dieldrin	Diazinon	Endrin	Heptachlor	Lindane	Malathion	Parathion	Methy- parathion	Ethion	Trithion	2,4-D	2,4,5-T	Silvex	Methyl Trithion	Chlordane Estimate	PCB Estimate	Toxaphene
11- 5-70	0.00	0.00	0.00	0.00	0.00	—	0.00	0.00	0.00	—	—	—	—	—	0.11	0.00	0.04	—	—	—	—
1-14-71	.00	.00	.00	.00	.00	—	.00	.00	.00	—	—	—	—	—	.00	.00	.00	—	—	—	—
4-15-71	—	—	—	—	—	—	—	—	—	—	—	—	—	—	.01	.00	.00	—	—	—	—
7-13-71	.00	.00	.00	.00	.00	0.00	.00	.00	.00	0.00	0.00	0.00	0.00	0.00	.03	.00	.03	—	—	—	—
9-22-71	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	0.00	—	—	—
1- 6-72	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.02	.00	0.0	0.0	—
4- 3-72	.00	.00	.00	.00	.01	.00	.00	.00	.00	.00	.00	.00	.00	.00	.03	.00	.01	.00	.0	.1	0.00
9-27-72	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.0	.0	—

Bottom sediments in micrograms per kilogram (ug/kg)

DATE	Aldrin	DDD	DDE	DDT	Dieldrin	Diazinon	Endrin	Heptachlor	Lindane	2,4-D	2,4,5-T	Silvex	Methyl Trithion	Chlordane Estimate	PCB Estimate
1-14-71	0.00	1.1	0.0	0.0	0.0	—	0.00	0.00	0.00	—	—	—	—	—	—
4-16-71	.00	.5	.4	.0	.1	—	.00	.00	.00	—	—	—	—	—	—
7-13-71	.00	2.6	1.8	14.0	.0	—	.00	.00	.00	0.00	0.00	0.00	—	—	—
9-22-71	.00	.6	.4	.0	.0	—	.00	.00	.00	—	—	—	—	0	0
1- 6-72	.00	23.0	19.0	.0	2.3	—	.00	.00	.00	—	—	—	—	160	110
9-27-72	.00	1.7	1.0	.0	.3	—	.00	.00	.00	—	—	—	—	5.0	0

limits are included in this standard. The FWPCA (Federal Water Pollution Control Administration) requires that in waters to be used for recreation and body contact activities, fecal coliforms shall not exceed a log mean of 200 colonies per 100 ml nor shall more than 10 percent of the total samples collected during any 30-day period exceed 400 colonies per 100 ml.

The nutrients and detergents and the high coliform levels in the Hollywood Canal come from wastes introduced into the Canal by three plants and by the many boats and marinas in the Hollywood and Dania cut-off Canals.

Pesticides are introduced into the canal from agricultural areas in western Broward County by way of South New River Canal and by urban runoff and waste water. The DDT family (DDT, DDD, and DDE) generally constitutes the highest level of insecticides and silvex the highest level of herbicides found in Broward County canals. The concentrations are generally much higher in the sediments. DDD and DDE are the first and second breakdown stages, respectively, of the insecticide DDT. Of water and sediment samples collected in Hollywood Canal from January 1971-September 1972, the water was almost free of pesticides (table 3C) and the DDT family constituted the major pesticides found in the sediment. The pesticide levels shown in table 3C are about average for most of the canals in Broward County on the basis of recurrent samples from canals collected during the same time span.

SALT-WATER INTRUSION

The inland extent of salt-water intrusion into coastal aquifers is, in part, governed by the elevation of the fresh water table above mean sea level. Studies by Kohout (1960, p. 2133-2141) shows that the depth and shape of the interface between fresh and salt water are altered somewhat by fresh water moving toward and discharging into the ocean. Even under dynamic conditions, if fresh-water levels are not maintained at a level appreciably higher than mean sea level, sea water will move inland.

Salt-water intrusion into the Biscayne aquifer, the chief threat to the fresh-water supplies in the Hollywood area, generally occurs by one of two methods: (1) intrusion from the ocean into coastal parts of the aquifer and from uncontrolled canals into inland parts of the aquifer and (2) upward movement of sea water that infiltrated the beds below the Biscayne aquifer during Pleistocene interglacial stages (McCoy and Hardee, 1970, p. 33).

The salt water in the aquifer along the coast, east of Dixie Highway, occurred from direct intrusion from the ocean. The Hollywood Canal used to drain the inland areas and divert the water to the ocean also serves as a con-

duct for salt water to move inland. During the dry season when there is little runoff to the canal and discharge is low, sea water is able to flow far inland and infiltrate into the aquifer.

Because the relation of specific conductance to chloride is direct in the range of values normally found in nature in waters that are predominantly sodium chloride, the specific conductance of water can be used to determine the chloride concentration. A specific conductance recorder was installed in Hollywood Canal (fig. 2) 0.3 mile north of Hollywood Boulevard to monitor the salt-water content. The area that the canal drains is small and ground-water gradients in the area are almost flat. Therefore, fresh-water discharge is low except when rainfall runoff is high.

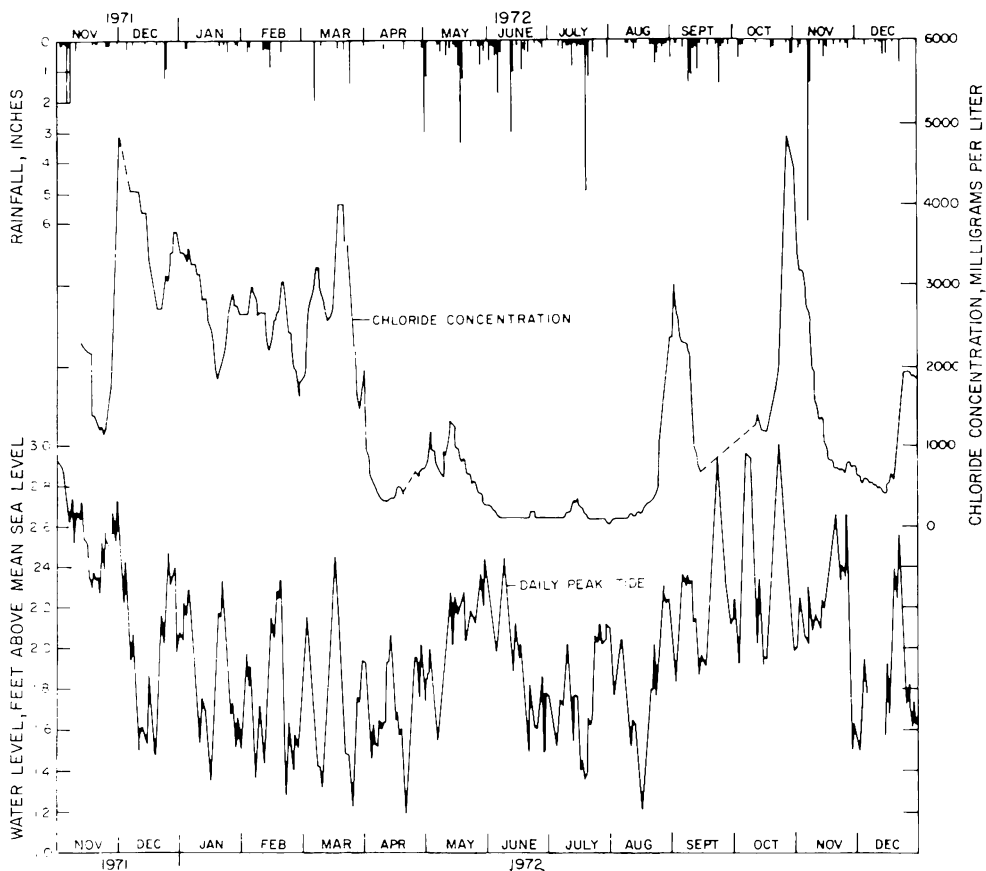
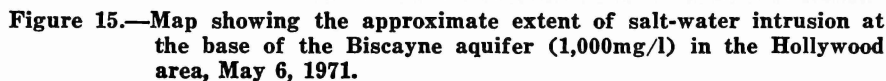


Figure 14.—Graph showing daily chloride concentration in Hollywood Canal, daily peak tides in the Intracoastal Waterway at Hollywood, and daily rainfall at Fort Lauderdale, November 1971-December 1972.



The extent of salt-water intrusion into the aquifer in the Hollywood area adjacent to Hollywood Canal by infiltration of salty water from the canal was determined by analyzing water from a series of test wells for salt content. The wells were sampled on May 6, 1971 (fig. 15) during the extreme drought. The

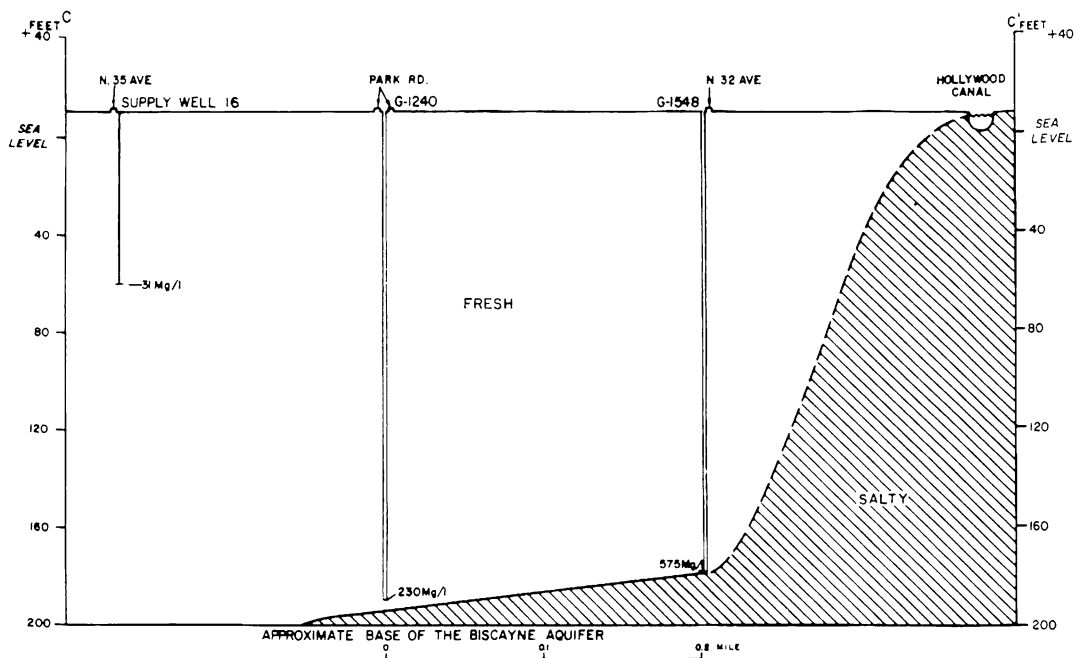


Figure 16.—Section C-C' (fig. 5) from Hollywood Canal through the northern part of the well field showing the extent of salt-water intrusion, May 6, 1971, near the end of the 1971 dry season.

chloride concentration of a water sample collected from the canal at Hollywood Boulevard, May 6, 1971 was 10,000 mg/l (the chloride concentration of sea water is 19,000 mg/l).

Salt water has moved inland at the base of the aquifer to within 0.1 mile of supply well 16 (fig. 16) in the north part of the well field (fig. 5) and within about 0.15 mile of supply well 12 (fig. 17) in the south part of the well field (fig. 5). The toe of the salt front fluctuates slightly with the wet and dry seasons. Owing to the proximity of the salt front to the well field, wells between the Hollywood Canal and the well field may need to be sampled periodically for chloride concentration, especially during the dry season when pumping is heavy, to detect any changes in the position of the salt-water front.

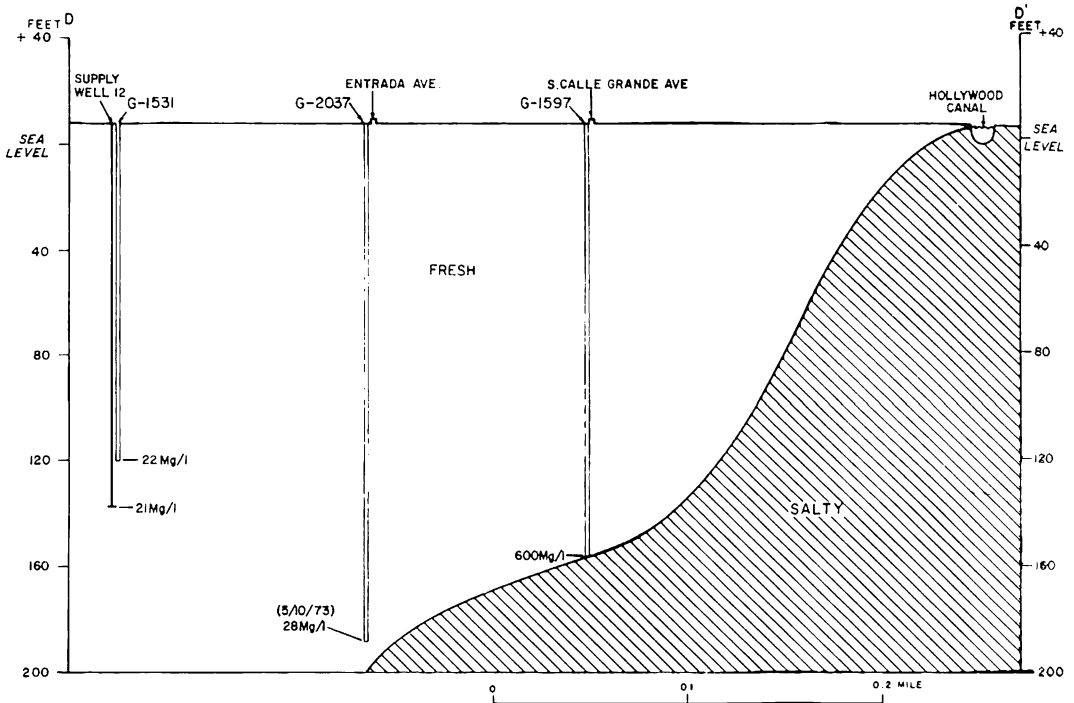


Figure 17.—Section D-D' (fig. 5) from Hollywood Canal through the southern part of the well field showing the extent of salt-water intrusion, May 11, 1972, near the end of the 1972 dry season.

The major threat to the to the ground-water supply in the Hollywood area is salt-water intrusion up Hollywood Canal from the Atlantic Ocean via the Dania Cut-Off Canal. Water management officials have considered the installation of salinity barriers to control the movement of sea water upstream from Dania Cut-Off Canal. One possible barrier location (site 1 on fig. 2) is southwest of the Dania well field. Another possible site (site 2 on fig. 2) has the advantage of helping protect both the Hollywood and Dania municipal water supplies. Barriers at either of these locations would permit the west reach of the canal to be used as a link with either South New River Canal or Snake Creek Canal; both are possible major sources of fresh water. If a salinity control is constructed, fresh water replenishment to the Hollywood Canal would insure that the Canal does not stagnate during the dry season. In addition, flow augmentation would keep a positive head on the upstream side of the

salinity barrier. Without this positive head salty water can intrude upstream around the barrier by flowing through the Biscayne aquifer.

WATER SUPPLY

Hollywood has the second largest water-supply system in Broward County and is the major municipal supplier in the southern part of the county. Its water-supply system consists of a water treatment plant with a design capacity of 20 mgd and 19 wells that will each produce from 1 to 1.5 mgd, with a total capacity of 27 mgd. The wells range in depth from 60 to 149 feet and in diameter from 10 to 16 inches.

Because of treatment problems that resulted from high carbon dioxide, chloride, total hardness, and alkalinity in water from supply wells 11-15 (fig. 5) the city was forced to stop using water from these wells except during emergencies. The area just west of these wells was once used as a landfill area. The wells average only about 62 feet deep and due to this shallow depth, chemicals probably leached from the landfill area causing the water-quality problems. A test well, G-1531 (fig. 5), was drilled to a depth of 128 feet between supply wells 11 and 12 to determine whether the quality of water improved at depths below that of the supply wells. The well was sampled for chemical analysis at a depth of 66 feet during drilling, and at the 128-foot depth upon completion in a permeable limestone. The quality of the water improved appreciably at the 128-foot depth. The specific conductance dropped from 1,200 to 520 micromhos per cm, dissolved solids from 708 to 304 mg/l, and chloride from 98 to 22 mg/l (table 2). Carbon dioxide, the major constituent causing difficulties with treatment but not listed in table 2, dropped from 119 to 22 mg/l. In addition, the specific conductance, pH, chloride, and carbon dioxide in water from a test well (city owned) 94 feet deep near well G-1531 were approximately the same as those of the 128-foot zone of well G-1531.

Because the data indicate that large quantities of water of good quality are available from the limestone formations below 100 feet, the city deepened their supply well 12. The supply well, initially 62 feet deep, was deepened to 149 feet with open hole in a limestone formation from 140 to 149 feet. The well yielded over 2,000 gpm (gallons per minute) and was pumped continuously for 2 months at a rate of 900 gpm with no appreciable change in water quality. The other four wells were then deepened and vary from 100 to 125 feet in depth. All five wells are now again in full production.

Large quantities of ground water can be obtained from the Biscayne aquifer in the western Hollywood area without appreciably affecting ground-water

levels. However, the threat of salt-water intrusion necessitates careful consideration of well spacing and water withdrawal to prevent lowering of water levels in the existing well field.

An area half a mile west of the water treatment plant and south of Hollywood Boulevard (fig. 2) is being considered by the city as an area in which to drill additional supply wells. This area is relatively safe from salt-water intrusion and receives some recharge from Snake Creek Canal during low-water periods. To determine whether the quantity and quality of water available in this area are suitable three test wells, G-2037, G-2038, and G-2039 were drilled in the median of Rainbow Drive near South Circle Drive (fig. 5) to depths of 20, 144, and 187 feet, respectively. Wells G-2037 and G-2038 were sampled on February 4, 1972, and February 14, 1973, for chemical analysis (table 2). The analyses show that the chemical character of water from these wells is similar to the chemical character of water from the existing supply wells. The pH indicates that the water is slightly alkaline, a characteristic of water from the Biscayne aquifer. The iron concentration of water in well G-2038 was 0.5 mg/l, about average for water from the existing supply wells. Evidently, the sample taken on February 4, 1972, was collected before the well had been pumped long enough and the iron concentration was affected by the new casing. The data in table 2 indicate that water of good quality is available less than 150 feet below land surface and with minimal treatment will meet U.S. Public Health Standards for drinking water.

Test well G-2039 taps permeable sections of sandy limestone, shell, and sand between 50 and 80, 134 and 159, and at 182 feet below land surface. The section from 134 to 159 feet contained less sand than the other sections and was permeable through the entire 25-foot section (fig. 6).

The permeability of the Biscayne aquifer in the Hollywood-Hallandale well fields is virtually the same as it is in North Miami Beach's Sunny Isles and Norwood well fields. Aquifer tests by Leach and Sherwood (1963), in the Norwood and Sunny Isles well fields indicated transmissivities ranging from 2.0 to 2.5 mgd per foot and storage coefficients ranging from 0.1 to 0.2.

SUMMARY

Hollywood is a coastal city in southeastern Florida with an area of about 25 square miles. It is primarily a residential community and is one of the fastest growing major cities in Florida. Population increased 203 percent from

35,237 in 1960 to 106,873 in 1970. The mild sub-tropical climate also attracts many winter vacationers.

In the Hollywood area fresh water for all purposes is pumped from the Biscayne aquifer which is composed chiefly of permeable beds of limestone, sandstone, and sand that range in age from late Miocene through Pleistocene. The aquifer is thickest along the coast and in the Hollywood area extends from land surface to about 200 feet and is underlain by beds of poorly permeable marl to a depth of about 900 feet. Rainfall that infiltrates through surface materials to the water table is the major source of recharge to the Biscayne aquifer.

Major water-level fluctuations in the aquifer in the Hollywood area result from rainfall and fluctuations of several feet a day have occurred. The water table slopes gently to the east and, on the average, is about 1.0 foot higher in the western part of the city than in the eastern part. Water levels rise sharply with heavy rainfall, but also decline sharply owing to high permeability of the aquifer.

The water levels in the Hollywood area are greatly influenced by the ocean and by Hollywood Canal and to a lesser degree by Snake Creek Canal, South New River Canal, and Dania Cut-Off Canal. Owing to the high permeability of the aquifer water levels in the well field area decline only about 0.1 foot when the wells are pumped because the drawdown is dispersed over a large area. West of Dixie Highway gradients slope gently downward to the Hollywood Canal and east of Dixie Highway to the ocean.

Salt-water intrusion from Hollywood Canal is the chief threat to the fresh-water supply in the Hollywood area. Hollywood Canal is a drainage canal that extends through the heart of the city and is connected to the tidal reach of Dania Cut-Off Canal. Salt water from Hollywood Canal has filtered into the aquifer. When fresh-water discharge in Hollywood Canal is low the chloride concentration of the water in the canal has been as high as 10,000 mg/l. At depth in the aquifer salt water has moved inland west of the canal to within 0.1 mile of some of the municipal wells.

Large quantities of ground water of good quality can be obtained from the Biscayne aquifer in the Hollywood area. Because of the high permeability of the aquifer in the area, large quantities of water can be withdrawn without appreciably affecting ground-water levels. However, the threat of salt-water intrusion necessitates careful consideration of well spacing and water withdrawal to prevent lowering of water levels in the existing well field.

WELL NUMBERS

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

County No.	Latitude-Longitude No.	County No.	Latitude-Longitude No.
F 291	260011N0800851.1	G 1447	260213N0800923.1
G 1224	260252N0800853.1	G 1474	260234N0800906.1
G 1225	260032N0801357.1	G 1476	260251N0800937.1
G 1226	260053N0801057.1	G 1531	260035N0801034.1
G 1227	260039N0801042.1	G 1548	260053N0801023.1
G 1237	260312N0801001.1	G 1597	260035N0801015.1
G 1238	260252N0800914.1	G 2000	260045N0801032.1
G 1240	260054N0801033.1	G 2035	260040N0801044.1
G 1241	255948N0800909.1	G 2037	260027N0801101.1
G 1346	260155N0801013.1	G 2038	260027N0801102.2
G 1434	255916N0800853.1	G 2039	260027N0801102.3
G 1445	260212N0800834.1	G 2040	260045N0801034.1
G 1446	260213N0800848.1	G 2073	260035N0801027.1

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