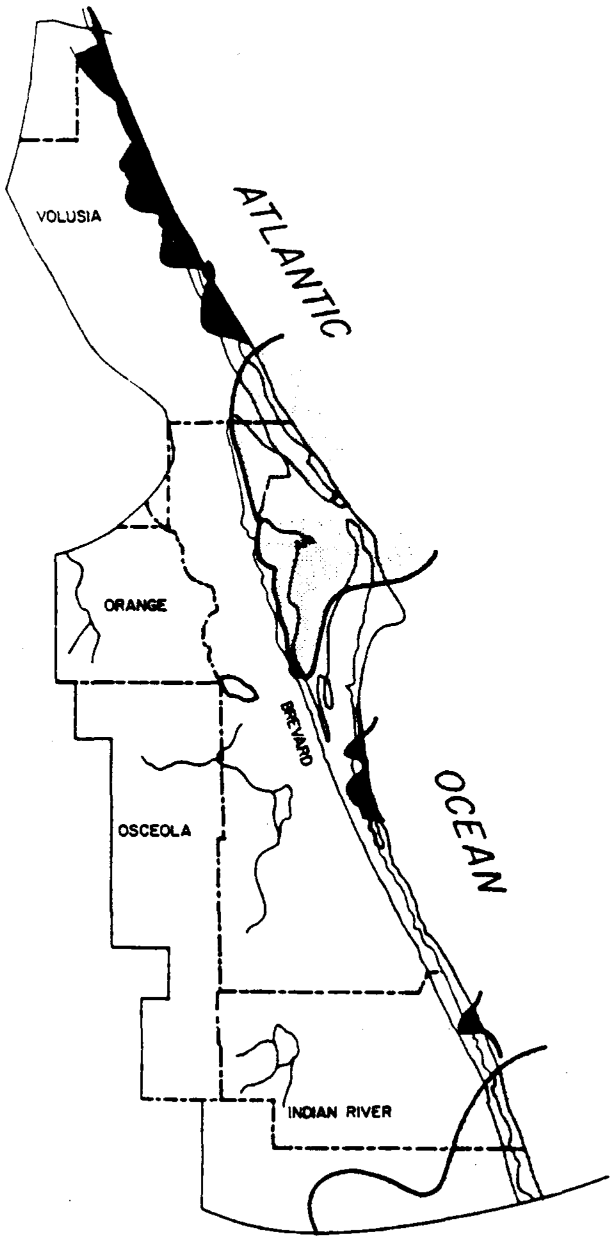
TECHNICAL PUBLICATION No. SJ 88-1
JANUARY 1988

SALT WATER INTRUSION IN COASTAL AREAS OF VOLUSIA, BREVARD, AND INDIAN RIVER COUNTIES



ST. JOHNS RIVER WATER MANAGEMENT DISTRICT
P.O. BOX 1429 PALATKA, FLORIDA 32078-1429

For explanation of cover see page 130.

TECHNICAL PUBLICATION SJ 88-1

SALT WATER INTRUSION IN COSTAL AREAS OF VOLUSIA, BREVARD, AND INDIAN RIVER COUNTIES

By

David J. Toth, Ph.D

St. Johns River Water Management District
Palatka, FL

January, 1988

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF TABLES

INTRODUCTION

The intrusion of salt water into coastal ground water aquifers is of significant concern to the St. Johns River Water Management District (District). The District is charged with managing ground water resources in a nineteen county area of northeast Florida. In 1976 the District initiated the Salt Water Intrusion Studies (SWIS) Program to examine salt water intrusion in coastal areas of the District.

The goal of the Salt Water Intrusion Studies (SWIS) program is to compile the hydrogeologic and water quality data necessary to make sound decisions about the management of the District's coastal ground water system. Of particular importance is the quantity and quality of water in coastal areas that is suitable for domestic, agricultural, public-supply, and industrial use. The SWIS program (Figure 1) provides a regional view of the coastal area, emphasizing water level and water quality characteristics of the Floridan, intermediate, and surficial aquifer systems underlying the study area.

The first phase of the program, SWIS I, was a cooperative project with the Coastal Plains Regional Commission and the Florida Department of Environmental Regulation and examined salt-water intrusion in eastern Nassau, Duval, St. Johns, and Flagler counties (Frazee, J.M., Jr., and McClaugherty, D.R., 1979). Phase II, SWIS II, was undertaken solely by the District. It consists of the reconnaissance studies of the coastal portions of the District not addressed in SWIS I - eastern Volusia, Brevard, and Indian River counties.

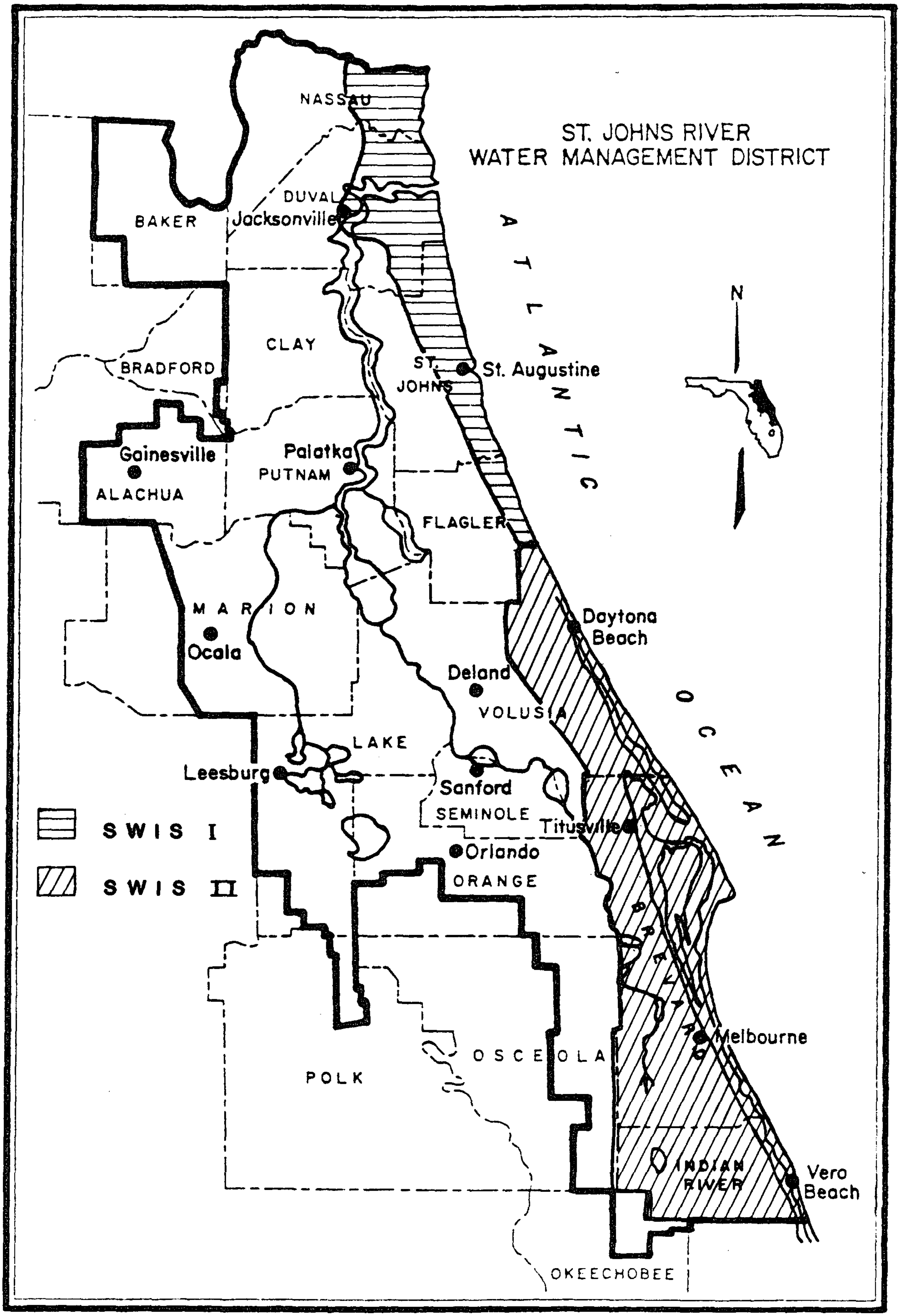


Figure 1. Coastal areas included in the SWIS program.

Ground water aquifers are the principal sources of drinking water in the District. The extent and quality of the aquifers vary significantly throughout the region. The Floridan aquifer is the most dependable water source. However, in many coastal areas chloride concentrations in the Floridan aquifer are already above the EPA recommended limit of 250 mg/l. Due to local geologic conditions, the intermediate and surficial aquifers contain limited freshwater supplies and are quite susceptible to salt-water intrusion.

PREVIOUS INVESTIGATIONS

Table 1 lists relevant publications which address the geology, hydrology, and ground water resources of the study area. The publications are listed by county, areal studies, and by general subject headings and are an alternate source of information for the reader. Additional reports are listed in the references and in the bibliographies of some of the publications mentioned.

Table 1.

Published Reports Covering the Project Area

Study Area	General Subject
Volusia County	
Knochenmus and Hughes (1971)	GW-SW appraisal
Rutledge, 1985	Brackish Water
Wyrick (1960)	GW appraisal
Brevard County	
Brown et al. (1962)	GW-SW evaluation
Indian River County	
Bermes (1958)	GW-Geology
Crain et al. (1975)	GW-SW evaluation
Area-wide Studies	
Bell et al. (1980)	Shallow aquifers
Black et al. (1953)	Salt Water Intrusion
Frazee and McClaugherty (1979)	SWIS I
Hughes (1979)	Salt water barrier lines
Klein (1971), (1975)	Base of potable water in Floridan aquifer
Knochenmus (1974)	Floridan aquifer recharge
Laughlin (1976)	Potentiometric surface
Pride (1979)	Water use
Puri (1960)	Central Florida geology

OBJECTIVES

The five principal objectives of the SWIS II Study are:

1. Describe the occurrence and movement of ground water in the Floridan, intermediate, and surficial aquifers.
2. Identify areas of salt water intrusion.
3. Examine the relationship between ground-water withdrawals and the occurrence of saltwater intrusion.
4. Determine the historical impact of ground water withdrawals on water levels and quality.
5. Synthesize all available data and assess the effect of growth on available potable water.

METHODOLOGY

Since the objectives are comprehensive and the study area large, the investigation relied primarily on previously published data and unpublished information from several governmental agencies, i.e. the Brevard County Water Resources Department, South Florida and Southwest Florida water management districts, and the U.S. Geological Survey. District personnel collected only limited new field data to supplement available information. The period of data collection extended through 1983. The following methods were selected to satisfy project objectives.

1. Collect historical ground water data describing water quality, water levels, and aquifer characteristics, and identify any changes in these variables through evaluation of available records.

2. Inventory additional wells to provide adequate coverage of the geology and water quality of the Floridan, intermediate and surficial aquifer systems.
3. Create an up-to-date data base of geologic information and use it to define the major stratigraphic and structural features of the area.
4. Use geochemical pattern analysis to define the occurrence of different water types and identify intrusion.
5. Inventory water use by aquifer, type, and county.

DESCRIPTION OF STUDY AREA

The study area is in east-central Florida and includes eastern Volusia, Brevard, and Indian River counties (Figure 2). It includes the urban areas of Ormond Beach, Holly Hill, Daytona Beach, Port Orange, and New Smyrna Beach in Volusia County, Titusville, Cocoa, and Melbourne in Brevard County, and Vero Beach in Indian River County.

Geomorphology

Major geomorphologic features of the study area are the numerous sand ridges which parallel the coast and the barrier islands offshore. The ridges are remnant offshore bars that formed during periods when sea level stood at a higher elevation than at present. Major ridges include the Atlantic Coastal and Ten-Mile ridges (Figure 2). The Atlantic Coastal Ridge ranges in

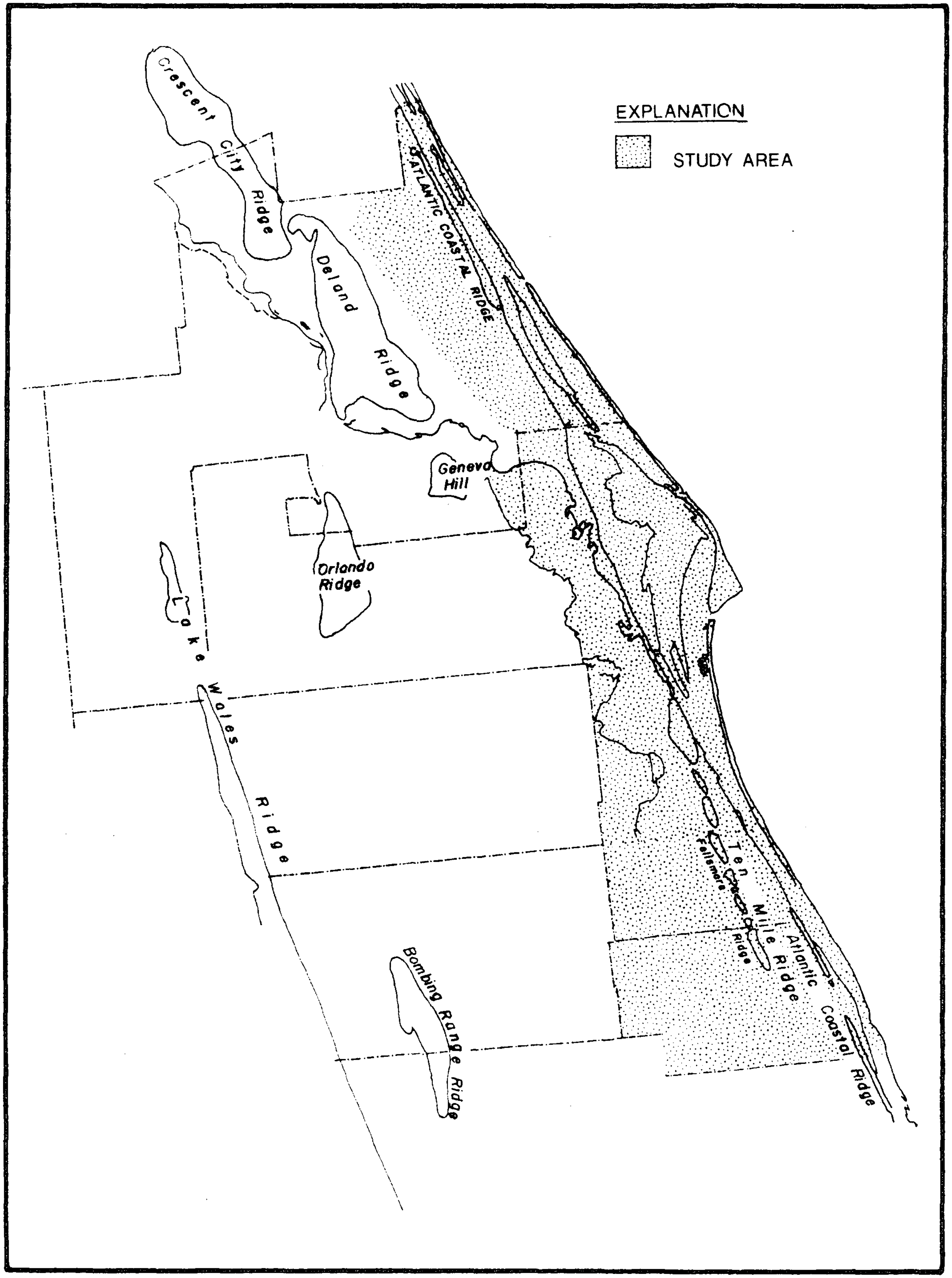


Figure 2. Major geomorphologic features of the study area.

east-west width from 1 1/2 to 3 miles and parallels the shoreline. It ranges in altitude from zero to 55 feet above sea level and is the highest feature east of the St. Johns River in Brevard County. Approximately seven miles west of the Atlantic Coastal Ridge in Indian River County is a less pronounced ridge named the Ten-Mile Ridge. It forms the drainage divide between the St. Johns River marsh and the Sebastian River.

Terraces are features of low relief that mark the ocean bottom at times when the sea stood higher than at present. Three terraces are present in the study area and are, in order of increasing age, the Silver Bluff, Pamlico, and Talbot. The Silver Bluff Terrace lies along the coastal margins and has an elevation of 10 feet above mean sea level (msl)*. The Pamlico Terrace covers the area from the coast inland for about 24 miles and is less than 25 feet above msl. In Indian River County the Pamlico Terrace is broken by three distinct ridges: an offshore bar, the Atlantic Coastal Ridge, and Ten-Mile Ridge. West of Ten-Mile Ridge it is represented by the broad, flat area of the St. Johns River marsh which forms the headwaters to the St. Johns River. At the western edge of the marsh in southwest Brevard and western Indian River counties, the land gradually rises to an altitude of 40 feet and flattens to a surface

---

* In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929) - a geodectic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level of 1929".

representing the Talbot Terrace. In Volusia County, the Talbot Terrace is represented by the central wetlands area which is bounded on both sides by the Deland and Atlantic Coastal ridges (Bush, 1978). It is the best preserved and most easily recognized terrace in Volusia County.

Climatic Conditions

The climate of the study area is humid subtropical with high annual rainfall, moderate annual temperatures with low diurnal and seasonal extremes, and high humidity.

The mean annual rainfall for the area averaged 54.38 inches for the period of 1878-1984 (Jenab, 1987). Rainfall is greatest during the months of May through October, occurring as short duration showers and thunderstorms. Hurricanes and other tropical disturbances contribute substantial quantities of rainfall which may amount to 20 inches in an event. During the winter months, rainfall is normally associated with frontal activity.

Variations in rainfall at four sites in the study area are shown in Figure 3. The most recent period of record low rainfall was during 1980-1981. During this period, annual rainfall deficiencies in some areas were as high as 25 inches (Figure 4). During 1980-1981, record low water levels in both ground water and surface water monitoring networks were observed.

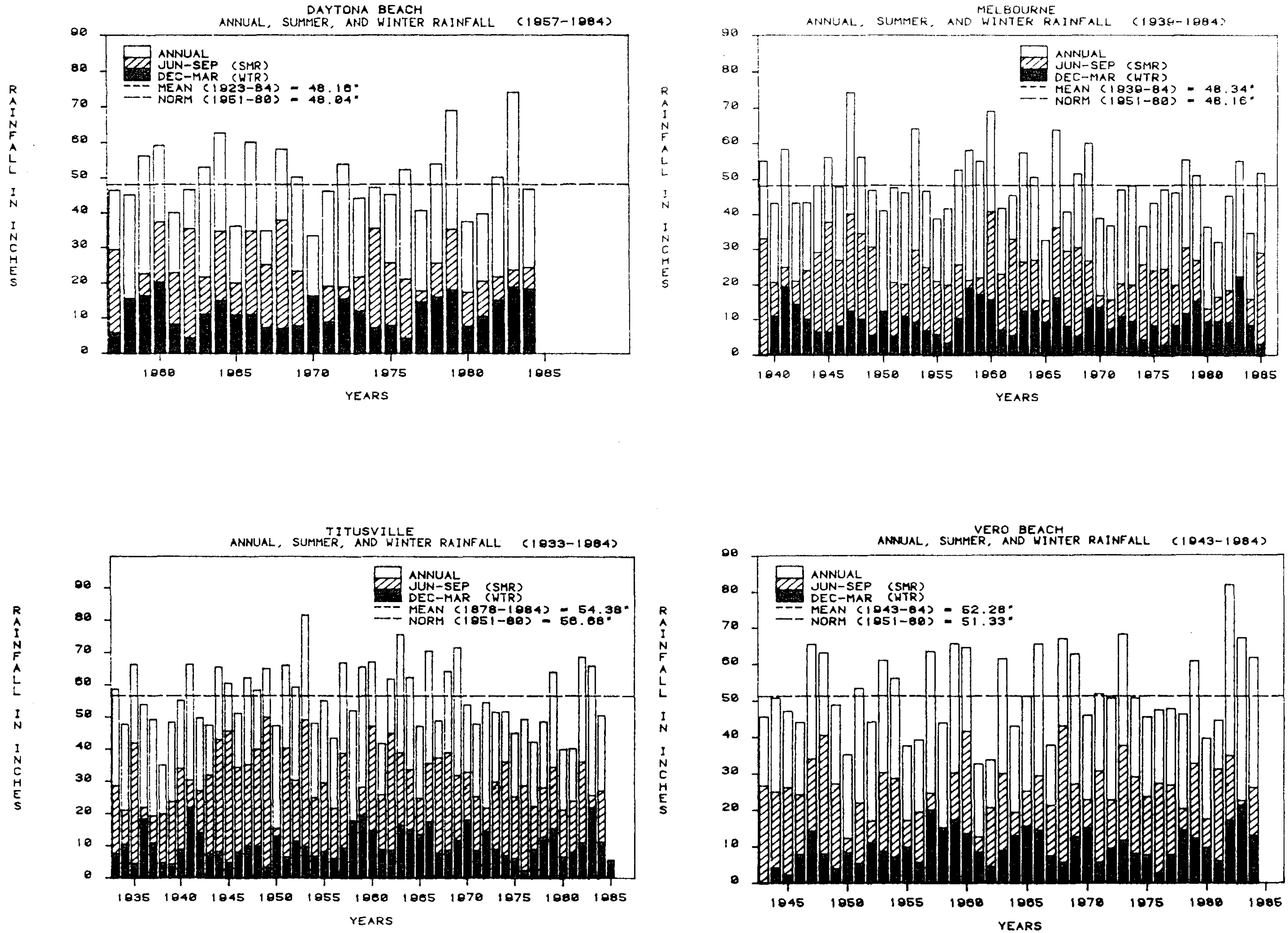


Figure 3. Variations in rainfall at Daytona Beach, Titusville, Melbourne, and Vero Beach (Jenab, 1988).

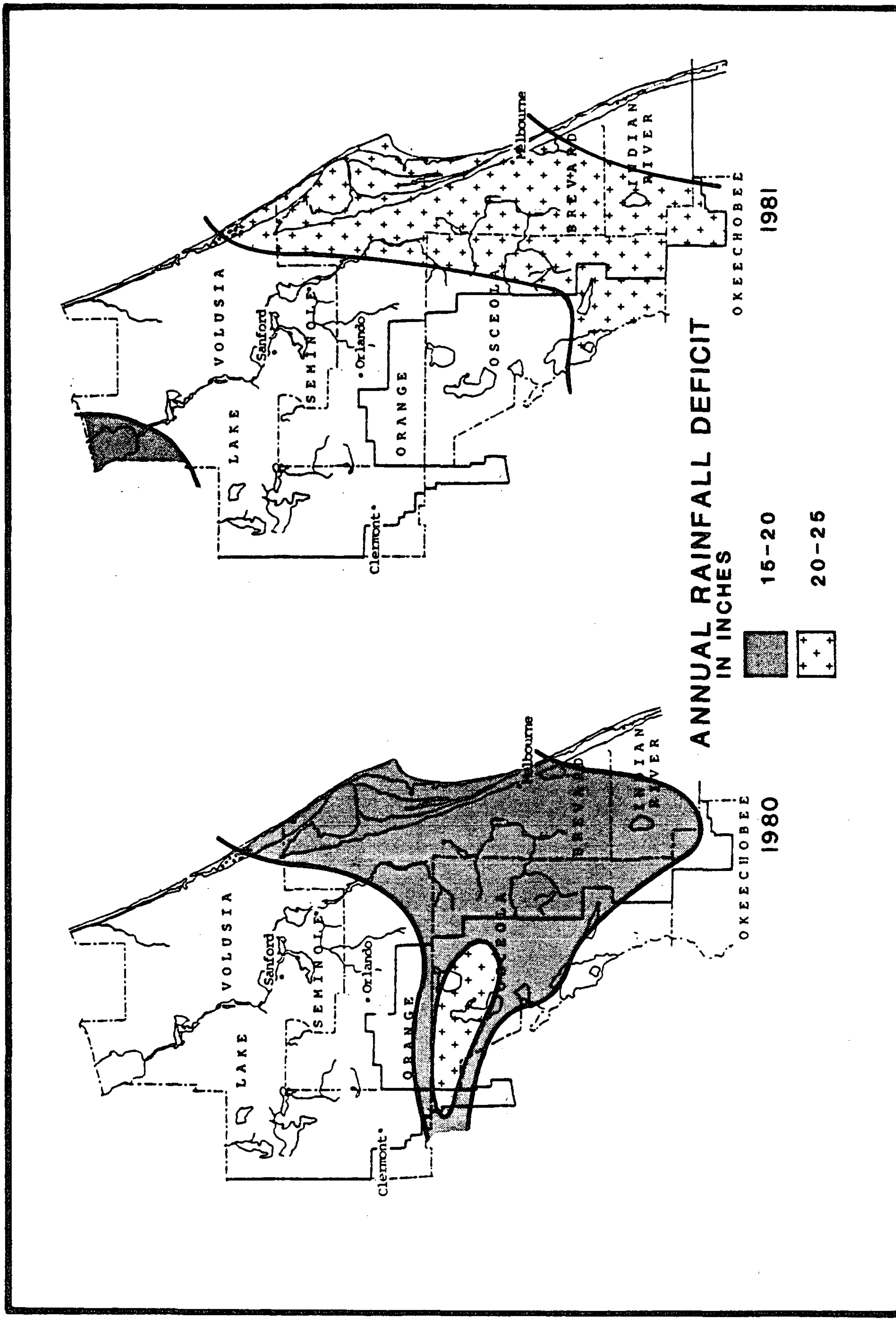


Figure 4. Annual rainfall deficiencies during 1980 and 1981 in and around the study area.

Population

Between 1950 and 1980 population more than tripled in each county. Figure 5 illustrates these population changes in Volusia, Brevard, and Indian River Counties (Dietrich, 1978; University of Florida, 1986). In Volusia County, population increased from 74,229 to 258,762 between 1950 and 1980. Brevard County had the largest population increase, 23,653 to 272,959, during this 30 year period. In Indian River County, population increased from 11,872 to 59,896 between 1950 and 1980.

WATER USE

Water is used in Volusia, Brevard, and Indian River counties for domestic and public supply, agricultural irrigation, heat-pump/air conditioning, thermoelectric power generation, and industrial supply (Figure 6). In each county both ground water and surface water sources supply fresh water for public supply and agricultural use. In the study area during 1983, 335.7 and 170.5 million gallons per day (MGD) of freshwater was withdrawn from ground water and surface water sources respectively (Marella, 1984), with 50.9 and 92.6 percent respectively used for agricultural irrigation. Heat-pump/air conditioning in Volusia and Brevard counties was the second major water use category and amounted to 20.5 percent of ground water withdrawn. Domestic and public supply accounted for only 20.4 percent of fresh ground water used. Surface water is also used for public supply in Brevard County and in 1983 amounted to 7.0 percent of the total.

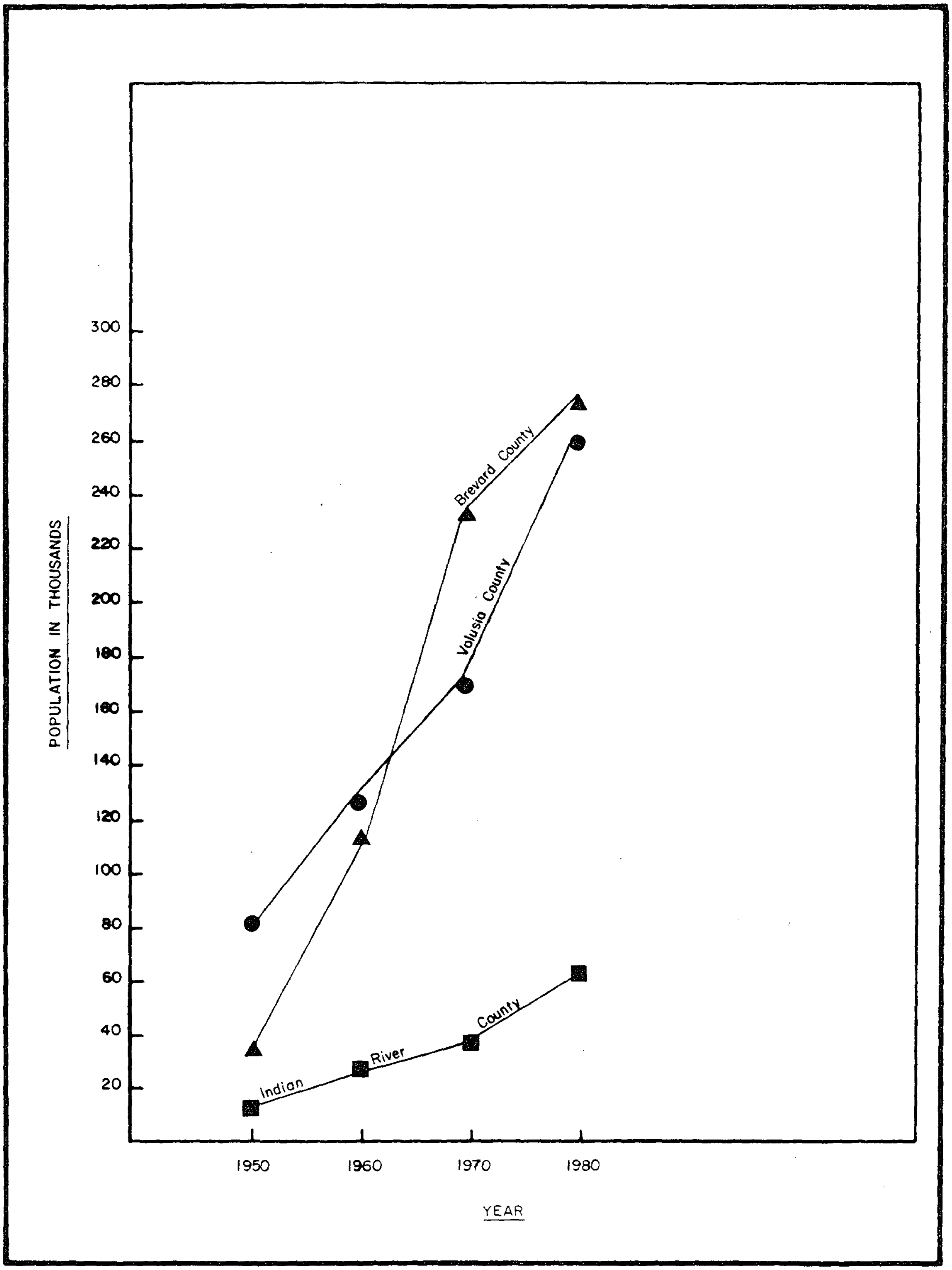


Figure 5. Population growth in Volusia, Brevard, and Indian River counties between 1950 and 1980.

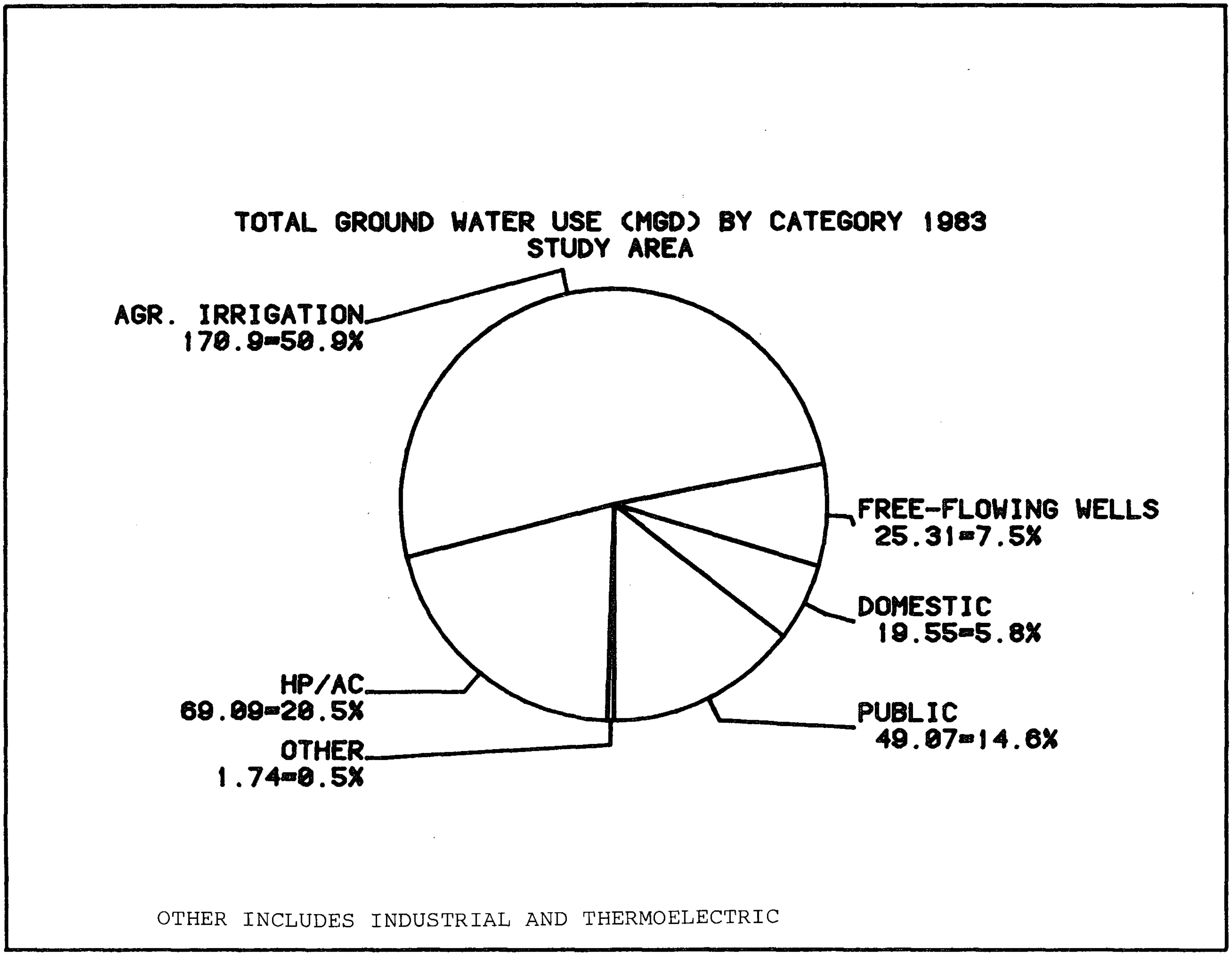


Figure 6. Water use by category in Volusia, Brevard, and Indian River counties for 1983.

Public Supply

Table 2 presents well, aquifer, and permit information as of March, 1985 for existing and proposed public supply ground water withdrawals of more than 0.10 MGD in east Volusia, Brevard, and Indian River counties. For comparison, 1983 water use values from Marella (1984) are also given. In many instances, the 1983 water use is near the permitted daily average allocation, even though the permit will not expire for another 2 to 11 years. Population in these areas is growing faster than projected and additional allocations will probably be required.

Figure 7 shows the location of each well field and the aquifer penetrated. Well field locations in Figure 7 are indicated with a dot which represents two or more wells. Locations of proposed wells, such as those for Holly Hill and Port Orange, are marked with a P when they differ from existing ones.

Table 2.—Permit, water use, and well inventory data for public supply well fields that withdraw more than 0.10 MGD from ground water aquifers in the study area. (Well field locations are shown in Figure 5.)

Well Field	# of existing and Proposed (P) Wells	Total Depth (ft)	Cased Depth (ft)	Aquifer[1]	Water use in 1983 (MGD)	Permitted Daily Withdrawals (MGD) Av	Permitted Daily Withdrawals (MGD) Max	Permit Expiration Date
Volusia Co.								
1. Halifax Plantation, Inc.	3	135-180	111-118	F	Not in use	0.65	1.30	Dec. 1994
2. Ormond Beach	25	182-300	50-111	F	3.79	4.07	5.14	Dec. 1994
	?P							
3. Holly Hill	8	175-200	82-105	F	0.96			
	7P	250	95	F				
Total	15			F	0.96	1.20	1.50	July 1990
4. Daytona Beach								
Eastern W.F.	12	200-290	96-110	F			7.0	Jan. 1992
Western W.F.	11	215-500	92-106	F			17.1	Jan. 1992
Total	23			F	12.97	16.0	24.1	Jan. 1992
5. Port Orange	14	120	45-65	F	3.04			
	15P	300	125	F				
Total	29			F	3.04	5.43	6.79	Jan. 1992
6. New Smyrna Beach	13	183-312	100-115	F	3.11			
	4P	250	110-115	F				
Total	17			F	3.11	6.95	11.40	Aug. 1991
7. Edgewater	5	158-200	90	F	0.84	1.13	2.27	Mar. 1987

Table 2.—Continued.

Well Field	# of existing and Proposed (P) Wells	Total Depth (ft)	Cased Depth)ft)	Aquifer[1]	Water use in 1983(MGD)	Permitted Daily Withdrawals(MGD) Av	Max	Permit Expiration Date
Brevard County								
8. Brevard Co. Utilities	4	120	85	F&S	0.50	0.44	0.87	June 1992
9. Titusville								
Area II	38	65-146	21-123	F&S	3.86	4.5	6.0	Dec. 1990
Area III	40P	100-150	60-78	F&S		3.0	4.3	Dec. 1990
Total	78			F&S	3.86	7.5	10.3	Dec. 1990
10. GDU-Port St. Johns	9	35-47	27.5-30	S	0.22	0.24	0.33	Dec. 1985[2]
Orange County								
11. Cocoa	20	490-794		F		14	17	Feb. 1989
						16	23	Feb. 2004
Total	20			F	16.70	30	40	
Brevard County								
12. Port Malabar	18	100-110	70	S	2.37	3.5	5.5	Dec. 1984
13. Malabar Woods	3	90-110	60-70	S	Not in use	0.19	0.37	Dec. 1986
14. Aquarina	2	550	450	F		0.45	0.77	Sept. 1987
15. Barefoot Bay	4	100	60	S	0.28	0.34	0.52	Jan. 1985
Indian River County								
16. Sebastian Highlands	2	102	65	S	0.13	0.43	0.78	Mar. 1987
17. North Beach Water Co.	2	966&1003	405&463	F	Not in use	0.80	1.20	Nov. 1985

Table 2.—Continued.

Well Field	# of existing and Proposed (P) Wells	Total Depth (ft)	Cased Depth (ft)	Aquifer[1]	Water use in 1983 (MGD)	Permitted Daily Withdrawals (MGD) Av	Max	Permit Expiration Date
18. Bent Pines	2	105-110	55-60	S	0.18	0.25	0.35	Sept. 1992
19. Vero Beach	24	80-140	43-65	S				
	2	677&688	313&420	F				
						4.6	6.4	Feb. 1989
						4.5	7.2	Feb. 2014
Total	26			S&F	8.00	9.1	13.6	
20. Village Green MHP	2	900	400	F	0.16	0.17	0.29	Feb. 1987
21. Indian River Co. Utilities	2	700&740	381&383	F	0.37	4.25	8.50	June 1991
22. Vero Beach Highlands	3	125	70	S	0.27	0.36	0.71	April 1985[3]

1. F = Floridan; S = Surficial
2. Port St. Johns is negotiating to buy water from Cocoa. Well field will then be plugged and abandoned.
3. Signed agreement with Indian River County Utilities to obtain water. Well field will be plugged and abandoned.

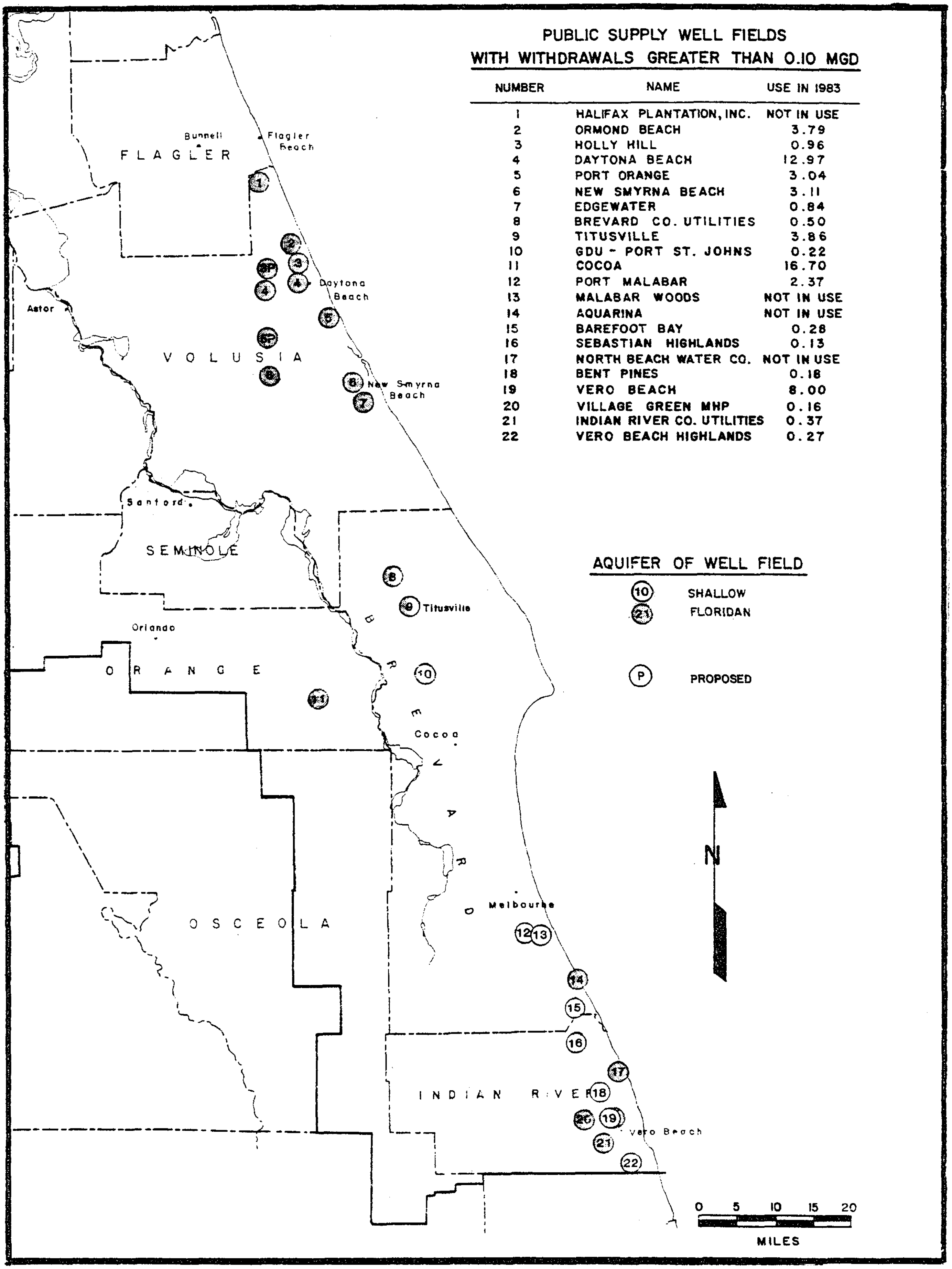


Figure 7. Public supply well fields in the study area with withdrawals greater than 0.10 MGD in 1983.

Volusia County

Ground water withdrawals in Volusia County are primarily from the Floridan aquifer. All public supply and most agricultural wells withdraw water from this aquifer. Surficial aquifer wells occur almost exclusively along the coastal stretches of the county and provide water for lawn irrigation.

In 1983 a total of 74.31 MGD and 1.95 MGD was withdrawn from ground and surface water sources respectively in Volusia County (Marella, 1984). Public supply and agricultural irrigation were the primary fresh ground water use categories in the county and accounted for 45.0 and 35.5 percent respectively of the total (Figure 8). Domestic and heat-pump/air conditioning categories were second and used 9.2 and 8.2 percent of the ground water withdrawn. Forty-one percent of the total ground water use in the county occurred in the area east of I-95. Here public supply was the major use and is expected to continue as the dominate type of water use in the county. Surface water was used only for irrigation (69.7%) and thermoelectric power generation (30.3%).

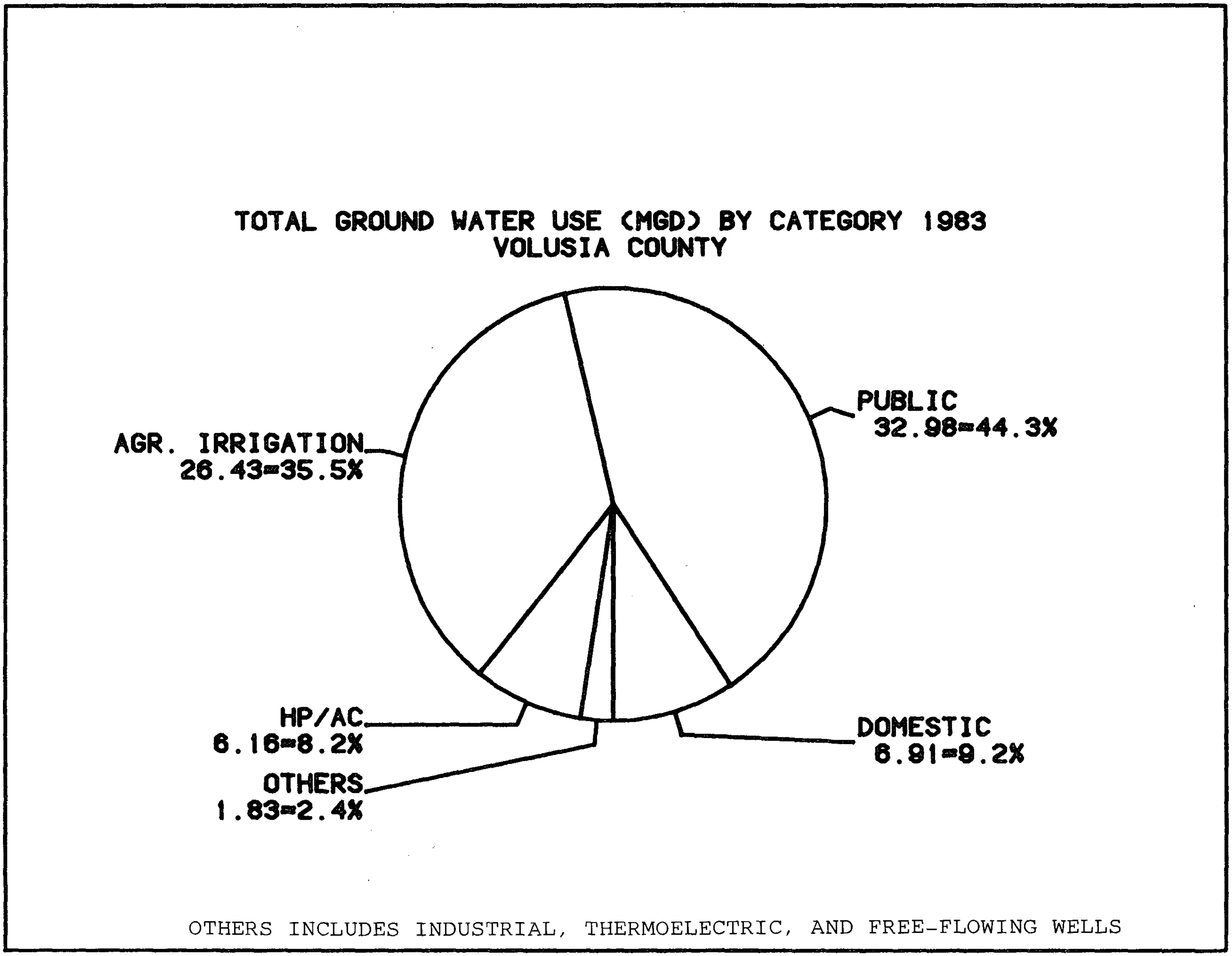


Figure 8. Total ground water use by category in Volusia County in 1983.

Brevard County

In Brevard County ground water is withdrawn from the Floridan, intermediate, and surficial aquifer systems. In the northern part of the county, wells penetrating the Floridan and surficial aquifer systems provide water for public and domestic supply. Along the Atlantic Coastal Ridge, surficial aquifer wells also supply water for heat-pump/air conditioning and lawn irrigation. In the central part of the county surficial aquifer wells are primarily used for domestic water supply. In this part of the county the number of wells that tap the Floridan aquifer increases to the east and south. The majority of withdrawals are for irrigation and heat pump use. In south Brevard County, wells penetrating the surficial, intermediate, and Floridan aquifer systems primarily withdraw water for heat pump/air conditioning and irrigation. The concentration of shallow wells exceeds 1,000 per square mile in central Melbourne. The concentration of wells penetrating the Floridan aquifer approaches this amount along the barrier islands. In southeast Brevard County the surficial aquifer also provides water for both public and domestic supply.

In 1983 a total of 205.5 MGD and 39.8 MGD was withdrawn from ground and surface water sources respectively (Marella, 1984, Revised 1986). Ground water use was primarily for agricultural irrigation (52.1%) and heat pump/air conditioning (30.6%, Figure 9). Ground water withdrawals for public supply were minimal because the City of Cocoa obtained its water from well fields in east Orange County and the City of Melbourne obtained its water from Lake Washington. Thirty percent of all surface water

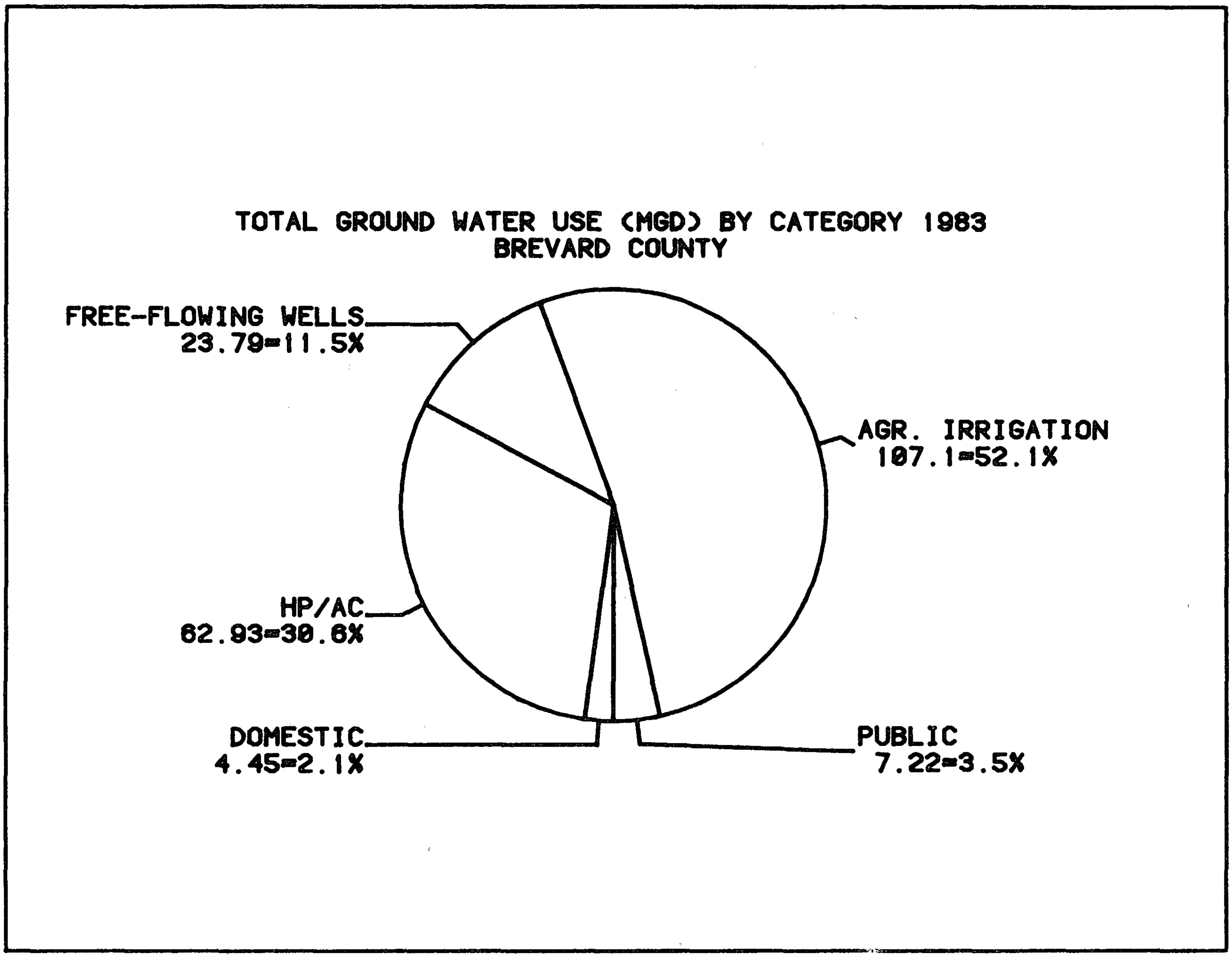


Figure 9. Total ground water use by category in Brevard County in 1983.

withdrawals were for public supply with the remaining 70 percent for agricultural irrigation. Brevard County is the only county in the study area in which surface water is used as a public supply source.

Indian River County

Ground water withdrawals in Indian River County are from the Floridan and surficial aquifers. Wells penetrating the surficial aquifer provide water for public and domestic supply, whereas wells penetrating the Floridan aquifer mainly provide water for irrigation. A small percentage of water from Floridan wells is also used for public and domestic supply.

In 1983 a total of 55.4 MGD and 128.7 MGD of water was withdrawn from ground and surface water sources respectively, (Marella, 1984, Revised 1986). Ground water was primarily used for irrigation (67.4%) with public and rural domestic supply comprising only 16.0 and 14.7 percent respectively of the total (Figure 10). Surface water is exclusively used for agricultural irrigation. Indian River County uses the largest amount of surface water in the study area.

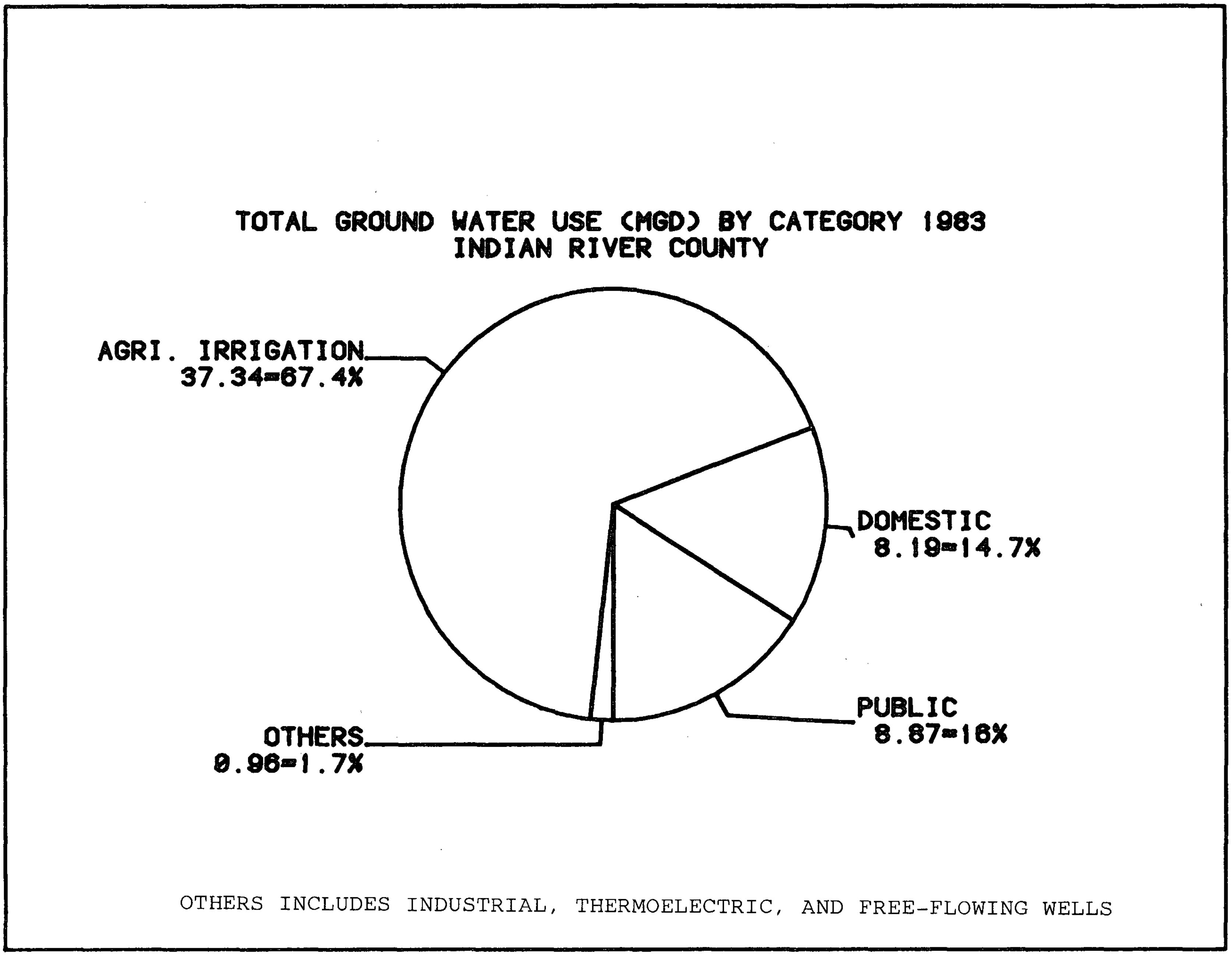


Figure 10. Total ground water use by category in Indian River County in 1983.

HISTORICAL WATER USE

In 1970, a total of 27.48 MGD of ground water was withdrawn in Volusia County, 65.5 MGD in Brevard County (Pride, 1973), and 37.1 MGD in Indian River County (Marella, personal communication). Comparing these values with 1983 water use (Figure 11) indicates that from 1970, ground water withdrawals increased by approximately 167 percent in Volusia County and 214 percent in Brevard County. In Indian River County, the total amount of ground water withdrawn since 1970 increased by only 49 percent.

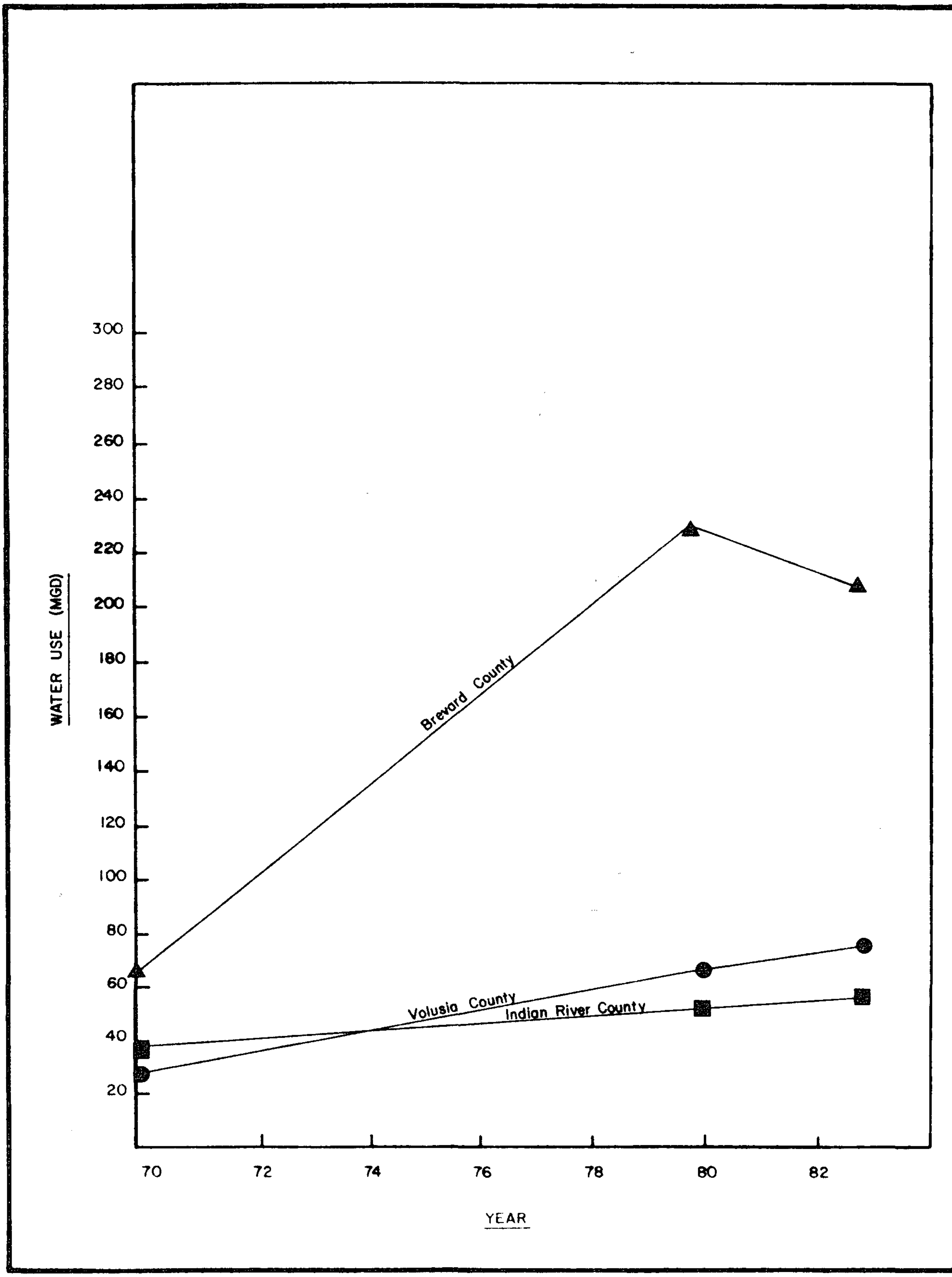


Figure 11. Total ground water use for Volusia, Brevard, and Indian River counties between 1970 and 1983.

GEOLOGY

The deposits of coastal Volusia, Brevard, and Indian River counties can be divided by age and sedimentary characteristics into four hydrogeologically significant subdivisions: (1) Eocene and Oligocene limestones; (2) Early to Middle Miocene clay, limestone, and layers of interbedded sand and shell; (3) late Miocene or possibly Pliocene clay, sand, shell, and limestone lenses; and (4) Pleistocene to Holocene sand and shell with clay lenses, locally called surficial clastics. In general, about 5,000 feet of sediments overlie the basement complex of granite and other crystalline rocks (Cederstrom, Boswell, and Tarver, 1979; p. 5).

Stratigraphic units are discussed below in order of decreasing age. Divisions between units are based primarily on interpretation of geophysical logs (gamma ray and resistivity, Johnson, 1984) and have been confirmed by interpretation of well cuttings. The divisions are in general agreement with the literature (Wyrick, 1960; Brown et al, 1962; Bermes, 1958).

Table 3 shows a generalized geologic column for the study area based on the work of previous authors and geophysical data collected by the District. Descriptions and interpretations of the geophysical response of strata of Paleocene to Pliocene age typically present in the study area can be found in Johnson (1984).

TABLE 3.--General Lithology of Formations Penetrated by Water Wells in Coastal Volusia, Brevard, and Indian River Counties

AGE	NAME OF UNIT	LITHOLOGY	AQUIFERS		WATER BEARING PROPERTY
PLEISTOCENE	N Surficial Materials	variable mixtures of sand, coquina, clay and organic material	shallow sand aquifer shallow water table aquifer	Surficial Aquifer System	small to moderate amounts of water
	S W Ft. Thompson Formation	variable mixtures of sand, coquina, limestone and organic material			
	E Anastasia Formation	coquina with variable amounts of sand, silt, limestone and organic material			
PLIOCENE and MIOCENE	Caloosahatchee Formation Undifferentiated Miocene and Pliocene materials	clay, sand and coquina			
	S W Gray Sand Zone	sand with mixtures of coquina and some clay	Gray Sand aquifer		moderate amounts of water
	E Tamiami Limestone	coquinoid bioclastic to recrystallized impure limestone	Shallow rock aquifer		
MIOCENE	Hawthorn Formation	dolosilt, sand, clay and thin carbonate beds and mixtures, all phosphatic	Secondary artesian	Intermediate Aquifer System or Confining Unit	moderate amounts of water
OLIGOCENE	Suwannee Limestone	impure to pure, bioclastic to chalky to recrystallized limestone	Floridan Aquifer System		large amounts of water
EOCENE	Ocala Limestone	pure foraminiferal bioclastic to recrystallized limestone, some dolomitic limestone near base			
	Avon Park Limestone	dolostone, massive to moderately indurated; limestone, bioclastic foraminiferal to chalky to recrystallized; and peat			
	Lake City Limestone	limestone and dolostone			

EOCENE AND OLIGOCENE LIMESTONES

Eocene deposits include the Lake City, Avon Park, and Ocala limestones. Oligocene deposits occurring within the project area have been tentatively identified as Suwannee Limestone.

Lake City Limestone

The Lake City Limestone of Middle Eocene age consists of alternating beds of white, fossiliferous, soft and crumbly to hard and recrystallized limestone; and hard, brown to reddish brown, low porosity to cavernous dolostone. The top of the formation is marked by a thick zone of relatively pure limestone. The formation becomes progressively harder below this upper zone, with an increasing amount of dolostone and hard recrystallized, low porosity limestone with increasing depth.

The depth to the top of the Lake City Limestone is shown in Figure 12. In western Volusia County it lies between 220 and 320 feet below msl and deepens to 500-550 feet below msl along the Atlantic coast at Daytona and New Smyrna Beach. In Indian River County, it is considerably deeper, ranging from about 700 feet in western Indian River County to 1200-1550 feet below msl on the barrier island.

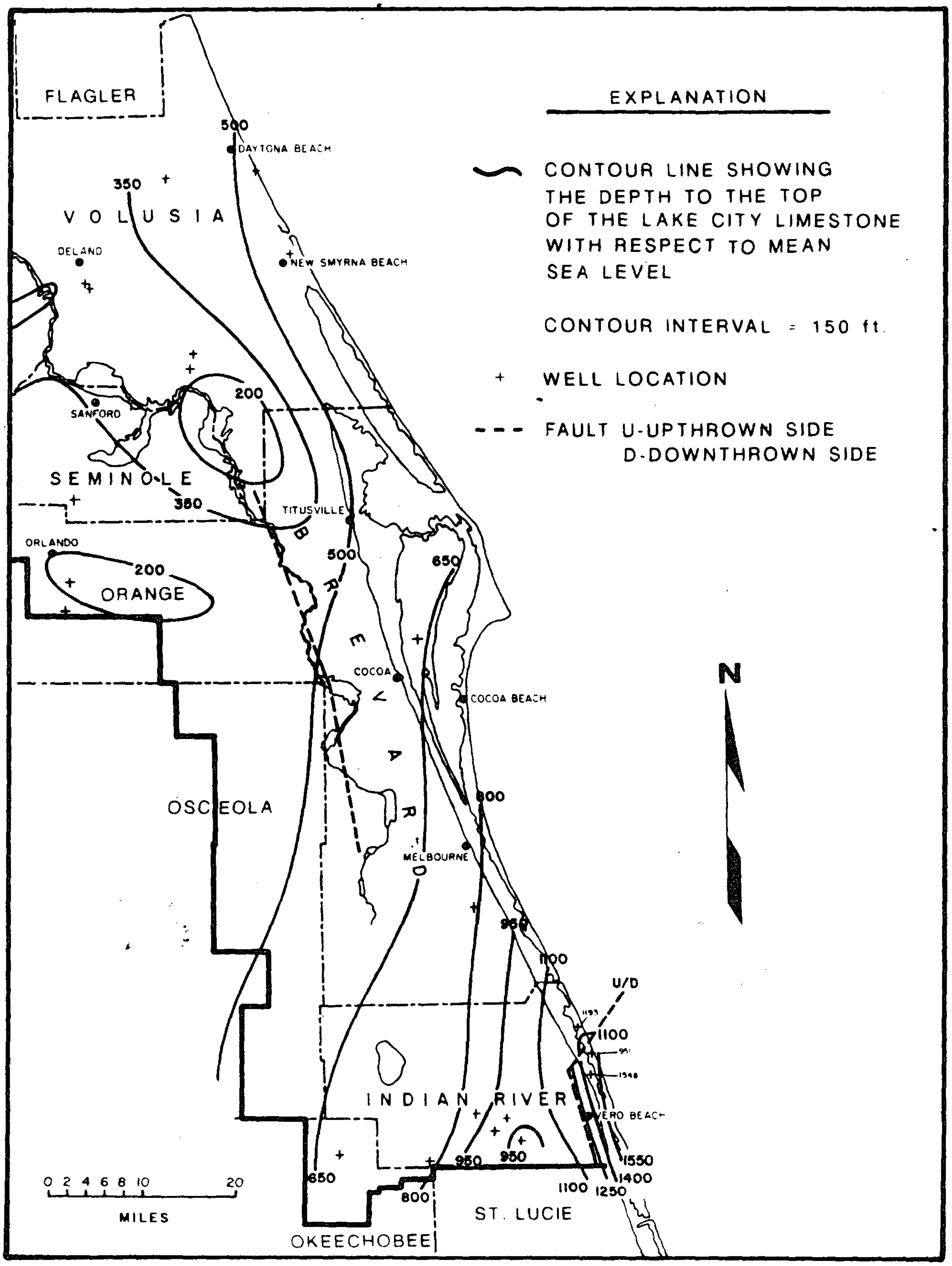


Figure 12. Depth below msl to the top of the Lake City Limestone in the study area. Faults from Bermes (1958) as redefined by Schiner et. al. (1988).

Avon Park Limestone

The Avon Park Limestone of Middle Eocene age consists of two distinct and correlatable lithologic zones; the basal low porosity dolostone zone and the upper Avon Park zone.

The lower zone is composed of very hard, low porosity, brown to dark brown, cavernous dolostone. Frequently, individual dolomite rhombs can be distinguished under low magnification. Because of the cavernous nature of the zone, permeability can be extremely high. In Volusia County the top of the lower zone lies between 160 and 380 feet below msl, with the deeper values characteristic near the Atlantic coast. In Brevard County it varies between 340 and 500 feet below msl, and at the southern end of the study area it ranges between 600 and 700 feet below msl.

The upper Avon Park zone occurs in the interval between the basal low porosity dolostone zone and the contact with the overlying Ocala Limestone. It is characterized by interbedded limestone and dolostone. The limestone is generally white to tan to light brown, hard and completely recrystallized to soft, and composed of weakly cemented, partially altered, foraminiferal tests. The dolostone is dark brown to brown, hard and recrystallized (micrite-like) to moderately well cemented calcarenite.

The top of the Avon Park is marked by an unconformity characterized by a thin clay or peaty clay bed, or by a hard, brown to tan, dolostone bed with incorporated peat or lignitic seams and stringers. The unconformity is not as well developed in the southern portion of the study area (Johnson, R., personal communication, 1983).

The top of the Avon Park lies between 0 and 90 feet below msl in west Volusia County. Toward the coast the depth increases to 125-190 feet below msl. In Brevard County it varies between 210 and 410 feet below msl. In Indian River County it ranges between 490 and 570 feet below msl, except on the barrier island north and south of Vero Beach where it is located at 894 and 889 feet below msl, respectively (Figure 13).

The thickness of the Avon Park is shown in Figure 14. It ranges from 150 to 340 feet thick in Volusia County and generally increases in thickness toward the south and east. In Indian River County it ranges from 350 feet thick inland to as much as 650 feet thick on the barrier island north of Vero Beach.

Ocala Limestone

The Ocala Limestone of Late Eocene age consists of white to light tan, soft and very weakly cemented to hard and recrystallized, foraminiferal coquinoid limestone. The coquina is composed of whole and fragmented foraminiferal tests with some intermixed echinoid, bryozoan, and other biological debris. Generally, two zones can be distinguished: a lower, more recrystallized micritic zone and an upper, less well-cemented zone of calcarenite. In some wells, the lower zone contains light tan, hard, thin beds of dolomitic limestone (Johnson, R., personal communication, 1983).

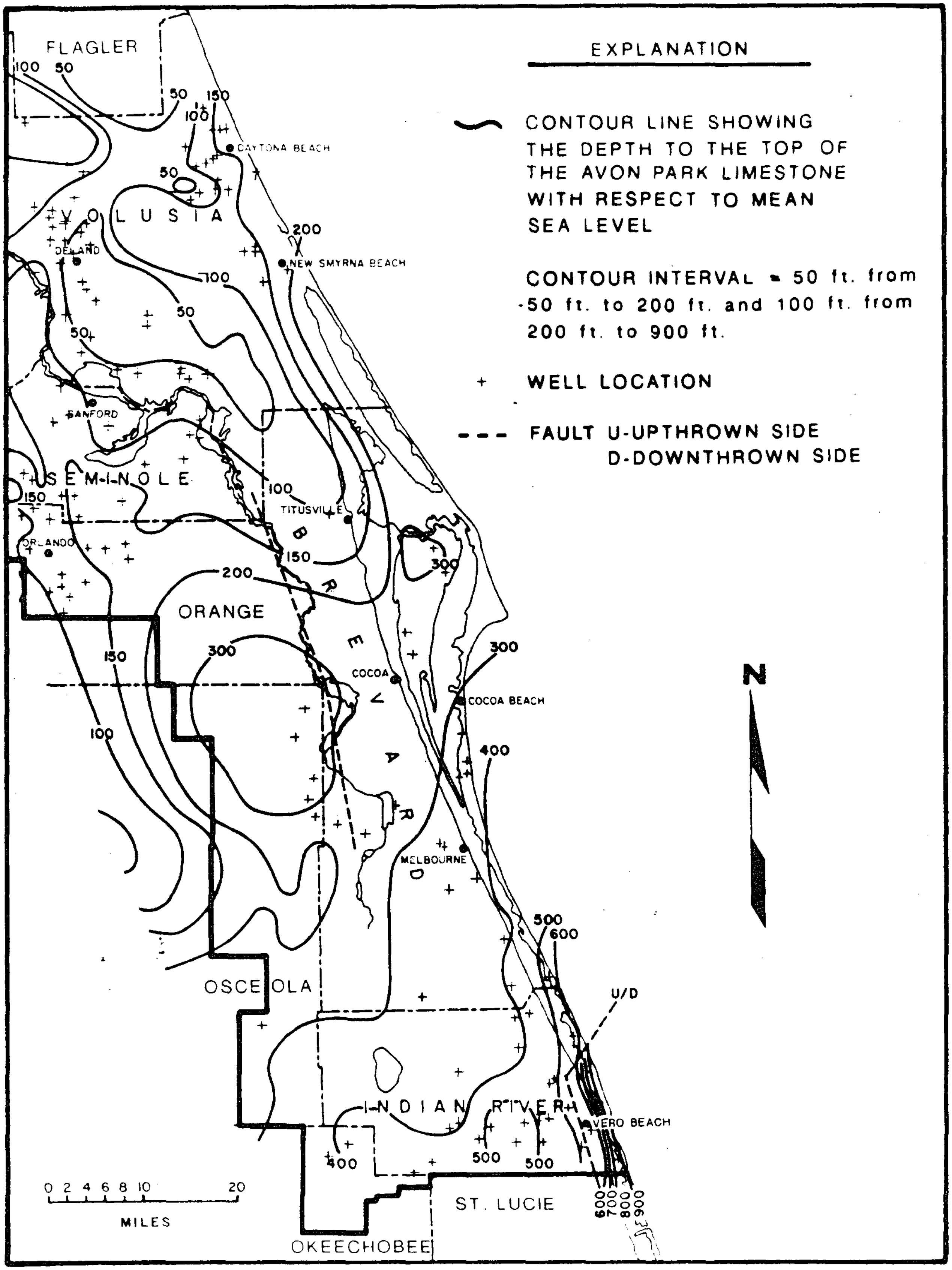


Figure 13. Depth below msl to the top of the Avon Park Limestone in the study area. Faults from Bermes (1958) as redefined by Schiner et. al. (1988).

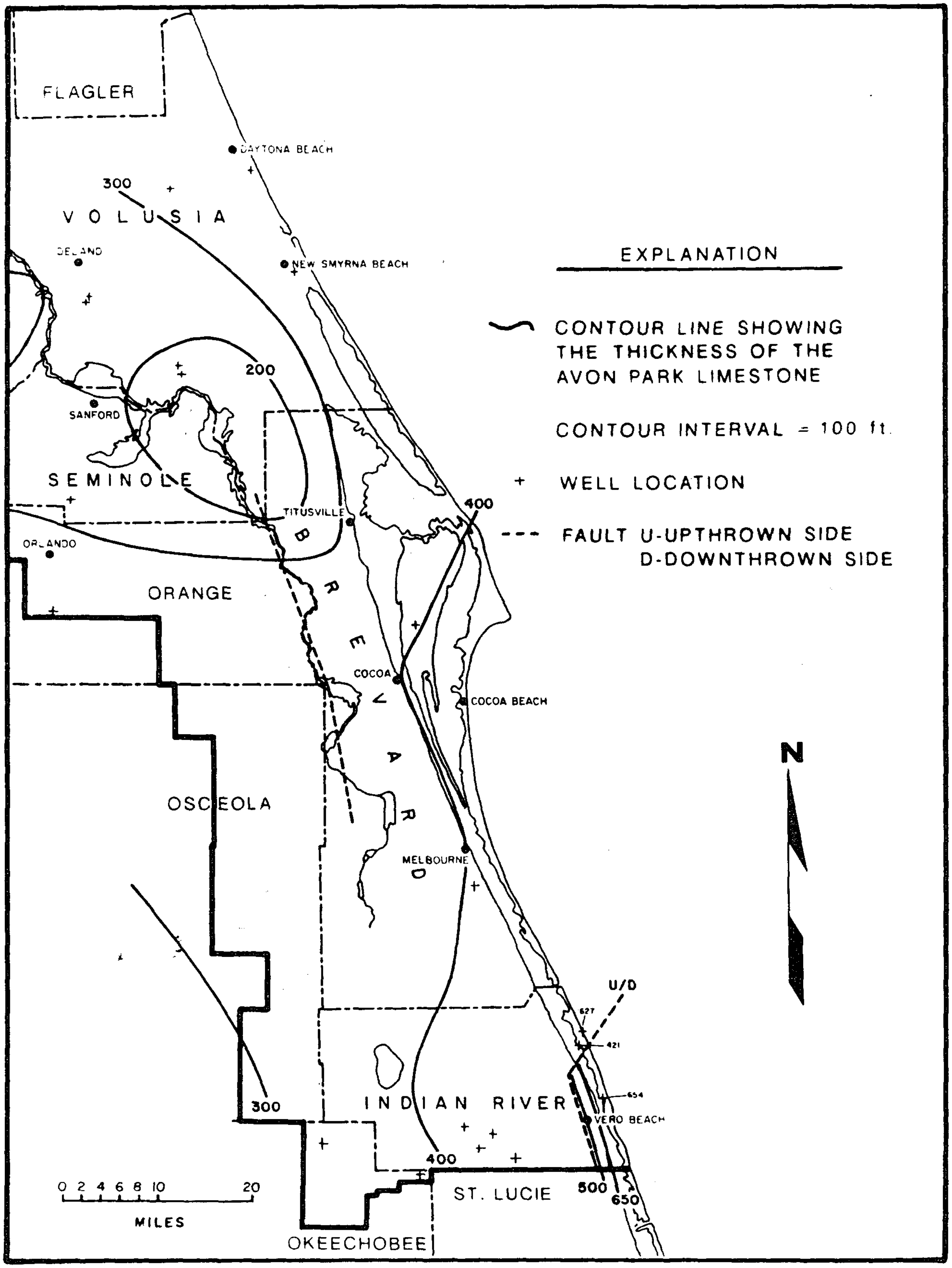


Figure 14. Thickness of the Avon Park Limestone in the study area. Faults from Bermes (1958) as redefined by Schiner et. al. (1988).

The top of the Ocala is an unconformity marked by direct juxtaposition of hard, phosphatic, arenaceous carbonate or phosphatic clay of the Hawthorn Formation with the extremely pure, white limestone of the Ocala. The upper surface of the Ocala is typically karstic, with paleosinkholes exhibiting relief as great as 400 feet (Johnson, R., personal communication, 1983).

The depth to the top of the Ocala Limestone is shown in Figure 15. The top of the Ocala generally increases in depth toward the coast (east) and to the south. In Volusia County the top of the Ocala varies from 5 to 125 feet below msl. A range of 75 to 390 feet below msl is characteristic in Brevard County. The top of the formation is relatively deep in Indian River County, from 280 to 530 feet below msl west of the Indian River and 781 feet to 836 feet below msl north and south of Vero Beach on the barrier island.

The thickness of the Ocala Limestone ranges from near 0 to 120 feet in Volusia and Indian River counties (Figure 16). In Brevard County it ranges from 40 to 160 feet in thickness. The Ocala generally thickens toward the east, attaining maximum thickness at or near the barrier island.

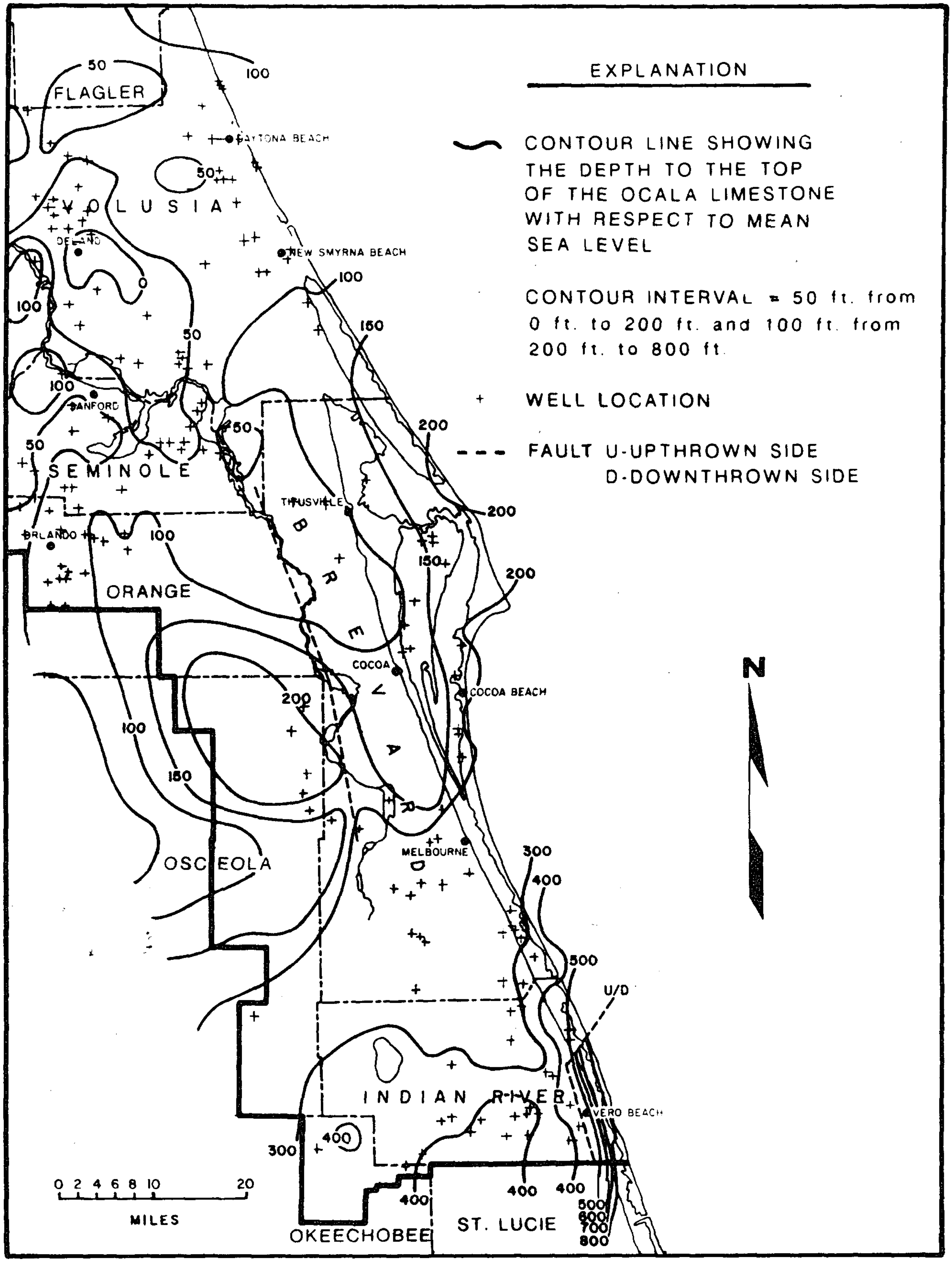


Figure 15. Depth below msl to the top of the Ocala Limestone in the study area. Faults from Bermes (1958) as redefined by Schiner et. al. (1988).

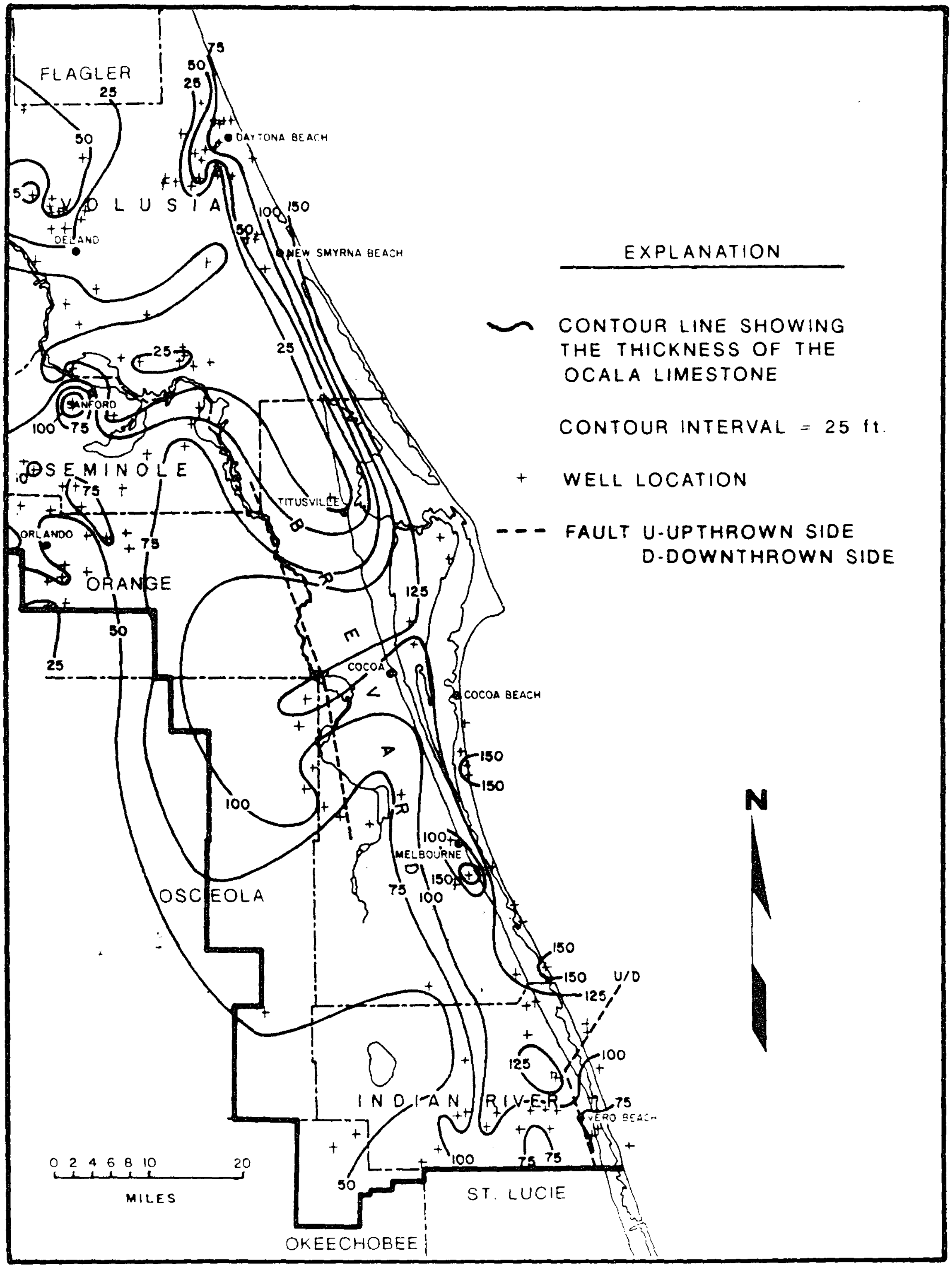


Figure 16. Thickness of Ocala Limestone in the study area. Faults from Bermes (1958) as redefined by Schiner et.al. (1988).

Suwannee Limestone

The Suwannee Limestone of Oligocene age consists of white to light tan, slightly argillaceous to arenaceous to pure, bioclastic to chalky limestone. Within the study area, the Suwannee Limestone is present only in portions of Indian River and Brevard counties, where it lies between the Ocala Limestone and the Hawthorn Formation.

The top of the Suwannee varies from 155 feet below msl in south Brevard County to 652 feet below msl on the barrier island southeast of Vero Beach. The thickness of the Suwannee Limestone ranges from 0 feet in south Brevard and western Indian River counties to 194 feet on the barrier island south and east of Vero Beach (Figure 17).

MIDDLE MIOCENE CLAY, MARL AND LIMESTONES

Hawthorn Formation

The Hawthorn Formation of Middle Miocene age consists of interbedded clay, silt, sand, and carbonate beds, all of which contain varying amounts of black to brown phosphatic material. The carbonate beds consist of sandy, hard, recrystallized, phosphatic limestone with some brown dolostone, except at the base of the formation where hard, brown to dark blue, sandy, phosphatic dolostone predominates. In Indian River County the base of the formation is green to dark green, hard, phosphatic clay.

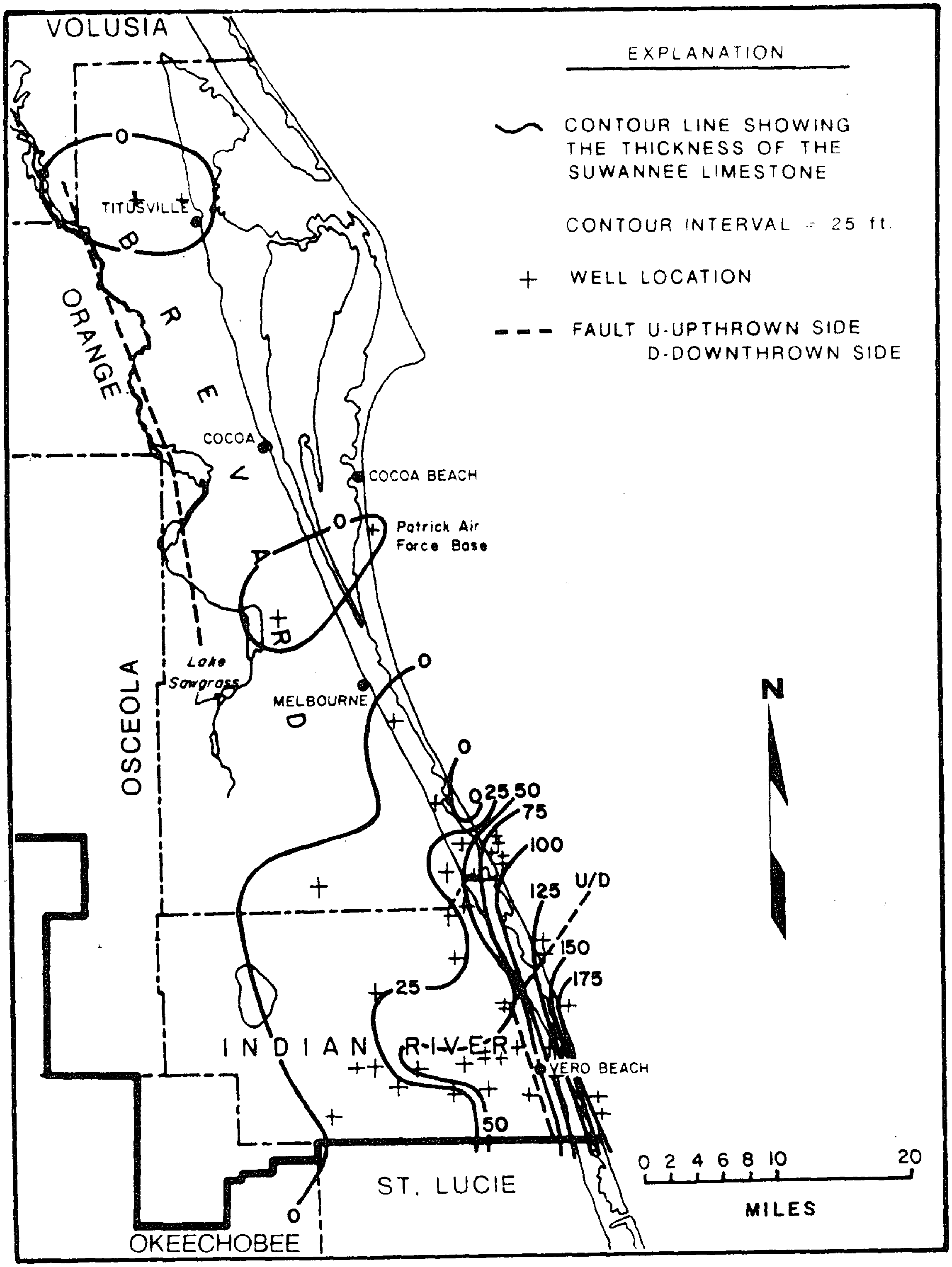


Figure 17. Thickness of the Suwannee Limestone in the study area. Faults from Bermes (1958) as redefined by Schiner et. al. (1988).

The Hawthorn Formation can be divided into two zones in the southern portion of the study area: an upper zone consisting of green clay and silt with relatively low phosphatic content and a lower zone consisting of interbedded clay and carbonate material containing much disseminated phosphatic material. In the northern part of the study area, the upper zone is generally absent or very thin.

The thickness and areal extent of the Hawthorn Formation is shown in Figure 18. The formation is absent in most of Volusia County and in the northern part of Brevard County. In northwest Volusia County and near New Smyrna Beach, the Hawthorn Formation ranges from 6 to 65 feet in thickness where present. In Brevard County, the Hawthorn increases in thickness to 185 feet toward the south. The Hawthorn is thickest in Indian River County where it ranges from 155 to 295 feet west of the Indian River to a localized maximum of 523 feet on the barrier island southeast of Vero Beach. The top of the Hawthorn ranges from 10 to 100 feet below msl in Volusia County where present, from 20 to 140 feet below msl in Brevard County, and from 70 to 205 feet, below msl in Indian River County.

LATE MIOCENE TO PLIOCENE DEPOSITS

Deposits of extremely variable lithology (clay, sand, coquina and limestone) overlie the Hawthorn Formation. These deposits, which blanket large areas, have been described in previous reports as undifferentiated clastics. Similar materials in the western part of the study area have been classified as the

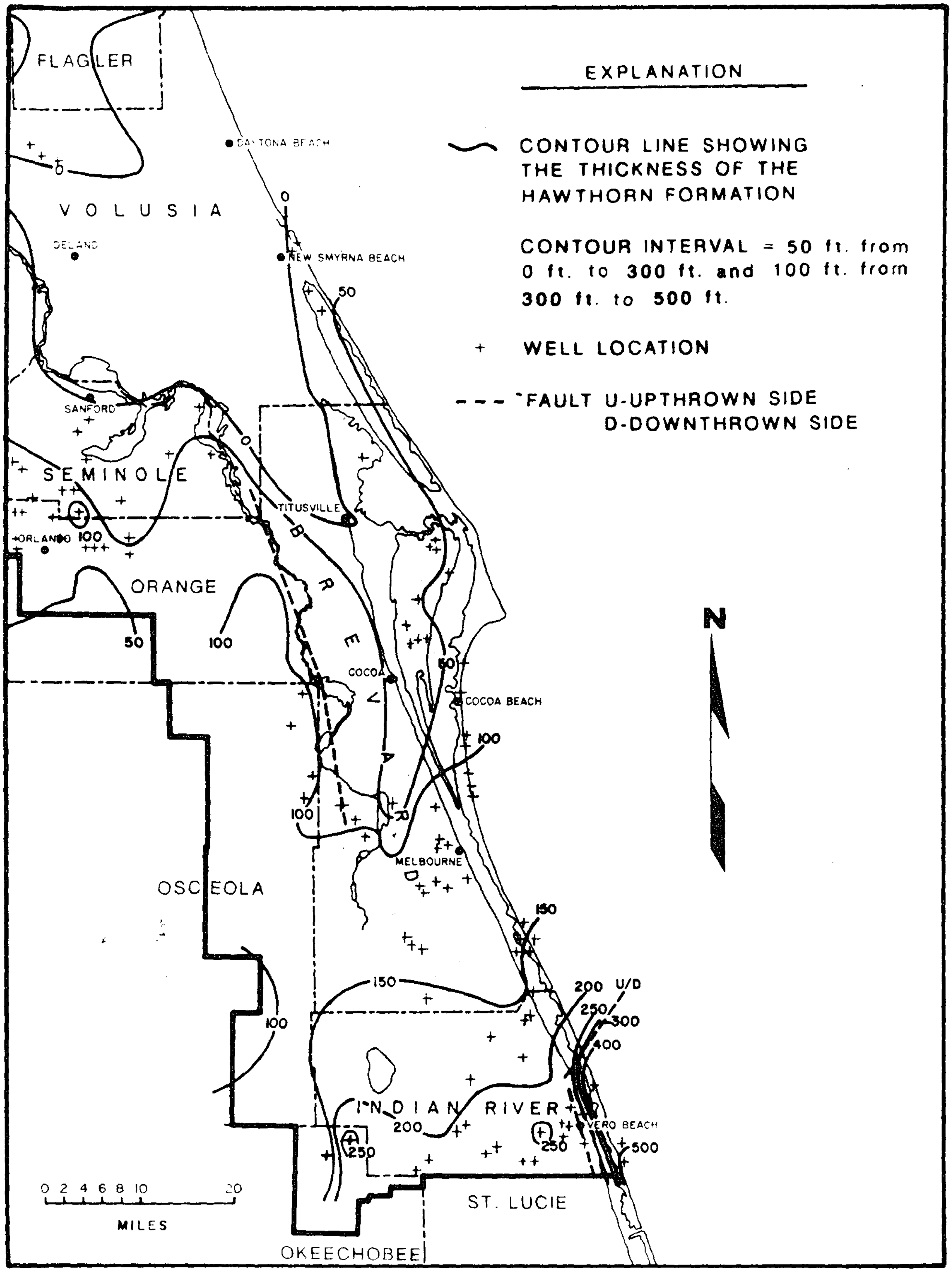


Figure 18. Thickness of the Hawthorn Formation in the study area. Faults from Bermes (1958) as redefined by Schiner et.al. (1988).

Caloosahatchee Marl of Pliocene Age by Cooke (1945) and as beds of Late Miocene Age by Vernon (1951). In Volusia County the unconsolidated beds of fine sand, shells, and calcareous silty clay which overlie the Ocala Limestone have been classified by Cooke (1945) as the Caloosahatchee Marl of Pliocene Age. According to Parker (1951) and Bermes (1958), deposits of clay, sand, coquina, and limestone in southeast Brevard and eastern Indian River counties are called the Tamiami Formation.

The Tamiami Formation

The Tamiami Limestone of Pliocene Age consists of interbedded limestone, quartz sand, sandstone, and siltstone in the type area of south Florida (Parker and Cooke, 1944). Where exposed along the Tamiami Trail (State Route 41), the limestone beds are hard, tan to white, with moderate moldic porosity. Within the study area the Tamiami is primarily composed of argillaceous to arenaceous, slightly phosphatic, bioclastic coquinoid limestone lenses and beds. A coquinoid calcisiltite is most common.

The areal extent and depth to the top of the Tamiami Formation in the study area is shown in Figure 19. The formation is limited to the coastal regions of Brevard and Indian River counties and pinches out to the west where it becomes a sequence of unlithified, unrecrystallized beds of similar lithology. Its top ranges from 50 to 115 feet below msl with depth increasing toward the coast. The formation appears to be similar to the "shallow-rock zone" found in Duval and Nassau counties described

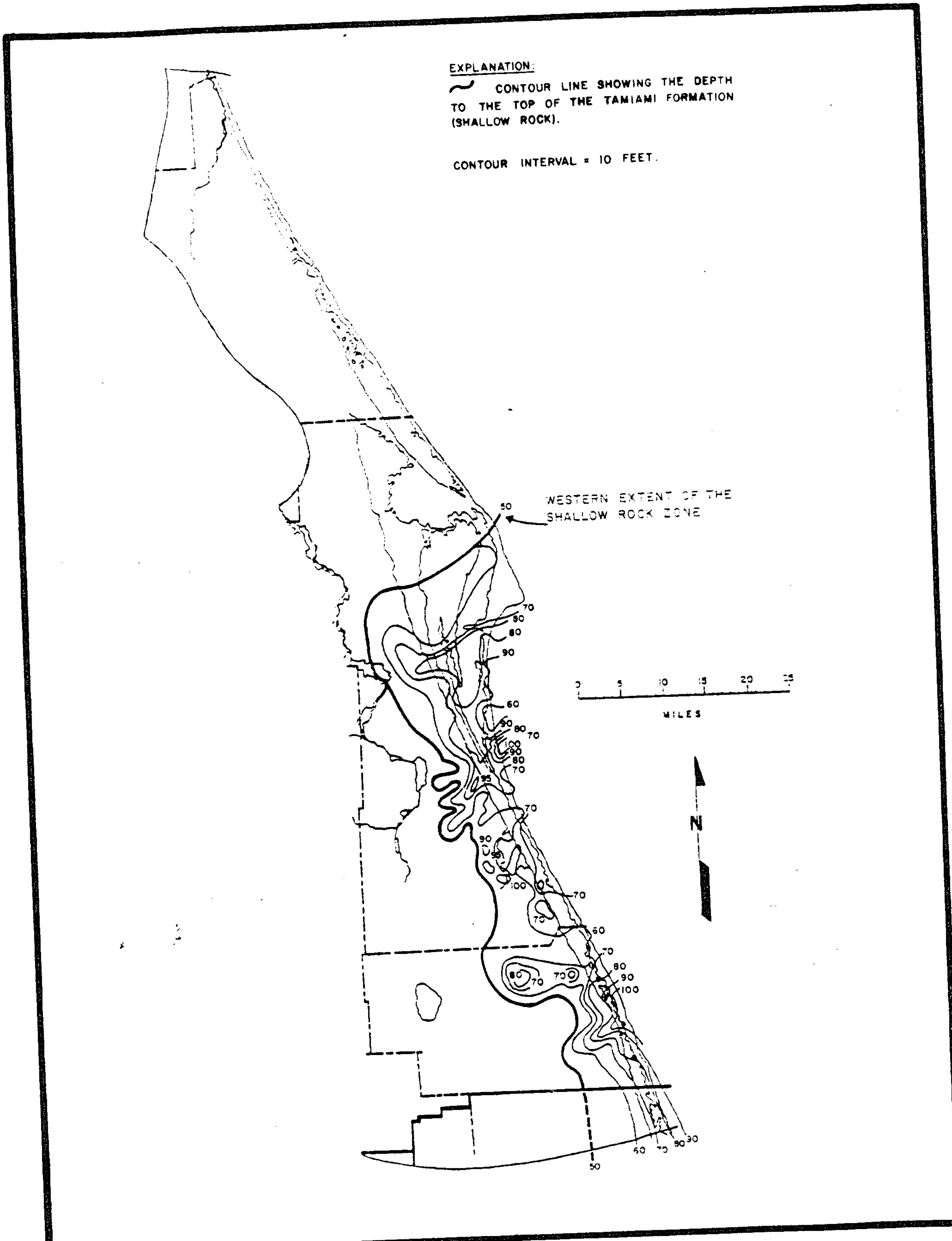


Figure 19. Depth below msl to the top of the Tamiami Formation in the study area.

by Fairchild (1972) as late (upper) Miocene or Pliocene Age and is commonly referred to by this name.

Local drillers identify two beds of the shallow-rock zone as "crunchy gray limestones", and "hardrock". These terms are a good description of the two-layer zone found in test wells along the Atlantic Coastal Ridge in Indian River County. Bermes (1958, P. 50-51) described the lithology as "limestone, light gray to dark gray, hard to soft, sandy, light olive-drab clay with phosphorite pebbles and white to dark colored mollusk fragments." A lithologic change occurs west of the Ten-Mile Ridge and the St. Johns River channel. Deposits of gray sand and shell interbedded with clayey sands increase in thickness to form a gray sand zone of Late Miocene or Pliocene Age. Maximum thickness of these deposits appears to occur near Fort Drum. These gray sands tend to pinch-out to the north and west with increasing amounts of clayey sands, lime shell and sand and clay.

Caloosahatchee Formation

The Caloosahatchee formation is a marl consisting predominantly of sand and shells. At many places the shells are so abundant that they make up a large part of the deposit, though elsewhere there are few or none. Compared to most shell marls, a larger proportion of the shells are preserved unbroken. Fresh, unweathered exposures of the Caloosahatchee are commonly white or light gray. The color changes to cream or yellow when oxidized.

PLEISTOCENE AND RECENT DEPOSITS

Pleistocene sediments are generally undifferentiated and highly variable throughout the study are. Brown (1962) described the materials to be white to brown and of varying grain size, with lenses of shell and sand in Brevard County. Thickness ranges from 20 to 100 feet, with the thicker deposits underlying the coastal ridges. Bermes (1958) and Crain (1975) indicated that these deposits are of similar thickness in eastern Indian River County, with transitions from primarily shell beds to sand deposits in the vicinity of Ten-Mile Ridge. Wyrick (1960) indicated that in Volusia County the base of Pleistocene sediments is marked "by a bed of coarse sand grains, water worn sheets, clay, and at a few places, a combination of these materials cemented together by calcium carbonate".

Anastasia Formation

The Anastasia Formation generally occurs along the coastal islands and inland for approximately three to ten miles (Figure 20). Puri and Vernon (1964, p. 282-283) describe the type section on Anastasia Island, St. Johns County, as "sandy coquina of mollusks held loosely together by calcareous cement." In the study area, the Anastasia Formation consists primarily of coquina with varying amounts of quartz sand, silt and organic material. The coquina is cemented and moderately hard to uncemented and loose. Bermes et al., (1963, p. 32-33) found shell beds five and

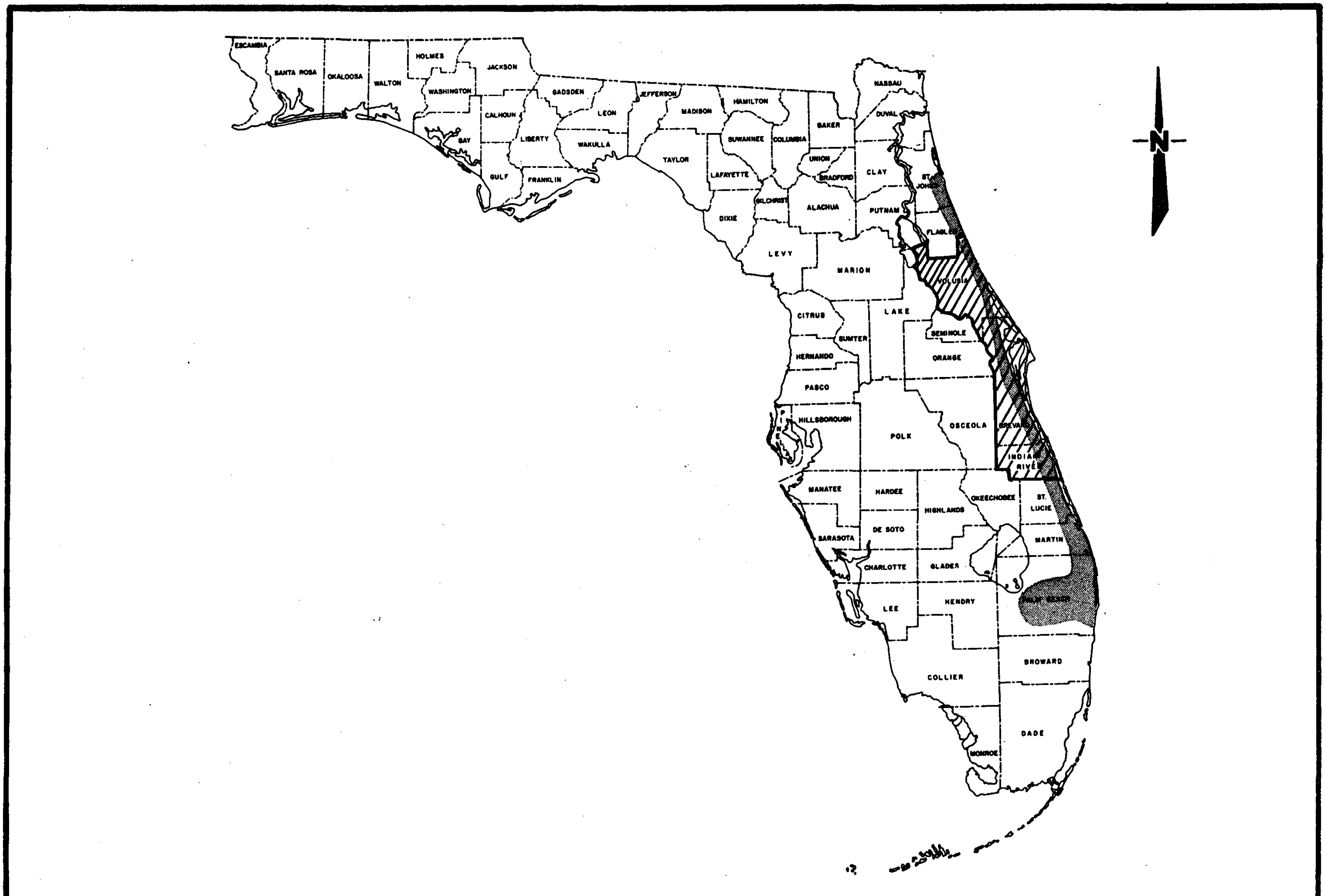


Figure 20. Areal extent of the Anastasia Formation in Florida (from Vernon and Puri, 1964)

eight miles inland from the coast in St. Johns and Flagler counties, respectively. They postulated that these were stringers of the Anastasia Formation. Between Ten-Mile Ridge and the Atlantic Coastal Ridge in Indian River County, thick Anastasia deposits overlie the shallow-rock zone. West of Ten-Mile Ridge, the Fort Thompson Formation forms the inland equivalent of the Anastasia, with less cemented coquina lenses, progressively greater percentages of sand, and some very sandy limestone beds (Bermes, 1958).

STRUCTURE

Faulting

The Eocene strata in the study area generally dip to the south and southeast and increase in thicknesses toward the coast (Figures 12-16). In western Brevard County the top of the Ocala Limestone displays locally variable depths which are related in some instances to local structure. A northward trending fault was identified in this area by Vernon (1951, p. 57-58, Plate 2), Brown et al (1962, p. 24), and Bermes (1958, p. 8-9). It occurs along the St. Johns River in Brevard County and extends to the south edge of the Puzzle Lake area in Volusia County (Figure 15). This fault is referred to as the St. Johns fault. It forms the eastern edge of the Osceola low a wedge-shaped down-thrown block open on the southwest (Vernon, 1951). The Osceola low is filled with Miocene clay, coquina and other beds of varying lithology. It forms a dam-like structure that affects ground water flow to the east. In south Brevard and western Indian River counties, the extension of the St. Johns fault coincides approximately with the western extent of the Suwannee Limestone.

Bermes (1958) hypothesized that three vertical faults exist along the eastern margin of Indian River County. He based this hypothesis upon the change in the apparent dip of the Ocala Limestone from nearly horizontal to "more than 70 feet per mile", the thickening of the Ocala limestone, and the presence of Oligocene rocks not found elsewhere in the county. He postulated that two of these faults strike roughly parallel to the present coastline and the third strikes northeast through Wabasso Beach.

Subsequent work by Schiner et. al. (1988) indicates that only one of these faults exists. It parallels the Indian River and extends approximately halfway through the county from the St. Lucie County line. The configuration of the top of rock and the thickness of the units as presented in Figures 12-18 also supports Schiner et al.'s placement of this fault.

HYDROGEOLOGY

The ground-water flow system in the study area is characterized by a vertical sequence of three individual aquifer systems - the Floridan, intermediate, and surficial aquifers. These aquifers are separated in varying degrees by less permeable confining units that influence the extent to which water is exchanged between the aquifers. The two primary confining units are those that separate the Floridan aquifer into an upper and lower aquifer system and the one that separates the Floridan from the intermediate and surficial aquifers. Although understanding the ground water system requires that the entire sequence of aquifers and confining units be viewed as a whole, each will be described separately in this report.

OCCURRENCE OF CONFINING BEDS

Minor confining beds of fine-grained materials occur locally throughout the surficial clastic deposits. Of major significance is the Hawthorn Formation (Figure 18) which lies beneath the clastic deposits. The clays of the Hawthorn Formation comprise the principal confining unit for the Floridan aquifer.

The thickness and vertical permeability of the Hawthorn clays are the principal variables that influence the rate at which water is exchanged between the Floridan aquifer and the overlying clastic deposits. The direction of the exchange depends on the difference in hydraulic head between the two units.

In Volusia County the Hawthorn Formation is thin to absent. Consequently, moderate to large amounts of water are exchanged between the Floridan and the surficial aquifer (see Figure 28). Ground water moves downward from the surficial aquifer to the Floridan aquifer throughout most of the County. The direction of exchange is reversed in the coastal zone and near the St. Johns River where hydraulic head in the Floridan aquifer is greater than that in the surficial aquifer.

Throughout much of north Brevard County the Hawthorn Formation is less than 50-feet thick. Over most of this area ground water moves vertically upward from the Floridan aquifer to the surficial aquifer. Near Titusville, the absence of the Hawthorn and the presence of a coastal ridge result in a reverse of this hydraulic gradient. The thickness of the Hawthorn Formation increases to the south and east, resulting in a decline in the rate at which water is exchanged between aquifers.

In Indian River County, the thickness and areal extent of the Hawthorn is sufficient to minimize or eliminate any exchange of water between the Floridan and surficial aquifers.

Hard, low permeability, dolomitic limestone beds in the Avon Park Limestone are the second important confining unit in the ground water system. Locally within the study area these beds effectively separate the Upper Floridan aquifer (Miller, 1986) into an upper and lower zone. Data on the depth to the top of the lower permeability dolomite beds within the Avon Park Limestone is sparse.

FLORIDAN AQUIFER

The Floridan aquifer includes all limestone strata including the basal limestone unit of the Miocene (Hawthorn Formation), Oligocene (Suwannee Limestone), Eocene (Ocala, Avon Park, Lake City, and Oldsmar Limestones), and Paleocene (Cedar Keys Limestone) (Franks, 1982). The Floridan aquifer underlies the entire study area at a depth which increases towards the east and south (Figures 15 and 17). In Volusia County, the depth to the top of the Floridan aquifer increases from 20 feet below msl near DeLeon Springs to over 80 feet below msl at the coast. In northern Brevard County, this depth increases from 100 feet below msl inland to 200 feet below msl on the coast. Moving southward, the depth continues to increase to approximately 300 feet below msl near Sebastian Inlet. In Indian River County, the top of the Floridan lies at a depth of 300 to 600 feet below msl.

The base of the aquifer has been described by Miller (1982) as anhydrite beds approximately 2,100 to 3,200 feet below msl in the study area. These anhydrite beds are interbedded with carbonate rocks in the Cedar Keys Formation and create a low permeability zone of regional extent.

Hydraulic Properties

Table 4 presents some calculated values for transmissivity (T), storage coefficient (S), and leakance (L) for the Floridan aquifer within the study area. Transmissivity measures the rate at which water moves through a unit width of the aquifer under a

Table 4. Transmissivity, Storage and Leakance Values for the Floridan Aquifer in Volusia, Brevard, and Indian River Counties.

County	Transmissivity T (gal/d/ft)	Storage Coefficient S	Leakance L (gpd/ft^3)	Penetration of Open Hole (ft)	References
Volusia					
	Northeast Volusia				
	12,200 & 14,100	$1.5x10^{-4}$ & $1.5x10^{-3}$	$1.0x10^{-3}$ & $2.9x10^{-3}$	40 & 50	Wyrick & Leutze (1955)
	81,000 & 200,000			150 & 120	" " "
	Daytona Beach Area - Upper Zone				
	28,000	$2.3x10^{4}$		66	Wyrick (1960)
	310,000 - 370,000	$1.1x10^{-4}$ - $2.2x10^{-4}$		95 - 100	Wyrick (1960)
	160,000			145	Wyrick (1960)
	Western Daytona Beach Area				
	71,350 - 99,600	$1.8x10^{-4}$ - $2.2x10^{-3}$		Greater than 100	Russel & Axon (1980)
	New Smyrna Beach				
	57,000	$1.1x10^{-4}$		9	Wyrick (1960)
	40,000	$2.7x10^{-4}$		16	" "
	190,000			233	" "

Table 4. Transmissivity, Storage and Leakance Values for the Floridan Aquifer in Volusia, Brevard, and Indian River Counties. (Continued)

County	Transmissivity T (gal/d/ft)	Storage Coefficient S	Leakance L (gpd/ft^3)	Penetration of Open Hole (ft)	References
	Deland Area				
	55,000	3.4×10^{-4}		87	Wyrick (1960)
	46,000	2.0×10^{-4}		88	" "
	55,000	3.4×10^{-4}		88	" "
Brevard					
	North Brevard - Scottsmoor				
	300,000	8.0×10^{-4}		50 - 90	Brown et al (1962)
	South Beaches				
	80,000 - 173,000	1.4×10^{-3}		150	Post, Buckley, Schuh & Jernigan (1981)
Indian River					
	North Beaches				
	150,000	1.4×10^{-3}		450	Bermes (1958)
	36,000 - 56,000	1.1×10^{-3} - 5.0×10^{-4}		600	" "
	South Taxing District				
	370,000 - 460,000	3.9×10^{-4} - 5.4×10^{-4}	2.2×10^{-2} x 3.0×10^{-3}	700	Geraghty & Miller (1981)

unit hydraulic gradient. The storage coefficient is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. Leakance is the recharge rate per unit area per unit of head loss and is equivalent to the ratio of the vertical hydraulic conductivity (K') and the thickness of the confining beds (b').

The transmissivity of the Floridan aquifer within the study area (Table 4) varies significantly, ranging from 12,000 to 500,000 gallons/day/ft. These variations may or may not be representative of true variations in the transmissivity of the aquifer. True variations result from differences in lithology and saturated thickness of the aquifer. However, calculated values of transmissivity may also vary with, among other things, variations in the percentage of the total aquifer thickness penetrated by the wells used in pump tests from which data is generated as well as the method used for the analysis of the data. In general, transmissivities tend to be lower near the coast and highest in the western portion of the study area, especially west of the St. Johns River. Lichler et al (1968) reported values ranging from 500,000 to 4.3 million gal/day/ft for wells penetrating the Ocala or Avon Park, and Lake City zones, respectively west of the St. Johns River. In the three coastal counties referred to in Table 4, the most productive wells are in Indian River County south of Vero Beach. Transmissivities in the central Brevard County area were calculated from specific capacity data reported in Brown et al (1962).

Leakance values were rarely reported in the works surveyed. The data available indicates a leaky regional aquifer system with water moving rapidly through surficial recharge areas to the Floridan aquifer. Within the Floridan, leakage between the upper and lower zones is very small (Tibbals, 1981). At Aquarina in south Brevard County, upper zone waters accounted for less than six percent of the daily withdrawals from the lower (Avon Park) zone of the Sebastian Lens (Post, Buckley, Schuh & Jernigan, 1981).

Potentiometric Fluctuations

The potentiometric surface of the Floridan aquifer defines the level to which ground water will rise in tightly cased wells that penetrate the aquifer. When this level is higher than land surface elevation, Floridan aquifer wells, unless capped or valved, will free flow at land surface. In the study area, land elevations are generally lower than the potentiometric surface and free-flowing wells exist.

The potentiometric surface of the Floridan aquifer displays seasonal, annual, and long-term fluctuations. Figure 21 illustrates the water level fluctuations over a 29-year period (1955-1983) at a well in Daytona Beach. The typical seasonal fluctuation includes a decline in water level during the spring which ends in May, followed by a water-level rise during the summer and continuing into October. This pattern is directly related to the seasonal dry and wet periods characteristic of the area.

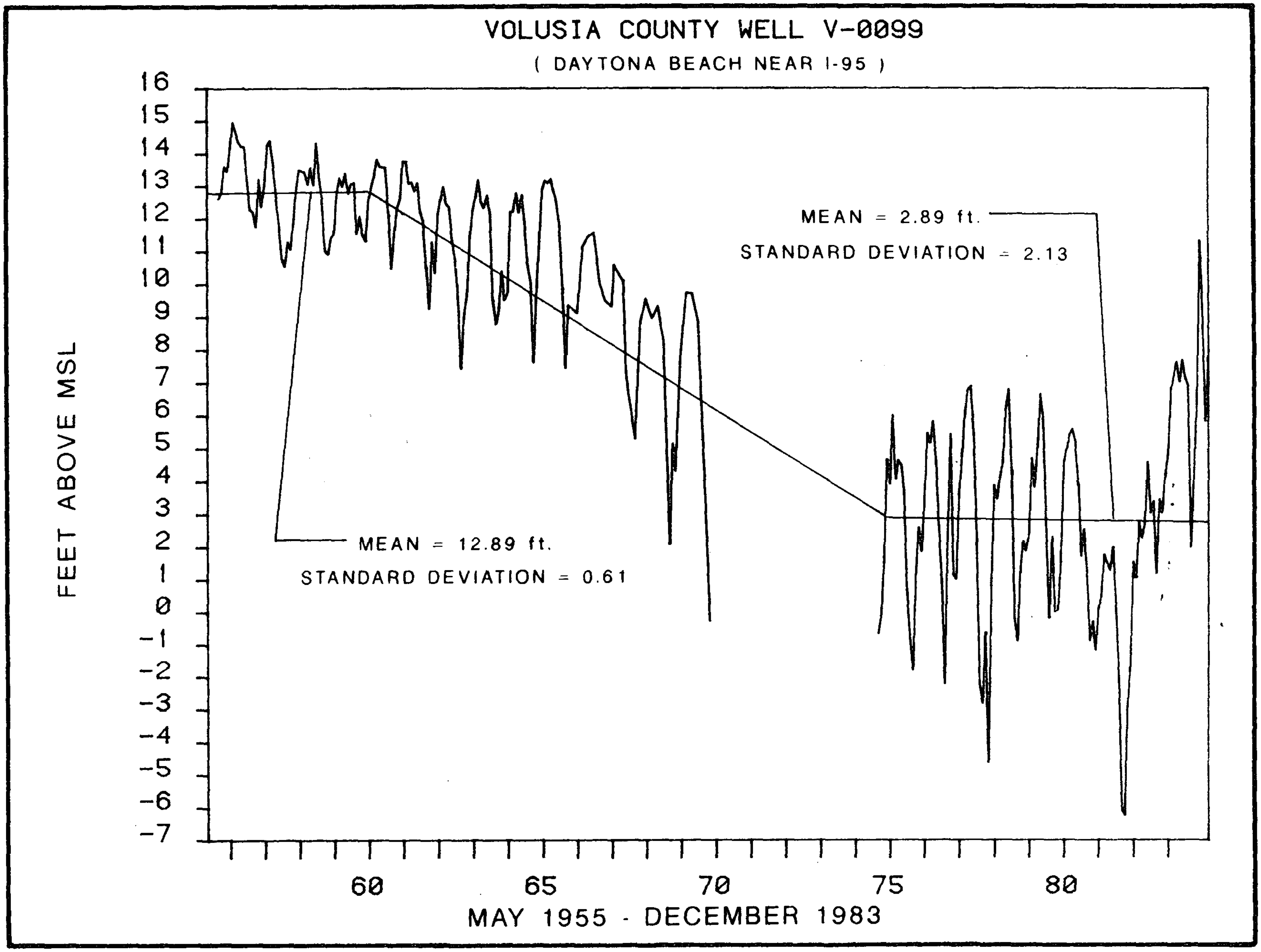


Figure 21. Water level fluctuations for well V-0099 in Daytona Beach, Volusia County.

Annual fluctuations are also clearly evident in Figure 21. During 1977-1978 water levels fluctuated 12 feet at V-0099 with a low of approximately 4.6 feet below msl. A prolonged dry period occurred at that time due to a delay in summer rains. Water levels were lowest at approximately 6.2 feet below mean sea level during 1981-1982. The low corresponded to the peaks of the 1981 drought.

Long-term fluctuations or tends are also clearly evident in Figure 21. These trends are approximated by the straight lines, which were obtained by fitting the data to a linear regression (Minitab, 1981). Between 1956 and 1960, the annual mean water level was 12.86 feet with a standard deviation of 0.61. During the next 15 years, water levels declined relatively uniformly at a rate of 0.66 ft/yr to 2.89 feet. Since 1975 water levels have fluctuated about this value with a standard deviation of 2.13. Standard deviation is a measure of the spread of values about the mean.

Figures 22(a) and (b) show well hydrographs for long term sites at the Cocoa well field in Orange County (Well No. OR0010, Figure 22a) and at Cocoa in Brevard County (Well No. BR0202, Figure 22b). These hydrographs show that since the mid 1970's, mean water levels have remained approximately constant at these sites. Prior to 1960 for Cocoa A and 1961 for Cocoa, water levels were approximately 4 to 5 feet higher, but declined during the next 15 and 14 years at rates of 0.28 and 0.35 ft/yr respectively.

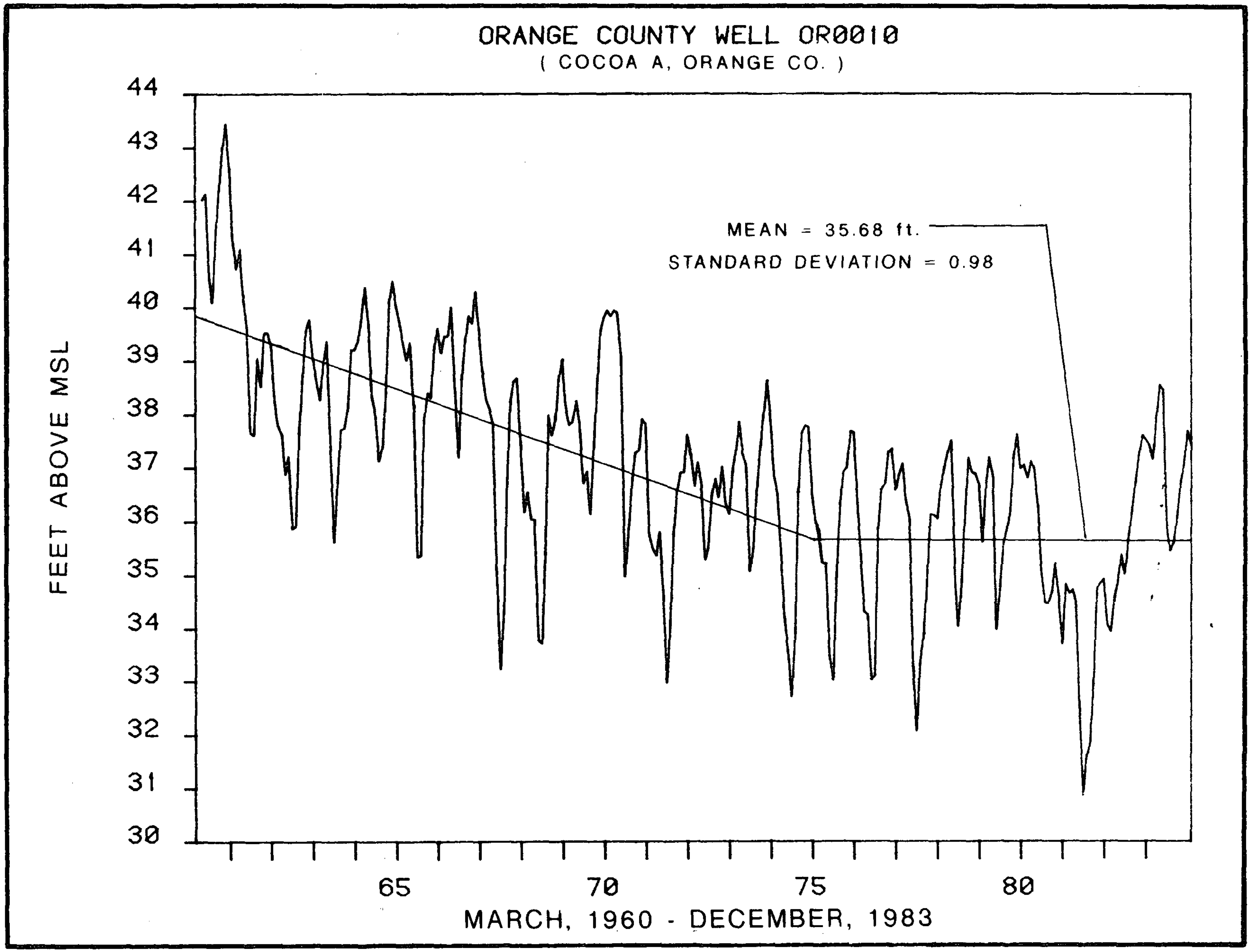


Figure 22a. Water level fluctuations for well OR0010 (Cocoa A) in Orange County.

Figure 22b. Water level fluctuations for well BR0202 at Cocoa in Brevard County.

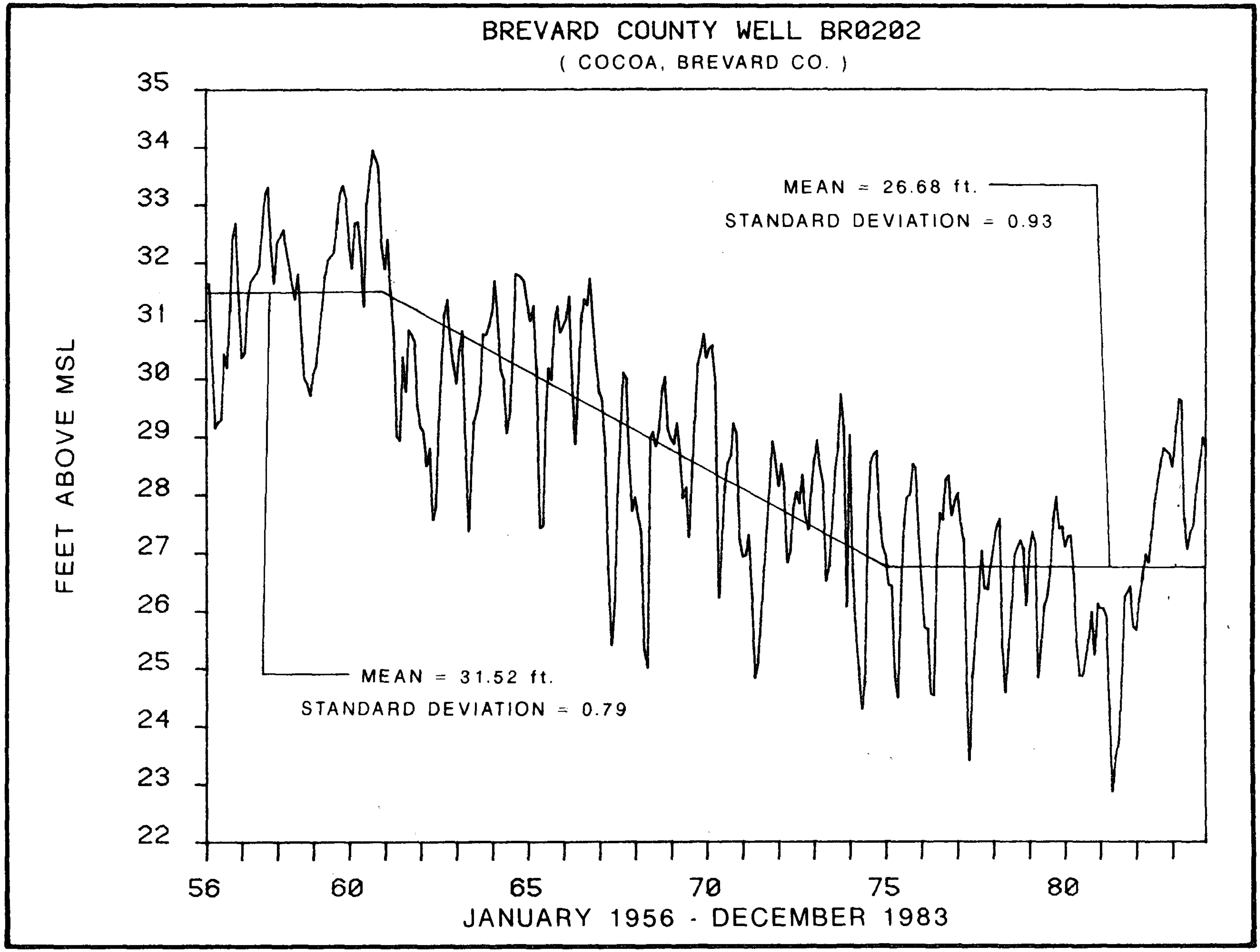


Figure 23 shows a hydrograph for a Floridan well near Melbourne which displays a similar pattern. Water-level fluctuations are typical of those in southwest Brevard County where citrus and agricultural development occur. Prior to 1955, the annual mean water level was 47.47 feet with a standard deviation of 0.27. During the next 18 years, water levels linearly declined at a rate of 0.43 ft/yr to 39.79 feet. Since 1973 they have fluctuated about this value with a standard deviation of 1.43.

Figure 24 shows fluctuations in the maximum September water levels for two Floridan aquifer wells at Vero Beach. The trends here also parallel those in Brevard County. At IR-313, September water levels declined approximately eight feet between 1959 and 1972, but were three feet higher in 1983 and 1984 than in 1972. The change in Floridan water levels at these wells is due to a change in withdrawals resulting from changes in land use. Citrus areas have progressively been pushed westward in Indian River County (Les Crain, 1970). Since the 1970's, citrus groves have been replaced by development at Vero Beach. As a consequence, withdrawals from the Floridan aquifer have decreased.

The above long-term changes in Floridan water levels are due to increased withdrawals caused by population growth at Daytona Beach and Cocoa (figure 21 and 22a) and agricultural expansion for citrus development, coupled with low rainfall, in western Brevard and eastern Indian River counties (figure 22b, 23, 24). Both population growth and citrus development increased during the 1960's. Rainfall during this period was normal at Daytona

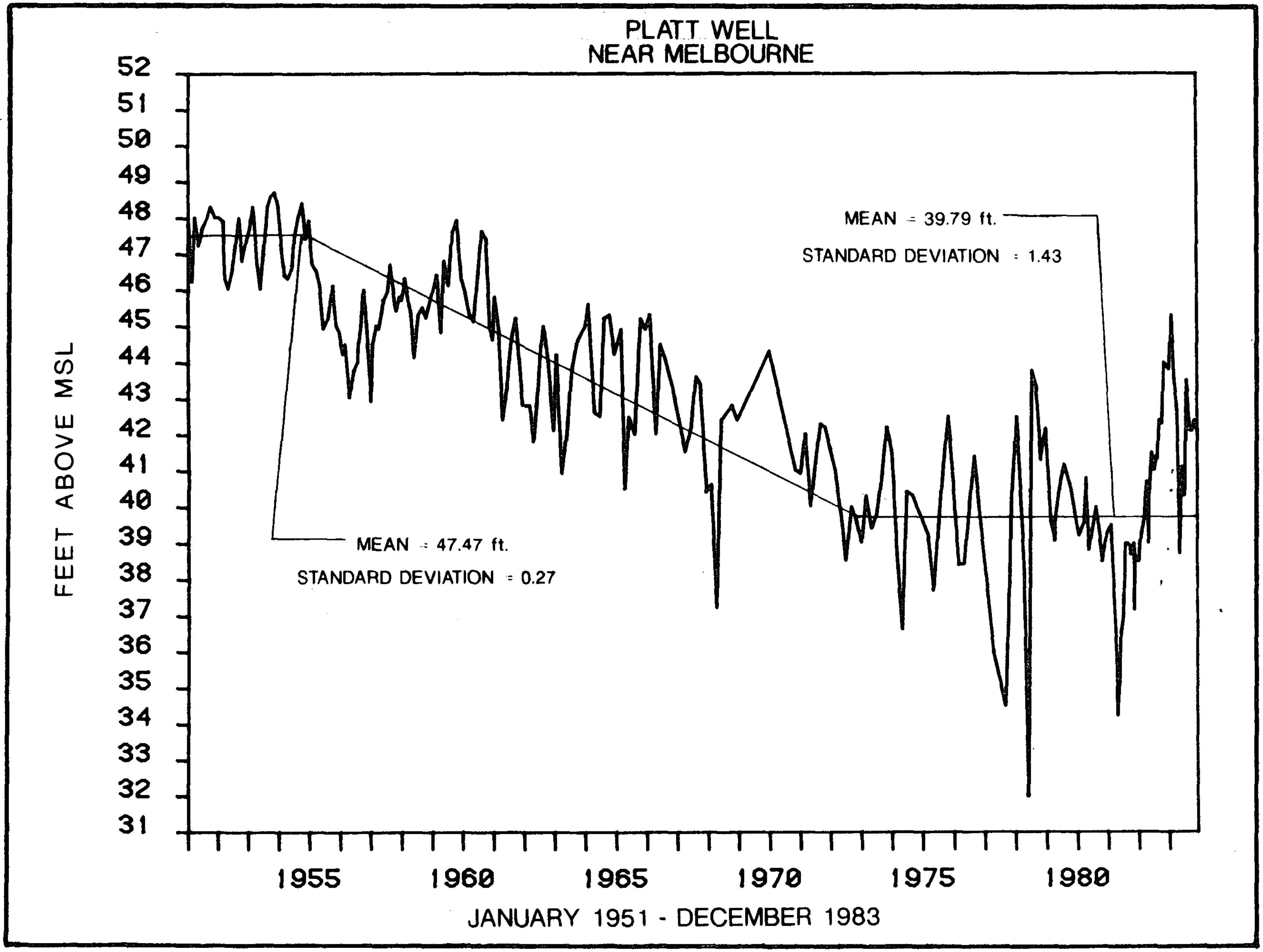


Figure 23. Water level fluctuations for the Platt well, near Melbourne in Brevard County.

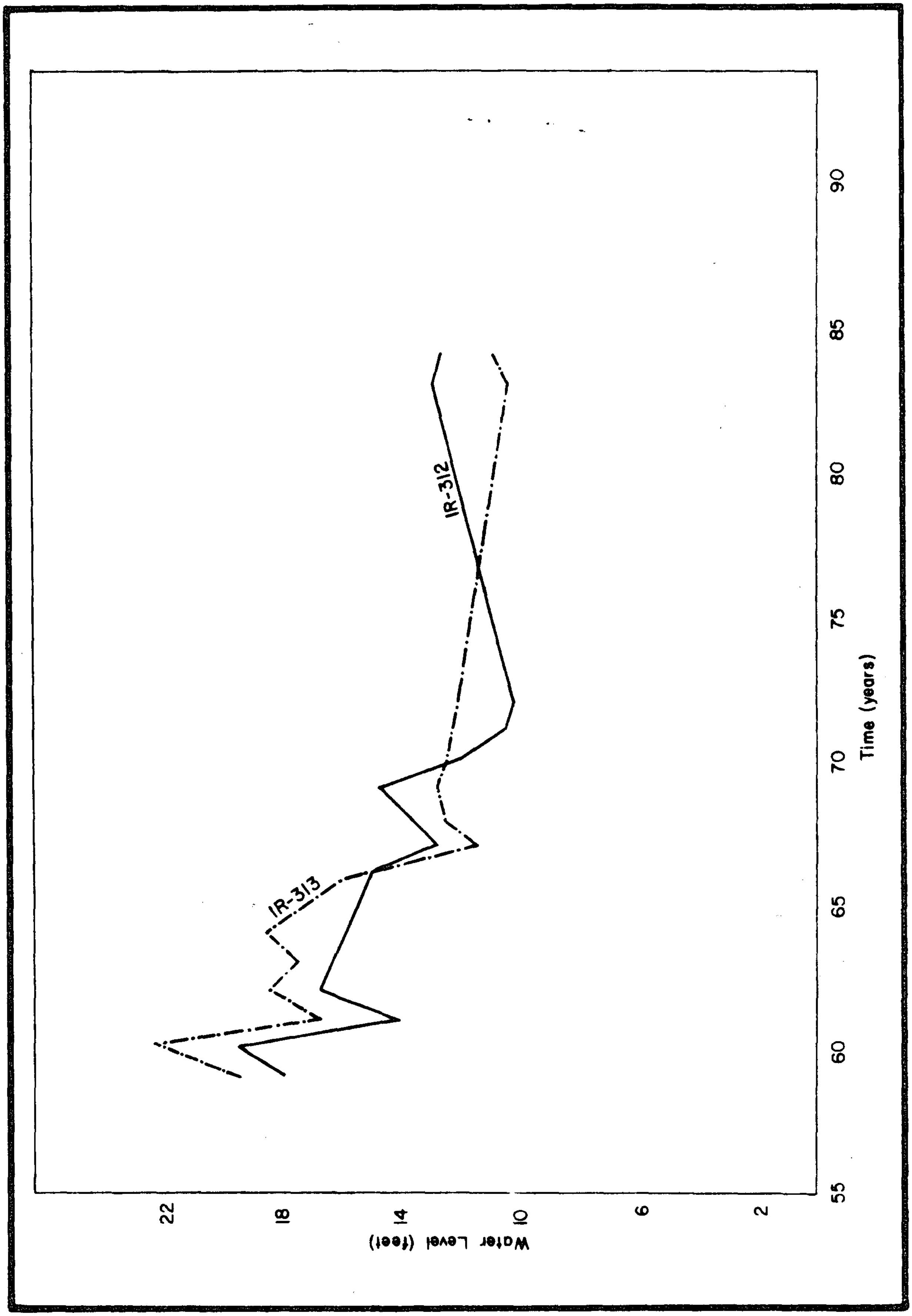


Figure 24. Fluctuations in the maximum September water levels for wells IR-312 and Ir-313 at Vero Beach, Indian River County.

Beach in Volusia County, but below normal at Sanford, Melbourne, and Vero Beach in Seminole, Brevard, and Indian River counties respectively.

Inspection of each of the above hydrographs indicates that following a period of drought during 1981, water levels rose significantly during 1982 and 1983. During 1982-83 rainfall was above normal.

The potentiometric surface of the Floridan aquifer in the study area in May 1981 is shown in Figure 25. Potentiometric highs occur along the western boundary of the area mapped in Figure 25. The surface is lowest along the coast between Ormond Beach and New Smyrna Beach, where it is 0 to 10 feet below sea level but increases to 30 feet above sea level at Sebastian Inlet. In Volusia County, ground water withdrawals from well fields located along the coast create large depressions in the potentiometric surface from Ormond Beach south to New Smyrna Beach. Along the barrier island in south Brevard County, declines in the potentiometric surface reflect the withdrawals from small diameter irrigation wells which exceed a concentration of 1000 per square mile.

Figure 26 shows the potentiometric surface of the Floridan aquifer in the study area in 1936 prior to the period of rapid growth and development (Johnston et al, 1980). Figure 27 shows the change in potentiometric levels between 1936 and May 1981. Figure 27 was constructed by the intersection of contours method, by subtracting the May 1981 potentiometric surface from the 1936 potentiometric surface.

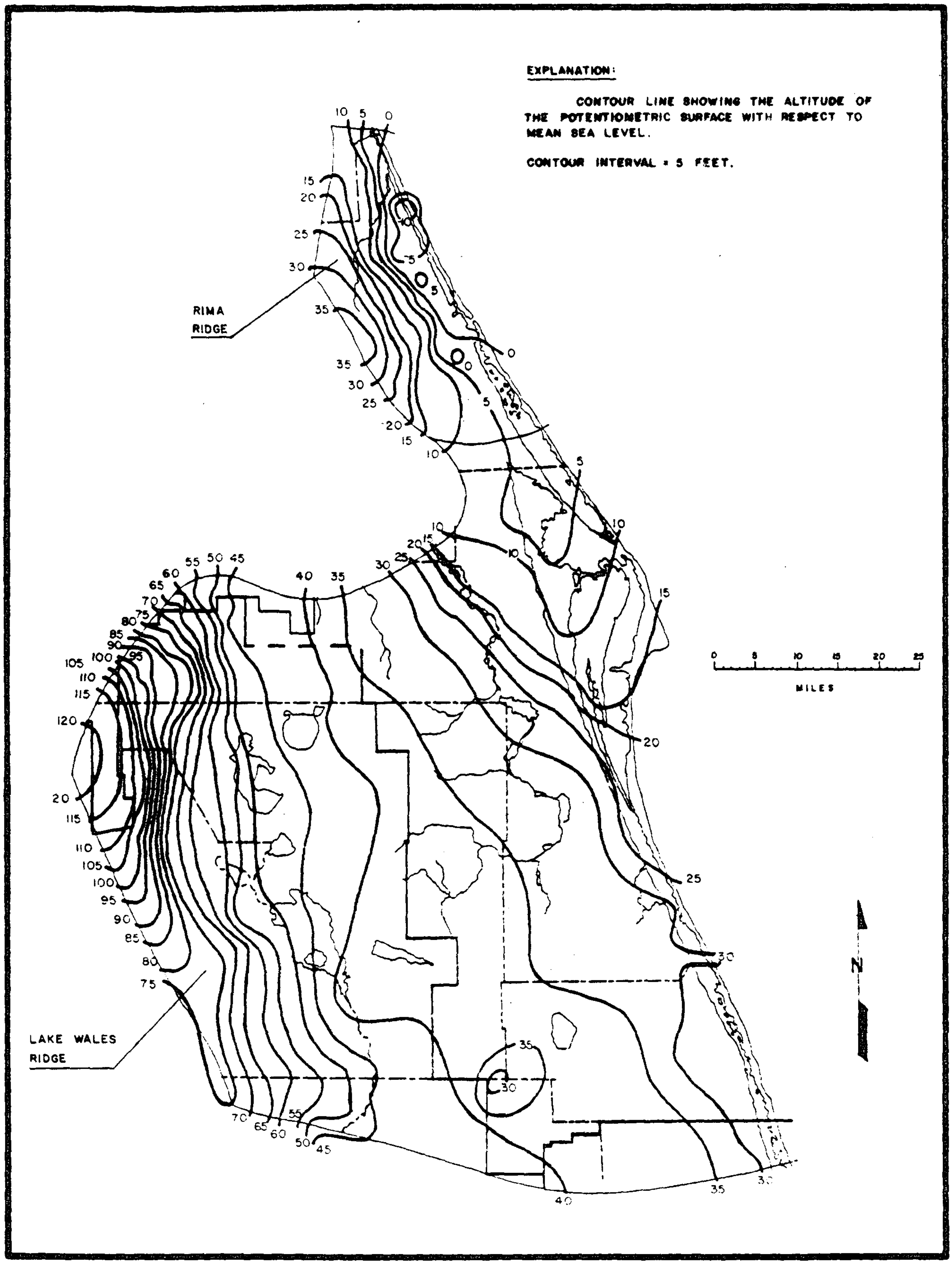


Figure 25. Potentiometric surface of the Floridan aquifer for May 1981 (from Schiner and Hayes, 1981a).

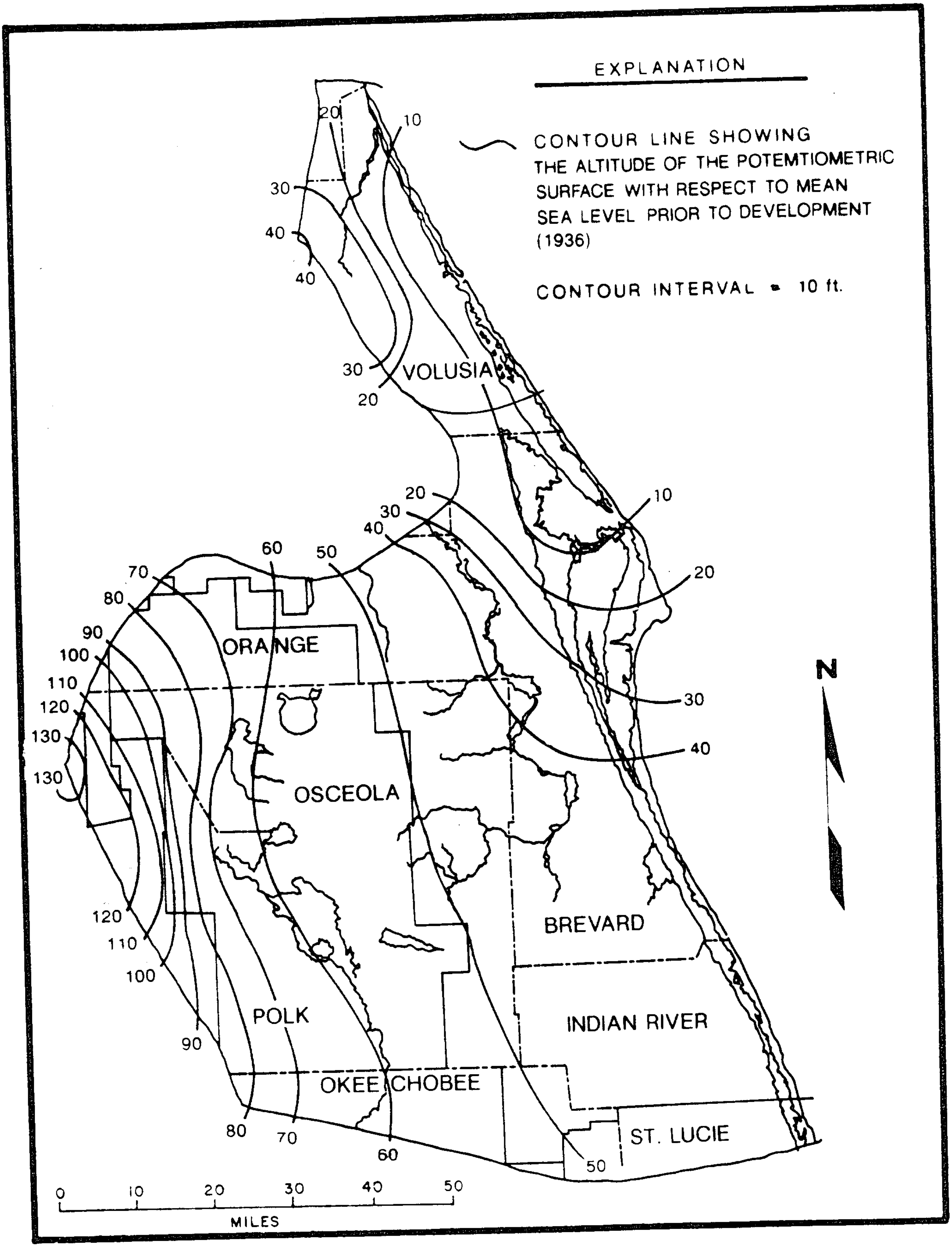


Figure 26. Potentiometric surface of the Floridan aquifer prior to development, 1936 (from Johnston et. al, 1980).

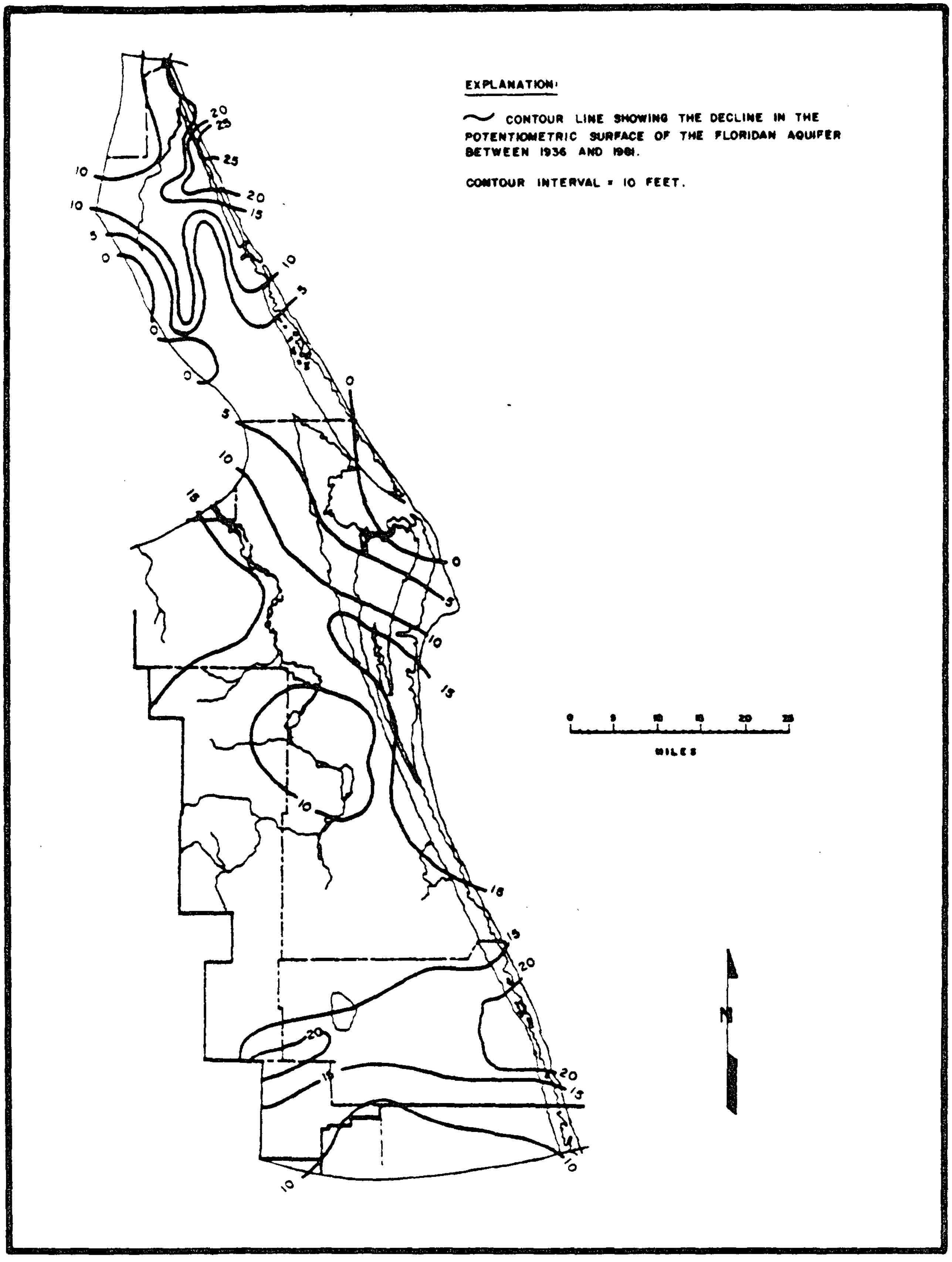


Figure 27. Decline in the potentiometric surface of the Floridan aquifer from 1936 to 1981 (data from Johnson, et.al. 1980; Schiner and Hayes, 1981a).

The potentiometric surface along the coast has declined 15 to 20 feet between 1936 and May 1981. Because 1981 was a record dry year the changes in the potentiometric surface from 1936 to 1981 represent the maximum change for the period of record. The change amounted to 10-15 feet in southwest Brevard and 15-20 feet in western Indian River County. Seasonal variations in these areas differ by a maximum of five to seven feet as seen by comparing the potentiometric surface in May and September for 1981 and 1982 (Figure 25 and Appendix I). Taking these seasonal variations into account, the change due to development between 1936-1981 is 5-10 feet in southwest Brevard County, and 10-15 feet in western Indian River County. As shown on the previous hydrographs, most of this change occurred prior to 1970. In fact, the potentiometric surface in Indian River County for May, 1970 (Les Crain, 1975: p. 29) approximates the potentiometric surface for May, 1983 in western Indian River County but is 0 to 5 feet lower in eastern Indian River County. Water levels in eastern Indian River County were less than 25 feet above msl east of I-95 between Wabasso and the St. Lucie County line. This may be due largely to the reduction of citrus acreage in this area from 1970 to 1983.

Head Relationships Within the Floridan Aquifer

The data available indicate that potentiometric elevations in the lower zone of the Upper Floridan aquifer are greater than in the upper zone. The data further suggests that the head differentials between the two zones increases with water use. For example, west of the Tomoka River in Volusia County, water levels in the upper and lower zones are within a few feet of one another (Wyrick, 1960: Skipp, 1985 personal communications). Except for New Smyrna Beach and the western well field for Daytona Beach, all of the well fields withdrawing more than 0.10 MGD of ground water from the Upper Floridan aquifer in east Volusia County are located east of the Tomoka River. Wyrick (1960) reported that at the Daytona Beach wellfield in 1955 and 1956 the water level at well 911-104-09 (open hole interval 480 to 500 feet below LSD) was four feet higher than that at 911-104-04 (open hole interval 100-235). However, after the Daytona Beach well field started pumping at about four to seven million gallons a day in February 1957, the above head differentials increase to eight feet (Wyrick, 1960; pg. 33). The increase resulted from lowering the water levels in the upper zone of the Upper Floridan aquifer. There was no corresponding lowering of water levels in the lower zone after pumping for nine months.

Since 1957, head differentials between lower and upper zone wells east of the Tomoka River at Daytona Beach have increased. In 1977, Russell and Axon (1978) noted a 15 foot difference in water levels in these lower and upper zone wells. The water level in the upper zone well changed from 12 feet above msl in 1955 to five feet below msl in 1977. In the lower zone well, the water level decreased from 17 to 10 feet above msl during the same period. The differences are the result of increased ground water withdrawals from both zones, the larger portion of which came from the upper zone.

Geraghty and Miller (1981) noted a difference in water level between the upper and lower permeable zones of the Upper Floridan aquifer in Indian River County. On December 15, 1980 water levels of 31.5 and 35 feet above msl were measured in wells with open hole intervals between 381-740 feet and 850-900 feet, respectively. Each well is finished into the Avon Park Limestone, but only the latter penetrates the lower permeable zone.

Directon of Ground-water Flow - Recharge and Discharge

Ground water flows from areas of higher potential (head) to those of lower potential. Areas of higher potential generally coincide with recharge areas. Such areas occur primarily where the rocks of the Floridan aquifer are exposed at or near land surface, where sinkholes commonly occur or where the confining unit is thin. Low potential areas generally coincide with discharge regions and low lying coastal areas. Movement is in the direction of greatest gradient or at right angles to potentiometric contours. In the study area, ground water flow is primarily to the east and northeast.

A significant deviation in the direction of ground water movement occurs in the northern section of Brevard County along the Indian River. Water moves towards the northeast in areas that are west of the Indian River and towards the northwest in the areas that are east of the Indian River. This area is one where substantial volumes of water leak from the Floridan aquifer to the overlying clastic deposits.

The potential for water movement varies both horizontally and vertically. Of interest is not only the variation in potential in a particular aquifer but also the variability in potential between aquifers. Recharge and discharge areas are determined, in part, by the latter. Recharge to the Floridan occurs where the potential in the surficial aquifers is greater than the potential in the Floridan; discharge occurs where this condition is reversed.

Figure 28 shows recharge and discharge areas for the Floridan aquifer in and around the study area. The recharge values were assigned after studying the evaluations of Wyrick (1960), Knochenmous and Beard (1971), Visher and Hughes (1969), Bush (1978), Stewart (1966, 1980), Lichtler (1968, 1972), Pride et al (1966), Bishop (1956), Knochenmous and Hughes (1976), Frazee (1980), and Grubb (1978). Although values were derived for each geographical area, these values must be considered approximations of annual recharge which are affected by rainfall variability, land cover, and localized ground water withdrawals. The values are considered to be reasonable for an average rainfall year.

In general, areas of significant recharge to the Floridan aquifer meet several basic criteria: (1) the principal confining unit (Hawthorn Formation) thickness is less than 50 ft. or is breached; (2) the hydraulic head in the surficial aquifers is significantly greater (more than 5 feet) than that in the Floridan aquifer; and (3) clastic materials overlying the

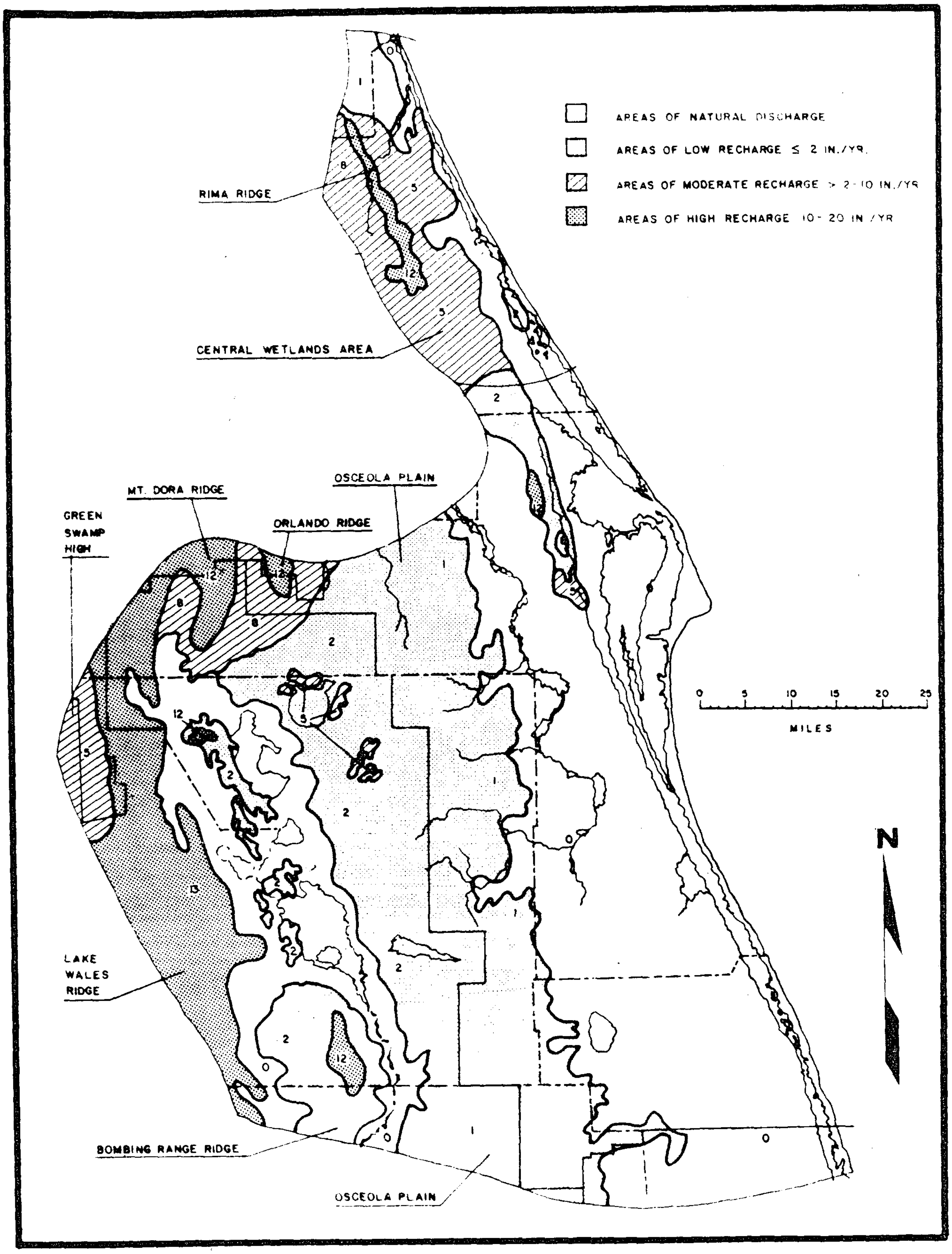


Figure 28. Recharge and discharge areas for the Floridan aquifer in and around the study area. Modified from Florida Dept. of Natural Resources Map Series 98.

Hawthorn or limestone strata have a minimal percentage of clay and excellent infiltration characteristics. The following six areas satisfy the first criteria (see Figure 18) and are areas of high (10-20 inches/yr) recharge: (1) Rima Ridge, (2) Geneva Hills, (3) Orlando Ridge, (4) Mt. Dora Ridge, (5) Lake Wales Ridge, and (6) Bombing Range Ridge. Only Rima Ridge lies within the study areas; the others lie to the west.

Natural discharge from the Floridan aquifer occurs throughout the project area. Discharge can also occur as well withdrawals, both controlled and free flowing. It occurs as leakage to overlying formations, or discharges to offshore springs wherever the potentiometric surface is greater than the elevation of the water table in the surficial aquifer. Most of Brevard and Indian River counties are discharge areas. In Volusia County, the coastal regions are discharge areas.

In areas where the Hawthorn Formation is absent or intermittent, upward leakage from the Floridan aquifer may create surficial aquifer water quality problems. The St. Johns River Basin north of Lake Poinsett in western Brevard County is an example. Here, discharge of saline water from the Floridan aquifer contaminates the shallow aquifer.

INTERMEDIATE AQUIFER SYSTEM

The intermediate aquifer system includes all rocks that lie between the overlying surficial and the underlying Floridan aquifer systems. These rocks are of Miocene Age and consist of fine grained clastic deposits interlayered with carbonate strata.

In places this aquifer system yields little or no water, has low permeabilities, and acts as a confining unit. In other places, this aquifer yields moderate amounts of water. This aquifer is artesian and is commonly referred to as a secondary artesian aquifer.

This aquifer consists of thin lenses of sand, shell, and limestone within the Hawthorn Formation. In Volusia and north Brevard counties, where Hawthorn deposits are thin or absent, little is known about intermediate aquifers. In north-central Indian River County the intermediate aquifer occurs as a thin zone less than 20 feet thick. According to Bermes (1958), "This aquifer yielded water by natural flow, but after a few years its yield decreased, and the wells were deepened to the Floridan aquifer".

In 1951, Bermes (1958) measured a water level of 38 feet in an intermediate aquifer well near Fellsmere. For comparison, he also recorded a water level of 49 feet for a Floridan well (SJRWMD well no. IR-258) in the area. During the next 31 years, the potentiometric surface in the Floridan aquifer declined 16 feet, but in the intermediate aquifer, the water level decreased only an estimated six feet.

The intermediate aquifer is recharged by water that leaks through the surrounding beds of low permeability. In Brevard and Indian River counties, recharge originates principally from the surficial clastic aquifer. Upward leakage from the underlying Floridan aquifer is insignificant in most areas. Discharge probably occurs as seepage to the east into the Atlantic Ocean.

SURFICIAL AQUIFER SYSTEM

The surficial aquifer system consists of materials younger than upper Miocene Age and includes well-indurated carbonate rocks, other than those of the Floridan aquifer system, that are at or near land surface. It includes the water table, shallow clastic, and shallow rock aquifers. These exist under unconfined conditions where clays and beds of low permeability are absent. In the system's deeper parts, semi-confined or confined conditions may prevail. The top of the laterally extensive and vertically persistent beds of much lower permeability in the Hawthorn Formation denote its base.

Shallow Rock Aquifer

The shallow rock zone overlies the Hawthorn Formation in Brevard and Indian River counties and is equivalent to the Tamiami Limestone of Pliocene Age. It is defined on drillers' logs and from geophysical interpretations as a water bearing hard limestone. Many municipalities such as Port Malabar, Malabar Woods, Sebastian Highlands, Bent Pines, Vero Beach, and Vero Beach Highlands withdraw water from the shallow rock zone for water supply.

Figure 19 shows the depth to the top of and areal extent of the shallow rock zone. The top of the shallow rock increases from 50 feet below mean sea level in the north and west to 100 feet below sea level at the coast near Satellite and Wabasso Beach.

The thickness of the shallow rock is variable and dependent on the erosional surface of the top of the Hawthorn. In general, it thickens to the west in northern Brevard County, whereas in Indian River and southern Brevard County it thickens to the east. This aquifer is thinner in north Brevard than in south Brevard or Indian River counties.

West of the Atlantic Coastal Ridge north of Vero Beach, water levels in the shallow rock aquifer are lower than those in the Anastasia Formation and other surficial aquifers. Consequently, the shallow rock aquifer receives recharge from these overlying units. East of the Atlantic Coastal Ridge it discharges to local domestic wells and by upward leakage into the overlying surficial aquifers.

The direction of ground water flow in the shallow rock aquifer is to the east and northeast at Port Malabar in Brevard County. In northern Indian River County the flow is toward the northeast, but in the southern part of the county flow is toward the southeast.

Values of the hydraulic properties of shallow rock aquifers in the study area are typified by those at Port Malabar. Transmissivity ranges from 7,600 to 15,800 gal/d/ft and averages 12,000 gal/d/ft. Average values for the storage coefficient and leakance at Port Malabar are 0.0002 and 0.01 gal/d/ft^3, respectively (Geraghty and Miller, 1982).

The average water level for the shallow rock zone for the period 1976 to 1982 is shown in Figure 29. Water levels are at a high of 25 feet above mean sea level near Fellsmere in northern

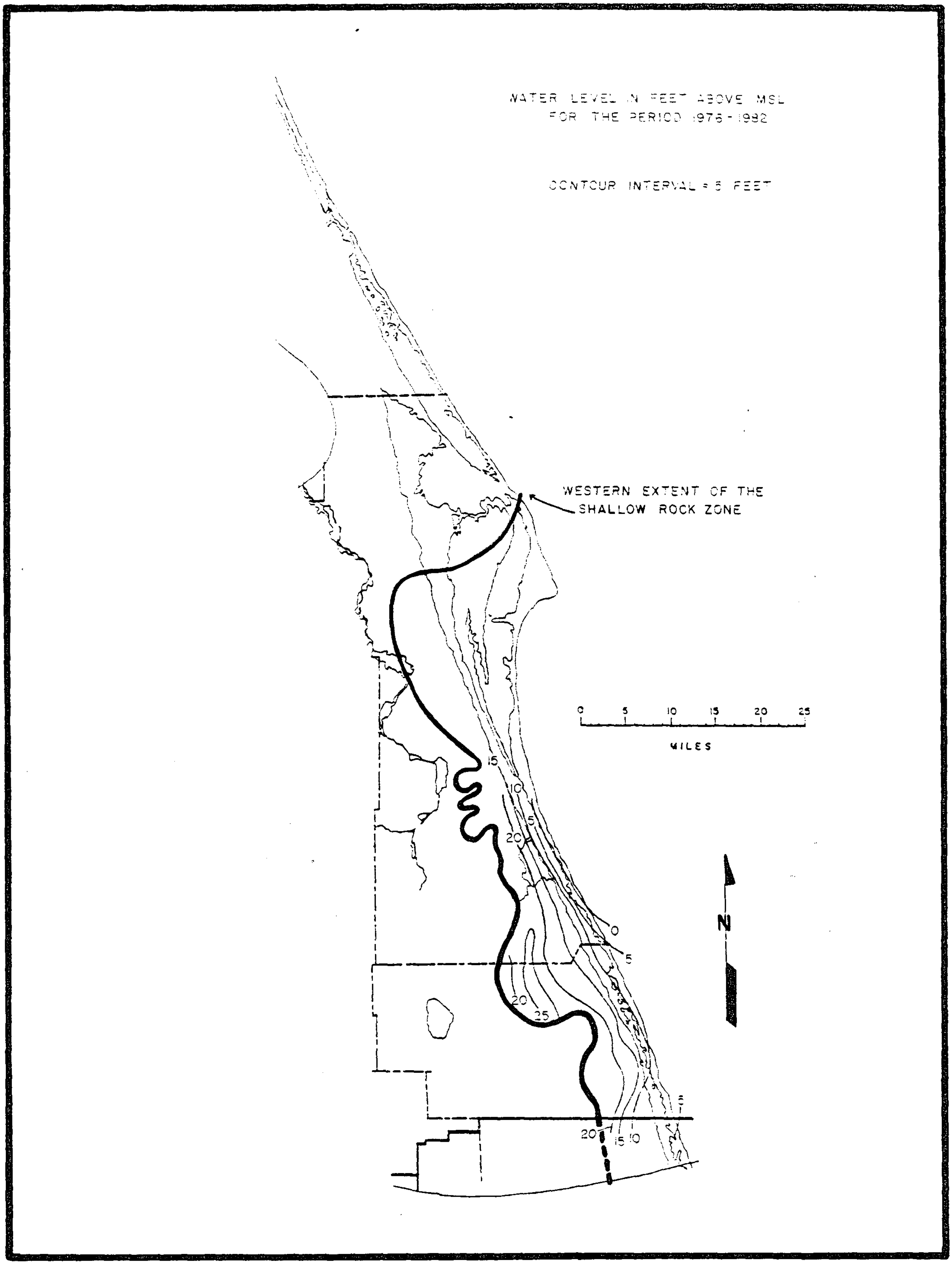


Figure 29. The average water level for the shallow rock zone for the period 1976 to 1982.

Indian River County and decrease to 0-5 feet above mean sea level at the coast.

Shallow Clastic Aquifers

Clastic aquifers are found throughout the study area and are associated with geomorphologic features such as ridges and coastal terraces. These aquifers provide water for domestic, irrigation, heat pump, and municipal supplies. Figure 30 identifies many productive clastic aquifers in the study area.

Table 5 gives representative values of hydraulic properties for the surficial aquifer in Volusia, Brevard, and Indian River counties. Transmissivity (T) and storage coefficient (S) values are charac- terized for both confined shell and water table aquifers. Transmissivities tend to be significantly higher in the Anastasia shell aquifer. Hydraulic conductivity generally averages 300 gal/d/ft^2 but may exceed 2,000 gal/d/ft^2 in shell deposits of large areal extent.

Water table aquifers are an extremely variable group of undifferentiated deposits with equally variable aquifer coefficients. Transmissivities in water table aquifers are generally less than in shell deposit aquifers, and storage coefficients average 10^{-1}, indicative of unconfined conditions. The greatest amounts of recharge occur locally where soil and sediment permeabilities are high and confining units such as hardpan are thin or absent.

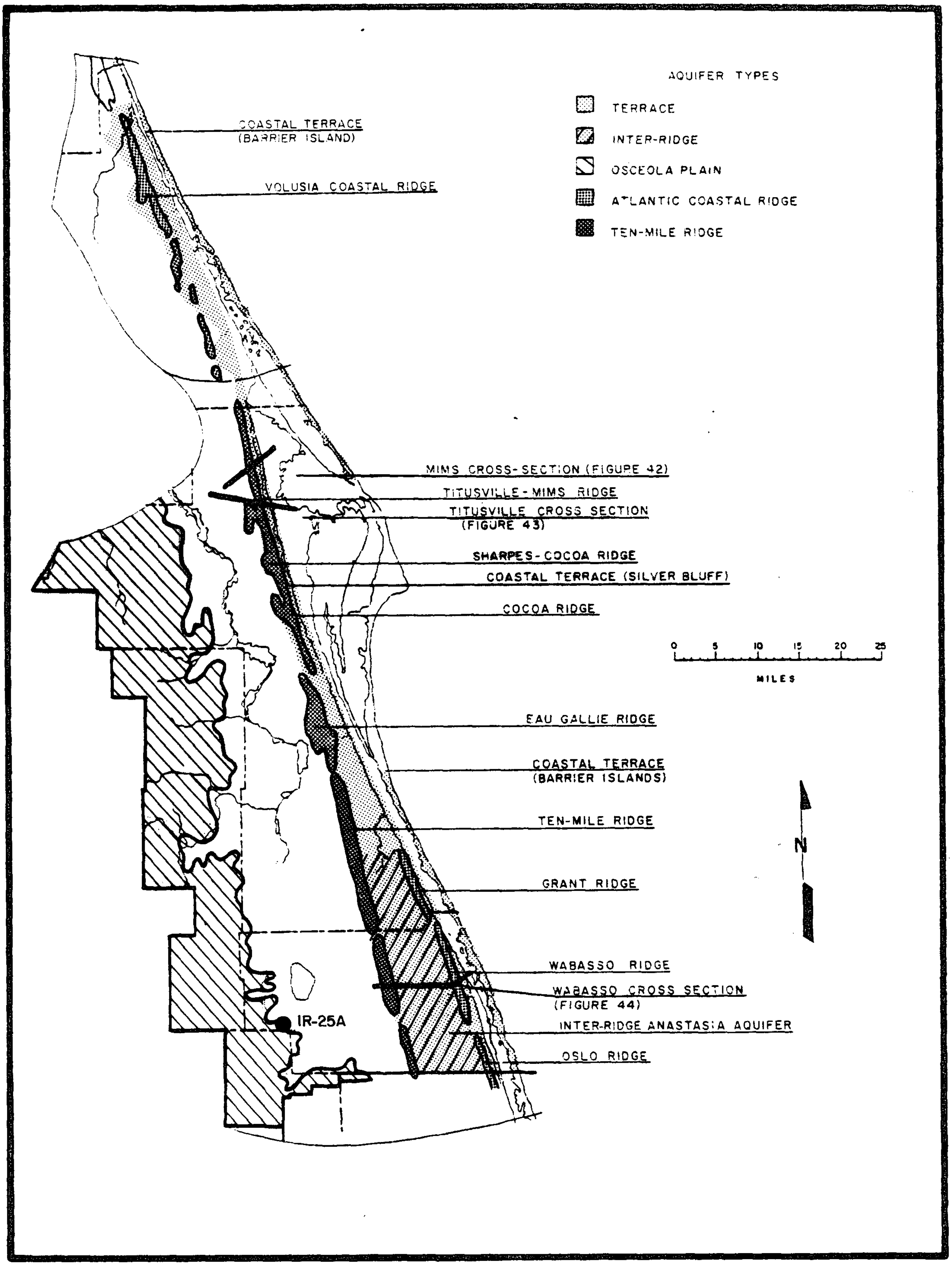


Figure 30. Clastic aquifers in the study area.

TABLE 5. Transmissivity, Storage Coefficient, Leakance, and Hydraulic Conductivity Values for the surficial clastic aquifers in Volusia, Brevard, and Indian River Counties

Area	Aquifer Type	Transmissivity (T) (Gal/d/ft)	Storage Coef (S) Non-Dimensional	Leakance (L) $(Gal/d/ft^3)$	Hydraulic Conductivity[1] (K) $(Gal/d/ft^2)$	Reference[2]
N.E. Volusia	Coastal Ridge					
	shell deposits	200-70,000	$1.6x10^{-4}$-$4.0x10^{-2}$	$8.5x10^{-2}$-$1.1x10^{-1}$	200-300	1
	water table	400-3000	$1.9x10^{-1}$			2
North Brevard	Coastal Ridge					
	shell deposits	2000-24,000	$2.5x10^{-4}$			3
	water table	4600-23,000	$1.3x10^{-1}$			4
South Brevard	Coastal Ridge					
	shell deposits	7600-17,160	$1.6x10^{-4}$ -$2.0x10^{-2}$	$1.0x10^{-2}$		5
	Coastal Terrace					
	water table	14,600			340	6
Indian River	Coastal Ridge					
	shell deposits	59,000	$1.4x10^{-2}$		840	7
	water table	11,500-14,500	$1.9x10^{-4}$		300-360	8
	Inter-Ridge					
	Anastasia Aq.	79,500	$1.0x10^{-4}$	$1.0x10^{-3}$	2600	9
Vero Bch Area	Coastal Ridge					
	shell deposits	17,700-47,100	$2.3x10^{-4}$ -$1.5x10^{-1}$		250-600	10

[1] Hydraulic Conductivity derived from T/m data, where T is transmissivity and m is the thickness of aquifer penetrated.

[2] See following page for References.

REFERENCES FOR TABLE 5

(1) Gomberg, D.N. (1978)

(2) Estimated from calculations made at Bulow Ruins in Frazee and McClaugherty (1979).

(3) Reynolds, Smith, and Hill (1981)

(4) Dawkins and Associates, Inc. (1980)

(5) Geraghty and Miller (1982)

(6) Post, Buckley, Schuh & Jernigan, Inc. (1981)

(7) Geraghty and Miller (1978)

(8) Estimated from the hydrograph recession method (Rorabaugh, 1960) using a USGS well at Winter Beach.

(9) Geraghty and Miller (1981)

(10) Gee and Jenson (1980)

Water levels fluctuate in response to changes in storage within the aquifer. The water that is stored in an aquifer is derived from rainfall. In water table aquifers, the absence of any competent overlying confining layer allows rain to infiltrate directly. Generally, water levels in such aquifers will rise very soon after a rainfall event. Conversely, a lack of rainfall will result in a lowering of water levels. The response time depends in part on the depth of the water table below land surface.

Within the study area, the depth to the water table generally ranges from 10-40 feet below land surface in the topographically high areas to near land surface in the coastal lowlands, swamps, or near surface water bodies. Perched water tables exist where clay lenses prevent normal infiltration to lower zones. Water levels in the shallow clastic aquifers are more sensitive to rainfall than are those in the Floridan aquifer. Discharge from shallow clastic aquifers occurs as natural seepage to surface water bodies, leakage to deeper zones where positive head differentials exist, evapotranspiration, and pumpage from wells.

Well yields vary with well depth, diameter, construction characteristics, seasonal water level fluctuations, and location. Land surface elevation is a very important factor influencing water quality in coastal areas, especially where salt water intrusion is a problem.

Many municipalities utilize water from the shallow clastic aquifer for water supply. They are Titusville, north Brevard

County at Mims, Port St. John, Barefoot Bay, Sebastian Highlands, Bent Pines, Vero Beach, and Vero Beach Highlands. Each of these municipalities also withdraws water from the underlying shallow rock aquifer except Titusville and north Brevard County at Mims, Port St. John and Barefoot Bay. The shallow rock zone is not present at Titusville and Mims.

Five different shallow clastic aquifers have been identified in the study area: (1) Terrace, (2) Atlantic Coastal Ridge, (3) Ten-Mile Ridge, (4) Inter-ridge, and (5) Osceola Plain. Each is representative of a different environment. Figure 30 shows the location of each of these aquifers.

(1) Terrace. Terrace aquifers occur on the barrier islands and portions of the Pamlico Terrace east of the Atlantic Coastal Ridge. The terrace deposits east of the Atlantic Coastal Ridge such as the Silver Bluff terrace and the eastern slopes of the Pamlico terrace, provide an important source of water for both domestic and irrigation uses.

Shallow fresh water lenses provide water to wells along most of the barrier islands. These lenses form as a result of the differences in density between fresh and salt water causing the fresh water to accumulate above the salt water. The salt water/fresh water interface is maintained at a point dependent on average rainfall, water levels, and land surface altitudes.

Shallow confining clay lenses provide some barrier to lateral and upward migration of saline water. In areas where these clay lenses are intermittent or missing, availability of potable supplies is dependent on regular rainfall replenishment to prevent intrusion resulting from pumping.

Volusia County. Terrace aquifers are tapped by small diameter wells throughout Volusia County, but withdrawals are most prevalent near Ormond-By-The-Sea, along the northeastern peninsula. Well depths range from 12 to 26 feet below land surface, and the wells are primarily used for lawn irrigation and/or heat pumps.

Brevard and Indian River Counties. In Brevard and Indian River counties the shallow clastic aquifer on the barrier island is used for public supply from Melbourne Beach in Brevard County south to Indian River Shores in Indian River County. Most shallow wells are located along or just west of the primary dune line where the thickest fresh water lens exists. Supply of potable water in this area is limited by the presence of salt water and extremely thin nature of the lens (less than 25 feet). Most wells in this corridor are used for domestic supplies although a few also provide irrigation water. Most lawn irrigation water, however, is withdrawn from the Floridan aquifer.

The amount of ground water flow within the surficial aquifer on the barrier islands is particularly sensitive to the daily tidal cycle. For example, the mean tide in the Atlantic Ocean is approximately 1.7 feet (Post, Buckley, Schuh, and Jernigan; 1981, p. 2-14). For comparison, water levels in the surficial aquifer at Aquarina vary one foot above msl during low tide in the drier months to a high of four feet during the rainy season. Using these water level values and mean tidal variation, Post, Buckley, Schuh, and Jernigan (1981) estimated a range of values for ground water flow of 90,000 to 400,000 gal/day. Approximately 70 percent of this flow is towards the Atlantic Ocean, east of the Aquarina site. The remainder (30 percent) flows toward the Indian River. At Aquarina, the average thickness, transmissivity, and vertical and horizontal permeability of the surficial clastic aquifer are 25.7 feet, 14,600 gal/d/ft, 205 and 507 gal/d/ft^2, respectively.

(2) Atlantic Coastal Ridge. Atlantic Coastal Ridge aquifers are found throughout the eastern portion of the study area. Because they underlie areas of higher land surface elevations, aquifer thickness is greater and water quality is generally better and more stable than that of the lower coastal terrace aquifers.

Volusia County. The Atlantic Coastal Ridge aquifers in Volusia County are relatively undeveloped due to their lack of reliability as a source of potable water. Water users will usually choose the Floridan aquifer when available to alleviate water quality problems and increase yields. The ridge system does store and provide recharge water for the coastal terrace aquifers to the east.

Brevard County. In Brevard County, clastic material beneath the Atlantic Coastal Ridge is thick enough (60-90 feet) to provide water for public supply. In the Titusville-Mims area of north Brevard County, a fresh water lens overlies the Floridan aquifer and is hydraulically connected to it. Brevard County

Utilities and the City of Titusville both withdraw water from this lens.

The Anastasia formation is the major producer of water for the Titusville wellfield. In the eastern part of the wellfield the Anastasia is a shell marl consisting of shell, sand, sandstone, lime, and clay. To the west, marl is overlain by coarse sand and shell deposits which produce water as good as or better than the marl. Recharge is high (12 inches/year, Frazee, 1984 personal communication) in the sand ridge area where some dunes are as high as 75 feet above msl, but low or non-existent in the low marshy areas. Good recharge areas correspond with land surface elevations greater than 20 feet above msl, which delineates the edge of the marshy areas. Frazee (personal communications, 1984) estimated a recharge of 10 inches/year for the Titusville well field area.

The average saturated thickness and permeability of the water table aquifer in the Titusville area is 90 feet and 17.3 gal/d/ft^2, respectively (Pittsburgh Testing Laboratory, 1979). Transmissivities range from 650 to 24,000 gal/d/ft and average 1,555 gal/d/ft; storage coefficients average 0.0005 (Reynolds, Smith and Hill, 1978). Water table elevations vary from 64 to 22 feet above msl. The potentiometric surface of the Floridan aquifer fluctuates between 10 and 15 feet above msl.

Differences between the water levels of the surficial and Floridan aquifers in the Titusville area create the potential for mixing of waters from each aquifer near a land surface elevation of 20 feet. For this reason, large withdrawals are located in areas above 30 feet msl where the fresh water thickness is greatest.

Because of poor water quality, wellfields have not been developed along the ridges in central Brevard County. From Bellwood south to Palm Bay, large concentrations of shallow wells are used for heat pumps, lawn irrigation, and domestic supply. Because of the low-volume of the withdrawals, saltwater intrusion has been minimal.

From Palm Bay south to Wabasso, the surficial aquifer is artesian wherever the natural flow has not been interrupted along the coastal ridge crest. Shallow clastic and shallow rock deposits at Port Malabar, are separated by a low permeability clayey sand approximately 10 feet thick. Clays and silty clays form a fairly extensive confining bed ranging from 10 to 40 feet in thickness and averaging 20 feet in thickness. Sands overlying the confining bed are too thin (6-10 feet) to be a potential source of water (Geraghty and Miller, 1982). At Port Malabar the surficial aquifer is comprised of sand, shells, and silts and ranges from 50 to 100 feet in thickness with an average thickness of about 80 feet.

Water levels in the shallow clastic aquifer in June, 1984 decreased from 18 feet above msl west of the Port Malabar wellfield to 3 feet above msl at the eastern edge of the field (Post, Buckley, Schuh, and Jernigan, Inc., 1984). Ground water flows to the east at an average horizontal velocity of 0.16 feet/day. The flow velocity is dependent upon seasonal rainfall patterns and pumping demands of the Port Malabar wellfield.

The shallow clastic aquifer at Port Malabar is recharged from rainfall at a rate of 18 inches/year, calculated as the difference between a mean annual rainfall of 55 inches and an evapotranspiration loss of 37 inches (Geraghty and Miller, 1982). This compares with an estimated average runoff of 17.1 inches/year from the Crane Creek drainage basin and 19.1 inches/yr from Turkey Creek (Lichtler, 1972).

<u>Indian River County.</u> At Vero Beach the Atlantic Coastal Ridge aquifer has excellent yields and is used for that city's water supply. Recharge to the shallow aquifer varies greatly, depending on rainfall and averages 16 inches annually at Vero Beach (Crain et al, 1975). Between Sebastian and Vero Beach, ridge areas provide significant recharge to coastal terrace aquifers along the Indian River shoreline.

A typical example of the effect of rainfall on water levels in a shallow ridge aquifer is presented in Figure 31. In this well near Winter Beach, water levels rise after heavy rainfall and decline in response to sparse or no rainfall.

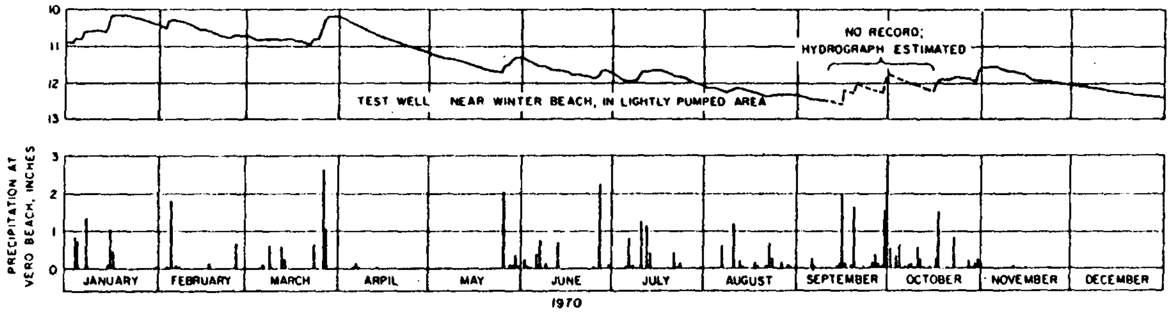


Figure 31. Relation between rainfall and water levels for a well near Winter Beach.

Aquifer coefficients for the Winter Beach area were discussed by Rorabaugh (1960, p. 314-323), and Frazee and McClaugherty (1979, p. 591). They indicated values of 11,200 and 14,700 gal/d/ft for transmissivity and 0.19 and 0.25 for storage coefficient, respectively. For comparison, a transmissivity of 13,000 gal/d/ft was calculated by Kreitman (1980) from a pump test at Saw Mill Ridge. A transmissivity of 85,000 gal/d/ft was calculated for the Wabasso well field (Geraghty and Miller, 1976).

(3) Ten-Mile Ridge. The Ten-Mile Ridge aquifer is found throughout the eastern portion of the study area in south Brevard and Indian River counties. This aquifer underlies areas above 25 feet msl and is similar to coastal ridge aquifers.

(4) Inter-Ridge. Within the study area, Inter-ridge aquifers occur from a point south of Malabar in Brevard County to the SJRWMD boundary at the Indian River County/St. Lucie County line. This area is bounded by the Ten Mile Ridge on the west and the Atlantic Coastal Ridge on the east. In this area the Inter-ridge aquifer can be divided into three sections; a section north of Sebastian Creek in Brevard County and sections north and south of Sebastian in Indian River County. The sections in Indian River County are defined by Crain et al. (1975, Figure 9, p. 19) as the greatest water producing potential (250-1000 gal/min) and moderate potential (100-250 gal/min) yield areas.

The Brevard County area has isolated water quality problems resulting from the infiltration of Floridan irrigation water with high chloride concentrations into surficial aquifers. West of Malabar, water is available in sufficient quantities for small public supplies. Within the southern portion of Brevard County the Inter-ridge aquifer is not very productive due to increasing percentages of fine-grain sediments, although quality may be good.

Both Indian River County sections contain potentially high-yield producing zones. Transmissivity values of 80,000 gal/d/ft and 11,000-47,000 gal/d/ft were reported at Sebastian Highlands (Geraghty and Miller, 1981) and Vero Beach (Gee and Jenson, 1980) respectively. Crain et al (1975) estimated that more than 76 MGD of water is available in this area for future development.

(5) Osceola Plain. The southern portion of the Osceola Plain is underlain by a thick, very permeable zone of gray sand mixed with increasing fractions of shell with depth. The Osceola Plain outlined on Figure 28 is part of a low recharge potential area of the Floridan aquifer.

Figure 32 shows a hydrograph for IR-25A, a long-term shallow well located at the eastern edge of the Osceola Plain (Figure 30). The water table showed normal fluctuations between 1973 and 1977 with annual springs recessions successively lower than those of the previous year. A relatively wet period between 1978 and 1980 was followed by the 1980-81 drought. The hydrograph during the drought is characterized by lower peaks. Water levels during the 1980-81 drought were only slightly lower than those during 1976-77 when Floridan aquifer levels along the Brevard coastline declined as much as seven feet.

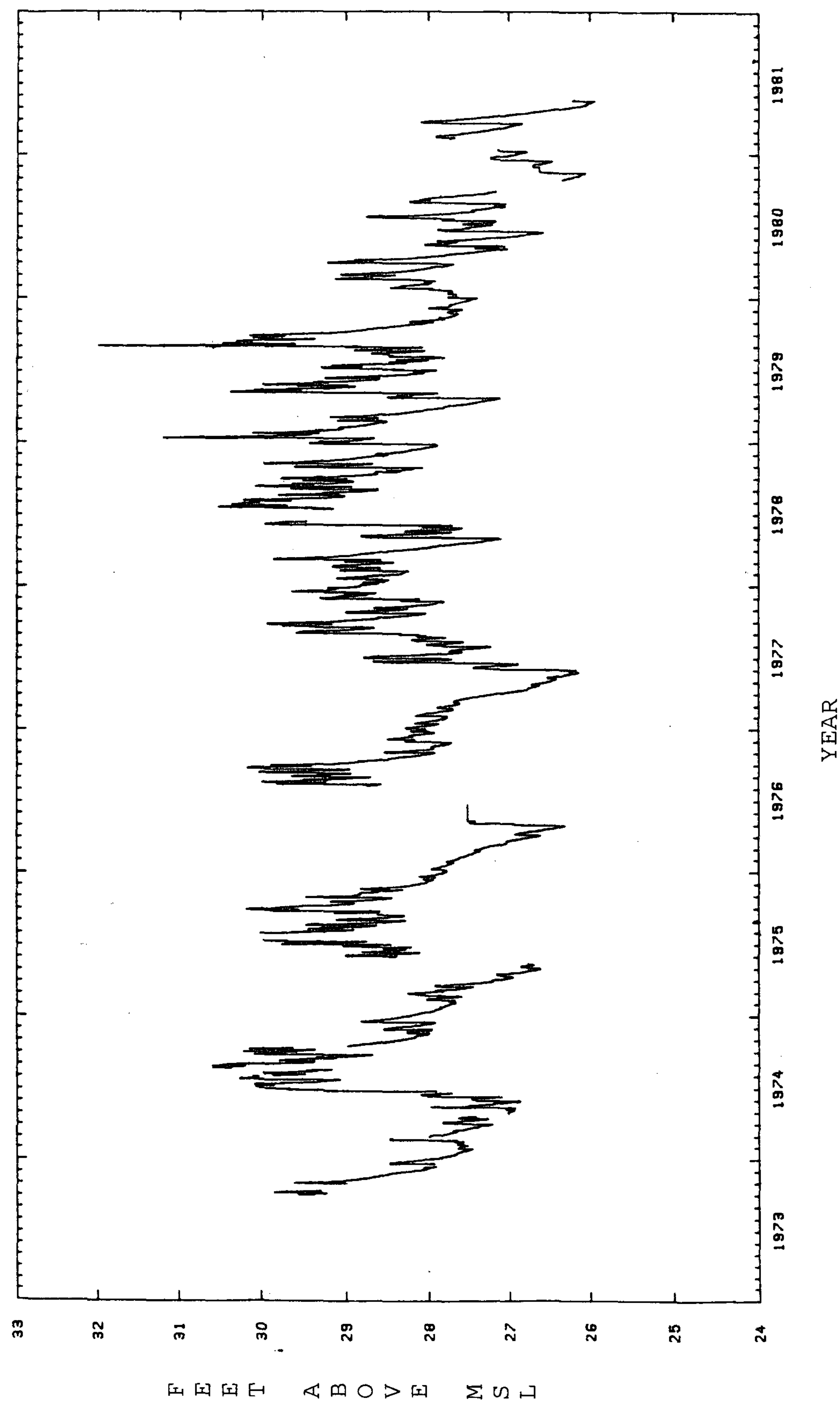


Figure 32. Hydrograph for IR-25A, a shallow well at the eastern edge of the Osceola Plan (Figure 30).

WATER QUALITY

Ground water contains dissolved minerals that vary in quality and concentration. The mineral content of ground water depends on the quality of water that enters an aquifer as recharge, the solubility and composition of soil and rock particles thru which water passes, and the length of time water is in contact with each material. In coastal areas, salts may also be derived from laterally intruded seawater. In inland areas, the composition of ground water may change due to the mixing of waters of different chemical compositions at depth, where ground water is more mineralized and exists under a higher artesian pressure. Wells in the study area contain tens to hundreds of feet of open hole and penetrate several producing zones. Hence water quality is a composite of all producing zones penetrated.

The primary dissolved minerals in ground water are sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), strontium (Sr), iron (Fe), bicarbonate (HCO_3), chloride (CL), sulfate (SO_4), and silica (SiO_2). Chloride is an inert element and does not enter into mineral or bacteriological reactions. Hence it is ideal for mapping the occurrence of laterally intruded seawater and/or the mixing between waters of differing salt content. In this study chloride concentration is used to map saltwater intrusion. Sulfate is primarily derived from the solution of gypsum and anhydrite, and the oxidation of iron sulfides and pyrite. It is commonly involved in bacteriological reactions where it is reduced to a sulfide. Bicarbonate is derived from the weathering of limestone, dolomite, and the oxidation of organic material. Combined, sulfate, chloride, and bicarbonate comprise 99 percent of the anion composition of the ground waters sampled in the study area.

CLASSIFICATION OF WATER TYPES

Water chemistry is dependent upon the source of the water and its duration of contact with each successive depositional, geologic environment. Water in contact with each environment has a characteristic composition. When this composition is plotted on a Piper diagram, a description of the flow can result, representing the progressive alteration of water chemistry as it traverses different depositional environments. Geochemical pattern analysis (Piper, 1944; Frazee, 1982) of water samples collected throughout the District between 1960 and 1983 suggests four general water types are present (Table 6). These are: (1) fresh water, (2) interface or transitional water, (3) connate (saline formation) water, and (4) seawater. These types describe the chemical characteristics of the water as it flows through the surficial and Floridan aquifer, starting with recharge waters and ending with saline formation waters or seawater.

Table 6. Water Type Criteria and Characteristics

	Water Type	Criteria	Characteristics
1.	Fresh Water		
	Fresh Recharge Water (FRW)	HCO_3 dominant and divided into two Sub-types.	Purest limestone water and typical of Florida-Georgia karst terrain.
	- Type I (FRWI)	$CaHCO_3$ Water	Rapid infiltration through sand column.
	- Type II (FRWII)	$NaHCO_3$ Water	Infiltration of clay-silt, esturine depositional environment related closely to transitional water.
	Fresh Formation Water (FW)	Ca-Mg-So_4 Water, CL concentration low	Vertical infiltration insignificant, older form of FRW Type I or II.
2.	Interface Water		
	Transitional Water (TW)	HCO_3-SO_4 mixing zone with increasing CL	Mixtures of fresh and seawater.
	Transitional Connate Water (TCW)	SO_4 begins to dominate HCO_3, CL increases.	Connate water dominates source water.
	Transitional Lateral Intrusion (TLI)	CL begins to dominate HCO_3, and increasing NaCL percent.	Seawater dominates source water.

3. Saline Formation Water		
Connate Water (CW)	$CaSO_4$ dominance, high TDS, highly mineralized FW	Presence of highly soluble minerals, H_2S gases prevalent, shut-down, wells build up H_2SO_4 and form FeS "bracket" deposits on casing wall and "black water" discharge.
	and	
	CW with little flushing and high TDS-CL concentrations	Related to paleo flow zones with no dilution.
Connate Mixing Zone (CMZ)	Mixing of $CaSO_4$ (CW) and NaCL (RSU) waters	As CW with higher TDS and Cl concentrations.
4. Seawater		
Lateral Intrusion (LI)	Modern NaCL Water	Lateral movement of sea-water interface
	or	
Relict Seawater (RSW)	In-Situ NaCL Water	Unflushed seawater with CL approaching brine. May be indicator of geologic discontinuities, i.e. faults, fracturing or deeply penetrating springs.
Relict Seawater Upwelling (RSU)	In-Situ NaCL Water	Indicator of geologic discontinuities, i.e. faults, fracturing, or deeply penetrating springs. Upwelling occurs inland.

White (1957) defined connate water, as "fossil water that has been out of contact with the atmosphere for at least an appreciable part of a geologic period". Lane (1908) recognized that some saline types were mixtures of "connate and meteoric water, and that some connate water may have been nonmarine". The term connate water in this reports shall refer to water of marine or non-marine origin which has been out of contact with the atmosphere for an appreciable part of geologic time. Excluded from the category of connate water is relict (fossil) seawater which is defined by White (1957) as water "born with the immediately enclosing rocks". It is similar in composition to seawater and can only be distinquished from it by isotopic analysis.

FLORIDAN AQUIFER SYSTEM

Table 7 lists representative water quality data for wells tapping the Floridan aquifer in the study area. Water quality is illustrated by the chloride, sulfate, and bicarbonate concentration of the sample. The chemical characteristics of different water types can be ascertained from the data in this table. For example, in Volusia County chloride concentration is less than 35 mg/l in the Rima Ridge area where the best recharge potential is thought to exist. Bicarbonate is also the predominant anion, which is typical of ground water in recharge areas. Further east, chloride concentrations increase to 160 and 720 mg/l in the Holly Hill and east Daytona Beach areas,

Table 7. Representative water quality data from wells tapping the Floridan aquifer in the study area.

Area	Well	Lat	Long	Depth (ft)	Concentration (mg/l)			Composition (%)			Date
					Cl	SO_4	HCO_3	Cl	SO_4	HCO_3	
Eastern Volusia County											
Central Wetlands	V-12	290541	811329	1200	35	0	267	18.4	0	81.6	4/1/80
Rima Ridge	V-14	290840	810845	83	15	0	305	8.4	0	91.6	4/1/80
Holly Hill Area	V-23	291444	810222	220	160	20	120	67.4	3.1	29.5	11/2/77
East Daytona Beach	V-18	291159	810202	187	720	50	253	81.3	2.1	16.6	4/2/80
Brevard County											
Titusville-Mims Ridge	BR-174	284240	805335	150	39	20	317	16.9	3.2	79.9	6/18/80
East Titusville	BR-164	283639	804832	150	12,600	10,000	156	76.9	22.6	0.5	8/20/80
Agricultural Area	BR-3	275003	803913	475	660	180	156	80.7	8.2	11.1	5/14/75
St. Johns Fault Area	BR-74	282204	805143	495	2,519	252	-	96.4	3.6	-	9/11/80
Sebastian Lens	BR-5	275224	802909	-	200	85	181	59.3	9.4	31.3	5/14/75
Indian River County											
Sebastian Lens	IR-1	275003	802604	-	220	80	163	63.9	8.6	27.5	4/8/80
Wabasso Area	IR-266	274308	802256	500	260	48	146	71.7	4.9	23.4	4/6/82
	IR-165	274512	802427	650	655	140	169	81.3	6.4	12.3	10/5/82
Vero Beach Area	IR-193	273823	802431	450	370	98	158	74.3	7.3	18.4	12/6/82
	IR-179	273814	802234	960	475	37	154	82.1	2.4	15.5	12/7/82
Oslo Area	IR-38	273536	802401	704	277	130	198	62.9	10.9	26.2	12/19/80
Agricultural Area	IR-258	274558	803505	397	370	110	154	74.0	8.2	17.8	3/25/82
Seawater					19,000	2,700	140	94.6	5.0	0.4	

respectively. Chloride also becomes the dominant anion and its relative composition increases from less than 20 to more than 80 percent, as the coastal area is approached. For comparison, the chloride and bicarbonate composition of seawater is 94.6 and 0.4 percent, respectively. Similarly, in Brevard County chloride concentrations are less than 50 mg/l on the Titusville-Mims Ridge but increase to 12,600 mg/l in east Titusville. The respective chloride composition increases from 16.9 to 76.9 percent and the bicarbonate composition decreases from 79.9 to 0.5 percent.

Also evident in Table 7 is the effect of agricultural withdrawals and geologic control on water quality. Chloride concentrations are 660 and 397 mg/l respectively in agricultural areas of Brevard and Indian River counties and 2530 mg/l in the proximity of the St. Johns fault area. The corresponding chloride compositions are 80.7, 74.0, and 96.4 percent, respectively. Large withdrawals in agricultural areas result in upconing of more highly mineralized water from depth into fresher zones of the Floridan aquifer. Chloride concentrations and relative compositions from wells in both the Wabasso and Vero Beach areas in Table 7 illustrate this increase with depth.

Figure 33 illustrates the areal distribution of the different water types in the study area. Laterally intruded, connate, and transitional waters occur along the coast and relict seawater upwells inland along the St. Johns fault. Relict seawater also occurs in the southeast corner of Indian River County. The boundaries for this water type approximates the faults mapped in Figure 12.

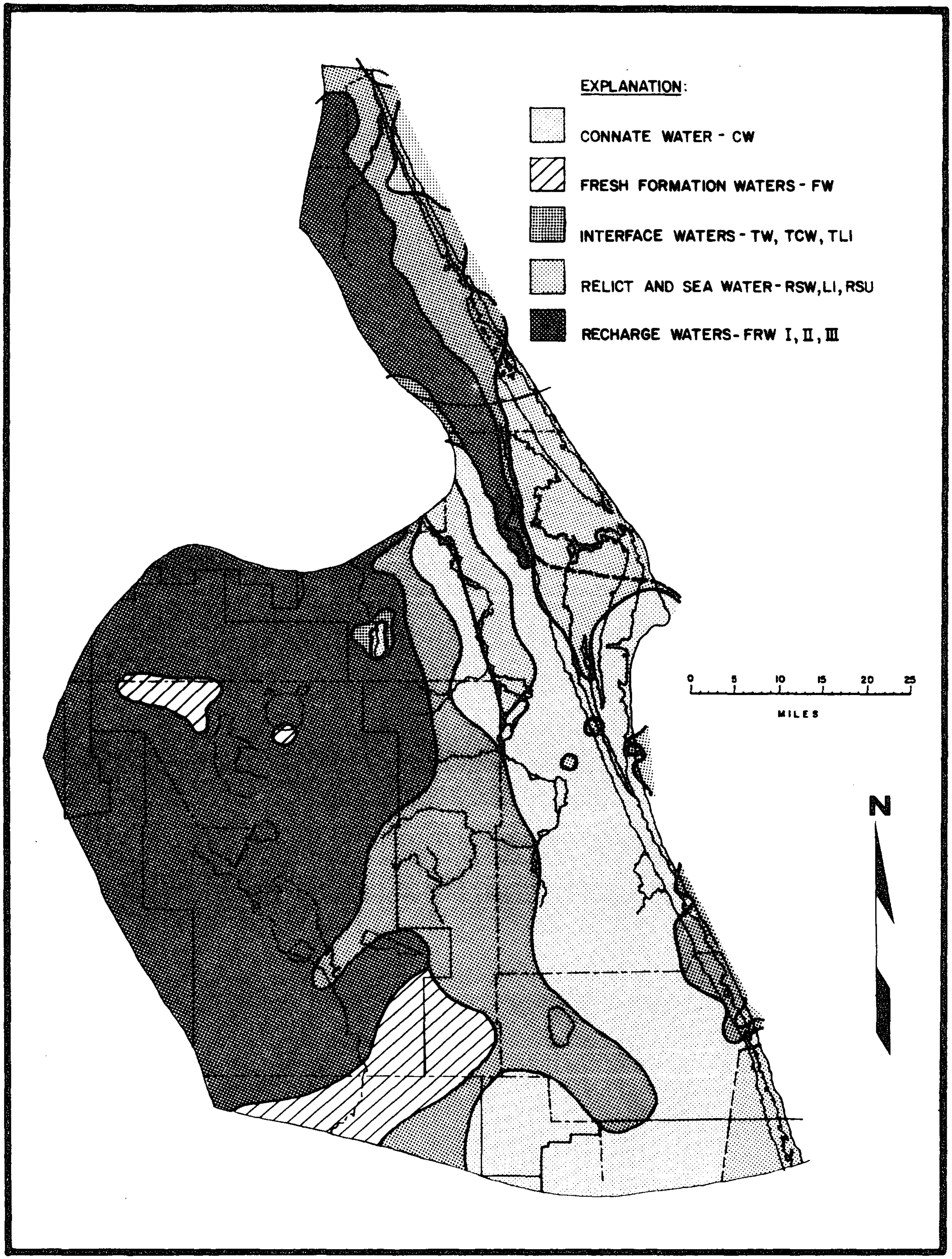


Figure 33. Areal distribution of the different water types in and around the study area.

As previously described (p. 54) the Upper Floridan aquifer within the study area is divided into an upper and lower zone based on the presence of low permeability within the Avon Park Limestone. Inadequate information is available to accurately describe the water quality characteristics of the lower zone. Therefore, the subsequent discussion is limited to the water quality of the upper zone.

Upper Zone. Figure 34 shows the chloride concentrations in the upper zone. Concentrations were measured on samples collected from 1976 to 1983. Chloride concentrations in water from this zone generally increase from west to east and with depth. With the exception of eastern Volusia County, the portions of the study area with chloride concentrations lower than 250 mg/l are small. The recharge occurring in the Rima Ridge in Volusia County is an important source of low chloride water for the upper zone. This water provides the source for the large well fields in eastern Volusia County. The thickness of the low chloride water is greatest under the Central Wetlands area and decreases to the east and west.

The Titusville-Mims Ridge is underlain by a lens of low chloride water in the Floridan aquifer. The aquifer is locally recharged, and hydraulically connected to the shallow aquifer. It is the only area in either Brevard or Indian River counties

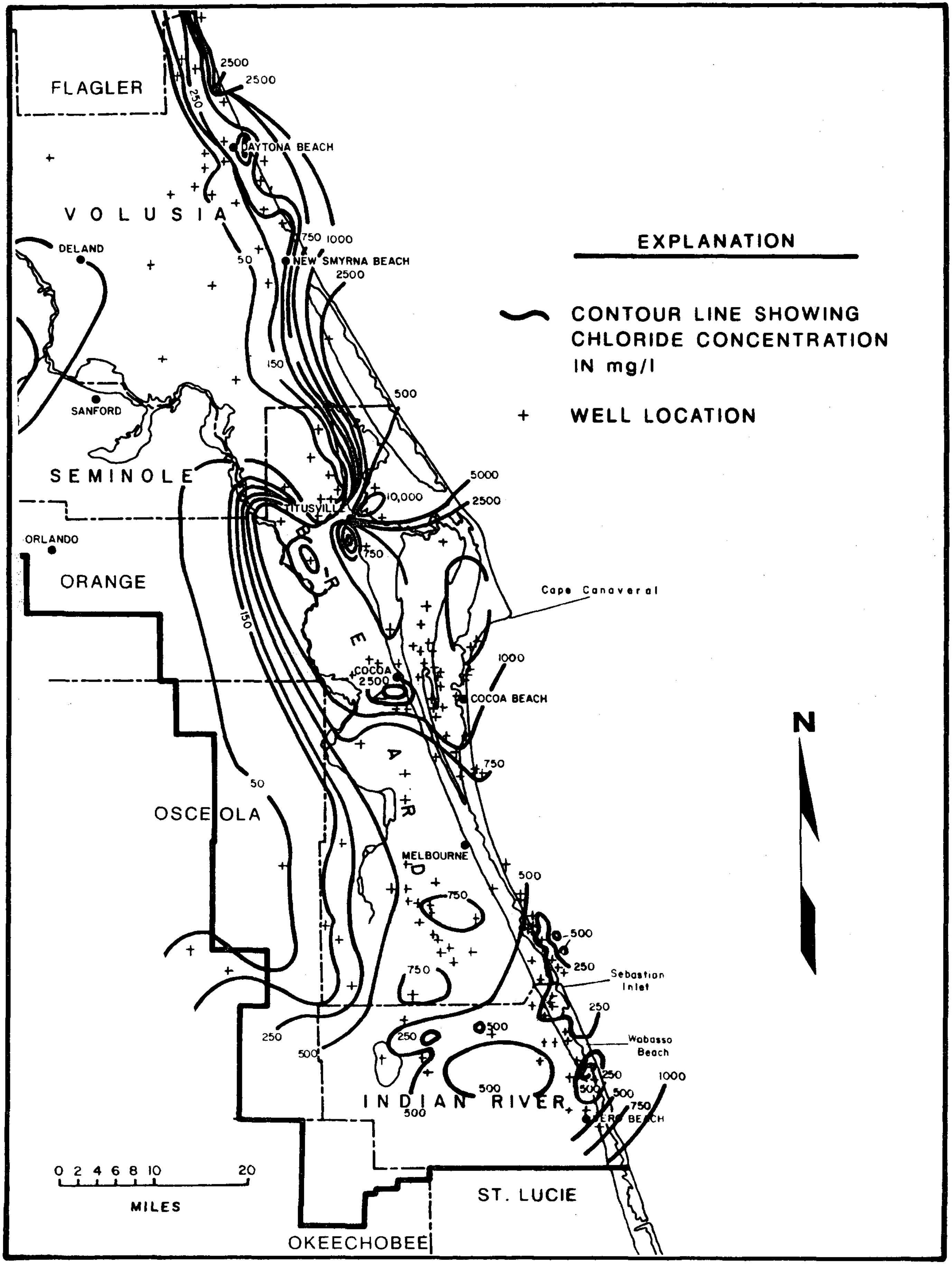


Figure 34. Chloride concentration in the upper zone of the Floridan aquifer in the study area.

where Floridan aquifer water contains less than 80 mg/l of chloride (Figure 34). Connate water underlies this lens of low chloride water.

Closer inspection of Figure 34 indicates two areas of low chloride water along the coastal regions of Brevard and Indian River counties: (1) an area near Sebastian Inlet referred to as the "Sebastian freshwater lens" and (2) an area near Cape Canaveral.

Sebastian Freshwater Lens. In the Sebastian freshwater lens area, chlorides are as low as 180 mg/l but increase to more than 250 mg/l. The area where chloride concentration is below 250 mg/l occurs east of the Indian River and underlies the barrier island. The lens extends from near Floridana Beach in Brevard County to News Cut in Indian River County and is divided into three lobes of potable water at Mathers and Ballard Cove in Brevard County where chloride concentrations between 250-321 mg/l occur (Toth, 1987). The lens receives no recharge from overlying deposits, and fresh water withdrawn from the lens is replaced by highly mineralized water with chloride concentrations ranging from 300-500 mg/l (Figure 34).

The original shape of the Sebastian lens is presumed to have been irregular (Figure 35). Although the northern pre-development boundary of the lens is thought to be south of Spessard Holland Park, the original lens may have extended north to Melbourne Beach where Sellards and Gunter (1913), and Matson

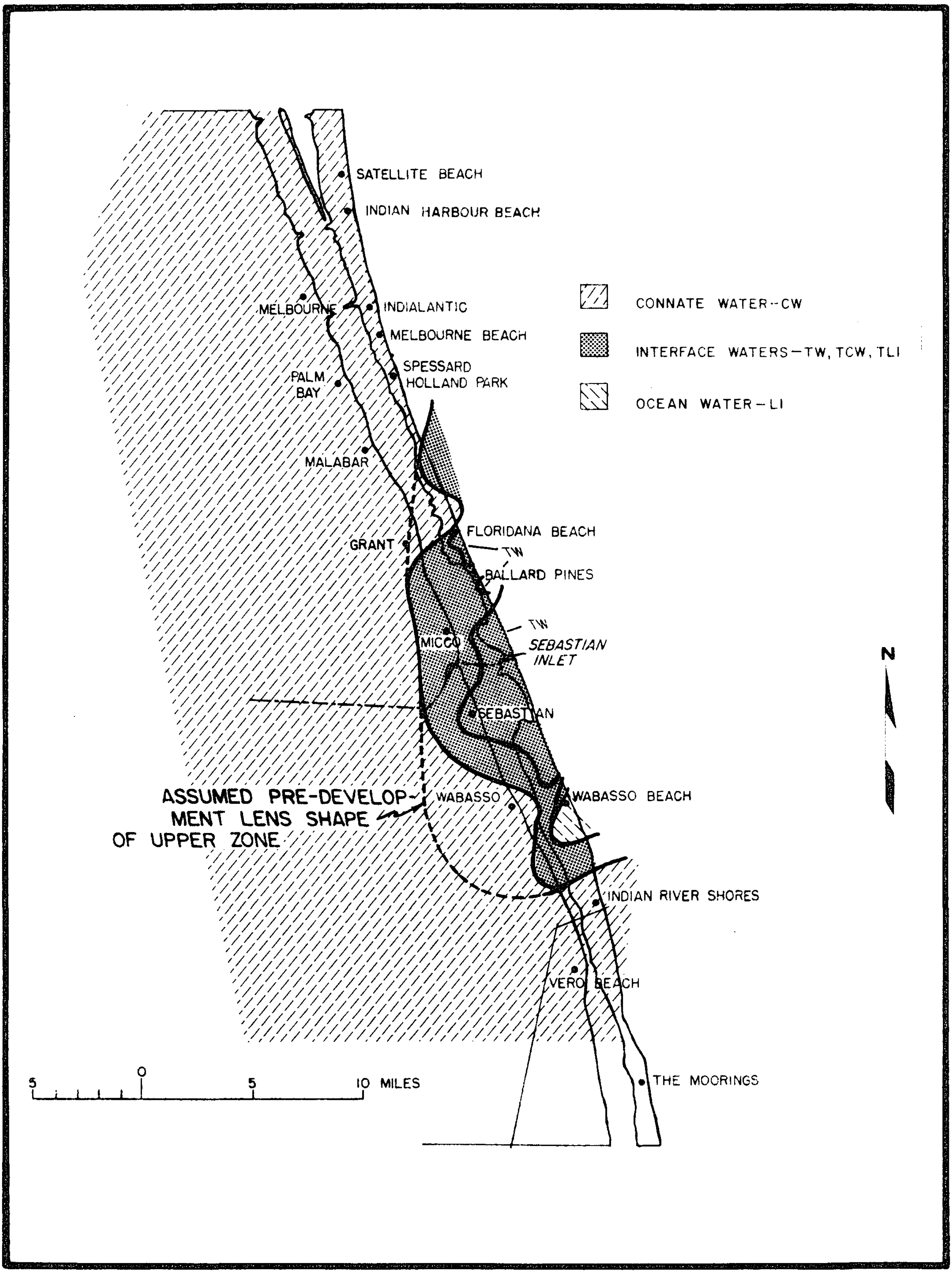


Figure 35. Assumed shape of the Sebastian freshwater lens in 1936 and existing water types in and around the lens.

and Sanford (1913) reported chlorides near 300 mg/l. In 1975, water from the upper 50-feet of the Floridan aquifer contained less than 300 mg/l of chloride in isolated areas near Melbourne (Frazee and Laughlin, 1979-1980).

The water of the Sebastian freshwater lens is classified as a transitional type and probably originated from the mixing of fresh and saline waters. It is bordered by connate water to the west, the prevailing water type in south Brevard and Indian River Counties (Figures 33 and 35).

Figure 36 shows a north-south cross-section through the Sebastian freshwater lens. At present, data indicates that three reservoirs of fresh water separated by laterally intruded connate water from the west, exist along the north-south axis. However, their lateral extent is not known. They may only be separated under the barrier island.

Three distinct zones have been identified within the lens area. These are, 1) an upper zone which is currently deteriorating; 2) a lower zone of fresh water that is largely untapped by wells; and, 3) a base zone related to the regional highly mineralized water area west of the lens. Deterioration of the upper zone is indicated by changes in the chloride content of wells since 1956 (Toth, 1987). Prior to 1983, free-flowing wells discharged 2.6 MGD and 4.1 MGD from the north and south lobe of the lens, respectively. Withdrawals for domestic supply, lawn irrigation, and ground water heat pumps were secondary (Marella, 1982; Brevard County Development Division 1975-77; Frazee, 1982).

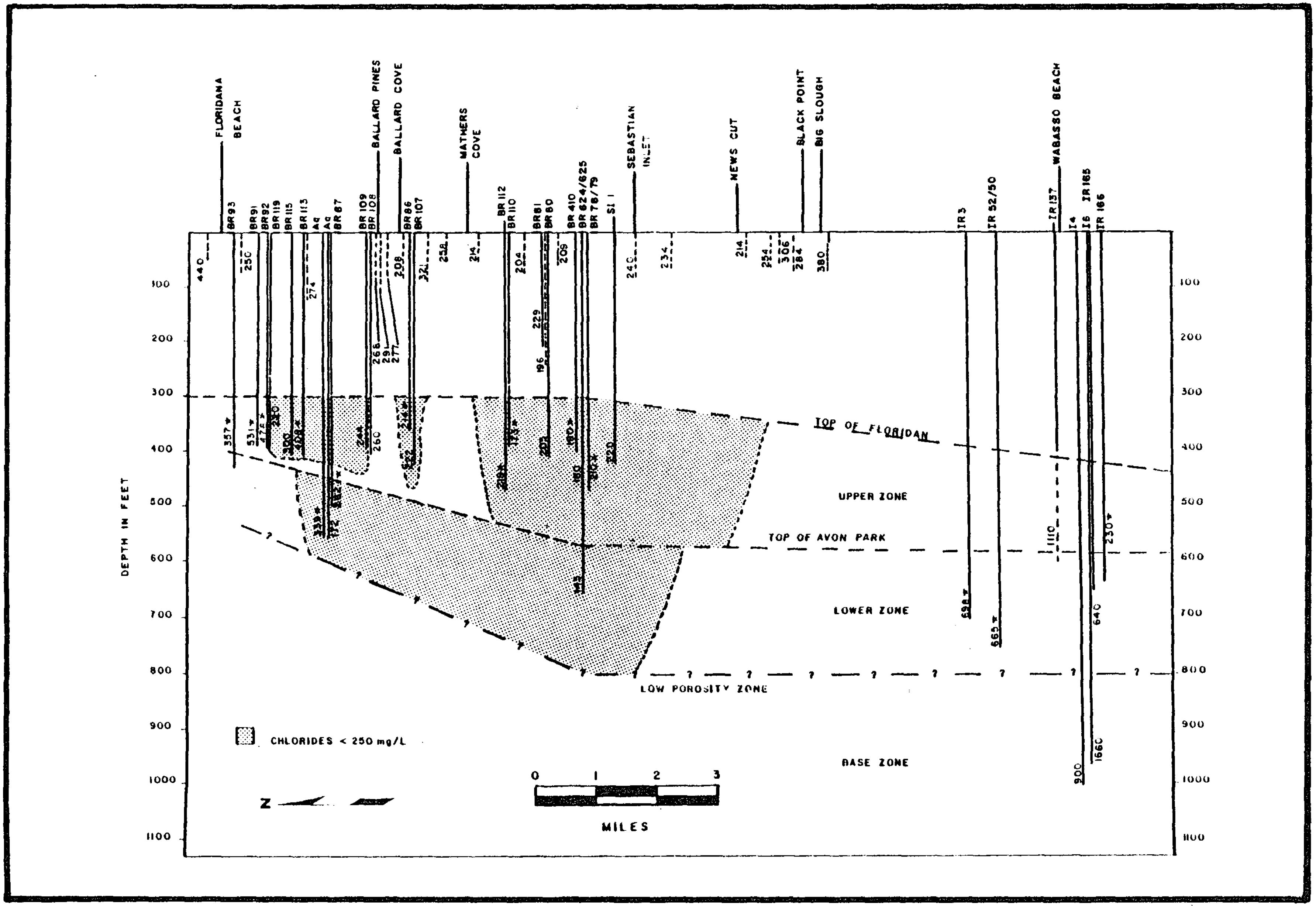


Figure 36. North-south cross-section through the Sebastian freshwater lens in 1985, indicating well depths and chloride concentration. Values with stars refer to samples collected prior to 1985 (between 1969 and 1984).

In 1983, fourteen free-flowing wells on the barrier island were plugged. This reduced the rate of deterioration of the upper zone of the lens.

Cape Canaveral. The other area of low chloride water in the upper zone is centered at Cape Canaveral (Figure 34). The chloride concentration near the center of this lens is 720 mg/l and has been relatively stable since the mid 1950's. The lens is bound on the north and west by relict sea water of quality similar to that of the water sample listed in Table 4 as BR-164 which has a chloride concentration of 12,600 mg/l. Near Port Canaveral the water quality in the lens deteriorates with chloride concentrations increasing to 1000 mg/l and more.

Long-Term Changes in Water Quality

To assess the extent and magnitude of changes in water quality in the study area, chloride concentrations from Floridan wells were examined. The resulting conclusions, however, are general and based on fragmentary data. Many wells lacked historical water quality data and were sampled sporadically. These data are listed in Appendix II.

Chloride concentrations fluctuate seasonally and are dependent on rates of ground water withdrawals, localized recharge, potentiometric head, upward leakage, and contributions from flow zones of differing water quality. Withdrawals for irrigation and freeze protection vary on a seasonal basis and utilize large volumes of ground water over a relatively short time period. In an attempt to minimize differences in chloride concentrations due to seasonal differences in irrigation or freeze protection withdrawals, chlorides measured during the same month for each well are compared in Appendix II. Where available, the measured high and low values in a year for each well are also presented. This provides an indication of possible annual fluctuations in chloride concentration. Because the sampling period for historical chloride data does not always coincide with that for recent measurements, a few chloride concentrations measured during different months are also listed in Appendix II. If chlorides measured during the same month for different years differ by more than the annual fluctuation, the changes are considered significant. Where sufficient measurements were not available, the change between measurements is considered significant.

Within each county, the wells were grouped by geographic location to better identify the mechanism for change, (i.e., upconing or lateral intrusion), and to assess the changes more easily. Attempts were also made to identify well depths and relate water quality changes to the formations penetrated. This was not possible, however, because depth information is not available for many wells. The geographic areas used are: (a) west of I-95; (b) east of I-95; and (c) the barrier island. Volusia County was further subdivided into (1) the region between I-95 and US 1 and (2) the area east of US 1.

Volusia County. The location of wells in Volusia County examined for long-term water quality changes are shown in Figure 37. Appendix IIA contains chloride values for these wells.

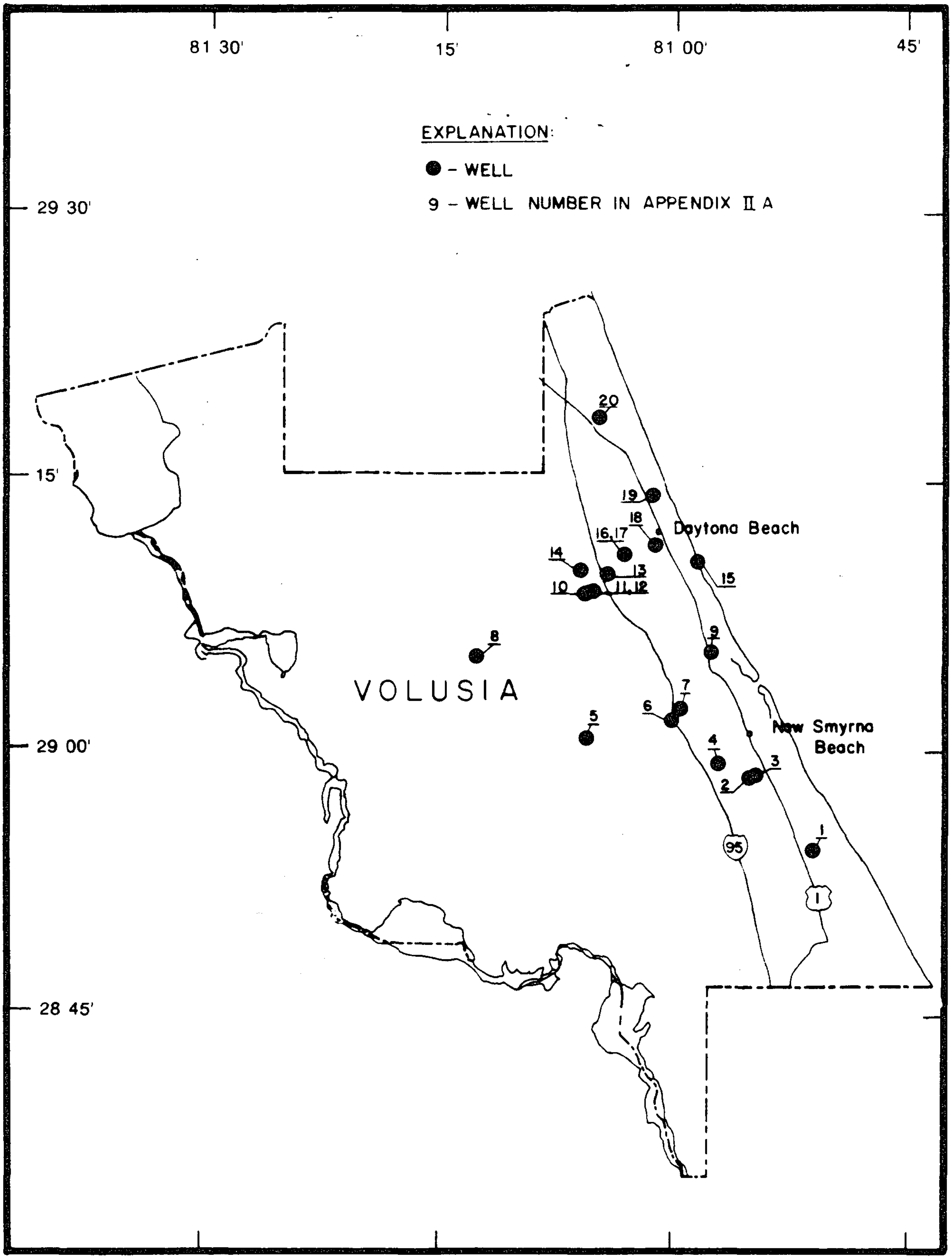


Figure 37. Location of wells penetrating the FLoridan Aquifer in Volusia County examined for long-term water quality changes (Appendix IIA).

West of I-95 chlorides are less than 132 mg/l and have not changed significantly in seven wells sampled between 1955 and 1981. Representative annual fluctuations for wells in this area are 35 to 122 mg/l in 1955 (Well no. 10, Appendix IIA) and 22 to 132 mg/l in 1965 (Well no. 6, Appendix IIA). The high chlorides probably result from upconing of poorer quality Floridan aquifer water during periods of heavy pumping for freeze protection. Chlorides attained a high of 122 mg/l (Well 10) west of south Daytona in February, 1955, but declined to 35 mg/l in April, 1955.

In the area between I-95 and US 1, chlorides increased in six of eight wells between 1950 and 1982. The largest change occurred at Well V18 (Well no. 18, Appendix IIA) where chloride concentrations were 134 mg/l in 1950, 1000 mg/l in April 1981 and 300 mg/l in December, 1982. The 1981 value coincides with a low in the potentiometric surface of the Floridan aquifer which was 5 to 10 feet below msl at Daytona at that time. Subsequently, as water levels rose, chloride concentrations decreased.

At Edgewater (Well no. 2) chlorides increased from 64 to 210 mg/l between 1957 and 1982. However, most of the increase, or approximately 72 mg/l, occurred between 1980 and 1982.

East of US 1 chlorides increased from 71 to 160 mg/l between 1954 and 1977 in a well (Well no. 19) at Holly Hill. Chlorides may have increased in other areas, but adequate water quality records are not available to evaluate the change.

Finally, chlorides increased from 198 to 1400 mg/l between 1956 and 1981 on the barrier island at Daytona Beach Shores (Well no. 15). The largest increase occurred between 1979 and 1981 and is due to a short-term lowering of the potentiometric surface as discussed for V18 at Daytona Beach above.

Brevard County. The location of wells in Brevard County examined for historic water quality changes are shown in Figure 38. Appendix IIB contains chloride values for these wells.

Based on the chloride concentrations measured at the 25 wells sampled west of I-95 in Brevard County between 1955 and 1981, no long-term changes in chlorides are apparent. Possible annual fluctuations are 1170-1700 mg/l for BR 408 (Well No. 57, Appendix IIB) in 1946 and 520-780 mg/l for BR 60 (Well No. 1, Appendix IIB) in 1979.

Of the 13 wells sampled east of I-95 in Brevard County between 1947 and 1981, no long term trend in chloride concentration occurs.

Chloride concentrations at nineteen wells from the barrier island and Merritt Island in Brevard County were examined. The data spanned the period 1956-1981, but the majority were collected after 1975. No trend in chloride concentration was apparent.

Indian River County. The location of wells in Indian River County examined for historic water quality changes is shown in Figure 39. Appendix IIC contains chloride values for these wells.

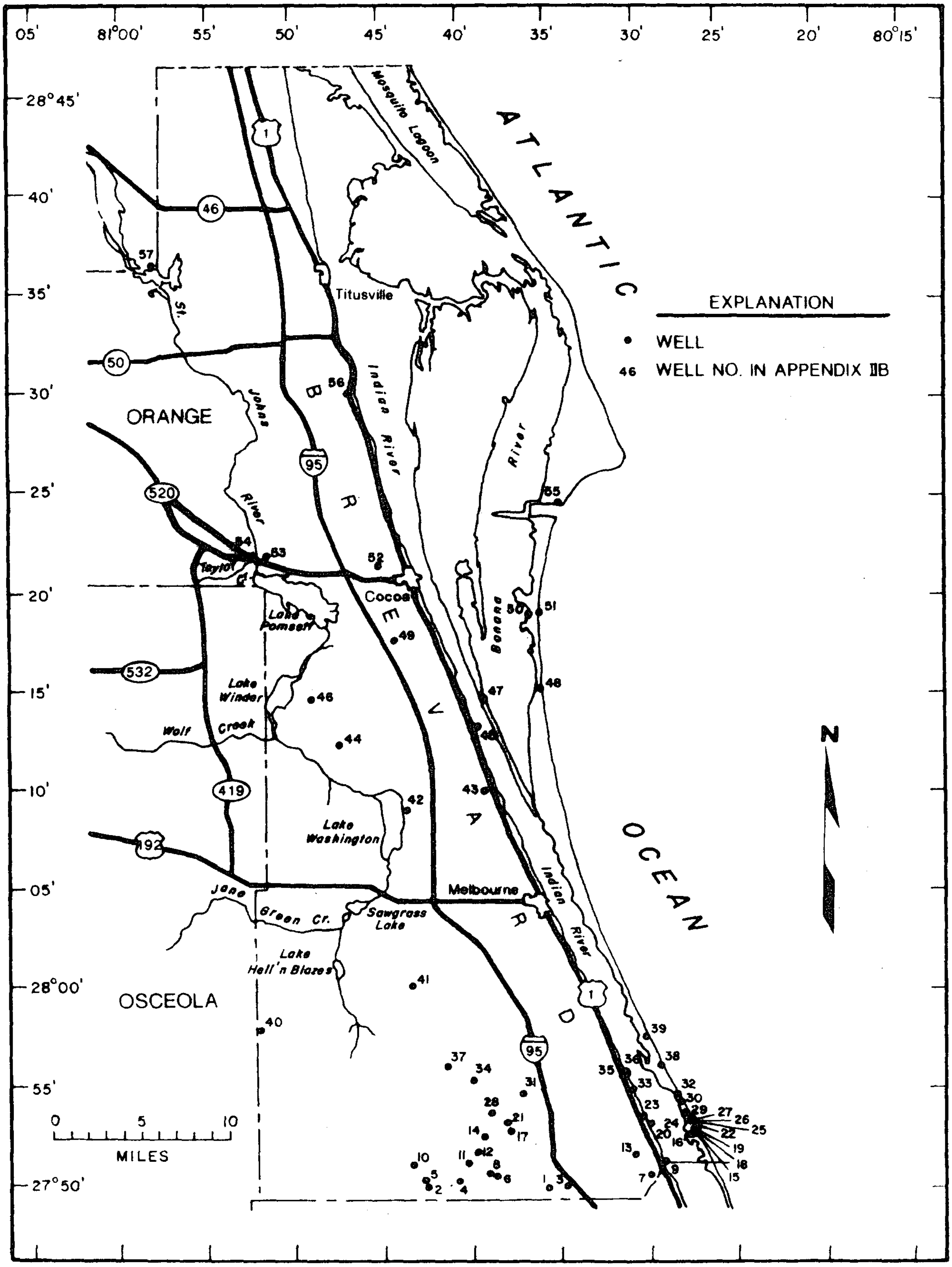


Figure 38. Location of wells penetrating the Floridan aquifer in Brevard County examined for long-term water quality changes (Appendix IIB).

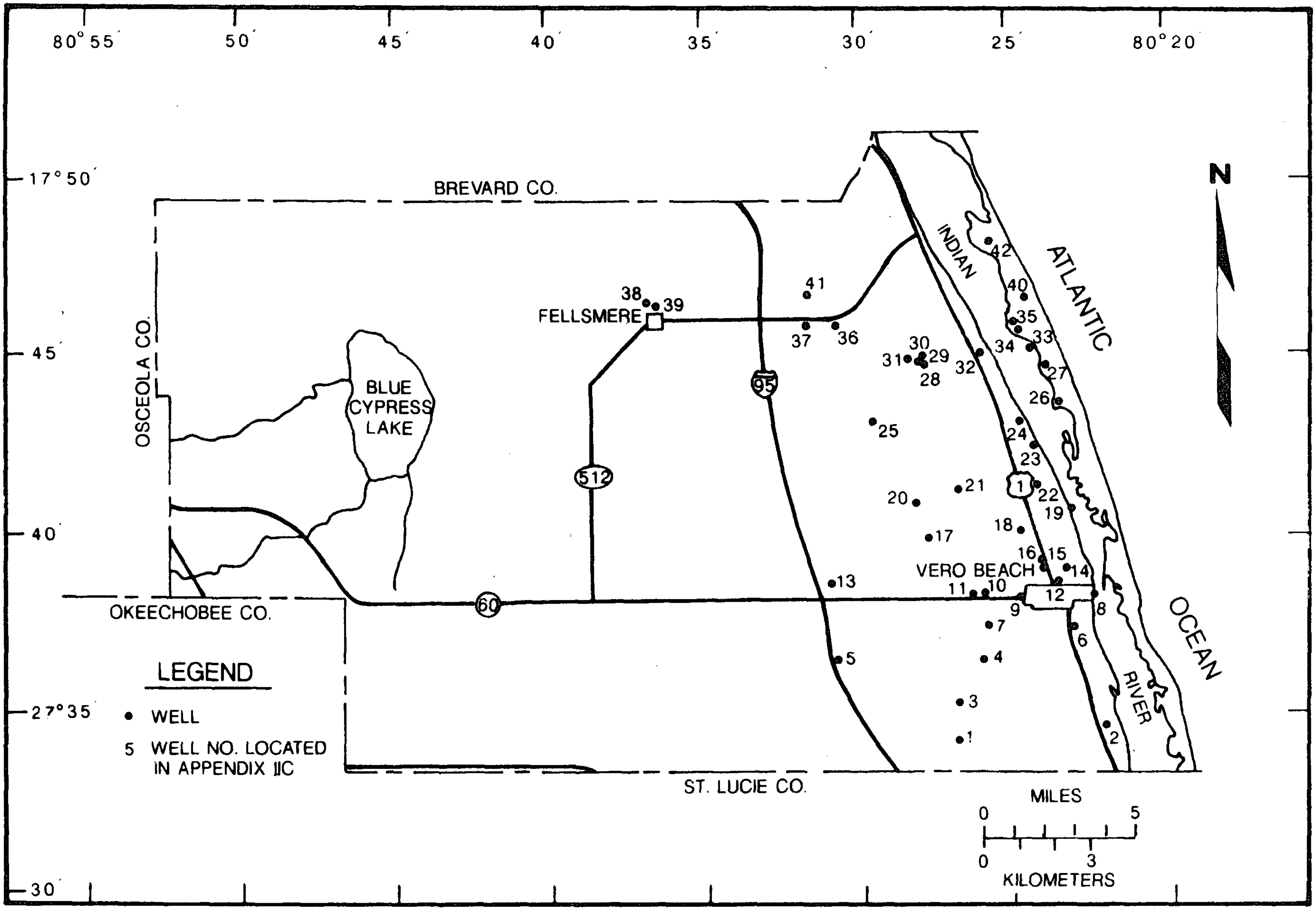


Figure 39. Location of wells penetrating the Floridan aquifer in Indian River County examined for long-term water quality changes (Appendix IIC).

Chlorides in wells sampled west of I-95 have not changed appreciably between 1960 and 1983. Possible annual fluctuations for wells in this area are 470-640 mg/l in 1969 (Well no. 38, Appendix IIC). However, no long term change is apparent. The increase in chlorides probably results from upconing of poorer quality Floridan aquifer water during periods of heavy pumping.

East of I-95, chlorides increased from 45 to 240 mg/l in eight wells in Indian River County between 1950 and 1983. Most of this change occurred prior to 1970. For the few wells sampled between 1969 and 1983, chlorides did not change by more than 35 mg/l, except at two wells in Vero Beach. Here chlorides increased by 77 and 136 mg/l between 1979 and 1983. The small changes in chloride concentrations during the 1970's are associated with declines in the potentiometric surface. These declines can be attributed to changing land use as citrus irrigation has been pushed westward and coastal areas developed.

Along the barrier island chloride concentration increased 120 mg/l between 1950 and 1970 in Well No. 42 (Figure 39) north of Wabasso Beach. Chloride concentration remained unchanged in Well nos. 26 and 27 and actually decreased in Well no. 35. Hence, additional sampling is required to establish a pattern of water quality changes along the barrier island.

INTERMEDIATE AQUIFER SYSTEM

Water quality samples were collected from three wells that tap the intermediate aquifer system in southern Brevard and northern Indian River counties. Table 8 lists the location and

Table 8. Representative water quality data from wells tapping the intermediate aquifer system.

County	Well	Lat	Long	Depth (ft)	Concentration (mg/l)			Composition (%)			Date
					CL	SO_4	HCO_3	CL	SO_4	HCO_3	
Brevard											
	BR-66	281320	804102	175	157	1	352	43.3	0.1	56.6	12/21/44
Indian River											
	IR-60	274905	802814	200	230						8/31/81
	IR-256	274559	803446	297	150	25	246	49.6	3.1	47.3	3/25/82

anion composition of water from the wells. The water is classified as transitional and contains very little sulfate, suggesting that it is recharged from the overlying surficial aquifer system. Chloride concentrations are 150, 157, and 230 mg/l. The highest concentration occurs nearest the coast.

For comparison, Table 7 lists water quality from a Floridan aquifer well (IR-258) located near IR-256 (Table 8), an intermediate aquifer well. Chloride concentrations in water from the Floridan aquifer are approximately 200 mg/l higher than in the secondary artesian aquifer. In 1951 the chloride concentration in IR-256 and IR-258 was 155 and 260 mg/l, respectively (Bermes, 1958). During the succeeding 31 years water quality did not change.

SURFICIAL AQUIFER SYSTEM

Shallow Rock Aquifer. Table 9 lists representative water quality data from wells tapping the shallow rock aquifer in the study area. Excluding the coastal areas, chloride concentrations are below 75 mg/l in Indian River County, but exceed 250 mg/l in parts of Brevard County. In Indian River County, water in the shallow rock aquifer is typically bicarbonate. This indicates that this aquifer is recharged from the overlying shallow clastic aquifer. In Brevard County, chloride becomes the dominant anion and constitutes 84 to 95 percent of the anions. The water type in this area is transitional, connate, or laterally intruded seawater.

Table 9. Representative water quality data from wells tapping the shallow rock aquifer in the study area.

County	Well	Lat	Long	Depth (ft)	Concentration (mg/l)			Composition (%)			Date
					CL	SO_4	HCO_3	CL	SO_4	HCO_3	
Brevard County											
	BR-312	282517	804516	90	97	45	172	45.3	7.9	46.8	9/18/80
	BR-138	281935	803937	90	988	92	100	91.4	3.2	5.4	10/6/80
Indian River County											
	IR-289	274948	802916	134	44	1	304	19.9	0.2	79.9	12/27/83
	IR-287	274603	803457	140	56	14	144	38.6	3.7	57.7	12/27/83
	IR-274	274517	802618	133	29	1	212	19.0	0.3	80.7	12/28/83
	IR-282	274240	802532	144	35	1	311	16.2	0.2	83.6	12/28/83
	IR-280	274002	802619	150	73	1	372	25.2	0.1	74.7	12/28/83
	IR-276	273732	802410	123	60	1	322	24.2	0.2	75.6	12/28/83
	IR-278	273607	802328	143	41	1	291	19.4	0.2	80.4	12/28/83

Figure 40 shows the areal distribution of chloride concentrations within the shallow rock zone for samples collected from 1976 to 1982. The region where chloride concentration is below 50 mg/l generally defines the best potential recharge areas.

The region in south Brevard and Indian River counties that contains less than 50 mg/l chloride appears as an elongated lobe that increases in width near Sebastian and Vero Beach. The width near Sebastian results from an extensive clastic recharge basin between the Ten-Mile Ridge and Atlantic Coastal Ridge. The other width near Vero Beach is representative of similar clastic material and highly permeable rock.

The 50-250 mg/l region narrows east of the 50 mg/l zone, especially at Wabasso and Vero Beach. This area is one of transition between fresh recharge and laterally intruded seawaters. At Wabasso, the interface is in a state of flux. At Vero Beach the interface is relatively stable; hence, chloride concentrations in this area did not change significantly from 1978-1983.

The highest chloride concentrations occur along the barrier islands, which generally contain laterally intruded seawater. Concentrations range from 1200 mg/l at Cape Canaveral to 7500 mg/l near the St. Lucie County line. In the Sebastian Inlet area concentrations range from 250-1000 mg/l (Figure 40).

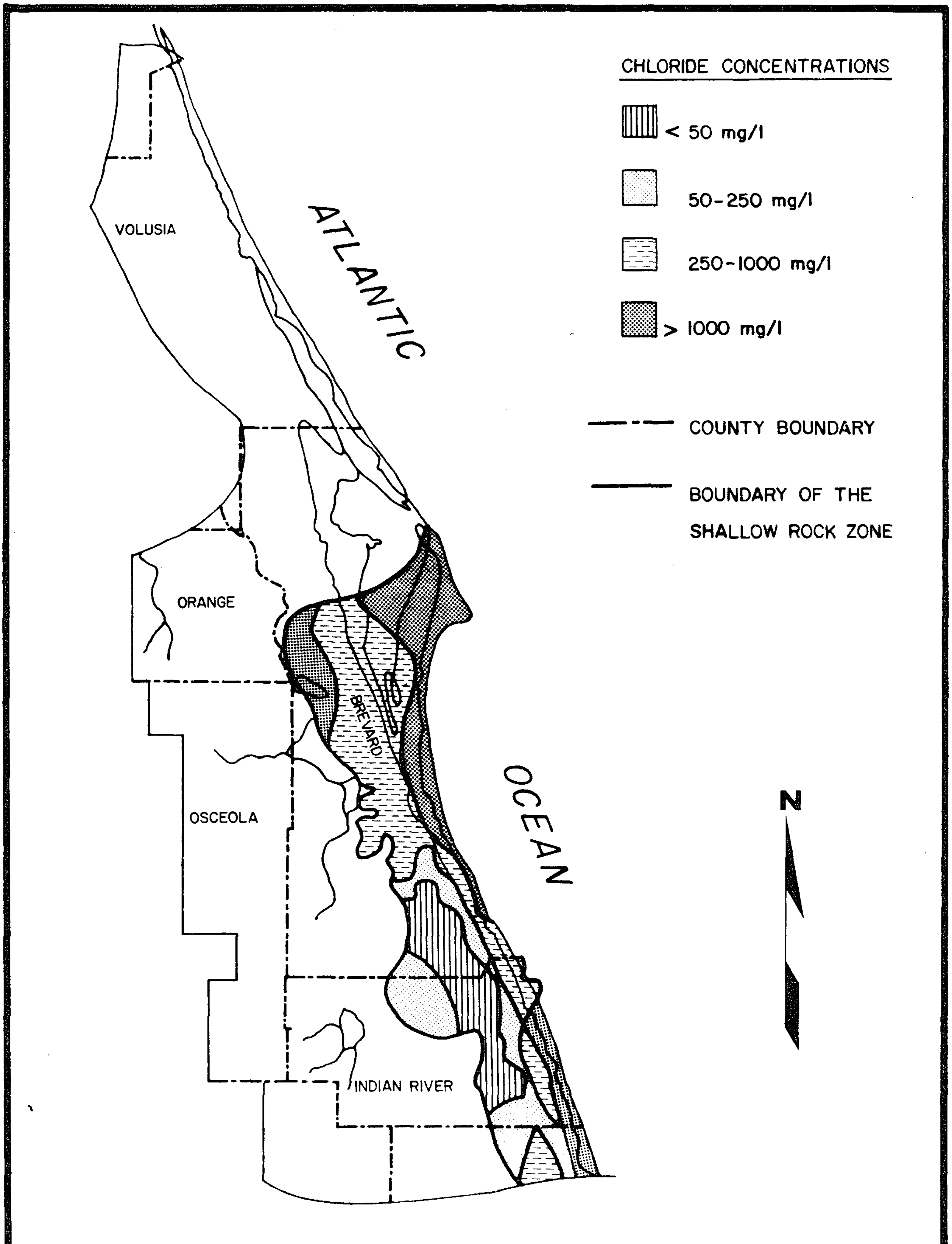


Figure 40. Areal distribution of chloride concentrations within the shallow-rock zone.

Public-Supply Well Fields. Well fields at Port Malabar, Brevard County and Vero Beach, in Indian River County withdraw water from the shallow rock zone. The Port Malabar well field produces water with chloride concentrations exceeding 300 mg/l seasonally. The seasonal variation is due in part to well construction: screens are installed in both the overlying ridge shell aquifer and the shallow rock zone where chloride concentrations range from 50-250 mg/l (Figure 40). The well field is just south of an area where chloride concentrations vary from 250-1000 mg/l in the shallow rock zone. The high chloride concentrations result from the lateral movement of higher chloride water within the shallow rock zone in response to seasonal withdrawals.

At Vero Beach, chloride concentrations are generally below 150 mg/l and increase toward the Indian River. The 250 mg/l interface occurs approximately one and three-forths (1 3/4) miles west of the Indian River at the northern boundary of the City, and three-forths (3/4) miles west of the Indian River at the southern boundary of the City (Figure 41). The interface lies further inland in areas where ground-water withdrawals are greatest. The majority of production in the Vero Beach well field is from wells in the northeast part of the City.

Chloride concentrations are also above 250 mg/l in an area south of Main Canal. The higher chloride concentrations in this area may result from water leaking through the corroded iron casings of abandoned, buried Floridan aquifer wells.

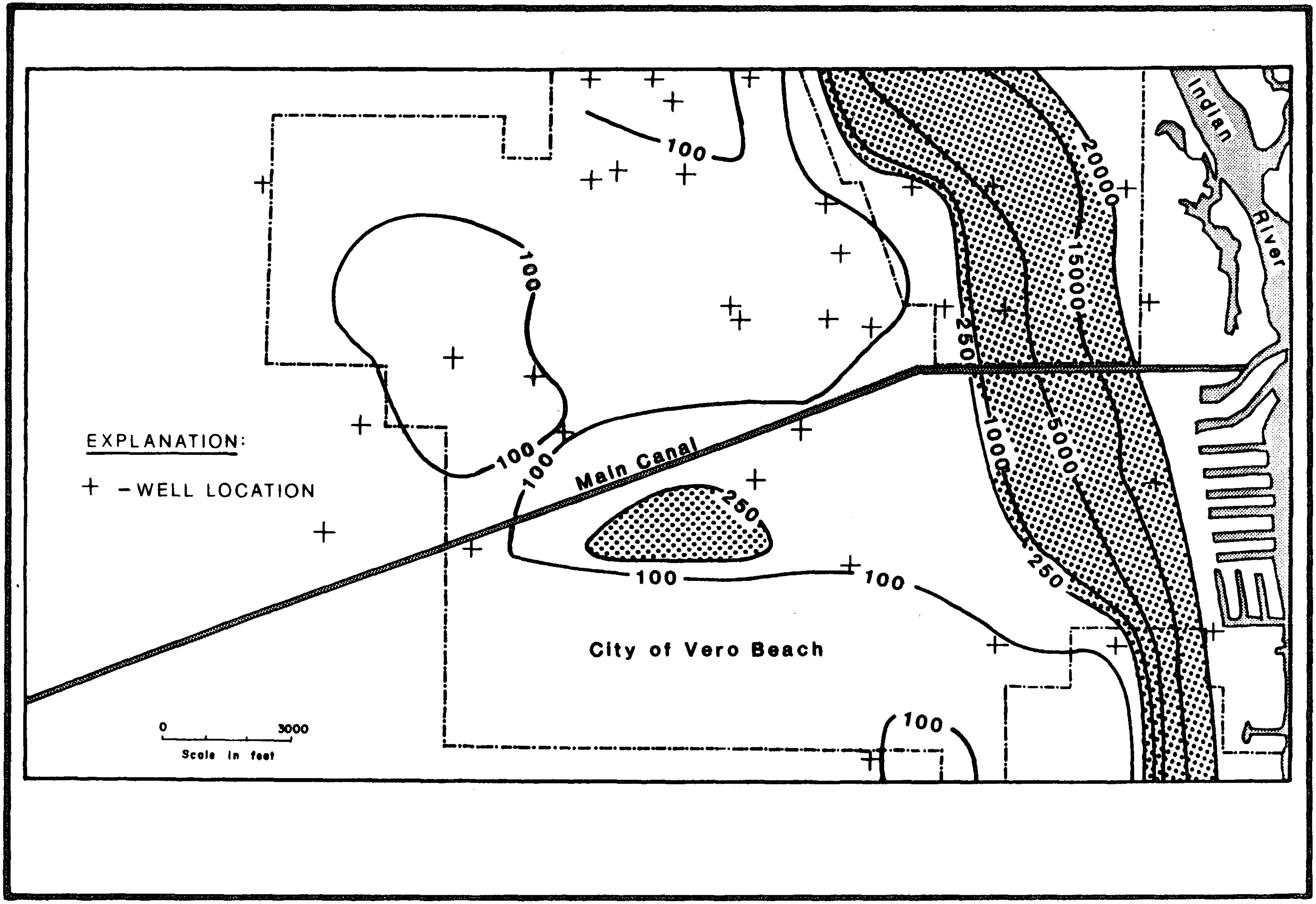


Figure 41. Chloride concentration in shallow wells at Vero Beach.

Long-Term Changes in Water Quality

Chloride concentration in water from several shallow rock wells in the study area is listed in Appendix III. Appendix III also includes chloride concentration data from several production wells in the Vero Beach well field and observation wells east of the well field. Concentrations were measured after 1976 and, as such, do not provide an adequate period of record to assess long-term changes. However, the data demonstrate that chloride concentrations fluctuate seasonally. In Brevard County, chlorides varied by 94 mg/l at BR-138 in 1980. In Indian River County, chloride concentrations generally were below 100 mg/l and fluctuated by as much as 65 and 48 mg/l in two production wells in the Vero Beach well field. Here the average chloride concentration increased approximately 36 mg/l between 1976 and 1983 in six production wells. Chloride concentrations in four other production wells remained unchanged during the same time period. The increase in chlorides has resulted from increased pumpage from 5.44 to 8.00 MGD during 1976 and 1983, respectively.

Shallow Clastic Aquifer

Water quality data for shallow clastic aquifer wells in Volusia, Brevard, and Indian River counties is presented in Table 10. Chloride, sulfate, and bicarbonate concentrations are variable and independent of depth. Water with chloride and sulfate concentrations above 250 and 10 mg/l, respectively, occur in each county. These concentrations indicate areas where connate waters or mixtures between connate and fresh waters occur.

Table 10. Representative water quality data from wells tapping the shallow clastic aquifer in the study area.

County	Well	Lat	Long	Depth (ft)	Concentration (mg/l)			Composition (%)			Date
					Cl	SO_4	HCO_3	Cl	SO_4	HCO_3	
Volusia County	V-46	292116	810809	15	20	5	73	30.9	2.9	66.2	2/14/80
	V-48	292053	810546	20	290	0	342	59.3	0	40.7	12/14/79
	V-0109	290107	810620	21	19	0	150	18.0	0	82.0	4/27/66
	V-16	291006	811010	39	30	0	38	57.6	0	42.4	4/1/80
Brevard County	BR-118	275616	802938	15	450	45.3	146	81.6	3.0	15.4	6/2/83
	BR-217	282557	804523	18	188	72	252	52.1	7.3	40.6	9/16/80
	BR-221	282751	804236	32	100	41.6	16	80.3	12.3	7.4	5/16/83
	BR-223	282924	804638	38	36	8	234	20.5	1.7	77.8	9/17/80
	BR-353	281301	804007	43	325	21.3	228	69.8	1.7	28.5	5/25/83
	BR-289	275804	803256	45	325	44.2	222	69.1	3.4	27.5	5/17/83
	BR-56	283726	805108	60	12	–	290	–	–	–	1/16/76
	BR-287	275407	803146	75	150	3.7	300	46.0	0.5	53.5	5/17/83
Indian River County											
	IR-164	274505	802603	24	85	36	181	41.7	6.5	51.8	2/24/82
	IR-223	273814	802824	45	365	160	265	63.1	10.3	26.6	12/7/82
	IR-222	273817	802828	47	360	180	253	62.6	11.7	25.7	12/7/82
	IR-180	273756	802301	50	725	32	320	78.5	1.3	20.2	12/6/82
	IR-46	274509	803048	65	75	5	368	25.8	0.6	73.6	2/24/82
	IR-63	274843	802814	65	40	1	245	21.9	0.2	77.9	2/24/82
	IR-133	274735	802832	74	20	1	358	8.7	0.2	91.1	2/24/82

On the barrier island in Volusia County chloride concentrations in 1980 ranged from 3 to 9560 mg/l. It is difficult to correlate chloride concentration with depth due to the inability to account for the variation in withdrawals at the wells. On terrace deposits east of the Atlantic Coastal Ridge, chlorides increased from 42 to 370 mg/l over a seven foot change in depth (Table 11). This increase demonstrates the high potential for salt water intrusion of clastic aquifers in Volusia County.

A finger of fresh water, coinciding with the Titusville-Mims Ridge, occurs in northwest Brevard County. A similar situation occurs in the Floridan aquifer in this same area. The shallow clastic aquifer in the remaining northern half of the County generally contains connate water which arises by upward leakage from the Floridan aquifer. Brevard County, except for the Titusville-Mims Ridge area, is a discharge area for the Floridan aquifer (Figure 28). The principal confining unit, the clays of the Hawthorn Formation, is less than 100 feet thick over the northern portion of the County (Figure 18).

In Indian River County, the shallow clastic aquifer generally contains fresh recharge water. Localized areas of connate and/or transitional waters occur where Floridan aquifer water is used for citrus irrigation and infiltrates into this aquifer.

Between Sebastian Inlet and Indian River Shores in Indian River County, shallow clastic wells are also susceptible to

Table 11. Composite profile of chloride concentrations in the shallow terrace aquifer for an area near Ariel, Volusia County.

Aquifer	Depth Below Land Surface (ft)	Chloride Concentration (mg/l)
Shallow Terrace	20	25
	26	35
	38	42
	45	370
	53	415
Floridan	98	621
	215	560

lateral intrusion. Wells IR-150 and IR-152 located at the center point of the barrier island just north of Wabasso Beach, are good examples. They exhibit dramatic differences in chloride concentrations with a change in depth of only 2 feet. The depths of IR-150 and IR-152 are 18 and 20 feet, respectively. The corresponding chloride concentrations are 220 and 1020 mg/l.

SUMMARY

Several aquifer systems are found in Volusia, Brevard and Indian River counties. These include the regional Floridan aquifer, and sub-regional secondary artesian, shallow rock, and shallow clastic aquifers. The depth to the top of the Floridan aquifer is variable throughout the study area but generally increases from west to east and from north to south. In Volusia County it lies at 20 to 80 feet below msl and deepens to 300 to 600 feet below msl in Indian River County. Anhydrite beds at 2100 to 3200 feet below msl in the study area mark its base.

The Floridan aquifer is separated from the overlying surficial aquifer by the silts and clays of the Hawthorn Formation throughout much of the study area. Over much of Volusia County the Hawthorn Formation is absent and the Floridan and surficial aquifers are connected directly. In Brevard County the thickness of this confining unit generally increases to the east and south. In Indian River County its thickness and areal extent are sufficient to effectively separate Floridan and surficial producing zones.

Principal recharge areas for the Floridan aquifer are (1) Rima Ridge, (2) Geneva Hills, (3) Orlando Ridge, (4) Mt. Dora Ridge, (5) Lake Wales Ridge, and (6) Bombing Range Ridge. Only Rima Ridge lies within the study area; the others lie to the west. Recharge is as high as 10 to 20 inches/year in these areas. The source of recharge is primarily rainfall. Discharge occurs throughout much of the coastal region.

Rainfall varies throughout the study area and fluctuates yearly. Short periods (2 to 8 years) of below normal rainfall occur and are separated by periods of above normal rainfall. The most recent period of record low rainfall was during 1980-1981. During this period, annual rainfall deficiencies in some areas were as much as 25 inches. During 1980-1981, record low water levels in both ground water and surface water monitoring networks were observed.

Water levels in the Floridan aquifer have declined 5-15 feet in western portions of Brevard and Indian River counties between 1936 and 1981. Water levels declined 4-5 feet between 1960 and 1975 in USGS monitor wells in Orange (Cocoa A) and Brevard counties (Cocoa), but had remained approximately constant in both wells between 1975-1983. At the Platt well near Melbourne, water levels have declined 7.7 feet between 1955-1973 (Figure 23). During the next ten years the average water level remained relatively constant at 39.8 feet msl. In Indian River County water levels declined 8 feet in two Floridan wells at Vero Beach between 1959-1972, but changed very little during the next 12 years. Similar magnitudes of change are evident in both counties by comparing the 1936 potentiometric surface map of the Floridan aquifer with the 1982 and 1983 potentiometric maps. For southwest Brevard and western Indian River counties, the declines in water levels resulting from population and agricultural growth are 5 to 10 and 10 to 15 feet, respectively.

Along the coast of Volusia and Brevard counties the decline is nearly double with a 15 to 20 foot change in water levels between 1936-1981 at Cocoa and Indian Harbour Beach and 10 feet between 1960 and 1975 at Daytona Beach. In coastal portions of Indian River County the potentiometric surface of the Floridan aquifer fluctuated between 1974-1983 but no net decline is apparent. The declines in water levels in coastal areas correlate with increased withdrawals from the Floridan aquifer since the 1960's and reflect the dramatic increase in coastal development. Between 1970 and 1983, ground water withdrawals from the Floridan aquifer have increased by approximately 270 and 350 percent in Volusia and Brevard Counties respectively, but remained approximately constant in Indian River County.

In Volusia County well fields located along the coast tap the Floridan aquifer and withdrawals create large area-wide depressions in the potentiometric surface from Ormond Beach south to New Smyrna Beach. In south Brevard County withdrawals from small diameter Floridan wells with concentrations in excess of 1000 wells/mi^2 along the barrier island have caused the potentiometric surface to decline. In Indian River County declines in water level are primarily caused by withdrawals for citrus irrigation.

Chloride concentration generally increases from west to east and with depth in the Floridan aquifer. Concentrations are less than 100 mg/l in recharge areas and increase toward the coast. Chloride concentrations average 660 and 370 mg/l in the agricultural areas of Brevard and Indian River counties, respectively and 2,530 mg/l in the area of the St. Johns fault.

Along the barrier island in south Brevard and north Indian River counties the Floridan aquifer contains a lens of potable water called the Sebastian freshwater lens. Within the lens potable water occurs in two different depth zones. The upper zone has been decreasing in volume annually due to discharge from free-flowing wells and domestic withdrawals. In 1983 fourteen free-flowing wells on the barrier island were plugged. This reduced the rate of deterioration of the upper zone of the lens.

Since the 1950's water quality in the Floridan aquifer has changed in the coastal areas of Volusia County. The change is due to withdrawals from the Floridan aquifer which induces saltwater to move inland resulting in increased chloride concentrations. The change is greatest beneath the barrier island and near the urbanized areas of Ormond Beach, Daytona Beach, and New Smyrna Beach.

In northwest Brevard County relict sea water upwells along the St. Johns fault and contaminates the shallow aquifer and the upper zone of the Floridan aquifer. This upwelling limits the thickness of fresher water west of the fault. East of the fault, relict, unflushed sea water occurs along the eastern edge of the Titusville-Mims Ridge. Recharge which occurs along the ridge sustains a lens of fresh water (Figure 34) that acts to force relict sea water toward the flanks of the ridge.

Along the eastern edge of Brevard and Indian River counties, areas of laterally intruded water exist at Satellite and Wabasso Beach (Figure 42). Withdrawals from numerous small diameter wells for cooling and irrigation on the barrier island in Brevard

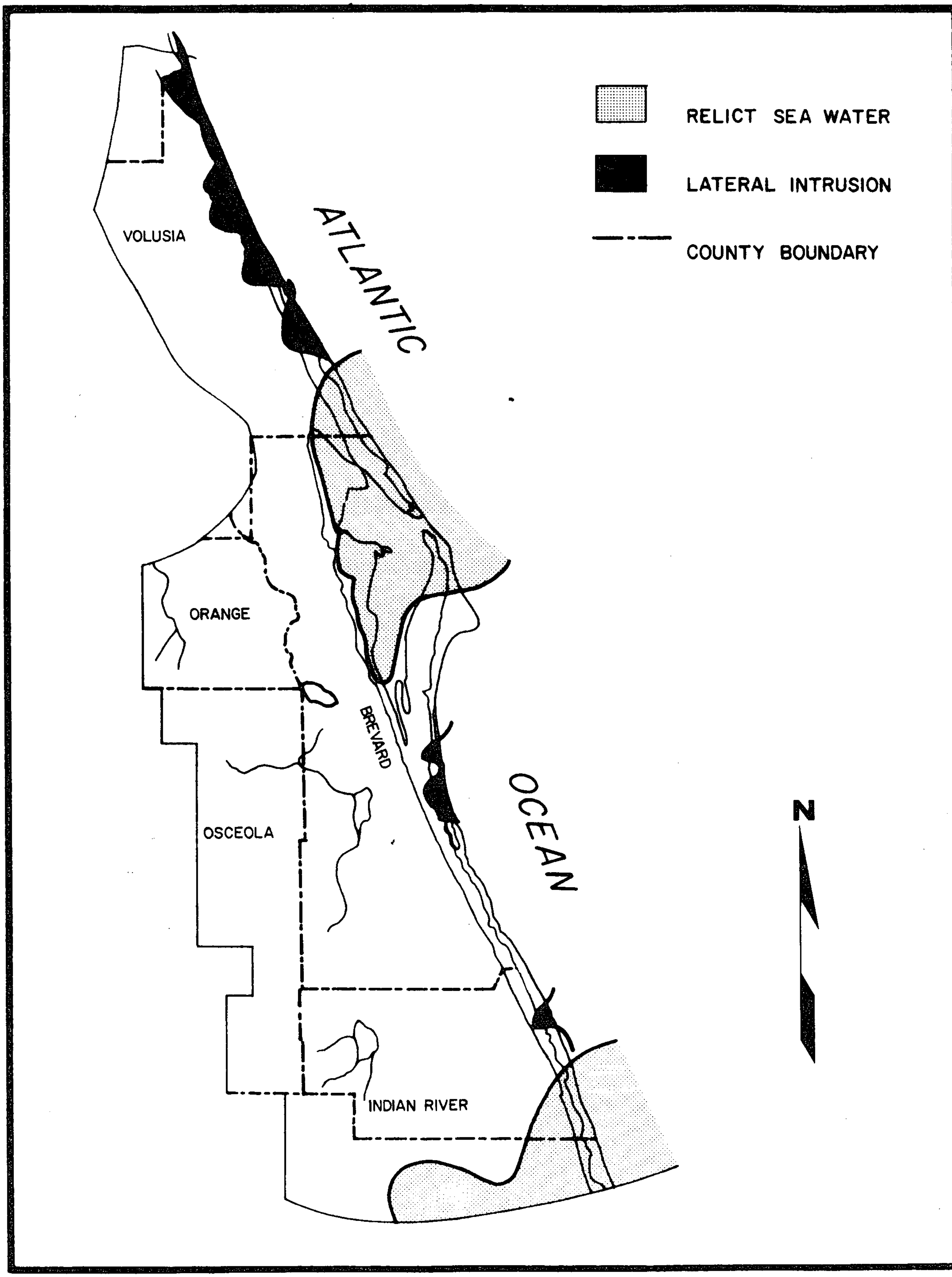


Figure 42. Location of saltwater fronts in the Floridan aquifer in 1982.

County has caused lateral movement of the interface south of Melbourne. Near Wabasso Beach, lateral intrusion occurs in the lower zone of the Floridan aquifer. The intrusion is the result of an estimated 20 foot decline, between 1936 and 1981, in the potentiometric surface of the Floridan aquifer (Figure 27). This decline was the result of large withdrawals for citrus irrigation to the west of the interface.

Secondary artesian aquifers occur only in south Brevard and north Indian River counties. These aquifers contain potable water with chloride concentrations of 150 to 230 mg/l. Over the past 31 years, water levels in an intermediate aquifer well in north Indian River County declined 6 feet, but chloride concentrations remained unchanged.

The shallow rock aquifer of the surficial aquifer system overlies the Hawthorn Formation in Brevard and Indian River counties. Its thickness is very irregular and dependent upon the erosional surface of the Hawthorn. Average values of transmissivity, storage coefficient, and leakance for this aquifer are 12,000 gal/d/ft, 0.0002, and 0.01 gal/d/ft^3, respectively. Recharge occurs west of the Atlantic Coastal Ridge as a result of the downward movement of water from the Anastasia Formation and other surficial aquifers. East of this ridge the shallow rock discharges into the overlying surficial aquifer.

The highest concentrations of chloride in the shallow rock aquifer occur along the barrier islands, which generally contain laterally intruded seawater. Chloride concentrations range from 1,200 mg/l at Cape Canaveral to 7,500 mg/l near the St. Lucie County line. Excluding the coastal areas, the shallow rock aquifer contains potable water in south Brevard and Indian River counties. In north Brevard County, chloride concentrations in shallow rock wells are generally greater than 250 mg/l.

Clastic aquifers are found throughout the study area and generally relate to local geomorphologic features such as ridges and coastal terraces. These aquifers provide water for domestic, irrigation, heat pump, and municipal supplies. The utility of each aquifer varies with land surface altitude, proximity to salt water bodies, and the thickness and permeability of sediments. Clastic aquifers are used as a water source on the barrier island from Melbourne Beach in Brevard County south to Indian River Shores in Indian River County. Between Sebastian Inlet and Indian River Shores, shallow clastic wells are extremely susceptible to lateral intrusion.

In south Brevard County the surficial aquifer has limited development potential. Most current supplies are affected by downward seepage of Floridan aquifer irrigation water and upconing of laterally intruded seawater during droughts or extended pumping sequences. In Indian River County, the surficial aquifer is a more stable source of freshwater. In eastern Indian River County the surficial aquifer is capable of supplying about 76 MGD (Crain, 1975), indicating that well field expansion can continue to support development. Factors which limit the surficial aquifer's development potential revolve around connate or relict seawater infiltration.

Several areas of the study areas with significant potential for salt water intrusion are summarized in the following sections.

VOLUSIA COUNTY

The coastal margin east of the Rima Ridge is a hydrogeologically sensitive area. This area has a history of deteriorating water quality in water from wells tapping several formations. The cause of these changes can be related to the location of well fields and multizone well penetrations.

Intrusion is greatest in the lower permeable zone of the Floridan aquifer and withdrawals from wells tapping this zone east of the Atlantic Coastal Ridge result in upconing of laterally intruded seawater. Higher head in the lower zone results in the movement of poorer quality water into the upper zone. In 1955, at Daytona Beach, water levels in wells penetrating the lower zone were five feet greater than levels in wells penetrating the upper zone. During the next 22 years this difference increased to 15 feet coinciding with increased withdrawals from the upper zone. In response to this problem the City of Daytona Beach has taken remedial action including reconstruction of existing wells to limit withdrawals to the upper zone, reduction of pumping rates, and shifting of withdrawals to new wells west of the Atlantic Coastal Ridge.

Water quality improves in the lower zone west of this ridge. East of this ridge only shallow and upper zone Floridan aquifer wells provide moderately dependable supplies of potable water.

BREVARD COUNTY

The only potable water available in the Floridan aquifer in Brevard County is located along the Titusville-Mims Ridge, in the Sebastian lens, and along the southwest corner of the County near the Osceola County line. Water withdrawn from the Floridan aquifer in the Titusville-Mims Ridge area affects the availability of fresh water in this area and approximately equals the quantity recharged. The Sebastian lens has been shrinking annually due to discharge from abandoned free-flowing and domestic wells. The southwest corner of Brevard County has shown slight indications of increasing chloride concentrations. Water in this area is still of potable quality.

Most of Brevard County is a Floridan aquifer discharge area. The absence of confining beds north of Lake Poinsett combined with upconing of relict sea water in this area has lead to the deterioration of water quality in both the shallow aquifer and upper permeable zone of the Floridan aquifer along the St. Johns River. Along the coastal regions of south Brevard County withdrawals from large concentrations of two-inch heat-pump wells has caused salt water intrusion into the Floridan. The effect of these withdrawals can also be seen in the water quality of the shallow rock aquifer at Satellite Beach where chlorides increased by a factor of 10 due to infiltration of Floridan aquifer water.

Structural features along the St. Johns River created the large area of relict seawater in north Brevard County. The vast area of connate water in central and south Brevard County has limited available potable water since development began. Future use of this connate reservoir by agricultural interests will depend largely upon the thickness of connate water overlying relict seawater.

Withdrawals from the surficial aquifer occur along the coastal ridge. Major users in this area are the communities of Titusville, Port St. John, Port Malabar, and Barefoot Bay, as well as numerous domestic users. Both Floridan and shallow rock wells in the Titusville and Port Malabar areas have experienced saltwater intrusion. The Port Malabar wellfield experiences chloride concentrations in excess of 300 mg/l seasonally. These high concentrations result from lateral movement of connate water in the shallow rock aquifer during large seasonal withdrawals.

The long-term water supply potential of the surficial aquifer is an important factor to consider as growth increases throughout Brevard County. Special management techniques may be necessary to preserve the integrity of the resource in those areas where the surficial aquifer is the only naturally potable ground water source.

INDIAN RIVER COUNTY

In Indian River County, water is withdrawn from the surficial and Floridan aquifer systems. The Floridan aquifer is used principally for agricultural purposes and the shallow aquifer for individual domestic and public supply purposes.

The surficial aquifer is presently developed along the Atlantic Coastal Ridge. The principal threat to the surficial aquifer is infiltration of Floridan irrigation water which has high concentrations of chloride. In isolated areas plumes of non-potable water reduce the volume of surficial aquifer water that is available for individual domestic or public supply.

In areas where the surficial aquifer is contaminated by infiltration of citrus irrigation water, the intermediate aquifer may provide a good alternate domestic supply source. This aquifer may also provide a source of water for mixing with the more mineralized Floridan aquifer water to increase potable water supplies.

The shallow rock zone of Brevard and Indian River counties is the basal water producing zone of the shallow aquifer system and is the unit controlling lateral movement of seawater along the coast. Floridan wells cased only to the top of the shallow rock zone allow movement of saline water to the Floridan aquifer during period of heavy pumping. This problem occurs in many of the areas along the barrier island.

CONCLUSION

This report examines the geology, hydrology, and water quality of the Floridan, intermediate, and surficial aquifer systems. The manner in which each aquifer is used depends on its water quality and availability. For instance, in Volusia County, the Floridan aquifer is primarily used for individual domestic and public supply. It contains good quality water and is usually penetrated by wells less than 100 feet deep. In Brevard County, the Floridan aquifer contains potable water in the Titusville-Mims Ridge area, the Sebastian Lens area, and in the southwestern part of the County. In other areas of Brevard County, the Floridan aquifer contains connate water. Hence water withdrawn from the Floridan aquifer in Brevard County is primarily used for irrigation and ground water heat pumps. In Indian River County, the Floridan generally contains connate water. Here the surficial aquifer system is used for individual domestic and public supply. Water from the Floridan aquifer is primarily withdrawn for irrigation.

In the study area land use is an important variable influencing changes in water levels in the Floridan aquifer. Water levels in the Floridan aquifer declined during periods of citrus expansion in western Brevard and Indian River counties and during periods of population growth in eastern Volusia and Brevard counties. The declines resulted primarily from increased withdrawals from the Floridan aquifer in these areas.

Water quality in coastal areas of Volusia and Brevard counties has changed as a consequence of lower water levels. In coastal areas of Volusia County, the Floridan aquifer is intruded by water with chloride concentrations above 250 mg/l. This water extends farthest inland in areas where ground water withdrawals are the largest. In coastal portions of Brevard County, saltwater intrusion also occurs and is greatest at Satellite Beach where there is a large concentration of heat pump wells. Saltwater intrusion in the Floridan aquifer also occurs at Wabasso Beach in Indian River County. The intrusion is probably due to ground water withdrawals for citrus irrigation which has lowered the potentiometric surface by an estimated 20 feet over a 45 year period.

Rainfall also affects water levels and, consequently, water quality. The most recent period of record low rainfall was during 1980-1981. During this period annual rainfall deficiencies in some areas were as high as 25 inches and coincided with record low water levels. The low water levels resulted from increased ground water withdrawals from Floridan and surficial aquifer system wells for irrigation during dry periods.

The surficial aquifer system is an important source for public and domestic supply where the Floridan aquifer contains nonpotable water. In south Brevard and Indian River counties, the shallow rock aquifer contains potable water. Along the coast, however, the shallow-rock aquifer contains laterally intruded seawater. Saltwater intrusion occurs beneath the barrier

barrier island and extends inland in areas of large withdrawals. At Vero Beach the freshwater/saltwater interface extends one and three-fourths (1 3/4) miles west of the Indian River at the northern boundary of the city and three-fourths (3/4) miles west of the Indian River at the southern boundary of the city.

In eastern Volusia County, the shallow clastic aquifer generally contains potable water. In northern Brevard County, the shallow clastic aquifer generally contains nonpotable water which is derived from upward leakage from the Floridan aquifer. The Titusville-Mims Ridge area of north Brevard County is an exception. Shallow clastic aquifers along the ridge contain potable water. In south Brevard and Indian River counties the shallow clastic aquifer generally contains fresh water. Localized nonpotable areas of connate and/or transitional waters occur in the shallow clastic aquifer where Floridan connate water used for citrus irrigation has entered this aquifer.

REFERENCES AND BIBLIOGRAPHY

Applin, P.L. and Applin, E.R., 1944. Regional subsurface stratigraphy and structure of Florida and southern Georgia: Am. Assoc. Petroleum Geologists Bull., Vol. 28, No. 12, pp. 1673-1753.

American Water Works Association, 1980. The safe drinking water act, self-study handbook, community water systems: AWWA, 99 p.

Back, W., 1960. Origin of hydrochemical facies of ground water in the Atlantic Coastal plain: International Geologic Conference, 21 Session, Part I, Geochemical Cycles, pp. 87-95.

-----, 1961. Techniques for mapping of hydrochemical facies: U.S. Geol. Survey Prof. Paper 424-D, pp. 380-392.

-----, 1966. Hydrochemical facies and ground water flow patterns in northern part of Atlantic coastal plain: U.S. Geol. Survey Prof. Paper 498-A, 42 p.

Back, W. and Hanshaw, B., 1965. Chemical geohydrology: In V.T. Chow (ed.), Advances in hydroscience, Academic Press, Inc., New York, Vol. 2, pp. 49-109.

-----, 1971. Geochemical interpretations of groundwater flow systems: Water Res. Bull., Vol. 7, No. 5, paper 71090, pp. 1008-1016.

Barille, Diane D., 1976. An environmental study of the Melbourne-Tillman Drainage District and an evaluation of alternate land use plans for the City of Palm Bay, Florida: Masters Thesis, Florida Institute of Technology, 317 p.

Barraclough, Jack T., 1962. Ground-water resources of Seminole County, Florida: Florida Geol Survey Rept. of Inv. No. 27, 10 plates, 91 p.

Bell, L.A. and others, 1980. Florida surface impoundment assessment-final report: Dept. of Envir. Regulation, multiple pagination.

Bermes, B.J., 1958. Interim report on geology and groundwater resources of Indian River County, Florida: Bur. of Geol. Inf. Circ. No. 18, 75 p.

Bishop, E.W., 1956. Geology and groundwater resources of Highlands County, Florida: Florida Geol. Survey Rept. of Inv. 15, 115 p.

Black, A.P. and Brown, E., 1951. Chemical character of Florida's waters -- 1951: Florida State Bd. of Cons., Water Survey and Research Paper 6.

Black, A.P., Brown, E., and Pearce, J.M., 1953. Salt water intrusion in Florida, 1953: Florida State Bd. of Cons., Div. Water Survey and Research Paper 9, 38 p.

Brevard Co. Development Division, 1975-77. Data reports and library of inventory data: four spiral bound volumes, various pagination, unpublished.

Brevard County Dev. Div., 1979. Brevard County 208 areawide waste treatment management plan: 2 volumes, multiple pagination.

Brown, D.W., Kenner, W.E. and Brown, E., 1957. Interim report of the water resources of Brevard County, Florida: Florida Geol. Survey Inf. Circ. 11.

Brown, D.W., Kenner, W.E., Crooks, J.W. and Foster, J.B., 1962 Water resources of Brevard County, Florida: Florida Geol. Survey Report of Inv. No. 28, 104p.

-----, 1962. Water-resources records of Brevard County, Florida: Florida Geol. Survey Inf. Circ. No. 32, 180 p.

Brown, M.P., 1980. Aquifer recovery test data and analyses for the Floridan aquifer system in the Upper East Coast Planning Area, South Florida Water Management District (SFWMD): SFWMD Tech. Pub. 80-1, 52 p.

Brown, M.P. and Reece, D.E., 1979. Hydrologic reconnaissance of the Florida aquifer system, Upper East Coast Planning Area: South Florida Water Management District Tech. Map Series 79-1, 10 sheets.

Brown, R.H., 1963a, Estimating the transmissivity of an artesian aquifer from the specific capacity of a well; In Bentall, Ray, compiler, Methods of determining permeability, transmissivity, and drawdown: U.S. Geol. Survey Water Supply Paper 1536-I, pp. 336-338.

-----, 1963b, Ground-water movement in a rectangle aquifer bounded by four canals; In Bentall, Ray, compiler, Shortcuts and special problems in aquifer tests: U.S. Geol. Survey Water Supply Paper 1545-C, pp. 86-100.

Buono, A. and Rutledge, A.T., 1979. Configuration of the top of the Floridan aquifer, Southwest Florida Water Management District and adjacent areas: U.S. Geol. Survey Water Resources Invest. 78-34, 1 sheet.

Buono, A., Spechler, R.M., Barc, G.L. and Wolensky, R.M., 1979. Generalized thickness of the confining bed overlying the Floridan aquifer Southwest Florida Water Management District: U.S. Geol. Survey Water-Resources Invest. 79-1171, 1 sheet.

Bush, P.W., 1978. Hydrologic evaluation of part of central Volusia County, Florida: U.S. Geol. Survey WRI 78-89, 50 p.

-----, 1979. Connector well experiment to recharge the Floridan aquifer, east Orange County, Florida: U.S. Geol. Survey WRI 78-73, 40 p.

Callahan, J.T., 1964. The yield of sedimentary aquifers of the coastal plain southeast river basins: U.S. Geol. Survey Water Supply Paper 1669-W, 56 p.

Cederstrom, D.J., Boswell, E.H., and Tarver, G.R., 1979. Summary appraisals of the nation's ground water resources - South Atlantic Gulf Region: U.S. Geol. Survey Prof. Paper 813-0, 35 p.

Chen, C.S., 1965. The regional lithostratigraphic analysis of Paleocene and Eocene rocks of Florida: Florida Geol. Survey Bull. No. 45, 97 p.

CH_2M Hill, 1979. Injection test well and multizone monitor well Indian River plant, Hercules, Inc.: Project report GN54801.80, various pagination, appendices and data files.

-----, 1979, Evaluation of water availability in the Cocoa well field: CH_2 M Hill preliminary report, various pagination, appendices.

Collins, W.P. and Howard, E.S., 1928. Chemical character of waters of Florida: U.S. Geol. Survey Water Supply Paper 596-C.

Cole, W.S., 1944. Stratigraphic and paleontologic studies of wells in Florida -- No. 3: Florida Geol. Survey Bull. 26, 188 p.

Cooke, C.W., 1939. Scenery of Florida: Florida Geol. Survey Bull. 17, 118 p.

-----, 1945. Geology of Florida: Florida Geol. Survey Bull. 29.

Cooper, H.H., Kenner, W.E. and Brown, Eugene, 1953. Ground water in central and northern Florida: Florida Geol. Survey Rept. of Inv. No. 10, 37 p.

Cooper, H.H. Jr. and Jacob, C.E., 1946. A generalized graphical method for evaluating formation constants and summarizing well field history: Am. Geophs. Union Trans., Vol. 27, No. 4, pp. 526-534.

Crain, L.J., Hughes, G.H. and Snell, L.J., 1975. Water resources of Indian River County, Florida: Bur. of Geol. Rept. of Inv. No. 80, 75 p.

Dalton, M.G. and Upchurch, S.B., 1978. Interpretation of hydrochemical facies by factor analysis: Ground Water, 16: 228-233.

Davis, S.N. and DeWiest, R.J.M., 1967. Hydrogeology, 2nd Ed.: Wiley, 463 p.

Dawkins & Associates, Inc., 1980. Aquifer performance evaluation, shallow aquifer system. Windover Lakes Development, Brevard County, Florida: Engineers Project Report No. W08-X03, various pagination, appendices.

Dietrich, T.S., 1978. The urbanization of Florida's population: an historical perspective of county growth 1830-1870: Bureau of Economic and Business Research, University of Florida; Gainesville, Florida, 210 p.

Domenico, P.A., 1972. Concepts and models in groundwater hydrology: McGraw-Hill, 405 p.

Ferris, J.G., Knowles, D.B., Brown, R.H., and Stallman, R.W., 1962. Theory of aquifer tests: U.S. Geol. Survey Water Supply Paper 1536-E, 174 p.

Florida Dept. of Health and Rehabilitative Services, 1969. Review of selected properties of Florida waters, 1969:State of Florida, Dept. of Health and Rehabilitative Services, Div. of Health, Bur. Sanitary Engineering, Water Supply Section, Jacksonville, Florida, 50 p.

Florida State Board of Health, 1965. Some physical and chemical characteristics of selected Florida waters, Supplement, June 1964: Florida State Board of Health, Bur. Sanitary Engineering, Div. Water Supply, Jacksonville, Florida, 54 p.

Florida State Board of Health, 1969. Some physical and chemical characteristics of selected Florida waters, Second Supplement, June 1968: Florida State Board of Health, Bur. Sanitary Engineering, Div. Water Supply, Jacksonville, Florida, 23 p.

Franks, B.J., ed., 1982. Principal aquifers in Florida: U.S. Geol. Survey WRI 82-255, 4 sheets.

Frazee, J.M. Jr., 1978. Hydrologic overlay maps of the Orsino quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 78-194, 5 pls.

-----, 1980. Ground-water resources of Osceola County and adjacent areas, Florida: U.S. Geological Survey Open-File Report 79-1595, 1 sheet.

Frazee, J.M. Jr., and Laughlin, C.P., 1978a. Hydrologic overlay maps of the Aurantia quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 78-195, 7 pls.

-----, 1978b. Hydrologic overlay maps of the False Cape quadrangle, Brevard County, Florida U.S. Geol. Survey Open-File Rept. 78-196, 5 pls.

-----, 1978c. Hydrologic overlay maps of the Mims quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 78-72, 7 pls.

-----, 1978d. Hydrologic overlay maps of the Maytown quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 78-189, 5 pls.

-----, 1978e. Hydrologic overlay maps of the Titusville SW quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 78-190, 5 pls.

-----, 1978f. Hydrologic overlay maps of the Oak Hill quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 78-191, 5 pls.

-----, 1978g. Hydrologic overlay maps of the Titusville quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 78-192, 7 pls.

-----, 1978h. Hydrologic overlay maps of the Wilson quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 78-193, 5 pls.

-----, 1979a. Hydrologic overlay maps of the Cape Canaveral quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 79-3, 5 pls.

-----, 1979b. Hydrologic overlay maps of the Cocoa quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 79-337, 7 pls.

-----, 1979c. Hydrologic overlay maps of the Cocoa Beach quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 79-338, 5 pls.

-----, 1979d. Hydrologic overlay maps of the Courtenay quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 79-338, 5 pls.

-----, 1979e. Hydrologic overlay maps of the Lake Poinsett quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 79-340, 5 pls.

-----, 1979f. Hydrologic overlay maps of the Fellsmere SW quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 79-503, 5 pls.

-----, 1979g. Hydrologic overlay maps of the Kenansville SE quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 79-504, 5 pls.

-----, 1979h. Hydrologic overlay maps of the Sebastian NW quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 79-505, 5 pls.

-----, 1979i. Hydrologic overlay maps of the Grant quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 79-506, 7 pls.

-----, 1979j. Hydrologic overlay maps of the Kenansville NE quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 79-507, 5 pls.

-----, 1979k. Hydrologic overlay maps of the Fellsmere NW quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 79-508, 7 pls.

-----, 1979l. Hydrologic overlay maps of the Deer Park NE quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 79-516, 5 pls.

-----, 1979m. Hydrologic overlay maps of the Eau Gallie quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 79-518, 7 pls.

-----, 1979n. Hydrologic overlay maps of the Melbourne East quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 79-519, 7 pls.

-----, 1979o. Melbourne West quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 79-520, 7 pls.

-----, 1979p. Hydrologic overlay maps of the Tropic quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 79-521, 5 pls.

-----, 1979q. Hydrologic overlay maps of the Sharpes quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 79-341, 7 pls.

-----, 1979r. Hydrologic overlay maps of the Sebastian quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 79-501, 5 pls.

-----, 1979s. Hydrologic overlay maps of the Fellsmere quadrangle, Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 79-502, 5 pls.

Frazee, J.M. Jr., and McClaugherty, D.R. 1979. Investigation of ground water resources and salt water intrusion in the coastal areas of northeast Florida: St. Johns River Water Management District Technical Rept. No. 3, 245 p., 4 pls.

Freeze, R.A. and Cherry, J.A., 1979. Groundwater: Prentice-Hall, 604 p.

Gee and Jenson, 1979. Test well completion report for water supply development program, Vero Beach, Florida: Project Report 79-69, 21 p., appendices.

-----, 1980. Future water supply development for the City of Vero Beach: Project Report 79-197, 52 p., appendices.

-----, 1980. Well completion report for well field conditioning program for City of Vero Beach, Florida: Consultant's Report 79-197, 18 p., appendices.

Geraghty & Miller, 1978. Availability of ground water at Hobart Park, Indian River County, Florida: Project Report, 29 p., appendices.

-----, 1981. Drilling and testing for public water supply from the shallow aquifer, Sebastian Highland, Indian River County, Project Report, 21 p., appendices.

-----, 1981. Installation and testing of production and monitoring wells, South Taxing District, Indian River County, Florida: Project Report, 29 p., appendices.

-----, 1982. Availability of water from the Port Malabar well field, Brevard County, Florida: Project Report, 17 p., 1 plate.

Goggiani, N.G., and Lamonds, A.G., 1978. Chemical and biological quality of lakes Faith, Hope, and Charity, at Maitland, Florida, with emphasis on the effects of storm runoff and bulk precipitation, 1971-74: U.S. Geol. Survey Open-File Rept. 77-491, 94 p.

Gomberg, David N., 1978. Assessment of potential for water supply development at Halifax Plantation, Volusia and Flagler Counties, Florida: Missimer and Associates, Inc., 34 p.

-----, May 1980. Available groundwater at National Gardens Trust, Volusia County, Florida: David N. Gomberg, Water Resources Consultant, 64 p., appendices.

-----, April 1981. Water resources and available groundwater at Halifax Plantation, Volusia and Flagler Counties, Florida: David N. Gomberg, Water Resources Consultant, 98 p., appendices.

Goodell, H.G. and Yon, J.W. Jr., 1960. The regional lithostratigraphy of the post-Eocene rocks of Florida In Puri, H.S., Editor, 1960, Late Cenozoic stratigraphy and sedimentation of central Florida: Southeastern Geological Society, 39 p.

Grubb, Hayes, F., 1978. Potential for downward leakage to the Floridan aquifer, Green Swamp area, central Florida: U.S. Geol. Survey Water-Resources Invest. 77-71, 1 sheet.

Grubb, H.F., Chappelear, J.W. and Miller, J.A., 1978. Lithologic and borehole geophysical data, Green Swamp area, Florida: U.S. Geol. Survey Open-File Rept. 78-574, 270 p.

Grubb, H.F. and Rutledge, A.T., 1979. Long-term water supply potential Green Swamp area, Florida: U.S. Geol. Survey Water-Resources Invest. 78-99, 76 p.

Hampton Assoc., and Quentein, L., 1981. Groundwater supply evaluation, City of Port Orange, Florida: Project Report, 12 p.

Healy, H.G., 1974. Water levels in artesian and non-artesian aquifers of Florida, 1971-72: Bur. of Geol. Inf. Circ. 85, 94 p.

-----, 1977. Public water supplies of selected municipalities in Florida, 1975: U.S. Geol. Survey, Water Resources Inv. 77-53, 309 p.

-----, 1978. Appraisal of uncontrolled flowing artesian wells in Florida: U.S. Geol. Survey WRI 78-95, 26 p.

-----, 1978. Water levels in artesian and non-artesian aquifers of Florida, 1975-76: U.S. Geol. Survey Open-File Rept. 78-458, 115 p.

-----, 1980. Water levels in artesian and non-artesian aquifers of Florida, 1977-78: U.S. Geol. Survey Open-File Rept. 80-693, 99 p.

Heath, R.C. and Barraclough, J.T., 1954. Interim report on the ground-water resources of Seminole County, Florida: Florida Geol. Survey Inf. Cir. No. 5, 43 p.

Hedges, R.E., 1979. Water use by selected municipalities in Florida, 1917 (Computer printout in letter format): U.S. Geol. Survey, WRD, Ocala, Florida, 6 p.

Hem, John D., 1970. Study and interpretation of the chemical characteristics of natural water, Second Edition: U.S. Geol. Survey WSP 1473, 363 p.

Hughes, J.L., 1979. Saltwater-barrier line in Florida: concepts, considerations, and site examples: U.S. Geol. Survey WRI 79-75, 29 p.

Hughes, G.H., 1979. Analysis of water-level fluctuations of lakes Winona and Winnemissett -- two landlocked lakes in a karst terrain in Volusia County, Florida: U.S. Geol. Survey WRI 79-55, 24 p.

Hughes, G.H., and Frazee, J.M. Jr., 1979. Surface-water features in Osceola County and adjacent areas, Florida: U.S. Geol. Survey Open-File Rept. 79-1289, 1 sheet.

ICDC, 1978. Comprehensive Land Use Plan, Palm Coast, Flagler County, Florida, Vol. 3, Water Management, Chapter 3.5, Water supply and appendices.

Jenab, A., 1988. Rainfall analysis for Northeast Florida. Part III: Seasonal Rainfall Data; St. Johns River Water Management District, Palatka, FL: Technical Publication Draft.

Irwin, G.A., and Healy, H.G., 1978. Chemical and physical quality of selected public water supplies in Florida, August-September 1976: U.S. Geol. Survey Water Resources Inv. 78-21, 200 p.

Johnson, E.E., publisher, 1966. Ground water and wells: Edward E. Johnson, Inc., St. Paul, Minn., 440 p.

Johnson, Richard A., 1981. Structural geologic features and their relationship to salt water intrusion in west Volusia, north Seminole, and northeast Lake counties, Florida: St. Johns River Water Management District Tech. Pub. SJ 81-1, 32 p.

Johnson, R.A., Frazee, J.M. Jr., and Fenzel, F.W., 1982. Hydrogeology of the St. Johns River Water Management District, In Proceedings of the first annual symposium of Florida Hydrogeology: Northwest Florida Water Management District Public Information Bull. 82-2, pp. 83-104.

Johnston, R.H., Krause, R.E. and others, 1980. Estimated potentiometric surface for the tertiary limestone aquifer system, Southeastern United States, prior to development: U.S. Geol. Survey Open-File Rept. 80-406, 1 sheet.

Kimrey, J.O., 1978. Preliminary appraisal of the geohydrologic aspects of drainage wells, Orlando area, central Florida: U.S. Geol. Survey Water-Res. Invest. 78-37, 24 p.

Klein, H., 1971 (Revised 1975). Depth to base of potable water in the Floridan aquifer; 1971: Bureau of Geol. Map Series 42, 1 sheet.

Knochenmus, D.D., 1968. Surface drainage characteristics of Volusia County: Florida Geol. Survey Map Series 30, 1 sheet.

Knochenmus, D.D., 1974. Hydrologic concepts of artifically recharging the Floridan aquifer in eastern Orange County, Florida - a feasibility study: Bureau of Geol. Rept. of Inv. 72, 36 p.

Knochenmus, D.D. and Beard, M.E., 1971. Evaluation of the quantity and quality of the water resources of Volusia County, Florida: Bureau of Geol. Rept. of Inv. No. 57, 2 plates, 59 p.

Knochenmus, D.D. and Hughes, G.H., 1976. Hydrology of Lake County, Florida: U.S. Geol. Sur. WRI 76-72, 100 p.

Kohout, F.A. and Meyer, F.W., 1959. Hydrologic features of the Lake Istokpoga and Lake Placid areas, Highlands County, Florida: Florida Geol. Survey Rept. of Inv. 19, 73 p.

Kreitman, A., 1980. Hydrogeologic report of the Saw Mill Ridge properties, Indian River County, Florida: Project Report, 8 p., appendices.

Laughlin, C.P., May 1973. Potentiometric Surface of the Floridan aquifer in east-central Florida: U.S. Geol. Survey Open-File Rept. 73-030, 1 sheet.

-----, May 1974. Potentiometric Surface of the Floridan aquifer in east-central Florida: U.S. Geol. Survey Open-File Rept. 74-025, 1 sheet.

-----, May 1975. Potentiometric Surface of the Floridan aquifer in east-central Florida: U.S. Geol. Survey Open-File Rept. 75-677, 1 sheet.

-----, May 1976. Potentiometric Surface of the Floridan aquifer in east-central Florida: U.S. Geol. Survey Open-File Rept. 76-813, 1 sheet.

Laughlin, C.P. and Hayes, E.C., 1977. Potentiometric surface map of the Floridan aquifer in the SJRWMD and vicinity, Florida, May 1977: U.S. Geol. Survey Open-File Rept. 77-629, 1 sheet.

Laughlin, C.P. and Hughes, D.M., 1972. Hydrologic records for Volusia County, Florida: U.S. Geol. Survey Open-File Rept. 72-030, 1 sheet.

Laughlin, C.P. and Schol, M., 1971. Hydrologic records for Lake County, Florida 1970-71: U.S. Geol. Survey Open-File Rept. 71-001.

-----, 1972. Hydrologic records for Lake County, Florida: 1971-72: U.S. Geol. Survey Open-File Rept. 73-009.

Lawrence, F.W. and Upchurch, S.B., 1976. Identification of geochemical patterns in ground water by numerical analysis: Proc., 12th Ann. Smp., Advances in Ground Water Hydrology, Amer. Water Resources Assn.

Leach, S.D., 1978. Fresh water use in Florida, 1975: Map Series No. 87, Bur. of Geol., 1 sheet.

Leach, S.D., 1978. Source, use, and disposition of water in Florida, 1975: U.S. Geol. Survey Water Resources Inv. 78-17, 90 p.

Lichtler, William F., 1972. Appraisal of water resources in the east central Florida region: Bureau of Geol. Rept. of Inv. No. 61, 1 plate, 52 p.

Lichtler, W.F., Anderson, W. and Joyner, B.F., 1968. Water resources of Orange County, Florida: Bureau of Geol. Rept. of Inv. 50, 150 p.

Lohman, S.W., 1972. Definitions of selected ground water terms - revisions and conceptual refinements: U.S. Geol. Survey Water Supply Paper 1988, 21 p.

MacNeil, F.S., 1949, Pleistocene shorelines in Florida and Georgia: U.S. Geol. Survey Prof. Paper 221-F.

Manheim, Frank T., 1967. Evidence for submarine discharge of water on the Atlantic Continental slope of the southern United States, and suggestions for further search: Transactions of the New York Academy of Sciences, Series II, Vol. 29, No. 7, pp. 839-853.

Marella, R., 1984. Annual water use survey: 1983: St. Johns River Water Management District, Palatka, Florida, Technical Publication SJ 84-5, 103p.

-----, 1984. Annual water use survey: 1983 (Revised 1986): St. Johns River Water Management District, Palatka, Florida, unpublished.

-----, 1984. Individual public and industrial water users: 1983: St. Johns River Water Management District, Palatka, Florida, Suppliement to Technical Publication SJ 84-5, 35 p.

-----, 1986. Annual water use survey: 1985: St. Johns River Water Management District, Palatka, Florida, Technical Publication, SJ 86-5, 117 p.

Matson, G.C. and Sanford, Samuel, 1913. Geology and ground waters of Florida: U.S. Geol. Survey WSP 319, pp. 273-277.

Matthess, George, 1982. The properties of groundwater: Wiley-Interscience, 397 p.

McWhorter, D.B. and Sunada, D.K., 1977. Ground water hydrology and hydraulics: Water Resources Publications, Ft. Collins, Colorado, 290 p.

Meadows, P.E., and Hughes, D.M., 1974. Hydrologic records for Volusia County, Florida, 1972-73: U.S. Geol. Survey Open-File Rept. 74-021.

Miller, J.A., 1982. Geology and configuration of the base of the Tertiary limestone aquifer system, Southeastern United States: U.S. Geol. Survey WRI 81-1176, 1 sheet.

-----, 1986. Hydrogeologic framework of the Floridan Aquifer System in Florida and in parts of Georgia, Alabama, and South Carolina: U.S. Geol. Survey Professional Paper 1403-B, 91p.

Millette, J.R. and others, 1980. Aggressive water: Assessing the extent of the problem: Journal of the American Water Works Assoc., May issue, pp. 262-266.

Mooney, R.T. III, 1980. The stratigraphy of the Floridan aquifer system east and northeast of Lake Okeechobee, Florida: South Florida Water Management District Tech. Pub. 80-9, 45 p.

Munch, D.A., 1979. Test drilling report of Northwest Volusia County: St. Johns River Water Management District Tech. Pub. SJ 79-3, 32 p.

Munch, D.A., Ripy, B.J., and Johnson, R.A., 1979. Saline contamination of a limestone aquifer by connate intrusion in agricultural areas of St. Johns, Putnam, and Flagler counties, northeast Florida: St. Johns River Water Management District Technical Publication SJ 79-4, Part 1, 89 p.

Munch, D.A., Ripy, B.J., and Johnson, R.A., 1979. Supplemental data for report of saline contamination of a limestone aquifer by connate intrusion in agricultural areas of St. Johns, Putnam, and Flagler counties, northeast Florida: St. Johns River Water Management District Tech. Pub. SJ 79-4, Part 2, 75 p.

National Oceanic Atmospheric Administration, 1978. Climatological data: Vol. 84, Nos. 1-12.

Neill, R.M., 1955. Basic data of the 1946-47 study of the ground-water resource of Brevard County, Florida: U.S. Geol. Survey Open-File Rept. 55-001.

Parker, G.G., 1951, Geologic and hydrologic factors in the perennial yield of the Biscayne Aquifer: Jour. of the Amer. Water Works Assoc., V 43, pt. 2, p. 817-834.

Parker, G.G., and Cooke, C.W., 1944, Late Cenozoic geology of southern Florida, with a discussion of the ground water: Florida Geol. Survey Bull. 27, 119p.

Parker, G.G., Ferguson, G.E., Love, S.R., and others, 1955. Water resources of Southeast Florida: U.S. Geol. Survey Water-Supply Paper 1255, 965. p.

Pascale, C.A., 1975. Estimated yield of fresh-water wells in Florida: Bureau of Geol. Map Series 70, 1 sheet.

Phelps, G.G., 1978. Methods of estimating recharge to the Floridan aquifer in northeast Florida: U.S. Geol. Survey Water-Resources Investigations 77-109, 19 p.

Piper, A.M., 1944. A graphic procedure in the geochemical interpretation of water analyses: Trans. Amer. Geophys. Union 25, pp. 914-923.

Pirkle, E.C., Yoho, W.H., and Hendry, C.W., Jr., 1970. Ancient sea level stands in Florida: Bur. of Geol. Geological Bull. 52, 61 p.

Pittsburgh Testing Laboratory, 1979. Subsurface investigation, Area III test well program, City of Titusville, Florida: Project Report No. JA-2112 (Report No. 1 revised), 16 p., appendices.

Post, Buckley, Schuh & Jernigan, Inc., 1981. Water supply study, Brevard County, Florida: Aerial Report T16-001.62, various pagination.

Pride, R.W., 1970. Estimated water use in Florida, 1965: Florida Dept. of Natural Resources, Florida Bureau of Geology Map Series 36, 1 sheet.

-----, 1973. Estimated use of water in Florida, 1970: Florida Dept. of Natural Resources, Bur. Geology, Inf. Circ. 83, 31 p.

Pride, R.W., Meyer, F.W. and Cherry, R.N., 1961. Interim report on the hydrogeologic features of the Green Swamp area in central Florida: Florida Geol. Survey Inf. Cir. No. 26, 96 p.

-----, 1966. Hydrology of Green Swamp area in central Florida: Florida Geol. Survey Rept. of Inv. 42, 17 plates, 137 p.

Puri, Harbans S., 1957. Stratigraphy and Zonation of the Ocala Group: Florida Geol. Survey Bull. No. 38, 3 plates, 248 p.

-----,Editor, 1960. Late Cenozoic stratigraphy and sedimentation of central Florida: Southeastern Geol. Soc., 9th Field trip, Tallahassee, Florida, 134 p.

Puri, H.S. and Vernon, R.O., 1964. Summary of the geology of Florida and a guidebook to the classic exposures: Florida Geol. Survey Spec. Publ. No. 5 (revised).

Putnam, A.L., 1975. Summary of hydrologic conditions and effects of Walt Disney World Development in the Reedy Creek Improvement District, 1966-73: Bur. of Geol. Rept. of Inv. No. 79, 115 p.

Rammy Water Collector Corporation, 1947. Report on underground survey for the City of Cocoa, Florida: Project Report, various pagination, appendices.

Reece, D.E., Brown, M.P. and Hynes, S.D., 1980. Hydrogeologic data collected from the Upper East Coast Planning Area: South Florida Water Management District Tech. Publ. 80-5, 117 p.

Reynolds, Smith and Hills, 1978. 10-year water master plan, City of Titusville, Florida: Project Report AEP No. 77175-00, various pagination.

-----, 1981. Area III well field development program, City of Titusville, Florida: Project Report AEP No. 77175-00, various pagination.

Rorabaugh, M.I., 1960. Use of water levels in estimating aquifer constants in a finite aquifer: I.A.S.H. Publication No. 52, Comm. of Subterranean Waters, pp. 314-323.

Rosenau, J.C., Faulkner, G.L., Hendry, C.W. Jr., and Hull, R.W., 1977. Springs of Florida: Bur. of Geol. Bulletin 31 (revised), 461 p.

Ross, F.W. and Munch, D.A., 1980. Ground water investigation of the potentiometric high centered about the Crescent City Ridge, Putnam County, Florida: St. Johns River Water Management District Technical Publication SJ 80-3, 75 p.

Russell & Axon, 1977. Raw water supply and service area expansion report, New Smyrna Beach, Florida: Project Report 620-711-07, various pagination, appendices.

-----, 1978. Comprehensive water report Daytona Beach, Florida: Project Report 61461-09, various pagination, appendices.

-----, 1980. Raw water supply expansion report, City of Holly Hill, Florida: Project Report 61701-16-1, various pagination.

Rutledge, A.T., 1985, Ground-Water hydrology of Volusia County, Florida, with emphasis on occurrence and movement of brackish water: U.S. Geol. Survey WRI 84-4206, 84 p.

Schlee, J., 1975. Stratigraphy and tertiary development of the continental margin east of Florida: U.S. Geol. Survey WRI 75-430.

Schiner, G.R. and Hayes, E.C., 1980. Potentiometric surface map of the Floridan aquifer in the SJRWMD and vicinity, May 1980: U.S. Geol. Survey Open-File Rept. 80-1002, 1 sheet.

-----, 1981a. Potentiometric surface map of the Floridan aquifer in the SJRWMD and vicinity, May 1981: U.S. Geol. Survey Open-File Rept. 81-1052, 1 sheet.

-----, 1981b. Potentiometric surface map of the Florida aquifer in the SJRWMD and vicinity, Florida, September 1981: U.S. Geol. Survey Open-File Rept. 82-118, 1 sheet.

-----, 1982a. Potentiometric surface map of the Floridan aquifer in the SJRWMD and vicinity, Florida, May 1982: U.S. Geol. Survey Open-File Rept. 82-915, 1 sheet.

-----, 1982b. Potentiometric surface map of the Floridan aquifer in the SJRWMD and vicinity, Florida, September 1982: U.S. Geol. Survey Open-File Repot. 83-30, 1 sheet.

Schiner, G.R., Laughlin, C.P., and Toth, D.J., 1988, Geohydrology of Indian River County, Florida, 1985: U.S. Geol. Survey, Water Resources Investigations, (Draft)

Sellards, E.H. and Gunter, H., 1913. The artesian water supply of eastern and southern Florida: Florida Geol. Survey 5th Annual Rept., pp. 232-245.

Shampine, W.J., 1963. Quality of water from the Floridan aquifer in Brevard County, Florida, 1963: Florida Geol. Survey Map Series 17, 1 sheet.

-----, 1965. Chloride concentration in water from the upper part of the Floridan aquifer in Florida, Revised 1975: Bureau of Geol. Map Series 12, 1 sheet.

-----, 1965 (revised 1975). Sulfate concentration in water from the upper part of the Floridan aquifer; 1965: Bureau of Geol. Map Series 15, 1 sheet.

Simmonds, E.P., McPherson, B.F., and Bush, P.W., 1980. Shallow ground-water conditions and vegetation classification, central Volusia County, Florida: U.S. Geol. Survey Water-Resources Investigations 80-752, 1 sheet.

Simpson, T.R., 1946, Saline basin investigation: Calif. Div. of Water Res. Bull. 52, 230 p.

Sinclair, W.C., 1978. Preliminary evaluation of the water-supply potential of the spring-river system in the Weeki Wachee area and the lower Withlacoochee River, west-central Florida: U.S. Geological Survey WRI 78-74.

Snell, L.J. and Anderson, W., 1970. Water resources of northeast Florida: Bureau of Geol. Rept. of Inv. 54, 77 p.

Spicer, H.C., 1947, Electrical resistivity studies in Brevard County: U.S. Geol. Survey unpublished manuscript.

Stangland, Herb, 1973. Groundwater recharge in Florida: Florida Section, Amer. Socity of Civil Eng. 40 p.

Stewart, Herbert G., 1966. Ground-water resources of Polk County Fla. Bureau of Geol. Rept. of Inv. 44, 177 p.

Stewart, J.W., 1980. Areas of natural recharge to the Floridan aquifer in Florida, 1980: Florida Bureau of Geol. Map Series 98, 1 sheet.

Stiff, H.A., Jr., 1951. The interpretation of chemical water analysis by means of patterns: Jour. of Petrol. Tech. 3: 15-16.

Stringfield, V.T., 1936. Artesian water in the Florida Peninsula: U.S. Geol. Survey Water - Supply Paper 773-C, pp. C115-C-195.

-----, 1966. Artesian water in tertiary limestone in the southeastern states: U.S. Geol. Survey Prof. Paper 517, 226p.

Stringfield, V.T. and Cooper, H.H., 1951. Water resource studies II - Geologic features of an artesian submarine spring east of Florida: Florida Geol. Survey Rept. of Inv. No. 7, pp. 57-72.

Szell, G.P., 1980. Salt water intrusion in coastal aquifers: a bibliography: St. Johns River Water Management District Tech. Pub. SJ 80-1, 57 p.

Theis, C.B., 1963. Estimating the transmissivity of a water table aquifer from the specific capacity of a well; In Bentall, Ray, compiler, Methods of determining permeability, transmissivity, and drawdown: U.S. Geol. Survey Water Supply Paper 1536-I, pp. 332-336.

Tibbals, C.H., 1975. Recharge areas of the Florida aquifer in Seminole County and vicinity, Florida: Bureau of Geol. Map Series 68, 1 sheet.

-----, 1977. Availability of ground water in Seminole County and vicinity, Florida: U.S. Geol. Survey water-resources investigations 76-97, 15 p., 4 sheets.

-----, 1978. Effects of paved surfaces on recharge to the Floridan aquifer in east-central Florida - a conceptual model: U.S. Geol. Survey WRI 78-6, 42 p.

-----, 1981, Computer simulation of the steady-state flow system of the Tertiary Limestone (Floridan) aquifer system in East-Central Florida: U.S. Geol. Survey WRI Open-file Rept. 81-681, 31 p.

Tibbals, C.H. and Crain, L.J., 1972. Hydrologic records for Orange County, Florida 1970-71: U.S. Geol. Survey Rept. 72-022, 101 p.

Tibbals, C.H. and Frazee, J.M., 1976. Ground water hydrology of the Cocoa well field area, Orange County, Florida: U.S. Geol. Survey Open-File Rept. 75-676, 67 p.

Todd, D.K., 1960. Ground water hydrology: John Wiley and Sons Inc., New York, 336 p., pp. 208-211.

-----, 1980. Ground water hydrology, Second Edition: John Wiley and Sons, Inc., New York, 535 p., pp 494-520.

Toth, D.J., 1987. Appraisal of the Floridan aquifer producing zones in the Sebastian Freshwater Lens: St. Johns River Water Management District, Palatka, Florida, Technical Publications SJ 87-1, 75 p.

U.S. Geological Survey, 1970-78. Cocoa well field ground-water monitoring network: Administrative Reports, various pagination.

-----, 1976-80. Water resources data for Florida, Vol. 1, Northeast Florida: U.S. Geol. Survey Water Data Rept. Fl-(76-80)-1.

USGS (Belles, R.G. Compiler), 1978-81. Annual data summary for 1778-81, Cocoa well field ground-water monitoring network: U.S. Geol. Survey Computer Retrieval Report, Various pagination.

Vernon, R.O., 1951. Geology of Citrus and Levy counties, Florida: Florida Geol. Survey Bull. 33, 256 p.

Visher, F.N. and Hughes, G.H., 1969. The difference between rainfall and potential evaporation in Florida: Florida Dept. of Natural Resources, Bur. of Geol., Map Series 32, 1 sheet.

Walton, W.C., 1970. Ground water resource evaluation: McGraw-Hill, Inc., New York, 664 p.

Watkins, F.A., Laughlin, C.P., and Hayes, E.C., 1979. Potentiometric surface map of the Floridan aquifer in the St. Johns River Water Management District and vicinity, Florida, May 1978: U.S. Geol. Survey Open-File Rept. 79-257, 1 sheet.

-----, 1980. Potentiometric surface map of the Floridan aquifer in the SJRWMD and vicinity, May 1978: U.S. Geol. Survey Rept. 79-257, 1 sheet.

Wenzel, L.K., 1942. Methods for determining permeability of water-bearing materials, with special reference to discharging well methods: U.S. Geol. Survey Water-Supply Paper 887.

White, O.E., 1957. Magmatic, connate, and metamorphic waters: Bull. of the Geol. Soc. of Amer. Vol. 68, pp. 1659-1682.

White, William A., 1958. Some geomorphic features of central peninsular Florida: Florida Geol. Survey Bull. No. 41, 92 p.

-----, 1970. The geomorphology of the Florida peninsula: Florida Bureau of Geol. Geological Bull. No. 51, 164 p.

Wolansky, R.M., Barr, G.L. and Spechler, R.M., 1979. Generalized configuration of the bottom of the Floridan aquifer, Southwest Florida Water Management District: U.S. Geological Survey Water-Resources Investigations 79-1490, 1 sheet.

Wolansky, R.M., Spechler, R.K. and Bueno, A., 1979. Generalized thickness of the surficial deposits above the confining bed overlying the Floridan aquifer, Southwest Florida Water Management District: U.S. Geol. Survey Water Resources Investigations 79-1071, 1 sheet.

Wyrick, G.G., 1960. The Ground-water resources of Volusia County, Florida: Florida Geol. Surv. Rept. of Inv. 22, 65 p.

Wyrick, G.G. and Leutze, W.P., 1955. Interim report on the groundwater resources of northeastern part of Volusia County, Florida: Florida Geol. Survey Inf. Circl. No. 8.

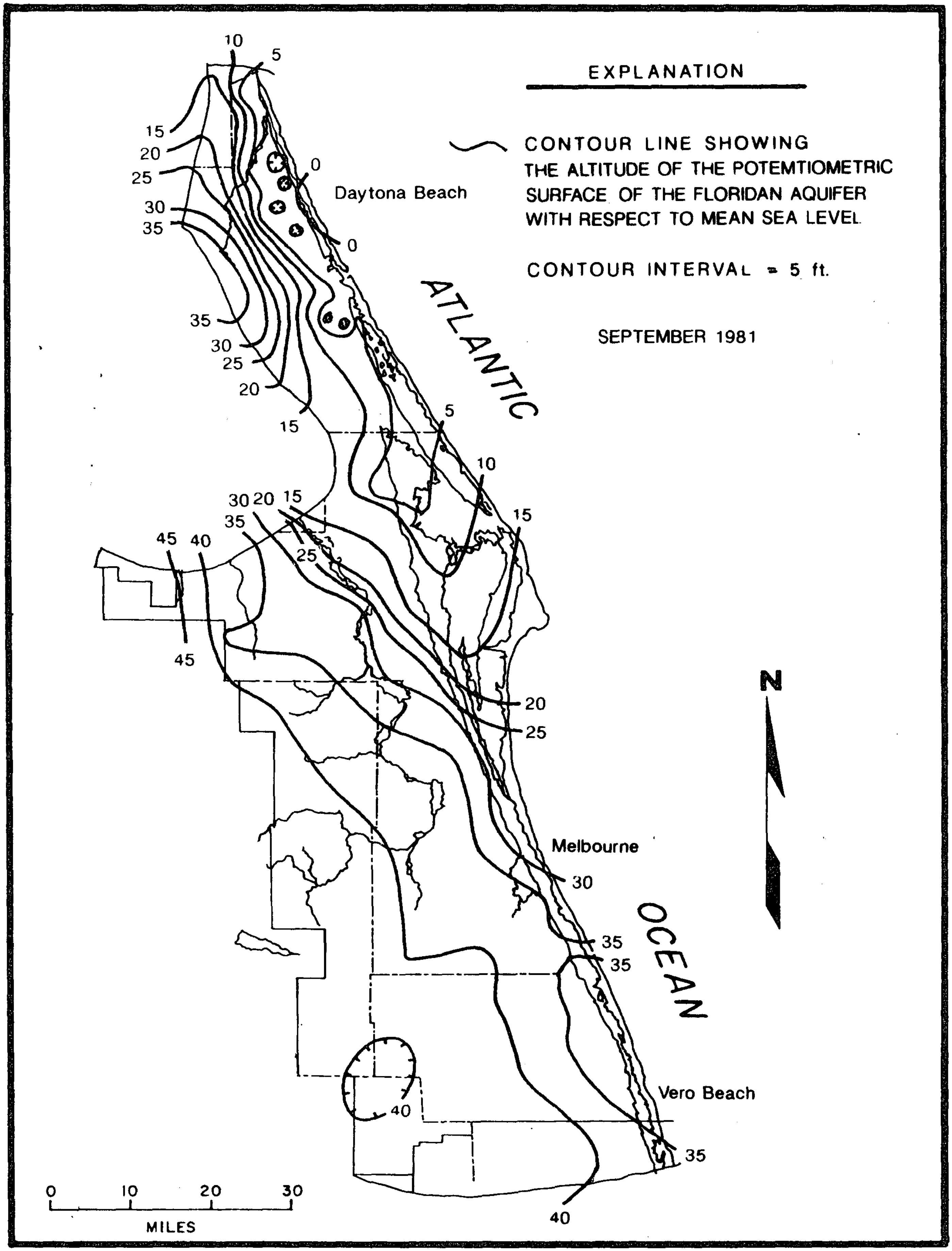
Vernon, R.O., and Puri, H.S., 1964, Geologic map of Florida: Florida Geological Survey Map Series 18, 1 sheet.

Vernon, R.O., 1951. Geology of Citrus and Levy counties, Florida: Florida Geol. Survey Bull. 33, 256 p.

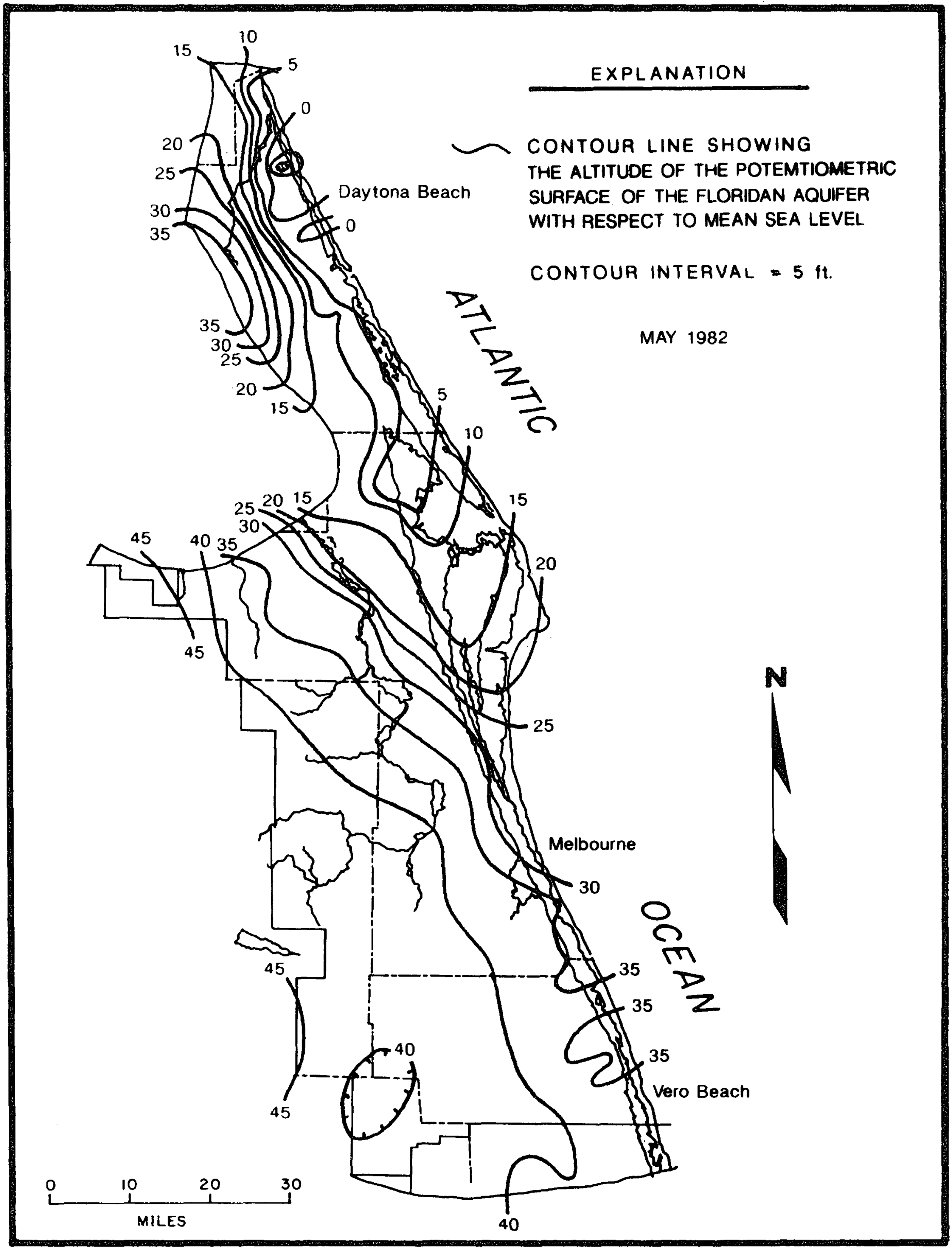
Zaporozec, A., 1972. Graphical interpretation of water-quality data: Ground Water, Vol. 10, No. 2, pp. 32-43.

APPENDIX I

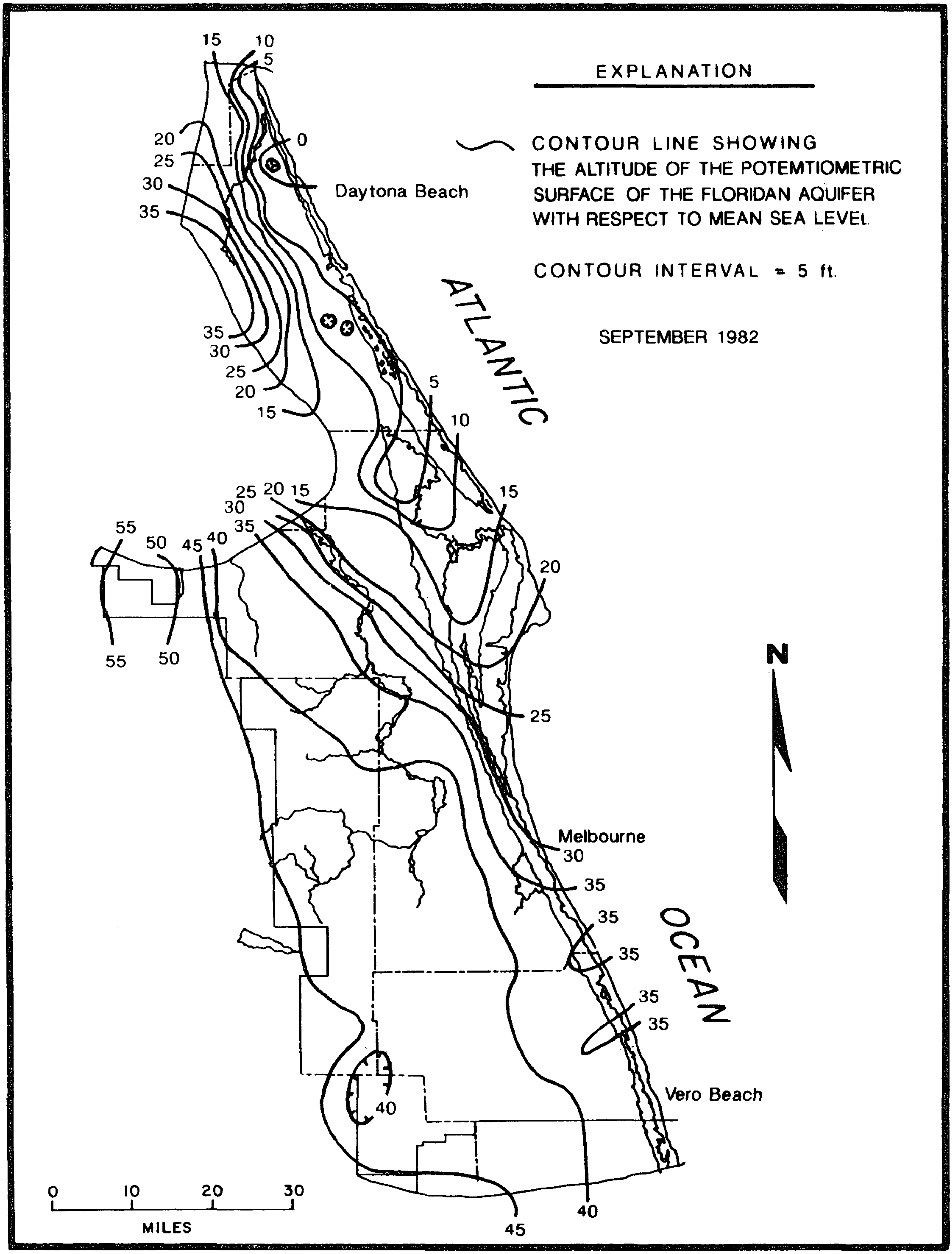
Potentiometric surface of the Floridan aquifer in the study area for September 1981 and May and September 1982.



From Schiner and Hayes, 1981b.



From Schiner and Hayes, 1982a.



From Schiner and Hayes, 1982b.

APPENDIX II

Chloride concentration in Floridan aquifer wells in Volusia, Brevard, and Indian River counties.

APPENDIX IIA

Chloride Concentration in Floridan Aquifer Wells in Volusia County

Well No.	Latitude	Longitude	Station	Depth	Chloride	Date
1	285502	805141	85505101	-	620	10/24/55
					650	5/7/69
					618	5/7/70
					620	5/14/71
2	285904	805546	85905501	-	64	12/57
					210	12/08/82
3	285907	805535	V5	-	84	3/31/75
					138	3/26/80
					125-138	1/77-10/77
4	285951	805747	85905705	-	73	5/07/70
					56	5/14/71
					80	5/10/72
					56-53	5/71-6/71
5	290107	810620	V-0106	111	17	4/26/66
					18	4/11/79
					19-24	7/78-12/78
6	290214	810051	Test Well I	-	22-132	11/65
7	290251	810014	V-0119	700	22	11/10/65
					235	11/01/67
					285	11/04/68
					310	9/07/72
					269	9/05/79
					22-132	11/65
8	290541	811329	90511303	-	20	4/08/55
					18	11/23/65
					15	11/12/71
9	290606	805819	90605804	-	460	9/07/54
					469	9/07/79
					458	5/07/70
					460	5/14/71
10	290920	810630	V-0080	235	35-122	2/55-4/55
11	290923	810612	V-0093	496	53-122	2/55
12	290926	810602	90910601	-	53-122	2/55
13	291025	810502	V-0099	220	34-255	3/55

APPENDIX IIA

Well No.	Latitude	Longitude	Station	Depth	Chloride	Date
14	291032	810652	91010601	-	34	7/14/72
					27	3/11/80
					31	3/22/82
					27-30	3/80
15	291107	805916	91105902	-	108	2/14/56
					390	2/16/66
					450	5/06/69
					500	5/14/71
					576	9/07/79
					1400	4/01/81
16	291130	810406	9110407	-	32	3/13/57
					99	3/22/82
					35-99	8/82-3/82
17	291133	810406	V-0084	500	56	5/07/70
					79	5/14/71
					60	5/05/72
					65	9/06/72
					60	9/06/79
					79-62	5/71-11/71
18	291159	810202	V18	187	113	1939
					134	1950
					186	2/28/54
					720	4/2/80
					1000	4/28/81
					300	12/08/82
					750-1000	4/28/81
19	291444	810222	V23	220	71	11/16/54
					160	11/02/77
					70-75	4/50-9/50
20	291904	810555	91910501	-	168	5/08/67
					185	5/21/68
					160	5/05/72
					160	9/15/67
					160	9/06/72
					148	9/10/79
					175-160	2/67-9/67

APPENDIX IIB

Chloride Concentration in Floridan Aquifer Wells in Brevard County

Well No.	Latitude	Longitude	Station	Depth	Chloride	Date
1	274925	803617	BR60	-	520	5/18/79
					740-1023	2/80-7/80
2	274931	804259	749042001	-	850	5/13/75
					750	12/11/78
3	274933	803518	BR246	-	600	5/18/79
					538	3/10/81
4	274947	804115	749041001	-	600	5/13/75
					606	5/11/79
					620	5/16/79
5	274950	804309	BR104	356	680	11/19/79
					796	7/28/80
6	275003	803913	BR3	475	660-700	5/75
7	275005	803038	750030126	-	410	6/01/76
					410	6/01/77
8	275012	803938	750039003	-	500	5/13/75
					600	5/16/79
9	275041	803002	750030027	-	200	5/22/76
					200	5/22/77
10	275041	804346	750043001	-	700	5/13/75
					680	5/11/79
11	275046	804043	750040002	-	650	5/13/75
					620	5/11/79
					800-650	8/78-12/78
12	275111	804026	BR105	-	680	5/16/79
					780-728	7/80-10/80
13	275113	803130	751031007	-	420	11/19/79
					454	1/07/82
					497-448	3/80-10/80
14	275207	803952	759039002	-	760	7/09/56
					855	4/08/75
					500	8/29/78
					768	3/11/81

APPENDIX IIB

Well No.	Latitude	Longitude	Station	Depth	Chloride	Date
15	275208	802717	BR78	449	180	7/26/79
					227	2/02/81
					180-215	7/80-10/80
16	275217	802803	BR106	-	160	8/16/78
					221	8/14/80
					221-200	5/80-10/80
17	275226	803823	BR247	-	745	4/08/75
					720	5/30/79
					725	3/10/81
18	275227	802803	BR80	406	245	8/21/78
					247	8/14/80
					220-267	10/80
19	275231	802807	BR81	203	175	8/21/78
					221	8/14/80
					221-195	8/80-10/80
20	275250	803008	BR6	600	230	10/23/56
					200	8/16/83
21	275253	803832	BR248	399	745	3/15/57
					705	3/12/81
22	275301	802804	BR82	393	294	1/24/75
					344	2/03/81
					338-345	5/80-10/80
23	275301	803043	755030044	-	390	1/30/75
					300	1/10/79
24	275303	802815	BR84	-	190	1/27/75
					254	8/18/80
					220	2/03/81
25	275305	802804	BR83	363	215	1/24/75
					240	2/03/81
					228-250	6/80-10/80
26	275307	802758	BR110	384	177	1/24/75
					200	7/15/81
					188-221	5/80-10/80
27	275310	802758	BR111	384	175	1/24/75
					175-200	10/80-5/80

APPENDIX IIB

Well No.	Latitude	Longitude	Station	Depth	Chloride	Date
28	275321	803924	BR252	-	750	12/14/78
					695	3/12/81
29	275328	802805	753028007	-	250	5/14/75
					200	5/12/76
					210	5/10/79
					267	2/10/81
30	275357	802817	BR85	-	273	1/28/75
					267	2/09/81
					293-270	8/80-10/80
31	275422	803740	BR288	-	692	6/05/79
					715	12/01/81
					754-550	7/80-10/80
32	275425	802831	BR107	420	210	5/12/76
					220	5/10/79
					254	5/12/80
					254-200	5/80-10/80
33	275435	803110	BR38	-	340	5/12/76
					360	11/19/79
					455	11/05/80
					385-455	3/80-11/80
34	275502	804024	BR260	389	692	6/14/79
					701	3/17/81
35	275523	803208	BR89	-	500	5/19/47
					661	2/26/81
36	275524	803137	755031003	-	585	5/22/47
					475	2/11/79
37	275546	804145	BR262	299	700	7/09/79
					820	6/07/84
38	275552	802944	BR115	400	290	2/16/56
					255	2/06/75
					364-170	5/80-8/80
39	275720	803006	BR179	300	350	8/15/78
					416	8/21/80
					416-400	8/80-10/80
40	275738	805210	757030030	-	200	6/08/56
					234	8/06/81
					218-200	4/79-11/79

APPENDIX IIB

Well No.	Latitude	Longitude	Station	Depth	Chloride	Date
41	275955	804346	759043002	-	550	5/22/47
					540	5/16/70
					550	5/04/72
					540	5/08/79
					525-585	2/80-7/80
42	280853	804359	BR352	348	540	3/21/56
					560	8/09/78
					592	8/05/80
43	280951	803940	BR383	550	700	10/12/75
					440	8/08/78
					572	8/05/80
					552-572	3/80-8/80
44	281215	804746	BR125	450	620	9/22/76
					640	5/09/79
					721-675	6/80-11/80
45	281306	804012	BR127	400	700	11/21/79
					740	11/05/80
					722-780	3/80-11/80
46	281435	804920	BR130	227	600	9/22/76
					640	5/09/79
					650-688	6/80-11/80
47	281446	803924	BR28	325	670-750	5/76
48	281509	803630	BR69	410	645	1/20/55
					650	9/12/63
					643	9/8/80
49	281744	804440	BR134	343	950	11/29/79
					985	11/04/80
					935-985	2/80-11/80
50	281904	803750	BR192	125	1050	9/14/76
					838	9/2/80
					838-852	9/80-10/80
51	281914	803705	BR193	-	950	9/23/76
					332	9/02/80
					332-949	9/80-10/80
52	282135	804536	BR73	206	880	11/14/55
					1128	11/17/80
					968-1128	9/80-11/80

APPENDIX IIB

Well No.	Latitude	Longitude	Station	Depth	Chloride	Date
53	282204	805143	BR0074	495	2270	5/05/55
					2420	5/19/65
					2450	7/30/70
					2270-2380	5/55
54	282207	805218	BR204	-	2050	4/16/55
					2150	5/11/62
					2040	5/24/79
					2071	4/13/81
					2161-2188	9/80-11/80
55	282423	803536	BR208	331	450	2/01/76
					696	2/04/80
					696-767	2/80-9/80
56	283017	804649	BR158	210	5700	5/05/77
					6000	5/10/79
57	283655	805750	BR408	-	1170	11/28/46
					1706	9/16/80
					1170-1700	11/46-12/46

APPENDIX IIC

Chloride concentration in Floridan aquifer wells in Indian River County

Well No.	Latitude	Longitude	Station	Depth	Chloride	Date
1	273409	802652	734026	660	425	1/07/52
					630	1/25/83
2	273431	802210	734022	850	232	1/04/52
					222	5/17/68
					235	5/15/70
					220	5/11/72
					220-227	5/71-11/71
3	273513	802652	73502604	760	445	1/07/52
					490	1/25/83
4	273629	802604	73602601	700	352	1/09/52
					540	1/25/83
5	273632	803045	73603602	-	295	1/22/52
					410	1/25/83
6	273719	802310	73702301	677	392	1/07/52
					305	2/12/69
7	273723	802554	73702501	575	310	1/09/52
					282	6/11/71
8	273814	802234	IR-179	960	475-480	1/82
9	273814	802452	IR-24	671	320	4/17/49
					440	4/26/83
					460	12/04/49
					460	12/04/69
10	273819	802601	73802602	-	265	1/03/52
					280	1/26/83
					270-280	1/83
11	273821	802624	IR-207	500	240-270	1/82
12	273833	802339	73802301	-	259	4/14/49
					465	1/16/69
					500	1/26/83
13	273840	803056	73803001	-	605	1/03/52
					665	5/21/70

APPENDIX IIC

Well No.	Latitude	Longitude	Station	Depth	Chloride	Date
14	273900	802323	IR-240	550	235	1/04/52
					310	5/07/70
15	273905	802411	VB-21	677	304	3/79
					420	3/82
					440	3/83
					440-400	3/83-8/83
16	273912	802414	VB-14	688	298	3/79
					370	3/82
					375	3/83
					295	5/79
					375	5/83
					370-410	3/82-12/82
17	273953	802748	73902701	-	315	3/06/69
					340	3/16/83
					410-340	1/83-3/83
18	274005	802449	74002401	720	188	1/03/52
					140	3/22/71
					130	2/09/83
19	274039	802315	IR-28	1165	620	1/03/52
					760	1/16/69
20	274055	802813	74002801	650	440	12/28/51
					390	3/06/69
21	274116	802650	74102601	-	342	12/28/51
					350	1/27/83
22	274121	802417	74102401	635	216	4/01/70
					300	2/09/83
23	274226	802425	IR-234	500	185	1/03/52
					400-530	1/83
24	274309	802450	IR-33	300	212	1/16/69
					290	3/02/83
25	274310	802933	IR-58	400	505	3/21/51
					582	2/14/69
					740	2/09/83
26	274337	802339	IR-35	650	262	1/29/69
					250	1/27/83

APPENDIX IIC

Well No.	Latitude	Longitude	Station	Depth	Chloride	Date
27	274445	802359	IR-104	1000	695	3/29/51
					698	4/01/70
28	274452	802755	74402701	-	304	5/17/68
					288	5/21/69
					262	5/15/70
					290	5/13/71
					290	5/11/72
					262-302	5/70-10/70
29	274453	802752	IR-228	350	300-310	2/82
30	274458	802757	IR-151	625	292	8/16/51
					330	2/14/69
31	274501	802821	IR-160	600	362	8/16/51
					318	6/10/71
					380	2/09/83
32	274505	802603	IR-144	525	280	10/13/81
					280	1/05/82
33	274512	802427	IR-165	650	340	11/04/81
					655	1/05/82
34	274549	802452	74502402	-	510	5/24/67
					510	5/08/68
					500	5/21/69
					484	5/15/70
					570	5/13/71
					610	5/11/72
					610-580	5/72-10/72
35	274553	802458	74502401	-	590	5/24/67
					596	5/08/68
36	274558	803042	IR-174	540	472	10/17/51
					495	4/01/69
					500	2/09/83
37	274601	803138	IR-175	600	492	10/17/51
					618	5/06/70
					640	2/09/83
38	274635	803636	IR-26	810	470-640	4/69

APPENDIX IIC

Well No.	Latitude	Longitude	Station	Depth	Chloride	Date
39	274635	803630	74603601	-	405	5/24/67
					428	5/08/68
					418	5/21/69
					408	5/15/70
					412	5/13/71
					420	5/11/72
40	274640	802434	IR-201	883	378	11/09/51
					535	1/29/69
41	274647	803134	IR-169	525	645	10/15/51
					678	6/10/71
42	274815	802541	74802501	-	390	3/14/51
					540	5/24/67
					520	5/15/70
					550	5/13/71
					548	5/11/72
					520-500	5/70-10/70

APPENDIX III

Chloride concentration in shallow rock wells in Brevard and Indian River counties.

APPENDIX IIIA

Chloride concentration in shallow rock wells in Brevard County

Latitude	Longitude	Station	Well Depth	Casing Depth	Chloride	Date
281935	803937	BR-138	90	-	894-988	7/80-10/80
282517	804516	BR-312	90	85	50	8/08/78
					111-97	6/80-9/80
283336	805019	BR-318	225	-	80	4/09/76
					70	9/23/80
283625	805133	BR-321	80	-	250	9/08/75
					75	9/23/80
284037	805158	BR-332	80	-	15	2/20/75
					25	10/02/80
284623	805232	BR-337	90	-	35	7/10/75
					84	9/18/80

APPENDIX IIIB

Chloride concentration in shallow rock wells in Indian River County

Latitude	Longitude	Station	Well Depth	Casing Depth	Chloride	Date
273755	802312	SO-9	125	-	127	3/15/82
					126-141	3/83-8/83
273756	802339	SO-10	140	-	70	3/15/82
					70	3/15/83
					68-76	6/82-12/82
273758	802252	SO-8	100	-	22,500	3/15/82
					21,500	3/15/83
					23,400-21,200	6/82-12/82
273814	802415	IR-191	90	-	25-60	1/82
273819	802429	IR-186	87	-	215-220	1/82
273819	802546	79-7	130	-	79	3/82
					85-78	3/83-8/83
273831	802303	SO-11	100	-	16,000	3/15/82
					20,000-17,000	3/83-5/83
273833	802437	VB-19	135	-	204	3/82
					218	3/83
					155-220	8/83-5/83
273844	802426	VB-20	105	-	178	3/82
					166-152	3/83-5/83
273844	802520	VB-16	93	-	66	11/76
					77	3/79
					89	3/82
					87	3/83
					77	5/79
					97	5/83
					66-78	1/77-9/77
273846	802609	79-1	130	-	71	3/82
					116-65	3/83-5/83
273900	802547	VB-18	130	-	86	11/76
					131	3/79
					144	3/83
					128-148	3/82-12/82

APPENDIX IIIB

Latitude	Longitude	Station	Well Depth	Casing Depth	Chloride	Date
273905	802409	VB-1	112	–	68	8/78
					67	3/79
					89	3/82
					84	3/83
					70	5/79
					84	5/83
					62–76	2/79–4/79
273907	802440	VB-13	130	–	31	12/76
					31	3/78
					29	3/79
					31	3/82
					26	3/83
					31	5/79
					27	5/83
					39–28	9/82–12/82
273908	802338	SO-2	120	–	4700	3/15/82
					4300	3/15/83
					4700–14,000	3/82–6/82
273932	802419	VB-7	112	–	57	1/76
					60	3/79
					79	3/82
					79	3/83
					70	8/78
					79	8/83
					130–62	2/78–11/78
273935	802340	SO-6	140	–	58	3/15/82
					60	3/15/83
					124–57	6/82–12/82
273938	802514	VB-12	122	–	65	11/76
					71	3/78
					67	3/79
					77	3/82
					69	3/83
					69	5/79
					68	5/83
					74–78	6/82–12/82
273938	802631	79-2	136	–	53	3/82
					58–52	3/83–8/83

APPENDIX IIIB

Latitude	Longitude	Station	Well Depth	Casing Depth	Chloride	Date
273939	802452	VB-11	100	-	29	11/76
					31	3/79
					29	3/82
					30	3/83
					31	5/79
					31	5/83
					86-31	8/78-11/78
273955	802455	VB-9	127	-	96	11/76
					96	3/79
					103	3/82
					103	3/83
					96	5/79
					146-98	5/83-8/83
274000	802437	VB-8	102	-	130	11/76
					99	3/79
					116	3/82
					120	3/83
					101	5/79
					127	5/83
					106-130	9/77-11/77
274000	802514	VB-10	120	-	82	11/76
					94	3/78
					96	3/79
					115	3/82
					110	3/83
					100	5/79
					109	5/83
					87-96	2/78-8/78
274525	802559	IR-146	135	-	230	10/21/81
					240	1/05/82
274710	802936	IR-243	110	-	100-110	2/82
274733	802913	IR-241	110	-	75-80	2/82
274937	803006	IR-56	126	-	400	8/31/81
					415	3/24/82