

HYDROGEOLOGIC CONDITIONS AND SALINE-WATER
INTRUSION, CAPE CORAL, FLORIDA, 1978-81

By Daniel J. Fitzpatrick

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 85-4231

Prepared in cooperation with the
CITY OF CAPE CORAL



Tallahassee, Florida

1986

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
Suite 3015
227 North Bronough Street
Tallahassee, Florida 32301

Copies of the report can be
purchased from:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Federal Center
Denver, Colorado 80225
(Telephone: (303) 236-7476)

CONTENTS

	Page
Abstract-----	1
Introduction-----	1
Description of area-----	2
Acknowledgments-----	4
Hydrogeologic conditions-----	4
Surficial aquifer system-----	4
Intermediate aquifer system-----	11
Floridan aquifer system-----	17
Saline-water intrusion in the upper limestone unit-----	19
Downward intrusion-----	27
Upward intrusion-----	29
Lateral intrusion-----	30
Summary and conclusions-----	30
Selected references-----	31

ILLUSTRATIONS

Figure 1. Map showing location of Cape Coral, Lee County-----	3
2. Generalized section showing geologic formations, lithology, and water-bearing units underlying Cape Coral-----	5
3. Map of Cape Coral showing generalized water-table contours of the surficial aquifer system near the end of the dry season, May 1980-----	7
4. Map of southeast corner of Cape Coral showing the density of the canal system connected to tidewater-----	8
5. Graph showing relation between chloride concentration and specific conductance in water from the surficial aquifer system-----	9
6. Map showing location of salinity monitor wells with reference to a tidal canal-----	10
7. Map of Cape Coral showing chloride concentration in water from wells that tap the surficial aquifer system, May 1980-----	12
8. Hydrographs of water levels of the intermediate aquifer system in wells L-581 and L-1059 that tap the upper limestone unit of the Hawthorn Formation, and municipal pumpage from the upper limestone unit by Cape Coral, 1966-80-----	14
9. Map showing contours of the potentiometric surface of the intermediate aquifer system from wells that tap the upper limestone unit of the Hawthorn Formation, near the end of the wet season, September 1979-----	15

ILLUSTRATIONS--Continued

	Page
Figure 10. Map showing contours of the potentiometric surface of the intermediate aquifer system from wells that tap the upper limestone unit of the Hawthorn Formation, near the end of the dry season, May 1980-----	16
11. Map showing contours of the potentiometric surface of the Floridan aquifer system from wells that tap the lower limestone unit of the Hawthorn Formation, near the end of the dry season, May 1980-----	18
12. Map showing boundaries of insets A through F (figs. 13-18) and chloride concentration in water from wells tapping the upper limestone unit-----	20
13-18. Maps showing lines of equal chloride concentration in water from selected wells that tap the upper limestone unit in:	
13. Inset area A (see fig. 12), 1979-81-----	21
14. Inset area B (see fig. 12), 1979-81-----	22
15. Inset area C (see fig. 12), 1979-81-----	23
16. Inset area D (see fig. 12), 1979-81-----	24
17. Inset area E (see fig. 12), 1979-81-----	25
18. Inset area F (see fig. 12), 1979-81-----	26
19. Map showing areas of potential downward movement of water to the upper limestone unit of the Hawthorn Formation, May 1980-----	28

HYDROGEOLOGIC CONDITIONS AND SALINE-WATER INTRUSION,

CAPE CORAL, FLORIDA, 1978-81

By Daniel J. Fitzpatrick

ABSTRACT

The principal source of freshwater for Cape Coral, Fla., is the upper limestone of the Hawthorn Formation, locally called the Hawthorn aquifer. This aquifer, which is within the intermediate aquifer system, has been contaminated by downward intrusion of saline water from the surficial aquifer system and by upward intrusion from the lower limestone of the Hawthorn Formation. The lower limestone is within the Floridan aquifer system and is under high artesian pressure. Much of the intrusion has occurred through open wellbores where steel casings are short or where casings have collapsed because of corrosion. Saline-water contamination of the upper limestone unit due to downward intrusion from the surficial aquifer system is most severe in the southern and eastern parts of Cape Coral; contamination due to upward intrusion has occurred in many areas throughout Cape Coral. Intrusion is amplified in areas of heavy water withdrawals and large water-level declines.

INTRODUCTION

The upper limestone unit of the intermediate aquifer system, locally referred to as the upper Hawthorn aquifer (in the upper part of the Hawthorn Formation) (Sproul and others, 1972), is the major source of freshwater for municipal and domestic supply and lawn irrigation for Cape Coral, Lee County, Fla. Over the years, problems resulting from development and utilization of ground water from this source have led to a deterioration in the water quality in some parts of the area, and to a potential for further deterioration in other parts. These problems, which relate to lack of detailed data in subsurface flow systems, have resulted in saline-water intrusion whereby: (1) wells were drilled to tap or penetrate not only the upper limestone unit but also hydraulically connect it to underlying or overlying limestones that contain saltwater, and (2) the head in the upper limestone unit at the well sites is below that in the hydraulically connected adjacent saltwater sources.

Between 1958 and 1975, nearly 8,000 2-inch steel-cased wells were drilled into the upper limestone unit in Cape Coral. Many of the wells also penetrated saline zones in the more shallow surficial aquifer system. With time, openings caused by corrosion of steel casings permitted downward leakage of saline water in areas where the head in the upper limestone unit had declined below that in the surficial aquifer system, and where the surficial aquifer

system contained saline water. Generally, prior to 1958, many flowing wells were constructed that tapped the deep saline aquifers for irrigation in the Cape Coral area. In many instances, these wells had short casings, allowing saline water from deep aquifers to flow freely into the upper limestone unit since the head in the deep aquifers is higher. Progressively larger areas have been affected by this process. This type of intrusion in Cape Coral and other areas of Lee County was first documented by Boggess and others (1977).

Increasing withdrawals from the upper limestone unit have caused a progressive decline and a widening of areas of lowered water levels, thereby increasing the potential for upward or downward saline-water intrusion as well as inland movement of saltwater from the Gulf of Mexico.

The declining water levels and saline-water intrusion led to an investigation of the water resources of the area by the U.S. Geological Survey, in cooperation with the City of Cape Coral. The objectives of the study, which covers not only Cape Coral but also adjacent areas, were to: (1) further define the areal extent of saline-water intrusion in the upper limestone unit and the sources of the intrusion, (2) establish a network of wells to monitor water-quality and water-level changes in the upper limestone unit, and (3) obtain water-level and water-quality data in water-bearing units above and below the upper limestone unit. Between 1978 and 1981, an inventory of privately owned wells was made in the populated eastern and southern parts of Cape Coral. Most of the wells tapped the upper limestone unit. Water samples were collected and analyzed to determine salinity content. Nearly 1,300 wells were sampled.

Description of Area

The City of Cape Coral, in western Lee County (fig. 1), occupies an area of 110 mi² between the Caloosahatchee River and bays of the Gulf of Mexico. The population of Cape Coral in 1984 exceeded 33,000, most of which was concentrated in the southern and eastern parts of the city.

Major development of the Cape Coral area began about 1958 with the construction of an extensive 350-mile canal system. About 40 percent of the canals, those in the eastern and southern parts of the city, are affected by gulf tides. Weirs separate tidal (salty) reaches from nontidal (usually fresh) reaches. Throughout most of the canal system, water levels in the nontidal reaches are higher than those in the tidal reaches. The land surface has been raised as much as 2 feet in some areas, using material dredged from canal construction.

The climate of the area is subtropical; temperature extremes are moderated by the Gulf of Mexico. As reported by the National Oceanic and Atmosphere Administration, U.S. Department of Commerce, the average annual air temperature at Page Field in Fort Myers, 3.5 miles east of Cape Coral, is 74°F; monthly averages ranged from 83°F in August to 64°F in January. Rainfall is distributed unevenly throughout the year; more than 60 percent of the average annual rainfall (54 inches) occurs from June through September and results mostly from localized convective storms. Rainfall data from two sites in Cape Coral are given by Fitzpatrick (1982).

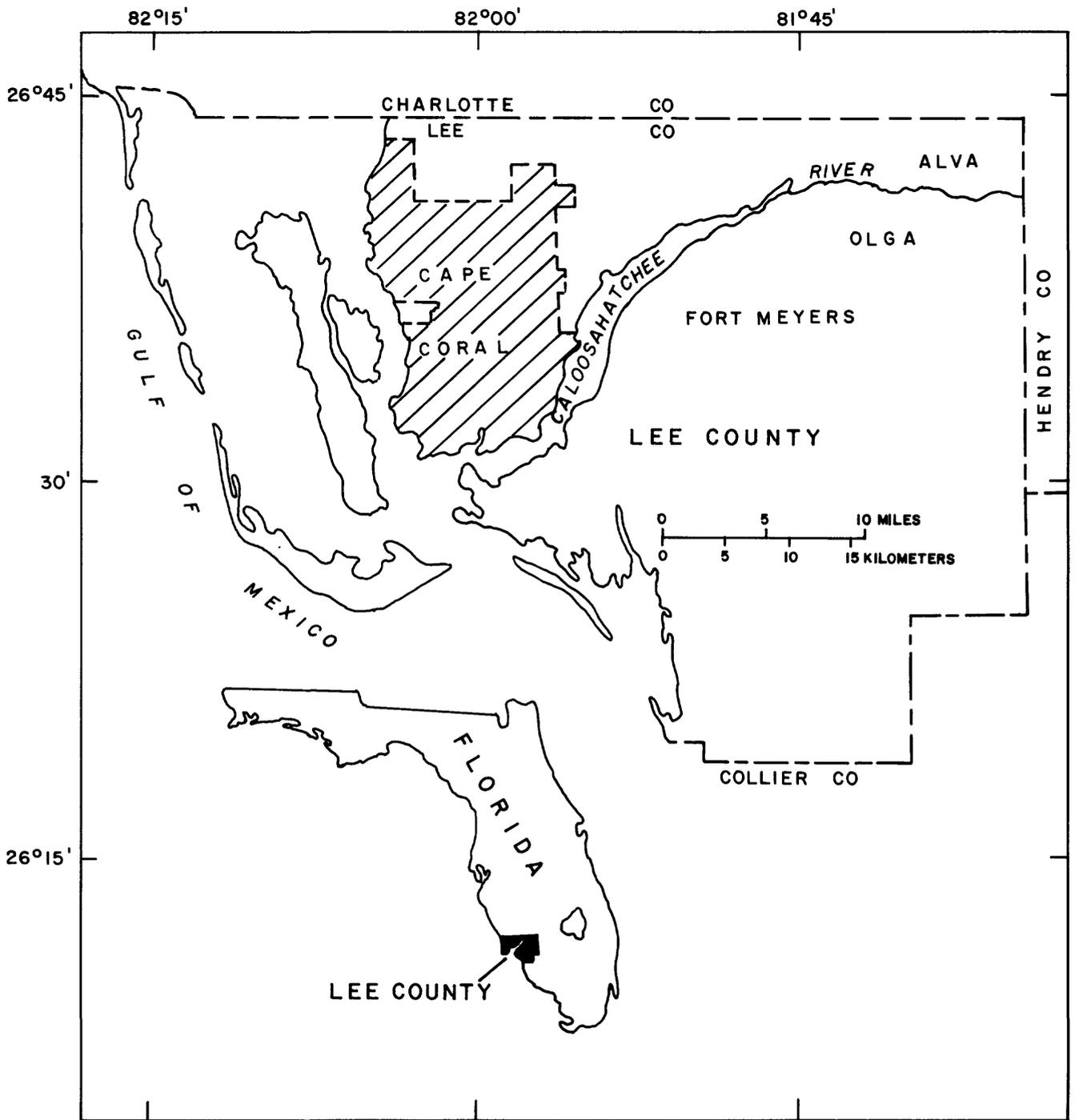


Figure 1.--Location of Cape Coral, Lee County.

Acknowledgements

The author thanks the residents and city officials of Cape Coral for their cooperation and assistance during this investigation. This investigation initiated a continuing water-resources monitoring program in cooperation with officials of the City of Cape Coral, whose continued interest and support are greatly appreciated.

HYDROGEOLOGIC CONDITIONS

The upper 700 feet of sediments in the Cape Coral area comprise the Tampa Limestone and the Hawthorn Formation of Miocene age, the Tamiami Formation of Pliocene age, and the undifferentiated surface materials chiefly of Pleistocene and Holocene age (fig. 2). This section of sediments includes the following aquifer systems that yield water for public supply, irrigation, industrial, and domestic uses: The Floridan aquifer system, an intermediate aquifer system which includes an upper water-bearing limestone unit within the Hawthorn Formation, and the surficial aquifer system which includes the Tamiami Formation along with the blanketing undifferentiated younger materials. The Floridan aquifer system, in general, yields nonpotable water in the Cape Coral area and will not be discussed as a usable source.

Chloride concentration of water is used in this report as an indicator of salinity. High chloride concentration is usually associated with high concentration of other salts or dissolved solids. Water with dissolved solids concentration more than 1,000 mg/L (milligrams per liter) is classified as saline (Krieger and others, 1957, p. 4).

Surficial Aquifer System^{1/}

The surficial aquifer system consists primarily of unconsolidated fine- to medium-grained quartz sand, interbedded sandy limestone and shell units, and gray or green sandy clay. The aquifer system generally ranges in thickness from about 20 to 60 feet but locally may exceed 100 feet. A detailed description of the upper part of the surficial aquifer system is given in Boggess and others (1981). The surficial aquifer system is not used extensively in Cape Coral; however, some wells, mainly in the northern part of the city, tap it for domestic use, and a small well field just east of the city taps it for public supply.

The Tamiami Formation, in the lower part of the surficial aquifer system, contains freshwater in central and eastern Lee County. Although it occurs in the eastern fringe of Cape Coral (Boggess and others, 1981), it is usually cased off in wells because it is composed of caving sand and sandy clay.

The water table in the unconfined surficial aquifer system is directly affected by rainfall. The water table declines in response to evapotranspiration and ground-water discharge into surface-water bodies. Other factors which can affect the water table include water discharging at land surface

^{1/}Deliberations among hydrogeologists active in southwest Florida that have occurred since this report was prepared and approved by the Director of the Geological Survey have resulted in placement of the regional base of the surficial aquifer system higher in the hydrogeologic section than shown in this report. Regionally, the base of the surficial aquifer system in southwest Florida is considered to be at the first areally persistent clay layer, which is commonly green and similar in lithology to the deeper lying clays of the Hawthorn Formation. In the Lee County area, the first clay is thin and affords seeming hydrologic continuity between the water table and the "sandstone aquifer," as evidenced by the similar configuration of the potentiometric surface of the "sandstone aquifer" with that of the water table. Therefore, on the basis of local data, this report regards the "sandstone aquifer" as part of the surficial aquifer system rather than as part of the intermediate aquifer system, which is the consensus recently arrived at based on regional considerations.

DEPTH (feet)	SERIES	FORMATION	LITHOLOGY	WATER-BEARING UNITS
100	HOLOCENE AND PLEISTOCENE	UNDIFFERENTIATED DEPOSIT	SAND FOSSILIFEROUS LIMESTONE, WHITE TO YELLOW, SANDY, MARLY, FOSSILIFEROUS	SURFICIAL AQUIFER SYSTEM
	PLIOCENE	TAMIAMI FORMATION	CLAY, CALCAREOUS, GREEN SAND & SANDSTONE, GRAY, CALCAREOUS CLAY, GRAY, SANDY, PHOSPHATIC	
200	MIOCENE	HAWTHORN FORMATION	LIMESTONE, GRAY-WHITE, CHALKY, SANDY, PHOSPHATIC	Upper limestone Unit
300			CLAY & MARL, GRAY AND GREEN, SOME LIMESTONE	
400				LIMESTONE, GRAY-WHITE SANDY, PHOSPHATIC
500	OLIGOCENE	TAMPA LIMESTONE	LIMESTONE, GRAY & TAN, SLIGHTLY PHOSPHATIC	AQUIFER SYSTEM
600		SUWANNEE LIMESTONE	LIMESTONE, TAN, MODULAR	
700				
800				

Figure 2.--Geologic formations, lithology, and water-bearing units underlying Cape Coral.

from wells tapping deeper aquifers, downward leakage, and tidal fluctuations in areas adjacent to the Gulf of Mexico and tidal canals. The water table in the Cape Coral area is generally highest during the wet season (June to September) and lowest at the end of the dry season (April or May) (Fitzpatrick, 1982, figs. 6-17). Fluctuations are generally 1 to 2 feet.

The water-table contours in figure 3 represent low water conditions near the end of the dry season (May 1980). As shown, water levels were highest in the northeastern part of Cape Coral and lowest along the coastal zone, which is dissected by canals. The extreme density of canals is indicated in figure 4, which represents the southeast corner of Cape Coral. These coastal canals, which are not controlled in lower reaches, are affected by tides and normally contain highly saline water which enhances the possibility of salt-water intrusion. The canals are equipped with weirs along inland reaches to retard overdrainage of ground water and to block the upstream flow of seawater. Thus, water levels higher than tide levels are maintained upstream of the weirs. Weir locations and crest elevations are shown in figure 3. The contours in figure 3 are highly generalized.

Water quality in the surficial aquifer system is variable. Chloride concentrations range from about 10 to 20,000 mg/L. Areas that contain highly saline water are significant because of their potential as sources of saline-water contamination by downward leakage to the intermediate aquifer system. The existence of saline water in the surficial aquifer system depends largely on proximity to the Caloosahatchee River, the Gulf of Mexico, and tidal reaches of the coastal canal system. Although water quality of the canal system has not been extensively monitored, highly saline water can be expected in canals open to the gulf and the river, particularly during the dry months. Sections of canals inland of the weirs, although not open to tidewater, may still contain saline water when insufficient head exists to counter the inland migration of saline water.

An example of the extent of intrusion of saline water from a canal into a line of wells penetrating surficial material is shown in the following table:

Source	Distance from canal (feet)	Specific conductance (micromhos/cm)
Canal	--	30,000
Well L-2286	60	28,200
Well L-2287	120	27,300
Well L-2288	180	1,380

Specific conductance, an indicator of chloride concentration (fig. 5), was measured in a tidal canal and in wells that tap the surficial aquifer system at different distances from the canal (fig. 6). A slight decrease in specific conductance is evident in the well up to 120 feet from the canal. However, at a 180-foot distance, the specific conductance in a well decreased

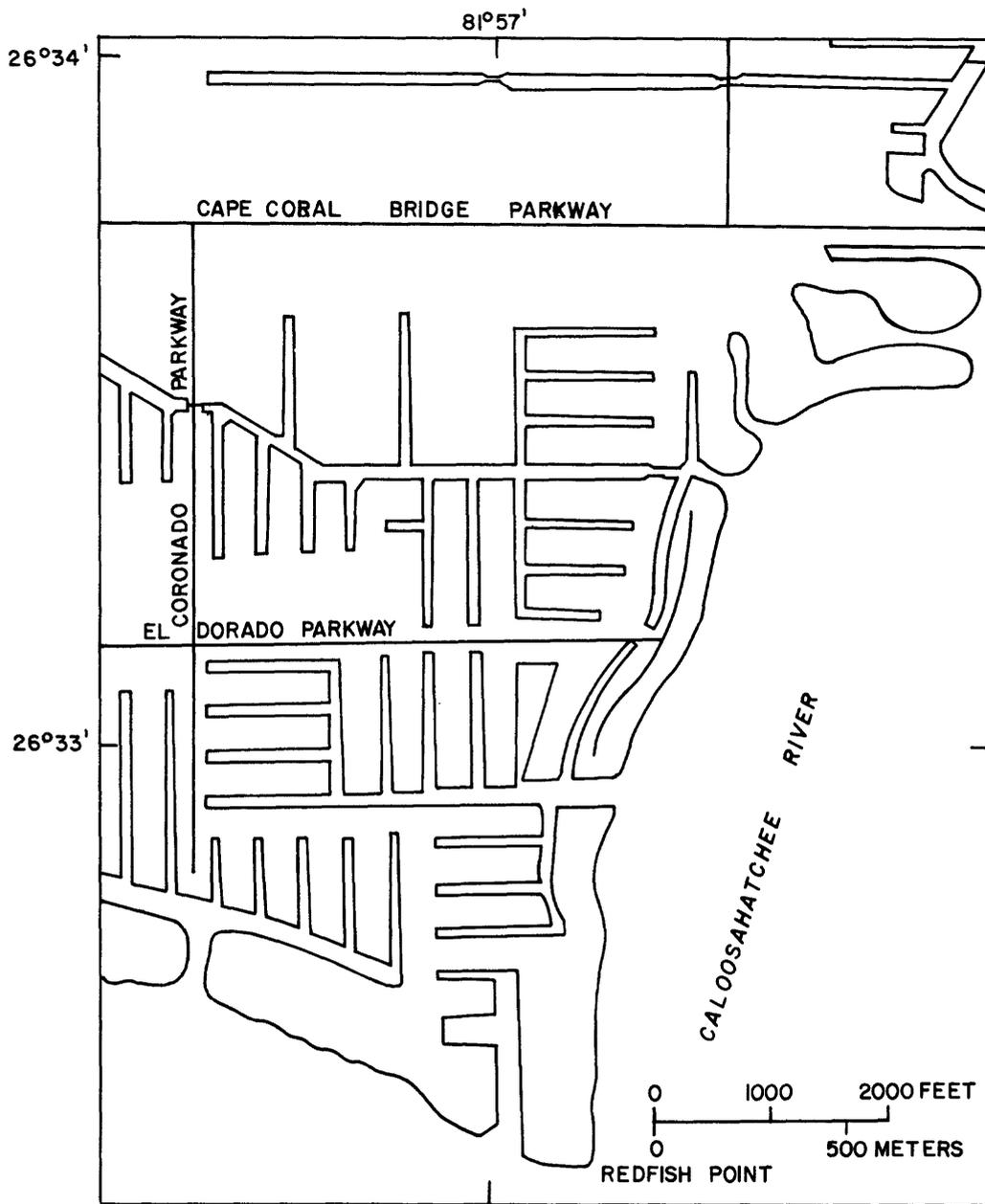


Figure 4.--Southeast corner of Cape Coral showing the density of the canal system connected to tidewater.

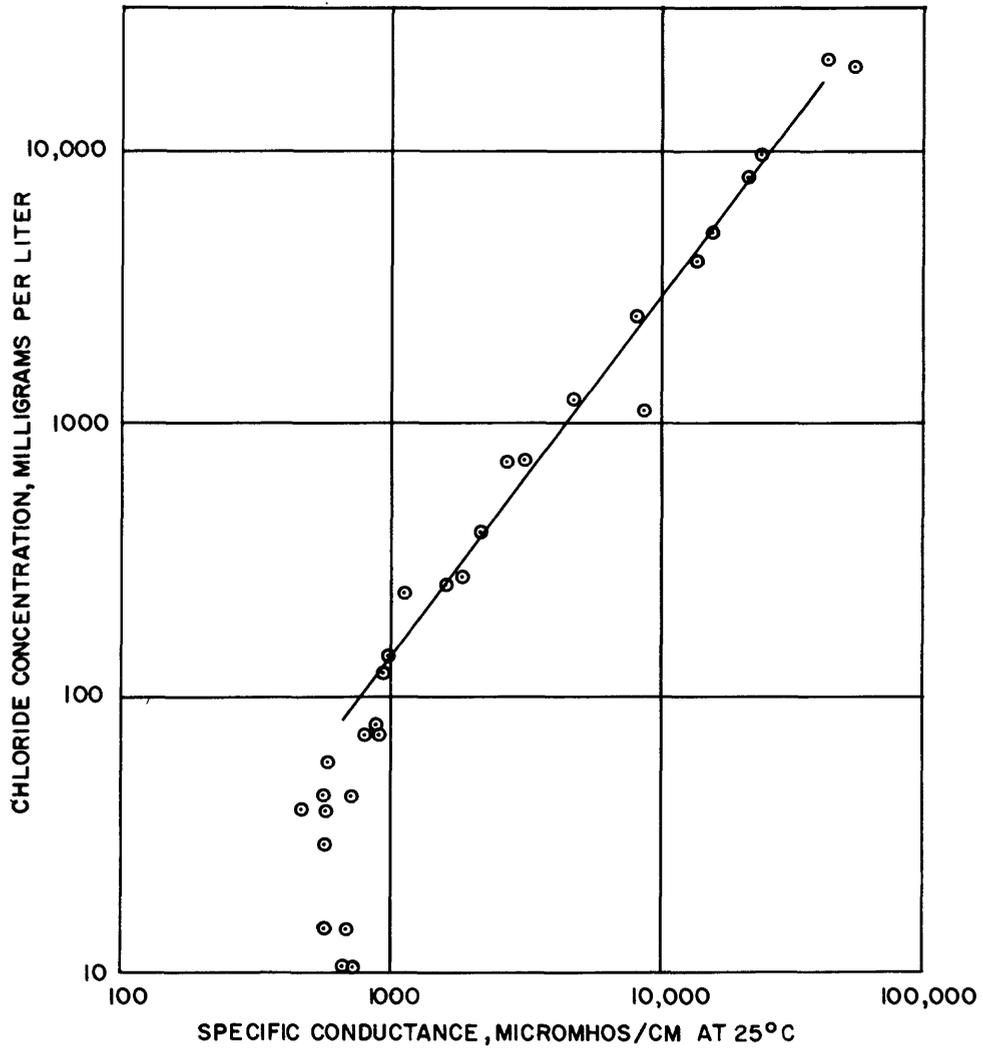


Figure 5.--Relation between chloride concentration and specific conductance in water from the surficial aquifer system.

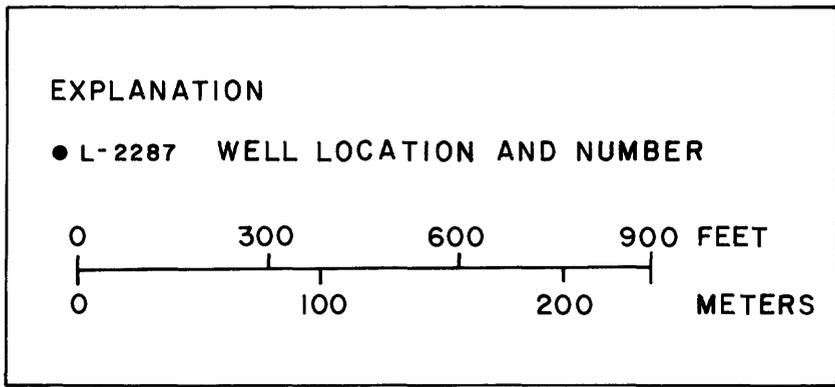
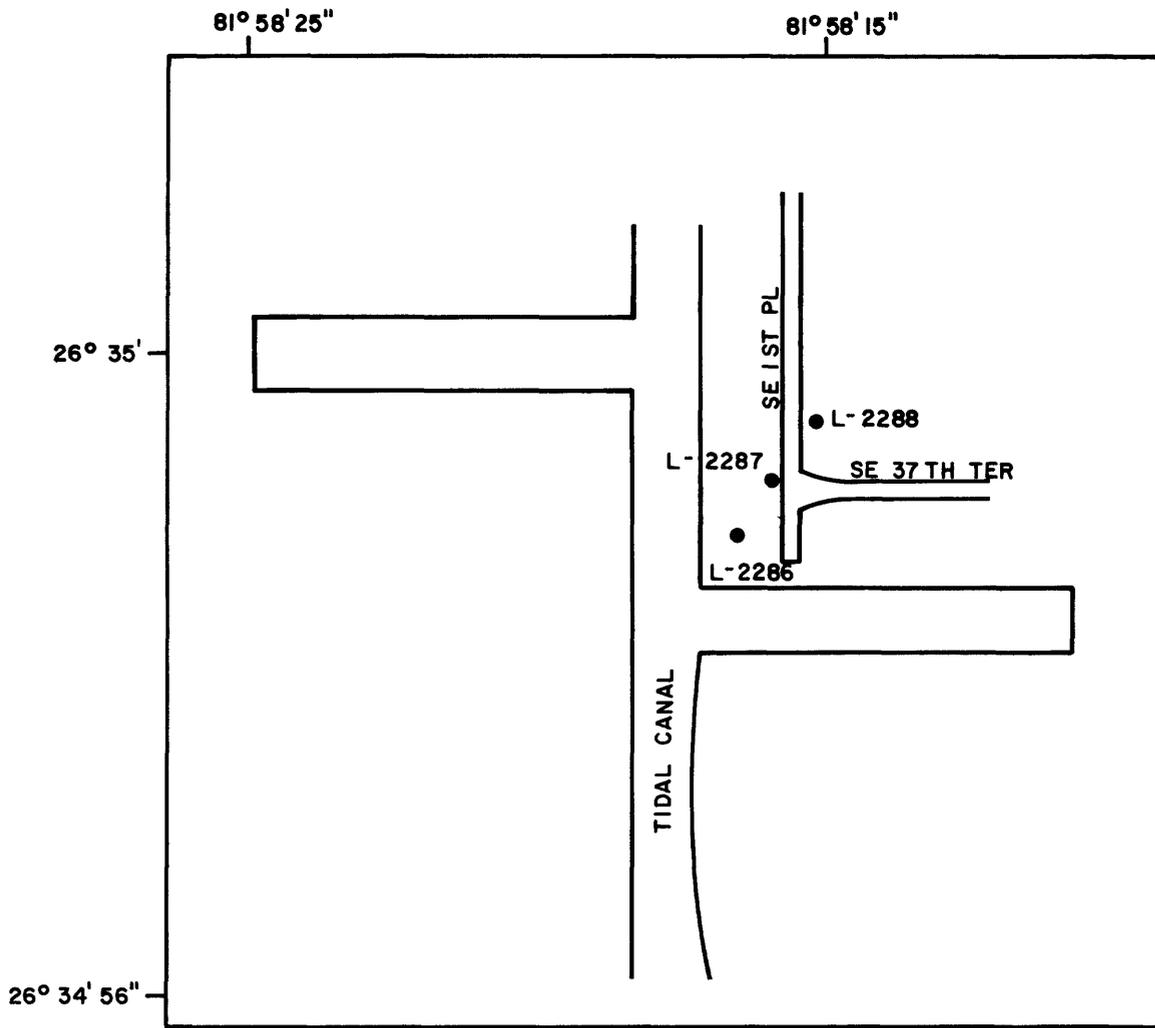


Figure 6.--Location of salinity monitor wells with reference to a tidal canal.

to less than 5 percent of that in the canal. The distance that saline water will intrude into the surficial aquifer system is governed largely by the hydraulic conductivity of the aquifer matrix and by the freshwater head maintained above sea level.

Chloride concentrations in water from selected wells that tap the surficial aquifer system were determined in May 1980 (fig. 7). These data and data obtained earlier by Boggess and others (1977, p. 24-25) were used to examine the occurrence of saline water in the surficial aquifer system. Although the data points are insufficient to define the full distribution of saline water, the following generalities can be made:

1. The most widespread occurrence of saline water in the surficial material is where the coastal zone is most dissected by tidal canals--specifically the areas south of Everest Parkway and east of Del Prado Boulevard, and the area south of Cape Coral Parkway and east of Chiquita Boulevard (fig. 3). Chloride concentrations range from 740 to more than 26,000 mg/L. For comparison, seawater contains about 19,000 mg/L of chloride.
2. In the remaining area of tidal canals (fig. 7), the occurrence of saline water in the shallow ground water is not widespread. Saline water is probably limited to those parts of the surficial aquifer system immediately adjacent to the tidal canals.
3. Analyses of water from wells in the area west of Chiquita Boulevard indicate saline water in parts of the surficial aquifer system. This area is also highly dissected by canals which, although not directly open to major tidal water bodies, probably became saline by lateral subsurface migration.

Intermediate Aquifer System

The intermediate aquifer system is heavily utilized in the Cape Coral area for both municipal supplies and individual residential purposes. It is composed of an upper limestone unit and a section of clay and marl of low permeability, as much as 150 feet thick, which effectively confines a limestone unit in the upper part of the Floridan aquifer system (fig. 2). Casings of wells tapping the intermediate aquifer system range in length from about 120 to 150 feet.

The upper limestone unit of the intermediate aquifer system consists predominantly of sandy, phosphatic limestone. It was described in detail by Boggess (1981) who referred to this unit as the upper Hawthorn aquifer (in the upper part of the Hawthorn Formation). It ranges in thickness from about 50 to 150 feet and is the major source of freshwater for Cape Coral and surrounding areas. More than 10,000 privately owned wells have been drilled to the upper limestone unit since development began in Cape Coral. About 8,000 wells are of small-diameter steel casings which were installed before a 1975 local ordinance was passed requiring the use of nonmetallic casing.

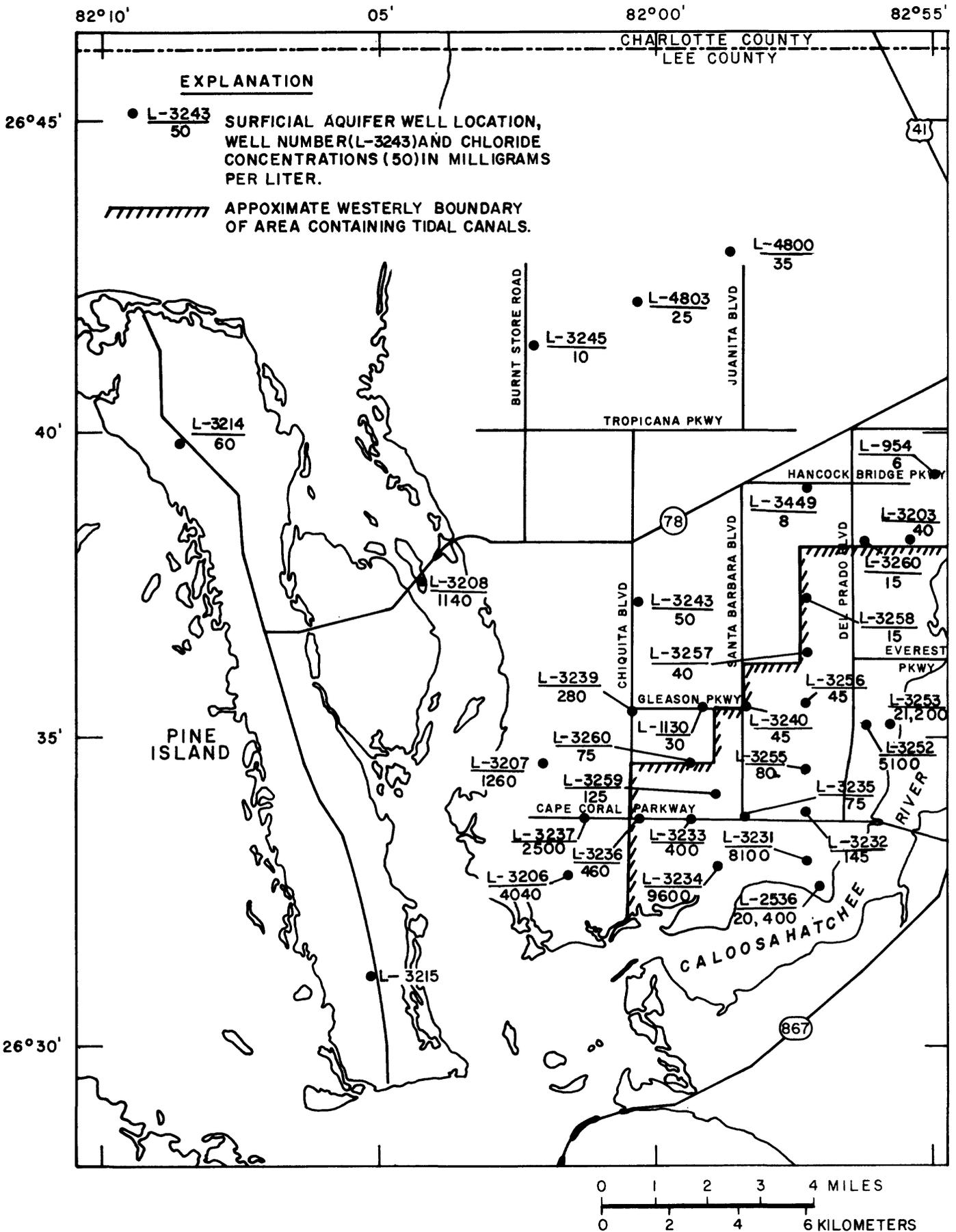


Figure 7.--Cape Coral showing chloride concentration in water from wells that tap the surficial aquifer system, May 1980.

The upper limestone unit is under artesian pressure so that the water level in wells tapping it rises above the top of the limestone. Increasing withdrawals for both municipal and domestic uses have resulted in a general downward trend in water levels in some areas. The effect of withdrawals on water levels in wells is illustrated in figure 8. The increase in municipal pumpage resulted in a corresponding decrease in water levels in well L-581, in south-central Cape Coral, from 1966 to 1977. Withdrawals from the upper limestone unit were reduced in 1977 when a reverse osmosis plant began producing potable water from saline water withdrawn from wells in the limestone unit of the Floridan aquifer system. This reduction is reflected in a short-interval rise in water levels in well L-581 followed by a resumption in decline in 1979. In contrast, a hydrograph of well L-1059 (fig. 8), in the northwestern part of Cape Coral, illustrates water-level fluctuations in an area relatively unaffected by withdrawals. Although water levels in well L-1059 indicate seasonal fluctuations, no downward trend occurred. Effects of pumping on water-level fluctuations in wells in the upper limestone unit in other areas of Cape Coral are illustrated by Fitzpatrick (1982).

Most recharge to the upper limestone unit occurs north and northeast of Lee County where the limestone is probably hydraulically connected with the surficial aquifer system. Beneath Cape Coral, some recharge probably occurs from upward or downward leakage through the confining beds in areas where the artesian pressure in the upper limestone unit has been lowered by pumping (Boggess and others, 1981).

Areawide water levels in wells in the upper limestone unit are illustrated by contours of the potentiometric surface in figures 9 and 10. The potentiometric surface is defined by Lohman and others (1972) as the level to which water will rise in a tightly cased well, and is a surface which represents the static head in the aquifer. Contours of the potentiometric surface representing high water levels are based on data collected in September 1979 (fig. 9), and contours representing low water levels are based on data collected in May 1980 (fig. 10).

The major areas of withdrawal for public water supply are immediately apparent in figures 9 and 10 by drawdowns of water level in central Cape Coral and in the area southeast of Cape Coral, east of the Caloosahatchee River. The coalescing of the cones of depression around both of these well fields probably affects the potential well-field production of each. Three smaller areas of withdrawal for public supply (figs. 9 and 10) also exist in Cape Coral and adjacent areas, but the drawdowns caused by these withdrawals are localized and not so prominent. Ground-water flow within the upper limestone unit is generally toward the centers of the two major withdrawal areas. The regional hydraulic gradient within this part of Lee County, however, is to the southwest.

Differences in water quality in the upper limestone unit generally reflect the varying degrees of saline-water intrusion that have occurred. Chloride concentrations generally range from about 40 to 100 mg/L in areas relatively unaffected by intrusion; chloride concentrations of several thousand milligrams per liter occur in severely affected areas. An example of the water-quality variations in Cape Coral is shown in Fitzpatrick (1982,

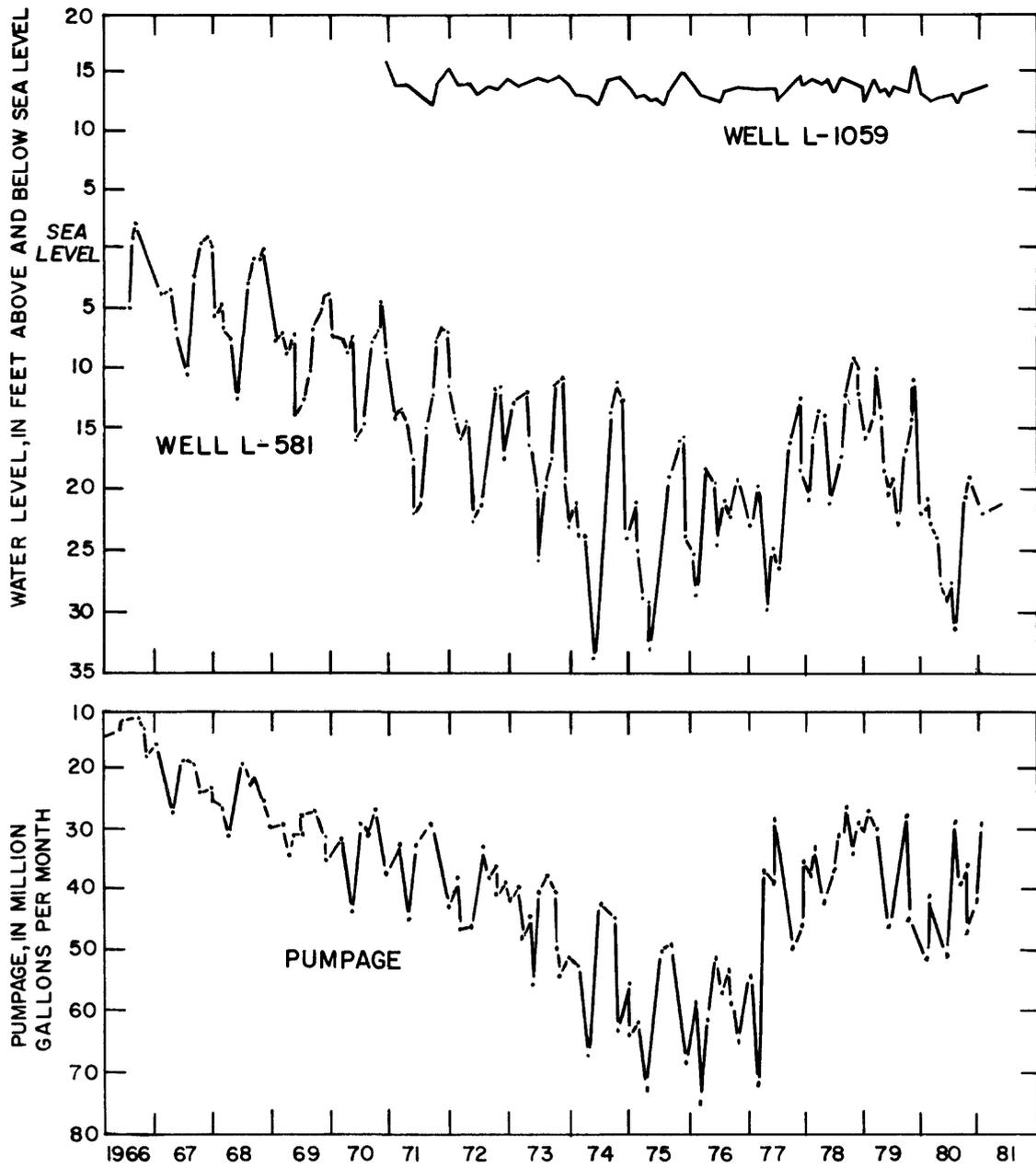


Figure 8.--Water levels of the intermediate aquifer system in wells L-581 and L-1059 that tap the upper limestone unit of the Hawthorn Formation, and municipal pumpage from the upper limestone unit by Cape Coral, 1966-80.

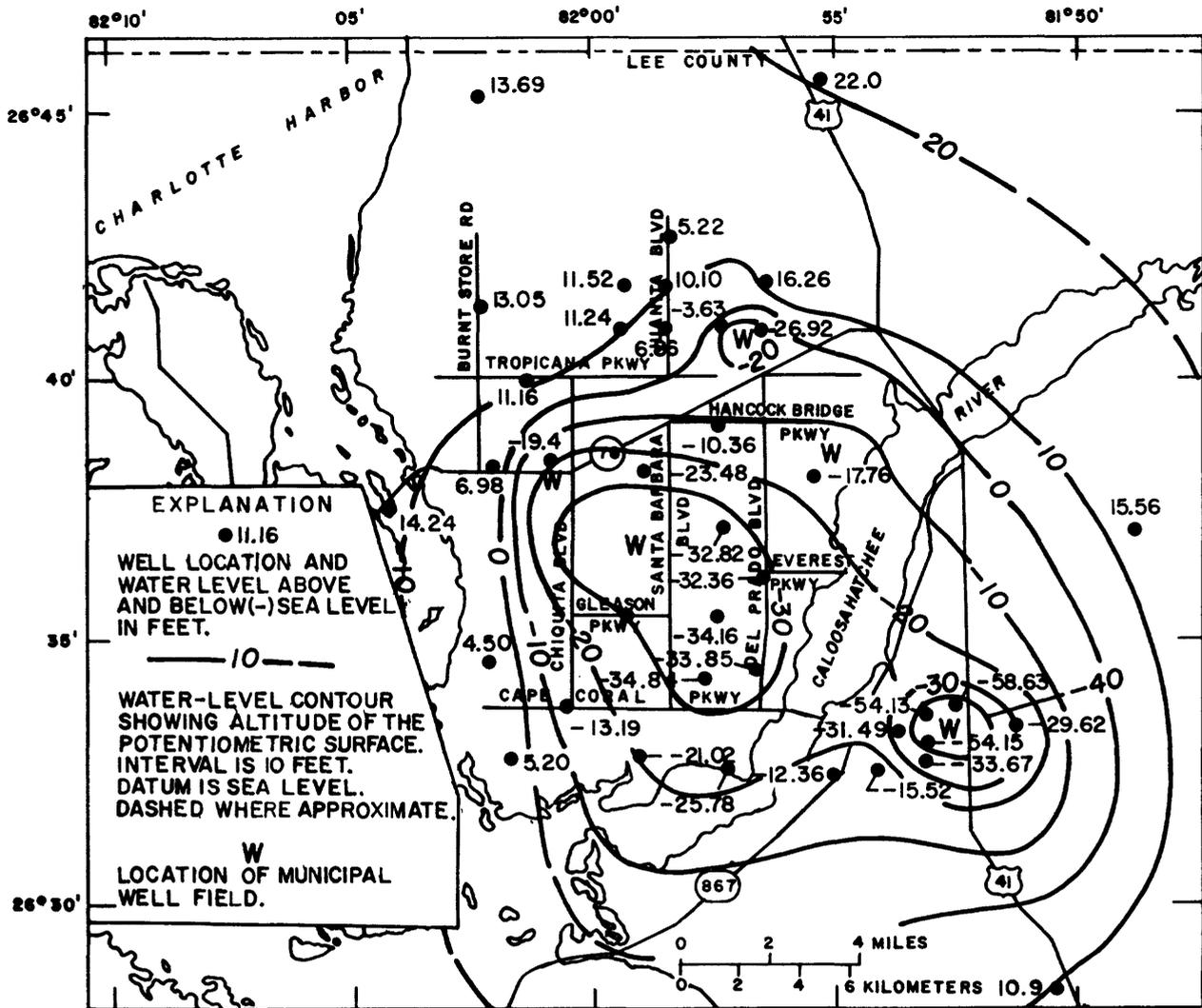


Figure 10.--Contours of the potentiometric surface of the intermediate aquifer system from wells that tap the upper limestone unit of the Hawthorn Formation, near the end of the dry season, May 1980.

table 5), which gives the major chemical constituents observed in water from monitor wells in Cape Coral and adjacent areas. In 1980, chloride and dissolved solids concentrations from these wells ranged from a low of 52 and 302 mg/L to a high of 1,100 and 2,340 mg/L. Concentrations of most other major constituents varied proportionately. Although these data do not reflect the total range of constituent concentrations, they do indicate the wide variations in water quality.

Floridan Aquifer System

Relatively few wells tap the Floridan aquifer system in the Cape Coral area. These wells withdraw water from the lower limestone unit of the Hawthorn Formation that underlies the thick clay and marl confining material of the intermediate aquifer system. The lower limestone unit consists predominantly of sandy limestone but also contains phosphorite. During early years of development of the area, wells were drilled to one or both of these limestone units of the Hawthorn Formation for irrigation because such wells will flow at the land surface and yield great quantities. A few wells possibly penetrated deeper limestones of the Floridan aquifer system, 750 to 800 feet deep, to obtain maximum yield. Casing in the wells was generally to the top of the upper limestone unit, leaving the wellbore open for interflow among the artesian limestones under differing heads. The number of these irrigation wells is not known; most are no longer used, some have been plugged, and others probably were capped and abandoned. Wells in the limestone of the Floridan aquifer system supply the saline water used in the reverse osmosis conversion system for the Cape Coral municipal supply.

Artesian pressures in the Floridan aquifer system are sufficient to sustain flow at land surface throughout Cape Coral and Lee County, except in a few localized areas of heavy withdrawals. In general, the artesian pressure is greater than that in the upper limestone unit of the intermediate aquifer system because of the greater withdrawals from the upper limestone unit. Water-level fluctuations in wells in the Floridan aquifer system are principally the result of withdrawal. Fitzpatrick (1982, fig. 4) showed a decline of about 15 feet in 3 years in an observation well near the reverse osmosis plant as a result of heavy withdrawals. Water levels in areas relatively unaffected by pumping generally vary 3 or 4 feet seasonally, as shown by Fitzpatrick (1982, figs. 18 and 19).

Areal variations of the potentiometric surface of the Floridan aquifer system in the Cape Coral area during May 1980 are shown in figure 11. The contours indicate a hydraulic gradient to the southwest. Healy (1962) showed an increase in the artesian head northward from Lee County, suggesting that recharge occurs there. The northeastward shift in the 30- and 40-foot contours (fig. 11) denotes a decrease in artesian pressure and is probably the result of discharge and leakage from the numerous artesian wells along the Caloosahatchee River (Bogges, 1974).

The Floridan aquifer system beneath Cape Coral generally contains water of varying degrees of salinity. Concentrations in water from monitor wells in Cape Coral and adjacent areas range from 400 to 1,900 mg/L for chloride

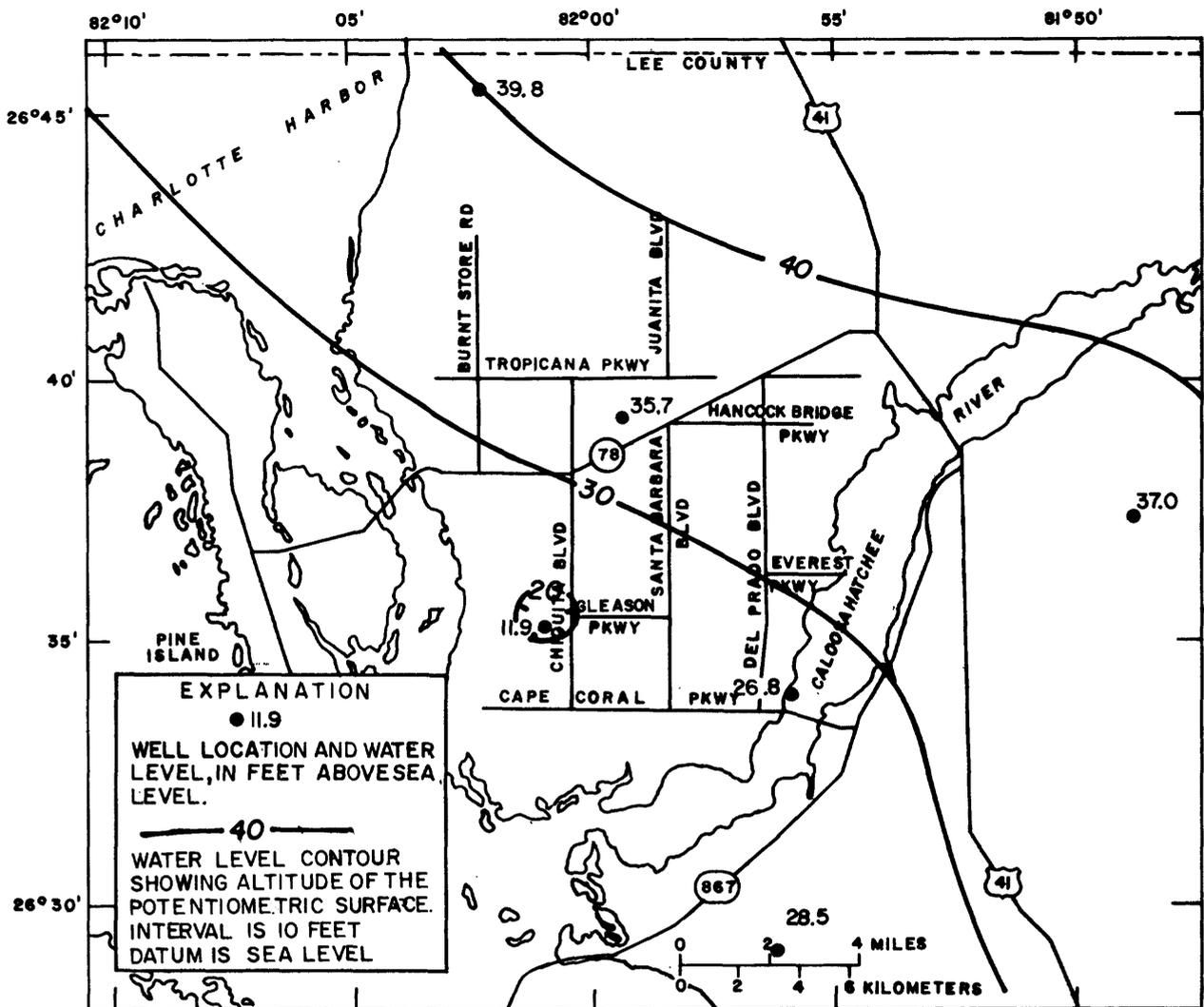


Figure 11.--Contours of the potentiometric surface of the Floridan aquifer system from wells that tap the lower limestone unit of the Hawthorn Formation, near the end of the dry season, May 1980.

and from 1,190 to 4,230 mg/L for dissolved solids (Fitzpatrick, 1982, table 7). Chloride data from Boggess (1974) showed concentrations ranging between 500 and 1,000 mg/L and a maximum of 2,380 mg/L in wells in the Cape Coral area that tap one or both units. Variations in the water quality can be attributed to the well locations, differences in length and depth of open borehole intervals, and differences in the rate of contribution of flow from the Floridan aquifer system.

SALINE-WATER INTRUSION IN THE UPPER LIMESTONE UNIT

Progressively larger segments of the upper limestone unit have been contaminated with saline water due to downward, upward, and lateral intrusion. A prime indicator of saline-water intrusion is chloride concentration in wells. Chloride concentrations in selected wells tapping the upper limestone unit, sampled during 1978-80, are shown in figure 12. Where intrusion has not occurred, chloride concentrations range from about 40 to 100 mg/L. Greater concentrations of chloride generally indicate saline-water intrusion. In much of the area unaffected by saline-water contamination, the potential exists for intrusion through lateral movement of saline water from areas of contamination, or through upward or downward movement from saline units.

Areas where intrusion is known to have occurred are circumscribed in figure 12, and the distributions of chlorides are delineated, by area, by lines of equal chloride concentration in figures 13 to 18. These lines generally encircle an intrusion source within which chloride concentration decreases with distance outward from that source. Thus, certain determinations and inferences can be made regarding the intrusion source and its effect on the water quality in the upper limestone unit including: (1) approximate location of the intrusion source, (2) extent of contamination in the upper limestone unit related to the intrusion source, and (3) direction of the saline-water movement from the source.

In places, upward or downward intrusion can be identified by the disposition of lines of equal chloride concentration around a source. Individual areas contaminated by deep wells through upward intrusion generally are more widespread than those contaminated by individual wells through downward intrusion. This is because many of the wells that tap the lower limestone unit are used for irrigation, are more than 40 years old, and because upward flow of saline water was unobstructed through the uncased section of the wells. Also, the hydraulic gradient between the Floridan unit and the intermediate unit is usually greater than that between the upper limestone unit and the surficial aquifer system. In some places, relatively large areas of the upper limestone unit are affected by downward intrusion of saline water due to many contaminating wells simultaneously leaking saline water. The source of intrusion can also frequently be defined by maximum chloride concentrations in an area of contamination. Wells tapping the upper limestone unit in areas where downward intrusion has occurred, commonly contain chloride concentrations of several thousand milligrams per liter. In areas where upward intrusion has occurred, the maximum chloride concentrations would not exceed levels in the deeper producing units, generally ranging between 500 and 1,000 mg/L.

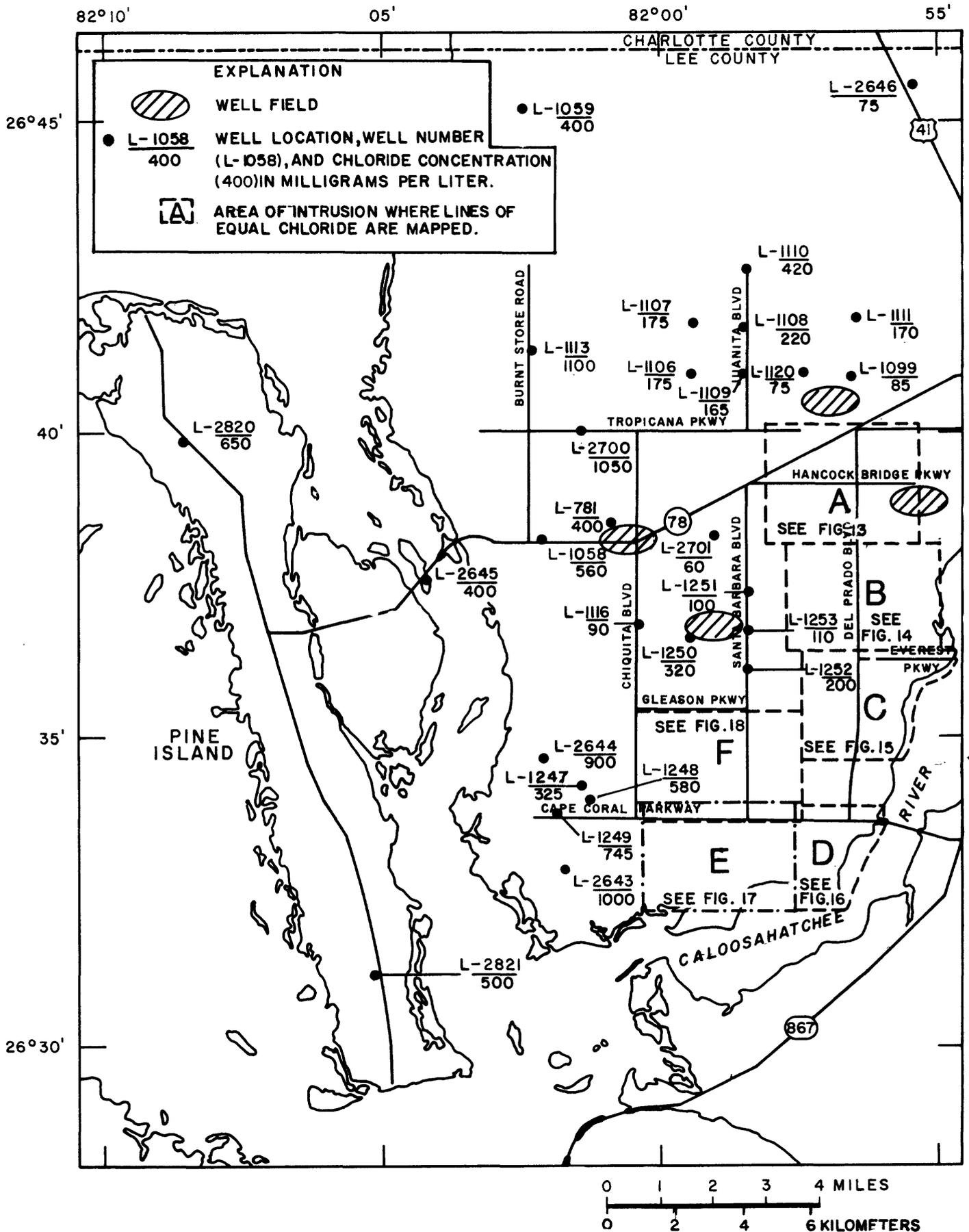


Figure 12.--Boundaries of insets A through F (figs. 13-18) and chloride concentration in water from wells tapping the upper limestone unit.

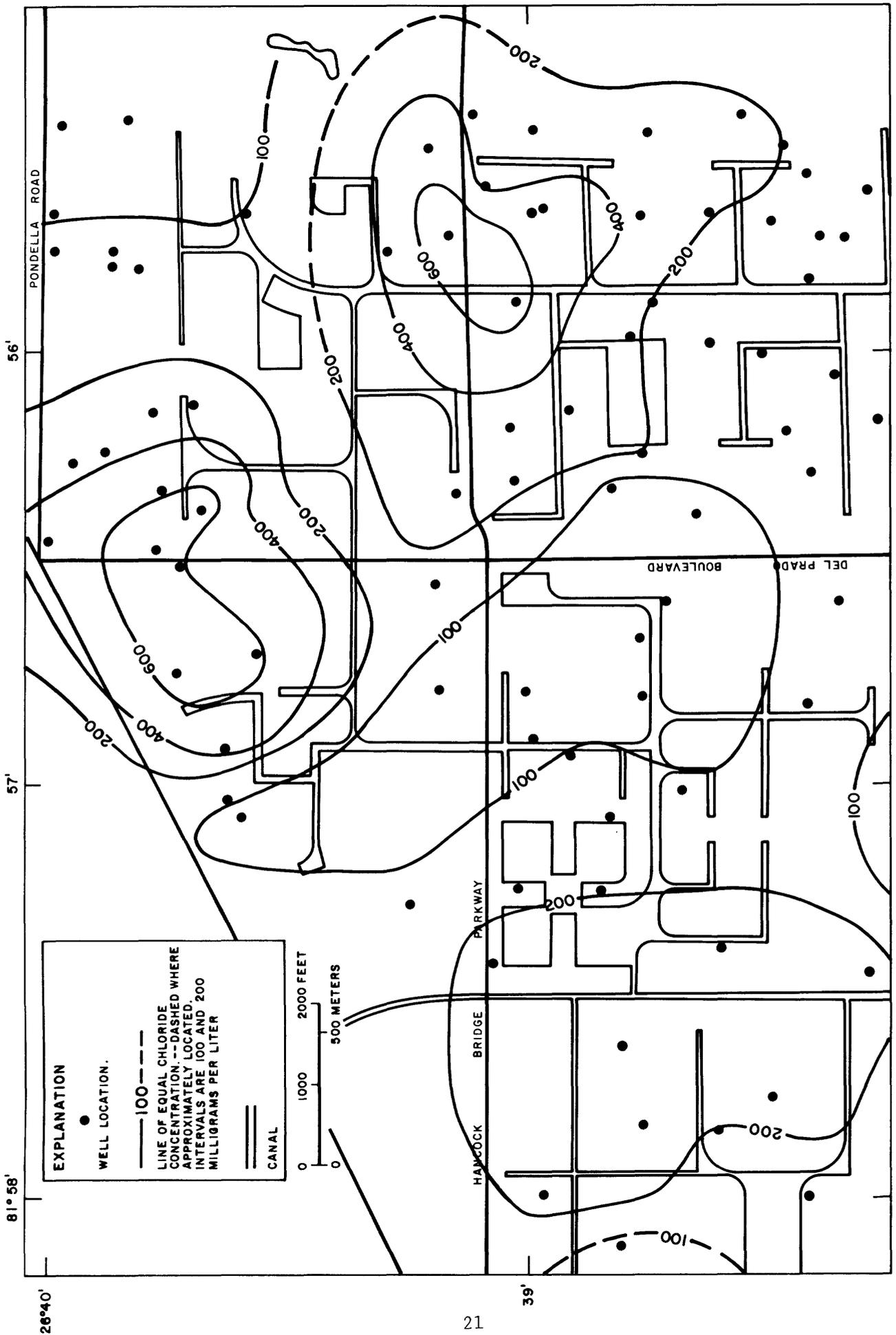


Figure 13. -- Lines of equal chloride concentration in water from selected wells that tap the upper limestone unit in inset area A (see fig. 12), 1979-81.

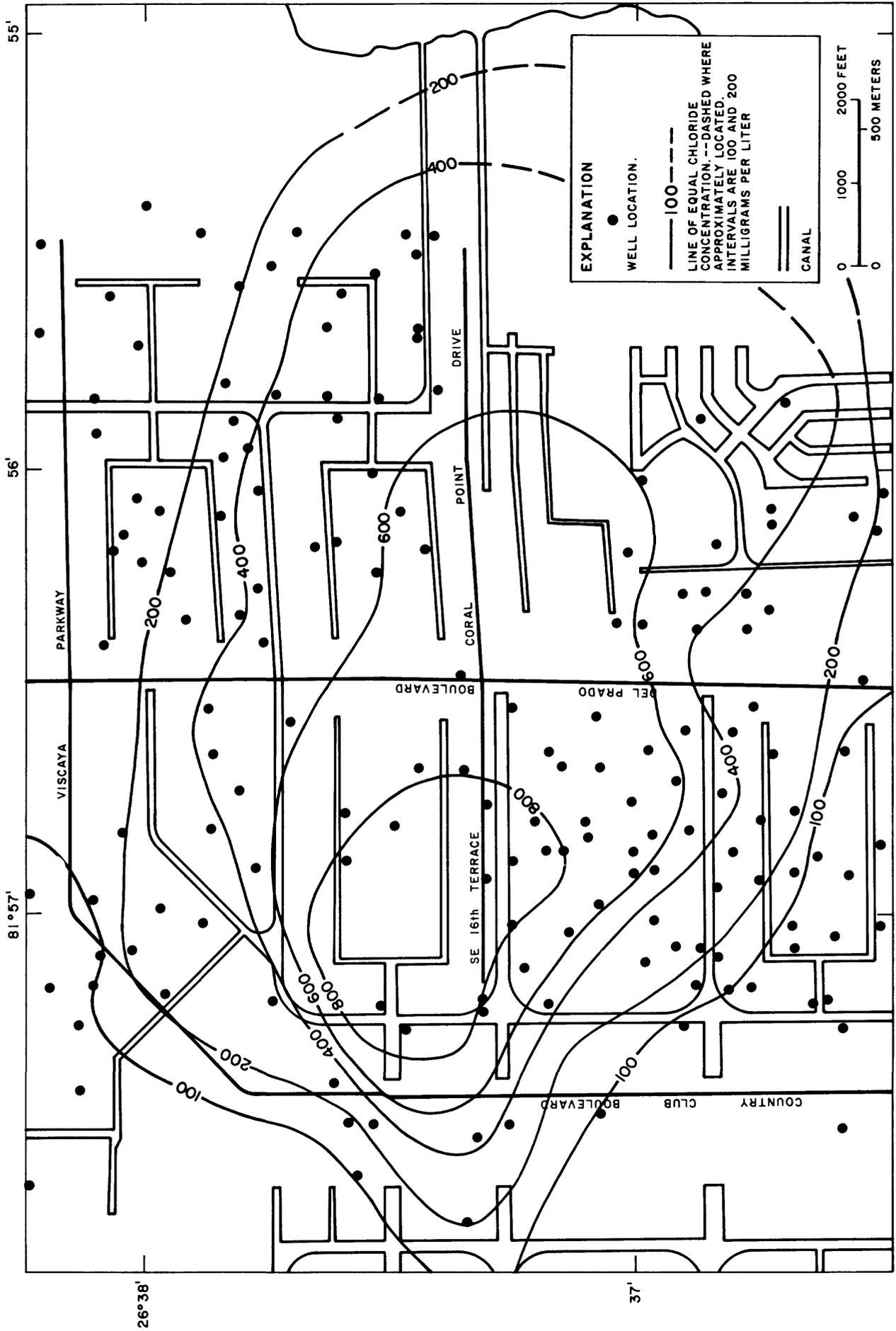


Figure 14.--Lines of equal chloride concentration in water from selected wells that tap the upper limestone unit in inset area B (see fig. 12), 1979-81.

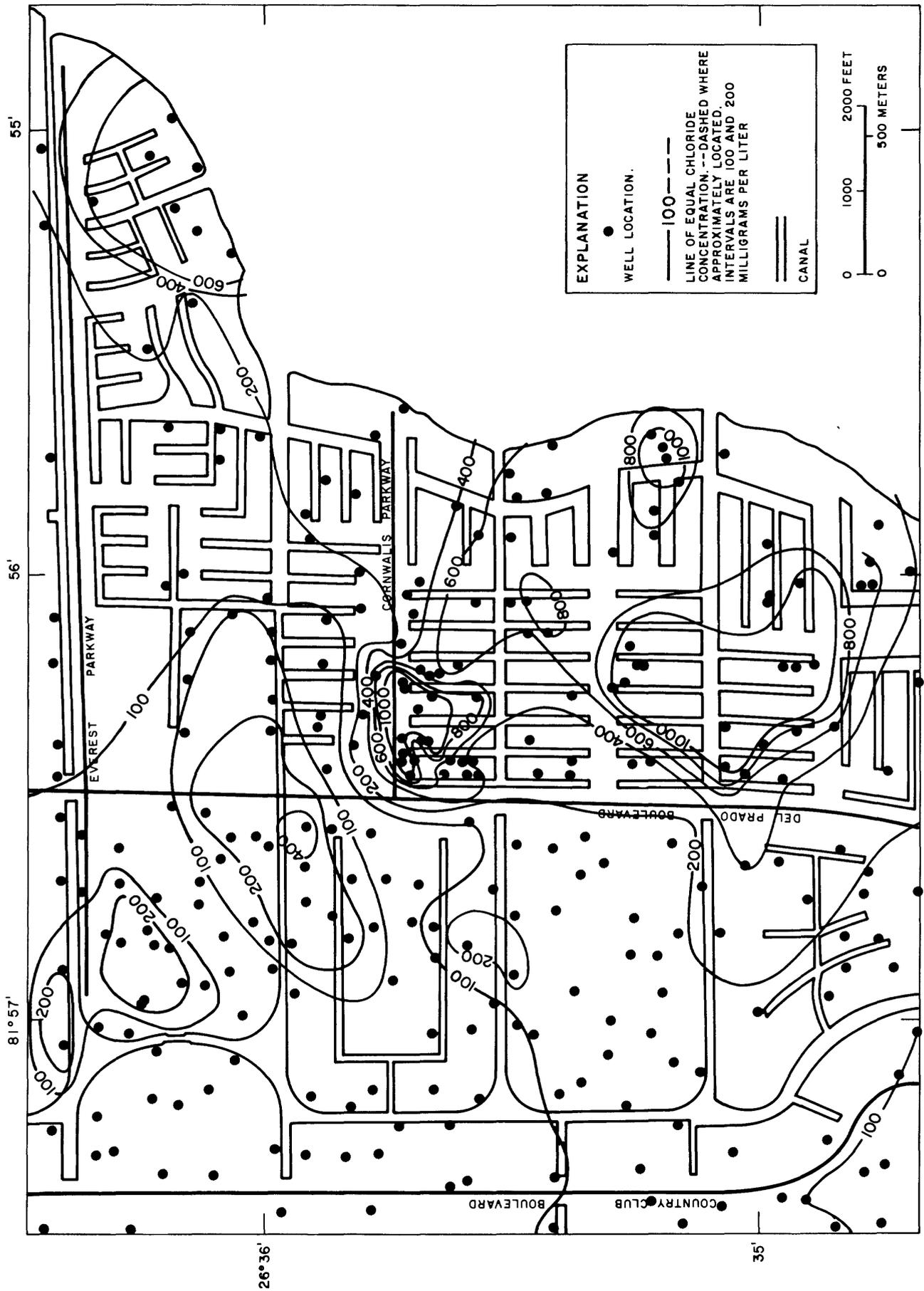


Figure 15. --Lines of equal chloride concentration in water from selected wells that tap the upper limestone unit in inset area C (see fig. 12), 1979-81.

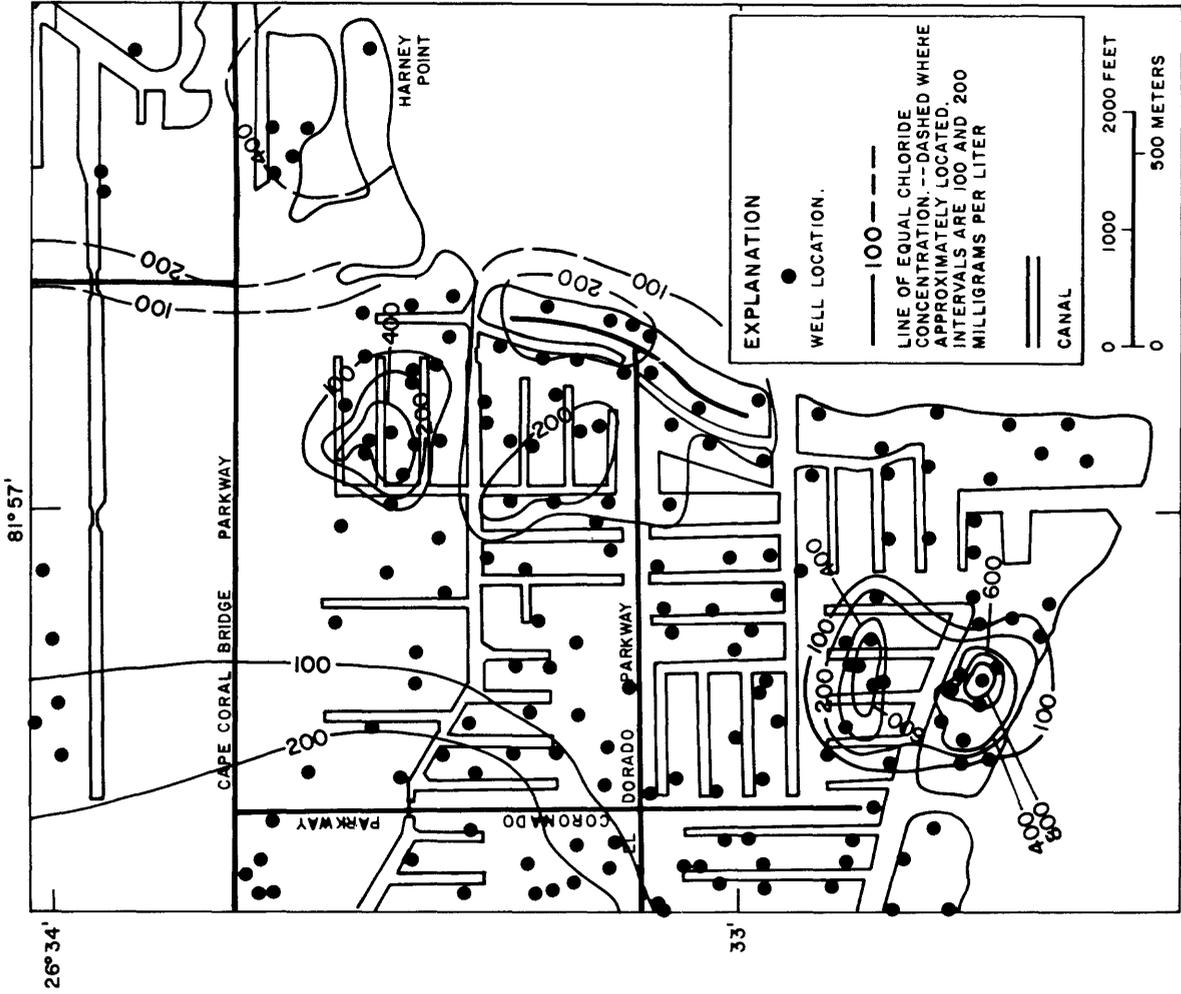


Figure 16.--Lines of equal chloride in water from selected wells that tap the upper limestone unit in inset area D (see fig. 12), 1979-81.

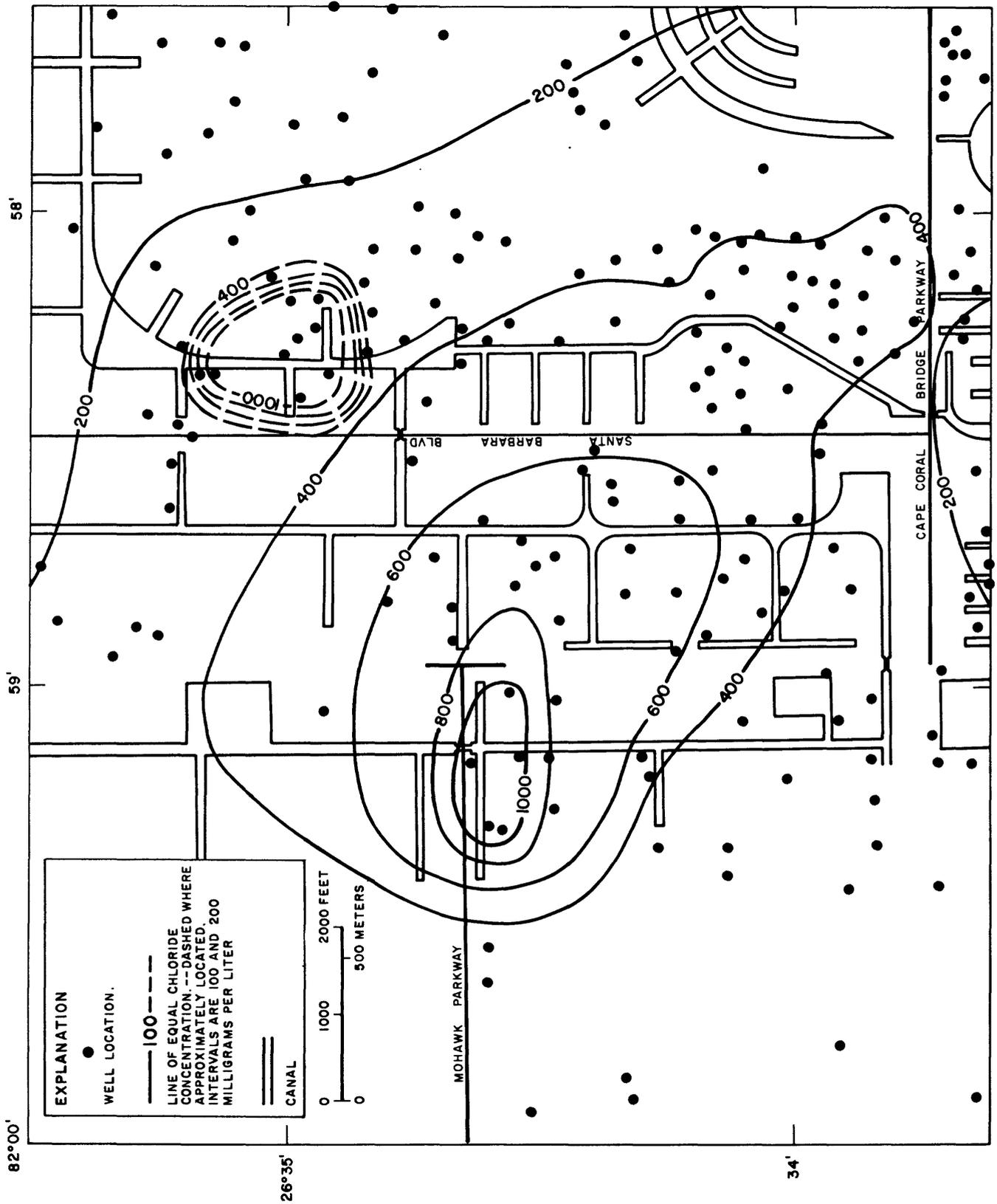


Figure 18.--Lines of equal chloride concentration in water from selected wells that tap the upper limestone unit in inset area F (see fig. 12), 1979-81.

Downward Intrusion

The downward movement of highly saline water from the contaminated coastal sectors of the surficial aquifer system to the upper limestone unit is usually through corroded openings in steel well casings or short well casing installations. It has occurred in areas of Cape Coral where: (1) the surficial aquifer system contains saline water, and (2) the hydraulic gradient between the two horizons is downward. The mechanism of downward intrusion related to well casing installation is explained in detail by Boggess and others (1977). Where these conditions are met, leakage of saline water may also occur through the confining layer above the upper limestone unit; however, leakage probably would be at a low rate.

The combined conditions necessary for downward intrusion of saline water do not exist throughout the Cape Coral area. In those areas where the artesian pressure is relatively unaffected by withdrawals, the potentiometric surface in the upper limestone unit is higher than that in the surficial aquifer system, and movement would be upward toward the surficial material. Also, the occurrence of saline water in the surficial aquifer system is not widespread but usually occurs in those areas adjacent to tidal water bodies.

Comparison of the potentiometric surfaces (figs. 3 and 10) indicates areas where the water levels in the surficial aquifer system are higher than those in the upper limestone unit. The shaded area in figure 19 approximates that part of Cape Coral where the hydraulic gradient was downward during the low water conditions of May 1980. The areal extent where this condition exists fluctuates along the northern and western fringes, primarily in response to seasonal changes in withdrawals from the upper limestone unit.

In parts of this area of potential downward movement, highly saline water occurs in the surficial aquifer system. These areas are south of Everest Parkway and east of Del Prado Boulevard, as denoted by the hachured pattern in figure 19. The occurrence of saline water in the remaining area of downward gradient is limited to those parts of the surficial aquifer system adjacent to tidal canals. Variations in salinity within the saline part of the surficial materials and the amount of head difference between the surficial aquifer system and the intermediate aquifer system influence the potential impact on the intermediate aquifer system.

Effects of downward intrusion are most severe in those areas with the highest potential; that is, south of Everest Parkway and east of Del Prado Boulevard (fig. 15) and in areas south of Cape Coral Parkway (fig. 16). Downward intrusion through wells within these areas was first documented by Boggess and others (1977, p. 22-27). Chloride concentrations of several thousand milligrams per liter were noted in two localized areas of the upper limestone unit within this boundary.

Downward intrusion east of Del Prado Boulevard (fig. 15) is a result of leakage from several wells. Smaller areas of intrusion west of Del Prado Boulevard are also evident (fig. 15), which may be due to upward or downward intrusion.

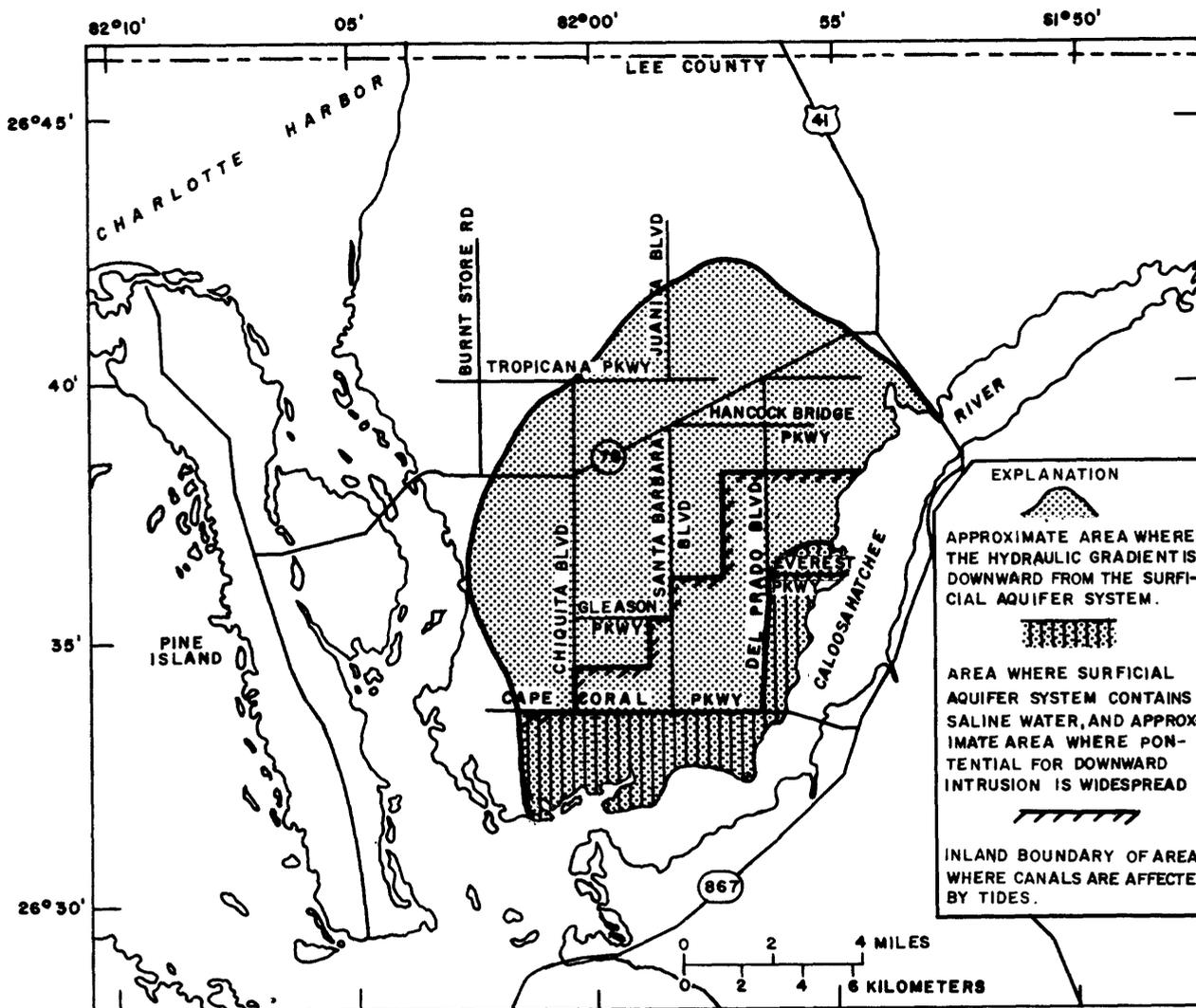


Figure 19.--Areas of potential downward movement of water to the upper limestone unit of the Hawthorn Formation, May 1980.

Downward intrusion south of Cape Coral Parkway (figs. 16, 17) is less widespread than it is east of Del Prado Boulevard. This may be due to smaller differences in hydraulic gradient. In both areas where downward intrusion has occurred, many contaminating wells have been plugged; however, the potential for further downward intrusion probably persists.

Contamination through downward intrusion has also occurred just east of Santa Barbara Boulevard (fig. 18). Wells in this area were sampled before 1976, and chloride concentrations were as high as 9,975 mg/L. Many of the wells sampled then were plugged and could not be resampled.

Upward Intrusion

The upward movement of saline water from the Floridan aquifer system to the upper limestone unit has occurred throughout Cape Coral through the open bore in wells that tap both limestone units. The potential exists for upward intrusion along open bore holes in wells where the Floridan aquifer system contains saline water, and its potentiometric surface is higher than that of the upper limestone unit. The mechanics of upward intrusion was explained in detail by Boggess and others (1977). The required hydrologic conditions for upward intrusion generally exist throughout the Cape Coral area. The potentiometric surface of the Floridan aquifer system is generally at least 20 to 25 feet higher than that in the upper limestone unit. Furthermore, saline water occurs throughout the Floridan aquifer system beneath Cape Coral. Some direct upward leakage of saline water probably occurs through the intervening confining layer. However, this leakage would be at a very low rate and would not be expected to have a significant impact.

Two, and possibly three, areas of upward intrusion from point sources are apparent in figure 13. The areas are relatively large; the maximum chloride concentrations are equivalent to those in wells that tap the Floridan aquifer system, and their locations are distant from areas where the potential for downward intrusion is likely (fig. 19).

The high chloride concentration in the western part of the area shown in figure 14 is probably a result of upward intrusion. Although this area is generally where there is potential for downward intrusion, the extent of the contamination is relatively widespread, and the maximum chloride concentrations are within the general range of those in the deeper unit. Some lateral movement of saline water toward the east seems to have occurred.

Contamination in the upper limestone unit in the vicinity of Mohawk Parkway (fig. 18) is also probably due to upward intrusion. Potentially, contamination could be by downward intrusion, but the widespread nature of the intrusion suggests that the source is from below.

High chloride concentrations in some parts of Cape Coral, north of State Road 78 (fig. 12), probably indicate additional areas where the upper limestone unit has been affected by upward intrusion. The areal extent of the saline-water contamination is not defined there. Wells sampled in the western part of Cape Coral (fig. 12) contain high chloride concentrations relative to

unaffected areas in other parts of the city. These high concentrations may, in part, reflect residual seawater from earlier inundations that was not flushed through natural processes over the years.

Lateral Intrusion

Lateral intrusion of saline water into the upper limestone unit of the intermediate aquifer system begins at a contaminating well. Saline water moves out laterally in the permeable aquifer materials, affecting a progressively larger area. Salinity levels are highest adjacent to the contaminating well and decrease with distance from the well. The rate of lateral movement depends largely upon the hydraulic conductivity of the aquifer and the prevailing hydraulic gradient at the contaminating source. Lateral movement is generally not radially symmetrical but, rather, exhibits certain directional preferences.

Potentially, the most severe impact on water quality in the upper limestone unit would be inland movement of seawater, assuming hydraulic connection exists offshore between the upper limestone unit and the Gulf of Mexico. Inland movement would occur if a reversal side of the seaward hydraulic gradient, caused by increased withdrawals, was to extend outward to intersect the area of offshore connection. The potential for inland movement increases as artesian levels decline.

SUMMARY AND CONCLUSIONS

The upper limestone unit of the Hawthorn Formation, the freshwater bearing unit of the intermediate aquifer system, is the principal source of municipal supply for Cape Coral. Many parts of the upper limestone unit no longer contain potable water. Short casings in wells, corroded iron casings, and declining water levels are major problems causing the deterioration of water quality. Although contamination due to well casing problems poses an immediate threat to the freshwater source, the potential for severe long-range impact on the water quality is the inland movement of saltwater along the coastal area. The probability for inland movement increases as water levels progressively decline.

Short casings or corroded casings in wells permit: (1) saline water from the surficial aquifer system to leak downward to the upper limestone unit, and (2) saline water from the lower limestone unit of the Hawthorn Formation, part of the Floridan aquifer system, to move upward into the upper freshwater source under high pressure. A progressive decline in water levels in the upper limestone unit due to increased withdrawals has enhanced the potential for upward or downward intrusion.

The potential areas for downward intrusion are near saline (tidal) surface-water bodies and are predominantly east of Del Prado Boulevard, south of Everest Parkway, and south of Cape Coral Parkway. The potential also exists to the west and north. The potential for upward intrusion exists throughout the Cape Coral area. Downward intrusion has principally occurred

south of Everest Parkway and east of Del Prado Boulevard, and south of Cape Coral Parkway where the highest potential for intrusion exists. Significant downward intrusion has also occurred just east of Santa Barbara Boulevard. A third type of intrusion moves out laterally from the problem well, expanding the contaminated area as dictated by hydraulic gradient and preferred paths of permeability of sediments.

SELECTED REFERENCES

- Boggess, D. H., 1974, Saline ground-water resources of Lee County, Florida: U.S. Geological Survey open-file report FL-74-247, 62 p.
- Boggess, D. H., Missimer, T. M., and O'Donnell, T. H., 1977, Saline-water intrusion related to well construction in Lee County, Florida: U.S. Geological Survey Water-Resources Investigations 77-33, 29 p.
- 1981, Hydrogeologic sections through Lee County and adjacent areas of Hendry and Collier Counties, Florida: U.S. Geological Survey Water-Resources Investigations Open-File Report 81-638.
- Fitzpatrick, D. J., 1982, Water-resources data of the Cape Coral area, Lee County, Florida: U.S. Geological Survey Open-File Report 82-772, 48 p.
- Healy, H. G., 1975, Piezometric surface and areas of artesian flow of the Floridan aquifer in Florida, July 6-17, 1961 (2nd ed.): Florida Bureau of Geology Map Series 4.
- Krieger, R. A., Hatchett, J. L., and Poole, J. L., 1957, Preliminary survey of the saline-water resources of the United States: U.S. Geological Survey Water-Supply Paper 1374, 172 p.
- Lohman, S. W., 1972, Ground-water hydraulics: U.S. Geological Survey Professional Paper 708, 70 p.
- Lohman, S. W., and others, 1972, Definitions of selected ground-water terms - Revisions and conceptual refinements: U.S. Geological Survey Water-Supply Paper 1988, 21 p.
- Sproul, C. R., Boggess, D. H., and Woodard, H. J., 1972, Saline-water intrusion from deep artesian sources in the McGregor Isles area of Lee County, Florida: Florida Bureau of Geology Information Circular 75, 34 p.