HYDROLOGY OF THE SOUTHERN PARTS OF OKALOOSA AND WALTON COUNTIES, NORTHWEST FLORIDA, WITH SPECIAL EMPHASIS ON THE UPPER LIMESTONE OF THE FLORIDAN AQUIFER

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CONVERSION FACTORS

The inch-pound units used in this report may be converted to metric units (SI) by the following conversion factors:

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
square mile (mi^2)	2.590	square kilometer (km^2)
square foot per day (ft^2/d)	0.0929	square meter per day (m^2/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per minute per foot [(gal/min)/ft]	0.207	liter per second per meter [(L/s)/m]

* *

Temperatures are converted from degrees Fahrenheit (°F) to degrees Celsius (°C) by the formula °C = 5/9 (°F - 32); from degrees Celsius to degrees Fahrenheit by the formula °F = 9/5 (°C + 32).

* *

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ABSTRACT

Increasing population, tourism, and commercial development in the southern parts of Okaloosa and Walton Counties in northwestern Florida have resulted in increased withdrawals of water from, and regional declines in the potentiometric surface of the upper limestone of the Floridan aquifer. Water levels have declined as much as 160 feet since 1940 in southern Okaloosa County, and during peak seasonal demand, as much as 190 feet.

The shallow sand-and-gravel aquifer may be artesian or unconfined, having direct contact with streams and with waters of the Gulf of Mexico. Use of the aquifer for public water supply is minimal. The lower limestone of the Floridan aquifer is not utilized as a water source.

The Pensacola Clay confining bed, overlying the Floridan aquifer, is present throughout the southern parts of Okaloosa and Walton Counties. The materials making up this unit inhibit vertical interchange of water between the Floridan aquifer and the surficial sand-and-gravel aquifer. The Floridan aquifer is underlain by the thick, relatively impermeable deposits of the Lisbon-Tallahatta confining unit. The Bucatunna clay confining bed occurs within the Floridan aquifer, separating it into upper and lower limestone units.

The Floridan aquifer underlies southern Okaloosa County from 50 feet above to 600 feet below sea level. The aquifer is recharged by infiltration of rainfall, principally in the northern parts of Okaloosa and Walton Counties and in its outcrop area in Alabama. The regional gradient of the potentiometric surface of the upper limestone of the Floridan aquifer, and presumably that of the lower limestone also, is south to the Gulf of Mexico. Pumpage from the aquifer is highly variable and ranged in 1978, for example, from 10.9 to 19.0 million gallons per day in January and June, respectively.

Quality of water in the sand-and-gravel aquifer is generally good although coastal areas may have undesirable levels of chlorides, iron, or pH. Chloride concentration in the upper limestone of the Floridan aquifer generally ranges from less than 10 milligrams per liter in the inland areas of Okaloosa County to nearly 150 milligrams per liter along the coast and greater than 150 milligrams per liter, locally, in the southern part of Walton County. The lower limestone of the Floridan aquifer contains water exceeding 250 milligrams per liter chloride from the coast to as much as 10 miles north of Fort Walton Beach.

INTRODUCTION

Ground-water withdrawals from the upper limestone of the Floridan aquifer in the Fort Walton Beach-Niceville area of coastal-panhandle Florida had increased steadily over the past 3 to 4 decades coincident with population growth, tourism, and commercial development. Consequently, by the latter 1970's excessive drawdowns and a concomitant threat of potential saltwater intrusion of the upper limestone of the Floridan aquifer, the principal source of freshwater supplies in the area, had resulted. In view of the uncertainties with regard to the hydrologic and economic consequences of continued development of the Floridan aquifer, it was deemed advisable by State and local officials to conduct a systematic investigation of the availability of water in the southern parts of Okaloosa and Walton Counties in northwest Florida (fig. 1). The investigation was conducted by the Northwest Florida Water Management District in cooperation with the U.S. Geological Survey; and was funded, in part, by a grant to the Water Management District from the Coastal Plains Regional Commission, by Okaloosa and Walton Counties through ad valorem taxes to the Water Management District, and by the U.S. Geological Survey.

PURPOSE AND SCOPE

The purpose of this report is to describe the hydrology and hydrogeology of the southern parts of Okaloosa and Walton Counties with emphasis on the upper limestone of the Floridan aquifer. The sand-and-gravel aquifer, lower limestone of the Floridan aquifer, the confining beds separating the three aquifers, and the surface-water conditions of the area are more briefly discussed, depending on their relation to the upper limestone.

The analysis incorporated all existing data pertaining to: (1) geology, geophysical logs of wells, and stratigraphic studies; (2) records of existing municipal, private, and test wells in the area, including owner, depth, pumping capacity, drawdown, and water quality; (3) ground-water levels with respect to both time and space in the aquifers as they relate to recharge, discharge, and pumpage; (4) the hydraulic properties of the aquifers and associated confining beds; and (5) water-quality variations in both time and space.

Ground-water monitoring networks were established to obtain needed information on aquifer water levels and to obtain water samples for chemical analyses. Wells were monitored on a quarterly basis throughout 1978 and 1979. This program was designed to coordinate with the established U.S. Geological Survey monitoring program in the area.

Aquifer tests, the results of which were reported by Barr and others (1981, p. 15 and fig. 32) and by Hayes and Barr (1983), were conducted in southern Okaloosa County and southern Walton County to evaluate transmissivity and storativity of the sand-and-gravel and Floridan aquifers and leakance of the confining beds. Production tests were also performed on selected wells to determine specific capacities and to evaluate potential yields.

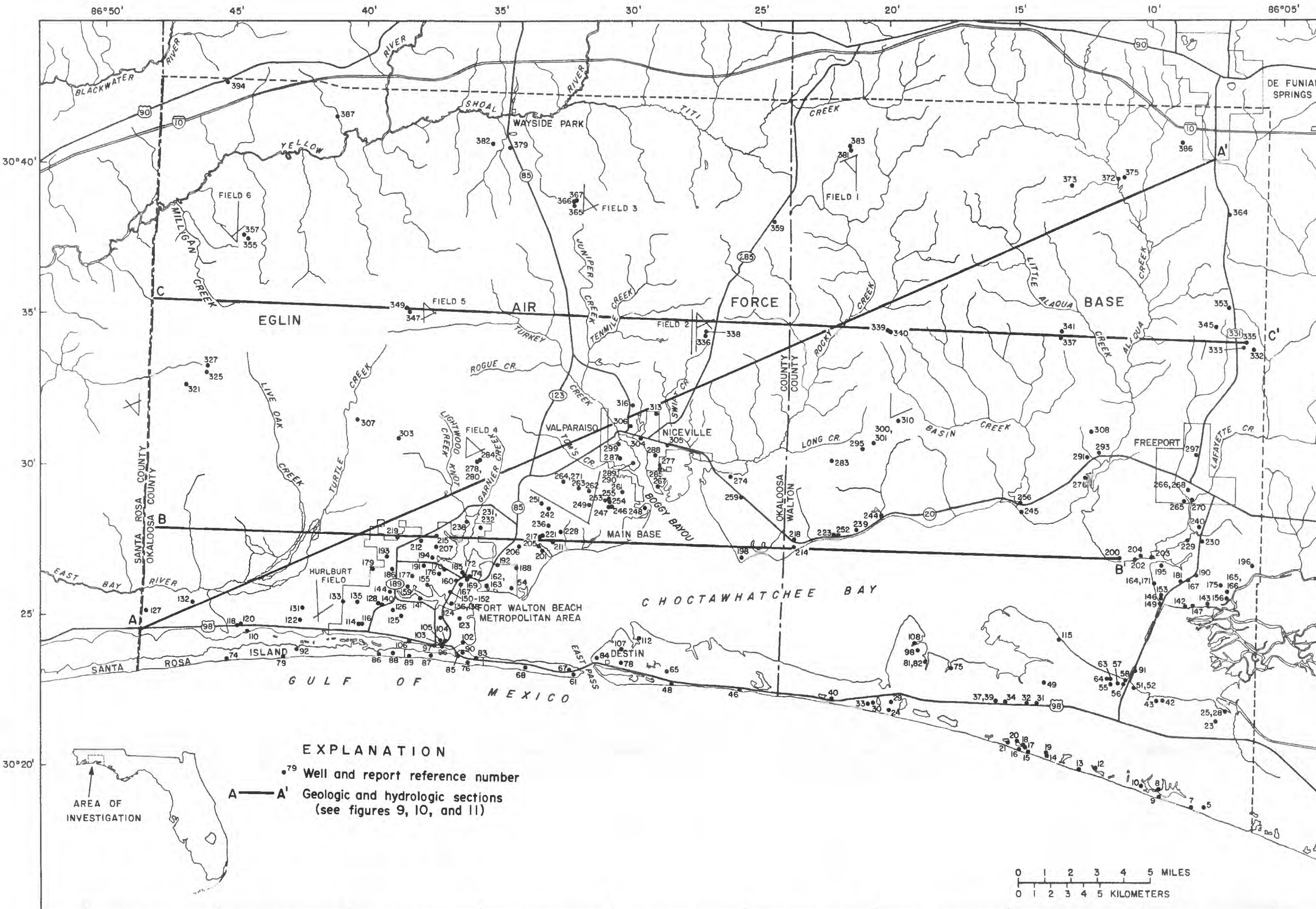


Figure 1.--Area of investigation, locations of selected wells in the Floridan aquifer, and locations of geologic and hydrogeologic sections in the southern parts of Okaloosa and Walton Counties (modified from Barr and others, 1981).

Test holes were drilled to obtain further information on the subsurface stratigraphy, the altitudes of the upper and lower parts of the aquifers and associated confining beds, the hydraulic properties of the hydrogeologic units, and to collect water samples for chemical analyses.

Throughout the investigation, caliper, electric, fluid resistivity, natural gamma, gamma-gamma, and neutron logs were run in selected wells to delineate and correlate hydrogeologic units. Geophysical logging was carried out by the Northwest Florida Water Management District's logger based in Tallahassee, Fla., and by the U.S. Geological Survey's logger based in Atlanta, Ga.

Water samples were collected from selected wells to determine the chemical character of water in the aquifers with respect to depth and location. Field determinations of pH, specific conductance, and temperature were made and samples from these wells were collected quarterly and analyzed for chloride concentration. Detailed chemical analyses were conducted by the U.S. Geological Survey National Water-Quality Laboratory--Atlanta in Doraville, Ga.

AREA OF INVESTIGATION

This report covers those parts of southern Okaloosa and Walton Counties that are bounded on the east by longitude 86°05', on the west by the Santa Rosa-Okaloosa County line, on the south by the Gulf of Mexico, and on the north by latitude 30°43' (fig. 1). Of the approximately 1,000 square miles in the study area, about 470 square miles are in Walton County and about 530 square miles are in Okaloosa County. The heavily populated coastal area surrounding the western part of Choctawhatchee Bay, here referred to as the Fort Walton Beach metropolitan area, is shown in figure 2.

PREVIOUS INVESTIGATIONS

A data and two interpretive reports have previously been published as products of this investigation. Wagner and others (1980) prepared a data report comprised of information collected during and prior to the study. Hayes and Barr (1983) specifically described the hydrology of the sand-and-gravel aquifer. Barr and others (1981) summarized the hydrology of the area.

The U.S. Geological Survey has conducted most of the previous investigations of the area. Trapp and others (1977) described the geology and hydrology of Okaloosa County and a small part of western Walton and eastern Santa Rosa Counties. Included are discussions of physiography and general geology, rainfall, streamflow, ground water, alternative water supplies, and saline-water contamination. Pascale (1974) completed a Walton County investigation of the ground-water and surface-water conditions and water availability. That study includes analysis and interpretation of six aquifer tests and a discussion of the hydrologic effects of increased irrigation pumpage in the east-central area of the county.

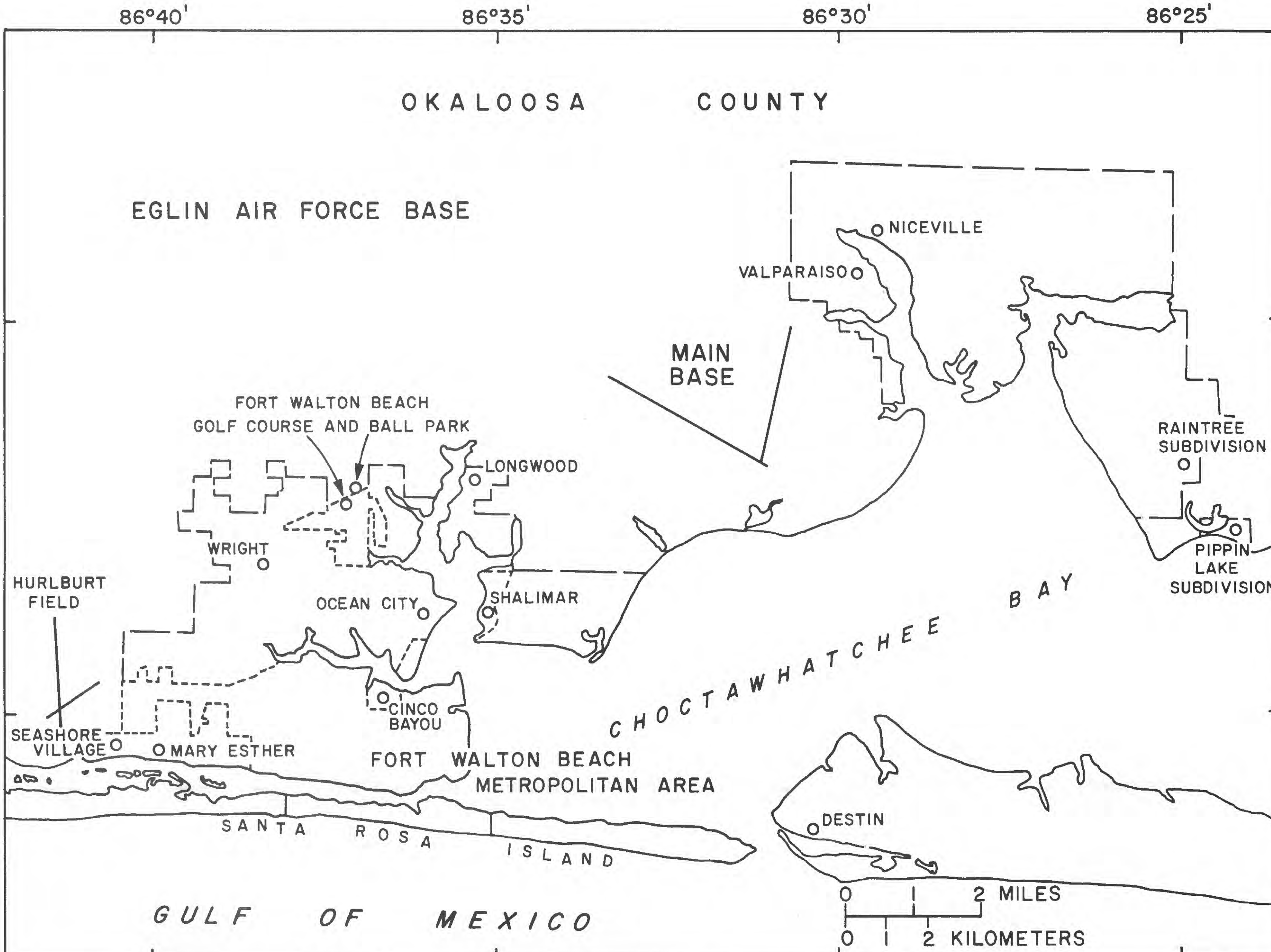


Figure 2.--Fort Walton Beach metropolitan area.

Foster and Pascale (1971) and Pascale and others (1972) listed data on streamflow, water levels, water quality, pumpage, and rainfall for Okaloosa and Walton Counties, respectively. Maps of well locations and surface-water gaging stations are also included. Water-level records of selected wells in the area have been published in U.S. Geological Survey Water-Supply Papers. Barraclough and Marsh (1962) described the general hydrology and water quality of aquifers along the coastal area from Walton to Escambia County. Earlier works, principally those of Sellards and Gunter (1912, p. 105-110) and Matson and Sanford (1913, p. 422-426), describe the water resources, physiography, geology, climate, and soils of what is now Okaloosa and Walton Counties.

WELL-NUMBERING SYSTEM

In this report, two numbering systems are used to identify wells and test holes. A one- to three-digit number is used to identify well stations and test holes on illustrations and in tables. The ground-water site identification system (GWSI) of the U.S. Geological Survey is used to identify ground-water stations (mostly wells). This number consists of 15 digits, based initially on the latitude and longitude of a point believed to represent the location of the station. The first six digits denote the degrees, minutes, and seconds of latitude; the next seven digits denote the degrees, minutes, and seconds of longitude; and the last two digits form a sequential number for stations within a 1-second grid. Once assigned, a well identification number does not change even though the latitude or longitude of that well site may be corrected later. The station identification number is thus a unique number, used in computer storage and retrieval of data.

ACKNOWLEDGMENTS

Appreciation is extended to the cities and many individuals who furnished information about their wells and gave access to their land and equipment for measurements, geophysical logging, and water-quality sampling. Special thanks are due to the staffs of the City of Fort Walton Beach, Eglin Air Force Base, and Okaloosa County for the use of wells and pumping equipment and for their permission to drill test wells on their property.

The courtesies and help extended by the following persons are sincerely appreciated: George Imes, Ronald Bailey, Charles Ingram, and Rex B. Griffin, Jr., of the City of Fort Walton Beach; A. N. Southard of Eglin Air Force Base; James Thomason of Thomason Well Drilling; Douglas Edge of Okaloosa County; and the men of the Red Horse Drilling Unit, Hurlburt Field, U.S. Air Force.

The authors are particularly grateful to Richard Milner and Paul Meadows of the U.S. Geological Survey and to William Albritton of the Northwest Florida Water Management District who collected much of the basic data and supervised drilling operations. Appreciation is also extended to Henry Trapp, U.S. Geological Survey, for insight gained during many discussions concerning the geology and hydrology of western Florida and to Glen Faulkner and Jack Rosenau, U.S. Geological Survey, for their considerable efforts during the review and final preparation of this report.

PHYSIOGRAPHY AND CLIMATE

The area of investigation lies within two physiographic divisions, as described by Puri and Vernon (1964, p. 7-15). The Western Highlands region generally ranges from 50 to 200 feet above sea level and consists largely of sand hills cut by streams that have high base runoff and generally occupy deep, narrow ravines. The Coastal Lowlands region consists of flatwoods and swamps a few miles inland and of sand dunes, beach ridges, and wave-cut bluffs along the coast.

For a detailed discussion of the physiographic features of Okaloosa and Walton Counties, refer to Trapp and others (1977, p. 10-22) and Pascale (1974, p. 8-10), respectively.

Okaloosa and Walton Counties have a humid, semitropical climate. Winters are mild, with occasional frost from November through February. Average annual rainfall at the National Weather Service Station in Niceville, Fla., is 64.1 inches (fig. 3). The annual rainfall from 1941 to 1979 has ranged from 31.01 inches in 1954 to 95.43 inches in 1975. Average monthly rainfall ranges from 3.5 inches in October to 8.8 inches in July (fig. 4). During 1977 and 1978, when much of the hydrologic data for the investigation were obtained, the 2-year cumulative rainfall was 136.6 inches, or about 8.3 inches above normal. Monthly temperatures in the hottest summer months, July and August, range from about a mean minimum of 70°F to a mean maximum of 88°F, with a mean of approximately 82°F (fig. 5). From December through February, the coldest months, monthly temperatures range from a mean minimum of about 18°F to a mean maximum of about 74°F, with a mean of approximately 50°F.

The occurrence of rainfall over the area of investigation is associated with convective- and with frontal-type weather systems. The frontal-type system results from the interaction of low- and high-pressure systems produced by the convergence of polar and tropical air masses and is particularly active from December through April, when the general atmospheric circulation system shifts southward.

The convective-type weather system commonly results in late afternoon and evening thunderstorms. Convective storms are produced by vertical overturning of air masses caused by the rising of warm, light air. Convective-type systems are most active in the summer when solar radiation strikes the Earth's northern hemisphere more directly and supplies great amounts of heat for the warming of air masses at the Earth's surface. Convective storms are at their peak during the summer months and are responsible for the high average rainfall from June through September (fig. 4).

Convective storms are characterized by strong, localized showers of relatively short duration as compared to winter frontal storms that are distinguished by less intense showers of longer duration that cover a greater area. Summer rainfall is the highest of the year and also the most variable. In July, the wettest month, for example, the record shows that rainfall can vary from a minimum of 2.5 to a maximum of 23.2 inches, a difference of about 21 inches. On the average, July is the wettest month, whereas October is the dryest.

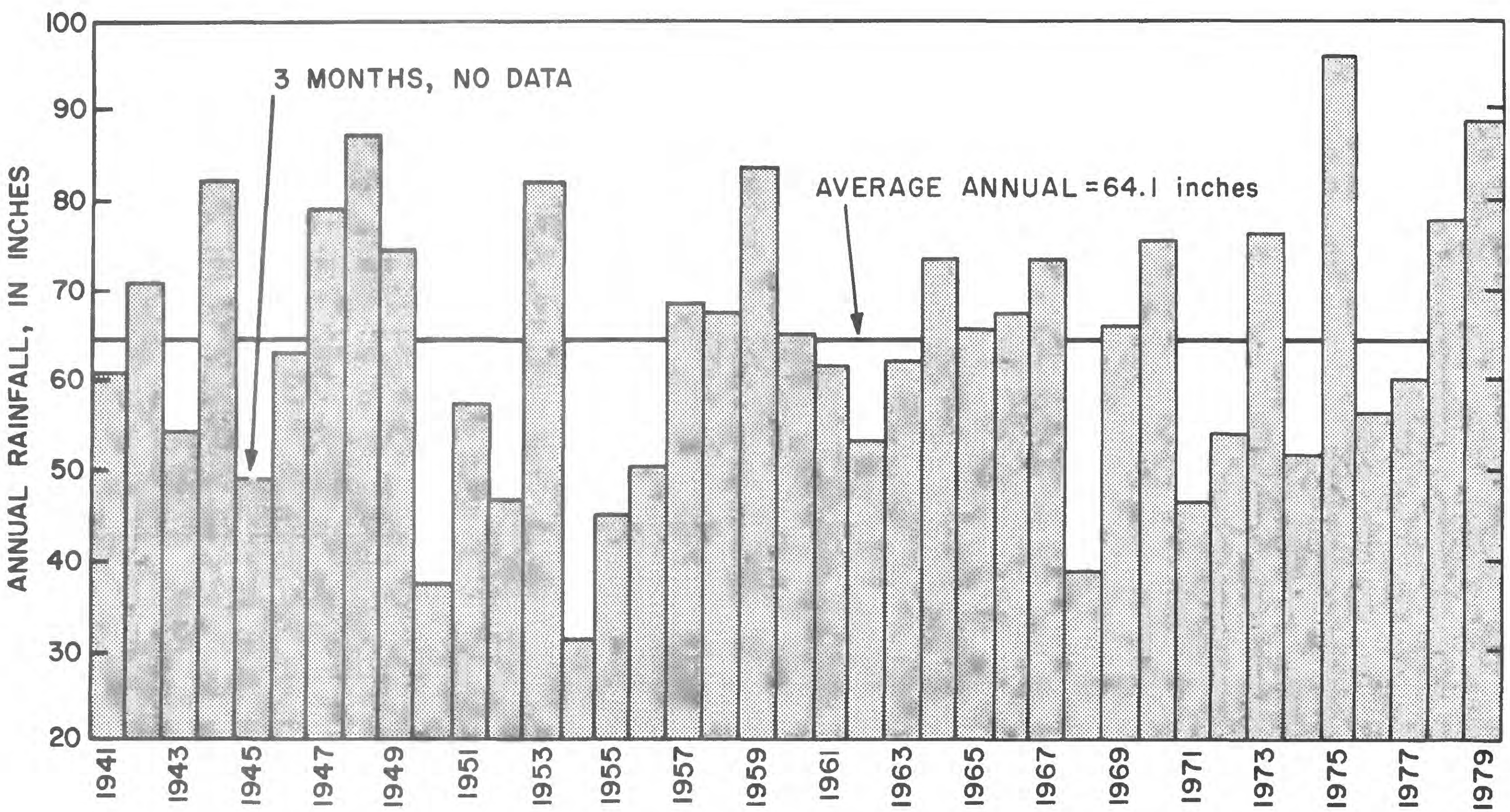


Figure 3.--Annual rainfall at Niceville, Fla., 1941 through 1979.

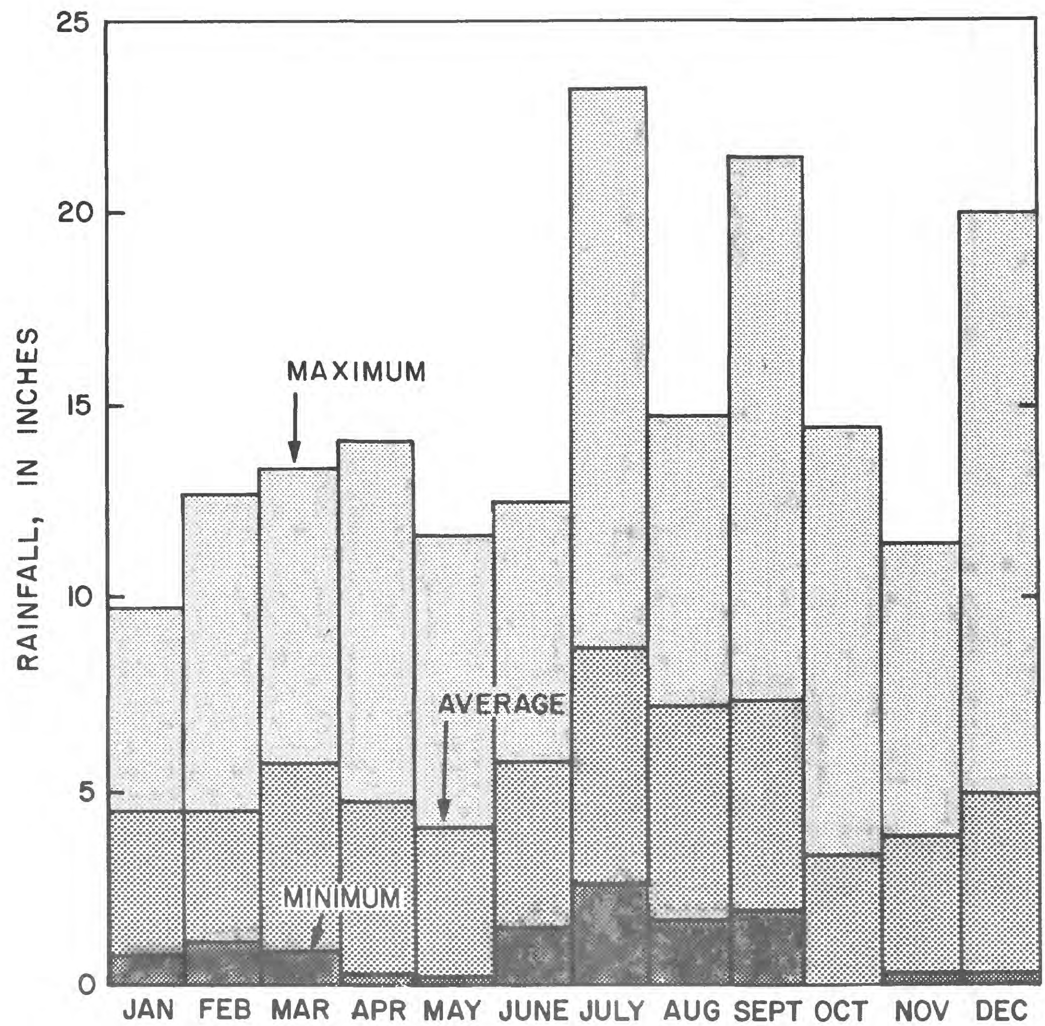


Figure 4.--Average, minimum, and maximum monthly rainfall at Niceville, Fla., 1941 through 1978 (modified from Barr and others, 1981).

The intense rains that fall during the passage of tropical storms and hurricanes have not been separated out of the Niceville rainfall records (figs. 3 and 4). Hurricanes and tropical storms may occur in the area from June through November, but more than 50 percent of these storms occur in September. Walker and others (1971, p. 32) reported that the September hurricanes of 1906, 1950, and 1953 each dropped 12 inches of rain on the area surrounding Choctawhatchee Bay.

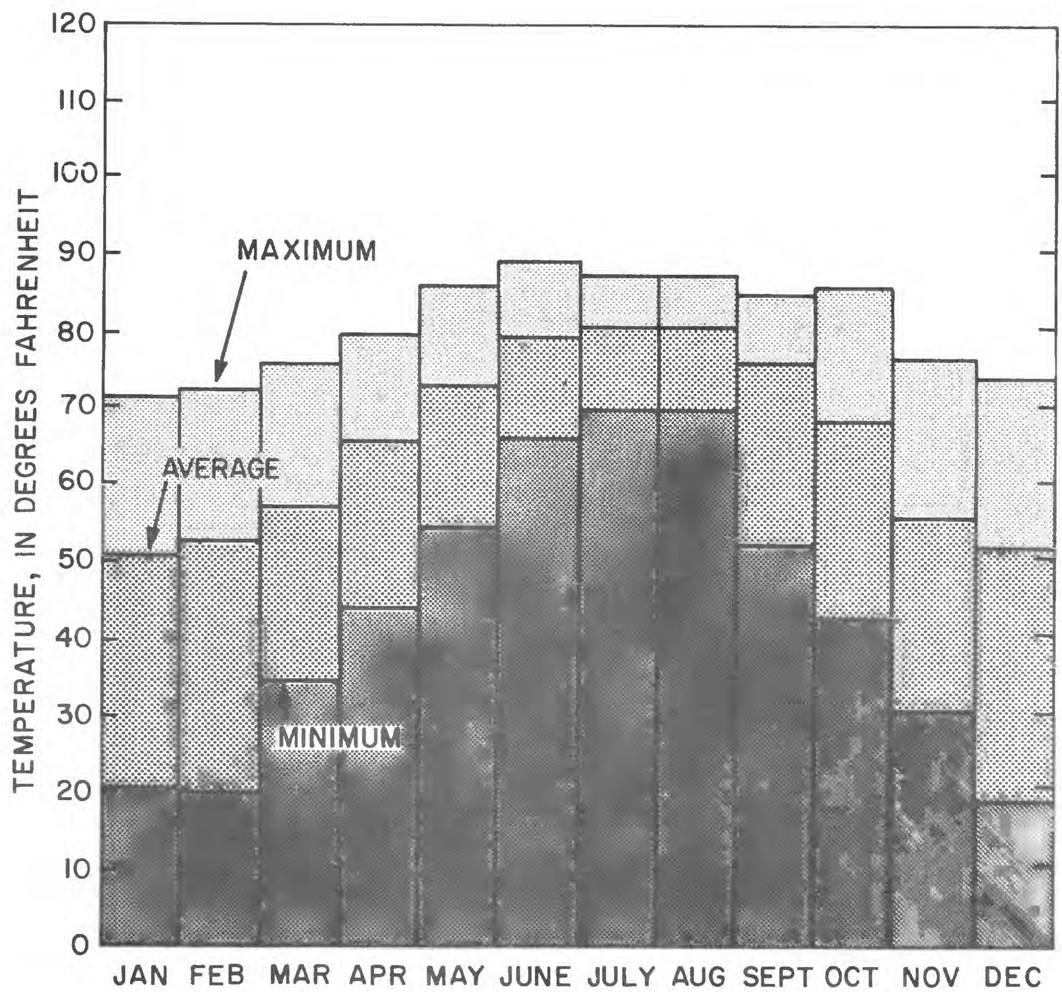


Figure 5.--Monthly distribution of daily average temperatures at Niceville, Fla., 1948 through 1976 (modified from Barr and others, 1981).

WATER USE

Most water used in the area of investigation is ground water; about 95 percent from the upper limestone of the Floridan aquifer and 5 percent from the sand-and-gravel aquifer. Approximately 95 percent of the total ground-water withdrawal in southern Okaloosa County is made by nine separate water-supply systems which include: the City of Fort Walton Beach, Okaloosa County, Eglin Air Force Base (including the main base and housing area, the auxiliary fields, and the test ranges and test sites), Valparaiso, Niceville, Mary Esther, Seashore Village, Hurlburt Field (USAF), and the unincorporated area of Destin. Table 1 summarizes annual water use by these systems for 1969 through 1978.

Table 1.--Summary of water use, from the upper limestone of the Floridan aquifer, by principal municipal, private, and Federal facilities

[e = estimated; -- = pumpage data not available]

Date	Destin	Fort Walton Beach	Eglin Air Force Base[1]	Hurlburt Field (USAF)	Mary Esther	Niceville	Okaloosa County	Seashore Village	Valparaiso
			Annual pumpage in millions of gallons						
1969	--	1,010.1	1,324.4	252.7	131.3	--	--	--	--
1970	--	1,012.0	1,354.3	269.2	143.1	--	--	11.4	--
1971	--	1,079.2	1,441.5	268.0	127.7	--	--	--	--
1972	--	1,125.7	1,859.1	267.5	133.0	--	--	--	135.2
1973	--	1,086.6	1,761.1	227.1	109.3	445.4	609.3	45.6	110.0
1974	342.7	1,126.8	1,652.8	e216	122.6	331.3	761.7	94.3	146.9
1975	319.2	1,063.9	1,701.5	e260	139.7	302.7	716.9	160.5	142.5
1976	383.5	1,115.8	1,537.4	e312	163.0	389.2	1,141.3	e100	162.8
1977	437.9	1,169.2	1,442.3	369.7	187.7	419.4	1,296.5	107.6	206.4
1978	499.4	1,176.9	1,205.2	292.0	181.9	492.0	1,359.1	92.9	200.5
			Daily pumpage in million gallons per day						
1969	--	2.77	3.63	0.69	0.36	--	--	--	--
1970	--	2.77	3.71	.74	.39	--	--	0.03	--
1971	--	2.96	3.95	.73	.35	--	--	--	--
1972	--	3.08	5.09	.73	.36	--	--	--	0.37
1973	--	2.98	4.82	.62	.30	1.22	1.67	.12	.30
1974	0.94	3.09	4.53	e .59	.34	.91	2.09	.26	.40
1975	.87	2.92	4.66	e .71	.38	.83	1.96	.44	.39
1976	1.05	3.06	4.21	e .85	.45	1.07	3.13	e .27	.45
1977	1.20	3.20	3.95	1.01	.51	1.15	3.55	.29	.56
1978	1.39	3.22	3.30	.80	.50	1.35	3.72	.24	.55

[1] Includes Eglin Main Base, the housing area, the auxiliary fields, test ranges, and test sites.

The daily average water use for the public, industrial, and military water systems in southern Okaloosa County increased from about 1.5 Mgal/d in 1940 to 11.8 Mgal/d in 1968 (Trapp and others, 1977), and to 15.1 Mgal/d in 1978. Water use varies considerably owing to the seasonal influx of tourists, changes in the military population, and seasonal lawn sprinkling; it has steadily increased with population growth. Water use is generally highest in May through July and lowest in November through February. Figure 6 graphically illustrates monthly and seasonal water use by the municipalities for the 5-year period, 1974-78.

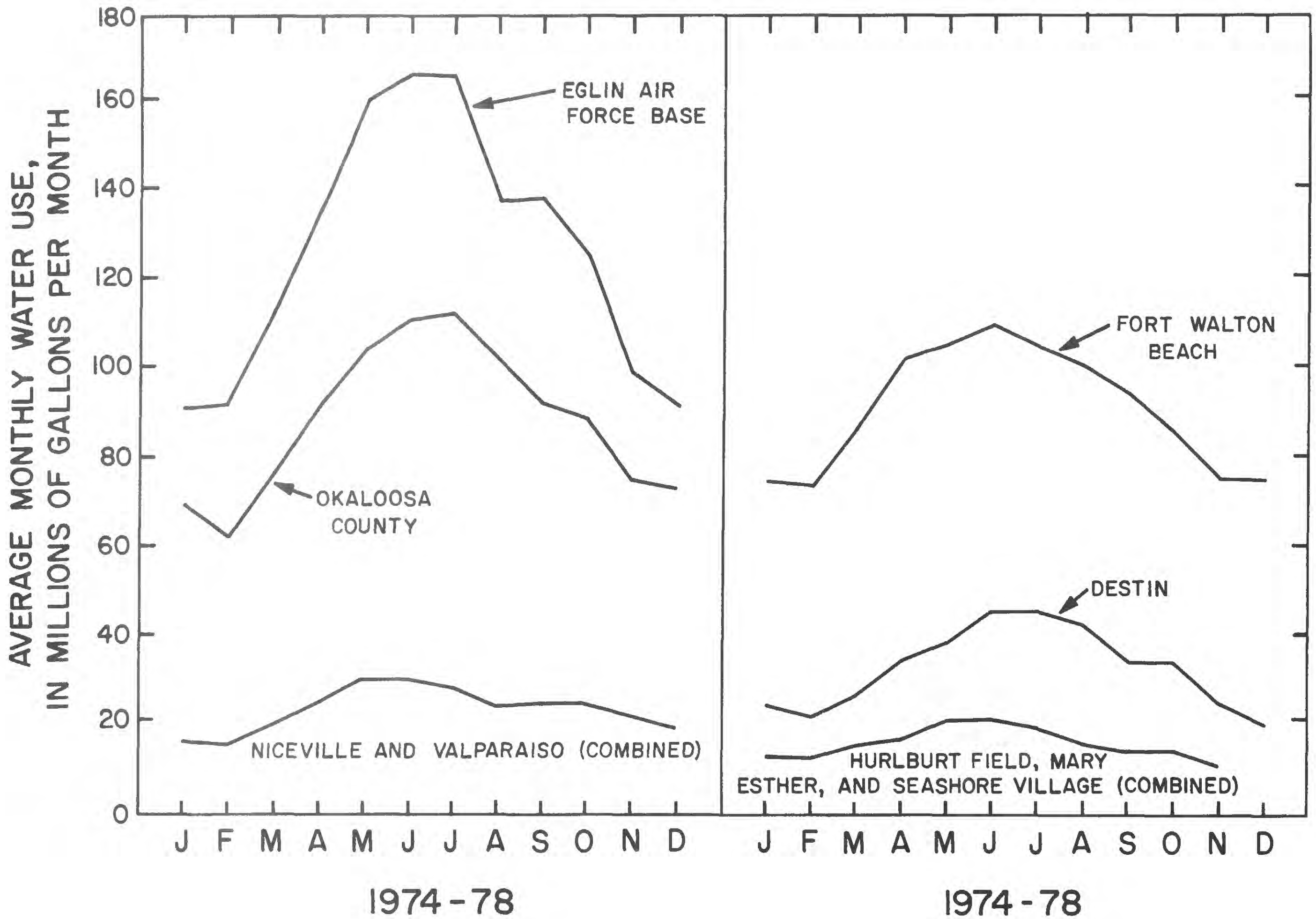


Figure 6.--Average monthly water use in the Fort Walton Beach metropolitan area, 1974-78.

OKALOOSA COUNTY

In 1978, Okaloosa County operated 14 wells in the Fort Walton Beach metropolitan area, five of which are located on Santa Rosa Island and nine inland. These wells tap the upper limestone of the Floridan aquifer and are the primary source of water for Santa Rosa Island, Wright, Ocean City, Shalimar, Cinco Bayou, Longwood, and Pippin Lake and Raintree subdivisions (fig. 2).

Average daily withdrawals for all uses by Okaloosa County ranged from 1.67 Mgal/d in 1973 to 3.72 Mgal/d in 1978 (table 1). Withdrawals vary seasonally and are generally highest in May through August and lowest in January and February (fig. 6). In 1978, the average monthly withdrawals ranged from 2.79 Mgal/d in January to 4.5 Mgal/d in June.

CITY OF FORT WALTON BEACH

The City of Fort Walton Beach operates nine wells that tap the upper limestone of the Floridan aquifer (fig. 1). City wells 1 (map No. 105), 2 (124), 3 (125), 5 (123), 8 (126), and 9 (128) are in the main part of the city, whereas wells 6 (215), 7 (207), and 10 (212) are at the municipal golf course north of the city.

Withdrawals by the city for public supply from the Floridan aquifer have increased from 2.77 Mgal/d in 1969 to 3.22 Mgal/d in 1978 (table 1). The volume of withdrawals is highly seasonal (fig. 6). It is greatest during April through August and lowest in November through February. In 1978, withdrawals ranged from 2.4 Mgal/d in January to 4.06 Mgal/d in April.

EGLIN AIR FORCE BASE

The water supply for Eglin Air Force Base is supplied from 16 wells that tap the upper limestone of the Floridan aquifer. Eglin Main Base, the housing area, the auxiliary fields, and most of the miscellaneous test ranges and test sites are supplied by wells in the Floridan aquifer.

Eglin Air Force Base is the largest water user in Okaloosa County (fig. 6). Withdrawals increased from 3.63 Mgal/d in 1969 (table 1), reached a peak of 5.09 Mgal/d in 1972, and have been declining since then to 3.30 Mgal/d in 1978. Withdrawals are generally highest during the 6-month period from April through September and lowest from November through February.

OTHER MUNICIPAL AND PRIVATE WATER SYSTEMS

The remaining systems, including Niceville, Valparaiso, Destin, Hurlburt Field, Mary Esther, and Seashore Village, each withdraw considerably less water than Okaloosa County, the City of Fort Walton Beach, and Eglin Air Force Base (table 1). Hurlburt Field and Niceville currently operate five wells each in the Floridan aquifer, Valparaiso and Destin three, and Mary Esther and Seashore Village two.

PROJECTED POPULATION AND WATER DEMAND

According to the U.S. Bureau of the Census, the southern parts of Okaloosa and Walton Counties had populations of 50,000, 78,000, and 99,000 in 1960, 1970, and 1980, respectively (U.S. Bureau of the Census, 1962, 1972, 1980). Most of the increase in population has been in southern Okaloosa County (the Fort Walton Beach metropolitan area), which has grown from approximately 44,000 in 1960 to 89,000 in 1980. The population of southern Walton County has grown much more slowly, increasing from approximately 6,000 in 1960 to 10,000 in 1980. Most of this increase (3,000) occurred between 1978 and 1980.

The source of virtually all the water used is ground water obtained from the upper limestone of the Floridan aquifer; the rest, or about 5 percent, is from near-surface sands of the sand-and-gravel aquifer.

Average water use has more than doubled from 7.4 Mgal/d in 1969 to 15.1 Mgal/d in 1978. Assuming a 1980 water use of about 20 Mgal/d and an increased use of about 0.25 Mgal/d per year, an assumption which may not be strictly valid, average daily water use in southern Okaloosa County can be expected to increase to 23 Mgal/d in 1990, 26 Mgal/d in 2000, and 31 Mgal/d in 2020. In the absence of more accurate figures, these projections provide a reasonable basis for assessing the availability of water for future needs.

SURFACE-WATER HYDROLOGY

Figure 7 shows the locations of stream-gaging stations. The major streams draining the study area are the Yellow, Shoal, and East Bay Rivers, and Live Oak, Turtle, Lightwood Knot, Garnier, Turkey, Titi, Juniper, Tenmile, Rocky, Magnolia, Alaqua, Basin, Lafayette, Long, Swift, and Tom's Creeks. Titi Creek and the Shoal and Yellow Rivers flow in a predominantly westerly direction and discharge into Blackwater Bay outside the area of investigation. Live Oak Creek and Turtle Creek flow southward into the East Bay River, which flows westward and discharges into East Bay outside the area of investigation. The rest of the streams generally flow to the south and discharge into Choctawhatchee Bay.

The surficial materials along parts of Turkey and Juniper Creeks are more clayey than for most streams in the area. Clay mixed with sand forms a less permeable surface for infiltration with a resultant increase in direct runoff and a more developed drainage pattern.

A summary of all streamflow data is presented in table 2 including mean, low, and high flows as well as the period of record at each gaging station. Minimum flows are relatively high compared with other streams in Florida (Stone, 1974).

Figure 8 shows the maximum, minimum, and mean monthly discharge of Turkey Creek at Government Railroad near Niceville (fig. 7, stream-gaging station 20). The mean monthly flows of Turkey Creek vary little during the year and are representative of most streams in the study area. This reflects close interaction between the surface- and ground-water hydrologic systems. Rainfall percolates rapidly into the surficial aquifer which in turn stores the water and releases it slowly by discharge into Turkey Creek. Consequently, the flow of Turkey Creek does not vary as much as a stream with comparatively little interchange with the ground-water system. Annual variations of flows of most streams in the area of investigation are small due to large contributions of ground water, which tend to counteract the effect of variations in rainfall.

Table 2.--Summary of streamflow data

Station				Streamflow (ft^3/s)			
Map location No.	Name	Downstream order or site ID No.	Latitude/ longitude	Period of record (water years)	Mean	Low	High
1	Lafayette Creek at Freeport	02366911	30°29'35" 086°07'33"	1969-70, 72-79	86	22	142
2	Alaqua Creek near Defuniak Springs	02367000	30°37'00" 086°09'50"	1951-78	173.18	27	14,500
3	Basin Creek near Portland	02367165	30°31'02" 086°14'09"	1969-70, 77	44.75	21	59
4	Rocky Creek near Portland	02367240	30°34'23" 086°22'01"	1965, 67, 77, 79	159.1	81	275
5	Little Rocky Creek near Niceville	02367242	30°36'34" 086°25'31"	1969-79	38.28	6.8	174
6	Rocky Creek near Niceville	02367250	30°32'07" 086°22'55"	1936, 66-70, 77	182.94	107	1,100
7	Long Creek near Portland	02367264	30°30'45" 086°23'24"	1967	9.8	--	--
8	Long Creek near Valparaiso	02367276	30°31'20" 086°24'42"	1967-77	6.5	4.9	8.1
9	Turkey Creek near Valparaiso	02367284	30°30'43" 086°25'30"	1967-77	6.4	--	--
10	Swift Creek near Niceville	02367300	30°31'40" 086°28'00"	1964-68, 77	23.44	11	53
11	Turkey Creek near Niceville	02367305	30°33'43" 086°32'10"	1967-68	77.59	53	224
12	Rogue Creek near Valparaiso	02367306	30°33'20" 086°33'46"	1966-67, 77	12.2	10	15
13	Tenmile Creek near Valparaiso	02367308	30°34'12" 086°31'00"	1966-67, 77	41	36	50

Table 2.--Summary of streamflow data--Continued

Station				Streamflow (ft^3/s)			
Map location No.	Name	Down-stream order or site ID No.	Latitude/ longitude	Period of record (water years)	Mean	Low	High
14	Anderson Branch near Valparaiso	02367309	30°33'35" 086°30'38"	1967-77	3.4	2.7	4.1
15	Juniper Creek at State Highway 85 near Niceville	02367310	30°33'26" 086°31'10"	1966-79	92.44	41	950
16	Turkey Creek at Valparaiso	02367312	30°30'22" 086°31'27"	1967-77	14.45	13.9	15
17	Tom's Creek near Niceville	(1)	30°30'15" 086°30'40"	1974-75, 77	35.73	28	49
18	Garnier Creek near Fort Walton Beach	02367313	30°25'53" 086°35'02"	1967	21	--	--
19	East Bay River near Wynnehaven Beach	02367400 (2)	30°25'53" 086°46'20"	1966-68, 77, 79	209.37	107	1,370
20	Turkey Creek at Government Railroad near Niceville	02367355	30°32'25" 086°31'15"	1977-79	281.66	180	822
21	Garnier Creek at Longwood	02367370	30°28'49" 086°35'07"	1967, 77-79	23.56	16	35
22	Lightwood Knot Creek at Longwood	02367377	30°28'41" 086°35'45"	1967, 77-79	51.72	37.8	68
23	Turtle Creek near Fort Walton Beach	02367388	30°31'28" 086°40'17"	1966-67	22	21	23
24	Turtle Creek near Ocean City	02367390	30°30'31" 086°40'13"	1977-79	61.47	48	94
25	Live Oak Creek near Florosa	02367397	30°30'39" 086°42'53"	1977-79	71.14	53.5	92.2

[1] Site ID number = 303015086304000.
[2] Formerly station number 02367320.

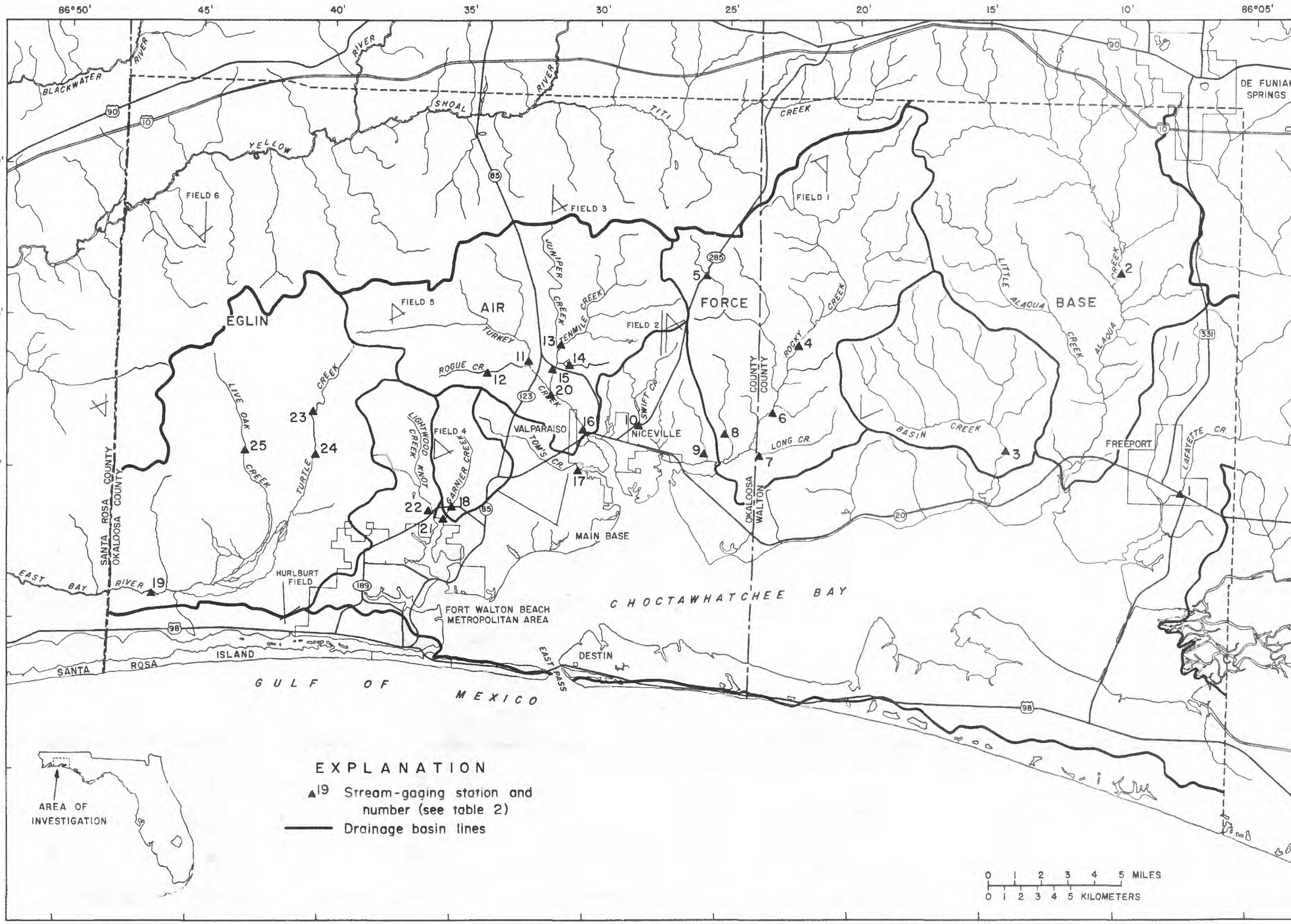


Figure 7.--Locations of stream-gaging stations (modified from Barr and others, 1981).

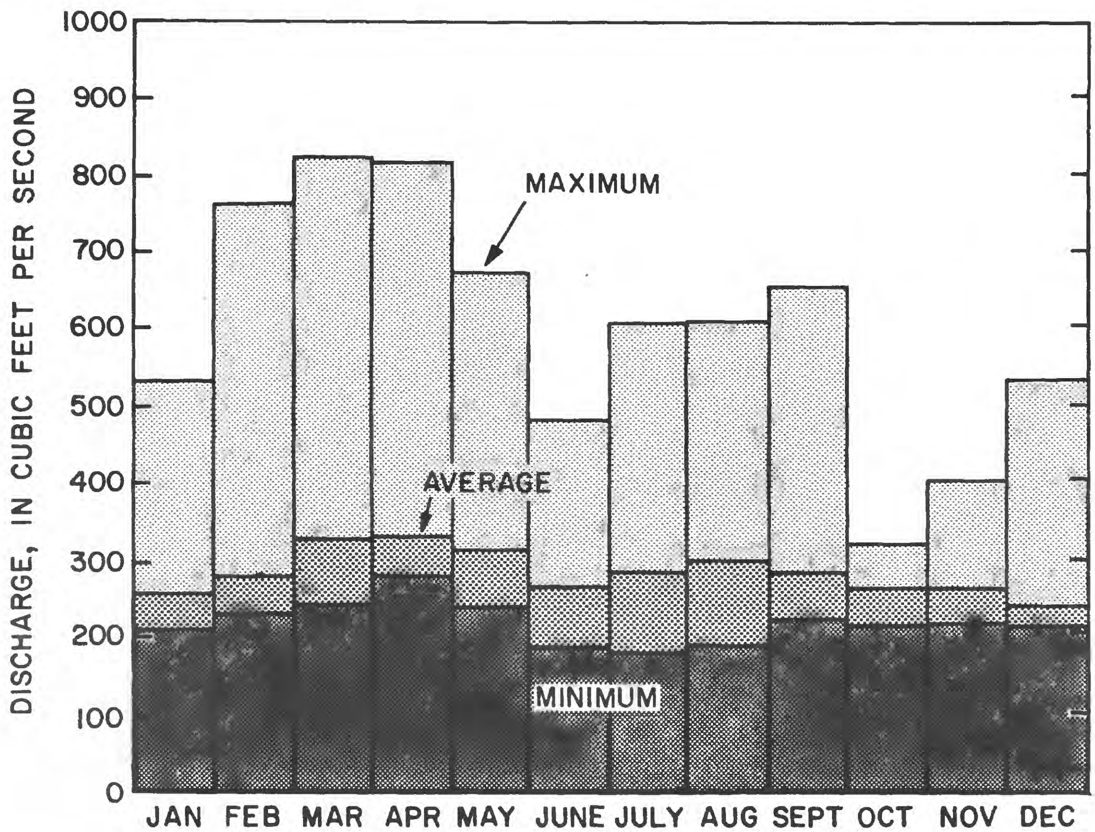


Figure 8.--Average monthly streamflow of Turkey Creek at Government Railroad near Niceville, Fla., June 1977 through September 1979 (modified from Barr and others, 1981).

Base, sustained, runoff of a stream is defined as the difference between streamflow (total runoff) and direct (overland) runoff. Base runoff is sustained ground-water acretion from aquifer storage into streams, ponds, or lakes.

The results of base-runoff analyses for Turtle, Juniper, and Turkey Creeks in southern Okaloosa County indicate that base runoff constituted 92 to 98 percent of the total runoff in water years 1978 and 1979 (Barr and others, 1981, table 8). Because of the high percentage of base runoff, or flow derived from stored ground water, streamflow does not diminish excessively during drought. Also, direct surface runoff during wet periods is small because of rapid infiltration of rainfall.

Surface water pH varies from 4.2 to 7.4 and averages 5.5 for all streams tested. The tendency toward acidic pH values indicates that these waters can cause corrosion problems in water distribution systems, problems which may include tuberculation, leaks, ruptures, discoloration, and loss of chlorine residual. Corrosion can also bring about an increase in concentrations of trace metals. Surface waters are low in dissolved solids, are very soft, and contain an average of 0.16 mg/L (milligrams per liter) iron for all the streams tested. Tom's Creek is the only stream where iron exceeds the maximum contaminant level for drinking water (0.3 mg/L). Water temperatures range from a low of 7°C to a high of 27.5°C (81.5°F), with an average of about 19.2°C. The quality of surface water is good, with only pH commonly occurring outside the range of drinking water standards (the desirable pH range is 6.5 to 8.5).

GROUND-WATER HYDROLOGY

GEOLOGIC SETTING

In the southern parts of Okaloosa and Walton Counties, the coastal plain sediments that make up the sand-and-gravel aquifer and the Floridan aquifer range in age from middle Eocene to Holocene. They are predominantly sand, clay, limestone, and dolomite. In general these strata dip gently south-southwest through the study area, their combined thickness ranging from 1,500 feet in the northeast part of the study area to greater than 2,500 feet in the southwest.

Table 3 shows the relation between the geologic and hydrogeologic units. Table 4 includes a brief lithologic description and water-bearing properties of these units. The locations of geologic and hydrogeologic sections are shown in figure 1.

Facies changes are pronounced as illustrated by geologic section A-A' (fig. 9). For example, some formations are argillaceous marls in the eastern part of the area but grade into limestone downdip to the southwest.

The sediments that make up the sand-and-gravel aquifer and the Floridan aquifer are subdivided into ten geologic (stratigraphic) units as shown in table 3 and figure 9. In table 3 this sequence of geologic units is grouped into six major hydrogeologic units. The vertical and lateral relations of these six units are illustrated by hydrogeologic sections B-B' and C-C' (figs. 10 and 11). The locations of the sections are shown in figure 1. The contacts between the hydrogeologic units do not necessarily correlate with stratigraphic contacts. Also, a single hydrogeologic unit may include two or more geologic formations that have similar hydrologic characteristics (table 3). In descending order, the six hydrogeologic units are: the sand-and-gravel aquifer, the Pensacola Clay confining bed, the upper limestone of the Floridan aquifer, the Bucatunna clay confining bed, the lower limestone of the Floridan aquifer, and the Lisbon-Tallahatta confining unit.

Table 3.--Geologic units in the southern parts of Okaloosa and Walton Counties and their hydrogeologic equivalents

[See table 4 for lithology and water-bearing properties of units]

Series	Formation or group	Thickness (feet)	Hydrogeologic unit
Holocene to Pliocene	Unnamed Holocene to Pliocene sands and Citronelle Formation, undifferentiated	50-250	Sand-and-gravel aquifer
Miocene	Miocene coarse clastics	50-200	Pensacola Clay confining bed
	Intracoastal Formation[1]	0-360	
	Alum Bluff Group (northern part only)	0-300	
	Pensacola Clay	0-190	
	Bruce Creek Limestone[1]	20-220	Upper limestone of the Floridan aquifer
Miocene / Oligocene	Tampa Limestone equivalent and Chickasawhay Limestone, undifferentiated	30-260	
Oligocene	Bucatunna Formation	0-130	Bucatunna clay confining bed
Eocene	Ocala Limestone	165-600	Lower limestone of the Floridan aquifer
	Lisbon and Tallahatta Formations	345-500 170-300	Lisbon-Tallahatta confining unit

[1]Of Schmidt and Clark, 1980.

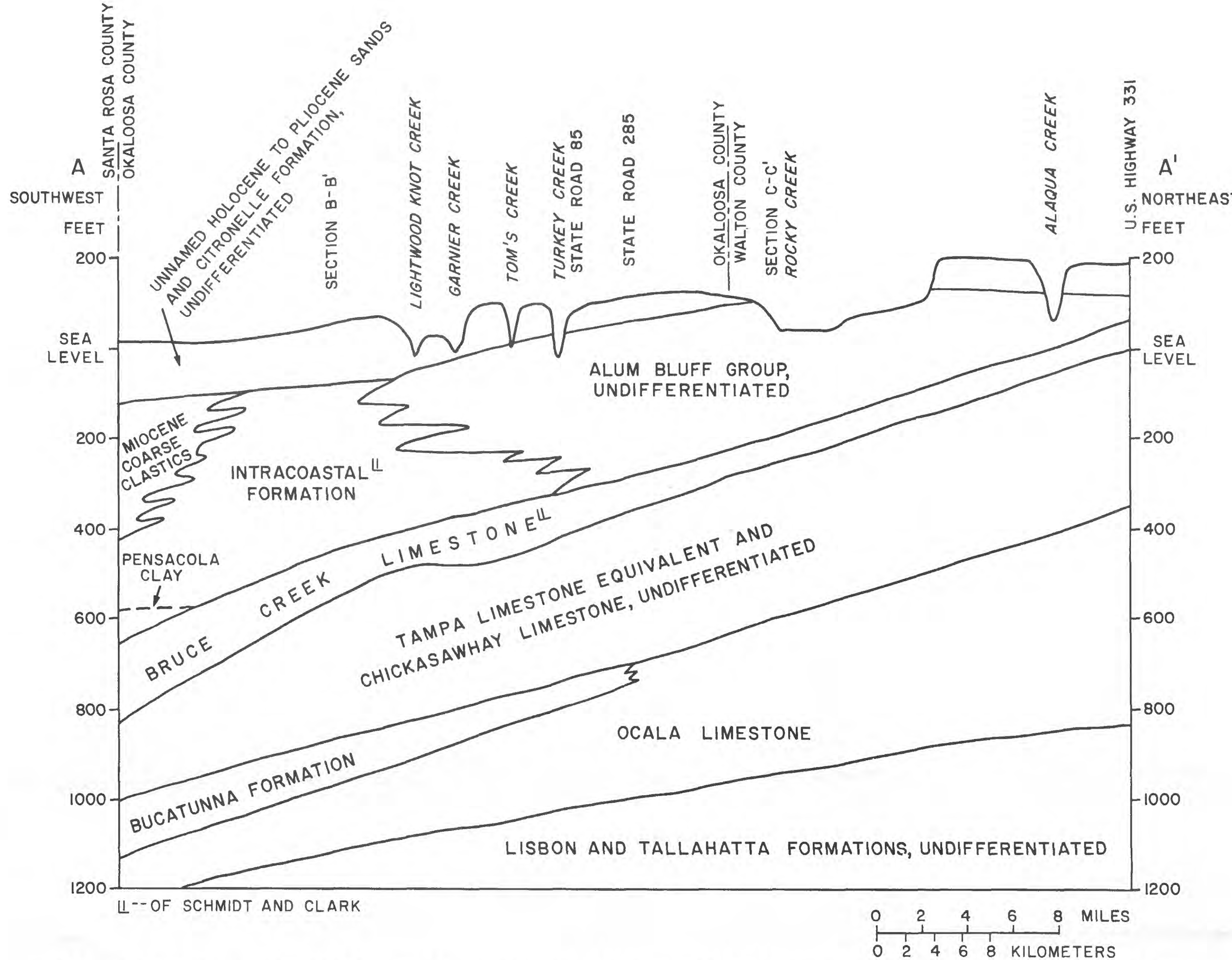


Figure 9.--Geologic section A-A', southwest to northeast through Okaloosa and Walton Counties (modified from Barr and others, 1981). See figure 1 for location of section.

Table 4.--Lithology and water-bearing properties of geologic and hydrogeologic units in the southern parts of Okaloosa and Walton Counties

Geologic unit	Lithology	Hydrogeologic unit	Water-bearing properties
Holocene to Pliocene sands	Unconsolidated, white to light gray, fine to medium quartz sand. Accessories include heavy minerals and phosphate.	Sand-and-gravel aquifer	Water mainly unconfined. In Fort Walton Beach, includes surficial unconfined unit and lower leaky artesian unit. Yields range from less than 20 gal/min in coastal lowlands of Walton County to 1,000 gal/min in uplands of western Okaloosa County. Tapped by shallow wells for domestic supply and a few larger capacity wells for irrigation. Currently not used by municipal systems for public consumption.
Citronelle Formation	Predominantly nonmarine quartz sands with thin stringers of clay or gravel discontinuous over short distances.		
Miocene coarse clastics	Present in the western part of study area, the Miocene coarse clastics comprise poorly consolidated sand, silt, clay, and beds of shell.	Pensacola Clay confining bed	Restricts vertical movement of water because of thickness and comparatively low permeability. In the area of investigation grades laterally from predominantly dense clay and sandy clay in western part to predominantly clayey, silty sand in the eastern part. Not a source of water.
Intracoastal Formation[1]	Upper and lower carbonate layers separated by a phosphatic sand. The carbonate is a poorly consolidated, sandy, clayey, microfossiliferous limestone.		
Alum Bluff Group (northern part only)	Mixture of sand, clay, and shell in relatively well-sorted thin beds. The matrix material is commonly clay or carbonate cement.		
Pensacola Clay	Present only in the western half of the study area in the coastal area, the Pensacola Clay interfingers with the Intracoastal Formation and Alum Bluff Group. The Pensacola is predominantly a bluish gray to olive gray, dense, silty clay.		

Bruce Creek Limestone[1]	Light gray to white, moderately indurated, granular, and occurs as a clastic limestone. Accessories include a sand fraction that increases north and east.	Upper limestone of the Floridan aquifer	Principal source of water in area of investigation. Yields large quantities of freshwater under confined conditions. Yields range from 250 gal/min to over 1,000 gal/min. Sustained yields are generally lowest immediately adjacent to the coast in Okaloosa County. Individual zones vary greatly in permeability and vertical connection. Contains over 250 mg/L chlorides in parts of southeastern Walton and southwestern Okaloosa Counties.
Tampa limestone equivalent	Lithologically similar to Chickasawhay Limestone but slightly less dolomitic. Silt and clay content increase toward the top.		
Chickasawhay Limestone	Primarily a tan sucrosic dolomite but may also occur as a cream to buff fossiliferous limestone. The gradations between the limestone and the dolomite occur both vertically and laterally within the formation.		
Bucatunna Formation	Medium brown to dusky, yellowish-brown calcareous clay. Accessories include up to 10 percent quartz sand and up to 1 percent phosphate. The top contact is sharp and well defined from the overlying limestone.	Bucatunna clay confining bed	Where present, restricts vertical movement of water between overlying and underlying hydrogeologic units. Generally present in coastal Walton and Okaloosa Counties but absent in northern parts of area. Not a source of water.
Ocala Limestone	A white to light gray, chalky, fossiliferous relatively pure calcium carbonate limestone. Occasionally the limestone is interlayered with thin streaks of light brown to tan dolomite layers.	Lower limestone of the Floridan aquifer	Comprises a separate hydrogeologic unit in coastal Walton and Okaloosa Counties. In other parts, cannot be hydrologically distinguished from upper limestone aquifer. Not used as a source of freshwater in the southern parts of Okaloosa and Walton Counties.
Lisbon and Tallahatta Formations	Massive shaly to chalky limestones often dark gray to brownish gray to cream in color. Thin shaly beds predominate with specks of glauconite in the more calcareous parts. Foraminifera are abundant.	Lisbon-Tallahatta confining unit	Predominantly impermeable strata. Comprises the base of the freshwater flow system.

[1]Of Schmidt and Clark, 1980.

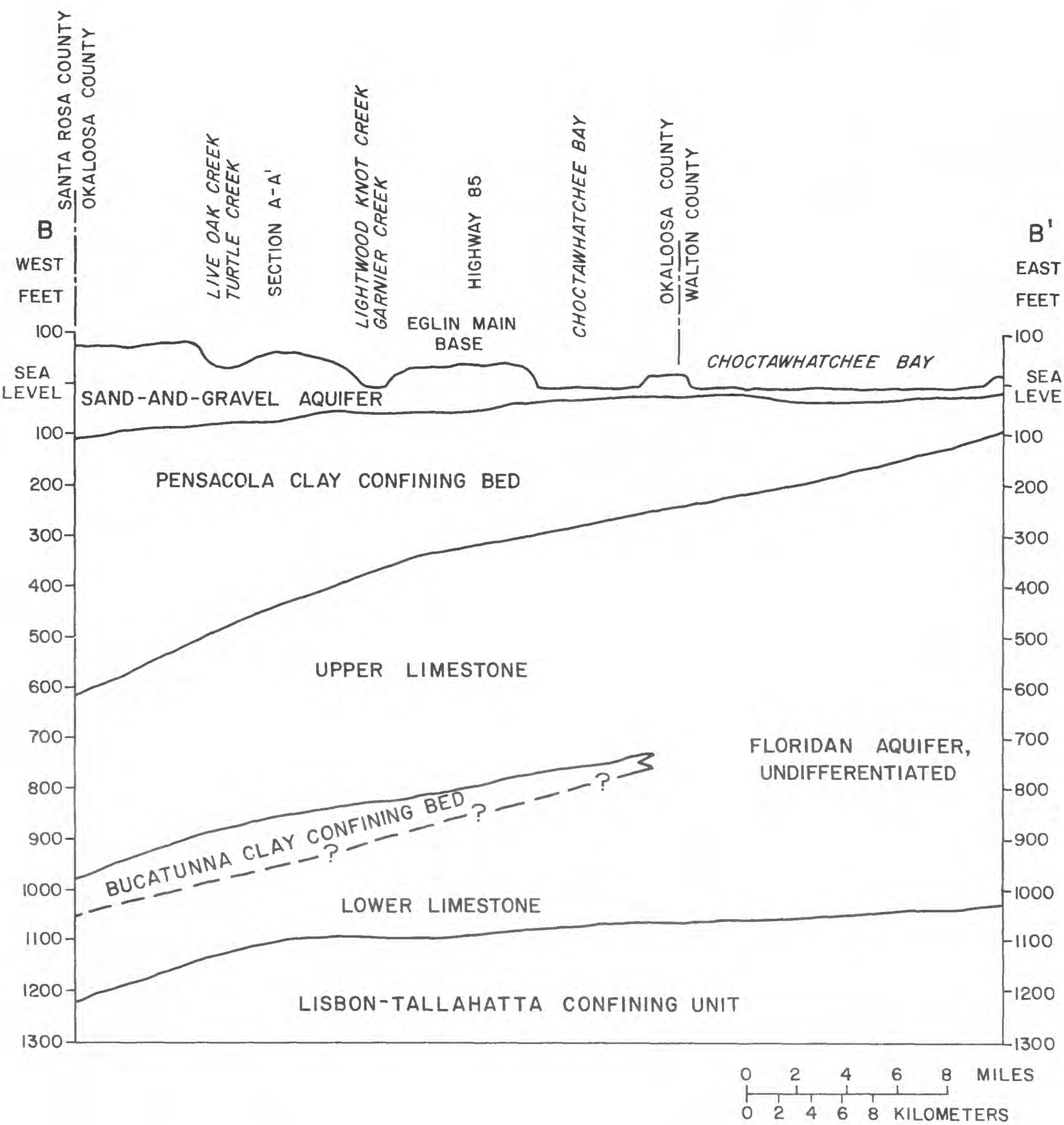


Figure 10.--Hydrogeologic section B-B', west to east through the southern parts of Okaloosa and Walton Counties (modified from Barr and others, 1981). See figure 1 for location of section.

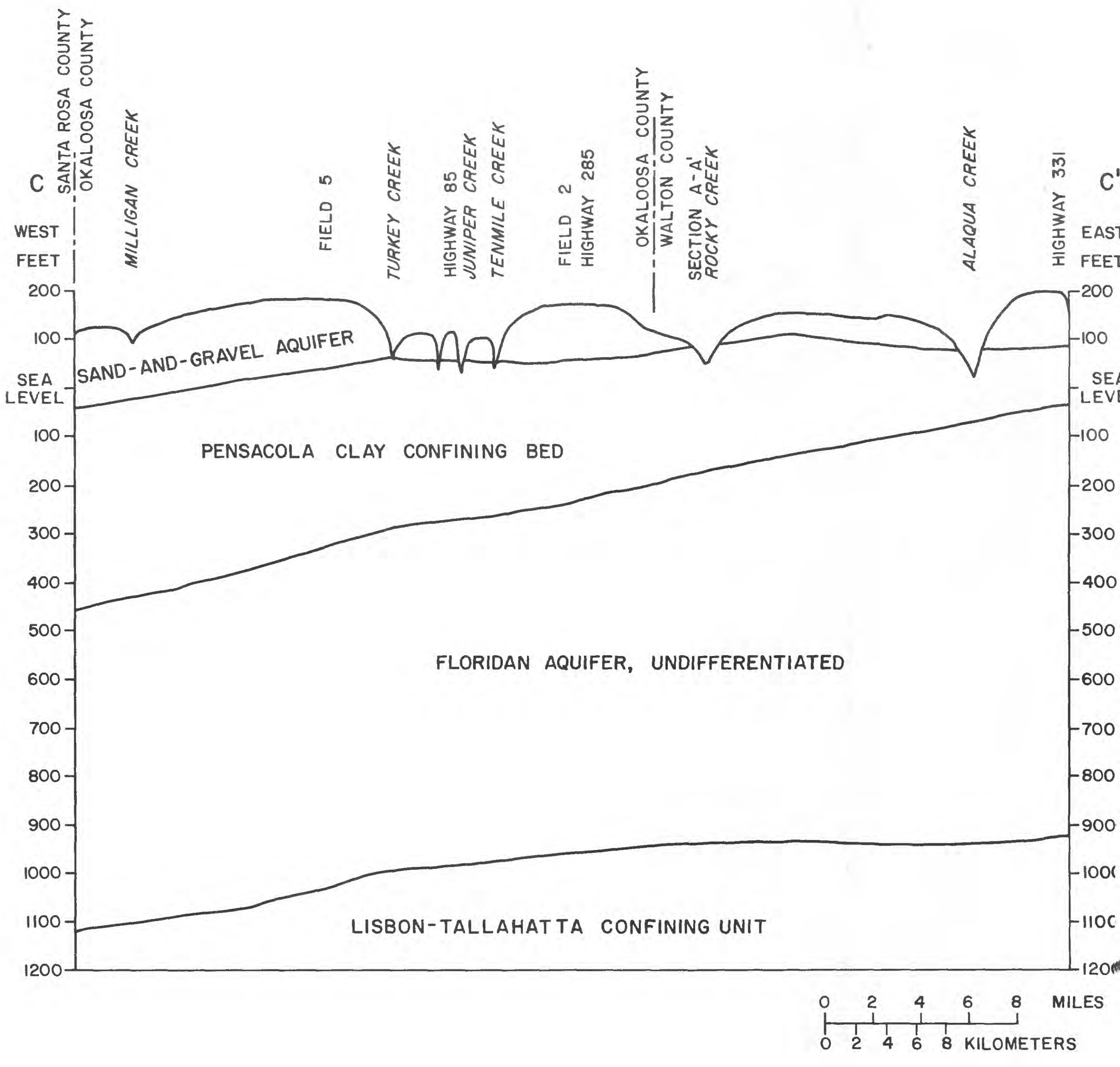


Figure 11.--Hydrogeologic section C-C', west to east through the southern parts of Okaloosa and Walton Counties (modified from Barr and others, 1981). See figure 1 for location of section.

HYDROGEOLOGIC UNITS

Sand-And-Gravel Aquifer

The sand-and-gravel aquifer consists of clean, fine to coarse sand and gravel but locally contains silt, silty clay, and peat beds. Included are unnamed strata of Holocene to Pliocene age and beds of the Citronelle Formation of Pliocene age (tables 3 and 4). The aquifer thickens from east to west. In the vicinity of Fort Walton Beach, the aquifer consists of: (1) a surficial unit of fine to medium, moderately well-sorted sand; (2) an intermediate unit of silty clay, poorly sorted fine to medium sand, and fine to very coarse, poorly sorted clayey sand; and (3) a lower unit of medium to coarse sand with some gravel. The lower unit is the main producing zone of the aquifer and is capable of yielding more than 300 gal/min of good quality water. Water in the sand-and-gravel aquifer may be artesian or unconfined; under unconfined or water-table conditions the aquifer has direct contact with streams, lakes, and with Choctawhatchee Bay, Santa Rosa Sound, and the Gulf of Mexico. In the Coastal Lowlands region, the water table is at, or within a few feet of, land surface. In the Western Highlands region, which makes up approximately the northern two-thirds of the area of investigation, the water table may occur at considerable depth below land surface. In the Western Highlands region, lakes and secondary water tables that may be perched occur where the surficial sands are underlain at shallow depth by clay and silt that restrict the downward movement of water to the regional water table. Small amounts of water are obtained from the sand-and-gravel aquifer by shallow domestic wells and greater amounts from a few larger wells used for irrigation of golf courses and other public recreation facilities in the western part of the area.

For additional information and greater details about the sand-and-gravel aquifer the reader is referred to the companion report by Hayes and Barr (1983).

Pensacola Clay Confining Bed

Throughout the southern parts of Okaloosa and Walton Counties, the Pensacola Clay confining bed as used in this report underlies the sand-and-gravel aquifer and separates it hydraulically from the underlying Floridan aquifer. Geologically, the unit, in descending order, includes the Miocene coarse clastics, the Intracoastal Formation of Schmidt and Clark (1980), the Alum Bluff Group, and the Pensacola Clay (table 3). Trapp and others (1977) named these sediments the Pensacola Clay confining bed because they correspond approximately to the lower part of the Pensacola Clay of Marsh (1966); they defined the Pensacola Clay confining bed as "the material of relatively low permeability between the sand-and-gravel aquifer above and the Floridan aquifer below. It may include material older, younger, or beyond the lateral limits of the lower Pensacola Clay stratigraphic unit." The confining bed restricts vertical movement of water between the sand-and-gravel and Floridan aquifers to varying degrees, depending on its thickness and lithologic character at a particular place. It also restricts saline water from Choctawhatchee Bay and the Gulf of Mexico from moving downward into the Floridan aquifer over most of the study area. Locally in southernmost Walton County, beds of shell and coral occur near the top of the unit and have been developed for small supplies of water.

The top of the Pensacola Clay confining bed dips south-southwest at about 15 feet per mile, ranging from about 140 feet above sea level in northeastern Walton County to more than 125 feet below sea level in southwestern Okaloosa County (fig. 12). The thickness of the unit ranges from about 475 feet in southwestern Okaloosa County to less than 50 feet in southeastern Walton County (fig. 13), and averages about 350 feet thick in Okaloosa County and about 150 feet thick in Walton County.

The Pensacola Clay confining bed consists predominantly of gray to bluish-black and light brown carbonaceous or calcareous clay; light gray to brown, very fine to coarse, clayey sand; coarse, angular, clayey gravel; and some limestone and shell fragments. The confining bed grades laterally from dense clay and sandy clay in the west to sandy clay, clayey sand, and limestone in the east. On the basis of geophysical and lithologic logs and aquifer test analyses (Barr and others, 1981, p. 9), the average vertical hydraulic conductivity of the confining bed is estimated to range roughly from $1x10^{-2}$ to $1x10^{-6}$ ft/d. It averages about $1x10^{-5}$ ft/d in Okaloosa County and $1x10^{-3}$ ft/d in Walton County.

Upper Limestone of the Floridan Aquifer

The upper limestone of the Floridan aquifer constitutes the principal source of water used in the southern parts of Okaloosa and Walton Counties. It was described as a distinct hydrogeologic unit by Barraclough and Marsh (1962, p. 4-18) and by Marsh (1966, p. 143-151) and consists of a thick and areally extensive sequence of interbedded limestones and dolomites of Miocene to late Oligocene age comprising, in descending order, the Bruce Creek Limestone of Schmidt and Clark (1980), Tampa Limestone equivalent, and Chickasawhay Limestone. Although these carbonate rocks differ vertically and horizontally in texture, porosity, and permeability, they can be treated as a single hydrologic unit in that their internal hydrologic dissimilarities are small compared to dissimilarities with overlying and underlying units. The upper limestone of the Floridan aquifer may be described as white to light gray or cream colored, highly fossiliferous, and slightly dolomitic.

In this report, the top of the Floridan aquifer is considered to be the top of the first regionally mappable and relatively continuous limestone immediately below sediments having a high phosphate or clay content. These phosphatic or clayey sediments, which show up as high peaks on natural gamma radiation logs, are included in the basal part of the Pensacola Clay confining bed. The top of the Floridan aquifer dips southwest 15 to 20 feet per mile and ranges from about 50 feet above sea level in the northeastern part of the area of investigation to more than 600 feet below sea level in the southwestern part (fig. 14). In the northeastern part, the upper limestone of the Floridan aquifer characteristically is 10 to 25 percent sand or silty clay and ranges in thickness from about 200 feet in eastern Walton County north of Freeport to about 400 feet in parts of coastal Okaloosa County.

Ground-water storage and movement in the upper limestone of the Floridan aquifer take place in a combination of interconnected, intergranular pore spaces, small solution fissures, and larger solution channels and cavities. Yields from wells are large, ordinarily in the range of 250 to more than 1,000 gal/min; and the water occurs under confined conditions throughout the area.

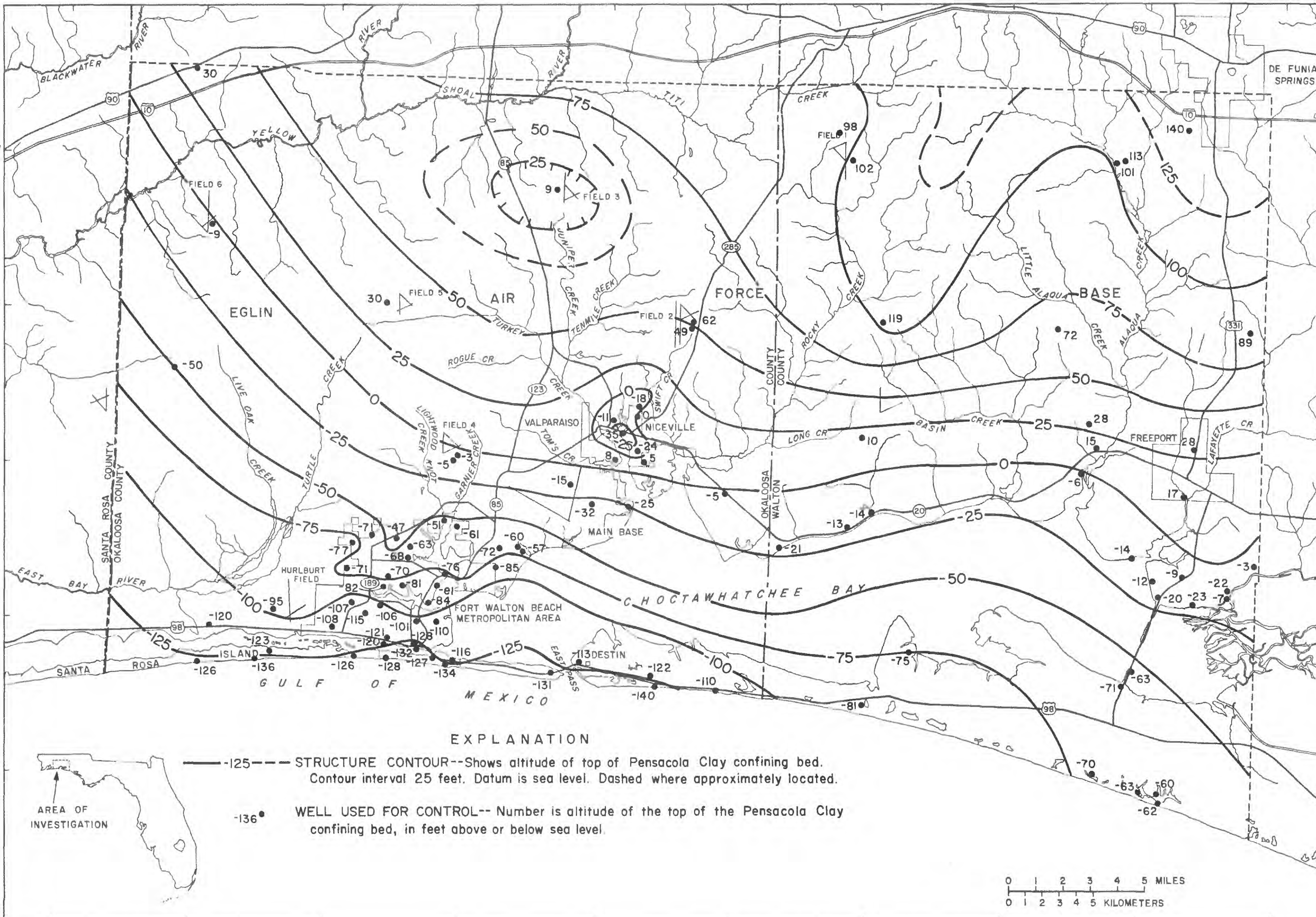


Figure 12.--Altitude of the top of the Pensacola Clay confining bed (modified from Barr and others, 1981).

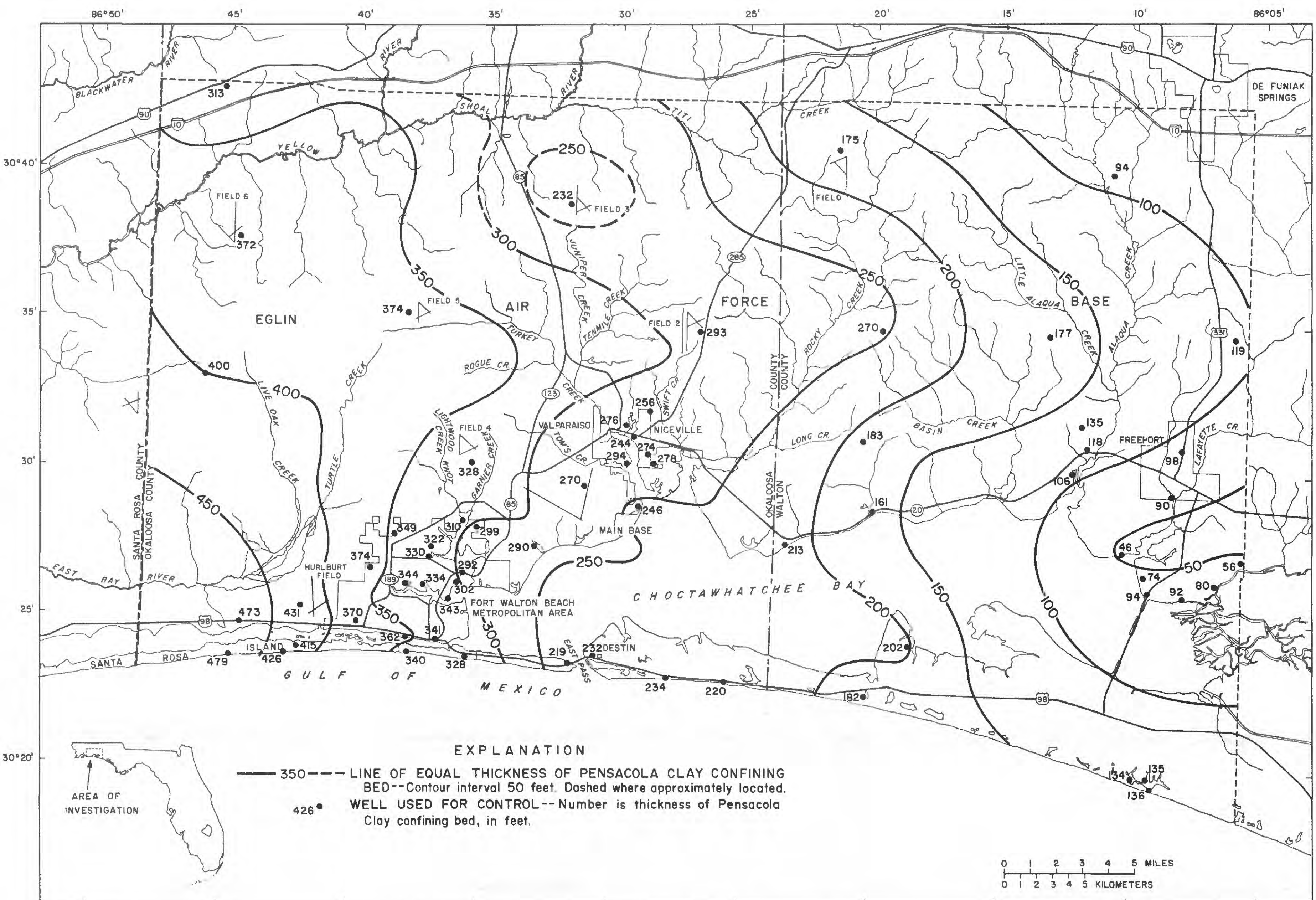


Figure 13.--Thickness of the Pensacola Clay confining bed (from Barr and others, 1981).

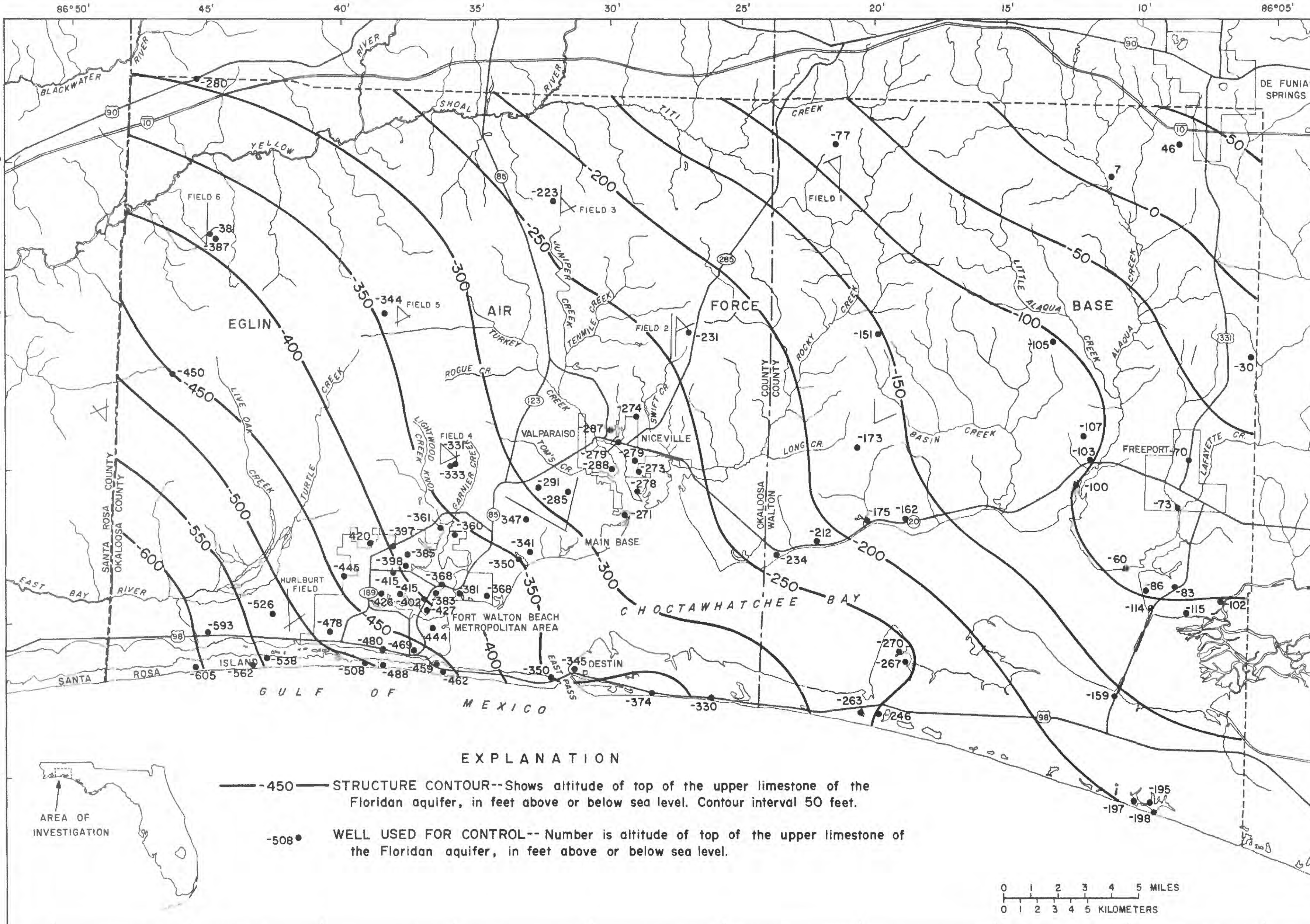


Figure 14.--Altitude of the top of the Floridan aquifer (from Barr and others, 1981).

Bucatunna Clay Confining Bed

The Bucatunna clay confining bed as used in this report underlies the upper limestone of the Floridan aquifer in part of the study area and, where present, separates it hydraulically from the lower limestone. Geologically, the unit is composed of the Bucatunna Formation and other noncarbonate, unconsolidated materials of low permeability that occur between the two principal parts of the carbonate Floridan aquifer. Areally, the confining unit is present in only the coastal part of Okaloosa County and a small part of Walton County. In southern Okaloosa County it is present to as far as 15 miles north of Fort Walton Beach and generally is present in western coastal Walton County (fig. 15). The top of the bed dips south-southwest at about 25 feet per mile, from about 700 to 1,000 feet below sea level. The Bucatunna is composed predominantly of low-permeability clay and sandy clay, which restrict the movement of water between the upper and lower limestones. The unit grades from a dense compact clay in the southwest to a silty marl (calcareous clay) in the structurally updip or northeast direction.

On the basis of core samples from two test wells in eastern Santa Rosa County, Pascale (1976, p. 28) reported the Bucatunna clay confining bed to consist of waxy, dark to medium gray, very dense clay. Vertical hydraulic conductivity of the samples ranged from 2.9×10^{-6} to 2.6×10^{-7} ft/d and effective porosity was 13 to 14 percent. However, gradationally eastward the clay of the confining bed takes on a more silty to sandy character. Consequently, drillers' samples, geophysical logs, and data from seven aquifer tests indicate that the vertical hydraulic conductivity of the confining bed is greater in the southern parts of Okaloosa and Walton Counties than in southeastern Santa Rosa County. Vertical hydraulic conductivity is about 1×10^{-3} ft/d near the northern edge of the confining bed and about 1×10^{-5} ft/d along the coast (Barr and others, 1981, p. 9).

Lower Limestone of the Floridan Aquifer

The lower limestone of the Floridan aquifer consists of carbonate rocks in the Ocala Limestone of late Eocene age. In southern Okaloosa County and in the western coastal part of Walton County where the Bucatunna clay confining bed is present, the lower limestone underlies the Bucatunna and is hydraulically separated by it from the upper limestone of the Floridan aquifer. Where the Bucatunna is absent (fig. 15), the upper and lower limestones are not separated hydraulically and thus are not differentiated into separate hydrogeologic units.

Lithologically, except for moderately thin sections of soft brown dolomite and fine- to medium-grain quartz sand, the lower limestone of the Floridan aquifer is white to gray, and soft to hard. Some sections, particularly in Walton County, are highly fossiliferous, being composed principally of foraminifera and shell fragments. Sparse subsurface control indicates that the structural attitude of the lower limestone conforms to the regional monoclinal southwest dip of the overlying beds, which is in the range of 15 to 20 feet per mile. Test-well data from a location in southern Okaloosa County, about 6 miles north of Fort Walton Beach, indicate that the top and bottom of the lower limestone are respectively at about 850 and 1,000 feet below sea level.

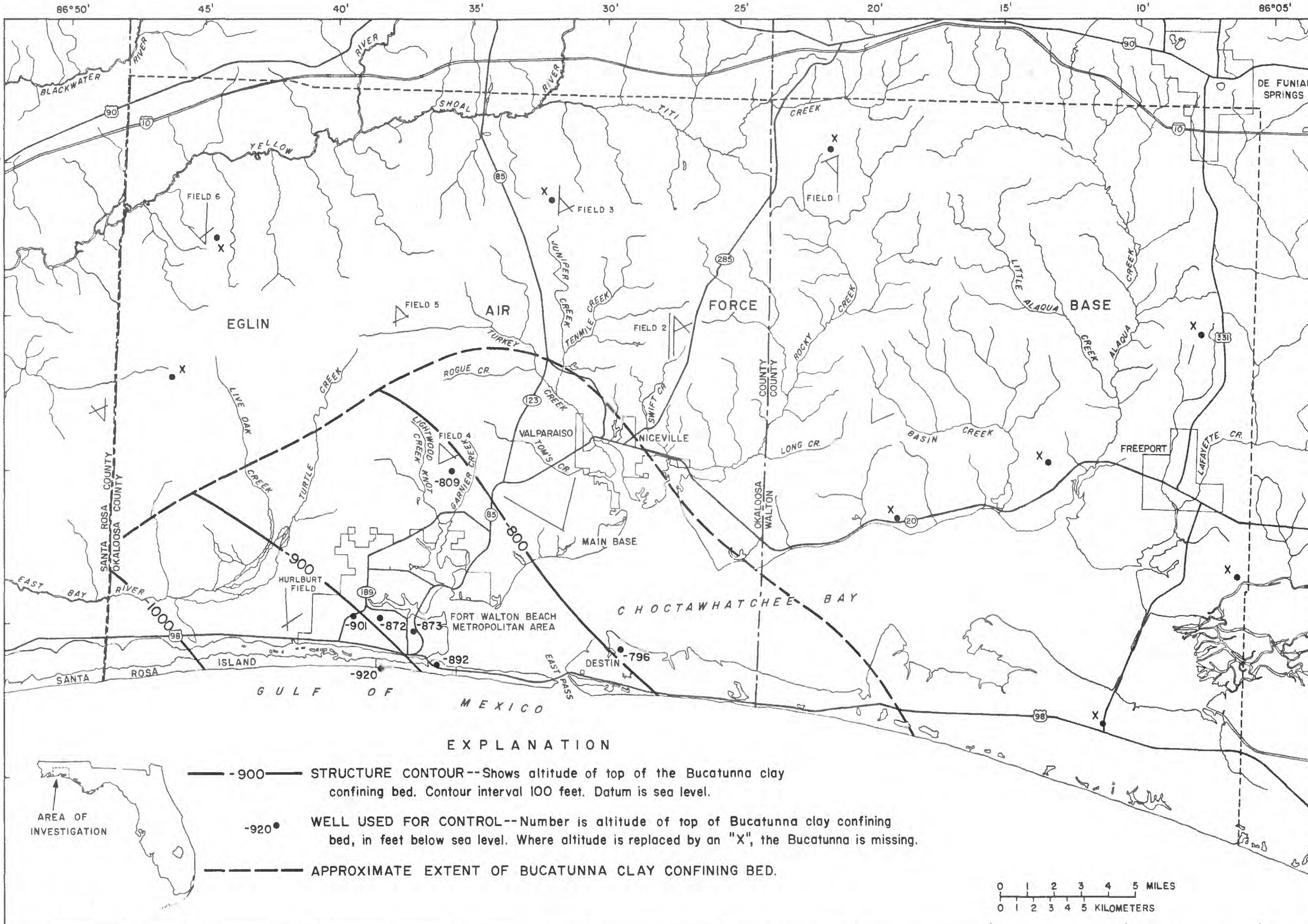


Figure 15.--Approximate altitude of the top and extent of the Bucatunna clay confining bed (modified from Barr and others, 1981).

As in the upper limestone, water occurs under confined conditions and moves through the aquifer primarily through interconnected and intergranular pores and solution openings. Saline water containing chloride in excess of 1,000 mg/L occupies the entire thickness of the lower limestone in southern Okaloosa and Walton Counties. Farther to the north, however, moderate to high sustained yields of freshwater likely could be obtained from wells penetrating the aquifer. The lower limestone is not used as a source of water.

Lisbon-Tallahatta Confining Unit

The Lisbon-Tallahatta confining unit, consisting of the Lisbon and Tallahatta Formations, underlies the Floridan aquifer and comprises gray to cream, shaly limestone; hard, light-gray, calcareous shale and siltstone with interbedded gray limestone; very fine to coarse sand; and some gray and brown clay (Marsh, 1966, p. 24 and 26). The confining unit dips south-southwest at approximately 12 to 16 feet per mile, the top ranging from about 900 to 1,300 feet below sea level (fig. 16).

RECHARGE AMD MOVEMENT OF GROUND WATER

Recharge to the Floridan aquifer is by rainfall in the north parts of Okaloosa and Walton Counties and in southern Alabama where the aquifer is at or near the surface (Trapp and others, 1977). In the area of investigation, the upper limestone of the Floridan aquifer may be recharged through the Pensacola Clay confining bed when heads are greater in the overlying sand-and-gravel aquifer. In southeastern Walton County, where the confining bed is thin or possibly breached, water may move vertically between the aquifers, depending on the direction of the head differential.

In a confined aquifer, as is the Floridan, ground water is always under hydraulic pressure greater than atmospheric, moving from points of high to points of low hydraulic head. The rate of movement of a particle of water depends on the permeability and porosity of the aquifer, on the viscosity of the water, and on the difference in head between two points. This head difference indicates the slope of the pressure surface or the hydraulic gradient and is generally expressed in feet per mile. By contouring or connecting measured water levels of equal heights in feet above or below a common datum in wells that tap a single artesian aquifer, a map of an imaginary surface, the potentiometric surface, is developed which indicates the height that water will rise in a well tightly cased into the aquifer at any given location in the mapped area.

Patterns of recharge, discharge, and water movement in the Floridan aquifer are complex. A potentiometric surface high (fig. 17) in extreme northern Walton County (Rosenau and Milner, 1981) indicates that this and perhaps adjacent areas in southern Alabama are the primary recharge areas of the Floridan aquifer for Okaloosa and Walton Counties. Water within the Floridan aquifer moves from these hydraulically upgradient areas southward into southern Okaloosa and southern Walton Counties across the northern boundary of the study area. Some water from the recharge area is withdrawn by the many wells that tap the upper limestone of the Floridan aquifer in southern Okaloosa County. The remaining water discharges to the Gulf of Mexico, to the Choctawhatchee River and Bay near State Highway 331, and perhaps to the sand-and-gravel aquifer.

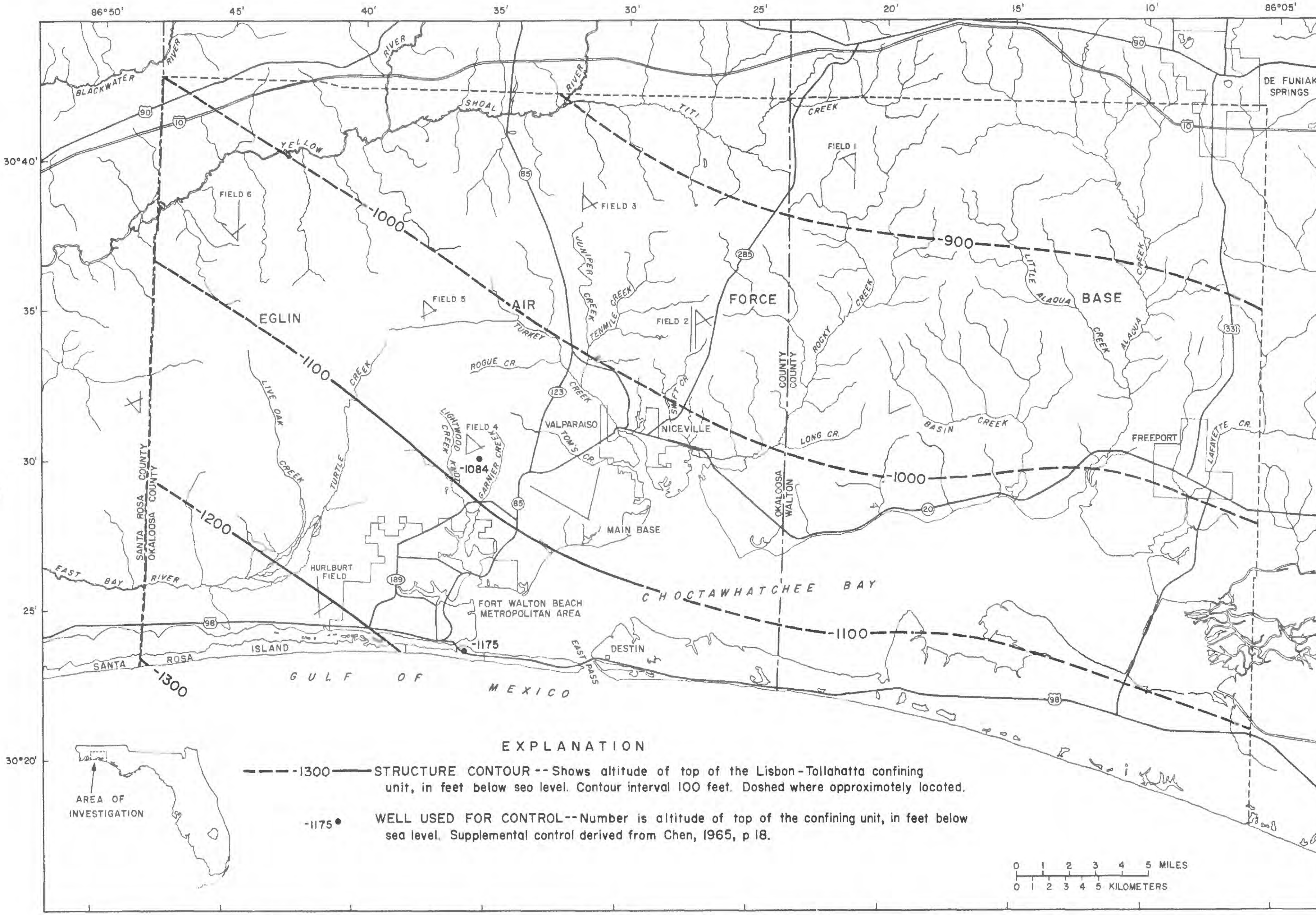
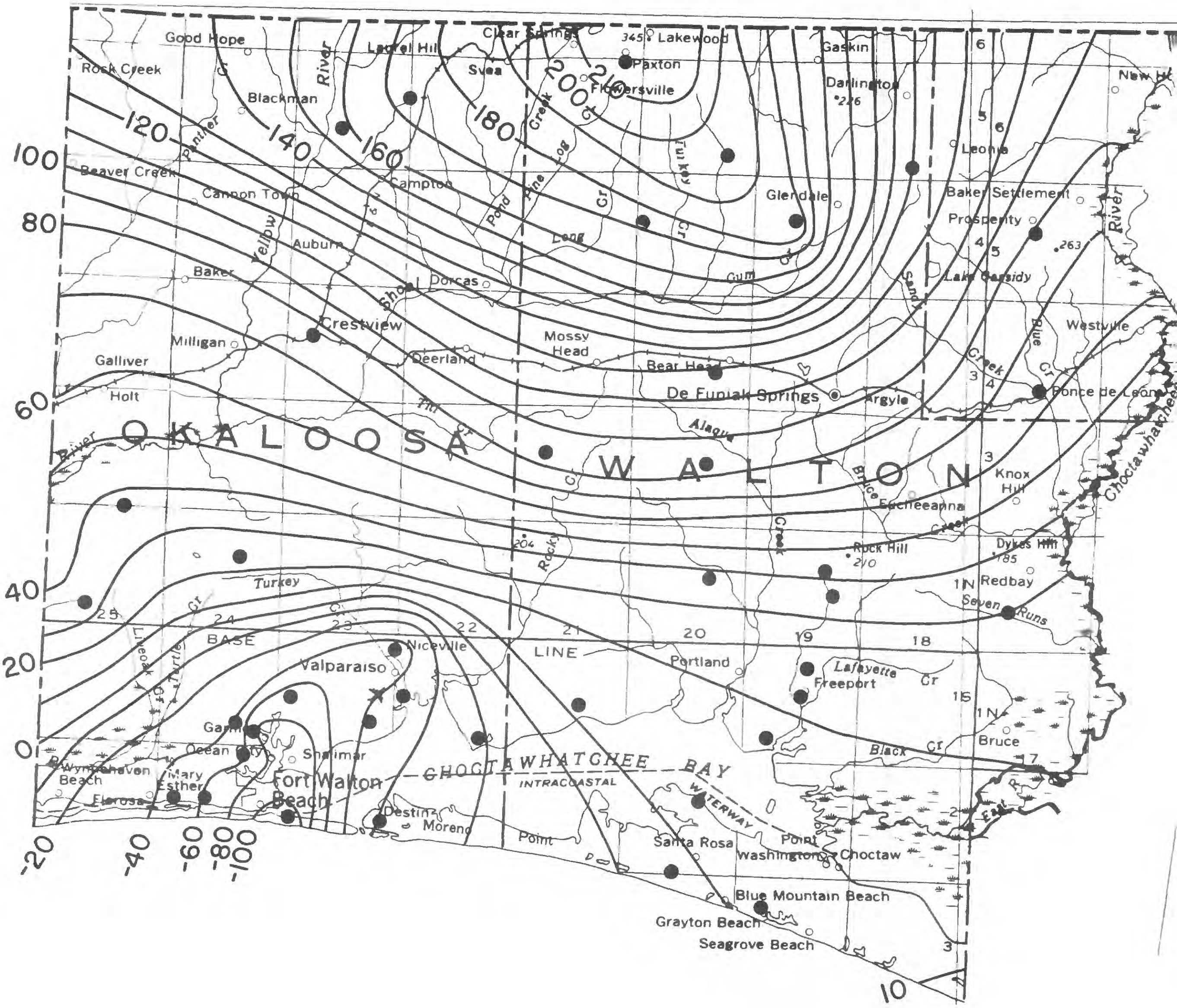


Figure 16.--Altitude of the top of the Lisbon-Tallahatta confining unit (modified from Barr and others, 1981).



EXPLANATION

——-60—— POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Contour interval 10 and 20 feet. Datum is sea level.

● WELL--Used for control.

0 10 MILES
0 10 KILOMETERS

N

Figure 17.--Potentiometric surface of the Floridan aquifer, May 1980 (from Rosenau and Milner, 1981).

Due to the paucity of data, it is difficult to draw specific conclusions regarding the hydrologic conditions within the lower limestone of the Floridan aquifer. Where the aquifer is hydrologically separated from the upper limestone by the Bucatunna clay confining bed, water levels in the lower limestone stand above the water levels in the upper limestone. Thus, water may move from the lower limestone upward through the Bucatunna clay confining bed; such movement is believed to be small, however, owing to the thickness and the density of the confining bed (Pascale, 1976, p. 28).

THE FLORIDAN AQUIFER

In much of western-panhandle Florida, including southern Okaloosa County and the extreme southwest corner of Walton County, the Bucatunna clay confining bed stratigraphically and hydraulically separates the Floridan aquifer into two hydrogeologic units, the upper limestone of the Floridan aquifer and the lower limestone of the Floridan aquifer. Twelve to fifteen miles north and east of Fort Walton Beach the Bucatunna wedges out (fig. 15). Beyond these northern and eastern extremities of the confining bed, the aquifer can no longer be differentiated hydrologically into two separate units. However, for purposes of this report, the terms "upper limestone of the Floridan aquifer" and "lower limestone of the Floridan aquifer" refer to the upper and lower parts, respectively, of the Floridan aquifer regardless of whether in the area where the aquifer is differentiated or where it's undifferentiated (figs. 10, 11, and 15). The overall thickness of the Floridan aquifer decreases southwestward across the area of investigation from about 850 feet in the extreme northeast corner to about 600 feet in the extreme southwest corner where the interval includes the Bucatunna, which is about 125 feet thick (fig. 9) at that location.

The upper limestone of the Floridan aquifer is the source of most of the water used in southern Okaloosa and Walton Counties, whereas the lower limestone of the Floridan aquifer is not used as a source of freshwater.

Upper Limestone of the Floridan Aquifer

Throughout the area of investigation the upper limestone of the Floridan aquifer is overlain and confined by the Pensacola Clay confining bed. In southern Okaloosa County and in the extreme west central area of Walton County where the upper limestone is underlain by the Bucatunna clay confining bed, it ranges in thickness from about 300 feet to about 500 feet, the directions of thickening being eastward and southward (figs. 9 and 10). The upper limestone stores and transmits large quantities of freshwater. As a consequence of major development of the water resource in the past 40 years, major declines in water levels in wells in the upper limestone have occurred in and spread from the large pumping centers in south central Okaloosa County. In addition to the placement of heavy pumpage, important variations in storativity and permeability from place to place in the aquifer have influenced the distribution of water-level declines.

To understand the hydrodynamics of the aquifer and to evaluate the long-term effects on the aquifer of current withdrawal and water-use patterns and various resource management alternatives, it was necessary to define the hydraulic characteristics of the aquifer and its confining beds, as well as the areal variations in those characteristics. Once defined, these values of hydraulic conductivity, transmissivity, and storage can be used to help determine where the aquifer can be developed most efficiently and economically so as to meet long-term water-supply needs and at the same time protect the resource from overdevelopment. These hydraulic data, in conjunction with the hydrogeologic data and other information on the water-yielding qualities of the aquifer such as the specific capacity of wells, may be utilized most effectively through application of a digital computer flow model to evaluate the various ground-water resource development alternatives.

Hydraulic Properties and Well Yields

Ground-water hydraulics is concerned with the natural or induced movement of water through permeable formations. The hydraulic properties of an aquifer are commonly determined by aquifer tests whereby the lowering of aquifer water levels due to withdrawal is related to both distance and time. The most common hydraulic properties derived from aquifer tests are transmissivity and storage coefficient.

An aquifer has a hydraulic conductivity (K) of 1 ft/d if it will transmit 1 ft^3 of water (7.48 gallons) in 1 day, at the prevailing viscosity, through a cross section of 1 ft^2 (measured at right angles to the direction of flow) under a hydraulic gradient of 1 ft/ft.

The transmissivity (T) of an aquifer is defined by Lohman (1979, p. 6) as "the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient." Transmissivity depends upon the properties of both the aquifer and the contained fluid. Transmissivity is equal to the hydraulic conductivity multiplied by the saturated thickness of the aquifer and is expressed in feet squared per day.

The storage coefficient (S) 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" (Lohman, 1979, p. 8). In unconfined aquifers, the storage coefficient is approximately equal to the specific yield because most of the water is released by gravity drainage and only a very small part results from compression of the aquifer and expansion of the water. By contrast, in an artesian aquifer the water added to or released from storage with a change in head comes from expansion or compression of the aquifer skeleton and from compression or expansion of the water in response to a rise or decline in pressure. The storage coefficient is dimensionless and ranges from 0.1 to 0.3 for most unconfined aquifers and from 10^{-5} to 10^{-3} for most confined aquifers.

Well yields are largely dependent upon hydraulic conductivity, length of well open to the aquifer, well efficiency, well diameter, and type of pump. Floridan aquifer well yields in the Okaloosa-Walton County area range from less than 50 gal/min to about 850 gal/min. Most wells do not penetrate the full thickness of the aquifer and, consequently, may yield less than the maximum possible.

A commonly used measure of well yield is specific capacity, which is related to the hydraulic properties of the aquifer penetrated. Specific capacity is defined as the yield per unit of drawdown and expressed as gallons per minute per foot of drawdown. The measured specific capacities of typical wells in the area of investigation are shown in figure 18 and they range from about 1 to 143 (gal/min)/ft. They are usually less than 5 (gal/min)/ft along the coast south of Fort Walton Beach.

Aquifer tests were used to determine the transmissivity, hydraulic conductivity, and storage coefficient of the materials comprising the upper limestone of the Floridan aquifer. Values of vertical hydraulic conductivity of the overlying and underlying confining layers were also determined, as noted in the "Hydrogeologic Units" section. Six aquifer tests were conducted in southern Okaloosa County and one in southern Walton County. Emphasis was placed on determining the hydraulic properties of the aquifer in the vicinity of Fort Walton Beach because: (1) most of the ground-water pumpage in the area is in southern Okaloosa County, (2) this area is where the greatest increases in pumpage are anticipated in the future, and (3) no aquifer tests are known to have been conducted in the area. The aquifer tests were reported in Barr and others (1981, p. 15 and fig. 32). The values for transmissivity and storage coefficient published in that report for the upper limestone are shown at the test-site locations in figure 18. The results of six other tests in Walton County were reported by Pascale (1974).

According to Barr and others (1981, p. 15):

> "Analyses of the aquifer tests indicated that no significant leakage occurs between the Floridan aquifer and sand-and-gravel aquifer over short pumping durations. The analyses also indicate the the more permeable limestone sections occur near the base of the [upper limestone of the] Floridan aquifer in the Fort Walton Beach metropolitan area. The wide variation in transmissivity (1,300-25,000 ft^2/d) [as calculated from the aquifer tests] is indicative of the extremely heterogeneous nature of the Floridan aquifer in the study area."

On the basis of aquifer test results and hydrogeologic data, including that derived from geologists' or drillers' lithologic logs and borehole geophysical logs, Barr and others (1981, fig. 38) mapped their best estimates of the variation in transmissivity of the full thickness of the upper limestone in the study area (fig. 19). Because of partial penetration, many of the transmissivity values derived from the aquifer tests were considered minimal. Consequently, transmissivity values on the map do not necessarily coincide with those of the tests shown in figure 18.

Fluctuations of Potentiometric Surfaces

Due primarily to pumping, the potentiometric surface of the upper limestone of the Floridan aquifer has declined as much as 160 feet in southern Okaloosa County in the past 40 years, developing a regional depression that extends over the study area and beyond. During peak seasonal demands, water levels may be drawn down an additional 20 to 30 feet in the center of the regional depression.

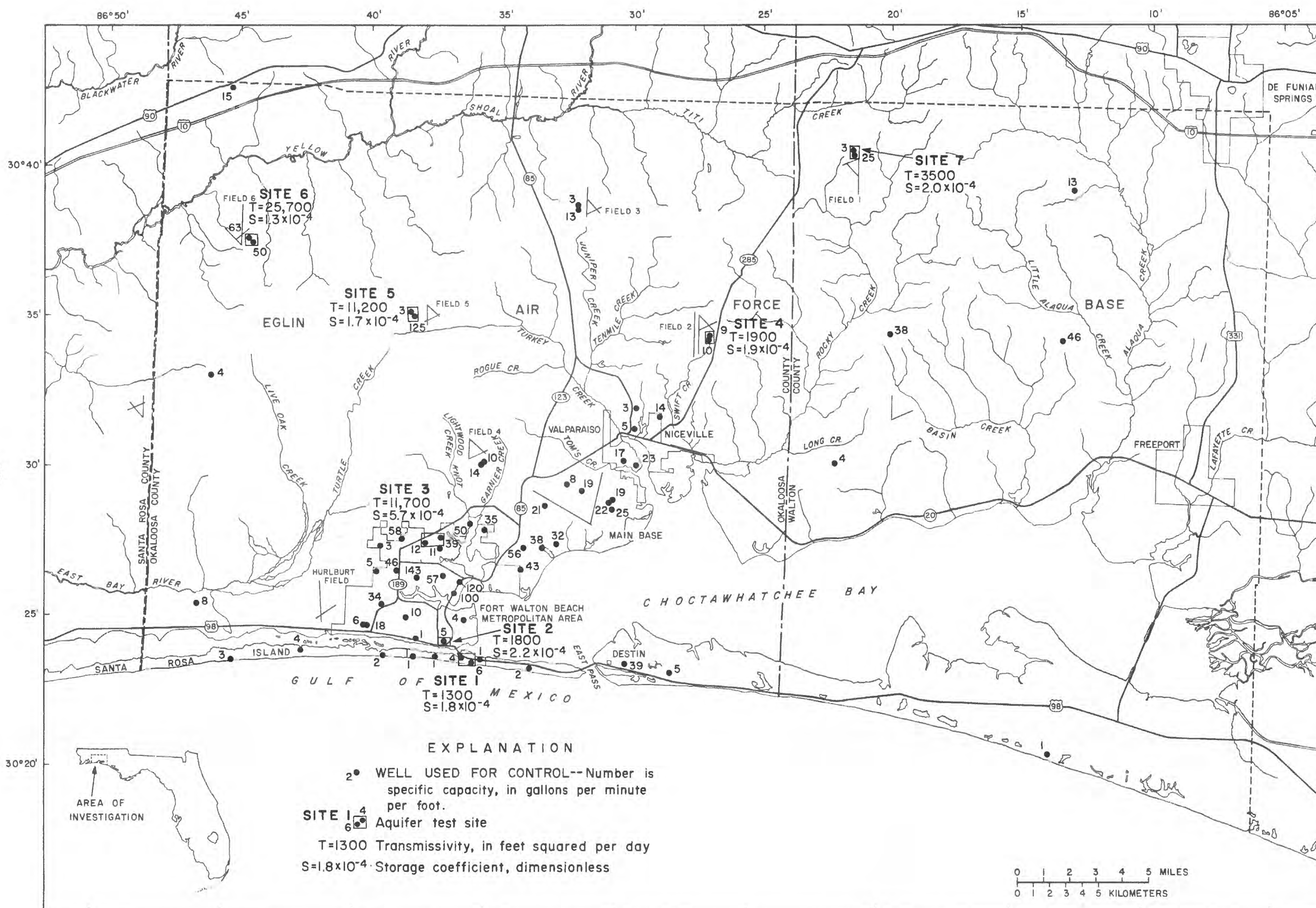


Figure 18.--Aquifer test sites and specific capacities of wells open to the upper limestone of the Floridan aquifer (modified from Barr and others, 1981, figs. 32 and 33).

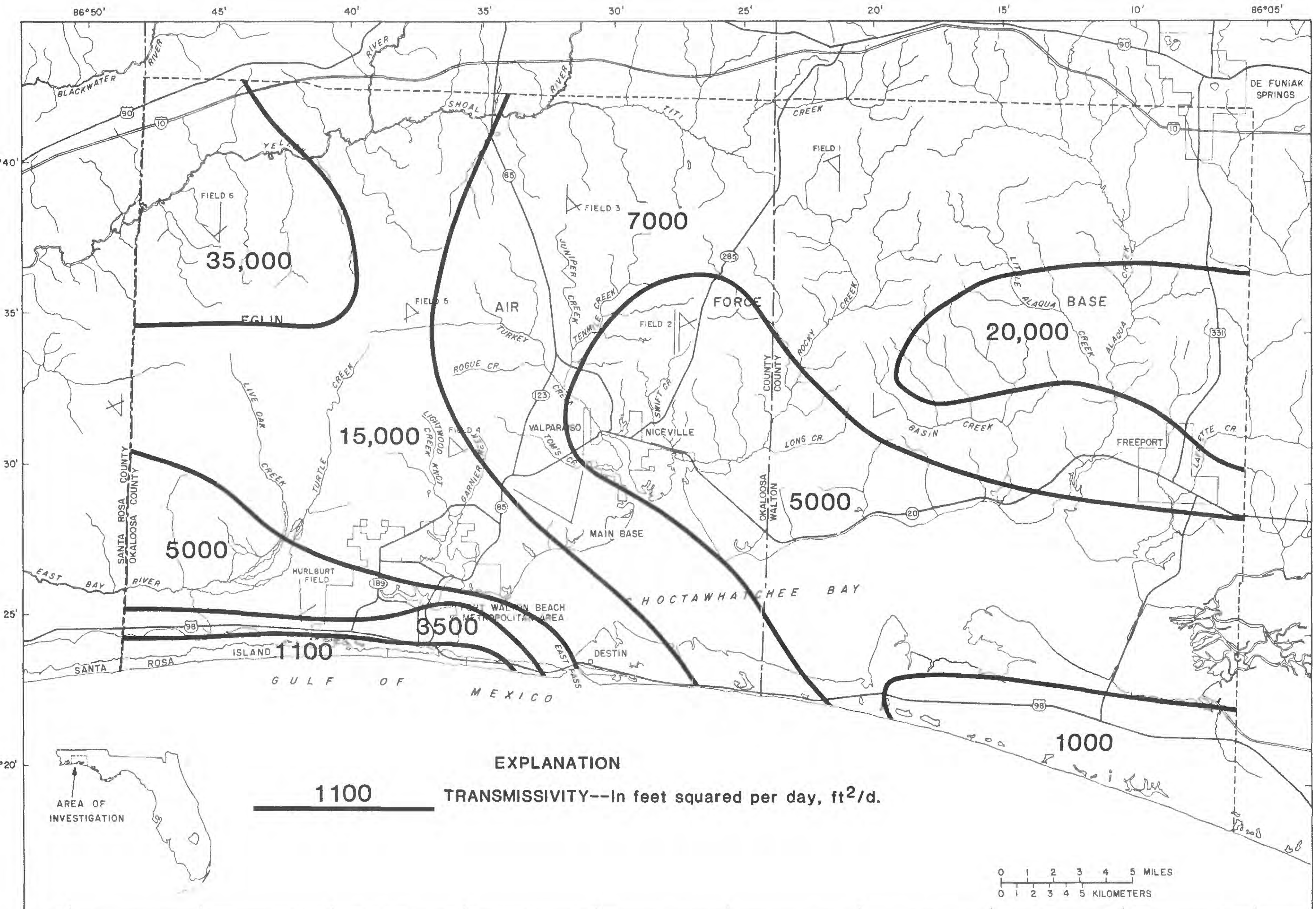


Figure 19.--Transmissivity of the upper limestone of the Floridan aquifer (from Barr and others, 1981).

Before withdrawal of large amounts of water by wells from the upper limestone of the Floridan aquifer, the potentiometric surface was controlled mainly by the hydraulic characteristics of the aquifer and the overlying and underlying confining beds, by the topography and altitude of the outcrop (recharge) areas, and by natural recharge and discharge. Prior to major declines in water levels in wells, the potentiometric surface, as illustrated by the map of the surface in 1947 (fig. 20), had a southerly slope of 3 to 4 ft/mi, with natural discharge occurring to the Gulf of Mexico and possibly Choctawhatchee Bay. Water levels in wells in the upper limestone of the Floridan aquifer were 27 to 121 feet above sea level, and many wells flowed naturally. After this time, development resulting in ever-increasing withdrawal from wells appreciably altered this pattern. Trapp and others (1977, p. 49-53) showed that water levels had declined more than 90 feet at Fort Walton Beach between 1942 and 1968. Prepared from limited 1947 data and by subtracting contours (Barr and others, 1981, figs. 29 and 32), figure 21 shows the approximate decline of the potentiometric surface from 1947 to July 1978. Declines in the Fort Walton Beach area are generally between 80 and 100 feet, and declines in Walton County range from about 20 to near 60 feet.

The potentiometric surface at the center of the regional depression in the Fort Walton Beach area, southern Okaloosa County, fluctuates annually by as much as 70 feet, mostly in response to a large range in seasonal water demand. Both the long-term downward trend and the annual fluctuation of the potentiometric surface are illustrated by the hydrographs in figure 22 and in figures 20-21 and 23-25. The hydrograph of observation well 104, a well located near the coast in Fort Walton Beach and at the center of the depression, shows a 130-foot decline in water level from 1947 to 1978. Well 248 is near shore, 2 to 3 miles east of Eglin Main Base and about equal distance south of Niceville. This well is similarly influenced by the Fort Walton Beach area pumping but also by heavy pumping in the Niceville area. Well 347 is near Eglin Field 5, approximately 12 miles north and northwest of wells 104 and 248, in an area of negligible pumping. Its hydrograph shows the seasonal and long-range effects of the coastal pumping. The annual water-level declines reflect the increase in water demand generated primarily by the influx of summer vacationists; water levels recover each fall but do not quite reach the same level as the previous year owing to a gradual population increase and therefore sustained increase in water demand.

The seasonal changes of regional water levels are shown by comparison of potentiometric surface maps showing the areal distribution of water levels in the upper limestone of the Floridan aquifer for March, July, and November 1978 (figs. 23, 24, and 25). During March, pumpage in the Fort Walton Beach metropolitan area was 204 million gallons, and water levels at the center of the Fort Walton Beach depression were from 100 to 130 feet below sea level; in July, when about 256 million gallons were withdrawn, water levels had declined 20 to 30 feet below March levels. March pumpage at Eglin Air Force Main Base (including housing area and auxiliary fields but not Hurlburt Field) was 74 million gallons, and water levels were 15 to 32 feet below sea level; in July, when about 113 million gallons were withdrawn, water levels were about 15 feet lower. Water levels in the Niceville-Valparaiso area were generally about 5 feet lower in July than in March because of slightly larger withdrawals in July--57 versus 53 million gallons. During November, when pumpage in these areas was about the same as in March, water levels recovered to about the March levels. November 1978 pumpage was 109, 95, and 52 million gallons, respectively, for the Fort Walton Beach, Eglin Air Force Main Base, and the Niceville-Valparaiso areas.

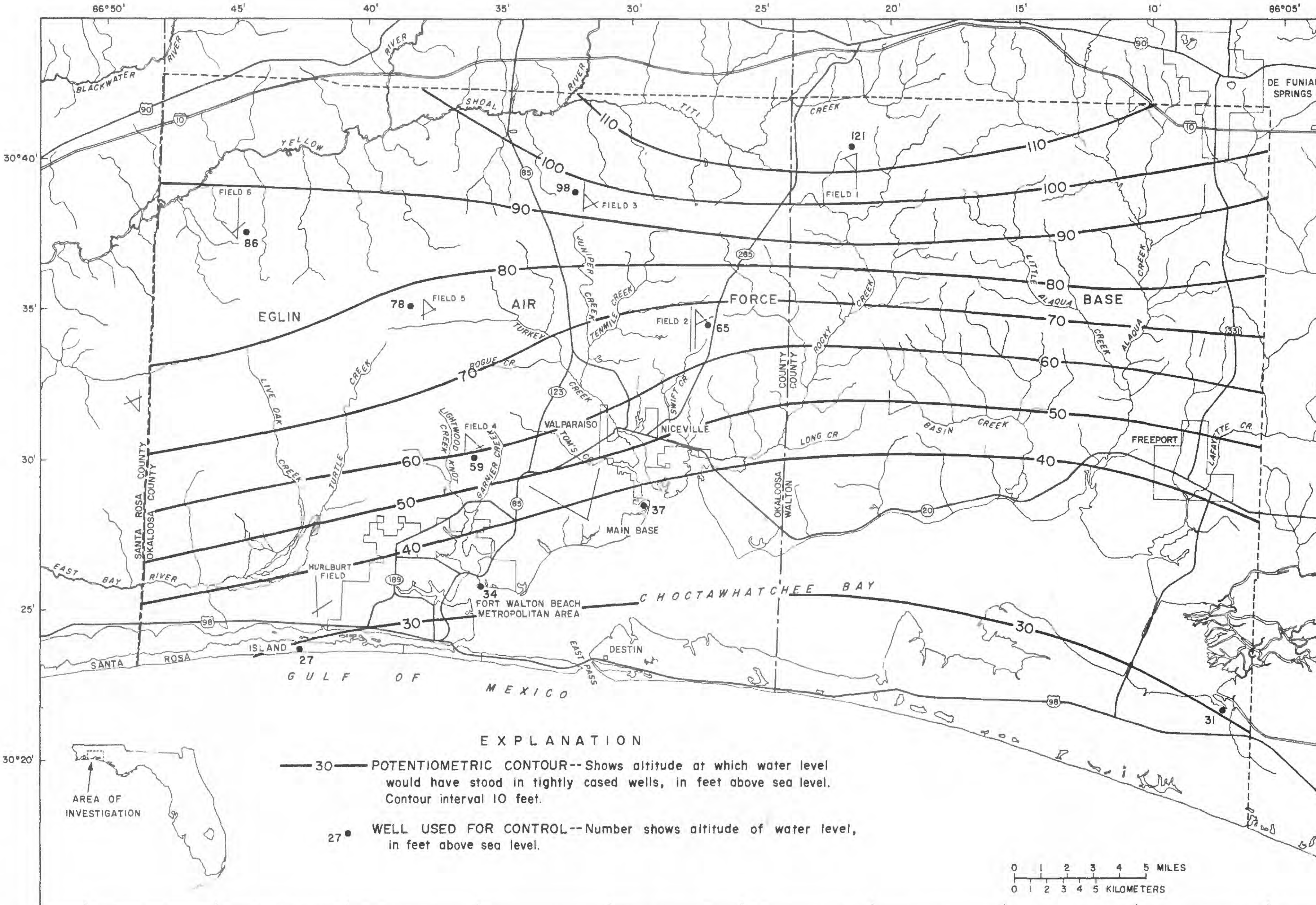


Figure 20.--Generalized potentiometric surface of the upper limestone of the Floridan aquifer, 1947 (from Barr and others, 1981).

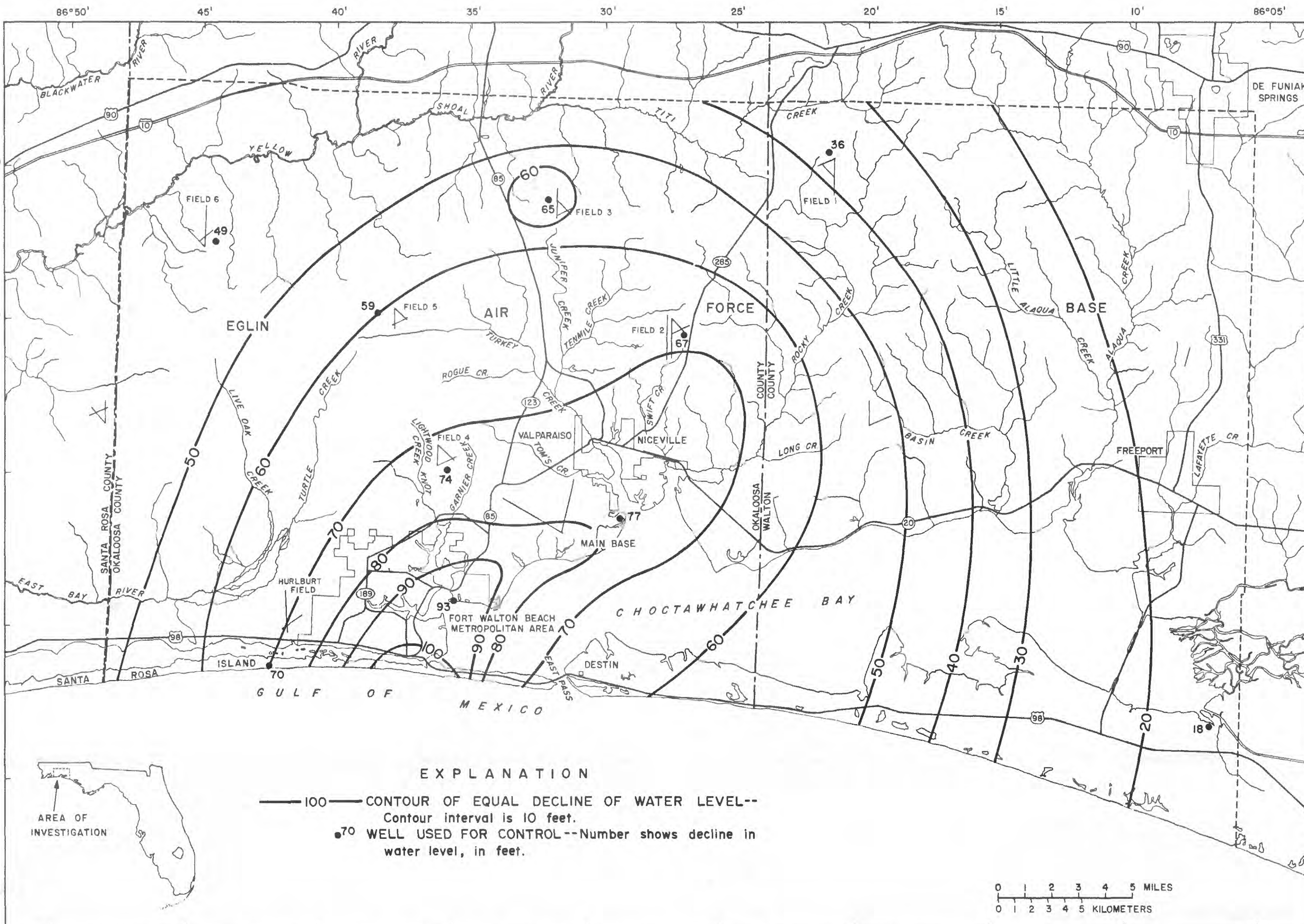


Figure 21.--Approximate net decline of the potentiometric surface of the upper limestone of the Floridan aquifer, 1947-July 1978.

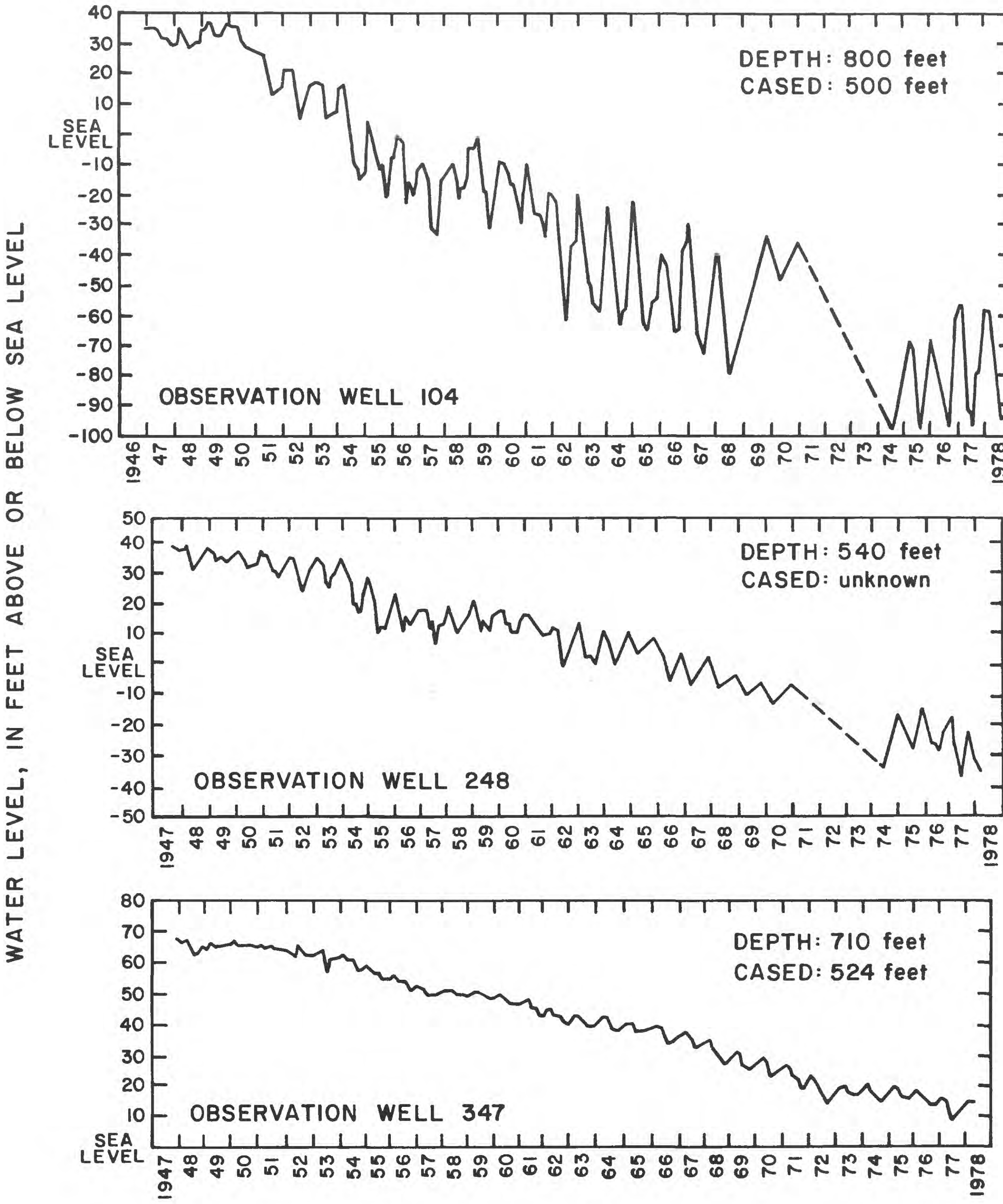


Figure 22.--Month-end water levels in three wells open to the upper limestone of the Floridan aquifer.

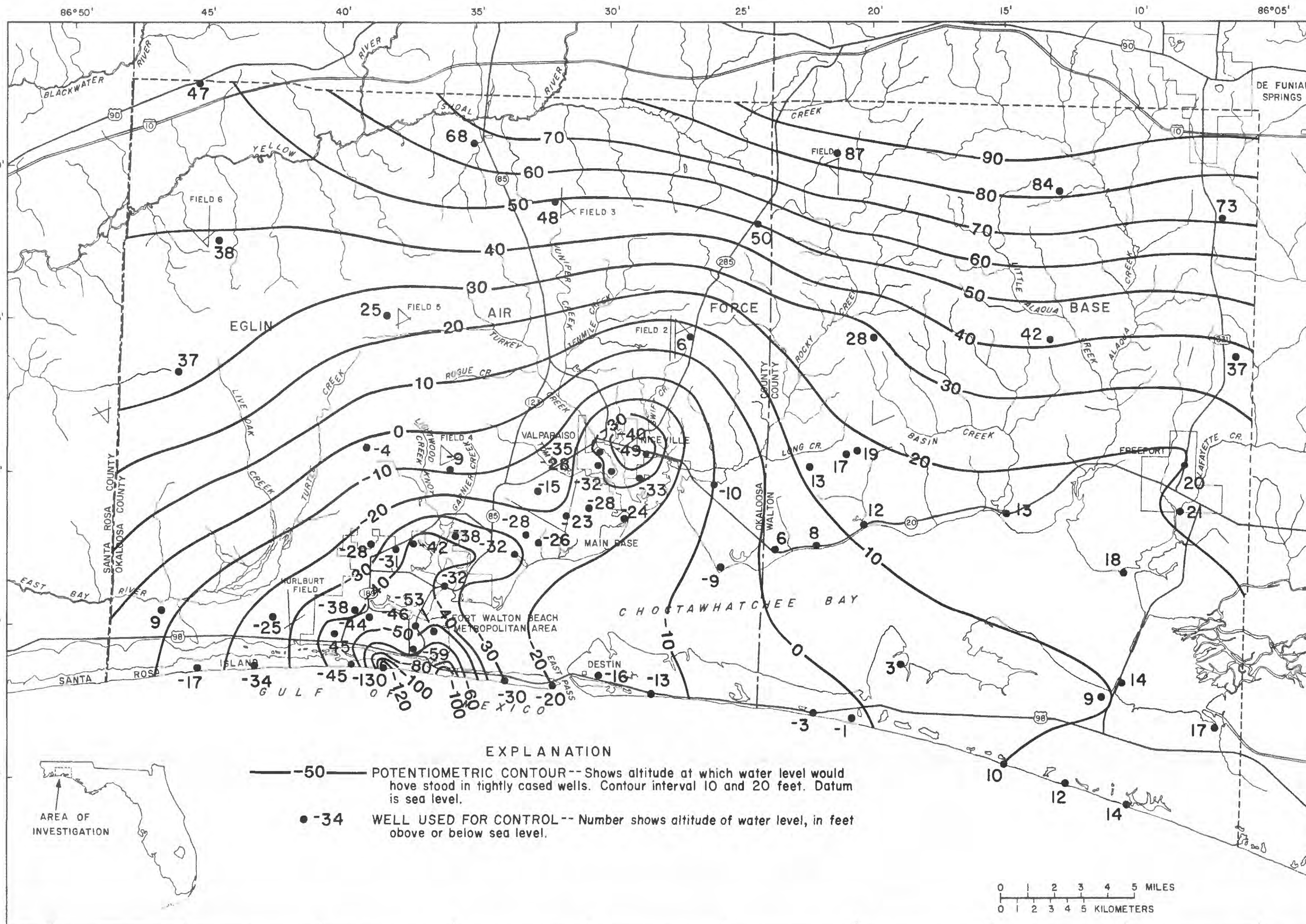


Figure 23.--The potentiometric surface of the upper limestone of the Floridan aquifer in March 1978 (modified from Barr and others, 1981).

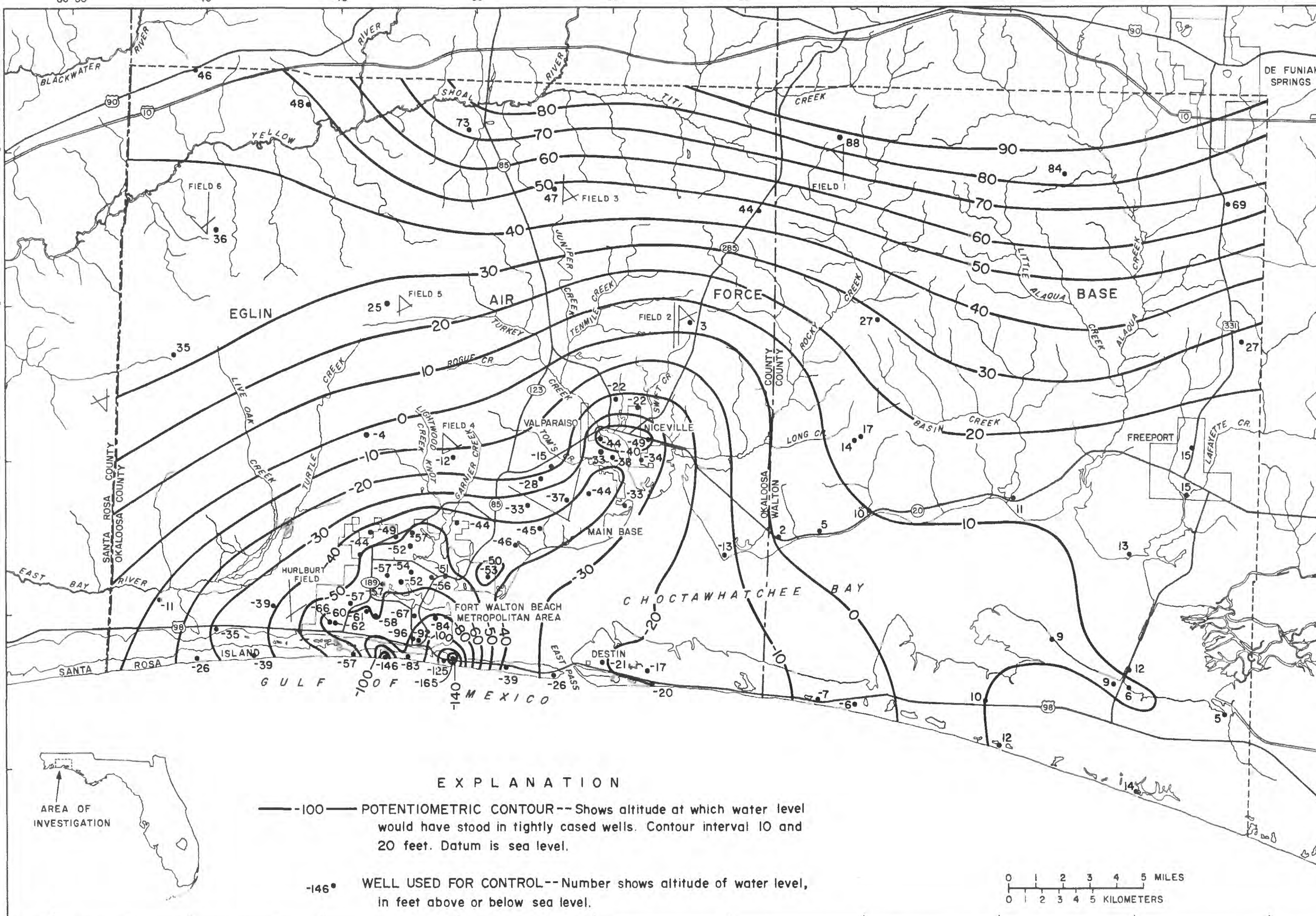


Figure 24.--The potentiometric surface of the upper limestone of the Floridan aquifer in July 1978 (from Barr and others, 1981).

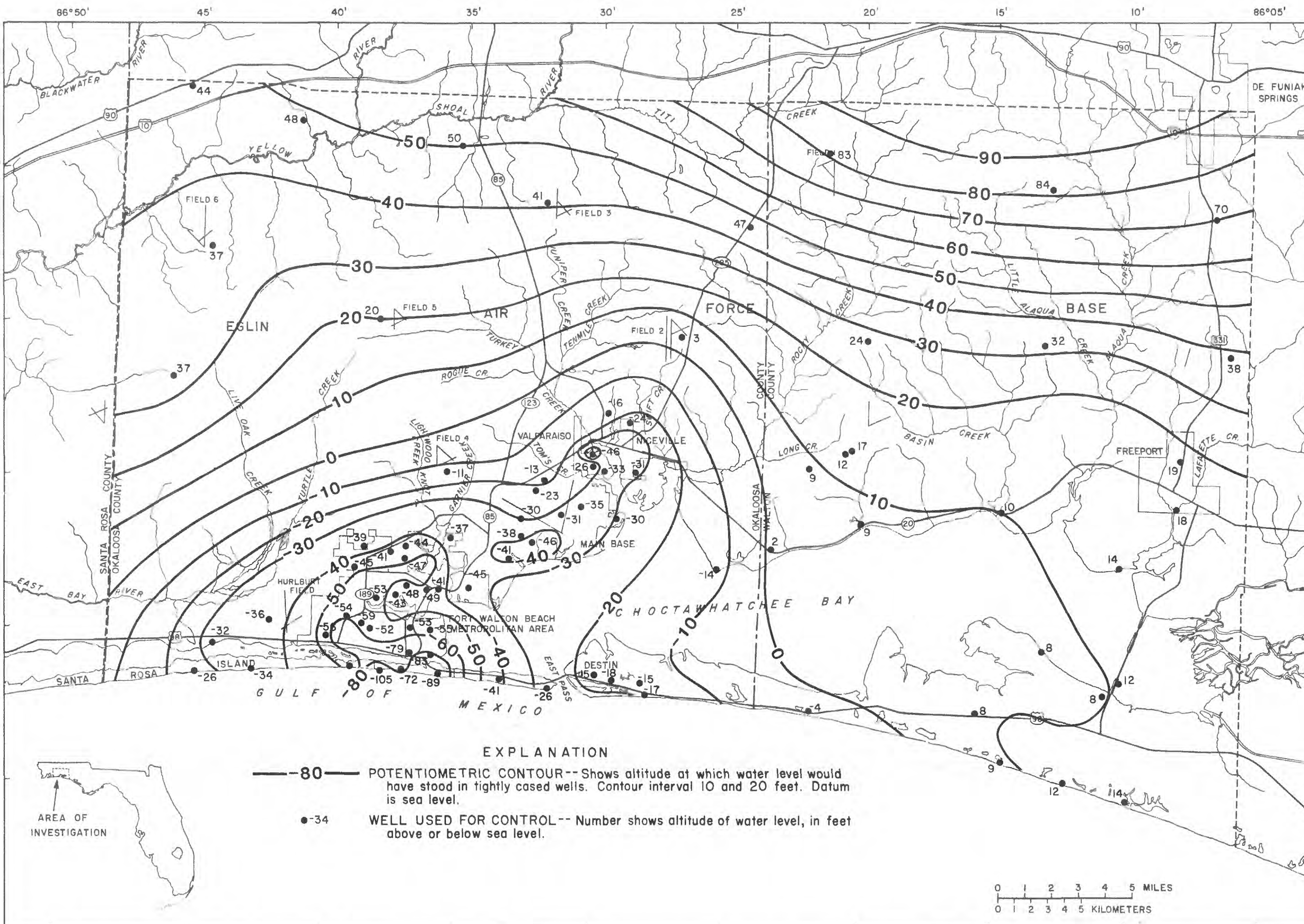


Figure 25.--The potentiometric surface of the upper limestone of the Floridan aquifer in November 1978.

Water Quality

Source of water-quality data

Information on the chemical quality of water from the upper limestone of the Floridan aquifer is available for the area of investigation from two previous studies: a water-resources investigation of Walton County initiated in 1968 and completed in 1970 (Pascale and others, 1972; Pascale, 1974); and a water-resources investigation of Okaloosa County initiated in 1966 and completed in 1969 (Foster and Pascale, 1971; Trapp and others, 1977). Additional water-quality data are available from U.S. Geological Survey monitor wells maintained in cooperation with the Northwest Florida Water Management District as part of a regional monitoring network covering northwest Florida. As a part of the present investigation (Wagner and others, 1980), chloride analyses were made on water samples from 78 wells on a quarterly basis. Complete water-sample analyses, including all parameters on the U.S. Envircmental Protection Agency's list of secondary and primary drinking water standards, were made on nine upper Floridan aquifer wells in the Fort Walton Beach area.

There are 84 U.S. Geological Survey monitoring wells in the area for which some data were available on the concentration of major cations and anions and selected trace metals. Most of the wells were sampled at specific times to provide data for the investigations referenced above.

Distribution of major inorganic constituents

Water from the upper limestone of the Floridan aquifer is generally of suitable quality for most uses. Temperature generally varies between 18 and 26°C but is nearly constant in any individual well. Hardness, as calcium carbonate, ranges up to 280 mg/L but normally is below 150 mg/L, the pH generally ranges between 7.5 and 8.5, and the chloride concentration is normally less than 10 mg/L. In coastal areas, however, chloride concentrations range between 25 and 75 mg/L, except in the eastern part of Choctawhatchee Bay where chloride concentrations exceed 500 mg/L.

The predominant ion in the water of the area is bicarbonate, which ranges in concentrations from near 100 mg/L in the east to 300 mg/L in the west.

Water from a cluster of wells in the eastern part of Choctawhatchee Bay has sodium concentrations exceeding 300 mg/L (well 58); and in coastal and western Okaloosa County the range is from about 100 to more than 160 mg/L.

Table 5 provides a summary of the sources and significance of major inorganic constitutents of water from 30 sites that tap the upper limestone of the Floridan aquifer.

Table 5.--Major inorganic chemical constituents in water from the upper limestone of the Floridan aquifer, 1965-75

Map location No. (fig. 1)	Station number	Date of sample	Bicarbonate (mg/L as HCO_3)	Carbonate (mg/L as CO_3)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
58	302317086103701	06-11-70	114	6	36	26	308	6.2	555	16
68	302325086332901	07-08-70	252	4	5.2	3.4	136	7.4	80	5.6
79	302342086424801	07-07-70	224	4	5.6	3.8	160	7.0	128	19
88	302351086382901	07-08-70	240	0	3.7	2.4	118	5.6	57	6.4
127	302516086475401	07-08-70	224	0	3.7	2.2	118	5.7	66	4.8
131	302521086415201	10-26-70	232	0	3.3	2.2	113	5.5	50	4.8
198	302711086251401	07-21-70	144	8	24	16	9.6	2.7	7.0	8.7
211	302733086321701	07-16-70	160	0	19	13	21	3.3	8.0	9.5
238	302811086353901	07-20-70	163	0	21	12	20	3.6	6.0	8.0
249	302857086310701	07-20-70	158	3	24	15	13	2.9	4.0	10
284	303021086351601	07-13-70	164	0	25	14	13	2.8	3.0	9.6
301	303103086201002	07-14-70	142	0	22	12	8.6	2.9	3.0	8.8
306	303126086292901	07-20-70	156	8	27	16	7.1	2.3	3.0	8.7
321	303241086461701	07-13-70	300	0	3.2	2.0	133	4.8	43	.0
338	303441086263901	07-13-70	142	0	23	13	6.8	2.4	3.0	8.0
339	303443086193901	07-14-70	140	0	21	11	10	3.0	2.0	8.0
349	303517086380101	07-13-70	162	0	21	9.2	24	3.0	3.0	5.6
219	302747086382001	07-22-66	252	0	16	4.9	95	4.5	40	8.4
357	303745086442101	07-13-70	224	0	14	7.8	78	5.2	38	4.0
307	303136086394601	08-30-66	248	0	5.4	3.2	106	5.9	38	.4

Table 5.--Major inorganic chemical constituents in water from the upper limestone of the Floridan aquifer, 1965-75--Continued

Map location No. (fig. 1)	Station number	Date of sample	Bicarbonate (mg/L as HCO_3)	Carbonate (mg/L as CO_3)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
359	303820086241801	07-15-70	124	0	17	7.2	16	2.9	3.0	.0
366	303854086314901	07-13-70	162	0	30	15	6.2	1.9	3.5	9.6
383	304055086211401	07-13-70	148	0	25	14	3.6	2.0	3.0	9.9
205	302724086325401	05-24-67	186	0	10	6.0	61	3.8	20	5.6
215	302739086364801	07-27-66	202	0	6.7	4.2	76	5.2	24	5.2
9	301945086092801	07-07-68	198	0	39	26	106	3.7	182	19
25	302214086065201	06-19-68	124	0	24	16	128	4.0	215	17
34	302229086154401	07-07-70	164	0	27	24	246	8.6	362	67
46	302254086251401	07-07-70	210	0	12	8.3	77	4.5	38	16
124	302507086363901	05-14-75	232	2	3.9	2.5	117	6.2	57	4.5

Character and geochemistry of water

Complete water-quality analyses available (Wagner and others, 1980) for wells in the area of investigation indicate significant differences in the chemical characteristics of water in the upper limestone of the Floridan aquifer. Trilinear and quadrilinear diagrams (fig. 26) have been used to graphically display the chemical characteristics of the water. These diagrams are useful because they facilitate rapid comparison of chemical analyses and the delineation of similarities and differences between large numbers of water analyses. In figure 26, the concentrations of bicarbonate, calcium, chloride, magnesium, potassium, sodium, and sulfate from 30 wells (table 5) are plotted as percent reacting values. The distinctions between the concentrations of the major constituents indicate that there are at least three types of water in the aquifer: calcium-magnesium-bicarbonate water (type I), sodium-chloride water (type II), and sodium-bicarbonate-chloride water (type III). The distribution of the three water types in the area of investigation is illustrated in figure 27.

Type I, calcium-magnesium-bicarbonate.--Calcium-magnesium-bicarbonate water is found in wells in the northeastern part of southern Okaloosa and most of Walton Counties (fig. 27). The dissolved constituents are almost wholly calcium and magnesium bicarbonates with low concentrations (generally less than 10 mg/L) of chloride, potassium, sodium, and sulfate. The range in general chemical character of type I water is:

	Median (mg/L)	Range (mg/L)
Bicarbonate	156	124 to 164
Calcium	23	17 to 30
Chloride	3.0	2.0 to 8.0
Magnesium	13	7.2 to 16
Potassium	2.9	1.9 to 3.6
Sodium	9.6	3.6 to 24
Sulfate	8.7	0.0 to 10.0

Type I water is most representative of water from the upper limestone of the Floridan aquifer where little or no mixing of fresh and saline water have occurred. Water of this type in the area of investigation has had a considerable residence time in the aquifer and is near equilibrium with the aquifer rocks.

Type II, sodium-chloride.--Water of a sodium-chloride type occurs in the southeastern part of the area of investigation in the vicinity of the east end of Choctawhatchee Bay. Chloride and sodium are the predominant cation and anion. The range in general chemical character of the type II water is:

	Median (mg/L)	Range (mg/L)
Bicarbonate	144	114 to 198
Calcium	31.5	24 to 39
Chloride	238	182 to 555
Magnesium	25	16 to 26
Potassium	3.8	2.2 to 8.6
Sodium	182	106 to 308
Sulfate	18	16 to 67

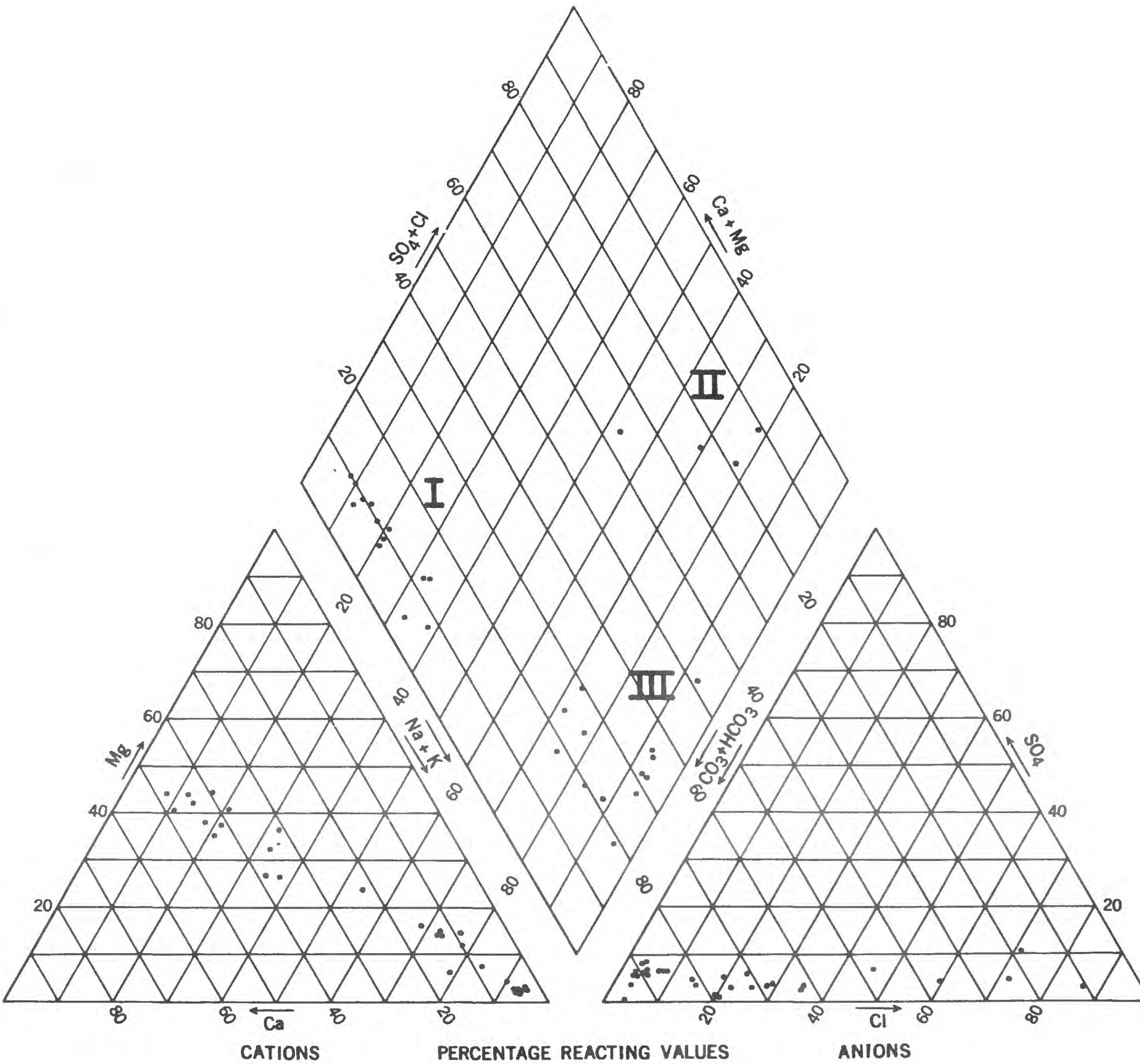


Figure 26.--Quadrilinear and trilinear diagram showing concentrations of major inorganic constituents in water from the upper limestone of the Floridan aquifer, 1965-75.

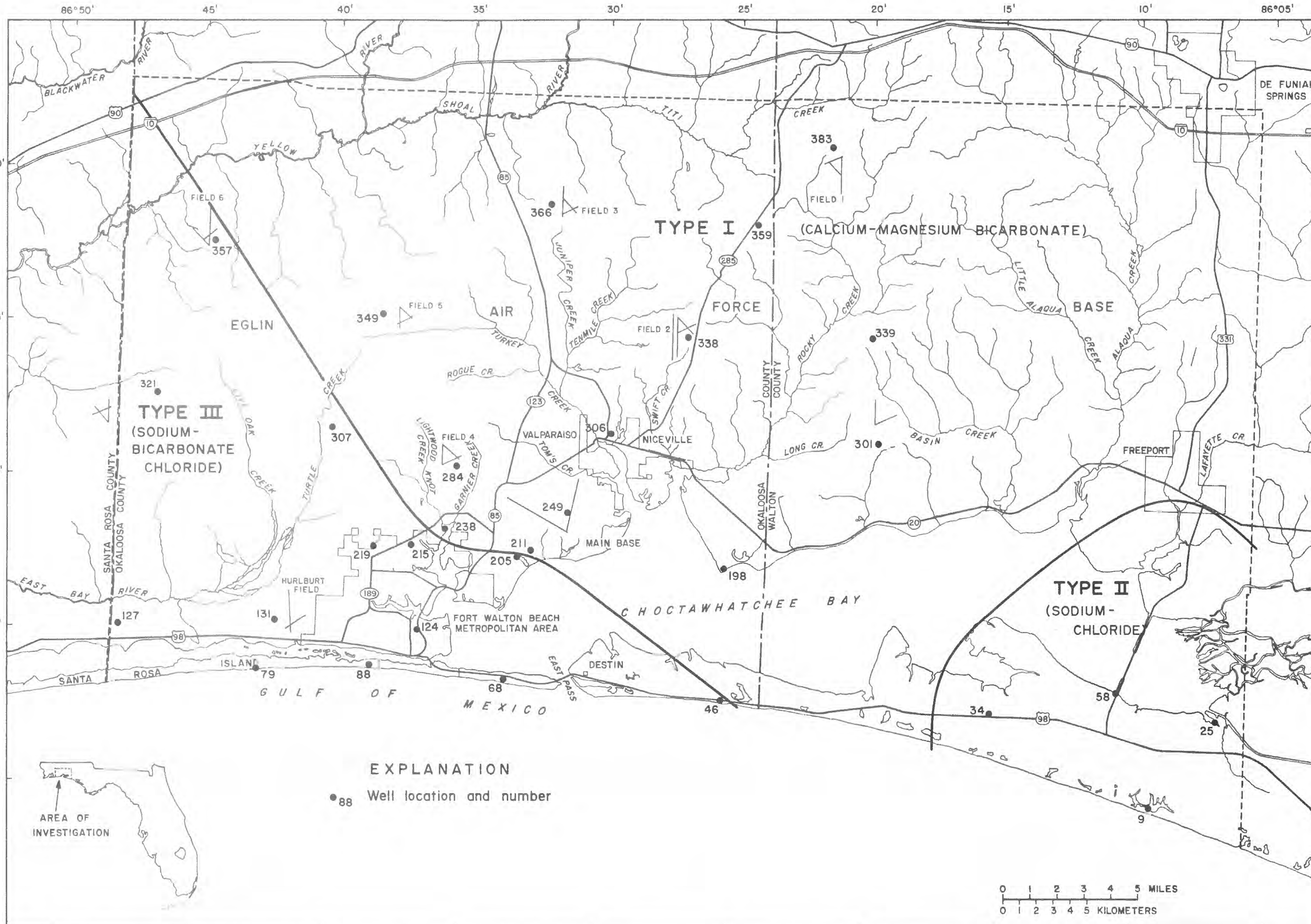


Figure 27.--Distribution of the three types of water that occupy the upper limestone of the Floridan aquifer, 1965-75 (modified from Barr and others, 1981).

This water is similar to type I water with the exception of chloride, sodium, and sulfate. Salinity generally increases with depth in the area (Pascale, 1974) indicating that the source of the high chlorides in some wells may be attributable to upward migration of saline water. In still other areas it is probable that type II water represents a mixture of type I with modern seawater, a situation that may exist near Choctawhatchee Bay or the Gulf of Mexico where, either by way of direct connections with the Floridan aquifer or by downward movement through a thin Pensacola Clay confining bed, saline water enters the aquifer.

Type III, sodium-bicarbonate-chloride.--Water of a sodium-bicarbonate-chloride type is obtained from wells in the south and west parts of southern Okaloosa County (fig. 27). Typically, the water has higher concentrations of bicarbonate and potassium and lower concentrations of calcium and magnesium than type I and II waters. The range in concentrations of the major inorganic constituents is summarized below:

	Median (mg/L)	Range (mg/L)
Bicarbonate	232	182 to 300
Calcium	5.6	3.2 to 16
Chloride	50	18 to 128
Magnesium	3.4	2.0 to 8.3
Potassium	5.5	4.0 to 7.4
Sodium	113	53 to 160
Sulfate	5.2	0 to 19

The high concentrations of sodium, chloride, and bicarbonate are indicative of water intermediate between the carbonate equilibrium water of type I and highly saline, sodium-chloride water present in the aquifer to the west of the study area in western Santa Rosa County. Type III waters, therefore, are representative of a broad zone of diffusion between the native carbonate equilibrium waters of type I and saline water in the aquifer in Santa Rosa County.

Saline water

The EPA recommended limit for chloride in public drinking water supplies is 250 mg/L (U.S. Environmental Protection Agency, 1977). Water containing more than 400 mg/L of chloride tastes salty to most people, and water containing more than 1,500 mg/L is generally considered unfit for human consumption. Water from Gulf coastal wells in Okaloosa and Walton Counties generally contains 60 to 80 mg/L of chloride, and water from a few Walton County wells contains more than 500 mg/L (fig. 28). The sources of high chloride concentrations may be: (1) connate saline water entrapped in the aquifer at the time of deposition, (2) relatively modern ocean water from the Gulf of Mexico or Choctawhatchee Bay moving downward into the aquifer through thin areas or gaps in the overlying Pensacola Clay confining bed, (3) saline water in underlying formations moving upward into the aquifer, (4) saline Gulf water moving laterally where the aquifer may crop out in the Gulf, or (5) any combination of the above.

Data in figure 28 indicate that chloride concentrations have remained about the same over the period of record and that saline-water is not widespread. Nevertheless, as water levels decline in response to pumpage, the potential exists for saline water to move into the aquifer.

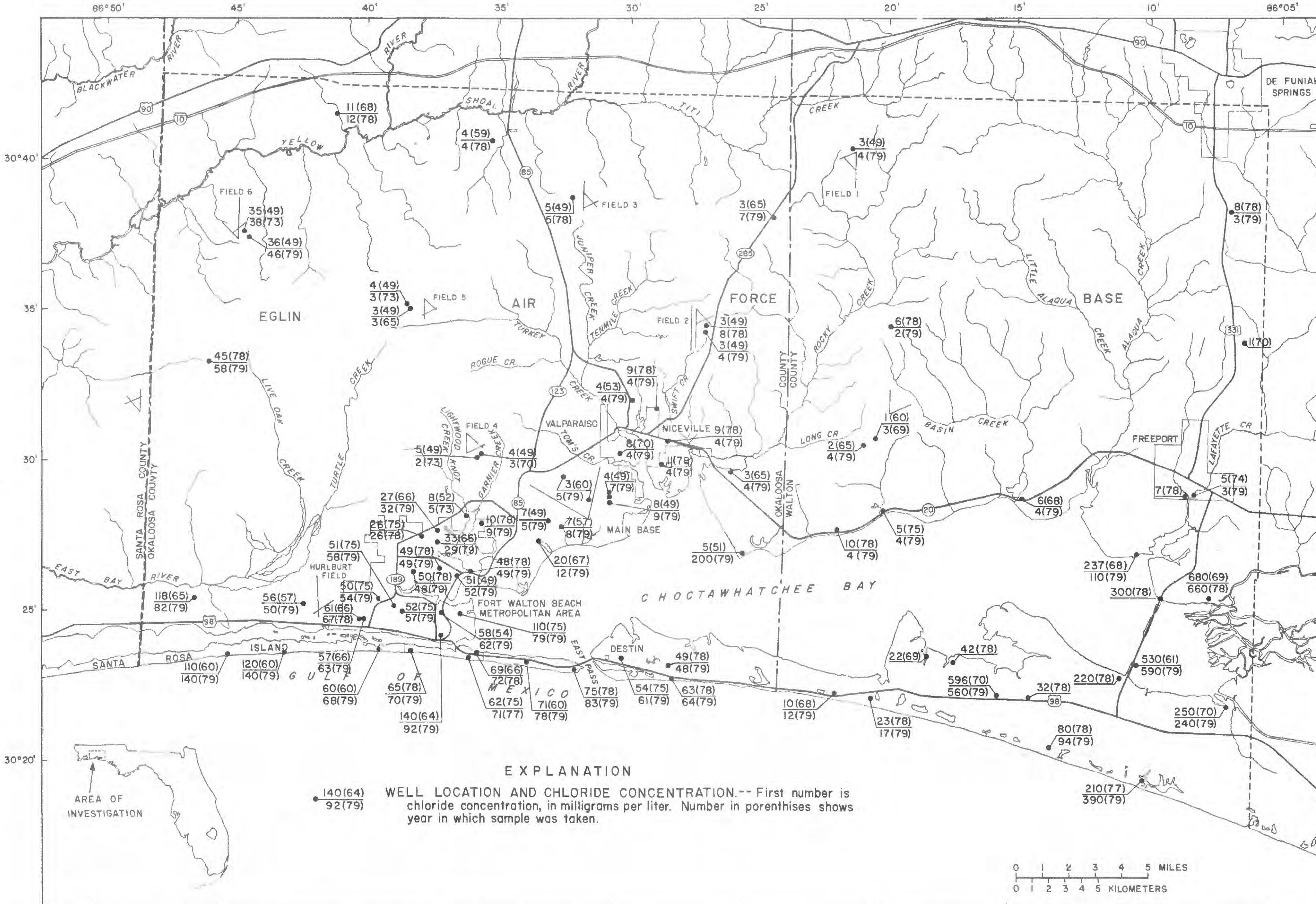


Figure 28.--Changes of chloride concentration with time in water from the upper limestone of the Floridan aquifer (from Barr and others, 1981).

Lower Limestone of the Floridan Aquifer

The lower limestone of the Floridan aquifer extends from the base of the overlying Bucatunna clay confining bed to the top of the Lisbon-Tallahatta confining unit in areas where the Bucatunna is present. The lower limestone is distinguished from the upper limestone as a separate hydrologic unit in southern Okaloosa County and a small part of coastal Walton County (fig. 15). Data obtained from four test holes (fig. 29) showed that the lower limestone, where distinguishable, dips southwest and tends to thicken eastward and southward. At test site 1, located approximately 6 miles north of Fort Walton Beach, the top of the unit is at 850 feet below sea level and there the unit is about 150 feet thick. About 3 miles south, along the east-west hydrogeologic section B-B' (fig. 10), the unit thins from about 330 feet at the east edge of the Bucatunna clay confining bed to about 170 feet 23 miles to the west at the western boundary of the study area. At the two test well sites in Walton County, the confining bed was absent and the two limestone units could not be differentiated.

In southern Okaloosa County, the Bucatunna clay confining bed confines the water in the lower limestone of the aquifer, and the potentiometric surface of the lower limestone is higher than that of the upper limestone, at least partly the result of lowered heads in the upper limestone due to pumping. At Fort Walton Beach (test well 2), the water level in the lower limestone is approximately 5 feet above sea level in contrast to water levels of 44 to 67 feet below sea level in the upper limestone. These differences illustrate the effectiveness of the confining bed in insulating the lower limestone from the effects of pumping in the upper limestone. At the other test sites, water levels were only slightly (1 to 5 feet) above those of the upper limestone of the Floridan aquifer.

Well yields as measured by specific capacity of the test wells ranged from 14.3 to 44.0 (gal/min)/ft of drawdown. These values are about the same as values for the upper limestone of the Floridan aquifer. The data indicate that the physical characteristics, particularly transmissivity, vary considerably.

Chemical analyses of water from the lower limestone of the Floridan aquifer, or lower part of the aquifer where the unit is not differentiated, are given in table 6. The potential for development of this part of the Floridan aquifer is considerable, although, the presence of saline-water must be considered. Saline and freshwater are in contact within the aquifer and presumed to be in equilibrium. With development, however, equilibrium could be upset by the applied pumping stress, and saline-water encroachment of the freshwater zone could result. The saline water in the aquifer is seawater that has not been completely flushed from the aquifer by freshwater. As freshwater flows through the aquifer, it floats over the more saline water because of its lower density, forming an inverted wedge with freshwater in the upper part of the aquifer and saline water beneath. This is illustrated by comparison of the two samples taken from test well 1 (table 6). Mixing between the two waters takes place in a zone of diffusion. The slow rate of movement of water through the aquifer tends to restrict mixing, leading to a fairly sharp interface as illustrated by comparing samples from test wells 1 and 2.

Table 6.--Major chemical constituents and physical properties of water from the lower limestone of the Floridan aquifer

[Units are in milligrams per liter (mg/L), except where noted. LSD, land surface datum]

Constituent or property	Well number, latitude, longitude, and date sampled						
	Test well 1 30°30'21"N, 086°35'16"W		Test well 2 30°25'29"N, 086°38'05"W		Test well 3 30°28'56"N, 086°18'34"W	Test well 4 30°22'34"N, 086°10'49"W	
	940-1,015 ft. below LSD 08/02/79	940-1,380 ft. below LSD 08/15/79	1,020-1,060 ft. below LSD 10/02/79	1,020-1,200 ft. below LSD 01/05/79	201-900 ft. below LSD 06/06/79	220-420 ft. below LSD 07/25/79	220-820 ft. below LSD 07/28/79
Alkalinity as $CaCO_3$, total	130	--	264	322	120	110	190
Arsenic, dissolved, ug/L	1	3	2	1	--	--	--
Bicarbonate	158	158	322	392	146	130	230
Boron, dissolved, ug/L	30	570	1,100	2,100	--	--	--
Bromide, dissolved	--	--	3.8	10	--	--	--
Calcium, dissolved	21	26	25	25	22	36	79
Carbon, dissolved total	3.0	--	6.1	1.0	--	--	--

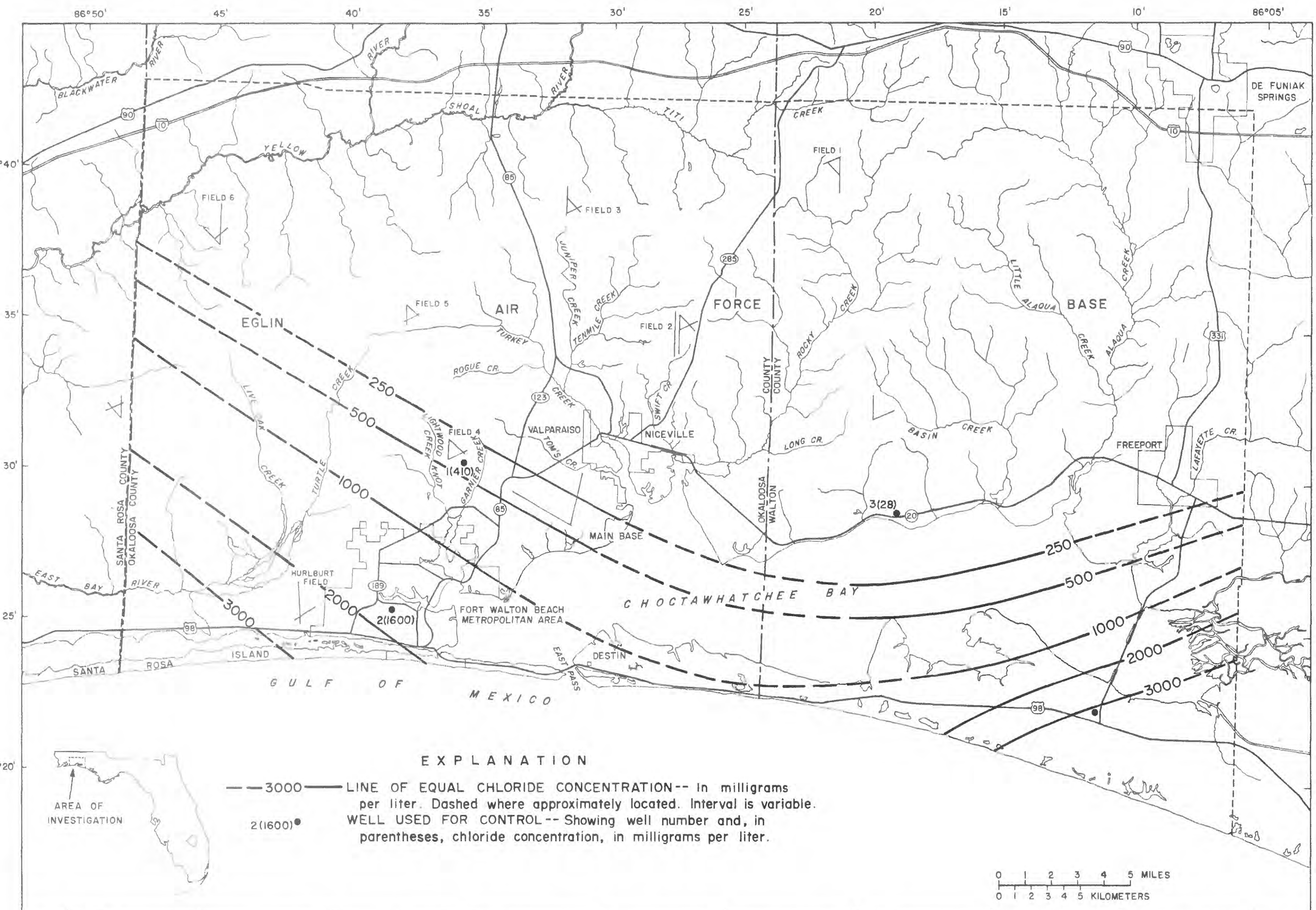


Figure 29.--Chloride concentrations of water in the lower limestone of the Floridan aquifer and locations of test holes drilled for control (modified from Barr and others, 1981).

Table 6.--Major chemical constituents and physical properties of water from the lower limestone of the Floridan aquifer--Continued

Constituent or property	Well number, latitude, longitude, and date sampled						
	Test well 1 30°30'21"N, 086°35'16"W		Test well 2 30°25'29"N, 086°38'05"W		Test well 3 30°28'56"N, 086°18'34"W	Test well 4 30°22'34"N, 086°10'49"W	
	940-1,015 ft. below LSD 08/02/79	940-1,380 ft. below LSD 08/15/79	1,020-1,060 ft. below LSD 10/02/79	1,020-1,200 ft. below LSD 01/05/79	201-900 ft. below LSD 06/06/79	220-420 ft. below LSD 07/25/79	220-820 ft. below LSD 07/28/79
Carbon dioxide	2.0	--	5.2	16	--	--	--
Carbonate	0	0	0	0	--	0	0
Chloride, dissolved	8.7	410	810	1,600	28	400	3,100
Color, platinum cobalt units	2	5	10	5	--	2	0
Copper, dissolved, ug/L	0	2	0	0	--	--	--
Dissolved solids, calculated sum	167	816	1,760	3,000	200	834	5,360

Table 6.--Major chemical constituents and physical properties of water from the lower limestone of the Floridan aquifer--Continued

Constituent or property	Well number, latitude, longitude, and date sampled						
	Test well 1 30°30'21"N, 086°35'16"W		Test well 2 30°25'29"N, 086°38'05"W		Test well 3 30°28'56"N, 086°18'34"W	Test well 4 30°22'34"N, 086°10'49"W	
	940-1,015 ft. below LSD 08/02/79	940-1,380 ft. below LSD 08/15/79	1,020-1,060 ft. below LSD 10/02/79	1,020-1,200 ft. below LSD 01/05/79	201-900 ft. below LSD 06/06/79	220-420 ft. below LSD 07/25/79	220-820 ft. below LSD 07/28/79
Dissolved solids, residue at 180°C	179	925	1,970	3,160	196	861	5,820
Fluoride, dissolved	0.2	0.8	2.1	3.1	0.2	0.6	2.3
Hardness, as $CaCO_3$ (Ca+Mg)	120	0	120	170	110	190	500
Hardness, noncarbonate as $CaCO_3$	0	150	0	0	0	84	320
Iron, dissolved, ug/L	10	130	0	280	0	--	--
Iron, suspended, ug/L	830	580	1,900	110	130	--	--

Table 6.--Major chemical constituents and physical properties of water from the lower limestone of the Floridan aquifer--Continued

Constituent or property	Well number, latitude, longitude, and date sampled						
	Test well 1 30°30'21"N, 086°35'16"W		Test well 2 30°25'29"N, 086°38'05"W		Test well 3 30°28'56"N, 086°18'34"W	Test well 4 30°22'34"N, 086°10'49"W	
	940-1,015 ft. below LSD 08/02/79	940-1,380 ft. below LSD 08/15/79	1,020-1,060 ft. below LSD 10/02/79	1,020-1,200 ft. below LSD 01/05/79	201-900 ft. below LSD 06/06/79	220-420 ft. below LSD 07/25/79	220-820 ft. below LSD 07/28/79
Iron, total, ug/L	840	710	1,900	390	130	--	--
Magnesium, dissolved	15	18	13	24	13	22	69
Nitrate, NO_3 as N	0.01	--	0.00	0.00	--	--	--
Nitrite, NO_2 as N	0.00	--	0.00	0.00	--	--	--
Nitrogen, NH_3 as N	0.06	--	1.3	2.0	--	--	--
Nitrogen, total organic as N	0.09	--	0.92	1.3	--	--	--
Nitrogen, total as N	0.16	--	2.2	3.3	--	--	--
pH	8.1	7.9	8.0	7.6	7.9	8.1	7.7

Table 6.--Major chemical constituents and physical properties of water from the lower limestone of the Floridan aquifer--Continued

Constituent or property	Well number, latitude, longitude, and date sampled						
	Test well 1 30°30'21"N, 086°35'16"W		Test well 2 30°25'29"N, 086°38'05"W		Test well 3 30°28'56"N, 086°18'34"W	Test well 4 30°22'34"N, 086°10'49"W	
	940-1,015 ft. below LSD 08/02/79	940-1,380 ft. below LSD 08/15/79	1,020-1,060 ft. below LSD 10/02/79	1,020-1,200 ft. below LSD 01/05/79	201-900 ft. below LSD 06/06/79	220-420 ft. below LSD 07/25/79	220-820 ft. below LSD 07/28/79
Phosphorus, total ortho as P	0.01	--	0.01	0.00	--	--	--
Phosphorus, total as P	0.02	--	0.04	0.02	--	--	--
Potassium, dissolved	3.0	10	16	24	3.0	7.7	36
Silica, dissolved	15	19	21	18	19	14	17
Sodium, dissolved	14	300	700	1,100	33	260	1,900
Specific conductance, umhos/cm	295	1,760	3,510	5,700	340	1,400	10,100
Strontium, dissolved, ug/L	8,000	5,300	2,600	4,700	--	9,100	20,000

Table 6.--Major chemical constituents and physical properties of water from the lower limestone of the Floridan aquifer--Continued

Constituent or property	Well number, latitude, longitude, and date sampled						
	Test well 1 30°30'21"N, 086°35'16"W		Test well 2 30°25'29"N, 086°38'05"W		Test well 3 30°28'56"N, 086°18'34"W	Test well 4 30°22'34"N, 086°10'49"W	
	940-1,015 ft. below LSD 08/02/79	940-1,380 ft. below LSD 08/15/79	1,020-1,060 ft. below LSD 10/02/79	1,020-1,200 ft. below LSD 01/05/79	201-900 ft. below LSD 06/06/79	220-420 ft. below LSD 07/25/79	220-820 ft. below LSD 07/28/79
Sulfate, dissolved	4.0	26	4.7	0.0	9.2	21	19
Temperature, °C	27.5	28.5	27.5	29.5	--	--	--
Turbidity, NTU units	7.0	--	10	5.0	--	--	--
Zinc, dissolved, ug/L	10	0	0	10	--	--	--

Figure 29 shows the locations of four deep test wells and the chloride concentrations of water recovered from the lower limestone of the Floridan aquifer. Isochlors, or lines of equal chloride concentrations, were drawn based on these and other available data. The 250 mg/L isochlor in the lower limestone aquifer is south of Valparaiso and Niceville in Okaloosa County and Freeport in Walton County. In areas north of the 250 mg/L isochlor, the possibility of saltwater encroachment must be considered prior to extensive new pumping.

The composite samples from each of the wells exceeded the U.S. Environmental Protection Agency concentration limits for chlorides and dissolved solids in three of the four wells. The chloride concentrations in the wells ranged from 28 to 3,100 mg/L and the dissolved-solids concentration from 198 to 5,820 mg/L. The available data are insufficient to make a reliable determination of the areal or temporal changes in water quality; however, the quality of water deteriorates with increasing depth and areally to the south.

SUMMARY AND CONCLUSIONS

The sequence of hydrogeologic units beneath the southern parts of Okaloosa and Walton Counties consists, from top to bottom, of: the sand-and-gravel aquifer; the Pensacola Clay confining bed, the upper limestone of the Floridan aquifer, the Bucatunna clay confining bed, the lower limestone of the Floridan aquifer, and the Lisbon-Tallahatta confining unit. The Pensacola Clay confining bed causes artesian conditions in the underlying Floridan aquifer. A downward hydraulic gradient, in much of the area due to pumpage drawdown in the Floridan aquifer, prevails from the sand-and-gravel aquifer through the Pensacola Clay confining bed to the Floridan aquifer, indicating the potential for downward leakage. The volume of leakage, however, is judged to be minor considering aquifer test results and the thickness and low permeability of the Pensacola Clay confining bed. An upward gradient, also thought largely due to pumpage drawdown in the upper limestone, exists from the lower limestone through the Bucatunna clay confining bed to the upper limestone of the Floridan aquifer; but the volume of leakage is probably minor due to the very low permeability of the Bucatunna clay confining bed. The limestones of the Floridan aquifer (undifferentiated) are recharged north of the Florida-Alabama state line by infiltrating rainfall in areas where the aquifer is near land surface. From the recharge area, water migrates to the south, part being intercepted by wells and the remaining eventually discharging to the Gulf of Mexico.

Seven aquifer tests were conducted to evaluate the hydraulic properties of the upper limestone of the Floridan aquifer, the hydraulic interconnection between the aquifer and the sand-and-gravel aquifer, and the response of the aquifer to pumping under controlled conditions. The results of the aquifer tests coupled with evaluation of geological and geophysical well logs, analysis of changes in potentiometric surfaces, and areal mapping of transmissivity distribution in the upper limestone of the Floridan aquifer indicate that:

- There is little hydraulic interconnection between the Floridan aquifer and the sand-and-gravel aquifer;

- The transmissivity of the upper limestone is lowest adjacent to the coast in southern Okaloosa County, the more permeable part is near its base; and

- A zone of high transmissivity occurs along the northern boundary of the Fort Walton Beach metropolitan area, and higher transmissivities occur in the vicinity of auxiliary field six in the northwest corner of the study area. Transmissivities are low in the central part of the study area.

Ground-water withdrawals in southern Okaloosa County have created a large depression in the potentiometric surface. Centered in Fort Walton Beach and surrounding communities, the depression extends over the entire area of investigation. Due to the generally nonleaky character of the aquifer in the Fort Walton Beach area and the distance between the pumping centers and the recharge area, it is likely that the depression would continue to expand even if pumping did not increase. With an increasing population, however, pumping will continue to increase and water levels will continue to decline.

Throughout southern Okaloosa and most of southern Walton Counties, the upper part of the Floridan aquifer yields freshwater which is acceptable for irrigation, public supply, and most industrial purposes. Encroachment of saline water from the Gulf of Mexico, Choctawhatchee Bay, or by upwelling of saline water (from the lower limestone of the Floridan aquifer) at the east end of Choctawhatchee Bay, is a potential water-quality problem in southern Walton County. High chloride water is confined to a few wells in the area, but increased pumpage in this and adjacent areas to the west could result in contamination of the Floridan aquifer. Saline-water occurrence is not pronounced in southern Okaloosa County, but encroachment is likely as naturally occurring saline water in the upper limestone moves eastward from Santa Rosa County toward pumping centers in Okaloosa County.

Water in the lower limestone of the Floridan aquifer is saline in the coastal areas of Okaloosa and Walton Counties. Consequently, the lower limestone cannot be considered a viable alternative source for water supply in these areas of greatest water demand.

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