STATE OF FLORIDA
DEPARTMENT OF NATURAL RESOURCES
Randolph Hodges, *Executive Director*

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

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

Report of Investigations No. 63

HYDROLOGY OF WESTERN COLLIER COUNTY, FLORIDA

By
JACK McCOY

Prepared by
U.S. GEOLOGICAL SURVEY
in cooperation with
COLLIER COUNTY
CITY OF NAPLES
BUREAU OF GEOLOGY
FLORIDA DEPARTMENT OF NATURAL RESOURCES

CONTENTS

ILLUSTRATIONS

TABLES

HYDROLOGY OF WESTERN COLLIER COUNTY, FLORIDA

By

Jack McCoy

ABSTRACT

Although the fresh-water-supply potential of western Collier County is large, water problems exist in that the 54 inches of annual rainfall are not evenly distributed throughout the year, salt-water intrusion threatens the Naples well field during prolonged dry periods, and contamination of existing and future ground-water supplies is possible by man-related activities.

The controlled surface-water flow system of the GAC (Gulf American Corporation) developments minimizes the threats of floods without an excessive lowering of water levels near the coast. Variable water quality and inadequate flows during the dry season preclude the use of the surface-water flow system as a direct source of municipal water.

Naples well-field expansion is limited by water of inferior quality in the shallow aquifer immediately east of the well field. The shallow aquifer in an area starting about 11 miles inland and extending eastward to State Road 29 contains water of good quality. The shallow aquifer extends from land surface to a depth of almost 100 feet near SR 84 and SR 951 and from land surface to more than 70 feet near SR 84 and SR 29. Available data indicate the aquifer in this area has a capacity several times that in the Naples coastal area.

INTRODUCTION

PURPOSE AND SCOPE OF INVESTIGATION

Collier County, in southwestern Florida (fig. 1), receives abundant rainfall, 54 inches annually. The western third of the county is underlain by permeable sediments about 100 feet thick containing water of good quality in most places. However, water problems exist in the county. The major problem is the development of additional fresh water supplies to meet the demands of the rapidly growing population. The projected rapid growth rate prompted officials to take action not only by expanding municipal water-supply systems but also by suggesting that investigations be made to establish

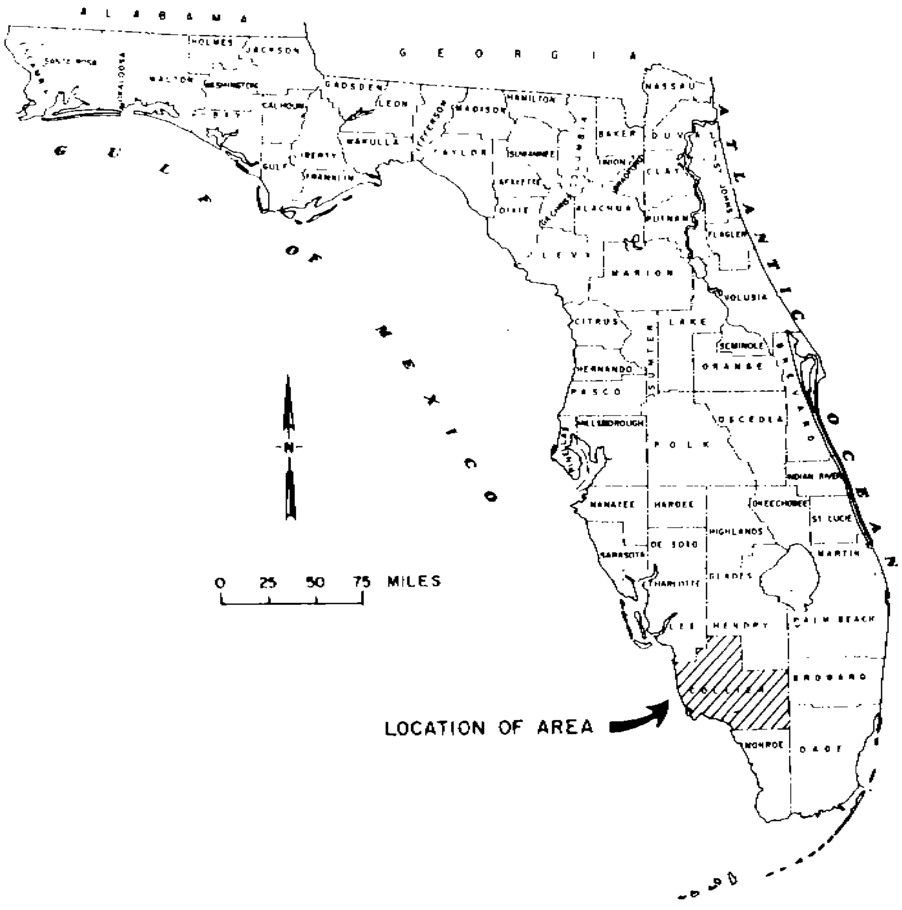

Figure 1.—Map of Florida showing location of Collier County.

possible new well-field sites in inland areas. The U.S. Geological Survey was requested in 1967 to locate areas that would most likely yield the greatest quantities of the best quality water to satisfy the projected municipal needs of western Collier County.

The investigation included the following phases: (1) evaluation of existing data; (2) determination of the hydrologic and geologic characteristics of the subsurface materials; (3) collection of miscellaneous discharge data in the inland canal complex and interpretation of the data; and (4) determination of the quality of water.

This report was prepared by the U.S. Geological Survey in cooperation with Collier County, the city of Naples, and the Bureau of Geology, Florida Department of Natural Resources. The work was under the immediate supervision of T. J. Buchanan, Subdistrict Chief, Miami, Florida, and under the general supervision of C. S. Conover, District Chief, Tallahassee, Florida, both of the U.S. Geological Survey,

PREVIOUS INVESTIGATIONS

Two reports, "Ground-water resources of the Naples area, Collier County, Florida, 1954", by Klein and "Ground-water resources of northwest Collier County, Florida, 1961", by Sherwood and Klein, summarize the geologic and hydrologic conditions in northwestern Collier County. The report "Ground-water resources of Collier County, Florida, 1962", by McCoy gives a general portrayal of the geologic and hydrologic conditions throughout the county. Some hydrologic and biologic aspects of the Big Cypress Swamp watershed are described in a preliminary report by Klein and others (1970). Day-to-day variations in physical, biological (including bacterial), and chemical character of the water flowing into, through, and discharging from the Big Cypress Swamp watershed during March 1970 are recorded in the report by Little and others (1970).

ACKNOWLEDGMENTS

Many public officials have contributed valuable information and assistance during the study. Among them were W. H. Turner, County Manager; Tom Peeke, County Engineer; and W. F. Savidge, Director of the Naples Public Works Department. Dr. J. I. Garcia-Bengochea and Robert Ghiotto of Black, Crow, and Eidsness, Inc. rendered many services and courtesies.

GENERAL FEATURES

Collier County consists of 2,119 square miles in the southwestern part of Florida, making it the second largest county in the State. The county is bounded on the west and southwest by the Gulf of Mexico, on the north by Lee and Hendry Counties, on the east by Broward and Dade Counties, and on the southeast by Monroe County. The principal municipalities are Naples, on the west coast, Immokalee in the north-central part, and Everglades City, on the south coast.

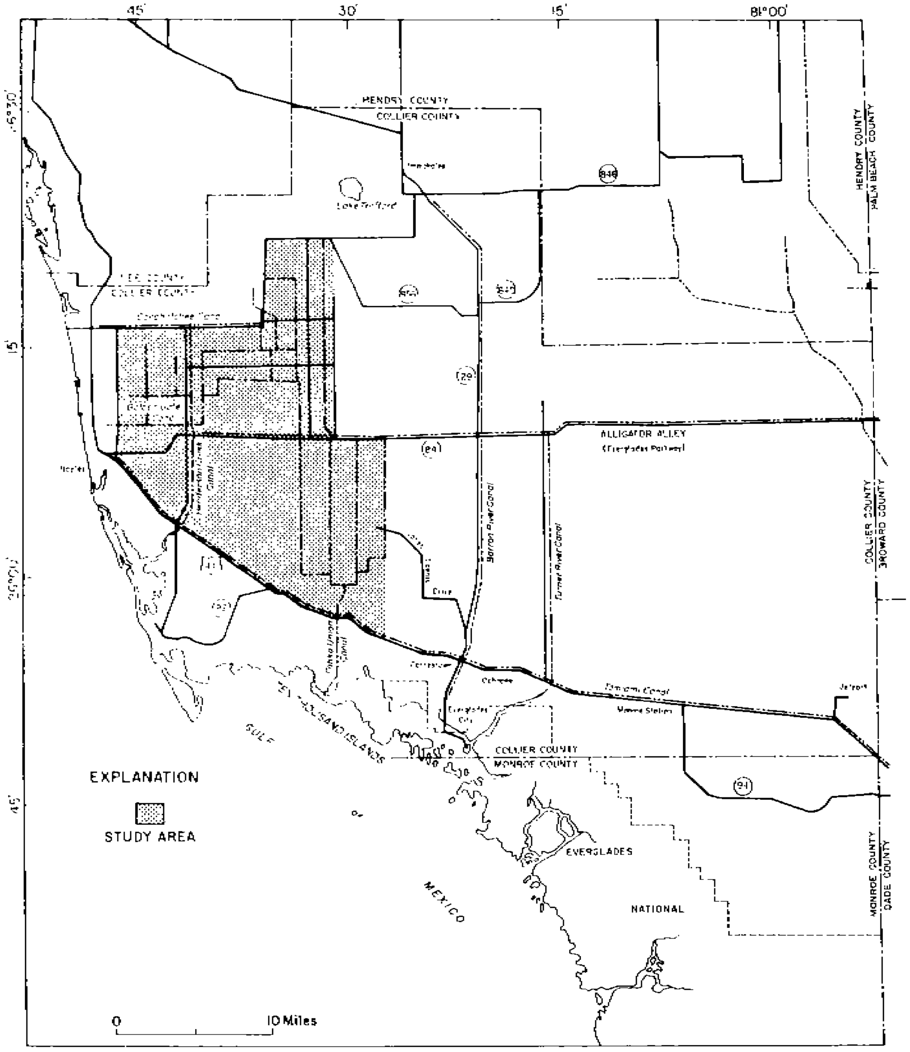

Figure 2.—Location of area of investigation.

TABLE 1.—AVERAGE MONTHLY AND 1970 MONTHLY TEMPERATURES AT NAPLES[1]

	Temperature (°F)		Rainfall (inches)	
	1942-1970	1970	1942-1970	1970
January	65.5	60.7	1.74	1.95
February	66.5	61.7	1.76	1.97
March	71.0	68.5	2.39	13.56
April	73.6	75.4	2.01	
May	77.1	75.9	3.98	5.32
June	80.9	80.4	8.16	6.48
July	82.4	82.0	8.30	5.26
August	82.9	82.7	8.19	4.68
September	81.9	81.7	9.55	13.32
October	77.1	77.5	4.96	2.87
November	71.1	67.1	1.39	.43
December	66.6	65.7	1.25	.02
Average	74.6	73.3	54.65	55.86

[1] U.S. Weather Bureau, Climatological Data, 1942-1970.

The area of investigation consists of about 280 square miles in the western quarter of the county (fig. 2). The area's boundaries are roughly the Naples city limits on the west, State Road 846 on the north, the Fakha Union Canal on the east, and U.S. Highway 41 (Tamiami Trail) on the south. About half the area has been platted for single and multiple-unit dwellings by GAC (Gulf American Corporation). Streets in nearly one-third of the platted segment have been completed. A massive canal system has been established by the developers to provide flood control. Weirs that have been placed throughout the canal system to control the flow prevent excessive drainage.

Collier County was the fastest growing county in Florida during 1960-70, increasing in population from almost 16,000 to slightly more than 38,000. In 1970, Naples and its environs accounted for about two-thirds of the population, and the population in the area of investigation was about 1,000, mostly residents of the Golden Gate Estates development. Projected population for Golden Gate Estates exceeds 50,000.

Agriculture is the principal industry in the area investigated. Several thousand acres of Golden Gate property in the northern part of the development is leased for growing cucumbers, watermelons, tomatoes, and peppers. Farming on a smaller scale is active along U.S. Highway 41 also.

CLIMATE

Climate in Collier County is humid subtropical: summers are warm and wet, and the winters are mild and dry. Total rainfall in Naples for 1949-70 averaged 54 inches (table 1). Most of the rainfall occurs during June through October. The summer rains are usually tropical, frequent, intense, and of short duration. Winter rains are associated with weather fronts and are usually longer but less intense, and they vary widely in frequency.

Because of the cooling effect of summer rains, the highest daily temperature during the summer is about 95°F. The lowest daily temperature for the winter is about 34°F. Cold periods usually follow the frontal rains and do not last more than a few days at a time. The average annual temperature in Naples is about 75°F (table 1), the summer average is 82°F, and the winter average is 66°F.

PHYSIOGRAPHY AND DRAINAGE

Davis (1943, fig. 1) divided Collier County into three physiographic regions: The Flatlands, the Big Cypress Swamp, and the Southwest Coast and Ten Thousand Islands (fig. 3). Most of the investigation area lies within the Big Cypress Swamp region and is characterized by swamps containing large cypress trees, islands of pine forests, and wet marl prairies. Most of this region is less than 15 feet above msl (mean sea level). The southern part of the area lies within the Southwest Coast and Ten Thousand Island region and contains tidal streams, bays, lagoons, and thousands of shoal-water islands. The area south of U.S. Highway 41 is primarily mangrove swamps and salt-water marshes.

Drainage in Collier County is determined by topographic configuration and canals. Because of the flat topography and slow natural drainage, no well-defined stream system is developed except for the Gulf Coast estuaries, where drainage is through tidal channels. In the fresh-water environment, most drainage is through sloughs and strands and by canals, as shown in figure 4.

Drainage in the area investigated is characterized by an extensive system of controlled canals, which drain southward and westward into the Gulf Coast estuaries (fig. 2). Outlets for the system are the Golden Gate Canal at Naples and the Fahka Union Canal northwest of Everglades City. Part of the area southwest of Immokalee is drained to the gulf north of Naples by the Cocohatchee River Canal. The Henderson Creek Canal, southeast of Naples, drains the southwestern part of the area investigated.

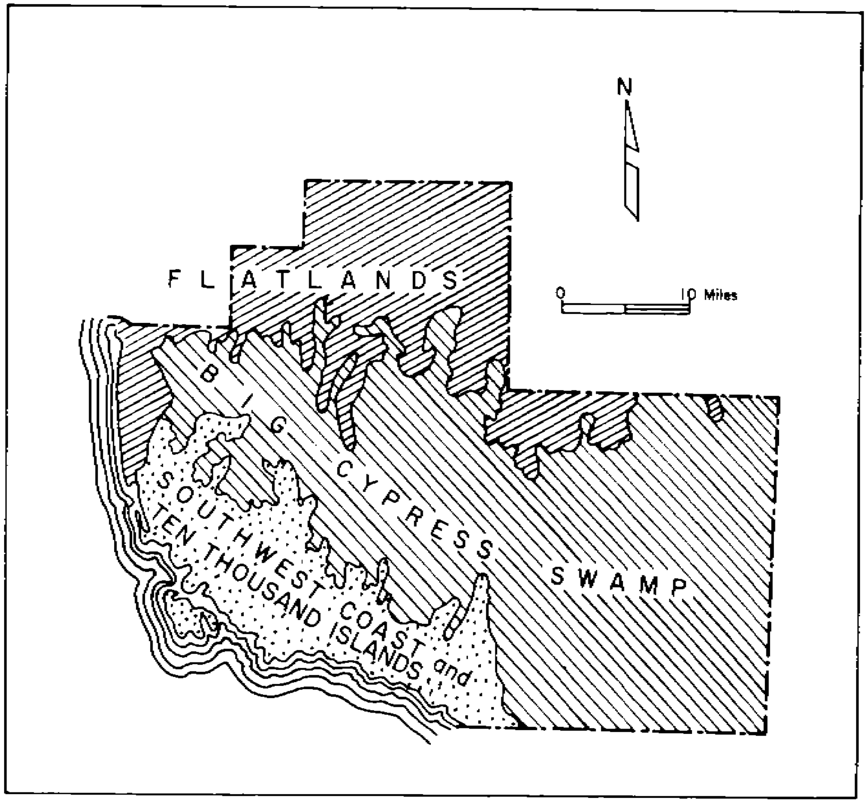

Figure 3.—Physiographic regions of Collier County, Florida (after Davis, 1943, figure 1).

WATER PROBLEMS

In western Collier County, as in most of southern Florida, the major water problems are:

1) Availability and protection of potable ground-water supplies in vicinity of population centers.
2) Quality of water in areas of potential well-field expansion.
3) Protection of ground-water supplies from excessive drain-

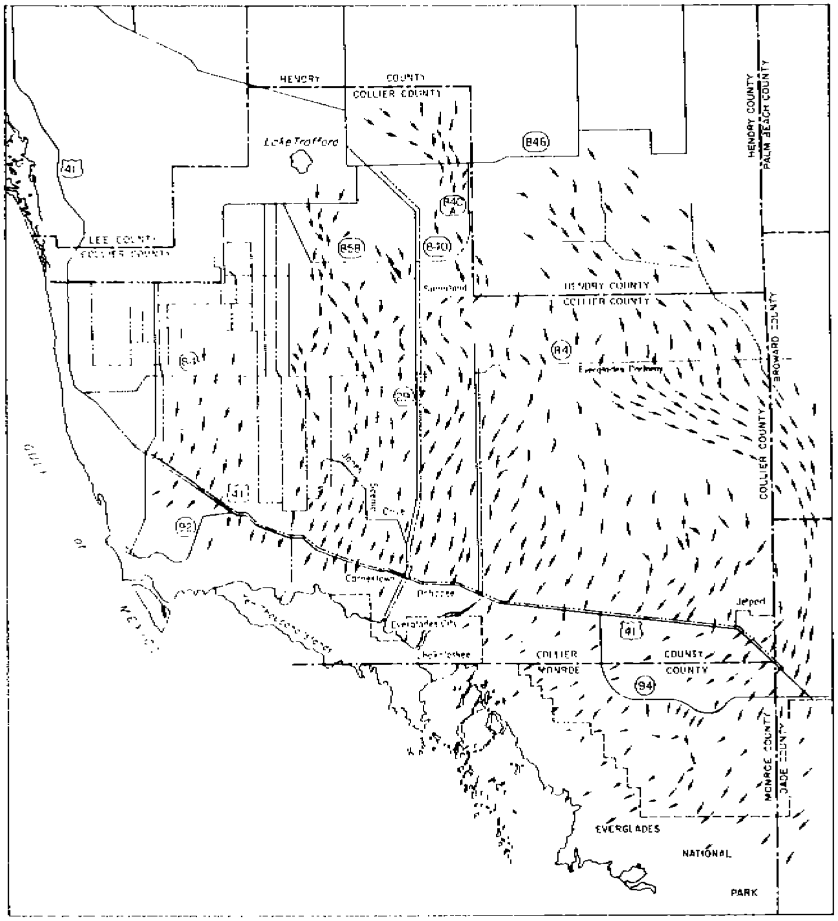

Figure 4.—Map of the Big Cypress Watershed showing flow directions in December, 1969 (after Klein and others, 1970, figure 3).

age by flood-control practices in the expanding urban areas, and

4) threat of contamination of potable ground-water supplies by man-made chemicals and wastes.

Nearly all ground water for public use in western Collier County is supplied by the city of Naples well field. The well field is less than 2 miles inland from the gulf and has always been threatened by salt-water intrusion. Production of treated ground water from the well field has increased from an average daily rate of 0.2 mgd (million gallons per day) in 1950 to 4.4 mgd in 1970 and is predicted to exceed 17 mgd by 1990. The withdrawal of 17 mgd without serious contamination resulting from salt-water intrusion will present a formidable problem for water managers.

Expansion of the Naples well field to the north and to the south is extremely limited by natural salt-water contamination in the aquifer. For about 10 miles inland the quality of the ground water is inferior to the water in the existing well field. Therefore, development of additional ground-water supplies will have to start in an area at least 10 miles inland, a considerable distance from the majority of the water users.

Urbanization in the inland areas required the construction of a large canal network to lower water levels in areas historically swampy and to prevent flooding. However, increased water needs resulting from the urbanization will require careful management of the canal network in order to avoid depleting ground-water supplies because of excessive drainage.

The possibility of contaminating fresh-water supplies by man-made wastes and chemicals continues to increase as more land is developed. The method and degree of treatment and the location of waste-disposal sites will have a significant effect on the quality and the quantity of future water supplies.

HYDROLOGY

SURFACE FLOW SYSTEM

Construction of the extensive canal system shown in figure 5 was begun in the early 1960's with the excavation of the Golden Gate Canal, the primary canal in the western part of the system. Excavation of the Fahka Union Canal, the primary canal in the eastern part of the system, was begun in 1968. Several secondary canals connect with the Golden Gate Canal, whereas the Fahka Union Canal is the combination of four parallel primary canals. The canal systems provide controlled drainage to permit development of the Golden Gate Estates, east of Naples, and the Remuda Ranch Grants, southeast of Naples. Before construction of the canals, much of the area was inundated each year during the rainy season.

The Golden Gate Canal extends about 20 miles inland from the Gordon River. The bottom of the canal is 5 feet below msl at its outlet to Gordon River and 6 to 8 feet above msl in the interior. The

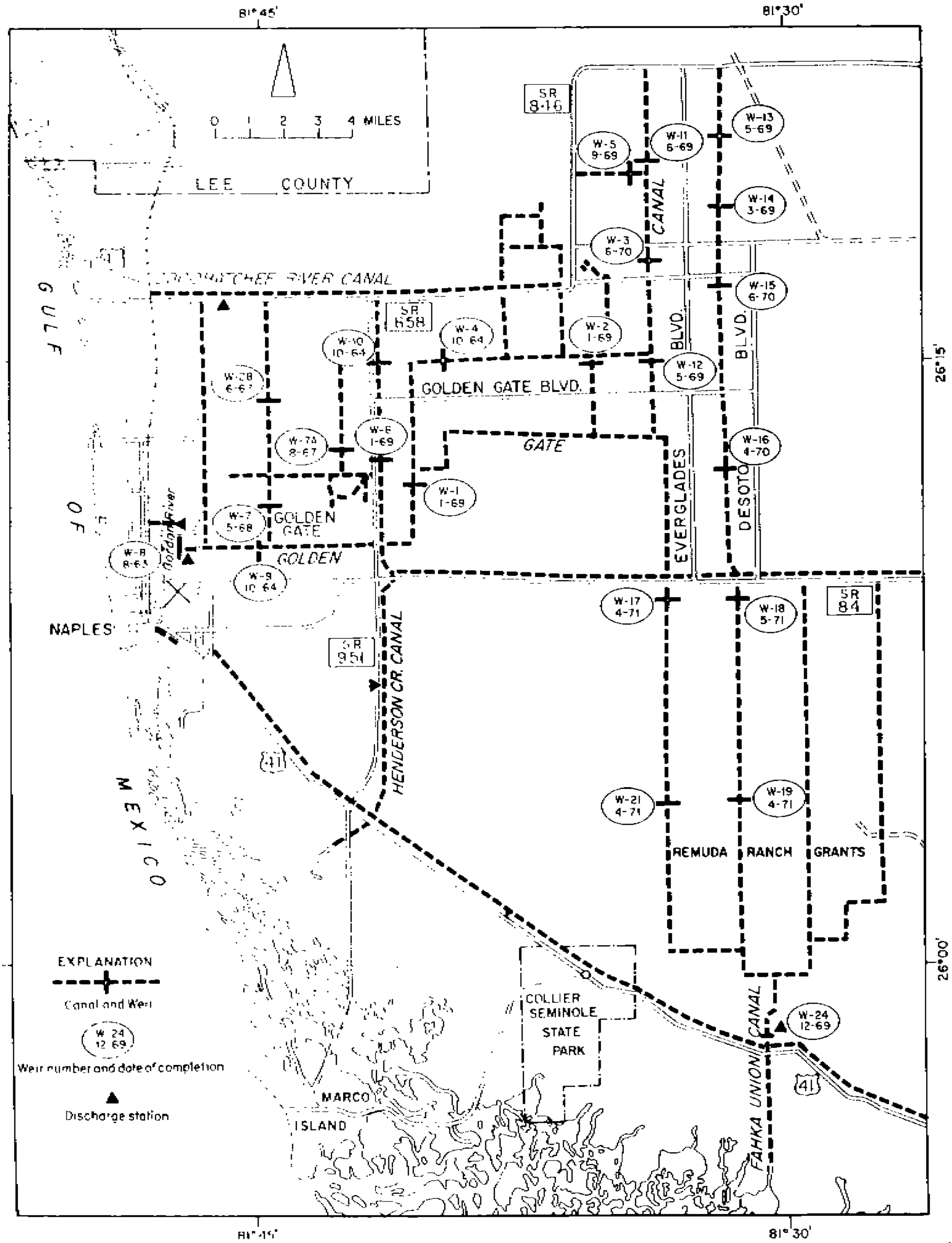

Figure 5.—Canals in western Collier County showing location of weirs and discharge stations.

design plans for the Fahka Union Canal call for similar bottom elevations. Distributed throughout the canal system are about 30 weirs, which increase in elevation toward the interior. The elevations of the coastal weirs on the Golden Gate and Fahka Union Canals (numbers 8 and 24) are 3 and 2 feet above msl. The elevation of the highest interior weir (number 13 near Immokalee) is 17 feet above msl.

The function of the canals is to lower annual peak water levels to prevent flooding during the rainy season. The function of the weirs is to control the canal flow and reduce the possibilities of overdrainage. During the rainy season, when water levels in the interior are high, water moves from aquifer storage into the canals and downstream over the weirs. At the beginning of the dry season, flow over the inlandmost weirs ceases but continues over the downstream weirs. Flow over the weirs ceases in succession downstream, as the dry season continues, until flow occurs only at coastal weirs on the primary canals. Water has continued to flow over the coastal weirs in both primary canals since the canals were completed. The shallow depth of the canals and the distribution of weirs at selected elevations within the canal system limit drainage from the shallow aquifer in the inland areas. By limiting drainage from aquifer storage, regional water levels near the coast are not lowered excessively, and, therefore, the problem of sea-water intrusion is not magnified.

Continuous records of discharge are obtained at all outlets of the canal system (fig. 5). Flow in the Golden Gate Canal is measured upstream from weir W8. The record began October 1964. Flow in Fahka Union Canal is measured upstream from weir W24, beginning in December 1969, and in the Henderson Creek Canal, about 4 miles south of Alligator Alley, (SR84), beginning in August 1968. Flow in the Cocohatchee River Canal was originally measured near a bridge on SR846 about 1 mile east of U.S. Highway 41, but channel improvements produced tidal effects at the gaging site, and the station was relocated to its present site in October, 1968. Hydrographs of these four canals for the periods of record are shown in figure 6.

The Golden Gate Canal is about 100 feet wide, less than 8 feet deep, and has several fixed weirs throughout its reach of about 26 miles; the Fahka Union Canal is similar in width and depth and about 30 miles long; the Henderson Creek and Cocohatchee River Canals are about 25 feet wide, less than 5 feet deep, and 7 and 13 miles in length, respectively. The Henderson Creek Canal is uncontrolled except for a constriction at Alligator Alley which acts as a surface-water divide most of the time. However, at the peak of the

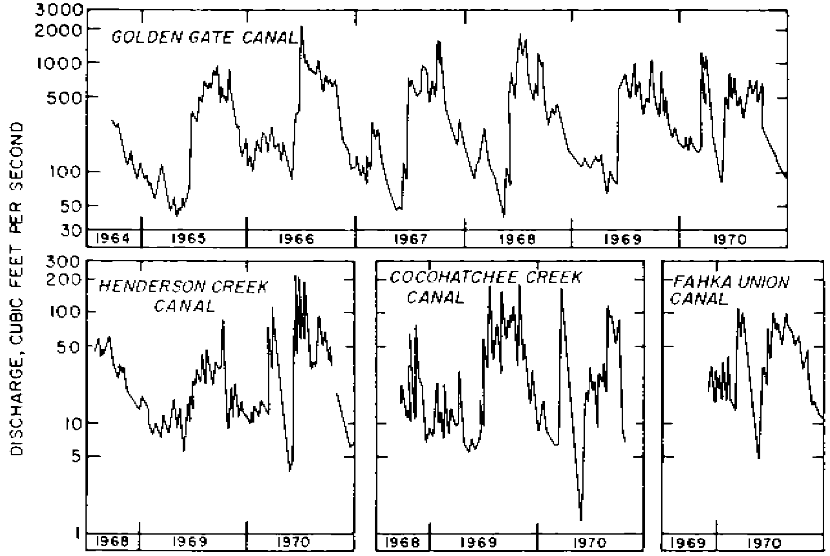

Figure 6.—Hydrographs of discharge for selected canals in western Collier County.

rainy season, the Henderson Creek Canal probably receives some flow from the Golden Gate Canal. The Cocohatchee River Canal has a control a short distance upstream from the gaging station. Farmers regulate the control according to irrigation needs. The Cocohatchee River Canal drains most of the area southwest of Lake Trafford, but it also helps drain the Golden Gate area during peak wet periods. Because of their larger channels and drainage basins, the Golden Gate and Fahka Union Canals discharge more water than the Cocohatchee River and Henderson Creek Canals.

The discharge of all the canals responds quickly to rainfall on their respective drainage basins, as demonstrated by the response to rainfall in early June, 1969. (See rainfall graph in fig. 11). On the other hand, rainless periods produced sustained declines of all discharges such as those of April and most of May 1970. Only a trace of rainfall was recorded at Naples during April and the first three weeks of May. The rapid decline of the flows throughout this period suggests very little ground-water inflow. This could be due to either low permeability of the aquifer or shallowness of canals or both.

The closeness of the water table to land surface throughout the area of investigation, the flatness of the drainage basins, and the

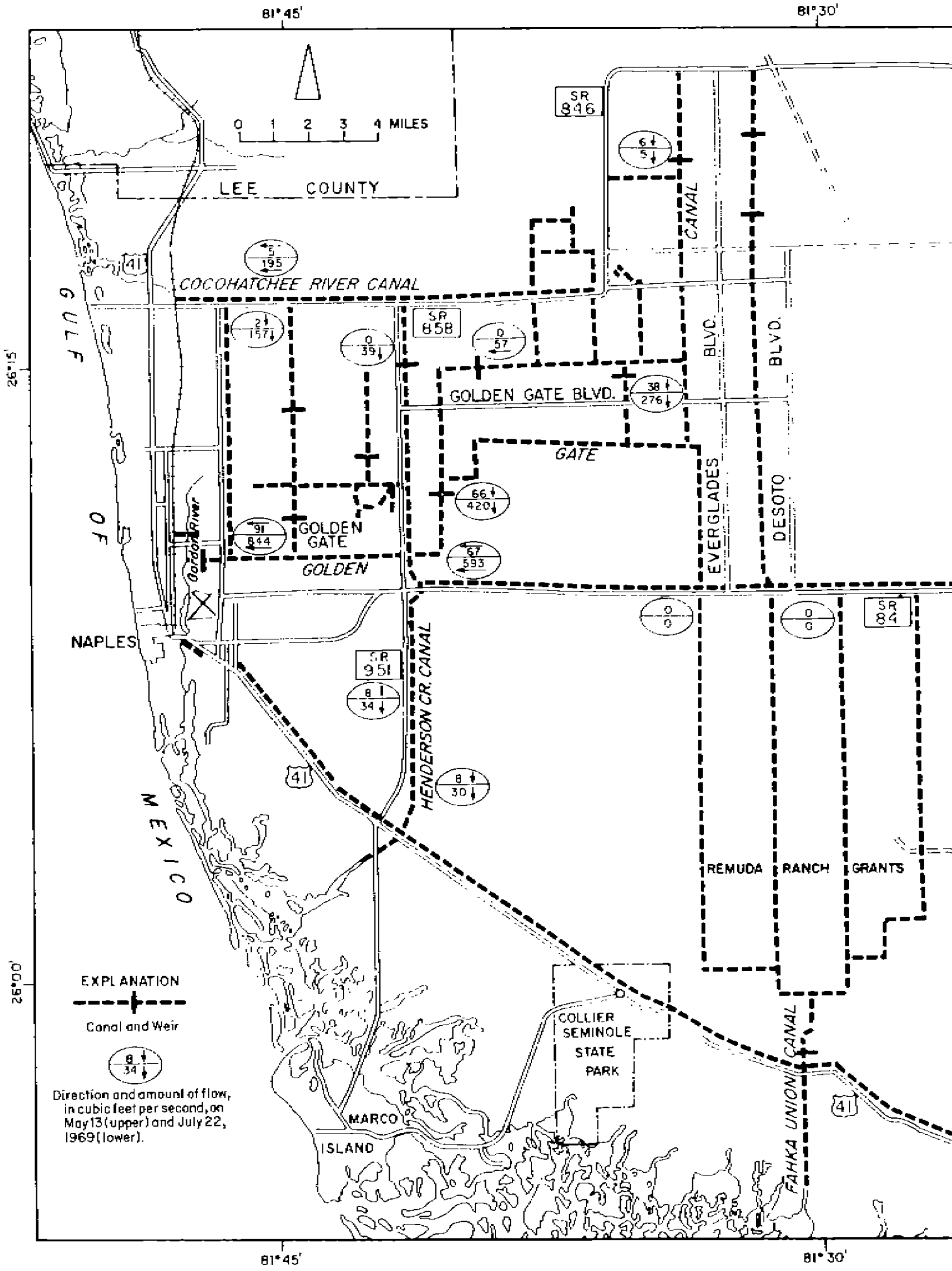

Figure 7.—Direction and amount of flow in the Golden Gate Canal system on May 13 and July 22, 1969.

intensity of most of the rainfall requires that drainage canals in developed areas be adequately designed to remove surplus rainfall quickly if flooding is to be prevented. The sharp rises of the discharge peaks in figure 6 indicate the rapid removal of flood waters; the short duration of the peaks and the rapid declines indicate that a minimal amount of water reaches the aquifer as recharge.

During 1970 the average discharge at each of the four stations was: (1) Golden Gate Canal, 250 cfs (cubic feet per second); (2) Fahka Union Canal, 270 cfs; (3) Henderson Creek Canal, 25 cfs; and (4) Cocohatchee River Canal, 15 cfs. Near the end of the dry season in 1971, discharge at the Golden Gate Canal outlet reached a record low of less than 20 cfs (about twice the average daily pumpage of the Naples water system in 1970).

Figure 7 shows the direction and amount of flow in the Golden Gate Canal system on May 13 and July 22, 1969. These periods were representative of flow conditions near the end of the dry season and near the beginning of the wet season, respectively. Weirs completed at the time of the measurements are identified by a symbol and number.

The contrast in flow on the 2 days is readily apparent, except for the inlandmost part of the system. Also apparent is the downstream increase in flow on both days. On May 13 this increase resulted largely from prolonged ground water seepage into the canal from aquifer storage. Even during this driest part of the year, 91 cfs, or about 60 mgd, was discharged into the tidal reach of the Gordon River.

Flow at every measuring site on July 22 was almost 10 times that on May 13, except for the unfinished inland part of the system, the Cocohatchee River Canal, and the Henderson Creek Canal.

SHALLOW AQUIFER

All fresh ground water used in western Collier County for municipal, domestic and industrial supplies, and for irrigation is obtained from a shallow unconfined aquifer. The shallow aquifer is composed of the Pleistocene terrace sands, the permeable limestones and sands of the Pleistocene Anastasia Formation, and the upper permeable limestones of the late Miocene Tamiami Formation (McCoy, 1962, p. 24). The aquifer is underlain nearly everywhere by a thick section of sand or clayey limestone. The maximum thickness of the shallow aquifer is about 130 feet in Naples, where the terrace sands and the Anastasia and Tamiami Formations are all present

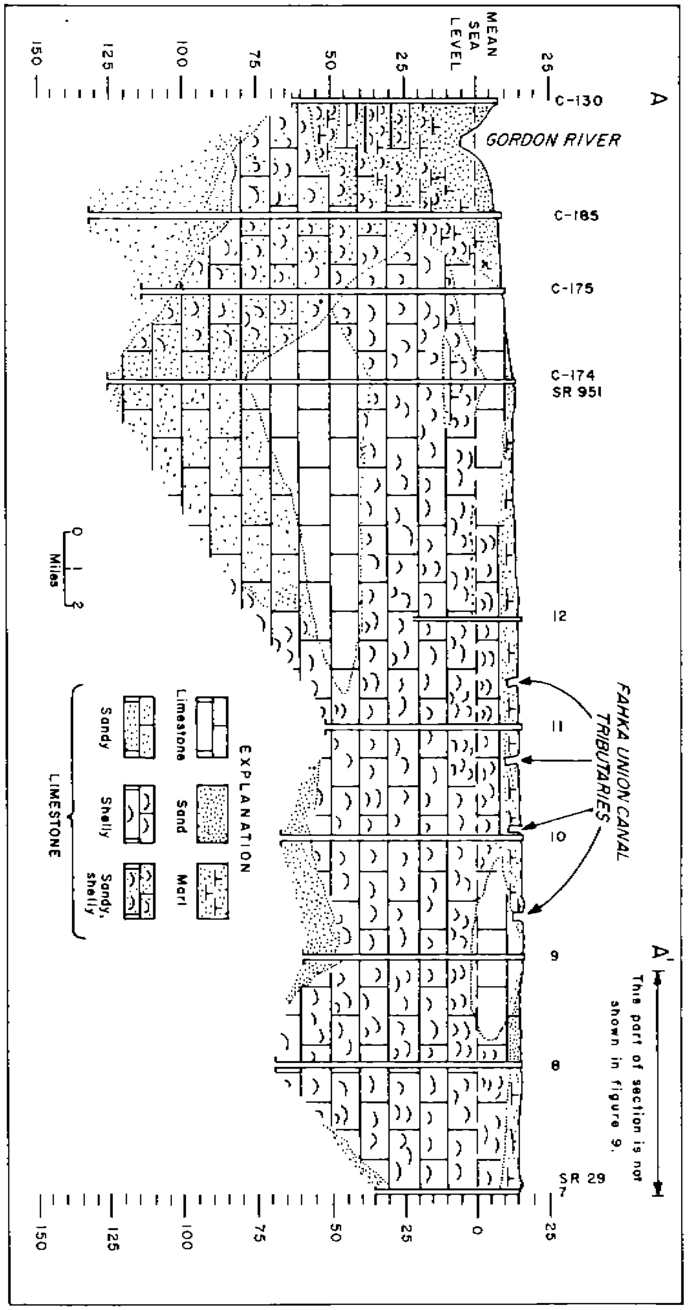

Figure 8.—Generalized geologic section along line A-A' in figure 9.

127b

and have some hydraulic connection. Thickness of the aquifer varies for several miles inland from the coast. The aquifer is usually thickest at the coast, thinning to the northeast, east and southeast.

Figure 8 is a generalized geologic section from Naples to SR 29 along line A-A' in figure 9. The figure shows the undulation of the bottom of the aquifer and the presence of sand and shelly marl in the upper 50 feet near the coast.

The permeability of the aquifer varies considerably. The limestone and shell beds near the coast are permeable, and 8-inch wells drilled in them will yield 500 gpm (gallons per minute) with 7 to 15 feet of drawdown. In the area east and southeast of Naples to about SR 858 and SR 84, the aquifer is less permeable, and the water in it is more mineralized. Also a localized shallow dense limestone (not shown in figure 8) retards rainfall infiltration in much of the area immediately east of the Naples well field, thus inhibiting the flushing of residual sea water (sea water trapped in the sediments during deposition) from the aquifer in this area. Farther inland, where the subsurface materials are more continuous and homogeneous, the aquifer is more permeable than it is in the coastal area, particularly from test hole 11 (fig. 9) eastward to SR 29 and north to about Golden Gate Boulevard.

RECHARGE AND DISCHARGE

Infiltration of rainfall and seepage from controlled canals are the means of recharge to the shallow aquifer. Recharge from rainfall is greatest during the rainy season, June to November. Recharge from canals is greatest during the dry season, December to May, when canal levels immediately upstream from the weirs are higher than adjacent ground-water levels.

Discharge from the aquifer is by evapotranspiration, by groundwater flow to canals and the gulf, and by pumping from wells. Groundwater and surface-water flow and losses by evapotranspiration are greatest during and shortly after periods of rainfall, when water levels in the aquifer are high; discharge by pumping is greatest during dry periods, although it constitutes only a small part of the total discharge from the area.

Changes in aquifer storage are indicated by fluctuations of the water table. When recharge to the aquifer is greater than discharge—which is usually only during a rain—the water table rises; when discharge from the aquifer is greater than recharge—which is most of the time—the water table declines. Fluctuations of the

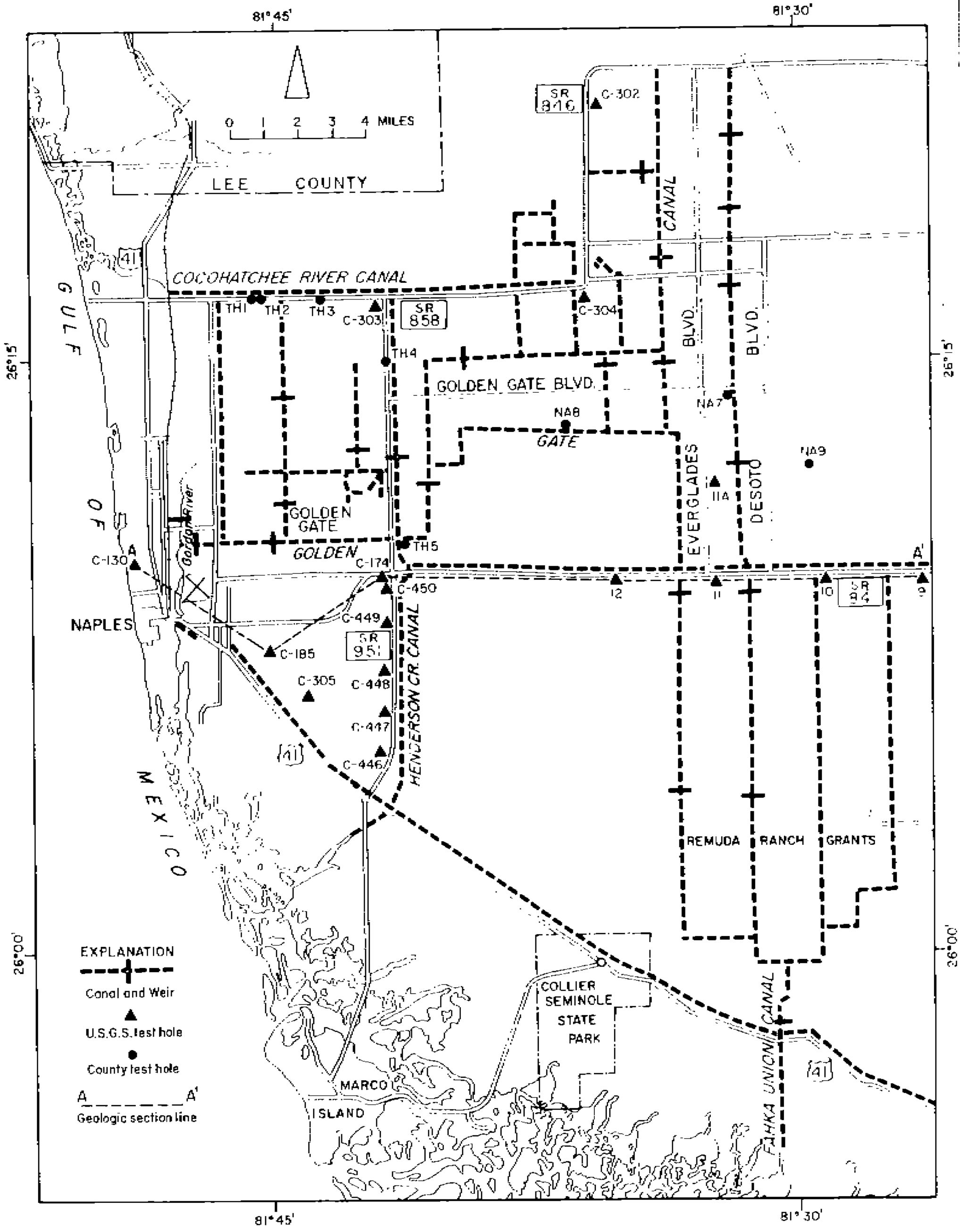

Figure 9.—Location of test holes and line of generalized geologic section.

water table are monitored by automatic recording instruments on five wells shown in figure 10. Hydrographs of these wells for their periods of record are shown in figure 11. Monthly rainfall at Naples is included for comparison.

Ground-water-level data are not available for the area east of Naples before the canals were constructed because the area was flooded or swampy through most of the year, and access was very difficult. Local lowering of levels began with the construction of the Cocohatchee River and Henderson Creek Canals, and regional lowering followed construction of the Golden Gate Canal and finally the Fahka Union Canal. The hydrographs in figure 11 began too late to reflect the lowering of water levels when canal construction started but show the changes that occurred as construction continued. Predrainage levels were above land surface much of the year, which would indicate the canal system lowered ground-water levels 1 to 2 feet before the weirs were installed.

Wells C-384 and C-381 are located, respectively, adjacent to the Cocohatchee River and Henderson Creek Canals near their outlets. The hydrographs of the two wells (fig. 11), plus early periodic measurements in well C-384 show that water levels in the two wells were higher in the rainy season of 1965 than in the two previous years, even though the 1965 rainfall was below average. This suggests that the completion of weir W-4 and W-8 in October 1964 may have caused the Cocohatchee River and Henderson Creek Canals to act as relief outlets for the Golden Gate Canal system during the wet seasons. However, as the Golden Gate Canal system was extended inland, surface water that normally drained to the Cocohatchee River Canal was diverted to the Golden Gate Canal system. This is indicated by the lowering, in 1970, of the peak levels in C-384 and the decrease in discharge of Cocohatchee River Canal. For the same period the area around C-381 was flooded most of the time, and the discharge of Henderson Creek Canal increased.

Wells C-383 and C-382 are within the influence of the Golden Gate Canal system (fig. 10); but C-383 is adjacent to a narrow borrow ditch, and C-382 is in the urbanized section of Golden Gate Estates and about three-quarters of a mile from the Golden Gate Canal. Since 1965, wet-season water levels in well C-383 appear to have risen about a foot; since mid-1967 the dry-season levels have risen about a foot also. These effects are probably the result of a combination of (1) improvements in the canal system, which allow the borrow canal to convey more water during the wet season, (2) the installation of weir 10 immediately downstream from C-383, and

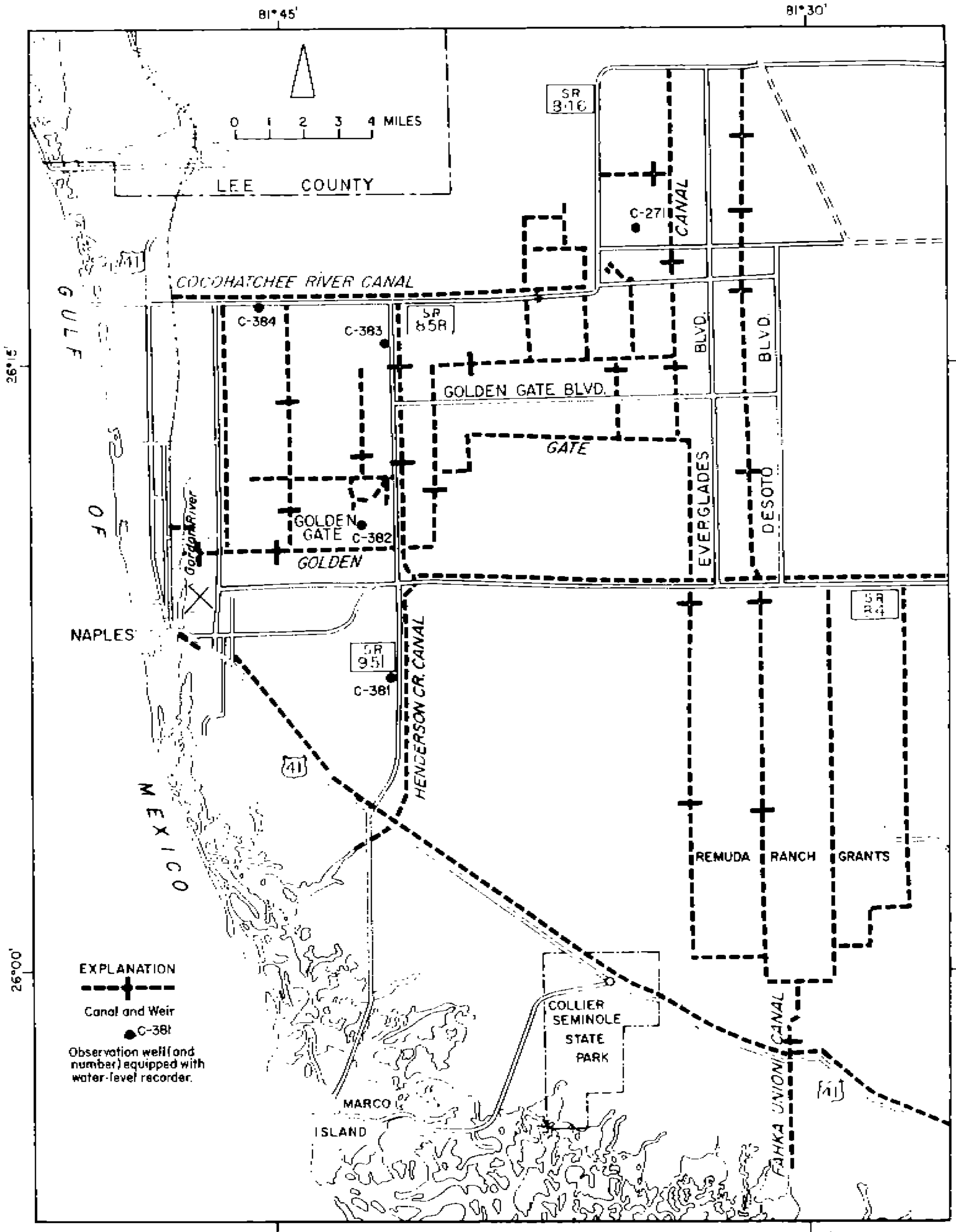

Figure 10.—Location of wells equipped with water-level recorders.

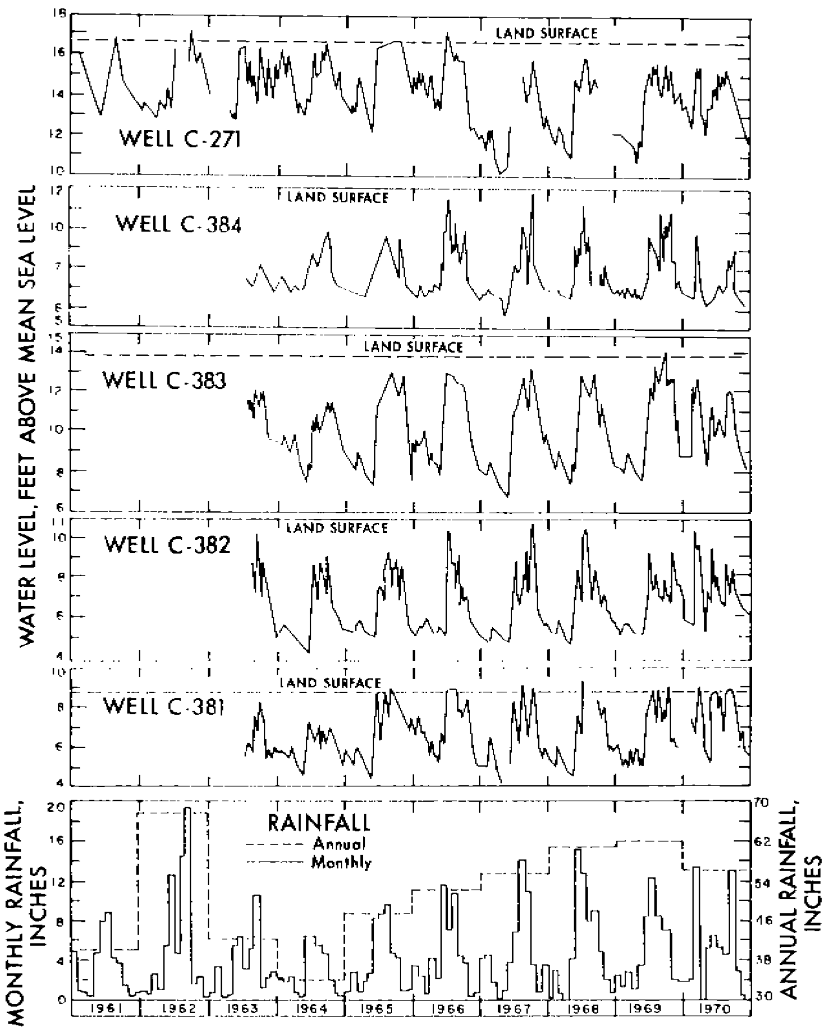

Figure 11.—Hydrographs of selected wells in western Collier County and monthly rainfall at Naples.

(3) the above-average rainfall starting in 1967 after 4 years of below-average rainfall. The hydrograph for well C-382 shows a generally consistent pattern for 1963-68. Except for short-term fluctuations due to abnormally high or low monthly rainfall, the seasonal water levels are generally similar. The slight rise in levels starting in 1969 is probably the result of above-average rainfall.

Well C-271 is near the inlandmost reach of the Golden Gate Canal. The hydrograph for the well shows little year-to-year variation before 1966. Completion of the Golden Gate Canal into the area near the well has doubtless caused the decline in seasonal water levels in 1967-69. Completion of the weir installations and above-average rainfall in early 1970 are probably responsible for the higher dry-season levels in 1969-70. Water levels in well C-271 during the last half of 1969 and all of 1970 indicate most graphically the effects of the canal system on the water levels in the shallow aquifer. If the trend of the last 18 months in the hydrograph for C-271 persists, the canal system will have been effective in lowering wet-season levels as much as 1.5 feet and dry-season levels about 1 foot below pre-construction levels.

In summary, the effects of the canal system on the shallow aquifer can be only approximately evaluated at this time (1971) because the data-gathering period since completion of weir installations is too short for detailed analysis. If trends indicated in 1969 and 1970 persist, the canal system may lower wet-season water levels at least 2 feet and perhaps as much as 4 feet in the far interior areas.

The hydrographs in figure 11 show the water level in the shallow aquifer fluctuates as much as 6 feet from wet season to dry season. Obviously the wet-season peaks must be lowered to prevent flooding and to minimize fill requirements if development is to be economically feasible in many areas. But if gated controls could be installed on canals in areas of low water levels—such as near coastal areas—the wet-season peaks would still be lowered, but the increased water levels during the dry season would increase aquifer storage, thereby providing a larger ground-water supply when demand is greatest.

HYDRAULIC PROPERTIES

Several determinations of hydraulic properties of the shallow aquifer in the Naples well field area have been made since 1952. In the original well field in the southern part of the city, the average transmissivity was 98,000 gpd (gallons per day) per foot, and the average storage coefficient was 0.0006 (Klein, 1954). In the southern part of the existing well field the transmissivity is 185,000 gpd per foot, and the storage coefficient is 0.0004 (Sherwood, 1961). Both storage coefficients are very low and reflect an artesian rather than a water-table condition: discontinuous overlying beds of low permeability cause the shallow aquifer to react to short-term stresses as an artesian aquifer.

The specific capacity of a well is the number of gallons of water produced per foot of drawdown when the well is pumped at a certain rate for a specific time. Using a method developed by Hurr (1966), transmissivities ranging from 500,000 to over 800,000 gallons per day per foot were obtained from specific capacities of test wells along the Alligator Alley and east of Naples. These data indicate that the permeability of the shallow aquifer in this area is several times that in the Naples well-field area.

The downstream pick up in flow in the Golden Gate Canal system during two periods in 1969 (see Surface Flow System section) indicated hydraulic connection between the aquifer and the canal. To confirm this connection, five wells (see fig. 9) on the west side of SR 951 (Henderson Creek Road) and about 100 feet from Henderson Creek Canal were pumped November 1, 1970. The specific conductance of the water pumped was determined at the beginning and end of each pumping test. The specific conductance of water from Henderson Creek Canal—sampled opposite the well being pumped—was determined only at the end of each pumping test. The results of those tests are listed below:

				CONDUCTANCE (micromhos at 77°F)		
				TIME		HENDERSON
WELL NO.	DEPTH (feet)	DRAWDOWN (feet)	DISCHARGE (gpm)	BEGIN	END	CREEK CANAL
C-450	31.7	0.22	250+	1000	900	785
C-449	31.5	0.49	200	1600	1350	845
C-448	23.5	5.81	200	850	820	815
C-447	22.3	4.57	200	1220	1170	1100
C-446	24.7	3.80	200	790	840	1000

The table indicates hydraulic connection between the aquifer and the Henderson Creek Canal in that where the canal water is fresher than the ground water, the water from the well freshens with pumping; where the canal water is less fresh, the water from the well increases in salinity with pumping.

FLORIDAN AQUIFER

In recent years waste water has been injected into the lower part of the Floridan aquifer at several locations in southeast Florida. At two locations, treated sewage is being injected and at a third, industrial water. The industrial well and one sewage disposal well are finished in the "boulder zone" of the aquifer, 2,000 to 3,000 feet below msl; the other sewage well is slightly more than 1,000 feet deep.

The suggestion has been made that the Floridan aquifer be used also as a storage reservoir for surplus fresh water. During the wet season, fresh water would be pumped into the aquifer though deep wells, and during the dry season the fresh water would be recovered for use.

The Floridan aquifer doubtless will become more important when water demands are such that conversion of slightly saline water to fresh water may become feasible.

WATER QUALITY

Along the coast in western Collier County, the quantity and quality of water are of equal concern because without sufficient quantity to maintain high fresh-water levels near the coast, salty water from the gulf would contaminate ground water of good quality. Eastward expansion of the city of Naples well field is not practical because immediately east of the city mineralized ground water occurs at relatively shallow depth in the shallow aquifer. However, the shallow aquifer 15 miles east of Naples seems to contain large quantities of ground water that is equal in quality to that of the coastal area.

The quality of ground water is determined largely by the quality of the rainfall, the materials through which the ground water moves, and the length of time involved in the movement of the ground water through the rocks and soil and down the streams. Domestic and industrial wastes as well as sea water are sources of mineral or biological contamination of streams and ground water.

NATURAL CONSTITUENTS

SURFACE WATER: Changes in water quality in the surface flow system are greater and more frequent than they are in the aquifer. This is due mainly to the system collecting unfiltered overland flow and lack of filtering in the open channels. When no overland flow

TABLE 2.—CHEMICAL ANALYSES OF WATER FROM SELECTED CANALS IN WESTERN COLLIER COUNTY.
(results in milligrams per liter except where noted)

Station or Site number	Date of Collection	Specific conductance in micromhos at 25°C ($Kx10^6$)	pH	Temperature (°C)	Color (cobalt-platinum units)	Turbidity (Jacksonville 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 Ortho	Phosphorus as PO_4 Total	Alkalinity as $CaCO_3$
Gordon River @ City Control Structure	10-26-70	906	7.4	27	25	10	8.4	0.05	0.02	110	13	1.0	63	2.4	260	56	130	0.2	0.02	0.05	213
	2- 4-71	1,700	7.7	19	20	6	1.4	.02	.01	110	31	1.3	190	8.8	264	87	380	.3	.03	.07	217
	3-30-71	32,900	7.6	21	30	7	2.6	.13	.04	330	590	---	6,500	230.0	204	1,700	12,000	1.0	.43	.46	167
	6-22-71	34,000	7.6	27	50	25	5.3	.16	.11	370	790	—	6,700	250.0	230	1,700	12,000	.9	.91	1.0	189
Golden Gate Canal @ SR 858 Bridge	10-26-70	708	7.3	27	50	55	7.3	.40	.02	120	5.0	.50	25	.8	316	62	41	.2	.00	.03	259
	2- 4-71	810	7.9	21	60	30	7.2	.04	.01	130	7.4	.66	36	1.2	348	70	64	.3	.02	.24	285
	3-30-71	850	7.7	22	40	20	8.9	.06	.01	120	9.0	--	47	1.4	292	67	94	.2	.02	.05	239
	6-22-71	790	7.9	27	35	30	9.6	.09	.00	120	11	--	60	1.5	308	68	120	.2	.05	.10	253
Gordon River @ U.S. 41 Bridge	10-26-70	33,400	7.6	30	35	15	4.6	.16	.02	340	760	4.2	6,600	260	216	2,000	12,000	1.0	.12	.14	177
	2- 4-71	40,000	7.6	19	20	5	4.2	.11	.04	340	500	10	8,100	310	196	2,100	14,000	1.5	.56	.57	161
	3-30-71	47,000	7.7	23	20	10	3.0	.15	.03	380	580	—	11,000	380	164	2,400	18,000	1.4	.69	.76	135
	6-22-71	34,000	7.8	30	30	5	4.5	.09	.02	320	810	—	6,700	250	192	2,000	12,000	.9	.54	.60	157
Golden Gate Canal Tributary	10-26-70	688	7.5	29	80	55	8.3	.29	.01	120	4.4	.54	20	.8	322	66	28	.3	.01	.01	264
	2- 4-71	680	7.7	20	70	30	5.3	.12	.01	130	5.2	5.6	10	1.0	348	62	24	.3	.02	.16	285
	3-30-71	640	7.6	20	60	40	7.6	.16	.01	110	4.6	—	18	.3	312	43	24	.2	.02	.05	256
	6-22-71	650	7.7	28	70	40	8.4	.16	.01	110	3.6	—	18	.6	300	43	26	.2	.04	.09	246
Cocohatchee River Canal nr Naples, Fla.	5-19-70	500	8.0	22	40	25	7.6	—	—	98	2.6	—	12	.8	268	26	18	.4	.05	.05	220
Henderson Creek Canal nr Naples	5-19-70	1,200	8.2	29	40	15	13	—	—	110	23	—	120	4.5	324	84	210	.3	.03	.05	266
Fahka Union Canal nr Everglades City	2-17-70	780	7.8	23	25	—	5.1	—	—	120	5.8	.30	37	7	354	16	68	.2	—	—	290

TABLE 2. (CONTINUED)

Station or Site number	Hardness as $CaCO_3$ Calcium-Magnesium	Hardness as $CaCO_3$ Non-carbonate	Dissolved solids Residue at 180 °C	Dissolved solids Calculated	Aluminum (Al)	Zinc (Zn)	Lead (Pb)	Copper (Cu)	Chromium (Cr^{6})	Arsenic (As)	Bromide (Br)	Iodide (I)	Boron (B)	MBAS (Detergents)	Nitrogen (N) Ammonium as NH_4	Nitrogen (N) Nitrate as NO_3	Nitrogen (N) Nitrate as NO_2	Nitrogen (N) Total organic nitrogen	Oil and grease
Gordon River @ City Control Structure	330	120	578	510	0.05	0.04	0.002	0.01	0.000	0.01	0.8	0.2	0.1	0.00	0.00	0.1	0.09	0.70	—
	400	190	955	940	.07	.08	.010	.01	.000	.01	—	—	.	.07	.03	.0	.01	.36	.0
	3,300	3,100	—	21,500	.11	.07	.004	.05	.000	.02	—	—	--	.36	.30	.0	.01	.35	.1
	4,200	4,000	—	21,900	—	.09	.000	.03	.000	.04	—	--	—	.26	.39	.1	.03	—	5.0
Golden Gate Canal @ SR 858 Bridge	320	62	473	420	.02	.03	.004	.01	.000	.00	.9	.2	.14	.00	.01	.1	.09	.50	
	360	71	502	490	.03	.05	.010	.00	.010	.01	—	—	—	.04	.03	.0	.02	.31	.0
	340	97	568	490	.08	.06	.030	.00	.000	.02	—	--	—	.09	10.	.0	.01	.55	5.0
	340	92	568	540	—	.07	.001	.01	.000	.02	—	-	--	.04	.08	.4	.03		6.0
Gordon River @ U.S. 41 Bridge	4,000	3,800	—	22,100	.05	.04	.001	.02	.000	.01	40	.2	2.6	.40	.00	.0	.08	.62	—
	2,900	2,800	—	25,000	.07	.09	.010	.08	.040	.00	—	.	—	.40	.49	.1	.04	-.94	.0
	3,300	3,200	—	32,800	.16	.07	.003	.05	.000	.01	--	—	—	.29	1.1	.0	.03	.70	1.0
	4,100	4,000	—	22,200	—	.07	.000	.04	.000	.01	--	—	—	.31	.26	.2	.03	—	5.0
Golden Gate Canal Tributary	320	54	468	410	.03	.04	.002	.00	.000	.01	1.6	.2	.14	.10	.00	.0	.08	.62	.0
	350	62	424	420	.03	.03	.010	.00	.050	.01	—	—		.03	.03	.0	.01	.37	.0
	290	38	436	360	.09	.11	.003	.00	.000	.01	.	—	.	.09	9.7	.2	.02	2.7	18.0
	290	44	345	360	—	.01	.000	.00	.000	.01	—	--	—	.04	.03	.0	.02		4.0
Cocohatchee River Canal nr Naples, Fla.	260	36	333	300		—	—	—	—	-	--				.06	.0	.01	.30	—
Henderson Creek Canal nr Naples	380	110	869	730		--	—	—	—	--	--	.	.		.08	.0	.07	.24	—
Fahka Union Canal nr Everglades City	330	44	466	430		—	—	—	—	—	—	—	—	—	--	.0	.01	—	—

TABLE 3.—CHEMICAL ANALYSES OF WATER FROM SELECTED WELLS IN WESTERN COLLIER COUNTY.

(results in milligrams per liter except where noted)

Station or Site number	Date of Collection	Specific conductance in micromhos at 25°C (K$\times 10^6$)	pH	Color (cobalt-platinum units)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Alkalinity as $CaCO_3$	Nitrate (NO_3)	Hardness as $CaCO_3$		Dissolved solids	
																	Calcium-Magnesium	Non-carbonate	Residue at 180 °C	Calculated
Naples well field	9-10-70		7.25	32		0.24	74					13	30	0.0			170	26	285	
[1]BCE TH 1	6-23-69		8.00	27		0.10	135	29				120	234	.24			337	117	912	
TH 2	6-24-69		7.32	23		0.05	135	29				105	220	.18			342	114	900	
TH 3	6-23-69		7.28	27		0.30	119	26				100	156	.3			340	66	756	
TH 4	6-25-69		7.13	28		0.25	119	22				50	122	.27			352	36	636	
TH 5	6-24-69		7.93	27		0.20	144	18				39	162	.15			348	88	711	
TH 6	6-25-69		7.35	25		0.10	160	26				66	274	.1			360	148	930	
NA 7	6-18-70		7.85	31		0.04	95	9.5				3	30	.0			276	0	420	
NA 8	6-30-70		7.70	15		0.04	82	15				16	36	.0			267	0	450	
NA 9	7-14-70		7.75	33		0.04	96	13				10	36	.0			295	0	420	
[2]USGS 7	6- 4-70	480	7.75	12		0.08	69	4.9			266	1	12	.75	218		245	3	277	
8	6- 4-70	610	7.35	32		0.16	101	3.6			354	2	21	.95	290		302	13	373	
9	6- 3-70	338	8.10	40		0.08	54	1.7			173	2	20	.35	142		139	9	202	
10	6- 3-70		8.05	60		0.08	30	1.2				6	11	.15			77	4	137	
11	6- 4-70	520	7.55	12		0.12	74	2.4			262	3	25	.95	215		236	14	310	
11A	6- 3-70	700	7.75	20		0.04	85	14			342	27	23	1.0	281		298	31	436	
C-302	7-24-59	625	7.6	2	25	0.01	72	16	39	4.6	336	11	32	.0		0.6	250	0	370	
C-303	7-28-59	911	7.1	15	25	0.10	170	6.3	26	.2	520	4.4	46	.0		.3	450	24	599	
C-304	8-10-59	609	8.1	15	10	0.01	70	15	40	4.6	308	14	41	.4		.2	240	0	365	
C-305	8-12-59	1,040	7.6		13	0.00	100	17	38	1.9	290	16	130	.2	290	.3	320	87	638	
C-450	11- 1-70	840	7.9	30	10	—	130	12	42	2.1	364	75	60	.3	299	.0	370	69	517	500
C-448	11- 1-70	770	8.0	0	8.5	—	110	9.8	43	1.6	378	5.2	72	.3	310	.0	320	11	449	440
C-446	11- 1-70	650	8.0	0	7.2	—	92	9.5	33	1.6	312	28	42	.2	256	.0	270	14	387	370

[1] Black, Crow and Eidsness Inc. test holes and analyses. [2] Analyses by Black, Crow and Eidsness, Inc.

occurs during the dry season, the canal flow is maintained chiefly by inflow from the aquifer. Evapotranspiration of surface water during the dry season causes chemical constituents to concentrate. Results of analyses of water collected from selected sites in canals (fig. 5) in western Collier County are shown in table 2. The chemical quality of the water is generally good except in the tidal reach of the Gordon River. The increase in concentration of certain chemical constitutents upstream from the control in the Gordon River resulted from sea water topping the control during high tides.

Surface water is seldom used in south Florida as a source of municipal supply because fresh ground water is usually available in large amounts and does not require expensive treatment that a surface-water supply needs to make it potable. Marco Island obtains water from a rock pit near the intersection of U.S. Highway 41 and State Road 95 because the rock pit is the nearest source of a dependable fresh-water supply.

Of the surface-water flow system of western Collier County, only in the Golden Gate and the Fahka Union Canals is the flow large enough to be considered a permanent source of water. However, during the dry season, when water demands are greatest, the minimum flow in Golden Gate Canal may be inadequate to meet future demands.

GROUND WATER: Figure 9 shows the location of wells from which water samples were collected for chemical analyses. Table 3 is a compilation of those analyses. Several of the analyses were made by Black, Crow, and Eidsness as part of a cooperative effort with the county and the Geological Survey. Also included in the table is a representative analysis of ground water from the Naples well field. A comparison of the data in tables 2 and 3 reveals that in some areas ground water is superior in quality to canal water. Also, both the coastal and inland ground water is superior in quality to the ground water immediately east of Naples. The area east of SR 951 is a potential source of ground water of good quality.

CONTAMINANTS

Contamination of water in western Collier County can be natural, man-made, or both. Salt-water intrusion into the aquifer and canals is the most common type of natural contamination in coastal regions; introduction of sewage and industrial wastes into canals or the aquifer constitutes man-made contamination. Because of its proximity, the gulf, is an ever-present source of natural contamination; the free interchange of water between the surface flow system and the aquifer increases the threat of man-made contamination.

NATURAL: Salt-water intrusion occurs when fresh-water levels in the aquifer are not of sufficient height above msl to prevent the inland movement of the heavier salt water; lowering water levels, either by pumpage or drainage, upsets the natural balance between fresh water and sea water.

The capacity of the well field (1971) in Naples is limited by the threat of salt-water intrusion. Consultants for the city have calculated that withdrawals exceeding 20 mgd along the coastal ridge would lower the water level in the aquifer between the well field and the gulf to the point where salt-water intrusion would be imminent.

The area 15 miles east of Naples, where the aquifer contains water of good quality, would not be threatened by salt-water intrusion because of the distance inland from the gulf.

Another source of natural contamination is residual mineralized water in the shallow aquifer immediately east of the Naples well field. During the drought of 1970-71, the quality of water in the Naples well field deteriorated because this mineralized water migrated into the area of influence of the municipal water-supply wells.

The area 15 miles inland would probably not be affected by water from this area of inferior water quality, but further exploratory drilling is needed to determine the eastward extent of the area of mineralized water.

MAN-MADE: Man-related contaminants that affect water resources have been categorized by the FWQA (1969) into eight general types: sewage and other oxygen-demanding wastes; disease-causing agents; plant nutrients; synthetic organic chemicals; inorganic chemicals and other mineral substances; sediment; radioactive substances; and heat.

Preliminary data collected from a current supplementary U.S. G.S. study in Collier County indicate man-made contaminants in the water resources of western Collier County are well within the safe limits established by federal water regulatory agencies.

WATER USE

Naples and the unincorporated areas of Golden Gate Estates and Marco Island maintain the only public water supplies in western Collier County. In 1970 the Naples well field pumped, on the average, 4.4 mgd and Marco Island, slightly less than 1 mgd. It is estimated the Golden Gate Estates well field pumped less than 0.5 mgd during 1970.

Acreage for agriculture in the investigation area varies yearly but probably averages approximately 5,000 acres. Average irrigation requirements for all crops are 1.5 to 2 feet per acre, or 6.5 to 10 mgd for the 5,000 acres. In western Collier County most of the crops are irrigated with ground water pumped into conveyance canals and ditches. Probably at least half the ground water pumped is consumed.

Most industrial water is obtained from municipal wells that tap the shallow aquifer. Also, private domestic supplies and lawn sprinkling systems plus self-supplied industries probably account for at least 1 mgd from the shallow aquifer. The combined demand approximated 15 mgd in 1970. Canal discharge from the surface-flow system in 1970 averaged about 350 mgd.

Consulting engineers for the city of Naples forecast that the maximum daily rate of pumpage at the municipal water treatment plant will exceed 20 mg by 1979. The 1970 maximum daily rate was about 8 mg. The 1979 estimate probably exceeds the amount that can safely be withdrawn from the aquifer by present well-field facilities. Therefore, additional supplies from another source will be needed at that time.

Analyses of data from both drilling of test wells and sampling of surface water and ground water indicate that ground water in quantities adequate to serve the future needs of western Collier County can be developed from an area centered about 15 miles east of the Naples city limits along Alligator Alley. Future drilling and chemical analyses will delineate the limits of the source more closely, but available data indicate water of good quality is available for development in the aquifer underlying about a 100-square-mile area.

SUMMARY AND CONCLUSIONS

Western Collier County has large fresh-water-supply potential because of its 54 inches of rainfall annually and its manmade surface flow system, hydraulically connected to a shallow permeable aquifer. However, water problems exist because the rainfall is not evenly distributed throughout the year, causing salt-water intrusion to threaten the Naples well field during prolonged dry seasons. Contamination of existing and future ground water supplies is possible by man-related activities and urbanization.

The controlled surface-water flow system and the distribution of weirs allow for water control without an excessive lowering of ground-water levels. The system also has the potential for recharging the coastal section of the shallow aquifer during the dry seasons. Variable water quality and inadequate flows during the dry season precludes the use of the surface-water flow system as a direct source of municipal water.

Water of good quality is contained in the shallow aquifer along the west coast and for about 2 miles inland. The quality then decreases for about 10 miles inland. East of this area of ground water of poor quality, thick sections of permeable limestone extend from near land surface to a depth of almost 100 feet near SR 951 and from land surface to more than 70 feet near Alligator Alley and SR 29. Quality of the ground water in this area is equal or better than that in the coastal area; the quantity is much greater—perhaps several times that of Naples coastal area.

More data collected in western Collier County are necessary to more accurately determine the effects of the surface-water flow system on the shallow aquifer in order for water managers to plan for future water-resources development. In addition, a water-quality monitoring network would be necessary to detect water-quality changes in the surface-ground-water flow system as a result of contaminants by man-related activities.

WELL LOGS

WELL C-130

Material	Depth, feet below land surface
Sand, quartz, white in upper part, brown-rust in lower part	0 - 21
Marl, shelly, tan-gray, clayey, sandy; few rock fragments	21 - 26
Limestone, soft, marly, very shelly	26 - 36
Marl, sandy, shelly, brown phosphate material	36 - 44
Limestone, gray to cream, very shelly, marl	44 - 51
Marl, tan-cream, sandy, shelly	51 - 58
Marl, white to light gray, very shelly and sandy, some limestone fragments	58 - 63
Limestone, white to gray, shelly, cavernous, sandy	63 - 71

WELL C-174

Material	Depth, feet below land surface
Sand, quartz, medium, gray	0 - 2
Limestone, tan, hard	2 - 10
Limestone, tan, shelly, softer than above	10 - 20
Limestone, white	20 - 25
Limestone, mostly shell, loosely cemented; thin beds of marl	25 - 41
Limestone, white to gray, very shelly	41 - 50
Limestone, white to gray, permeable	50 - 78
Limestone, white, sandy	78 - 88
Sandstone, calcareous, sand increasing at bottom	88 - 140

WELL C-185

Material	Depth, feet below land surface
Sand, quartz	0 - 9
Marl, dark, hard	9 - 13
Sand, quartz, fine to medium, marly, very shelly	13 - 25
Limestone, white to dark gray, shelly, sandy, permeable	25 - 92
Sand, quartz, very fine, gray to tan	92 - 115
Sand, quartz, very fine to medium, tan to green, phosphatic	115 - 141

WELL 7

Material	Depth, feet below land surface
Fill and marl	0 - 5
Limestone, some shell	5 - 45
Sand, quartz, clean	45 - 50

WELL 8

Material	Depth, feet below land surface
Fill	0 - 4
Limestone, dark gray, permeable, shelly	4 - 85

WELL 9

Material	Depth, feet below land surface
Limestone, low permeability, very hard	0 - 17
Limestone, alternating hard, low permeability layers with soft permeable layers, shelly	17 - 60
Sand, brown, "dirty"	60 - 75

WELL 10

Material	Depth, feet below land surface
Fill, brown	0 - 5
Limestone, large shells, permeable	5 - 32
Limestone, tan, very permeable, sulfur odor	32 - 62
Limestone, shelly	62 - 70
Sand	70 - 82

WELL 11

Material	Depth, feet below land surface
Fill	0 - 5
Limestone, varying hardness, permeable, shelly	5 - 67

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