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by

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Groundwater Division
Resource Planning Department
South Florida Water Management District
West Palm Beach, Florida

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EXECUTIVE SUMMARY

The purpose of this study was to assess the water resource availability of the mid and lower Hawthorn aquifers in the Cape Coral area based on existing information.

Data compilation was a major task in the study. Geologic logs were used to identify the location of the aquifers and their confining layers at all points available. All known aquifer transmissivities and storage coefficients were collected. Although they were limited for the lower Hawthorn aquifer, this information was used to map out the details of the aquifer system. In addition, reliability of each of the parameters was quantified.

Historical and projected population of the area was compiled to estimate different water requirement scenarios in future years. Distribution of future irrigation requirements were correlated to the projected future population distribution. Seasonal water use variations were also considered.

The U.S. Geological Survey two-dimensional groundwater flow model was used for this study. Each aquifer was considered to be semi-confined and independent with differing leakance levels. Different simulation scenarios are presented in map form in the text.

Based on this study, it is concluded that approximately 10.5 MGD can be pumped by Cape Coral from the lower Hawthorn aquifer through 1990 without major impacts on the water users in the area. It is recommended that the results obtained for the lower Hawthorn aquifer be verified by field observations through the installation of a monitoring network. Additionally, data collection should be initiated to compile hydraulic properties and water quality data within the Floridan Aquifer System for more precise predictions of future impacts.

The mid-Hawthorn aquifer is currently being overstressed with 80 percent of the water withdrawn coming from leakance from other aquifers. Continued excessive pumpage of the mid-Hawthorn in this area may result in wellfields running dry and/or irreversible deterioration of water quality to below public drinking water standards. Therefore, alternate sources of water to minimize the irrigation and municipal withdrawal from the mid-Hawthorn aquifer is recommended.

ACKNOWLEDGEMENTS

This investigation was initiated by the South Florida Water Management District in response to its long range planning responsibilities in water management and an awareness of acute groundwater problems in the Cape Coral area. Preparation of this report was carried out under the direction and supervision of Nagendra Khanal, P.E., Director of the Groundwater Division, Resource Planning Department. His guidance is gratefully acknowledged. Appreciation is also extended to Hedy Marshall, Barbara Dickey, and Kevin Rodberg of the Groundwater Division for their support which was essential to the completion of this report.

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Pete Cameau of the Cape Coral Reverse Osmosis Plant, Harold Fine of Florida Cities Water Company, Bob Hollander of the Island Water Association, and Larry Hollander of the Pine Island Water Association supplied pumpage and other pertinent information on their respective wellfields. Their assistance is gratefully acknowledged.

Tom Missimer of Missimer & Associates contributions to this report are also gratefully acknowledged.

PURPOSE AND SCOPE

The South Florida Water Management District initiated this study because of the continued decline of water levels in the mid-Hawthorn aquifer and a request by the City of Cape Coral for additional quantities of water from the lower Hawthorn aquifer. This report follows an interim summary of the hydrogeologic conditions in this area which was presented to the Governing Board in April of 1984. The purpose of this study is to:

1. Accumulate existing data on the hydrogeology of western Lee County.
2. Review population projections from several sources and develop future water requirement estimates.
3. Calibrate numerical models of the mid and lower Hawthorn aquifers.
4. Determine the impact of future water withdrawals on the aquifers using the calibrated numerical models.

This study is limited to the assessment of water resources for the mid and lower Hawthorn aquifers in the Cape Coral area. The U.S. Geological Survey two-dimensional flow model was used for groundwater simulations. Numerous simulation runs were made to determine the impact of withdrawals on the aquifers until the year 2005. In addition, aquifer parameters were varied in model runs, due to an insufficiency in existing data, to determine their effects on the potentiometric surfaces.

INTRODUCTION

The area of concern in this study is the western half of Lee County, Florida, specifically a 135 square mile area within latitudes 26°48'00"; 26°18'30" and longitudes 82°16'00"; 81°46'00" (Figure 1). Of primary concern in this area is Cape Coral, bordered by the Caloosahatchee River on the east and by the Gulf of Mexico on the west.

The area now occupied by Cape Coral was originally a low lying pineland subject to frequent flooding throughout the year. It was cleared and platted in the early 1960's for residential development. To alleviate the problem of flooding and to provide residents with access to the Gulf of Mexico, a complex network of canals was established throughout the development. Early residents utilized the mid-Hawthorn aquifer as a source of potable and irrigation water.

By the mid 1970's, several municipal wellfields were developed into the mid-Hawthorn aquifer to supply residents with potable water. The combined effects of municipal, domestic, and irrigational use of the mid-Hawthorn over the years resulted in large scale declines in the potentiometric surface of the aquifer. By the late 1970's it had become apparent that the mid-Hawthorn alone could not support the rapid growth in Cape Coral and a 3.0 MGD reverse osmosis (R.O.) plant was constructed and upgraded to 5.0 MGD in 1982 to withdraw and desalt water from the lower Hawthorn aquifer for potable supply. Despite the construction of the R.O. plant, water levels in the mid-Hawthorn aquifer continued to decline into the 1980's. In 1984, failure of the R.O. membranes resulted in additional pumpage from the mid-Hawthorn wellfields. Under the increased stress, the potentiometric levels within the mid-Hawthorn wellfields dropped below the base of well casings in the majority of the existing wells causing an emergency water shortage.

To prevent this problem from occurring in the future, the City of Cape Coral has approved the expansion of the existing R.O. plant to meet future

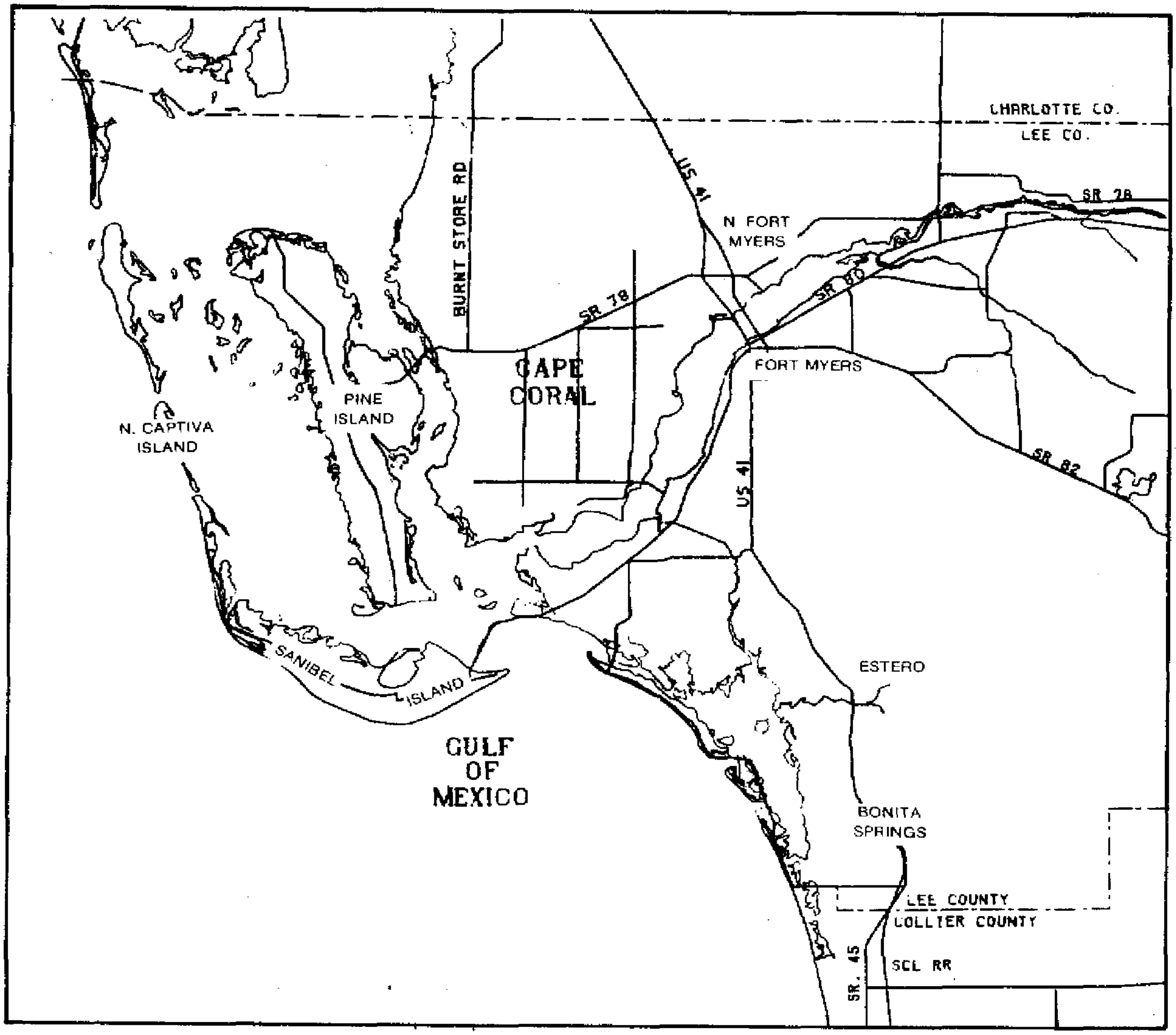


Figure 1 LOCATION OF STUDY AREA

potable needs. Therefore, the development potential of both the mid and lower Hawthorn aquifers needs to be defined in order to provide technical support to water managers.

GEOLOGY

Figure 2 shows the major stratigraphic and hydrogeologic units of concern in the study area. The stratigraphic column was constructed from a continuous core drilled in eastern Lee County and the descriptive terminology is based upon work done by Wedderburn, et. al. (1982) and Scott and Knapp (in press). The Suwannee Limestone, Tampa Formation, Hawthorn Formation, Tamiami Formation, and undifferentiated terrace deposits are the major stratigraphic units encountered in the upper 1000 feet of sediment. Structural contour and isopach maps referred to in this and following sections are shown in Appendix I. These maps were constructed using the statistical methods discussed later in the text. The majority of data points used to construct these maps were taken in the Cape Coral area alone (Figure 3). As a result of the limited data, even with the use of statistical methods, the maps become inaccurate outside of the Cape Coral area. For a more accurate regional picture of the hydrogeologic units in Lee County the reader is directed to Wedderburn et. al., 1982.

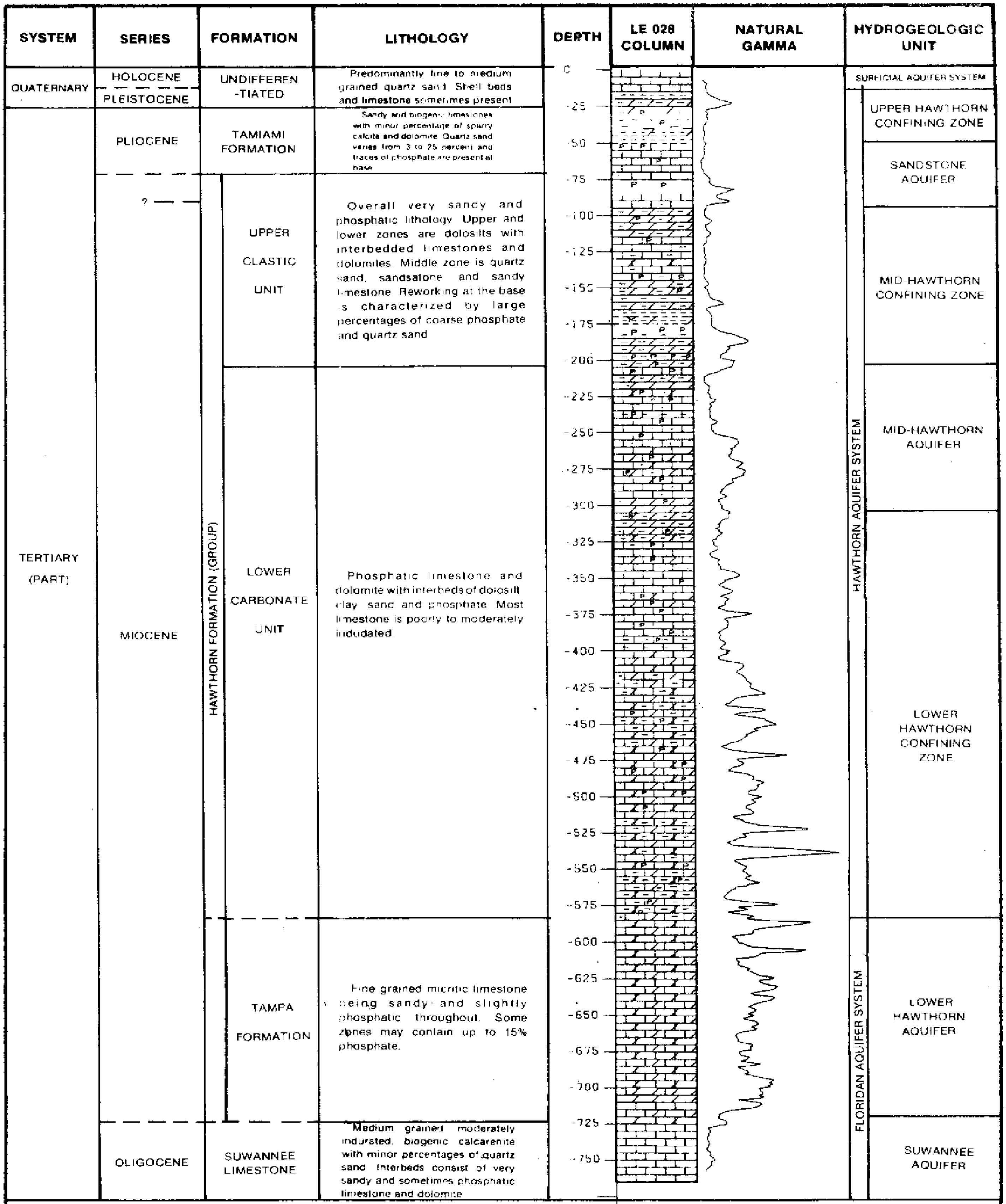
CENOZOIC ERATHEM

Oligocene Series

Suwannee Limestone

The term "Suwannee Limestone" was established by Cooke and Mansfield (1936) for limestone exposures along the Suwannee River, from White Springs to the confluence with the Withlacoochee River. These exposures contain the echinoid Rhyncholampas (cassidulus) gouldii, Bouve. Within the type area, the formation normally occurs as a very pale orange, moderately indurated, very porous calcarenite with numerous foraminifera, mollusks, and echinoids present (Ceryak, Knapp, and Burnsen, 1983).

The Suwannee Limestone in the Lee County area shows many variations from that of the type area. It is predominantly a very pale orange to tan medium



SYSTEM	SERIES	FORMATION		LITHOLOGY
QUATERNARY	HOLOCENE PLEISTOCENE	UNDIFFERENTIATED		Predominantly fine to medium grained quartz sand. Shell beds and limestone sometimes present
TERTIARY (PART)	PLIOCENE	TAMIAMI FORMATION		Sandy and biogenic limestones with minor percentage of sparry calcite and dolomite. Quartz sand varies from 3 to 25 percent and traces of phosphate are present at base
	?	HAWTHORN FORMATION (GROUP)	UPPER CLASTIC UNIT	Overall very sandy and phosphatic lithology. Upper and lower zones are dolosilts with interbedded limestones and dolomites. Middle zone is quartz sand, sandsalone and sandy limestone. Reworking at the base is characterized by large percentages of coarse phosphate and quartz sand
	MIOCENE		LOWER CARBONATE UNIT	Phosphatic limestone and dolomite with interbeds of dolosilt clay sand and phosphate. Most limestone is poorly to moderately indurated.
			TAMPA FORMATION	Fine grained micritic limestone being sandy and slightly phosphatic throughout. Some zones may contain up to 15% phosphate.
	OLIGOCENE	SUWANNEE LIMESTONE		Medium grained moderately indurated, biogenic calcarenite with minor percentages of quartz sand. Interbeds consist of very sandy and sometimes phosphatic limestone and dolomite

HYDROGEOLOGIC UNIT	
SURFICIAL AQUIFER SYSTEM	
HAWTHORN AQUIFER SYSTEM	UPPER HAWTHORN CONFINING ZONE
	SANDSTONE AQUIFER
	MID-HAWTHORN CONFINING ZONE
	MID-HAWTHORN AQUIFER
	LOWER HAWTHORN CONFINING ZONE
FLORIDAN AQUIFER SYSTEM	LOWER HAWTHORN AQUIFER
	SUWANNEE AQUIFER

Figure 2 STRATIGRAPHIC CHART

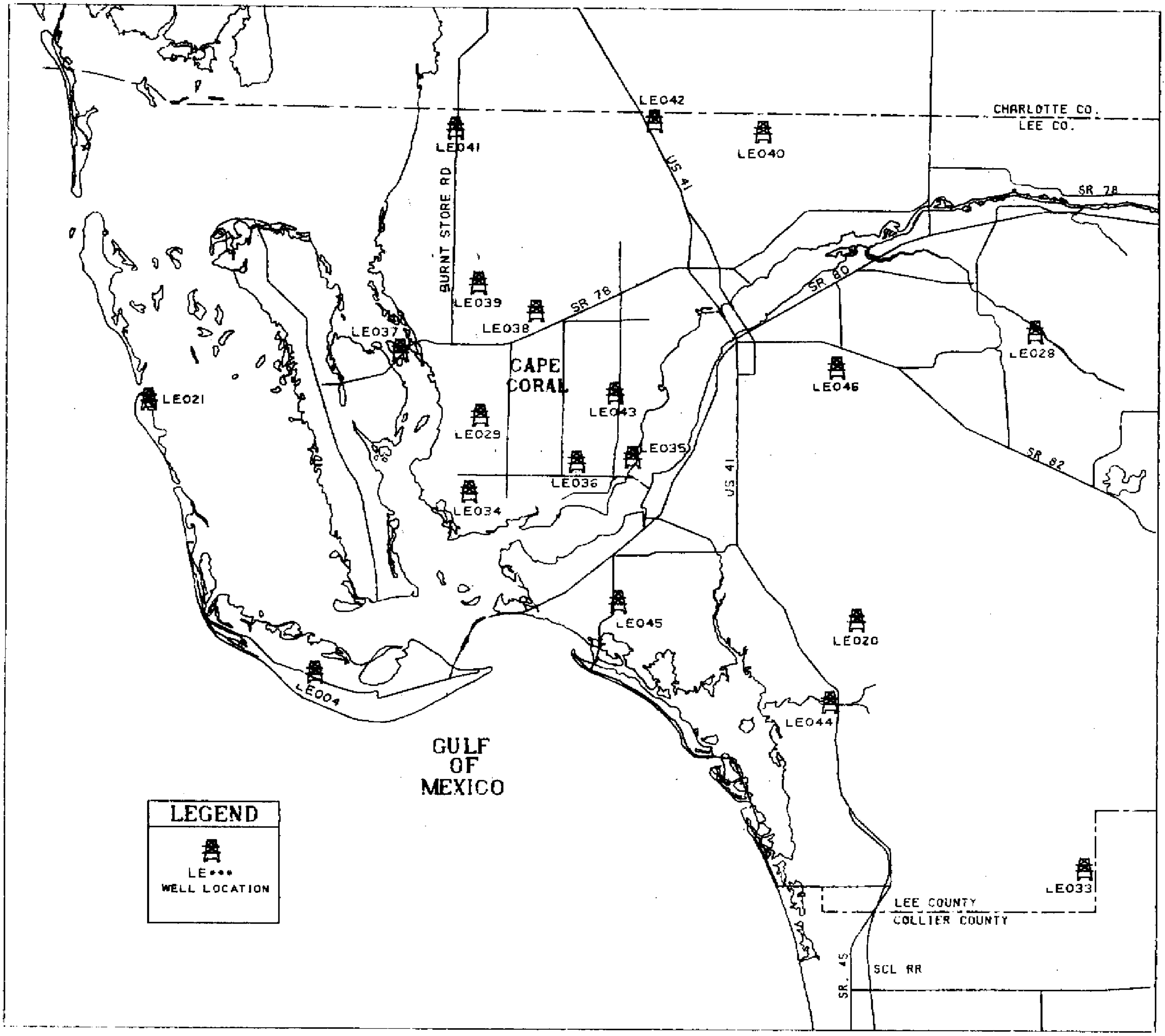


Figure 3 LOCATION OF LITHOLOGIC CONTROL WELLS

grained limestone (calcarenite), but tends to be very sandy and slightly phosphatic. Characteristic fauna that assist in delineating the formation in other areas of Florida are restricted to the lowermost intervals of the Suwannee in Lee County. The unit in Lee County is normally picked on a decrease in radioactivity as depicted on the natural gamma ray logs (Figure 2). Lithologically, however, the beds assigned to the Suwannee are more easily placed within the Tampa Formation (Scott and Knapp, in press). However, for the purposes of this study the top of the Suwannee is picked at the decrease in gamma activity.

The top of the Suwannee Limestone in the study area dips in a southerly direction ranging from -500 ft. NGVD at the Lee-Charlotte county boundary to near -750 ft. NGVD in the Ft. Myers Beach area (Wedderburn, et. al., 1982). The boundary between the Suwannee Limestone and the overlying Tampa is gradational and the two units could easily be placed within the same formation. The base of the Suwannee is known to lie disconformably upon limestones of the Ocala Group (Wedderburn, et. al., 1982) in this area. Within the study area the base of this unit probably lies between -900 ft. and -1200 ft. NGVD, although data is sparse.

Miocene Series

Tampa Formation/Hawthorn Formation

Miocene age sediments within the study area are placed within two formations, the Tampa and the Hawthorn (Figure 2). This is done in light of the recent proposal by Scott and Knapp (in press) to upgrade the Hawthorn to group status. The group can be divided into at least three lithologic units within the study area. In descending order, these formations are: an upper clastic, a lower carbonate, and the Tampa Formation.

The name "Tampa Formation" was first used by L. C. Johnson in 1888 for limestones that crop out near the City of Tampa in Hillsborough County, Florida. Within the Lee County area, Sproul (1972) described the "Tampa Limestone" as a "grayish yellow sandy limestone with some black phosphorite...". Missimer and Banks (1981) and Wedderburn, et. al. (1982), chose not to identify the Tampa as a separate formation and included it within the Hawthorn Formation. This was necessary because of the high percentages of phosphate present in the strata. Scott and Knapp (in press) chose to use the term Tampa Formation when correlating the Hawthorn "Group" within south Florida, because it showed marked differences from the lithologies in the upper portion of the Hawthorn. Despite the high sand and phosphate content within this zone, its overall texture, fauna, and lithology is equatable to the Tampa Formation in the type area. The Tampa Formation in southwest Florida and the study area is a white to very pale orange, biogenic, micritic very fine grained limestone that contains up to 10 percent quartz sand. Phosphate content varies from a trace to two percent, but in some intervals it may be as high as 15 percent (Scott and Knapp, in press). Dolomite beds occur infrequently throughout the unit.

The top of the Tampa Formation dips in a southerly direction from the Lee/Charlotte county boundary through the study area. The top has been logged as shallow as -350 ft. NGVD and as deep as -650 ft. NGVD in this area. The average thickness is generally 150 feet and normally does not exceed 200 feet. As mentioned previously, the contact between this unit and the underlying Suwannee is conformable and gradational in nature. In the future, the upper portion of the Suwannee will probably be included within the Tampa on the basis of sand content, texture, and microfauna.

Dall and Harris (1892) first used the term "Hawthorn beds" for phosphatic sediments being quarried for fertilizer near the town of Hawthorne, Alachua County, Florida.

The Hawthorn has long been a confusing unit in southwest Florida and Lee County in particular. The reason being that most author's have chosen to use Parker's (1955) definition of the Hawthorn and the overlying Tamiami. This definition does not comply with the U. S. Code of Stratigraphic Nomenclature (Hunter and Wise, 1980, 1980a). In recognition of this discrepancy, Wedderburn, et. al. (1982) and Scott and Knapp (in press) have placed the upper boundary of the Hawthorn in Lee County at the first occurence of a "green to gray phosphatic, sandy, slightly clayey dolosilt". No formal names have been applied to any beds within the Hawthorn in this area, although informal units such as the Cape Coral Clay, Lehigh Acres Sandstone, Ft. Myers Clay, and Twelve Mile Slough Limestone, have been associated with some beds (Missimer, 1984). These informal units, although useful on a local scale are difficult to correlate regionally.

More recently, the formation has been discussed in detail by Scott (1981) and Scott and Knapp (in press). They described the Hawthorn as "consisting of various mixtures of clay, quartz sand, carbonates (dolomite to limestone) and phosphates". In the latter publication the Hawthorn is discussed informally as a group and the recommendation is made to raise it to such.

On a regional scale, two units are recognized in southern Florida. These units, an upper clastic unit and a lower carbonate unit, are easily discerned in the study area. Figure 4 shows a stratigraphic column constructed from a continuous core drilled at the Cape Coral Reverse Osmosis Plant. The upper clastic unit was penetrated at 16 feet below land surface. It was 75 feet thick and consisted primarily of an olive gray, phosphatic, sandy and clayey dolosilt. The lower carbonate unit was logged from 90 feet to 425 feet below land surface. It consisted primarily of sandy and phosphatic dolomitic limestone, but was lithologically variable with interbeds of clayey sand and dolosilt.

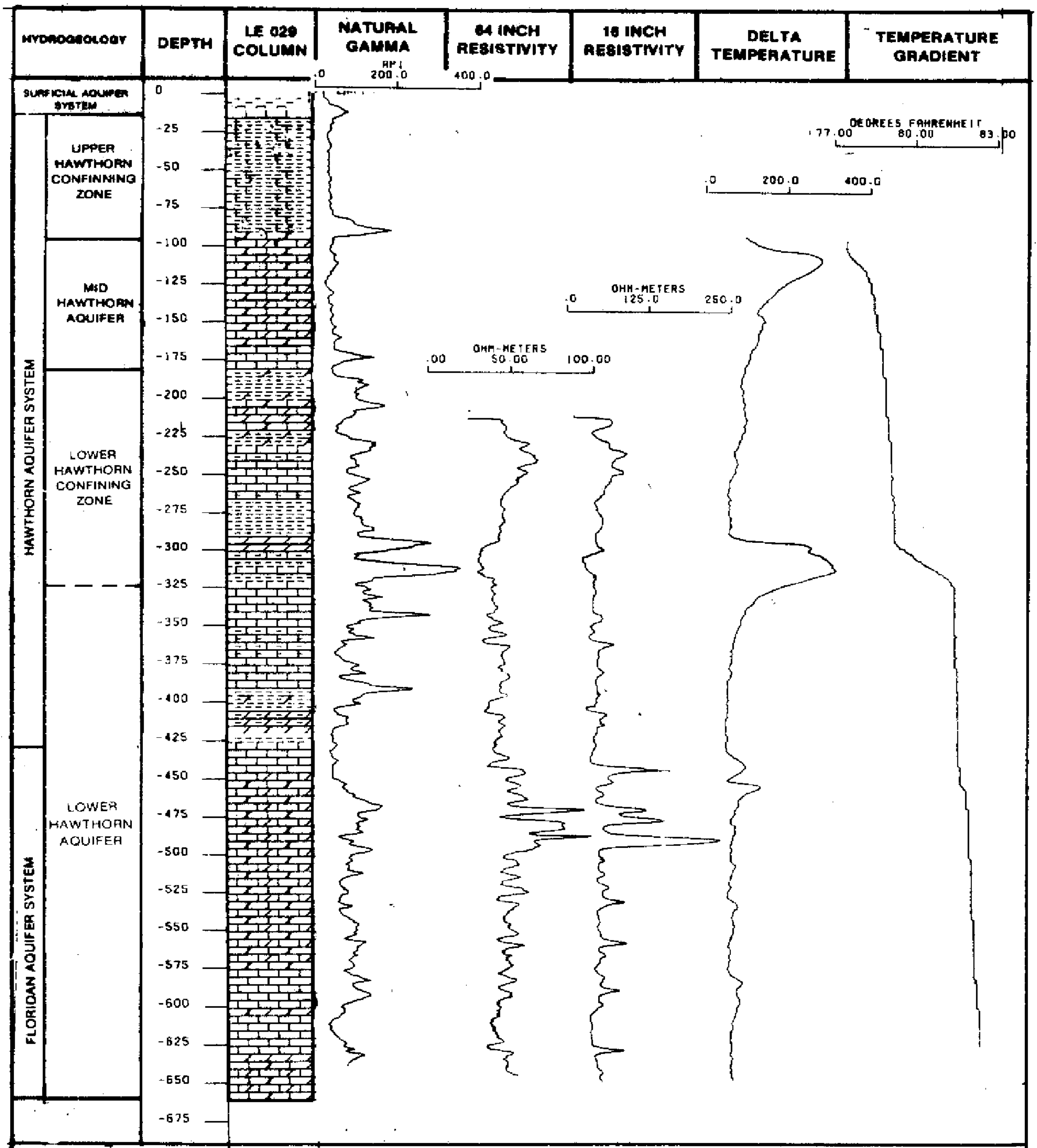


Figure 4 CAPE CORAL STRATIGRAPHIC CHART

Miocene/Pliocene Series

Tamiami Formation

The term "Tamiami Limestone" was proposed by Mansfield (1939) for a fossiliferous sandy limestone about 25 feet thick penetrated in shallow ditches along the Tamiami Trail (U. S. Route 41) in parts of Collier and Monroe Counties, Florida. The literature concerning this unit is extensive and the reader who desires more detail of its history is referred to Wedderburn, et. al. (1982) and Peck, et. al. (1979). In Lee County the base of the Tamiami was recognized at a major disconformity (Missimer, 1978) that has since been shown to be within the Hawthorn (Missimer and Banks, 1981, Wedderburn, et. al., 1982 and Scott and Knapp (in press)). The lower boundary of the Tamiami in the study area is recognized at the contact between the sandy limestones of the Tamiami and the olive gray, phosphatic, very sandy and clayey dolosilts of the Hawthorn.

Within the study area the Tamiami does not exceed 50 feet in thickness and averages about 20 feet. It normally occurs as a moderate to well indurated, biogenic, medium grained, fossiliferous, sandy limestone (Ochopee) or a poorly indurated slightly sandy, locally somewhat phosphatic, fossiliferous limestone (Buckingham). These two members appear to represent laterally equivalent facies.

Pleistocene/Holocene Series

Undifferentiated

Undifferentiated deposits of varying thicknesses and lithology blanket the surface of the Tamiami Formation throughout the study area. A large part of these deposits is composed of quartz sand with minor percentages of shell and clay (Knapp, 1980 and Lane, 1981). The sand is subangular with medium sphericity and sometimes frosted. In addition to the sand, numerous interfingering limestones, sandstones, and shell beds are present locally.

HYDROGEOLOGY

The sequence of rocks underlying the study area can be grouped into three major aquifer systems, the Surficial, Hawthorn, and Floridan (Figure 2). The Surficial Aquifer System includes all water bearing strata from land surface to the top of the Hawthorn Formation. The Hawthorn Aquifer System contains at least two major aquifers (the Sandstone and mid-Hawthorn), but the system acts as a confining layer to the Floridan. The Floridan Aquifer System is the largest regional water bearing unit in the southeastern United States. The upper two aquifers within this system in the study area are the lower Hawthorn and Suwannee.

Various problems arise with the terminology used by different government agencies and consultants when addressing the aquifers within the study area. Figure 5 shows the relationships of these designations within the study area. The two aquifers of primary concern to this study are the mid and lower Hawthorn.

Surficial Aquifer System

The Surficial Aquifer System in this area normally occurs as a water table aquifer. In areas further to the east and south it contains a lower semi-unconfined aquifer referred to here as the lower Tamiami aquifer. The beds comprising the Surficial Aquifer System in the study area are predominantly medium to fine grained sands with varying percentages of shell and sometimes calcareous clay. These beds exhibit intergranular porosity estimated between 15 and 40 percent with a moderate permeability. The basal beds within the system are normally sandy limestones assigned to the Tamiami Formation. These limestones sometimes exhibit high solution, moldic and channel porosity, but usually are moderately to poorly indurated and very fine grained with overall low permeability. They are relatively thin in Cape Coral, not exceeding 15 feet, and do not represent a significant water bearing unit.

The thickness of the Surficial Aquifer System averages about 30 feet in the Cape Coral area and increases to the southwest (Wedderburn, et al., 1982).

Water levels of the Surficial Aquifer System normally do not exceed +10 ft. NGVD in the Cape Coral area. The Matlachee Pass and Caloosahatchee River act as regional base levels for this system and aquifer gradients are towards these surface water bodies. However, during high tides, hurricanes, or other high rainfall events, the possibility exists for gradient reversals from surface water bodies.

The major source of freshwater recharge to the aquifer system is by direct infiltration of precipitation. This is evidenced by higher water levels during the wet season and the rapid response of hydrographs to rainfall events. Surface water bodies such as rockpits, canals, lakes, the Caloosahatchee River and adjacent coastal waters are another source of recharge when their water levels exceed that of the Surficial Aquifer System.

Estimated transmissivities for the Surficial Aquifer System in Cape Coral range from 10,000 to 50,000 gpd/ft. However, due to the relative thinness of the aquifer along with the proximity of saltwater, this system has poor potential for large scale water production.

The water quality of the Surficial Aquifer System in Cape Coral is generally within potable standards and is characterized by high dissolved iron and variable chloride concentrations. Chloride concentrations range from 50 to 10,000 mg/l with the highest levels occurring adjacent to the coast. Iron concentrations range between .1 and 1.0 mg/l, imparting a disagreeable taste as well as causing staining of fixtures, laundry and buildings.

Hawthorn Aquifer System

Within Lee County the Hawthorn Aquifer System consists of five zones (Figure 2). All of these zones tend to be sandy, phosphatic, calcareous and dolomitic. The confining zones are predominantly clayey dolosilts usually interbedded with shell beds or poorly indurated limestones. The water producing zones are formed by limestone, calcareous quartz sand, sandstone and dolomite. In the Cape Coral area three of these five zones are present (Figure 4). These zones are the mid-Hawthorn confining zone, mid-Hawthorn aquifer and lower Hawthorn confining zone. The mid-Hawthorn confining zone is present wholely within the upper clastic unit of the Hawthorn Formation. The mid-Hawthorn aquifer and the lower Hawthorn confining zone are part of the lower carbonate unit of the Hawthorn Formation.

The mid-Hawthorn confining zone in the study area has an overall very low permeability owing to the silt size and dense packing arrangement of matrix components. It is comprised of clayey dolosilts with thin interlayers of quartz sand and phosphate. This unit effectively retards vertical flow of water between the surficial system and the mid-Hawthorn aquifer. In other areas of Lee County the upper clastic unit can be divided into three zones; the upper Hawthorn confining zone, the Sandstone aquifer, and the mid-Hawthorn confining zone (Figure 2). The Sandstone aquifer is a regionally significant water bearing unit, however, it is not present in the Cape Coral area due to erosional and/or depositional processes.

The top of the mid-Hawthorn confining zone occurs between +10.0 ft. NGVD and -72 ft. NGVD in the study area. It dips in a southwesterly direction from the northern perimeter of the study area and attains thickness on the order of 150 feet.

The water producing limestone, dolomites, and sandstones that lie below a regional disconformity (Missimer, 1978) are referred to in this report as the mid-Hawthorn aquifer. This unit is also referred to as the "Upper Hawthorn Aquifer" by the U.S. Geological Survey (Sproul, et al., 1972; Boggess, 1974) and as "Hawthorn Aquifer System Zone 1" by Missimer and Associates (1984) (Figure 5). The term "mid-Hawthorn" (Wedderburn, et al., 1982) is used in recognition of the proper position of the aquifer in the stratigraphic column, as the Sandstone aquifer is the uppermost aquifer within the Hawthorn Formation.

The mid-Hawthorn aquifer is composed primarily of sandy and phosphatic limestones and dolomites that exhibit intergranular, moldic and possible fracture and solution porosities. The reworked zone at the base of the overlying confining beds consisting of quartz and phosphatic sands may also act as part of the aquifer. The aquifer is interbedded with less permeable clayey sands and dolosilts which lower the overall permeability.

The top of the mid-Hawthorn aquifer dips radially from the central portion of the study area. It normally occurs between -150 ft. NGVD and -200 ft. NGVD in the Cape Coral area. The thickness of the aquifer is quite variable and averages around 50 feet. Complex facies patterns within the lower Hawthorn carbonate unit and consequent lithology changes of the aquifer make exact correlations difficult. The aquifer appears to be thickest in the northern Ft. Myers area where it has been described at over 140 feet (Figure 6). In the Cape Coral area it varies between 20 and 60 feet with the thickest sections in the south portion of the city.

Water levels in the mid-Hawthorn in Cape Coral and adjacent areas have been experiencing noticeable declines in response to pumpage from municipal wellfields and other private wells. Pertinent hydrographs of USGS wells are available in Appendix II. Wells in this aquifer in pre-development conditions (Figure 7) would normally free flow at land surface (+10 and +20 NGVD). By 1979, however, the water levels on a regional scale had decreased to -20 ft. NGVD and move recently (1984) to -30 ft. NGVD. Water levels in production wells fell below -80 ft. NGVD in 1984.

The mid-Hawthorn does not receive direct recharge from precipitation anywhere in Lee County. Recharge occurs primarily upward leakance across confining beds and from lateral inflow from adjacent areas.

The transmissivity of this aquifer in the study area varies from 4,000 gpd/ft to 20,000 gpd/ft, with an average value of approximately 12,000 gpd/ft. These low transmissivities indicate that lateral movement of water is very slow. The cones of depression created by individual wells are very steep and not of great areal extent, unless several closely spaced wells create coalescing of cones.

Water quality is good for domestic uses throughout most of the study area, but becomes more saline along the western coastal area of Cape Coral. Chloride concentrations range from 50 mg/l to 1,000 mg/l (Figure 8). The chloride levels increase in a westerly direction and are greater than 1,000 mg/l in Pine Island.

The lower Hawthorn confining zone (Wedderburn, et al., 1982) lies below the mid-Hawthorn aquifer separating it from the Floridan Aquifer System. The confining zone consists primarily of sandy, phosphatic, poorly indurated limestones interbedded with phosphatic dolosilts (Figure 2). The overall low permeability of this zone results from the fine grained nature of the rocks and the interbedded dolosilts. Unlike most other areas of Lee County, a porous limestone occurs near the base of this zone in the Cape Coral and adjacent areas. These limestones were penetrated at the city R.O. plant at -325 ft. NGVD and -370 ft. NGVD (Figure 4). The core taken from this site also contained appreciable amounts of low permeability sediment above and below this interval. These beds act to restrict vertical flow of water from overlying and underlying aquifers. However, because these zones are left uncased in production and observation wells and are capable of producing significant quantities of water, they will be included in this report as the upper portion of the lower Hawthorn Aquifer.

U.S. GEOLOGICAL SURVEY (1972, 1974)	BLACK, CROW, AND EIDSNESS (1976)		MISSIMER AND ASSOCIATES (1978, 1979, 1981)		THIS REPORT	
WATER TABLE AQUIFER		WATER TABLE AQUIFER		WATER TABLE AQUIFER	SURFICIAL AQUIFER SYSTEM	WATER TABLE
			TAMIAMI AQUIFER SYSTEM	UPPER CONFINING BEDS		CONFINING BEDS
SHALLOW ARTESIAN AQUIFER				ZONE 1		LOWER TAMIAMI AQUIFER
				MIDDLE CONFINING BEDS	HAWTHORN AQUIFER SYSTEM	MID-HAWTHORN CONFINING ZONE
SANDSTONE AQUIFER				ZONE 2		
				LOWER CONFINING BEDS		
				ZONE 3		
				LOWER CONFINING BEDS		
UPPER HAWTHORN AQUIFER		UPPER HAWTHORN AQUIFER	HAWTHORN AQUIFER SYSTEM	ZONE 1		MID-HAWTHORN AQUIFER
				CONFINING BEDS		LOWER HAWTHORN CONFINING ZONE
				ZONE 2		
				CONFINING BEDS		
LOWER HAWTHORN AQUIFER	FLORIDAN AQUIFER	LOWER HAWTHORN AQUIFER		ZONE 3		LOWER HAWTHORN AQUIFER
				CONFINING BEDS		
				ZONE 4	FLORIDAN AQUIFER SYSTEM	
				CONFINING BEDS		CONFINING BEDS
SUWANNEE AQUIFER			SUWANNEE AQUIFER SYSTEM	ZONE 1		SUWANNEE AQUIFER
DEEPER AQUIFER			FLORIDAN AQUIFER SYSTEM	OCALA AQUIFER		DEEPER AQUIFER

Figure 5 RELATIONSHIPS OF AQUIFER NOMENCLATURE IN WESTERN LEE COUNTY, FLORIDA

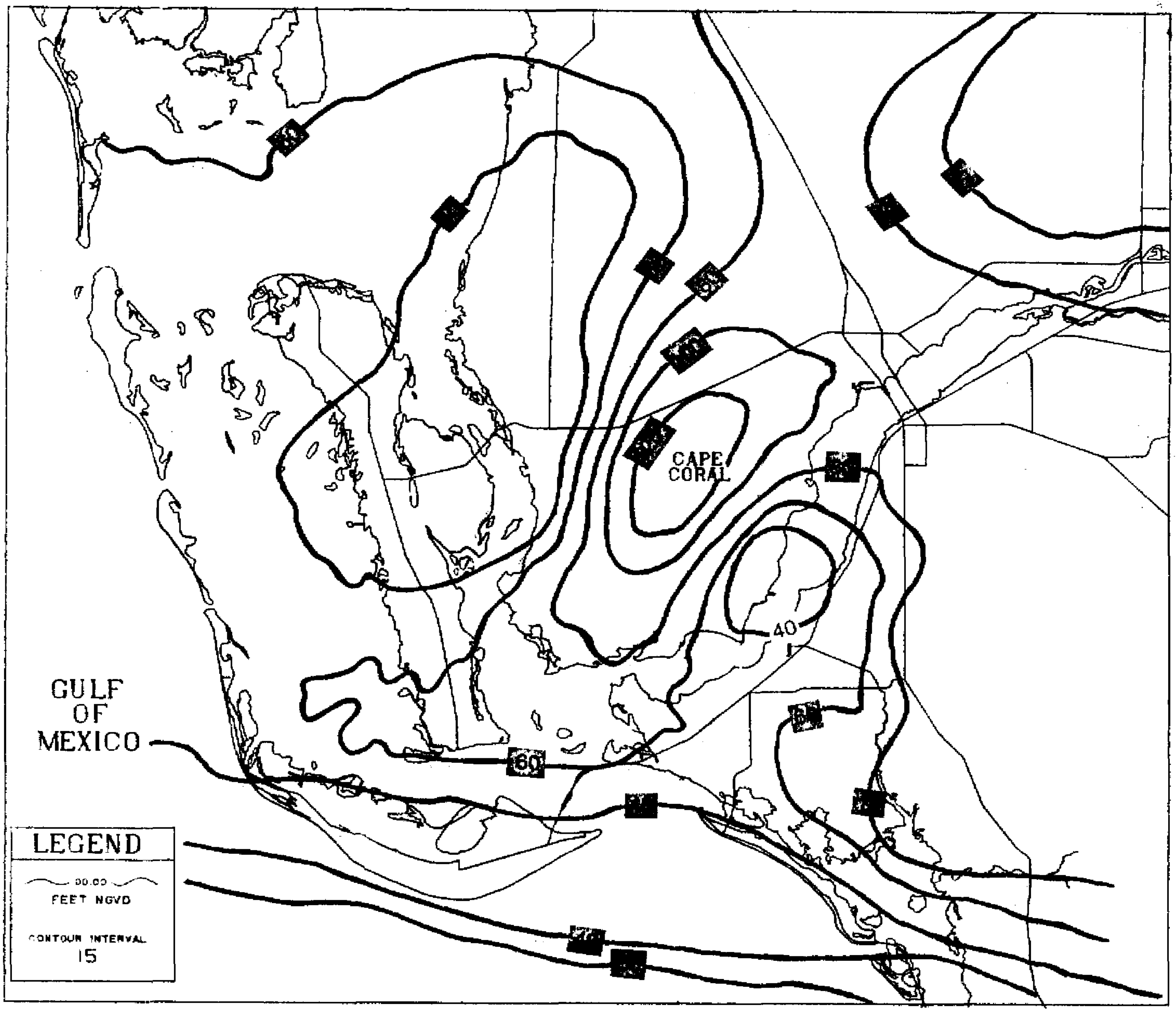


Figure 6 THICKNESS OF THE MID HAWTHORN AQUIFER

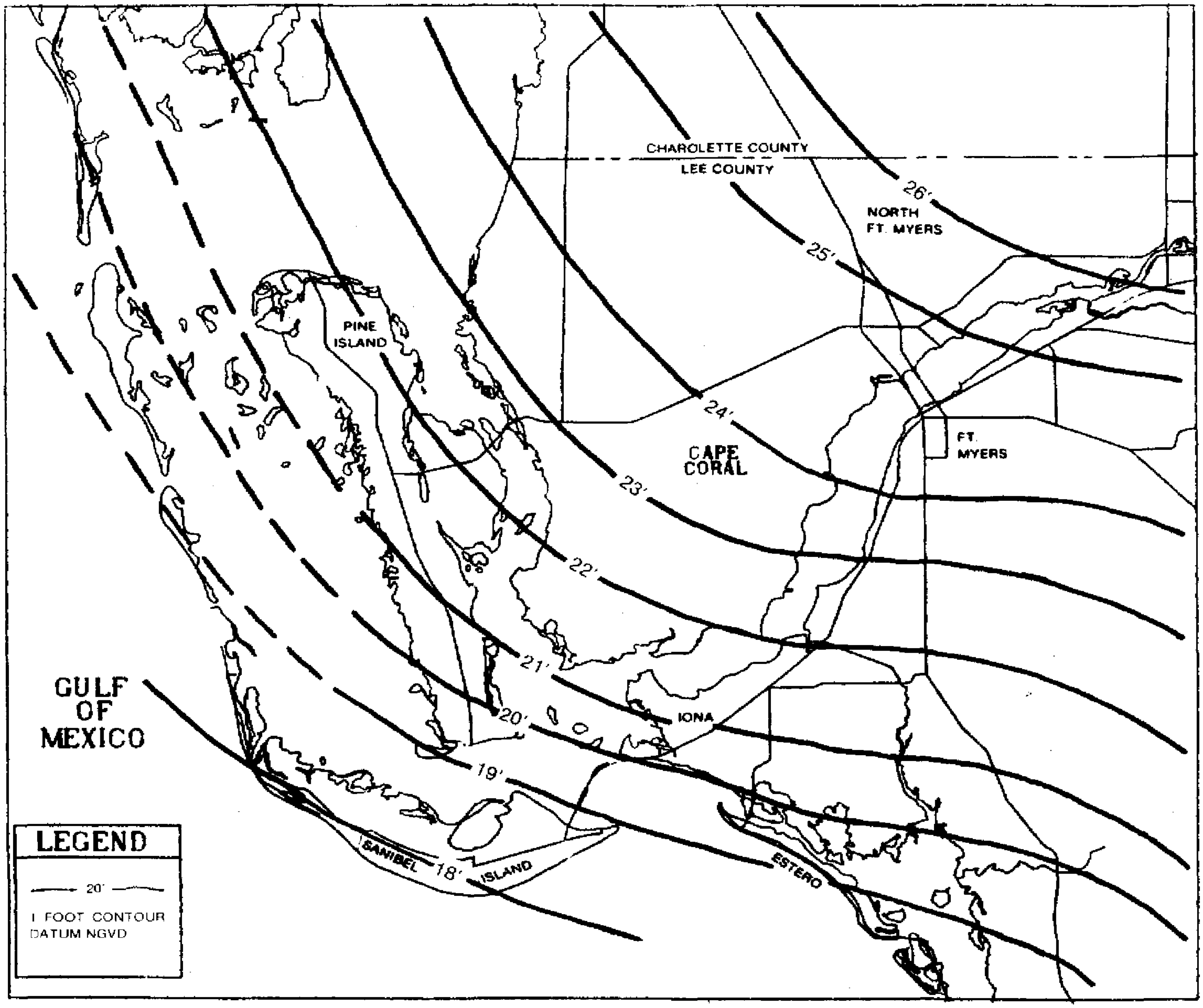


Figure 7 APPROXIMATE PRE-DEVELOPMENT WATER LEVELS FOR THE MID-HAWTHORN AQUIFER, 1942-1952 (USGS)

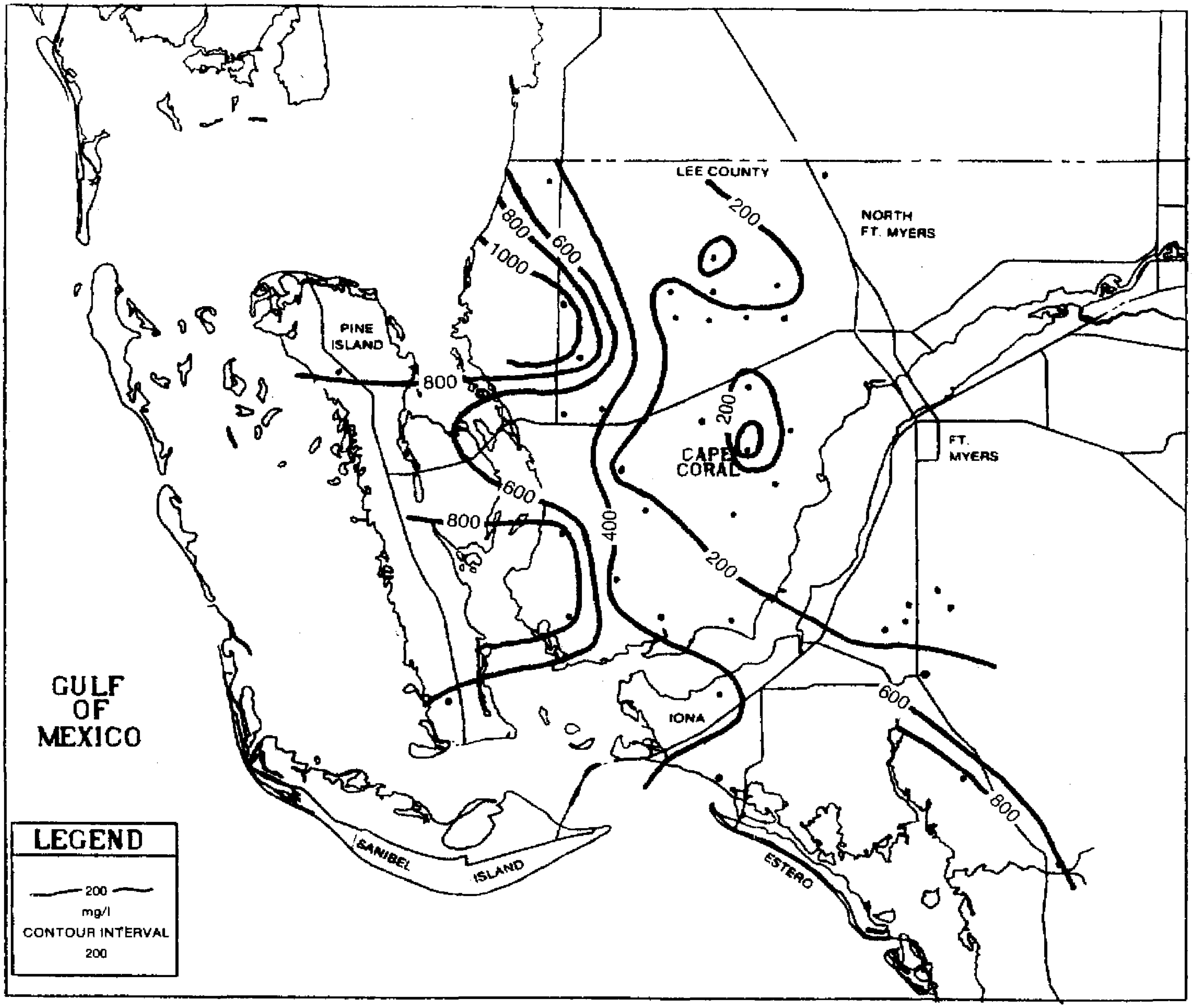


Figure 8 CHLORIDE CONCENTRATIONS IN THE MID HAWTHORN AQUIFER WITHIN WESTERN LEE COUNTY, 1984 DRY SEASON

Floridan Aquifer System

The term "Floridan Aquifer" was established by Parker and others (1955) for water bearing rocks associated with the Lake City Limestone, Avon Park Limestone, Ocala Limestone, Suwannee Limestone, Tampa Limestone, and permeable parts of the lower portion of the Hawthorn Formation. More recently the Southeastern Geological Society Committee on Hydrostratigraphic Nonenclature has designated the term "Floridan Aquifer System" to replace the name Floridan Aquifer (Vechiolli, personal communication).

In Lee County the Floridan Aquifer System (Wedderburn, et al, 1982) consists of an areally thick sequence of interbedded limestone and dolomite of Eocene to lower Miocene age, which show marked differences in vertical and horizontal porosity and permeability. The system can be divided into three aquifers; the lower Hawthorn/Tampa producing zone, Suwannee aquifer and Deeper aquifer. For the purposes of this study and as mentioned previously the term "lower Hawthorn aquifer" will be used herein to designate the uppermost portion of the Floridan Aquifer System in the Cape Coral area.

The lower Hawthorn aquifer (Sproul et al, 1972; and Boggess, 1974) consists of an interbedded sequence of phosphatic limestones, dolomites, and dolosilts that mark the top of the Floridan Aquifer System in the Cape Coral area. The uppermost limestones in this sequence are actually stratigraphically within the Hawthorn group, but for reasons mentioned previously are here included in the Floridan Aquifer System.

The top of the lower Hawthorn aquifer dips to the south and occurs between -400 and -500 ft. NGVD in the Cape Coral area. The average thickness of the aquifer is approximately 250 feet and thickens toward the south.

The Suwannee aquifer lies below the lower Hawthorn aquifer and is separated from it by less permeable calcareous clay and limestone. Data pertaining to the hydraulic conductivity of the confining bed is sparse.

Lithologically the Suwannee aquifer is quite diverse due to the complexities of the Suwannee Limestone in the study area. The major producing zones within the aquifer occur in isolated beds of relatively high porosity and permeability that are normally composed of calcarenitic limestones and occasionally sandstones. These zones are more prevalent near the top of the aquifer, normally occurring within 50 feet of the Suwannee/Tampa formational contact.

The elevation of the top of the Suwannee aquifer is between -500 and -700 ft. NGVD in the study area being high in the northernmost portion and dipping to the south. The thickness of the unit in the study area is between 350 and 600 feet.

The deeper aquifers are associated with porous beds of limestone and dolomite occuring in the Eocene formations at greater depths. Several zones of high permeability have been described in these strata (Puri and Winston, 1974) near the study area. Wedderburn, et al (1982) presented information on five wells that penetrated the deeper aquifer in Lee County. They show major producing zones occurring near formation boundaries within these strata.

The potentiometric surface of the Floridan Aquifer System slopes in a southwesterly direction across Cape Coral. In the northeastern portion of Cape Coral, the potentiometric surface stands at approximately +40 ft. NGVD and in the southwestern portion at about +30 ft. NGVD. Localized depressions in the surface occur in west central Cape Coral due to pumpage by the reverse osmosis plant.

Most of the recharge to the Floridan Aquifer System originates from outside the Lee County area, probably in the Polk County highlands and adjacent areas, where the aquifer crops out at higher elevations. The surface inflow enters Lee County on its northern and eastern borders.

Estimated transmissivities for the upper part of the Floridan Aquifer System in the Cape Coral area range from 30,000 to 350,000 gpd/ft. The high variability of transmissivities may be due to the number of producing zones penetrated in tested wells.

The water quality of the lower Hawthorn aquifer is not within potable standards within the study area. Table 1 presents Cl^- concentrations in USGS monitor wells taken in November of 1983. Well locations are shown in Appendix V. Chloride concentrations in Cape Coral range between 400 and 3,350 mg/l. The water quality of the deeper aquifers in this area is largely unknown due to the scarcity of deep wells. A deep well drilled to the Ocala Group in the Sanibel Island wellfield showed chloride concentrations in excess of 20,000 mg/l. Another deep well drilled into the Lake City limestone in north central Lee County produced water with chlorides in excess of 15,000 mg/l. However, a deep well (Ocala) drilled at the Fiddlesticks development in central Lee County had chlorides of less than 1,000 mg/l. As a general rule, chloride levels can be expected to increase with depth in the study area.

TABLE 1

CHLORIDE CONCENTRATIONS IN THE LOWER HAWTHORN AQUIFER

(NOVEMBER 1983)

USGS WELL NUMBERS	CHLORIDES mg/l
L-585	1500
L-588	1020
L-589	1080
L-590	1060
L-2434	405
L-2435	3350
L-2524	440
L-2525	420
L-2526	620
L-2527	1900
L-2528	920
L-2529	7000

AQUIFER PARAMETERS

The two dimensional models developed for the mid and lower Hawthorn aquifers consider aquifer parameters to be time invariant. The parameters required to define an aquifer are transmissivity, storage coefficient, confining layer leakance, elevations of top and bottom of the aquifer, and thicknesses of the aquifer and its confining layers. Unfortunately, not all the required parameters are available for modeling purposes. Only a few leakance values exist for the mid-Hawthorn and lower Hawthorn confining layers. Available measurements of these parameters are at irregularly spaced points. Values of each parameter usually vary from location to location, indicating a non-uniform spatial distribution. Because a very limited number of measurements are available, some statistical methods were used to compute the probable spatial distribution of a parameter from limited point measurements.

Trend Analysis and Kriging

Contour maps can be drawn by subjective judgements or by a set of "workable" procedures from irregularly spaced point data. Contour maps serve many purposes but normally do not indicate map reliability. Dependability of model results are directly related to the reliability of model input data. To define the limitations of the model input parameters, statistical methods were used to quantify the reliability of the spatial distribution of each aquifer parameter.

The first step in describing a set of irregularly spaced point measurements is to develop a best fit surface which explains the trends in the data. Once identified, the significant trend indicates the overall behavior of the parameters in large scale, e.g., local variations are averaged out. While the trend surface best describes all the data on a large scale, significant variations will occur locally in the vicinity of each measured value. Kriging (Skrivan, J.A., 1980) utilizes the difference between the trend surface and the measured values, known as the residuals, to further refine the contoured surface. If a residual exists at a point, some deviation from the trend is expected to occur in the neighborhood of this point. However, confidence in this assumption decreases as the distance from the measuring point increases. In addition to refining the trend surface, kriging also attempts to quantify the uncertainty associated with increased distance from the measuring point. Furthermore, kriging can also take measurement reliability into consideration. As a result, the distribution of reliability can also be mapped.

In summary, the procedures used to interpolate irregularly spaced point-measurements in two-dimensional contour maps are:

1. identify a "significant trend" from the given data
2. take the residuals of data from significant trends
3. use the residuals in Kriging analysis
4. compute the regular grid values by summing the trend and residual kriged values at each grid point coordinate
5. uncertainty of the map, in terms of variation coefficient, is concurrently obtained in step (4) computations.

Mid-Hawthorn Aquifer

1. Transmissivity: Thirty-four (34) transmissivity values were available in the study area. Ten were derived from duration pump tests and twenty four were estimates from well cuttings (Layne/Western, 1970 & 1977). Additionally, there were 26 specific capacity tests done for the aquifer. These specific capacity data were used in a regression analysis to find the corresponding transmissivities. Specific capacity values were calculated for all transmissivity values cited. This produced thirty-four data sets from which the regression equation was derived.

A weighted polynomial stepwise regression (Dixon, 1981) was used to develop the equation. The data was weighted according to its assessed reliability. Of all the tested polynomials, a simple linear relationship was proven to be the best, with squared correlation of .83. A linear equation was also obtained for standard error in converting specific capacity to transmissivity. A total of 60 transmissivity values and reliability in terms of standard error of estimation were thus obtained.

Many of the transmissivity data points were clustered together. When the 30 seconds grid system was imposed, many of these points fell within a single grid cell. When multiple points fell within one cell, the arithmetic mean was used to describe the transmissivity for the cell. Standard deviation of the mean was also computed. This standard deviation was added to the mean of original point standard errors to obtain the combined data standard error. This process reduced the number of data points to 48.

When trend analysis was run using these 48 transmissivity values, no significant trend other than mean (constant plane) was identified. Since a constant does not change other statistical properties of the data set, the original values, instead of residuals from the mean, were used in kriging analysis. Input data and results are in Appendix V.

As shown in Figure 9, the highest transmissivities occur in the central portion of the study area in the vicinity of Cape Coral and Cypress Lakes wellfields. However, lowest transmissivities occur to the northeast where lateral inflow enters the study area. These low values act to restrict the amount of inflow into the area. Therefore, it can be expected that when the aquifer is pumped over the recharging capability, excessive drawdown will occur. Depending on the relative heads among the adjacent aquifers, leakance may also be induced locally due to the pumpage in the mid-Hawthorn aquifer.

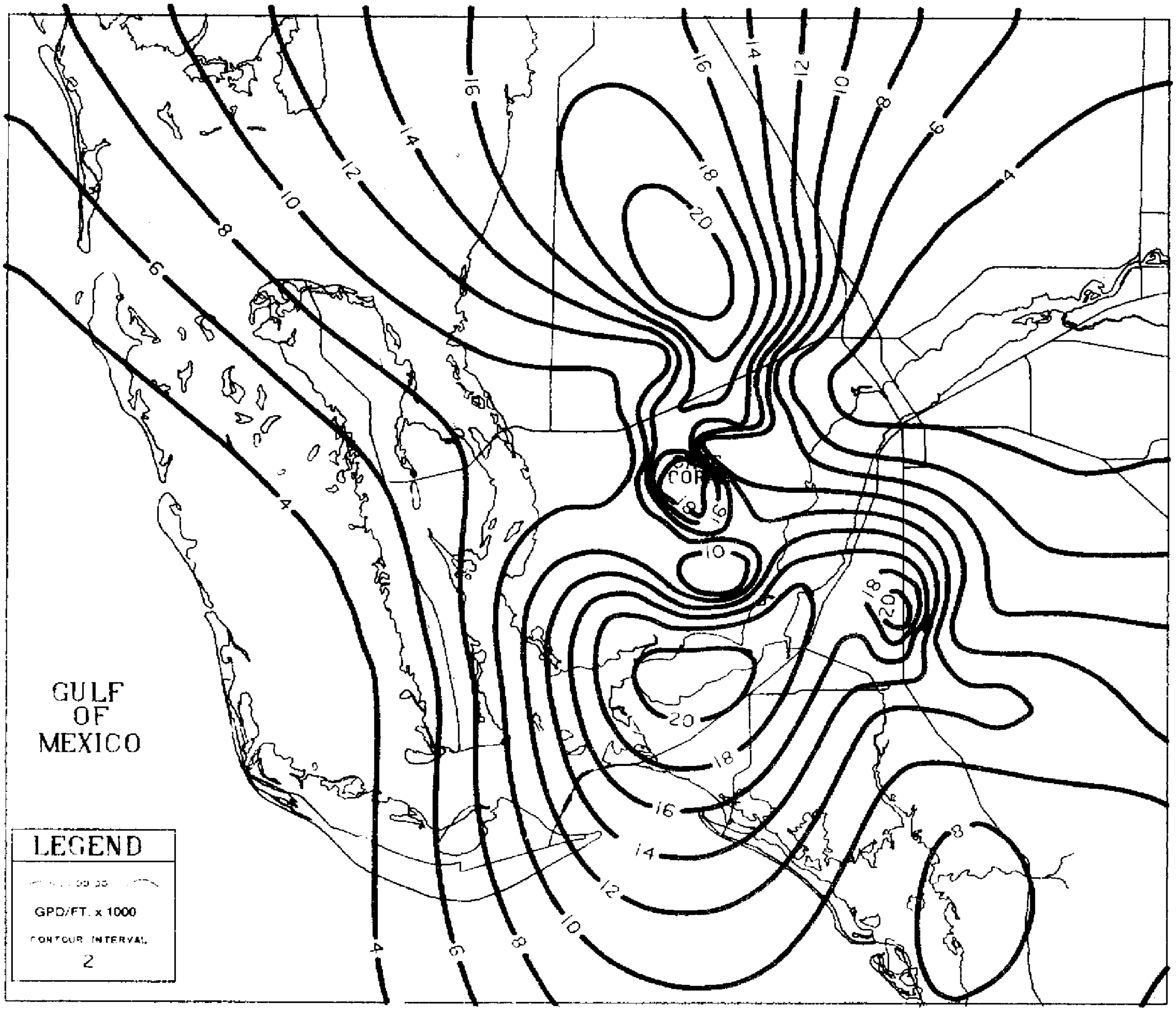


Figure 9 TRANSMISSIVITY OF THE MID HAWTHORN AQUIFER

The uncertainty map (Figure 10) indicates the realiability of the transmissivity map (Figure 9). The uncertainty is described by the variation coefficient, which is the square root of the estimation variance divided by the mean at each point. A value of .3 uncertainty means that one standard error of estimation is 30% of the estimated value. Since, in normal distribution about 70% of the total population is within the band of plus and minus one standard deviation, the .3 uncertainty means there is about 70% chance that the true value lies between ± 30% of the estimated value. Thus, the uncertainty map may help in deciding whether there is enough data to satisfy the desired reliability. The uncertainty map for the mid-Hawthorn aquifer transmissivity shows relatively high reliability in the Cape Coral area because of high data concentration. However, northeast of Cape Coral, in the direction of natural recharge, the estimation error of transmissivity can exceed 100 percent.

2. Storage Coefficient: There are only seven storage coefficient values available for the mid-Hawthorn aquifer. These values varied between 10^{-3} to 10^{-5}. It was decided to use a constant value of 10^{-4} for this study. Therefore, no computer mapping analysis was done for this parameter.

Lower Hawthorn Aquifer

1. Transmissivity: There are twelve data points of transmissivity in the area (Appendix V). The average transmissivity was computed to be 75,000 gpd/ft. However, the data varies by one order of magnitude. No significant trend was identified. Kriging analysis was done and the results are shown in Figures 11 and 12. The reported values were in most cases derived from aquifer tests on the lower Hawthorn and Suwannee aquifers combined. Therefore, the actual transmissivity of the lower Hawthorn aquifer alone may differ significantly from the reported values.

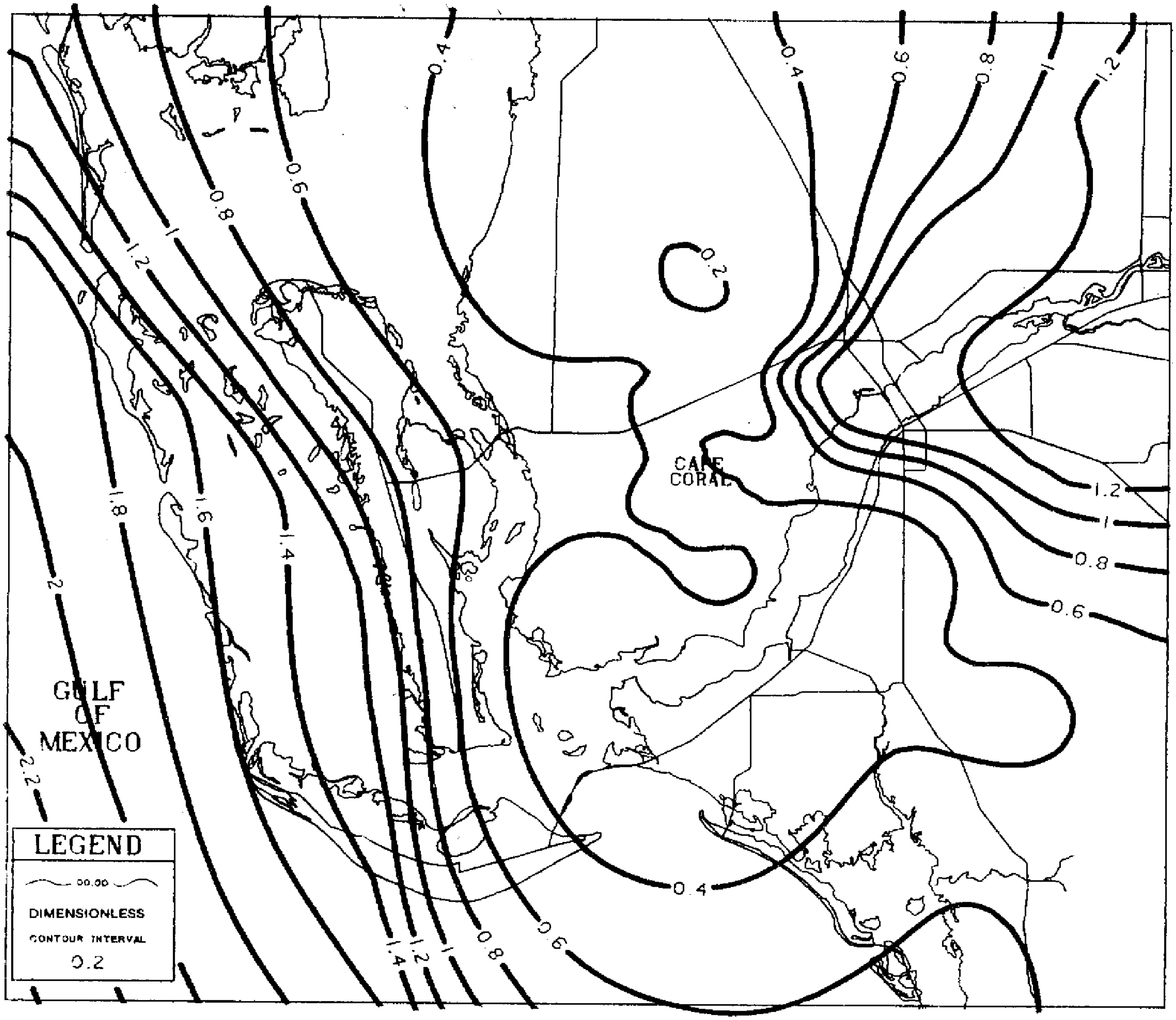


Figure 10 UNCERTAINTY TRANSMISSIVITY OF THE MID HAWTHORN AQUIFER

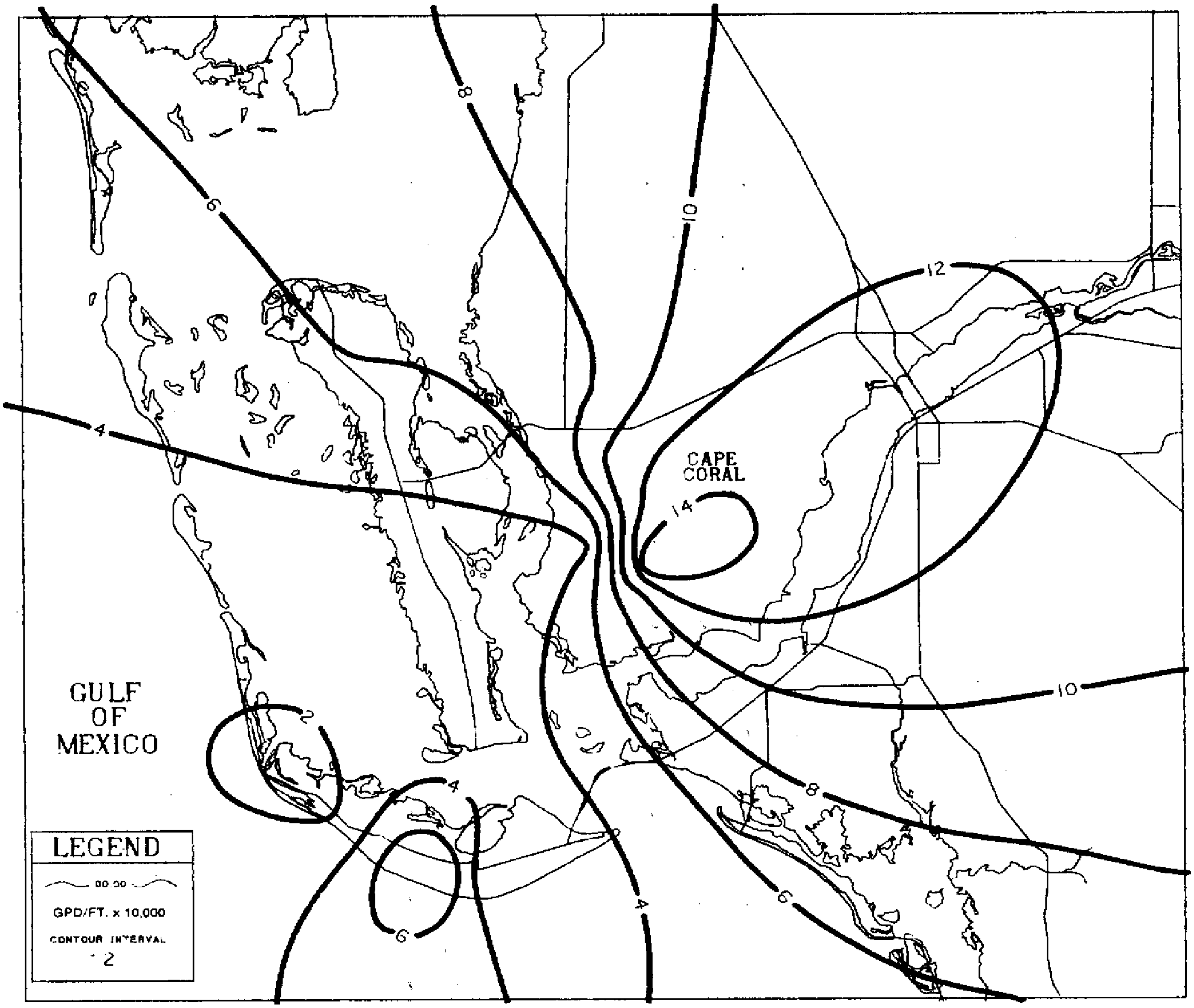


Figure 11 TRANSMISSIVITY OF THE LOWER HAWTHORN AQUIFER

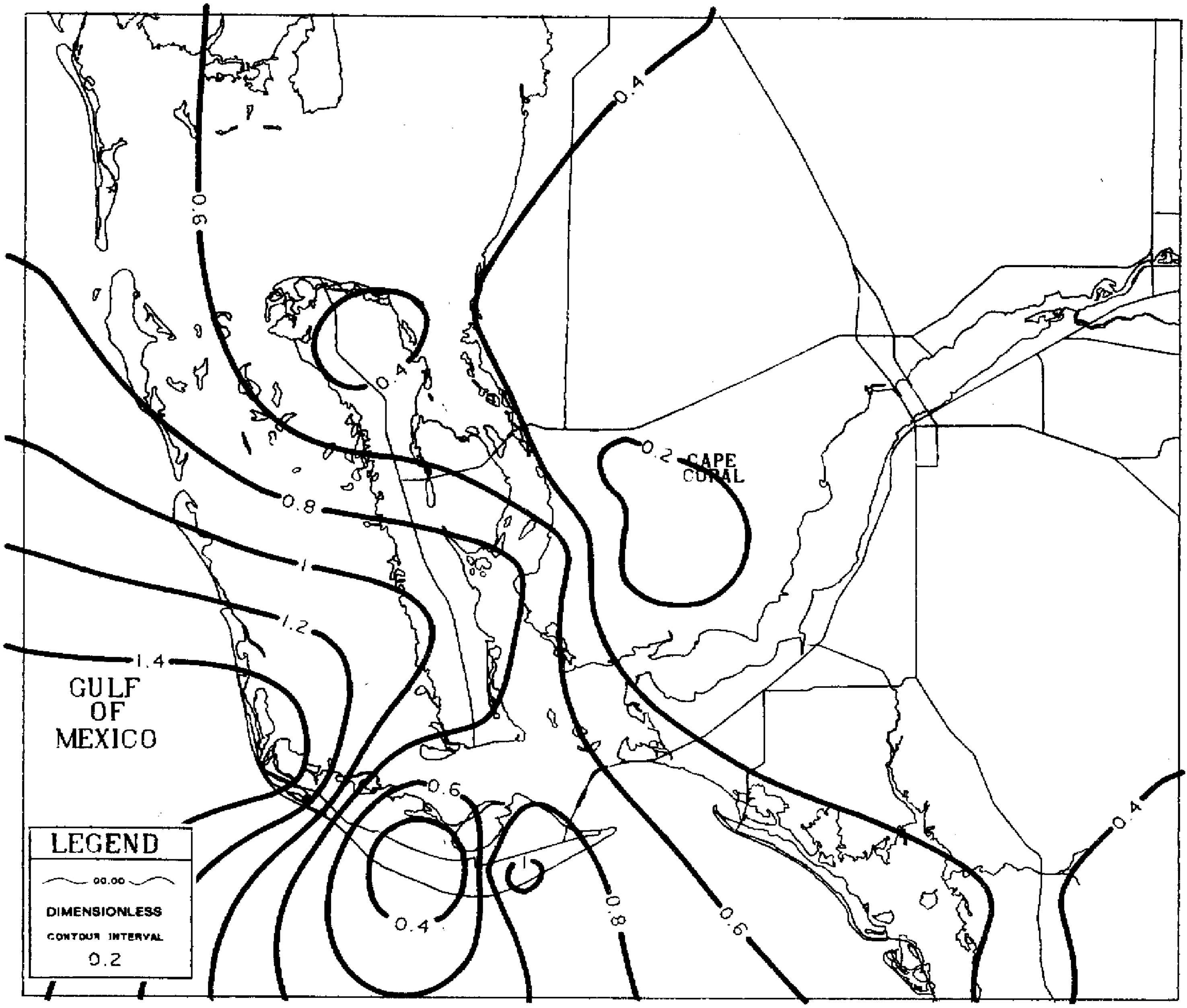


Figure 12 UNCERTAINTY TRANSMISSIVITY OF THE LOWER HAWTHORN

2. Storage Coefficients: The average storage coefficient was computed to be 3.7 X 10^{-3}. However, each estimation can be off by one order of magnitude; hence, the data variance is assumed to be in two orders of magnitude. These values were logarithmically transformed for easier handling. The kriging process was performed on the transformed data. The antilog of the kriged values were then used for mapping. There is a relationship between the smoothness of kriged map and the data reliability. Because of the large data variance the map is relatively smooth despite the large range of storativity. The map (Figure 13) shows two areas of high storativity in Cape Coral. However, the accompanying uncertainty map (Figure 14) shows a variation coefficient of 20 to 30 percent.

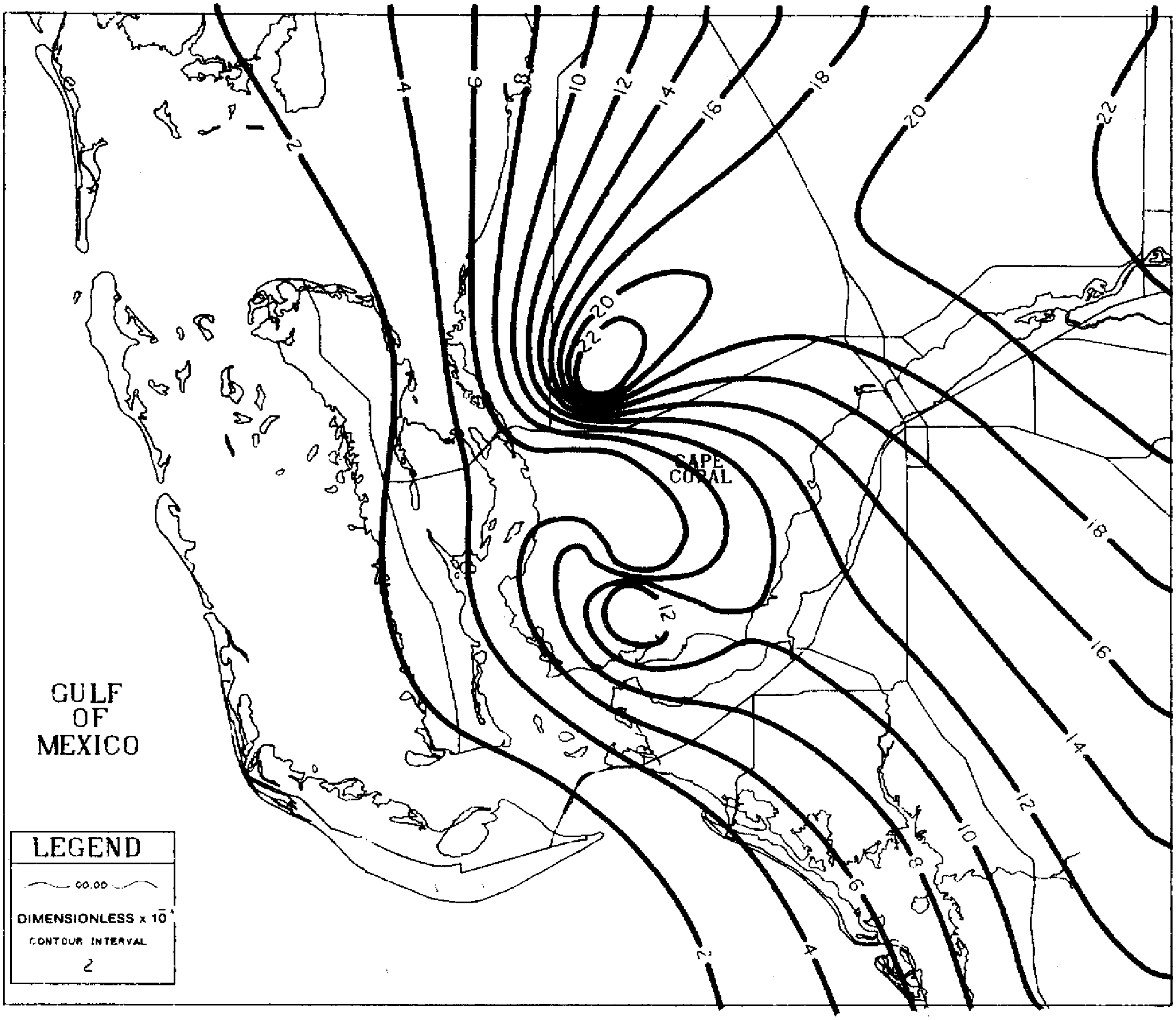


Figure 13 STORAGE COEFFICENT OF THE LOWER HAWTHORN AQUIFER

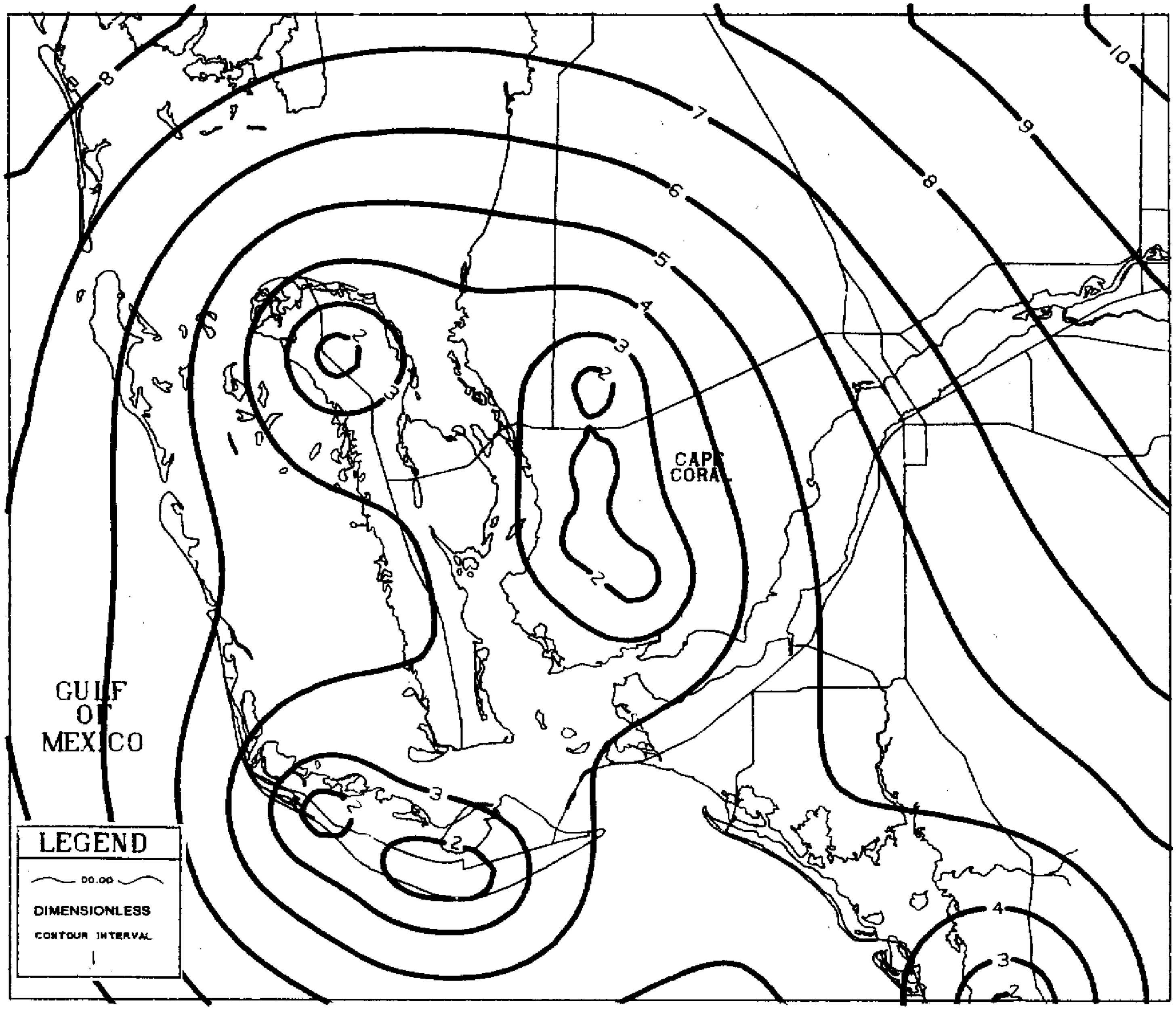


Figure 14 UNCERTAINTY STORAGE COEFFICENT OF THE LOWER HAWTHORN AQUIFE

WATER USE PROJECTIONS

Description of Water Use

Southwest Florida has continued to be one of the State's fastest growing areas. Lee County leads the population growth in this area and relies on groundwater as its primary source of potable and irrigation water. Unfortunately, the groundwater resources in Lee County are finite. In Cape Coral this rapid growth is beginning to exceed the supplying capability of the mid-Hawthorn aquifer.

There are nine municipal wellfields within the study area (Figure 15). These wellfields are:

1. Waterway Estates (mid-Hawthorn)
2. North Cape Coral (mid-Hawthorn and Surficial Aquifer System)
3. Santa Barbara (mid-Hawthorn)
4. Skyline (mid-Hawthorn)
5. Golf Course (mid-Hawthorn)
6. Pine Island Water Association (mid and lower Hawthorn)
7. Cypress Lakes (mid-Hawthorn)
8. Sanibel Island Water Association (lower Hawthorn and Suwannee)
9. Cape Coral R.O. (lower Hawthorn)

Seven of these nine wellfields withdraw some or all of their supply from the mid-Hawthorn aquifer.

The Cypress Lakes and Waterway Estates wellfields are owned by Florida Cities Water Company. They are located in the Iona-McGregor and the southwest corner of North Fort Myers areas, respectively. The Cypress Lakes wellfield serves approximately 25 percent of the south Fort Myers service area . This determination was made from estimates provided by Florida Cities officials (personal communication). The remaining 75 percent is supplied by the Green Meadows wellfield (Sandstone aquifer). These percentages were later used to determine the approximate number of residents being supplied by the Cypress Lakes wellfield.

The Waterway Estates wellfield, in conjunction with the north Cape Coral wellfield, serves a small area of northeast Cape Coral and southwest north

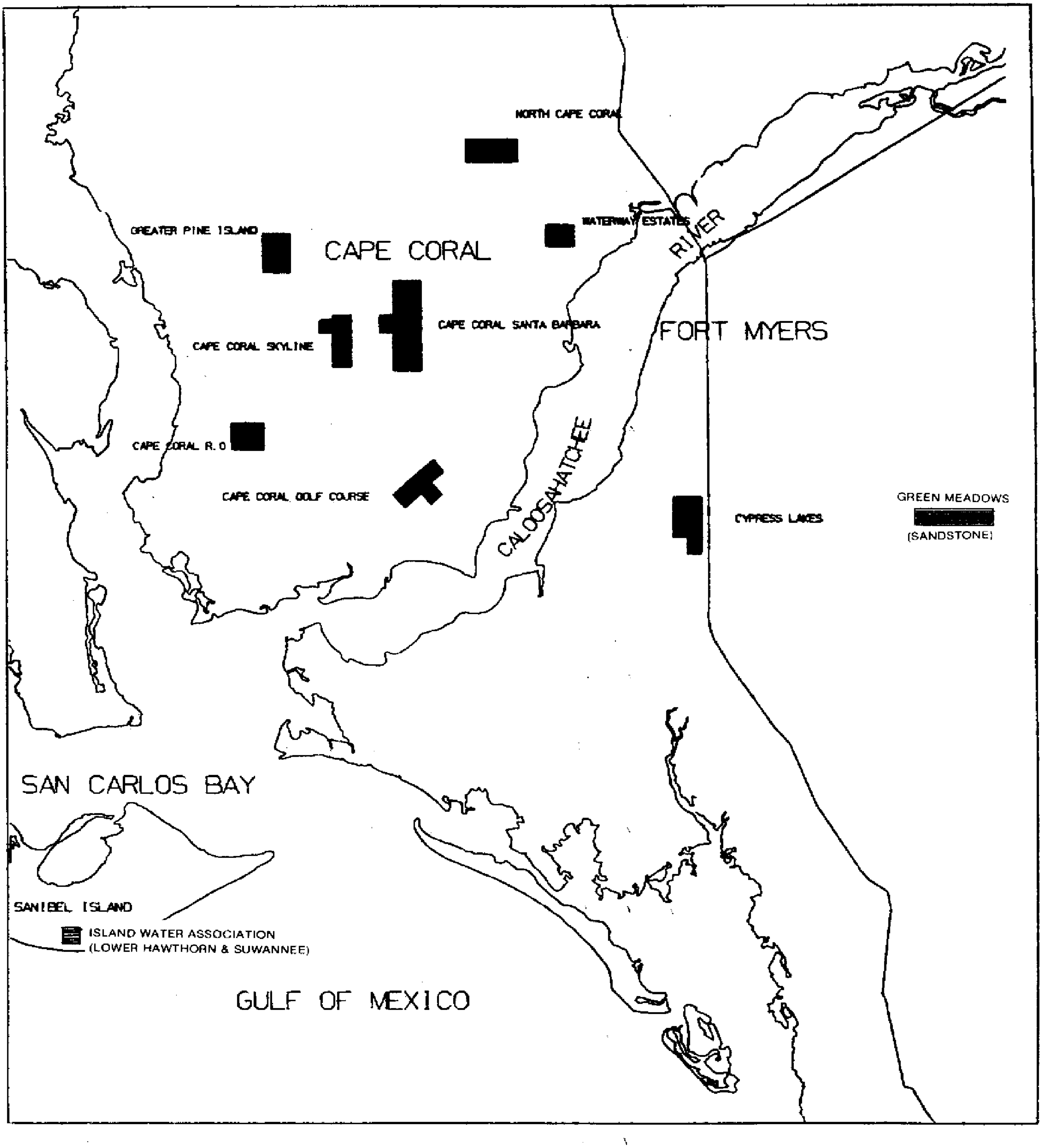


Figure 15 MUNICIPAL WELLFIELD LOCATIONS IN THE WESTERN HALF OF LEE COUNTY

Fort Myers. The water withdrawn from these two wellfields is in part from the mid-Hawthorn aquifer and the rest from the Surficial Aquifer System.

The City of Cape Coral uses mid-Hawthorn water from the Santa Barbara, Skyline, and Golf Course wellfields. This water is used in addition to the water desalted from the Reverse Osmosis (R.O.) plant and distributed to the residents of Cape Coral.

The Pine Island Water Association also withdraws water from the mid-Hawthorn aquifer. This water is used to dilute brackish water from the lower Hawthorn aquifer before it enters their reverse osmosis plant.

Sanibel Island Water Association does not withdraw any water from the mid-Hawthorn, but instead relies solely on the water from the lower Hawthorn and Suwannee aquifers. The raw water withdrawn from these aquifers is desalted through a reverse osmosis plant.

The mid-Hawthorn aquifer in Cape Coral is also used for irrigation through the installation of privately owned wells. From records obtained from the Cape Coral Utilities Department, it is estimated that there are approximately 3,500 of these wells within the Cape Coral platted area.

Most of the homes outside of the Cape Coral area also have mid-Hawthorn irrigation wells. However, the number of these wells is unknown and needs to be estimated, because so many were drilled prior to Lee County permitting records. Most of the wells drilled for irrigation in area twelve and thirteen (Figure 16) are withdrawing water from the mid-Hawthorn aquifer. In areas fourteen and sixteen withdrawal from the mid-Hawthorn is less extensive because readily available water from the Surficial and Sandstone aquifer occurs at shallower depths. The projected number of mid-Hawthorn irrigation wells for those areas reflect these facts. Actual estimation procedures are discussed in the methodology section.

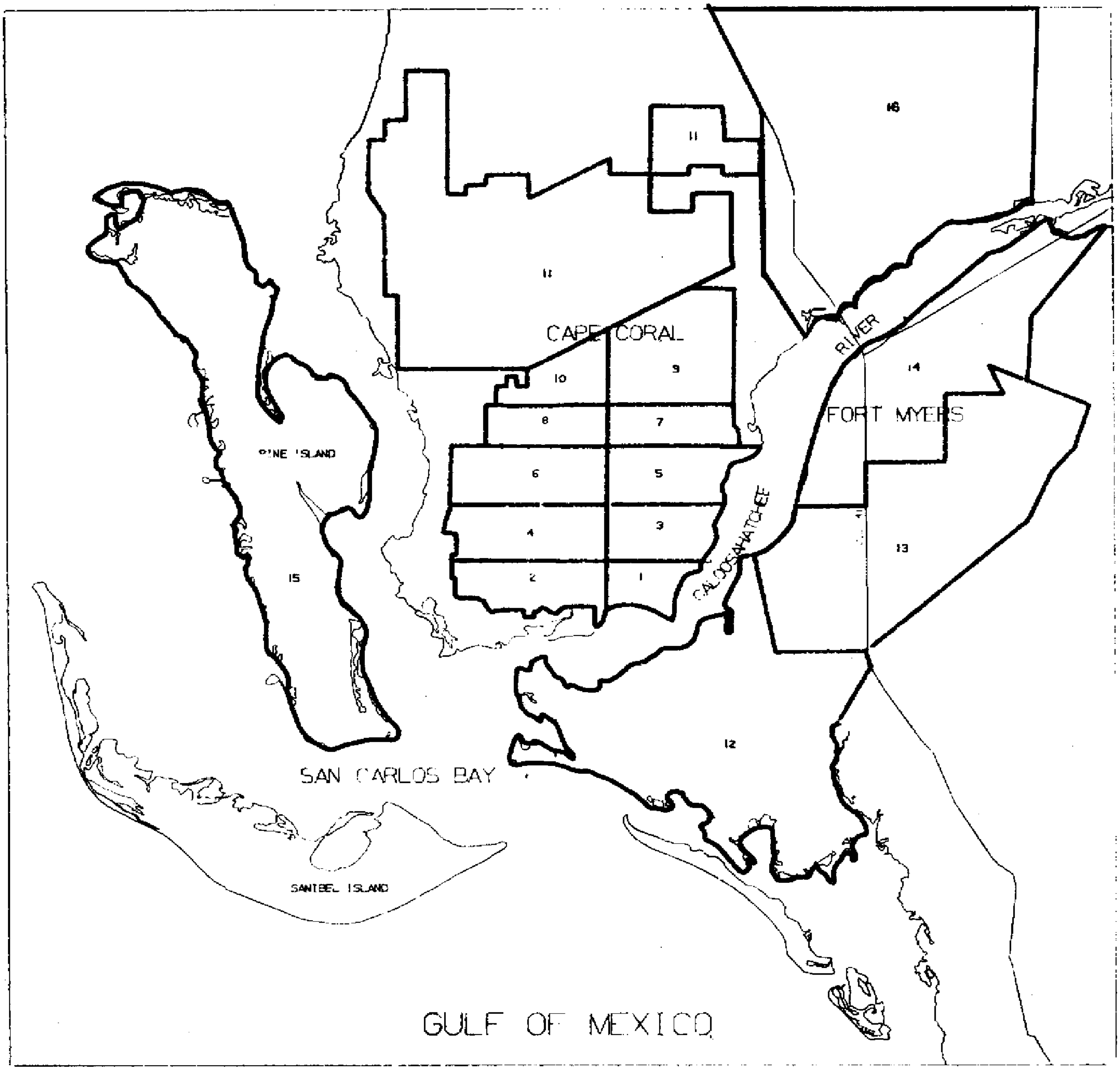


Figure 16 DESIGNATED PLANNING AREAS FOR POPULATION FORECASTING IN LEE COUNTY

There are, of course, other wellfields and private wells that lie outside the aforementioned areas. Most of these wells, however, do not tap into the mid-Hawthorn aquifer, and it is assumed that their affects are negligible.

Forecast Methodology

The techniques that were used to forecast the population and the number of irrigation wells in Cape Coral are listed below:

1. The platted areas of Cape Coral are divided into 6188 variable size city blocks.
2. Those blocks were combined into larger groups. These groups were designated by the letters A-Z and AA-KK.
3. Each group was then assigned a certain number of known mid-Hawthorn irrigation wells derived from the records of the Cape Coral Utilities Department.
4. Eleven areas (1-11), designated by the Cape Coral Planning Department as population planning areas, were plotted on a map overlying the groups of blocks (Figure 17).
5. The acreage of each group within each of the eleven areas (Figure 18) was calculated and used to determine the number of wells per acre.
6. The acreages were added together to determine the number of wells in each of the eleven areas (Table 2).
7. The present and the projected populations of the eleven areas were taken from the Cape Coral Population Forecasts Report (1983).
8. The number of dwelling units per area was calculated (excluding commercial, industrial and recreational units). First, the number of people per dwelling unit was determined for every five years beginning with 1985 (Lee County Dept. of Long Range Planning, 1982) (Figure 19). The population forecasts were then divided by the number of people per

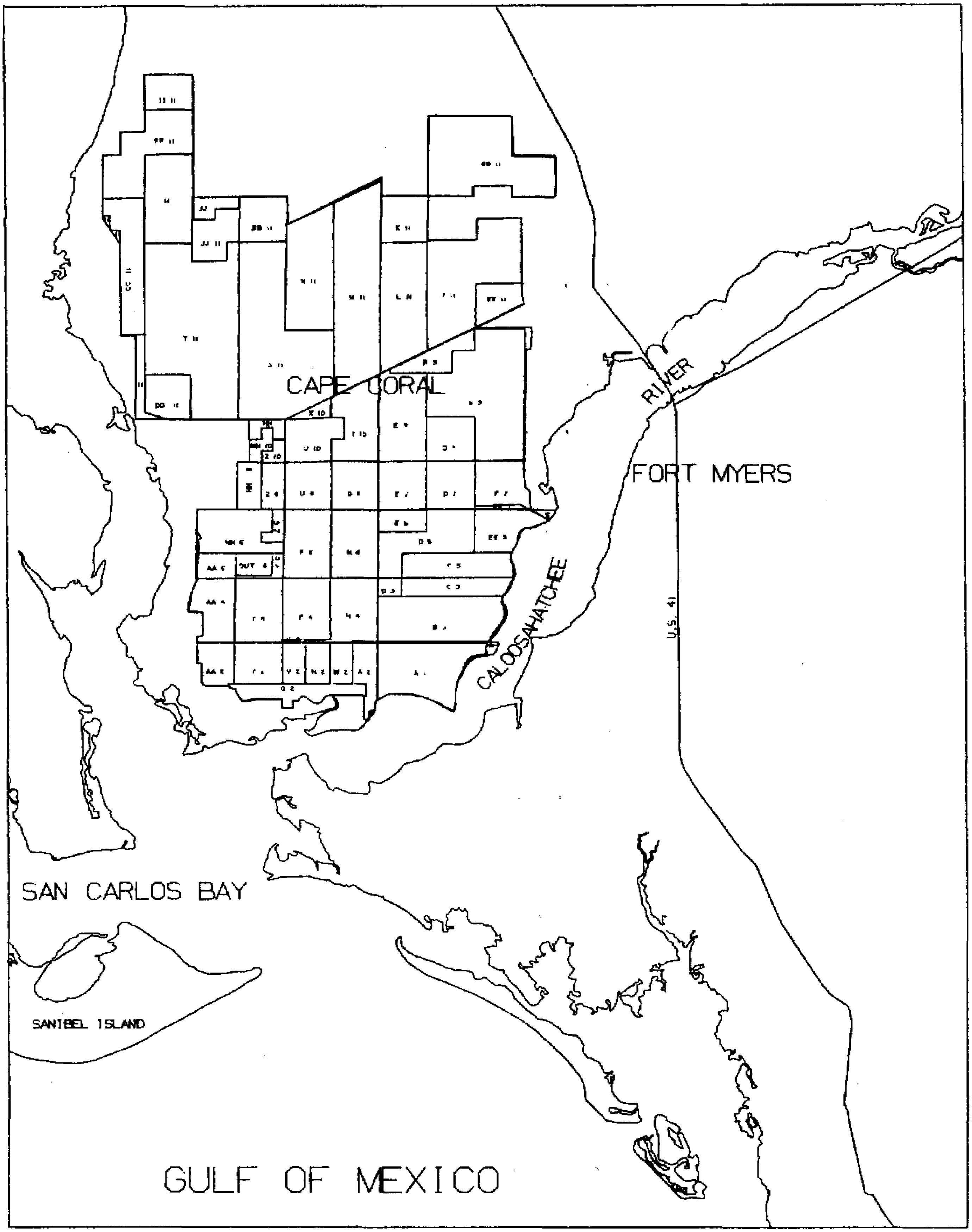


Figure 17 CAPE CORAL PLANNING AREAS (1-11) OVERLAIN WITH GROUPS OF BLOCKS (A-KK)

TABLE 2

DETERMINATION OF THE NUMBER OF FOUR INCH IRRIGATION WELLS WITHIN THE ELEVEN CAPE CORAL PLANNING AREAS

AREA	GROUP OF BLOCKS	ACRES	TOTAL NO. WELLS	WELL DENSITY WELL/ACRE
1	A	1,543	384	0.25
2	A,V,W,X,AA	3,012	217	0.07
3	B,C,D	2,565	267	0.10
4	H,P,V,Y,AA	3,648	211	0.06
5	C,D,E,EE	3,056	476	0.16
6	H,P,Y,Z,AA,HH	3,831	181	0.05
7	D,E,F,EE	2,212	253	0.11
8	O,U,Z,HH	2,071	69	0.03
9	E,D,G,R	5,402	933	0.17
10	O,I,U,Z,HH	2,191	154	0.07
11	K,L,J,N,M,S,T,FF JJ,BB,DD,KK,GG	27,237	279	0.01

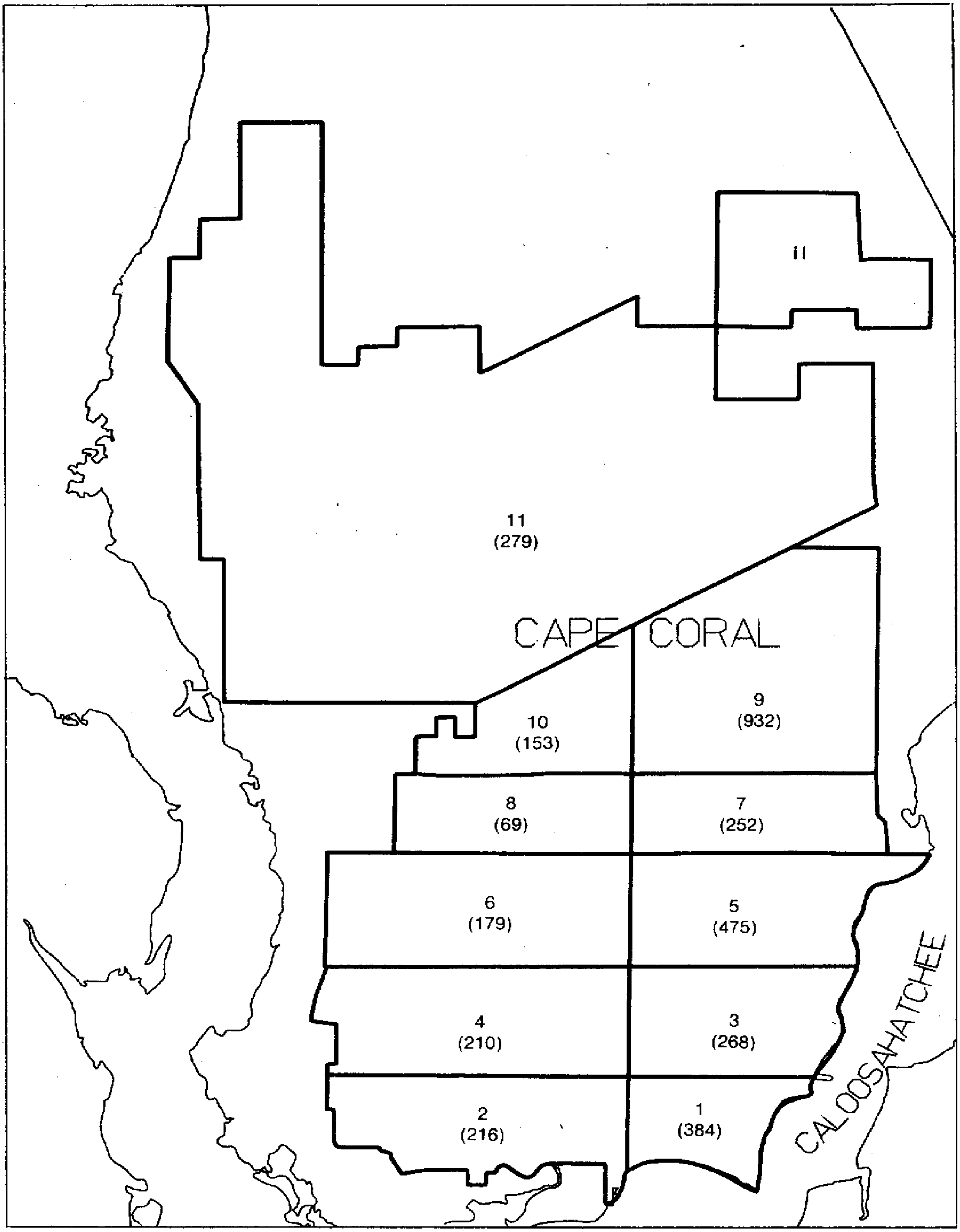


Figure 18 NUMBER OF 4 INCH IRRIGATION WELLS IN CAPE CORAL PLANNING AREAS

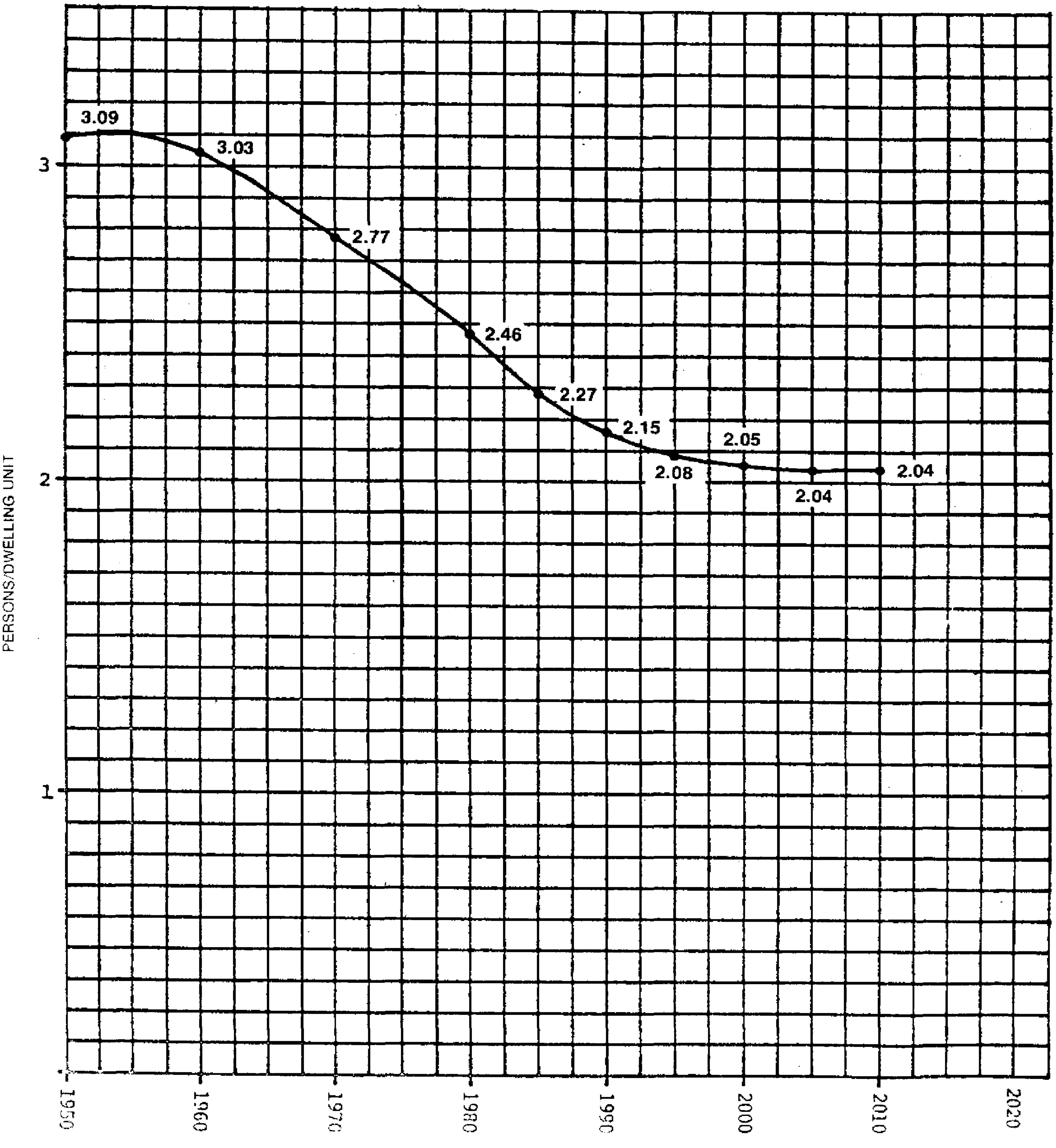


Figure 19 PERMANENT RESIDENT HOUSEHOLD SIZE IN LEE COUNTY (LEE COUNTY DEPARTMENT OF COMMUNITY PLANNING 1983)

dwelling unit, and the results were rounded off to the nearest whole number.

9. The percent increase of population in each of the eleven areas was calculated and applied to the number of dwelling units.
10. This increase was applied to the forecasted number of wells in each area.

In the five planning areas outside of Cape Coral (Figure 16) the population forecasts were determined from the "Lee County Division of Community Development (LCDCD, 1982). The actual number of wells in each of these areas are unknown, therefore, estimations were made as follows.

1. Each area was equated to a similar one within the eleven planning areas of Cape Coral by comparing population densities and percentages of total buildout.
2. The ratio of dwelling units to wells from the similar area compared in Cape Coral were calculated.
3. The number of dwelling units in each of these outside areas were determined. This was found by the same technique used in Cape Coral; ie. population divided by the number of people per dwelling unit. Since 1984 census reports were not available, estimates were made comparing 1980 and 1985 populations. An average population increase per year was subtracted from the 1985 forecasted population.
4. The number of dwelling units/well (3) was divided by the number of wells (2). This becomes the estimated number of wells for each area (12-16). The results of areas fourteen and sixteen had to be adjusted to reflect use of water from the Sandstone aquifer and/or Surficial Aquifer System. Estimations of total mid-Hawthorn irrigation well withdrawal within these areas are described in the modeling section.
5. This was done for all the forecasted years, 1985 through 2005.

Forecasted mid-Hawthorn and lower Hawthorn wellfield withdrawals were determined as follows:

1. The mid-Hawthorn and lower Hawthorn wellfield pumpage data were obtained from the 1984 monthly reports.
2. These values were divided by the present population (permanent) from each service area to calculate the per capita usages.
3. The per capita use was multiplied by the forecasted population to obtain the water use requirement figures for the years 1985 through 2005. These figures were then used for modeling the mid and lower Hawthorn aquifers.

To simplify the complexity of population and water use forecasting the following assumptions were made.

1. All housing units are hooked up to municipal distribution systems. This assumption may result in water use estimates that are larger than will actually exist.
2. Estimations of the number of dwelling units only considered permanent population, as opposed to functional population which is the combination of permanent and seasonal population. This was done because almost all seasonal residents reside in already established dwellings.
3. Total buildout will not be achieved in any of the areas by the year 2005.
4. As a result, dwelling units are assumed not to be a constraint on population growth within the planning areas.
5. All irrigation wells pump at a rate of approximately twenty-five gallons per minute.
6. Pumpage of these wells occurs for fifteen to thirty-five minutes per day during the wet season; and forty to seventy minutes per day during the dry season.

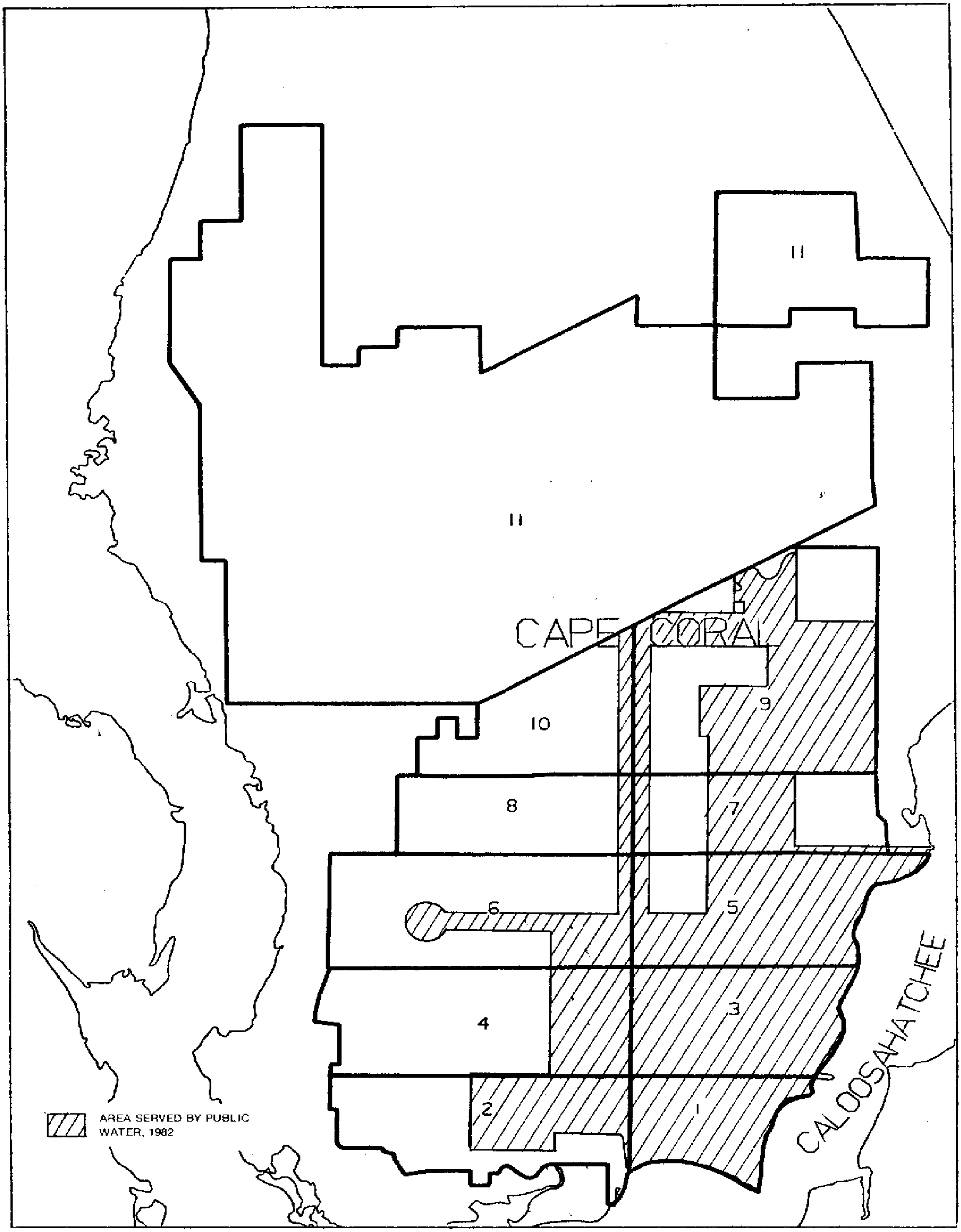


Figure 20 CAPE CORAL AREA SERVED BY PUBLIC WATER SUPPLY 1982

7. For forecasting purposes within Cape Coral, all irrigation water will continue to come from mid-Hawthorn wells regardless of the public water supply expansion (Figure 20). This does not take into account possible dual water systems.
8. The estimated number of mid-Hawthorn irrigation wells in areas 14 and 16 were adjusted to compensate for the possible use of the Sandstone aquifer and/or Surficial Aquifer System.
9. Per capita use does not change with time.
10. The pumpage from the Cypress Lakes wellfield was assumed to furnish 25% of the people within its service area. Green Meadows wellfield (Sandstone aquifer) would provide water for the rest of the area (75%).

More detailed methodology is presented in Appendix IV.

Results

The results of the projected future water requirements from municipal wellfields and private irrigation wells are presented in Tables 3 through 7. These results reveal the projected population, the daily per capita use, and the average water use, from each wellfield service area. The wellfields producing water from the mid-Hawthorn aquifer were grouped together, and the 1984 average daily water use figures were added to obtain the total municipal water withdrawal from the aquifer (Table 3). The same was done for the lower Hawthorn wellfields (Table 3).

Table 3 shows that 2.59 MGD of water is being withdrawn from the mid-Hawthorn aquifer by municipal wellfields in the year 1984. If by 1985 Cape Coral discontinues using its mid-Hawthorn wellfields, total daily water use will drop to 1.13 MGD (Table 4), but by the year 2005 withdrawal will be back up to almost 2 MGD (Table 6).

Additionally, the mid-Hawthorn aquifer is stressed from pumpage by thousands of irrigation wells scattered throughout western Lee County. Table 7 depicts the highest concentration of these wells in Cape Coral/Iona-McGregor area (areas 1-11 and 12, respectively, Figure 16), and the highest withdrawals occur here. The average annual irrigation use for the Cape Coral area alone was calculated at 1.03 MGD. This value is lower than previous estimates (4 MGD) presented by other engineers. However, the mid-Hawthorn flow models, discussed later, could only be calibrated using the lower estimate. Flow models using 4 MGD for irrigation in Cape Coral reveal excessive and unrealistic drawdowns. It is estimated that the City of Fort Myers uses 1.22 MGD (area 12) for irrigation, however, as previously mentioned, a major portion of this water is being withdrawn from the Sandstone aquifer and Surficial Aquifer System.

TABLE 3

PRESENT PUMPAGE FROM MID AND LOWER HAWTHORN WELLFIELDS

1984 - MID-HAWTHORN

WELLFIELD SERVICE AREA	POPULATION (PERMANENT)		PER CAPITA USE (GPD)	AVERAGE DAILY PUMPAGE (MGD)
Cape Coral (ALL)	45985		33[a]	1.50
Pine Island (PIWA)	4380		81[c]	0.36
Florida Cities				
(Waterway Estates)	949		274	0.26
(North Cape Coral)	803		274	0.22
(Cypress Lakes)	2504[d]		100	0.25
		Total	762	2.59

1984 - LOWER HAWTHORN

WELLFIELD SERVICE AREA	POPULATION (PERMANENT)		PER CAPITA USE (GPD)	AVERAGE DAILY PUMPAGE (MGD)
Cape Coral (RO)	45985		86[b]	3.95
Pine Island (PIWA)	4380		81[c]	0.35
Sanibel (SIWA)	3354		320[e]	1.07
		Total	387	5.37

a. Per capita use of the mid-Hawthorn alone.
b. Per capita use of the lower Hawthorn alone (total Cape Coral per capita use, 33+86=119 GPD).
c. Pine Island R.O. withdraws from mid-Hawthorn and lower Hawthorn in equal proportions (50:50).
d. This is only 25% of the total population since Green Meadows contributes 75% of the service area.
e. Sanibel has a high per capita use value due to the high concentrated influx of tourists, and lack of shallow fresh water wells for irrigation.

TABLE 4

ESTIMATED PROJECTED PUMPAGE FROM MID AND LOWER HAWTHORN WELLFIELDS

1985 - MID-HAWTHORN

WELLFIELD SERVICE AREA	POPULATION (PERMANENT)	PER CAPITA USE (GPD)	AVERAGE DAILY WITHDRAWAL(MGD)
Cape Coral(ALL)	47,798	33	1.50
Pine Island (PIWA)	4,532	81	0.37
Florida Cities (Waterway Estates)	985	274	0.27
(North Cape Coral)	803	274	0.22
(Cypress Lakes)	2,699	100	0.27
		Total Withdrawal	1.03

1985 - LOWER HAWTHORN

Cape Coral (RO)	47,798	185[a]	8.84[b]
Pine Island (PIWA)	4,532	81	0.36
Sanibel (SIWA)	3,410	320	1.09
		Total Withdrawal	10.29

a. For all model runs a per capita consumption figure of 185 g/d was used.
b. Assuming all housing units are supplied by R.O. plants.

TABLE 5

1990 - MID-HAWTHORN

WELLFIELD SERVICE AREA	POPULATION (PERMANENT)	PER CAPITA USE (GPD)	AVERAGE DAILY WITHDRAWAL(MGD)
Cape Coral[a]	56,863	0	0.00
Pine Island (PIWA)	5,292	81	0.43
Florida Cities			
(Waterway Estates)	1,131	274	0.31
(North Cape Coral)	949	274	0.26
(Cypress Lakes)	3,646	100	0.36
		Total Withdrawal	1.36

1990 - LOWER HAWTHORN

WELLFIELD SERVICE AREA	POPULATION (PERMANENT)	PER CAPITA USE (GPD)	AVERAGE DAILY WITHDRAWAL(MGD)
Cape Coral (RO)	56,863	185	10.52
Pine Island (PIWA)	5,292	81	0.43
Sanibel (SIWA)	3,691	320	1.18
		Total Withdrawal	12.13

1995 - MID-HAWTHORN

WELLFIELD SERVICE AREA	POPULATION (PERMANENT)	PER CAPITA USE (GPD)	AVERAGE DAILY WITHDRAWAL(MGD)
Pine Island (PIWA)	6,118	81	0.49
Florida Cities			
(Waterway Estates)	1,314	274	0.36
(North Cape Coral)	1,095	274	0.30
(Cypress Lakes)	4,705	100	0.47
		Total Withdrawal	1.62

1995 - LOWER HAWTHORN

WELLFIELD SERVICE AREA	POPULATION (PERMANENT)	PER CAPITA USE (GPD)	AVERAGE DAILY WITHDRAWAL(MGD)
Cape Coral (RO)	65,686	185	12.22
Pine Island (PIWA)	6,118	81	0.49
Sanibel (SIWA)	4,002	320	1.28
		Total Withdrawal	13.99

[a] It is assumed that Cape Coral will stop using the mid-Hawthorn aquifer by 1990.

TABLE 6

2000 - MID-HAWTHORN

WELLFIELD SERVICE AREA	POPULATION (PERMANENT)	PER CAPITA USE (GPD)	AVERAGE DAILY WITHDRAWAL(MGD)
Pine Island (PIWA)	6,800	81	0.55
Florida Cities			
(Waterway Estates)	1,460	274	0.40
(North Cape Coral)	1,204	274	0.33
(Cypress Lakes)	5,642	100	0.56
		Total Withdrawal	1.84

2000 - LOWER HAWTHORN

Cape Coral (RO)	74,200	185	13.73
Pine Island (PIWA)	6,800	81	0.55
Sanibel (SIWA)	4,348	320	1.39
		Total Withdrawal	15.67

2005 - MID-HAWTHORN

WELLFIELD SERVICE AREA	POPULATION (PERMANENT)	PER CAPITA USE (GPD)	AVERAGE DAILY WITHDRAWAL(MGD)
Pine Island (PIWA)	7,244	81	0.59
Florida Cities			
(Waterway Estates)	1,569	274	0.43
(North Cape Coral)	1,277	274	0.35
(Cypress Lakes)	6,197	100	0.62
		Total Withdrawal	1.99

2005 - LOWER HAWTHORN

Cape Coral (RO)	79,069	185	14.63
Pine Island (PIWA)	7,244	81	0.59
Sanibel (SIWA)	4,328	320	1.38
		Total Withdrawal	16.60

TABLE 7

POPULATION DENSITIES, HOMES/WELL RATIOS AND TOTAL IRRIGATION WITHDRAWAL FOR EACH PLANNING AREA

AREA	ACRES	POPULATION[1]	DENSITY PERSONS/ACRE[2]	NO. HOMES[3]	NO. WELLS[4]	RATIO HOMES/WELL[5]	TOTAL WITHDRAWAL(MGD)
1	1,543	5292-6608	3.40-4.30	1960-2447	384	5.1-6.4	0.12
2	3,012	2394-2955	0.79-0.98	867-1094	216	4.0-5.1	0.06
3	2,565	8165-10000	3.18-3.94	3024-3741	268	11.2-14.0	0.08
4	3,648	3431-4257	0.94-1.17	1271-1577	210	6.0-7.5	0.06
5	3,056	6898-8382	2.26-2.74	2555-3104	475	5.4-6.5	0.14
6	3,831	1791-2236	0.46-0.58	663-828	181	3.7-4.6	0.05
7	2,212	4906-5969	2.22-2.70	1817-2211	252	7.2-8.8	0.08
8	2,071	1158-1445	0.56-0.70	429-535	69	6.2-7.7	0.02
9	5,402	4734-5903	0.88-1.09	1753-2186	932	1.9-2.3	0.28
10	2,191	1364-1699	0.62-0.78	505-629	153	3.3-4.1	0.05
11	27,237	3969-4946	0.14-0.18	1470-1832	279	5.3-6.6	0.08
12	22,907	10,795	0.47	4,756	1,134	4.2	0.34
13	18,631	31,020	1.66	13,665	1,872	7.3	0.56
14	13,631	58,923	4.30	25,957	4,056	6.4	1.22
15	25,881	4,532	0.18	1,996	333	6.0	0.10
16	20,215	35,735	1.81	15,742	2,127	7.4	0.64
						TOTAL	3.88

TABLE 8

ESTIMATED PUMPAGE FROM THE MID-HAWTHORN AQUIFER IN MILLION GALLONS PER DAY

	1984	1990	1995	2000
Pine Island	.355	.425	.496	.551
Waterway Estates	.258	.313	.362	.405
North Cape Coral	.217	.257	.297	.332
Cypress Lakes	.250	.388	.470	.564
Cape Coral	1.489	1.489	1.489	1.489*
Irrigation	3.894	4.822	6.170	8.237
Total Pumpage	6.463	7.694	9.284	11.578

*Assuming Cape Coral continues to withdraw water from the mid-Hawthorn.

Total withdrawal from the mid-Hawthorn aquifer by private wells in the study area is estimated at 3.89 MGD (Table 8). This value, along with the projected total daily pumpages for successive five year increments up to 2000, is presented in Table 8. Table 8 depicts the irrigation withdrawal of the study area increasing to 6.17 MGD by the year 1995.

Future water requirements from the lower Hawthorn aquifer for 1984 through 2005 are presented in Tables 4 through 6. The lower Hawthorn aquifer, in 1984, is being stressed only by three wellfields which are withdrawing approximately 5.4 MGD (Table 3). If the current trend continues, production from the lower Hawthorn wellfields will be approximately 12.13 MGD based on Lee County Division of Community Development's population projection. However, if additional lower Hawthorn wells are installed in Cape Coral to replace existing mid-Hawthorn wells, the Cape Coral requirement alone would be 10.52 MGD. This is based on present allocations of the original wells plus the amount of water requested by the City of Cape Coral for their proposed wells. Impacts of these requirements are assessed in the modeling section.

INTRODUCTION TO AQUIFER SIMULATIONS

A series of numerical simulations were run for the mid and lower Hawthorn aquifers to assess the impact of future water withdrawals. The simulation runs were conducted using the U.S. Geological Survey finite difference two-dimensional flow model developed by Trescott, Pinder, and Larson (1976). This model was used to simulate two-dimensional flow in semi-confined, leaky aquifers, under present and future stress.

Two homogeneous 50 by 50 grid arrays were used for the aquifer simulation. For the calibration and early development runs, a 30 second latitude by 30 second longitude (approximately one half mile square) grid spacing was used. These models covered the area between longitudes 82°16'00"; 81°46'30" and latitudes 26°48'00"; 26°18'30" (Figure 21). In the cases where the cone of influence generated by additional pumpage approached the model border, the grid was expanded to a 60 second by 60 second spacing (Figure 22). In these simulations, the study area occurred between longitude 82°26'00"; 81°37'00" and latitudes 26°58'00"; 26°09'00".

The heterogeneous transmissivity values used in the model were calculated using trend and kriging analysis on existing data. The storage values for the lower Hawthorn aquifer were also derived in this manner. A constant storage value of 10^{-4} was used for the mid-Hawthorn aquifer. The constant leakance value used for each aquifer was derived emperically during calibration runs. Pumpage rates were calculated from existing and projected population figures presented by the Lee County Division of Planning (1983) and the Cape Coral Planning Department (1982)..

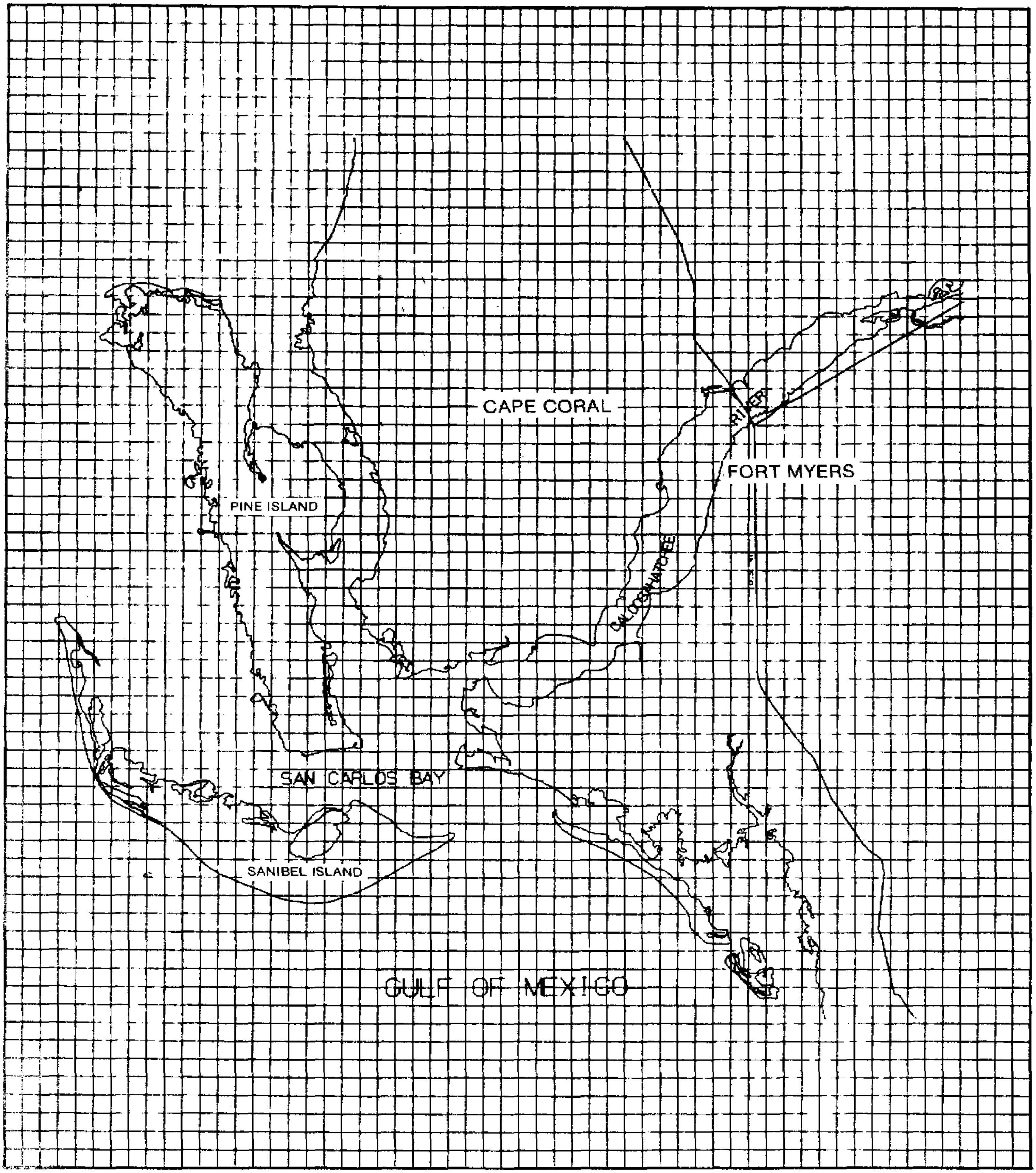


Figure 21 THIRTY SECOND GRID OVERLAIN ON LEE COUNTY PLANNING AREA

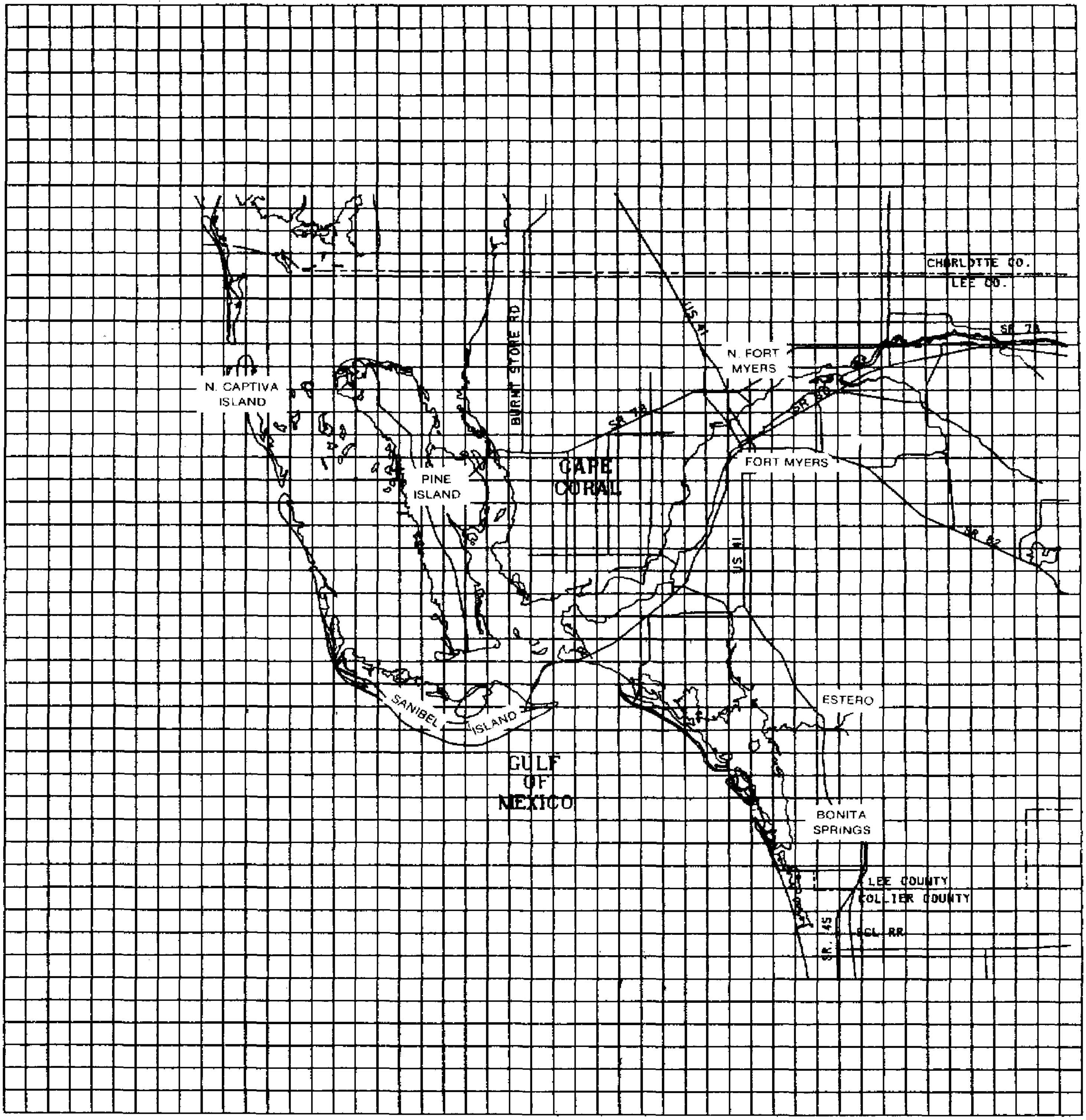


Figure 22 SIXTY SECOND GRID USED IN TWO DIMENSIONAL MODELING

MID-HAWTHORN AQUIFER SIMULATION

Pre-development Constant Flux Model

A calibrated constant flux model was used to duplicate the pre-development conditions of the mid-Hawthorn aquifer. The purpose of this model was to: a) fine tune the calculated aquifer parameters which are to be used in subsequent models, and b) to determine the amount of flow through the model area prior to development.

A heterogeneous transmissivity matrix consisting of 2500 values was generated through kriging analysis of 60 original data points. Of the original values, 10 were derived through duration pump tests, 26 were determined through regression analysis of specific capacity data, and 24 were derived from well cutting analysis (Layne-Western, 1977). The resulting transmissivity values ranged from 2720 to 25,600 GPD/ft. with a mean value of 12,000 gpd/ft. A constant value of 10^{-4} was used for the storage coefficient because there was not enough data to support kriging or trend analysis.

The pre-development potentiometric surface for the mid-Hawthorn aquifer was drawn using water level data collected by the USGS between 1942 and 1957 (Figure 7). These data define a gently dipping surface which trends from the northeast to the southwest closely paralleling the potentiometric surface of the lower Hawthorn aquifer. The average potentiometric gradient for the mid-Hawthorn aquifer at that time was 0.33 ft/mile.

A preliminary estimate of the amount of flow through the study area was determined by flow net analysis. Using an average transmissivity of 12,000 gpd/ft. and an average thickness of 70 feet, a value of 31,000 gal/per day was derived. This volume of water was distributed as inflow along the northeastern boundaries of the model area and as outflow along the southwest boundaries in the first model run.

The first run of the model using the orginal kriged transmissivities caused extremes in head levels in the northeast and southwest corners of the modeled area due to unrealistically low transmissivities. The low transmissivity values (650 gpd/ft) calculated by the kriging analysis, occurred in areas of highest uncertainty and are the result of continuing a downward trend too far away from control points. These low values were increased to 3,200 gpd/ft which corresponds to the lowest measured transmissivities in that area. After this modification, the model was successfully calibrated using a daily inflow/outflow of 50,000 gallons.

Constant Head Predictive Model

Because of the low volume of natural flow through the study area, it would be necessary to expand the model size several times in order to provide enough water for realistic results using a constant flux boundary. Due to the limitations of the computer, it was not possible to run a model of this size with the resolution needed for interpretation. Therefore, a constant head boundary, which provides an infinite source of water along the model boundaries, was used in subsequent simulations. The constant head boundary closely simulates the existing condition of the aquifer until expanding cones of influence approach the model boundary. At this point the cone of influence will be restricted in size and deformed in shape, and a larger modeling area will be required. The values assigned to the constant head boundaries were derived from the pre-development head map provided by the USGS.

A calibration run using 1983-84 pumpage data was undertaken to determine the dynamics of the model under stress. The amount of water pumped during the 1983-1984 water year was averaged for each wellfield and distributed among the production wells based on individual well capacity. This would result in moderate drawdowns which would fall in between the extremes of the observed data (Table 9). In addition, pumpage rates averaged over a year were much

TABLE 9

COMPARISON OF ACTUAL AND COMPUTED WATER LEVELS FOR THE MID-HAWTHORN AQUIFER; 1983-1984

WELL NO.	COMPUTED WATER LEVEL	ACTUAL WATER LEVELS 83-84 HIGH	LOW
L-581	-21.8	-21.7	-32.4
L-735	14.8	13.9	7.5
L-742	-9.7	-5.2	-46.2
L-781	-16.4	-10.8	-21.2
L-1058	3.0	7.1	5.1
L-1059	20.0	15.3	13.4
L-1116	-19.8	-17.1	-33.18
L-1598	-11.4	0.6	-19.8
L-1973	13.2	16.4	11.6
L-2640	-13.7	-6.0	-18.0
L-2641	-27.4	-23.4	-41.1
L-2642	-11.8	-5.0	-14.7
L-2643	2.0	8.2	4.3
L-2644	1.8	5.8	3.0
L-2645	13.4	15.6	13.7
L-2646	20.8	20.8	18.4
L-2700	5.7	12.4	11.7
L-2701	-21.7	-18.1	-24.0
L-2702	-21.4	-13.0	-28.6
L-2703	-20.5	-14.1	-24.1
L-2820	16.3	16.2	14.6
L-2821	11.6	15.2	14.3

lower than the actual instantaneous rates. This makes accurate determination of well head drawdown impossible in the simulation.

Total yearly pumpage data from the five major municipal wellfields from 1984 through 2000, shown on Table 8, were described by 17 discharge nodes in the model. Pumpage from private irrigation wells were described by 893 discharge nodes.

Results from the first model attempt produced excessive drawdowns at the municipal wellfields. As a result, leakance was added to the model. Due to the similarities in the configuration of the pre-development potentiometric surfaces of the mid and lower Hawthorn aquifers and from available well cuttings, the lower Hawthorn is considered to be the source of leakance in this model. The model was calibrated using an average confining bed thickness of 250 feet, and a hydraulic conductivity of 10^{-8} ft/sec. This translates to a leakance value of 3.10×10^{-4} gpd/ft^3 which compares reasonably well to measured values for the mid-Hawthorn (Missimer, 1978 and 1980). In areas of large drawdowns in the mid-Hawthorn aquifer, it is possible for the Surficial Aquifer System to provide some leakance recharge. However, there are no data to quantify this assumption at this time.

Once leakance was added, and after some minor modifications of the private irrigation pumpage, the model calibration was considered complete. The configuration of the potentiometric surface from the calibration run (Figure 23) compares favorably with the real case (Figure 24). Table 9 shows the computed heads at the nodes which best correspond to the location of an existing monitor well. Because of the low transmissivities, steep gradients adjacent to municipal wellfield cause large scale head variations over short distances. This necessitates accurate location of both the pumped and observation wells. Therefore, mislocation of wells due to the models block centering requirement affect the correlation of real to computed head levels.

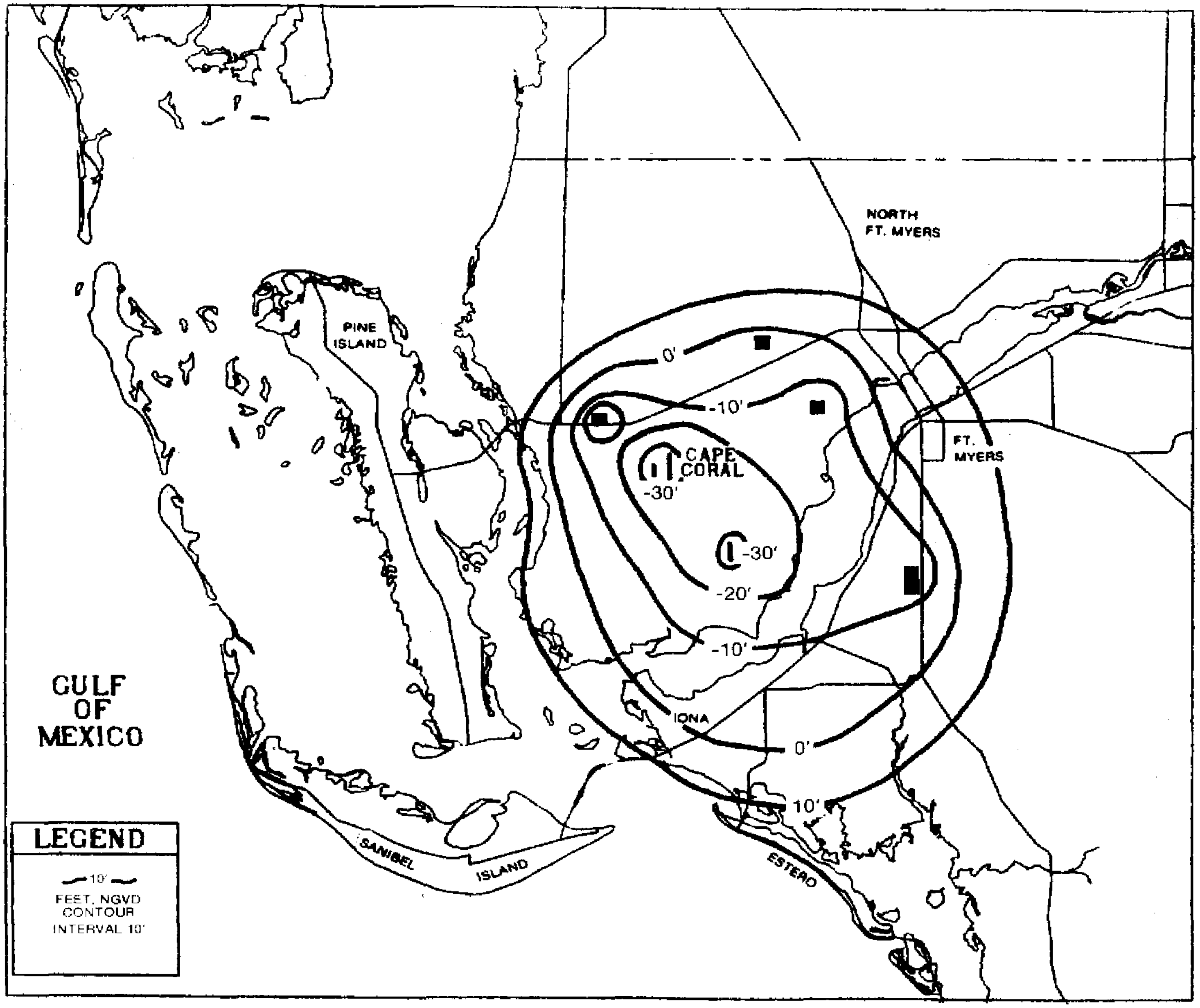


Figure 23 SIMULATED POTENTIOMETRIC SURFACE OF THE MID HAWTHORN AQUIFER, 1983-1984

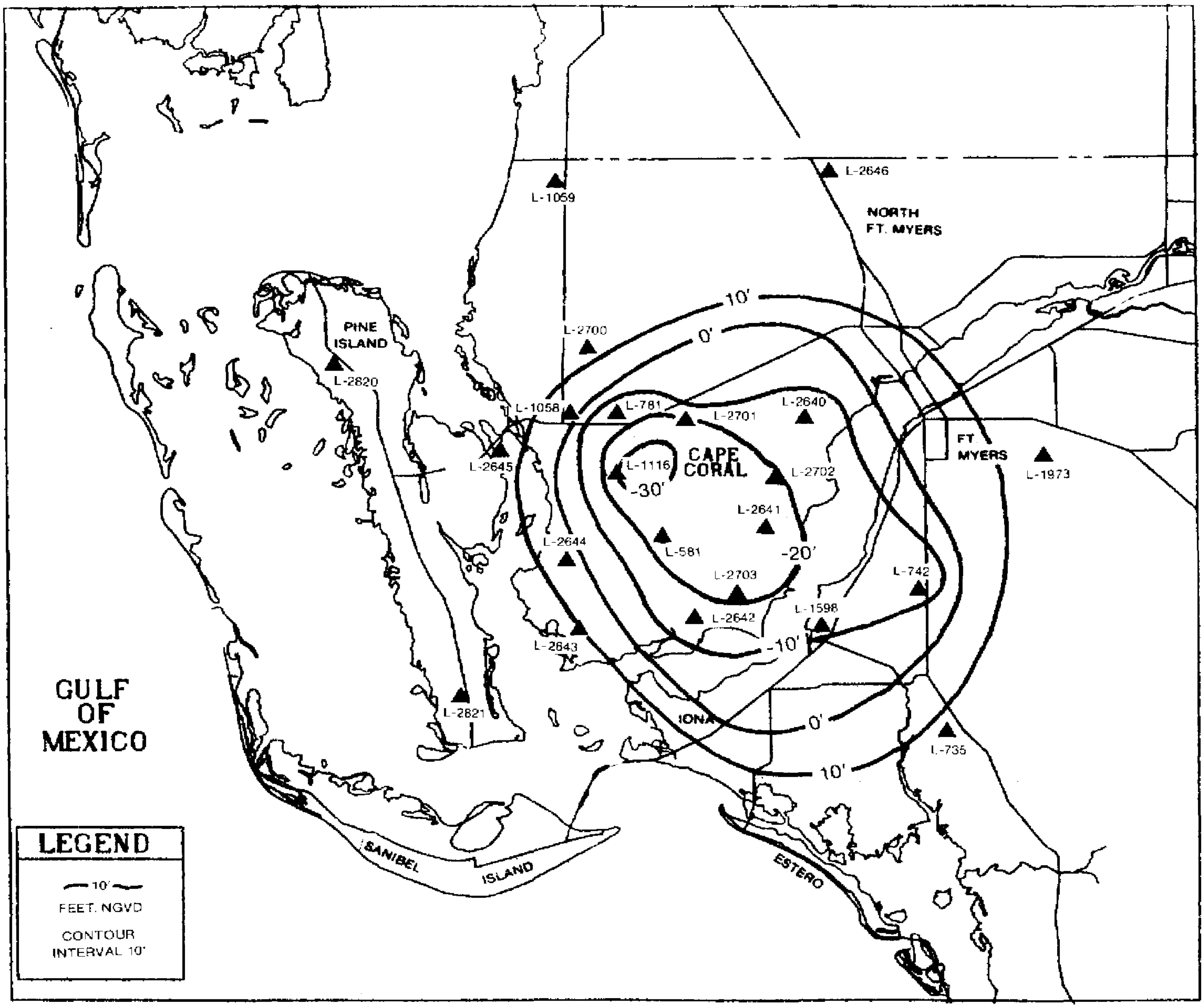


Figure 24 POTENTIOMETRIC SURFACE OF THE MID HAWTHORN AQUIFER JANUARY, 1984

Well L-1059 yields a value greater than five feet above the measured water levels. This is due to the proximity of the constant head boundary which is only three rows (1.5 miles) away. This can be improved by expanding the simulation area. Another variation occurs at well L-735 in which the computed value is about three feet too high. L-735 is located in a trailer park which uses the mid-Hawthorn as a source for private wells. Therefore, this high value could be adjusted by adding some pumpage at that node.

The most significant deviation occurs in several wells (L-1058, L-2643, L-2644, L-2700, and L-2821) which fall on a north-south line along the western coast of Cape Coral and westward on Pine Island. The computed water levels in these wells are three to five feet below the actual values. This has resulted in a slight westward extension of the cone of depression. This may indicate the presence of very low transmissivity values in this area which act as partial boundary conditions for the aquifer. This would explain why water levels in the Pine Island wellfield are -60 ft. NGVD while L-1058, located only two miles away, free flows at land surface.

Another exception may occur adjacent to the Cypress Lakes wellfield. Since the development of the Green Meadows wellfield in 1981, pumpage at the Cypress Lakes wellfield has been greatly diminished. However, during actual pumpage, the adjacent water levels drop sharply. The yearly average value used in the model does not reflect these short term large drawdowns.

Maximum drawdowns in Cape Coral occur adjacent to the Santa Barbara, Skyline, and Golf Course wellfields. During the 1984 dry season, Cape Coral attempted to withdraw additional water from the mid-Hawthorn aquifer after the clogging of the R.O. membranes. These attempts failed due to excessive drawdowns in the production wells. This indicates that the Cape Coral wellfields are operating at the maximum capacity attainable from the resource. From the model results, this pumpage (1.489 MGD) produced a circular depression with water levels below -30 ft. NGVD. It is felt that any further declines within the vicinity of the Cape Coral wellfields will cause the production wells to "run dry" during periods of peak use in the dry season.

With the 1983-84 pumpage, it took 4.11 years for the model to reach the steady state error criterion of .001 ft. Of the total amount of water pumped at steady state, 1.53% came from storage, 18.31% came from inflow from outside the model boundaries (ie. Charlotte County), and 80.16% is from leakance from other aquifers. However, water in other aquifers may be of inferior quality to that of the mid-Hawthorn. The large amount of water derived from leakance represents a limitation of the dependability of the mid-Hawthorn under long term stress.

Resulting drawdowns from projected water use in 1990 are shown in Figure 25. Under these conditions, the -30 ft. depression has expanded to encompass most of Cape Coral in the vicinity of the Santa Barbara, Skyline and Golf Course wellfields. The areal extent of the 0 ft. contour has not changed significantly due to the low transmissivity of the aquifer. In general, the projected increased pumpage in 1990 will produce an average additional drawdown of 8 feet throughout Cape Coral, with drawdowns in production wells increasing approximately 15 to 20 feet. These additional drawdowns would be sufficient to cause frequent production well failures in the Cape Coral wellfields throughout the dry season. The additional drawdowns in the other wellfields should not result in interuption of service. However, water quality in the Pine Island wellfield may be affected by saltwater encroachment from saline water located to the west.

Assuming that by 1990 Cape Coral will have developed alternate sources for supply, the same model was run without the Cape Coral wellfields (Figure 26). Water levels in this simulation range between -10 to -17 feet throughout most of Cape Coral and are controlled mainly by irrigation use (4.80 MGD). Water

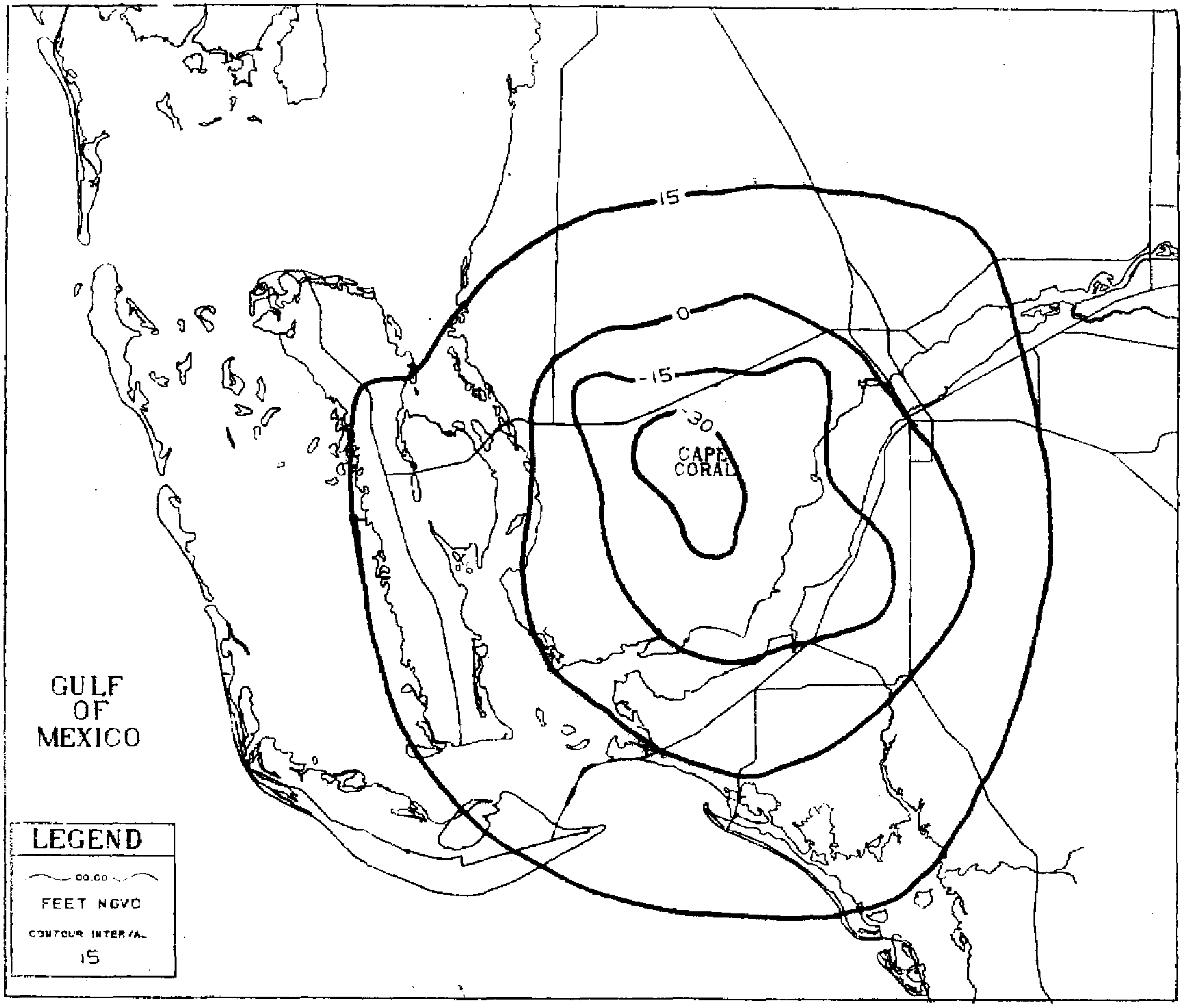


Figure 25 PROJECTED POTENTIOMETRIC SURFACE OF THE MID HAWTHORN AQUIFER, 1990 (INCLUDING CAPE CORAL WELLFIELDS)

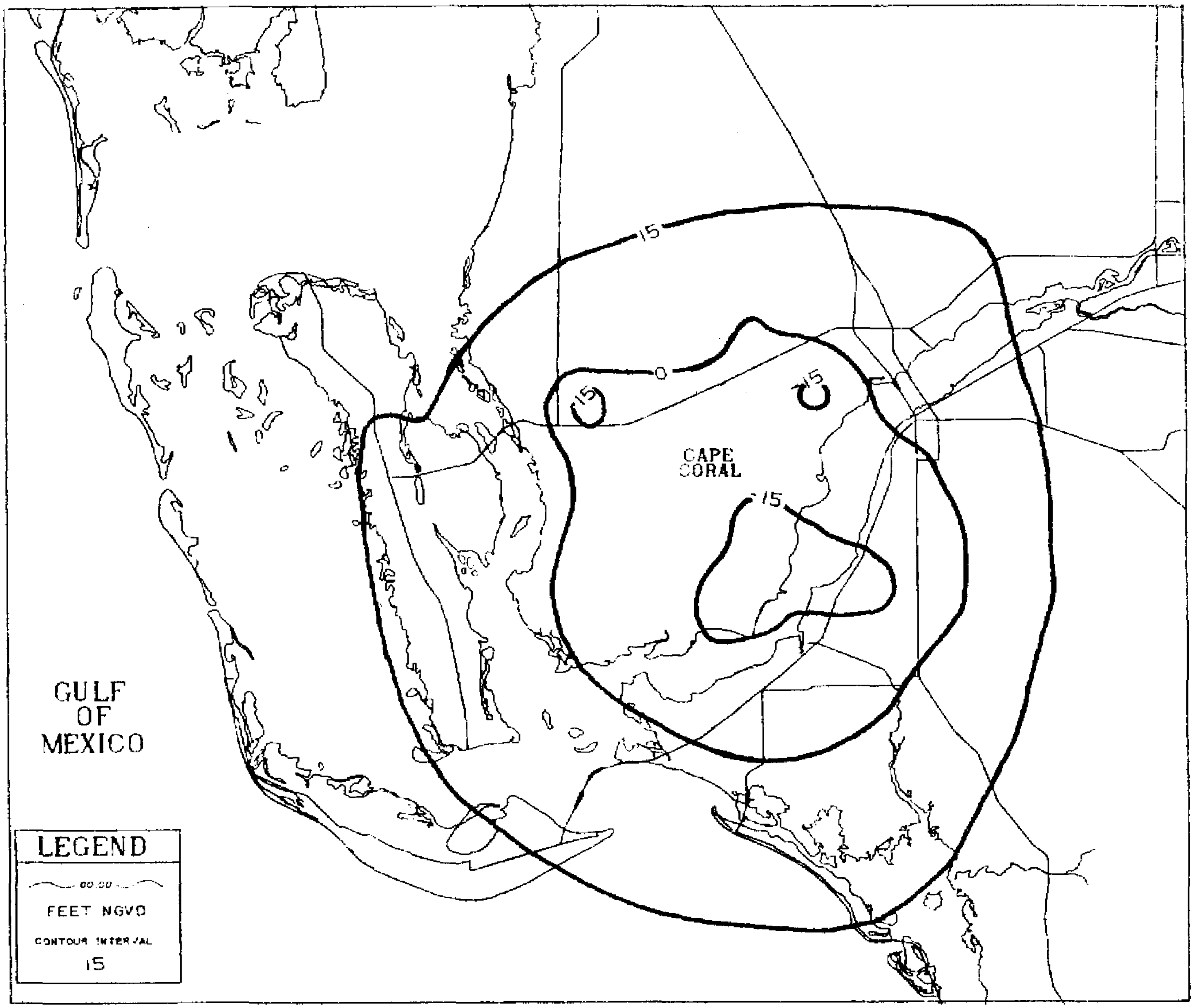


Figure 26 PROJECTED POTENTIOMETRIC SURFACE OF THE MID HAWTHORN AQUIFER, 1990

levels adjacent to the Pine Island wellfield range from -10 to -27 feet exhibiting a ten foot increase in water levels over the 1990 simulation with Cape Coral's pumpage. Water levels at the Florida Cities wellfield would exhibit an average increase of seven feet. Although the major source of water into the mid-Hawthorn is leakance, it appears that the aquifer can sustain this degree of development with minimum water quality deterioration. If irrigation withdrawals are reduced through the development of alternate sources, such as use of canal water, effluent reuse, and Surficial Aquifer System, the mid-Hawthorn aquifer may recover faster.

Figure 27 depicts the water levels for the year 1995 assuming the Cape Coral plants are not in operation. Increased development in western Cape Coral and north Ft. Myers will increase the area and magnitude of drawdowns. A yearly average of 6.17 MGD used in the model for irrigation may be an excessive amount for 1995.

Under these conditions, water levels near the Pine Island wellfields will drop below -30 feet NGVD. While the Pine Island mid-Hawthorn wellfield may still be capable of producing water, the quality of the water by this time may have deteriorated to below drinking water standards. Pine Island should be prepared to resort to an alternate supply in the event of water quality deterioration. Elsewhere in the study area, water levels will drop an additional five to ten feet. Despite these declines, the mid-Hawthorn should be capable of supplying the remaining municipal users. However, further regional deterioration of water quality may take place in the western portions of Cape Coral.

Water levels for the year 2000 are shown on Figure 28. Due to the increased size of the cone of influence, a 60 second grid was used for this run. This change reduces the resolution of the model especially in areas adjacent to the wellfields where actual drawdown will be greater than shown.

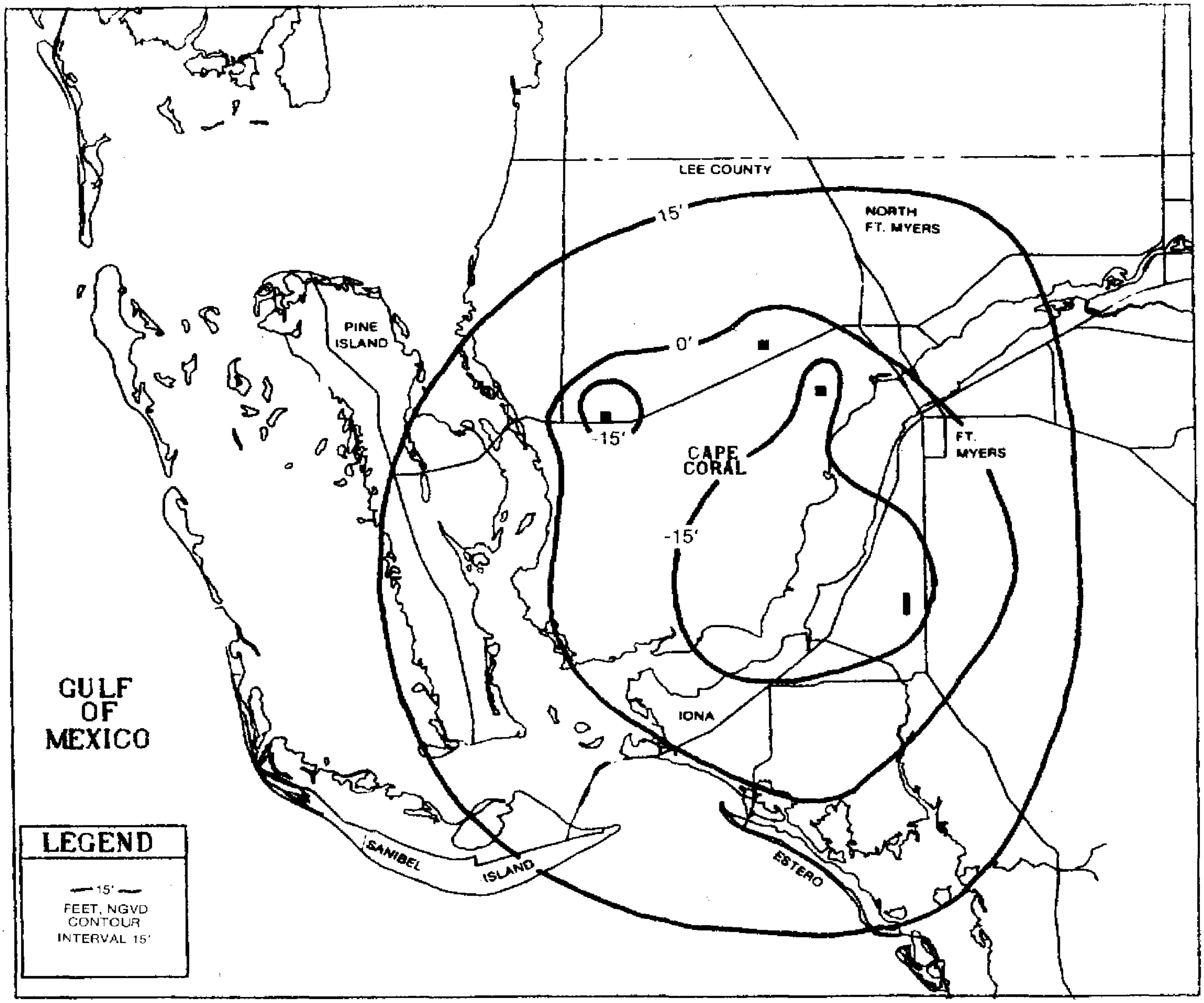


Figure 27 PROJECTED POTENTIOMETRIC SURFACE OF THE MID HAWTHORN AQUIFER, 1995

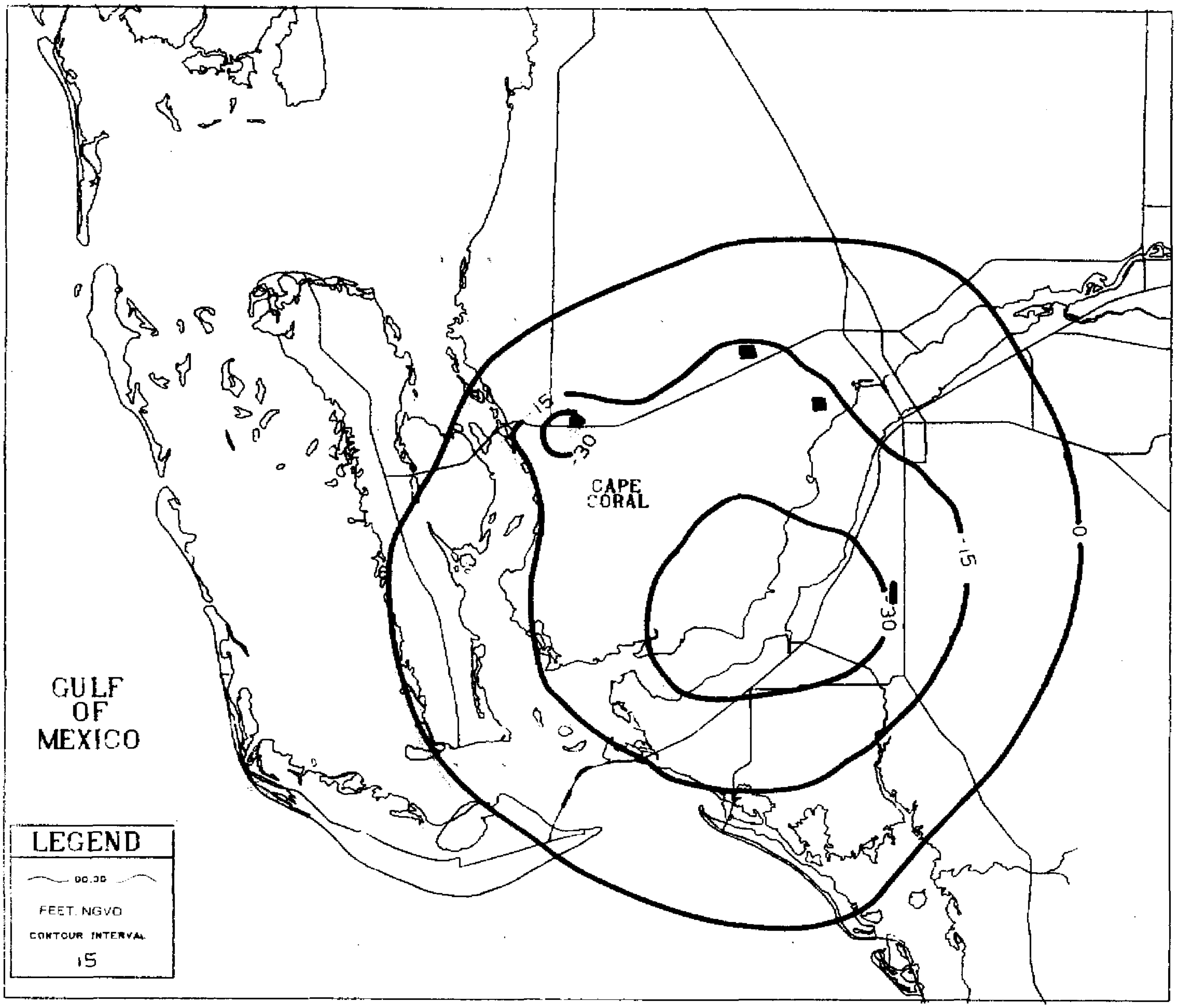


Figure 28 PROJECTED POTENTIOMETRIC SURFACE OF THE MID HAWTHORN AQUIFER, 2000

The projected irrigation use of 8.24 MGD represents the major use of the aquifer. This figure is considered to be the maximum use at buildout. Water levels in central Cape Coral and adjacent south Ft. Myers will be below -30 ft. NGVD. The water levels adjacent to Pine Island will be below -50 ft. NGVD. Drawdowns at Cypress Lake will also be below -50 ft. NGVD.

As previously mentioned, each model used leakance as a major supplier of recharge to the aquifer. In light of the expansion and increased pumpage of the Cape Coral R.O. plant, it is expected that the potentiometric head of the lower Hawthorn will decrease resulting in a reduction of the volume of water available to the mid-Hawthorn as leakance. Any reduction in leakance would cause larger drawdowns than those represented in the previous models. To accurately assess the effects of reducing potentiometric levels in the lower Hawthorn, a three-dimensional model is needed. The present computer facilities at the District are insufficient to run such a model. However, two levels of lower Hawthorn drawdowns were simulated for the years 1995 and 2000.

Figure 29 depicts the computed water levels for the mid-Hawthorn in 1995 assuming a 10 foot decline of water levels in the leakance recharge source. Water levels are generally between 5 and 10 feet lower as compared with Figure 27 except near the municipal wellfields where reduced leakance caused an additional 20 foot decline. Under such conditions, the Pine Island wellfield may experience water resource problems.

Figure 30 depicts the computed water levels for the mid-Hawthorn for the year 2000 assuming a 20 foot decline of water levels in the leakance source. The excessive drawdowns shown here are considered unrealistic to the east because the decline in the lower Hawthorn caused by the R.O. plants to the west would not extend that far.

In conclusion, the mid-Hawthorn aquifer does not have the capability of supplying both large scale municipal and irrigation requirements in the

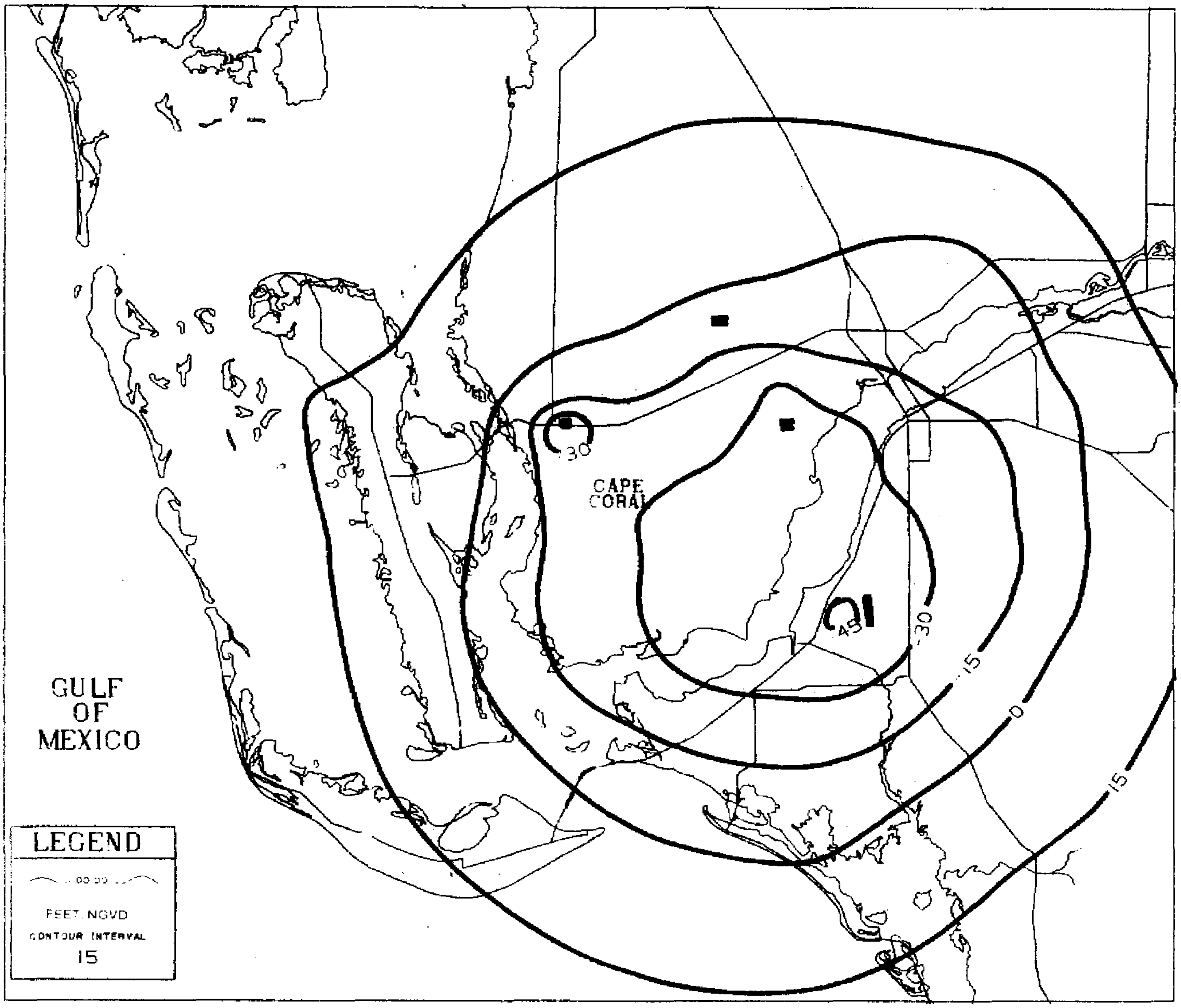


Figure 29 PROJECTED POTENTIOMETRIC SURFACE OF THE MID HAWTHORN AQUIFER, 1995 (WITH DECREASED LEAKANCE RECHARGE)

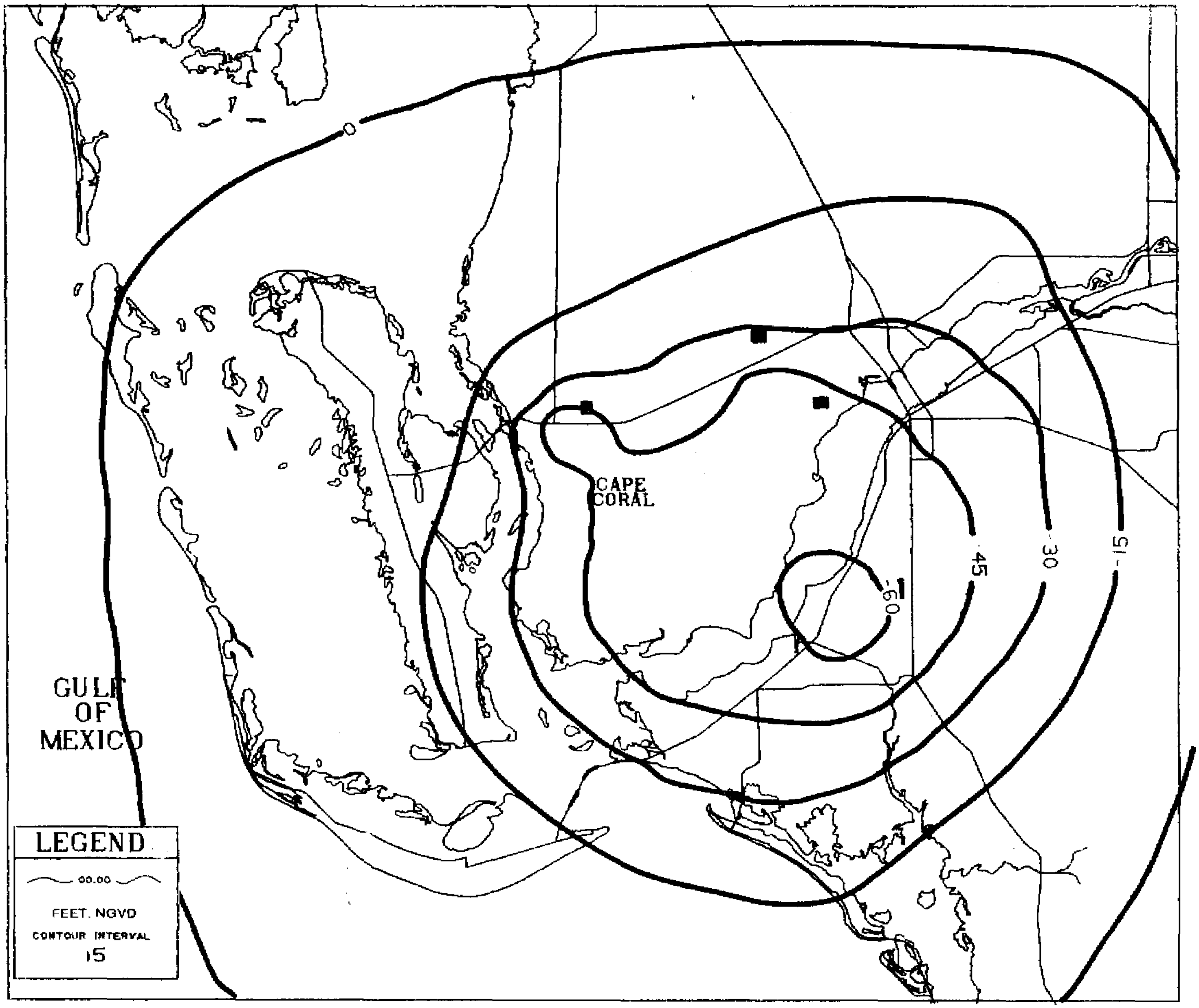


Figure 30 PROJECTED POTENTIOMETRIC SURFACE OF THE MID HAWTHORN AQUIFER, 2000 (WITH DECREASED LEAKANCE RECHARGE)

future. Continued overstress of the aquifer will lead to depletion of this fresh water resource. Based on the model results described previously, the Cape Coral wellfield may be operational up to 1990 with possible interruptions in service occurring during the dry seasons. Extended service may be possible if projected irrigation demands are reduced through the development of secondary irrigation sources. Assuming that Cape Coral's mid-Hawthorn wellfields are shut down, or irrigation demands are reduced, the Pine Island wellfields can produce water up to 1995. However, water quality deterioration may take place. If both the Cape Coral and Pine Island plants are shut down, the mid-Hawthorn should be able to sustain limited pumpage for the three remaining Florida Cities wellfields and up to 6 MGD of private irrigation use. These withdrawals, however, will cause water quality deterioration in the future, making the water unfit for potable purposes.

LOWER HAWTHORN SIMULATIONS

Four models were used for simulations of the lower Hawthorn aquifer. These included a calibrated constant flux model and three constant head models with differing aquifer parameter values. The constant head models each represented several pumpage scenarios.

A calibrated constant flux model was developed to simulate the predevelopment conditions of the lower Hawthorn aquifer. This model assisted in calibrating the aquifer parameters and quantifying the natural flow through the aquifer. Using the transmissivities and storage coefficients calculated from the trend and kriging analysis, the pre-development flow into the study area was about 120,000 gallons per day. The constant flux model was not used for predictive simulations because the model area could not be expanded enough to provide sufficient inflow while maintaining the high degree of resolution produced by a 30 or 60 second grid.

Constant Head Predictive Model

A constant head predictive model was used for the lower Hawthorn aquifer utilizing two possible population scenarios for the City of Cape Coral. Wellfield pumpages were proportionately divided among existing and proposed wells based upon well capacities, and then placed on 12 nodes in all of the following model grids. A heterogeneous transmissivity and storage matrix was developed from 12 published values (Appendix V). The average transmissivity in the vicinity of the Cape Coral wellfields was 100,000 gpd/ft. and storage was 10^{-4}. Hydraulic conductivity was set at 10^{-8} ft/sec. throughout the study area. A uniform thickness of the lower confining beds was set at 50 feet. These translate to an approximate leakance value of 11×10^{-4} gpd/ft^3. An average constant head value of 32 feet was set on the opposite side of the confining beds. These values represent the best approximations of aquifer parameters from the existing data. However, this model did not calibrate to the 83-84 pumpage levels and USGS observation well network. Possible explanations for this will be presented later in the text.

Two separate runs of the model were made to simulate different water requirement scenarios (Table 10). The first used population projections published by the Cape Coral Planning Department (CCPD, 1983). These figures represent liberal population forecasts. The second scenario used population projections presented by the Lee County Division of Community Development (LCDCD, 1982). The latter projected population figures were considered to be more conservative.

Figure 31 depicts the potentiometric surface for the year 1990 with an estimated population of 77,700 (CCPD, 1983) and an average pumpage rate of 14.4 MGD from the Cape Coral R.O. wellfield. The Sanibel wellfield will be pumping at a projected rate of 1.86 MGD and Pine Island at .42 MGD. The model shows the Pine Island wellfield drawdowns to be between 13 and 19 feet and Sanibel between 7 and 11 feet. The increased pumpages at the Cape Coral wellfield have minor effects on either of these wellfields. Water levels in the Cape Coral wellfield will be approximately -40 ft. NGVD with drawdowns in production wells estimated near -75 ft. NGVD. Under these pumping conditions, the lower Hawthorn aquifer in Cape Coral will receive over 47% of its recharge water in the form of leakance with greater leakance rates occurring at the wellfields.

Figure 32 depicts the water levels in 1990 using an estimated population of 56,850 (LCDCD, 1982) and an average pumpage of 10.53 MGD from the lower Hawthorn aquifer. The average water levels in the Cape Coral wellfield area will vary between 0 and -25 ft. NGVD. Drawdowns in the Sanibel and Pine Island wellfields are not affected by Cape Coral's additional withdrawal.

Figure 33 depicts a model simulation of the lower Hawthorn aquifer for the year 1995 with a projected population of 101,300 (CCPD, 1983) and an average

TABLE 10

POPULATION PROJECTIONS AND WATER USES FOR THE LOWER HAWTHORN AQUIFER

	POPULATION		PROJECTED WATER USE(MGD)[3]	
YEAR	CCPD[1]	LCDCD[2]	CCPD	LCDCD
1985	54,500	47,800	10.10	8.85
1990	77,700	56,850	14.40	10.53
1995	101,300	65,700	19.11	12.17
2000	128,500	74,200	23.82	13.75
2005	159,400	78,950	29.54	14.63

1. CCPD - Cape Coral Planning Department
2. LCDCD - Lee County Department of Community Development
3. Projected water use estimates assume all housing units will use R.O. water.

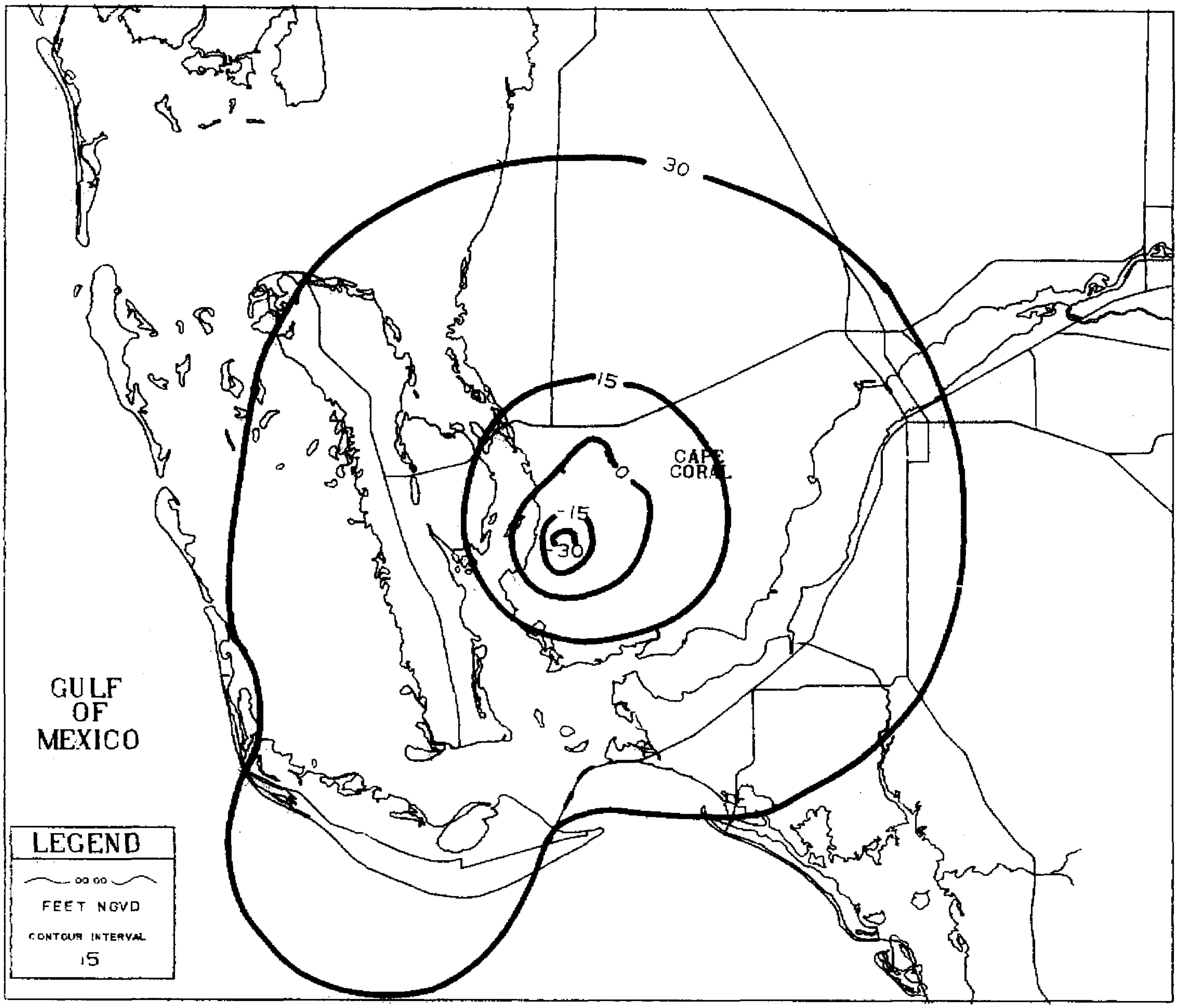


Figure 31 PROJECTED POTENTIOMETRIC SURFACE OF THE LOWER HAWTHORN AQUIFER, 1990
(DATA FROM CAPE CORAL PLANNING DEPARTMENT)

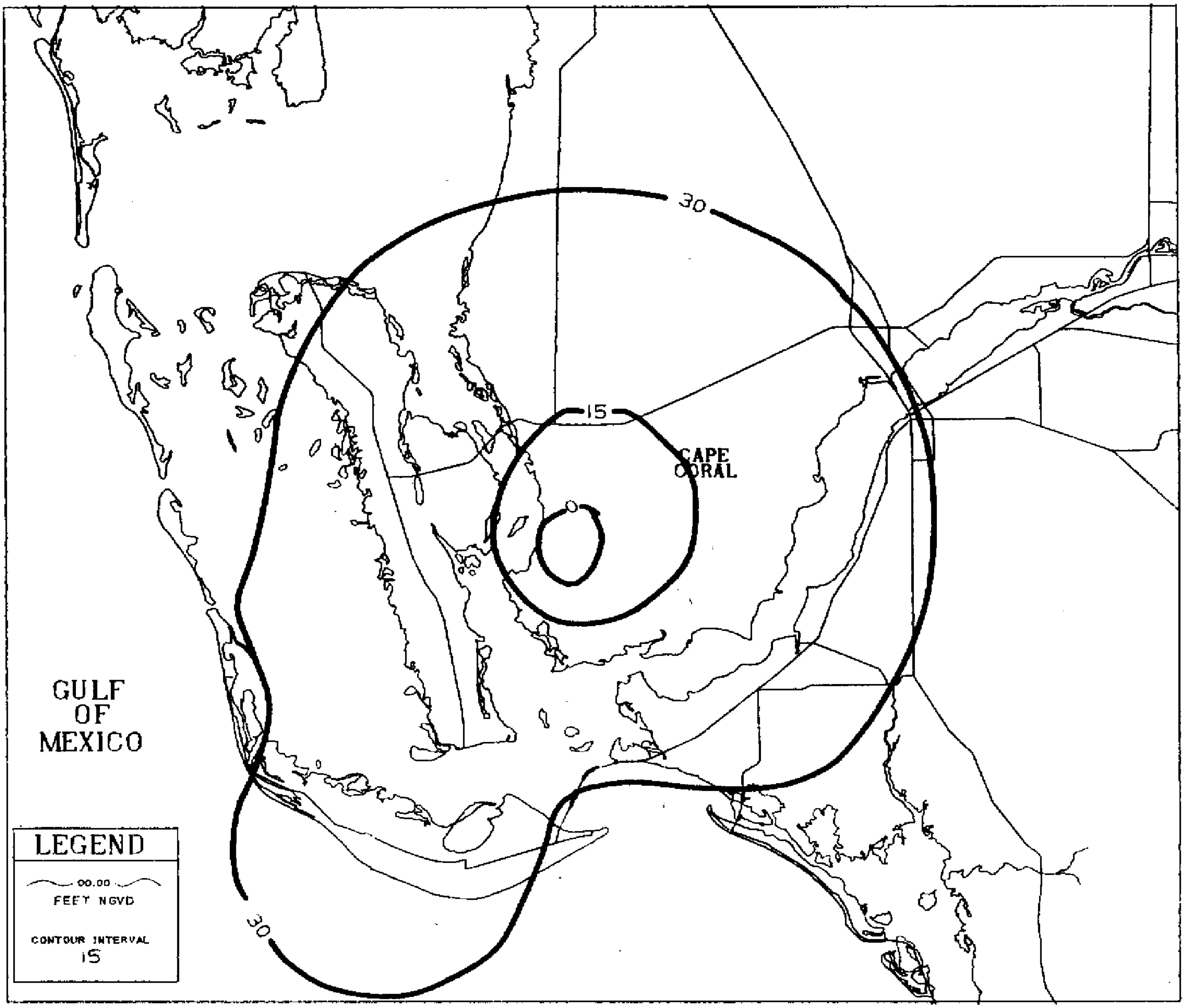


Figure 32 PROJECTED POTENTIOMETRIC SURFACE OF THE LOWER HAWTHORN AQUIFER, 1990
(DATA FROM LEE COUNTY DEPARTMENT OF COMMUNITY DEVELOPMENT)

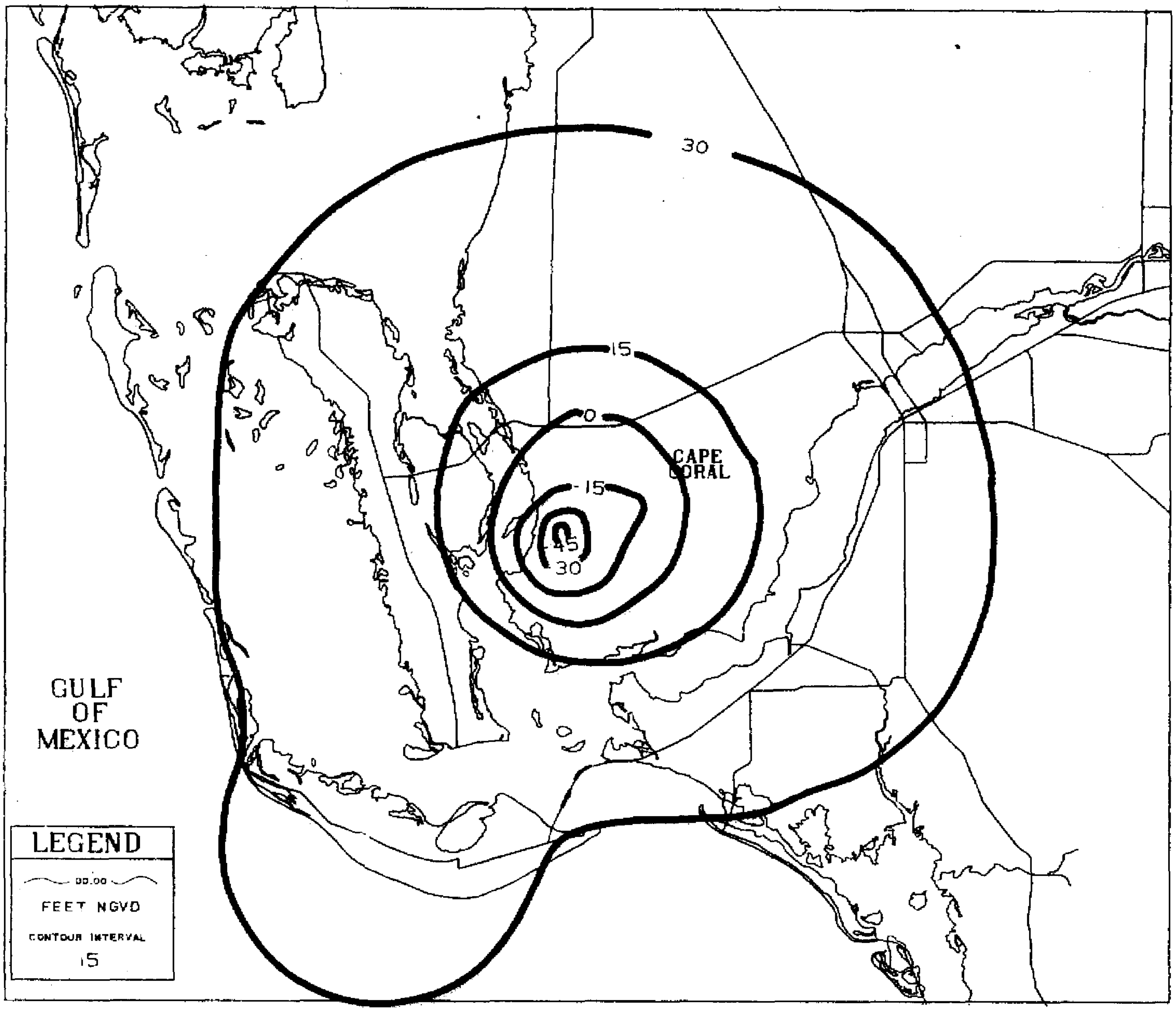


Figure 33 PROJECTED POTENTIOMETRIC SURFACE OF THE LOWER HAWTHORN AQUIFER, 1995 (DATA FROM CAPE CORAL PLANNING DEPARTMENT)

daily pumpage from the Cape Coral wellfield of 19.1 MGD. Projected pumpage rates at Sanibel were 2.0 MGD and 0.5 MGD at Pine Island. The cone of depression caused by this withdrawal will expand outward, with water levels in the Pine Island wellfield area reaching sea level. Within the area of the Cape Coral wellfield water levels will vary between -20 ft. and -75 ft. NGVD. Nearly 55% of recharge water will be contributed from leakance in Cape Coral and water quality deterioration may then be a concern. Water levels in individual pumping wells may be greater than 100 feet below land surface in the Cape Coral wellfield.

Figure 34 depicts the projected water levels for the year 1995 for a population of 65,700 (LCDCD, 1983) and an average pumpage of 12.17 MGD. Water levels within the Cape Coral wellfield area may vary between sea level and -36 ft. NGVD. The levels in the Pine Island wellfield area will be between +14 ft. and +17 ft. NGVD. No appreciable effects are noted in the Sanibel area with water levels varying between +17 and +20 feet adjacent to the wellfield area. Approximately 42% of the recharge water in this scenario is coming from leakance. Even with this lower pumpage rate water quality may be of concern.

Figure 35 depicts the projected potentiometric surface in the year 2005 with a population of 159,400 (CCPD, 1983) and an average daily pumpage from the Cape Coral wellfield of 29.54 MGD. Pumpage rates at Sanibel Island will remain unchanged. Pumpage at Pine Island was modeled at 1.0 MGD. It should be noted that by the year 2005 the mid-Hawthorn aquifer, which supplies Pine Island with half its water, may no longer be usable so actual Pine Island pumpage could be over 2.0 MGD at this time. This would result in greater drawdowns than shown in this model. Drawdowns near the center of the cone of depression in the Cape Coral wellfield will be deepened to -115.0 ft. NGVD, and the water levels in the area will be below -40 ft. NGVD. Drawdowns in the Pine Island wellfield will be between 38 and 48 feet and water levels will

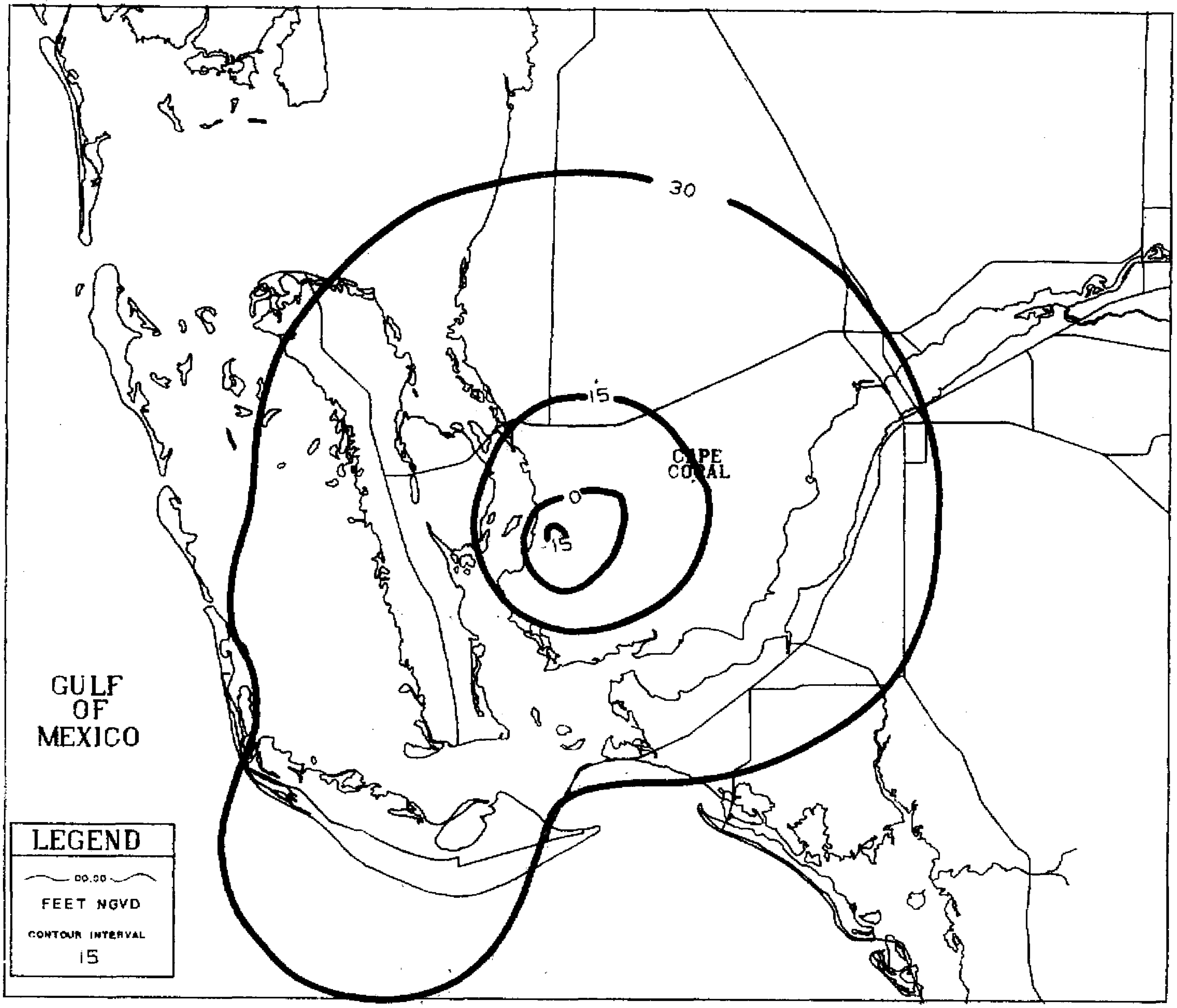


Figure 34 PROJECTED POTENTIOMETRIC SURFACE OF THE LOWER HAWTHORN AQUIFER, 1995 (DATA FROM LEE COUNTY DEPARTMENT OF COMMUNITY DEVELOPMENT)

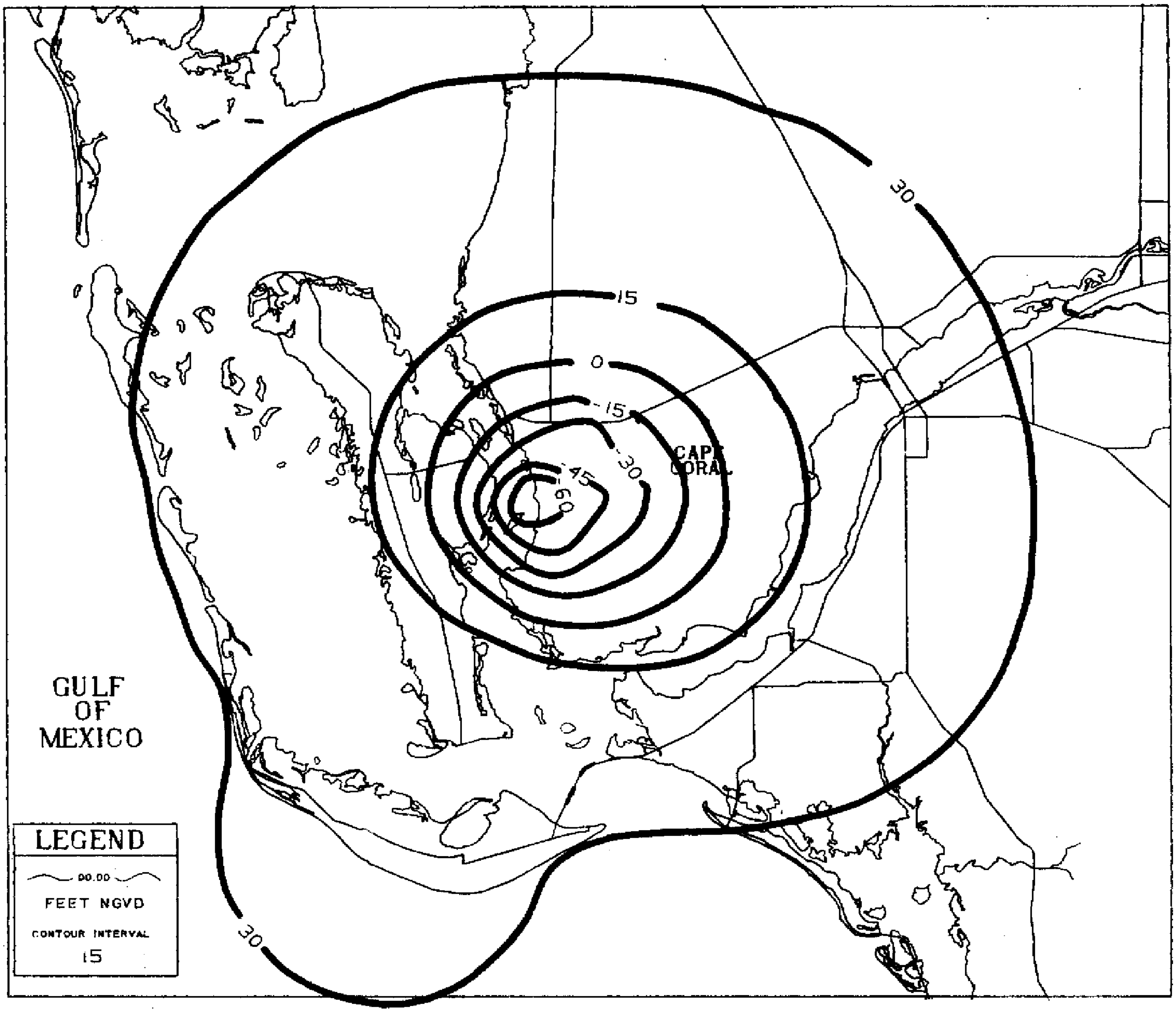


Figure 35 PROJECTED POTENTIOMETRIC SURFACE OF THE LOWER HAWTHORN AQUIFER, 2005 (DATA FROM CAPE CORAL PLANNING DEPARTMENT)

average -10 ft. NGVD. Sanibel may experience 10 to 13 feet drawdown near their wellfields with water levels averaging +17 ft. NGVD. The higher levels at Sanibel are due in part to a decrease or leveling off of population growth in that area.Leakance accounts for 62% of the recharge in this scenario.

Figure 36 is a model projection for the year 2005 with a pumpage rate of 14.63 MGD and a population of 79,000 (LCDCD, 1982). The outer rim of the cone marked by the +30 ft. NGVD contour interval will be open to the west. Water levels in the Cape Coral wellfield area will be approximately -60 ft. NGVD. Pine Island water levels will be between +6 NGVD and +12 NGVD with an average drawdown of 20 ft. in the wellfield area.

In summary, the results of these model simulations indicate that large quantities of water can be withdrawn safely from the lower Hawthorn aquifer at average daily rates not exceeding 10.5 MGD in the Cape Coral area. At average daily rates lower than this, there will be little effects on surrounding users. Water quality deterioration may be the limiting factor on wellfield development. Leakance accounts for over 50% of the water entering the cone of depression and increases at higher pumpage levels. It is not possible to determine the rate or degree of water quality degradation at this time. Further investigations of the deeper aquifers of the area will be needed.

As previously discussed, the aforementioned model could not be calibrated to the 1984 potentiometric levels. This is probably due to either: a) the value of hydraulic conductivity used to define leakance of the confining bed (1×10^{-8} ft/sec.) was too large for the transmissivity matrix (average T of 100,000 gpd/ft.) or b) the transmissivity values used are larger than those which actually exist in the lower Hawthorn aquifer.

The transmissivity values reported from the study area are largely derived from tests conducted on both the lower Hawthorn and Suwannee aquifers combined. Of 12 values used only two were from the lower Hawthorn alone. The

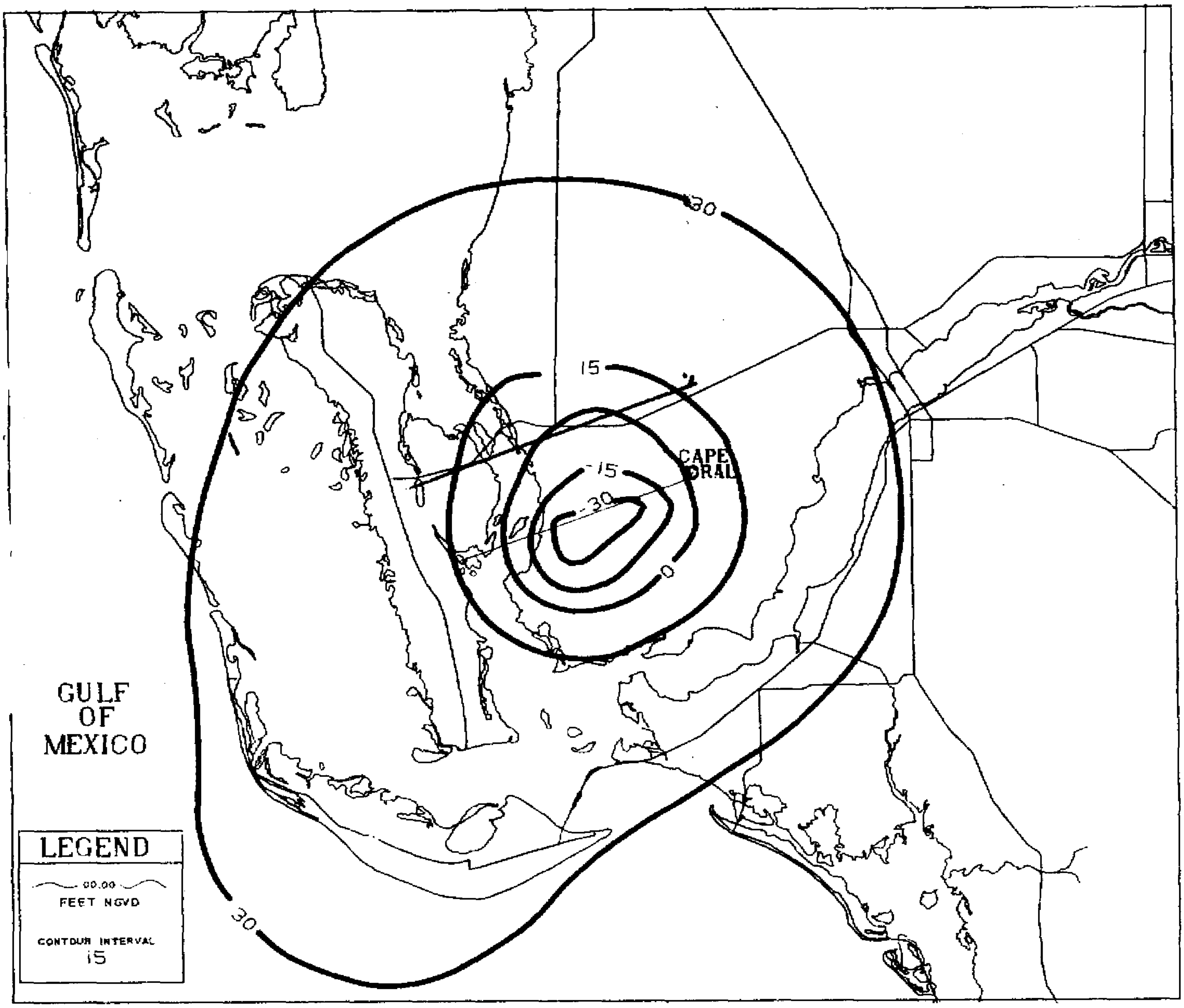


Figure 36 PROJECTED POTENTIOMETRIC SURFACE OF THE LOWER HAWTHORN AQUIFER, 2005 (DATA FROM LEE COUNTY DEPARTMENT OF COMMUNITY DEVELOPMENT)

values from these tests were 15,600 gpd/ft. and 74,000 gpd/ft. The remaining composite values ranged from 58,000 to 170,000 gpd/ft., the highest occurring in the Cape Coral wellfield area. The upper part of the Suwannee aquifer is known to be a high producer of water and transmissivity values used in the previously described model are probably being affected by this zone. There is a possibility that transmissivities within the isolated lower Hawthorn aquifer could be much lower than those previously used.

The hydraulic conductivity values may also be too high. Evidence for this is the presence of poorly indurated very low permeability micrites that were observed in well cores from the Cape Coral and Buckingham areas.

With these deficiencies of data in mind, two additional models were developed to simulate the potentiometric surface with a) high transmissivity and lower leakance, and with b) lower transmissivities and high leakance.

Calibration of the two additional models were accomplished by comparison of computed levels with known water elevations from 12 USGS monitor wells for 1983-1984 (Table 11). The models were calibrated for both a 30 second and a 60 second grid. The reason being the 30 second grids showed model-boundary effects with increased pumpage. A good match was achieved (Figure 37), on both models with two areas of exceptions. The first area was on the southern end of Pine Island at USGS monitor well L-2525. Water levels in this well were 10 feet higher than that projected by the models. The transmissivity values in the matrix surrounding this node were varied significantly, with only minor effects. Well construction details and geologic descriptions from the well indicated that it was probably also open to the Suwannee aquifer which has higher head. The other area of discrepancy was in the vicinity of McGregor Isles, where water levels were lower than those projected by the models. This is an area of known free-flowing artesian wells. A discharge node was placed in this area which brought the water level down to that of reported USGS monitor values.

TABLE 11

COMPARISON OF ACTUAL AND COMPUTED WATER LEVELS FOR THE LOWER HAWTHORN AQUIFER; 1983-1984

WELL NO.	COMPUTED WATER LEVELS MODEL 3	 MODEL 4	ACTUAL WATER LEVELS 83-84 HIGH	 LOW
L-585	25.8	21.1	30.9	29.4
L-558	16.4	19.8	21.0	16.0
L-589	15.0	22.3	25.0	17.0
L-590	21.6	16.0	25.0	16.0
L-2435	26.7	29.4	26.4	25.7
L-2524	13.8	18.6	21.0	11.5
L-2525	14.7	19.4	30.7	32.7
L-2526	30.4	35.9	42.0	40.8
L-2527	25.7	27.0	25.7	24.7
L-2528	25.1	29.0	37.0	36.0
L-2529	25.9	22.0	22.0	21.0
L-2434	5.9	15.7	17.0	4.0

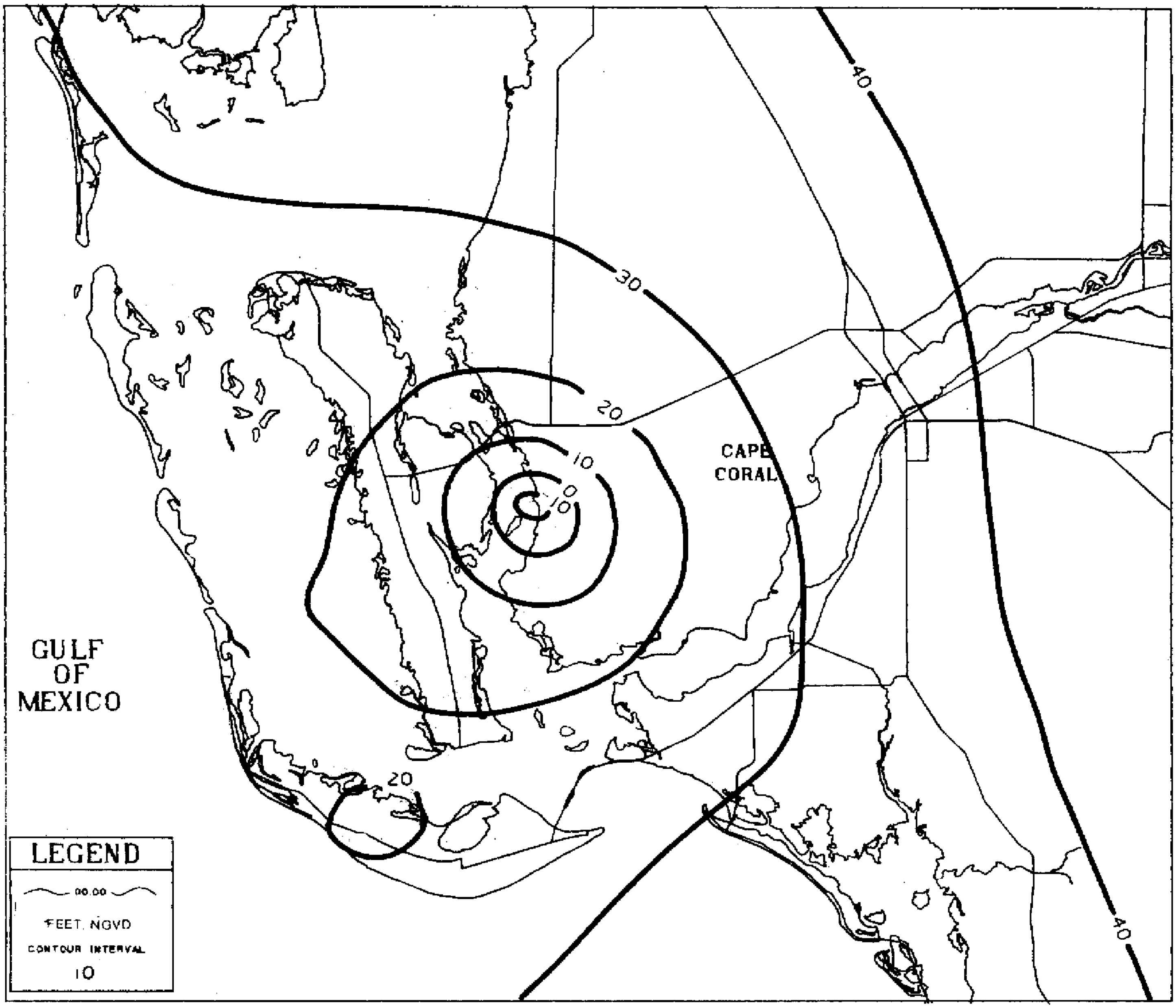


Figure 37 SIMULATED POTENTIOMETRIC HEAD OF THE LOWER HAWTHORN AQUIFER, 1984

The first constant head model (calibrated) used transmissivity and storage values derived from kriging and trend analysis. The transmissivity averaged 100,000 gpd/ft. and storage 10^{-4}. In order to calibrate this model a hydraulic conductivity of 10^{-11} ft/sec. was required. This translates to an approximate leakance of 10^{-6} gpd/ft^{3}.

Figure 38 shows the projected potentiometric surface of the lower Hawthorn aquifer for the year 1990 with an average daily pumpage of 14.1 million gallons and a population of 77,700 (CCPD, 1983). Water levels in the Cape Coral wellfield area will be approximately -75 ft. NGVD. Individual wells will be pumping more than 100 feet below the land surface. A cone of depression marked by the +15 ft. NGVD contour lines will surround an area from Ft. Myers to offshore in the Gulf of Mexico. Water levels in the Pine Island wellfield area will be between -15 ft. and -25 ft. NGVD. Sanibel wellfield water levels will range between -5 ft. NGVD and -10 ft. NGVD. Leakance contribution will be less than one percent due to the low hydraulic conductivity used in the model.

Figure 39 shows the projected potentiometric surface of the lower Hawthorn aquifer in 1990 based on an average daily pumpage of 10.5 MGD and a population of 56,850 (LCDCD, 1982). The areal extent of this cone of depression is virtually the same as the previous figure with water levels in the Cape Coral wellfield area being near -60 ft. NGVD. Water levels in the Pine Island wellfield range between -12 ft. and -17 ft. NGVD and in the Sanibel wellfield area between +3 ft. and -4 ft. NGVD. Water level projections using this model for the years 1995 and 2005 are shown in Appendix VI.

A second constant head model (calibrated) was developed that used an average transmissivity of 50,000 gpd/ft., a storage of 10^{-4}, and a hydraulic conductivity of 10^{-8} ft/sec.

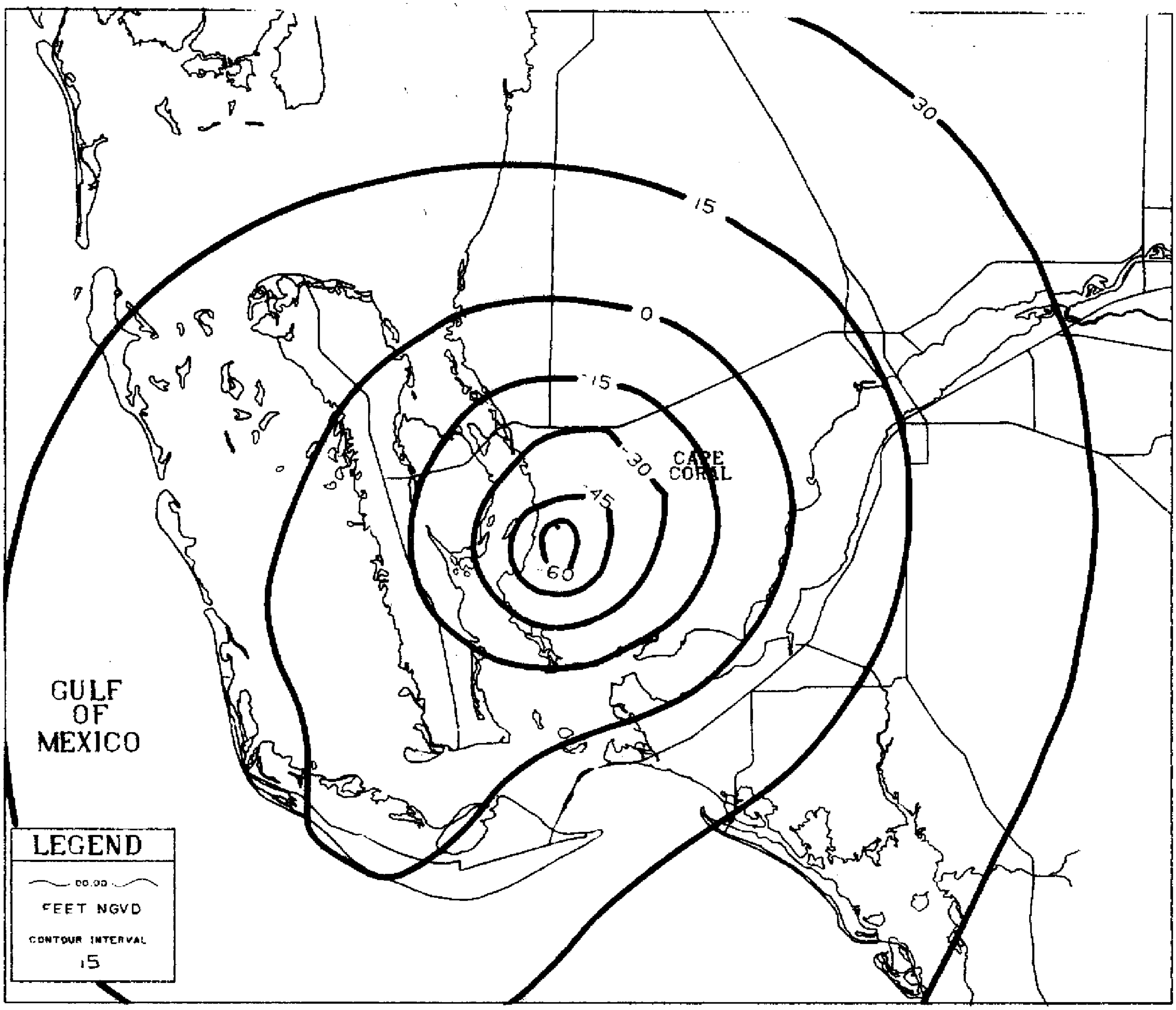


Figure 38 PROJECTED POTENTIOMETRIC SURFACE OF THE LOWER HAWTHORN AQUIFER, 1990 (CCPD AND REDUCED LEAKANCE)

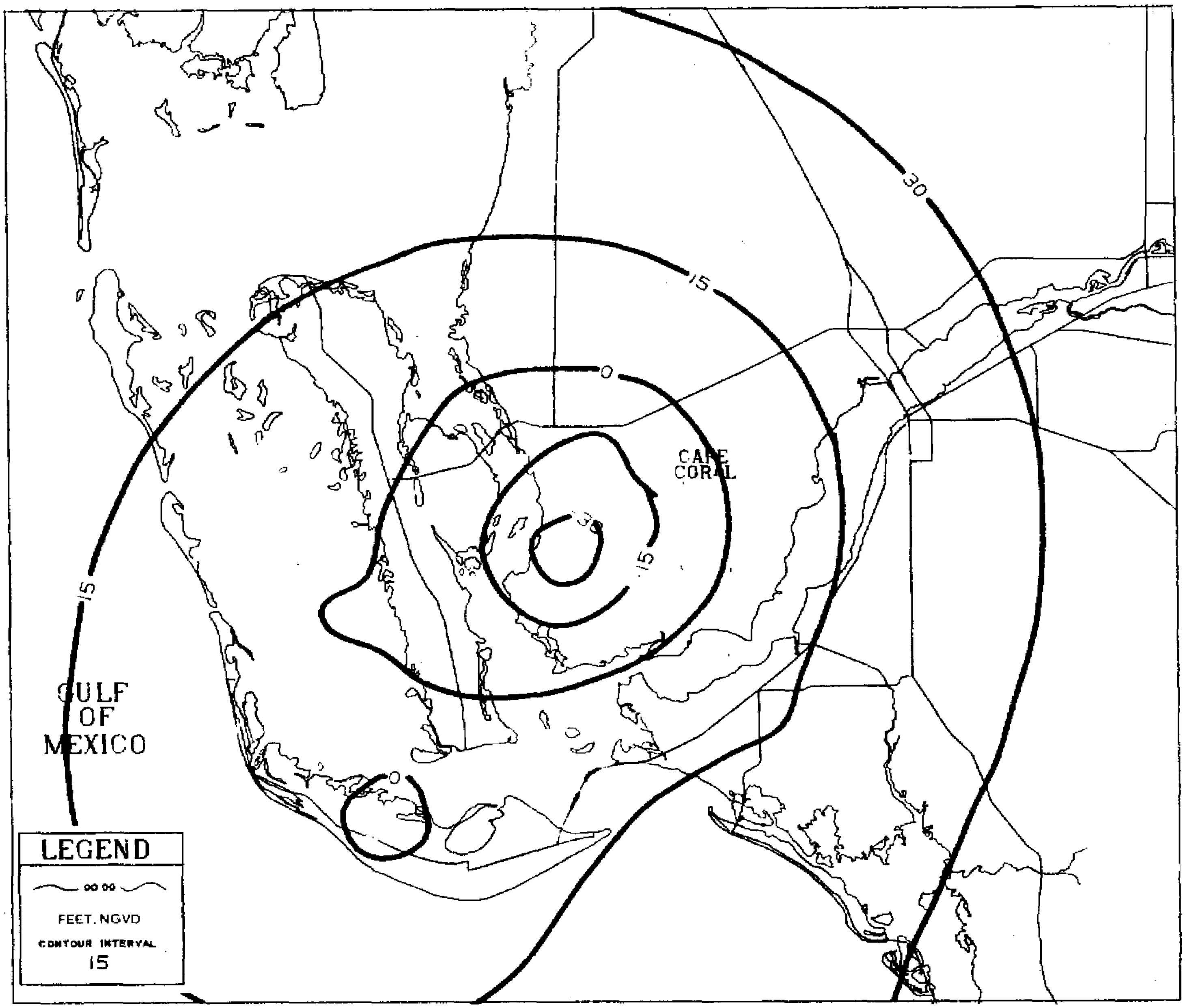


Figure 39 PROJECTED POTENTIOMETRIC SURFACE OF THE LOWER HAWTHORN AQUIFER, 1990 (LCDCD AND REDUCED LEAKANCE)

Figure 40 depicts the predicted potentiometric surface in 1990 with a population in Cape Coral of 77,712 (CCPD, 1982) and an average daily water use of 14.4 million gallons from the Cape Coral wellfield. The zero NGVD contour has expanded to include all of the lower Hawthorn wellfields in the area. Water levels in the Sanibel wellfield area will be below sea level. The Pine Island water levels will be in excess of -20 ft. NGVD. Elevation near the center of the cone will range from -80 ft. to a -110 ft. NGVD.

Figure 41 depicts the projected water levels of the lower Hawthorn aquifer for the year 1990 with an average daily pumpage of 10.5 MGD from the Cape Coral wellfield. Water levels in the Pine Island wellfield area will range between -10 ft. to -22 ft. NGVD. The lowest levels encountered in the Sanibel wellfield is -7 ft. NGVD. Elevations near the center of the cone will be about -80 ft. NGVD.

In comparison to the first model that uses a higher transmissivity and higher hydraulic conductivity, this model shows significant drawdowns in all wellfields, directly caused by pumpage in Cape Coral. Leakance is near 40% and coupled with these significant drawdowns may cause water quality deterioration. A series of wet/dry season projected potentiometric surfaces were prepared (Appendix VI) using the Lee County Division of Planning population projections. These maps can be referred to as pumpage increases over the coming years. If the potentiometric surface in the area begins to resemble these maps, pumpages should be reduced in the Cape Coral wellfield. Therefore, an extensive monitoring network needs to be established in both the lower Hawthorn and Suwannee aquifers.

In summary, the first predictive model presents the highest likelihood of occurrence based upon the existing data. However, the existing data is more representative of a combination of the lower Hawthorn and Suwannee aquifers. There is a possibility that the actual transmissivities of the isolated lower

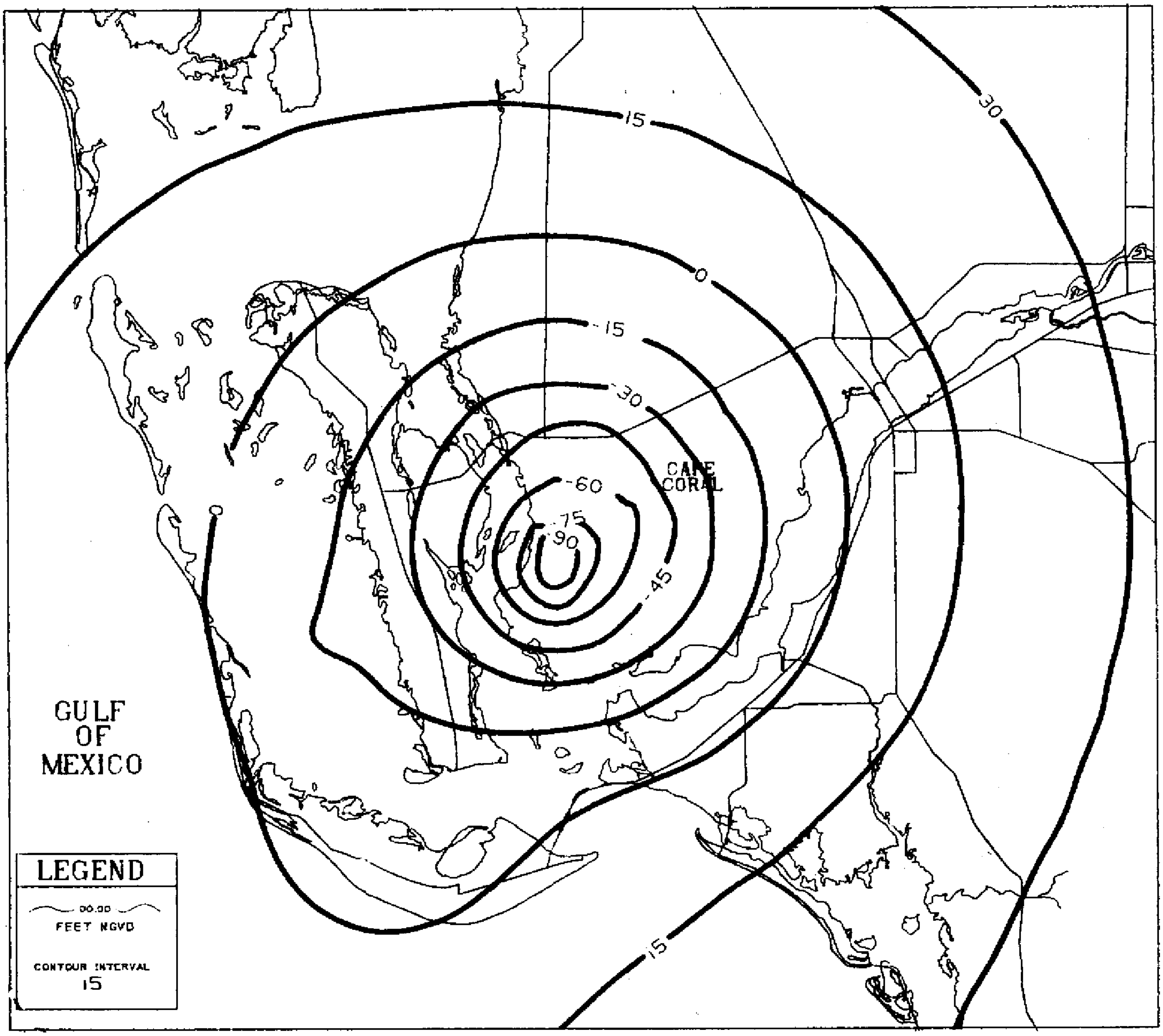


Figure 40 PROJECTED POTENTIOMETRIC SURFACE OF THE LOWER HAWTHORN AQUIFER, 1990 (CCPD AND REDUCED TRANSMISSIVITY)

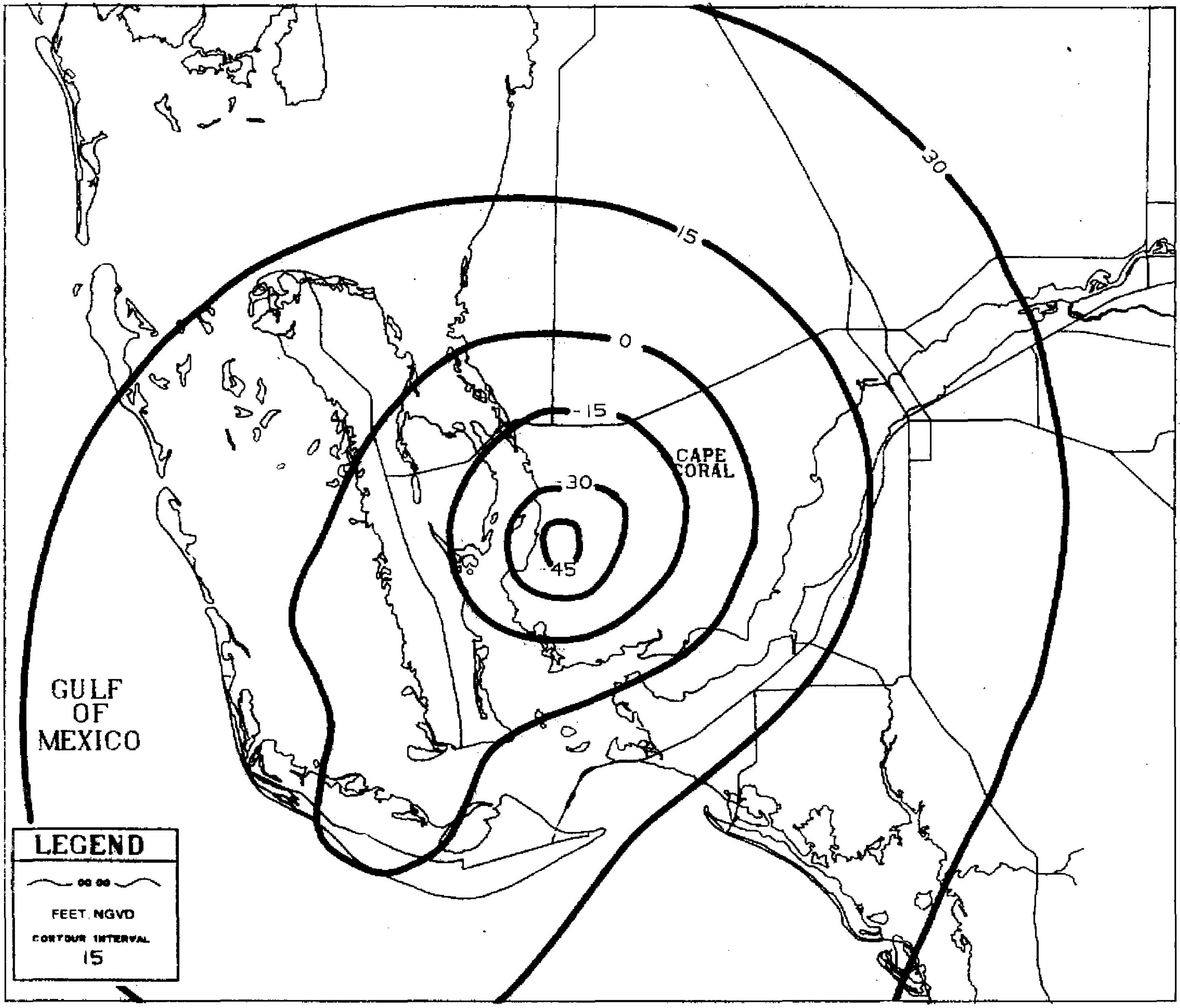


Figure 41 PROJECTED POTENTIOMETRIC SURFACE OF THE LOWER HAWTHORN AQUIFER, 1990 (LCDCD AND REDUCED TRANSMISSIVITY)

Hawthorn aquifer are much lower, which would have a significant effect on water levels and water quality throughout western Lee County.

SUMMARY AND CONCLUSIONS

I. MID-HAWTHORN

A. A two-dimensional groundwater flow model was developed and calibrated to study the impact of various future withdrawal scenarios for this aquifer.

B. The potentiometric surface elevation of the mid-Hawthorn aquifer around Cape Coral has declined approximately 40-50 feet since pre-development on a regional scale. Additionally, drawdowns have exceeded 80 feet within the wellfield. In addition, the model shows that the mid-Hawthorn aquifer is currently being overstressed. Of the total water pumped during 1984 (6.5 MGD), it is estimated that only 20 percent is derived from this aquifer. The remaining 80 percent comes as leakance from other aquifers.

C. Out of the total pumpage of 6.5 MGD, it is estimated that as much as 3.9 MGD is used for lawn irrigation. It is estimated from current trends that by the year 1995 the irrigation demand will increase to 6.2 MGD.

D. Presently, the source(s) and the quality of leakance water is unknown. However, if it is determined that the primary source of leakance is from the lower Hawthorn, the quality of the water in this aquifer will deteriorate to below potable drinking water standards, some time in the future.

II. LOWER HAWTHORN

A. A two-dimensional groundwater flow model was developed and calibrated to study the impact of future withdrawal scenarios from this aquifer.

B. The current existing information on aquifer parameters for the lower Hawthorn aquifer are not adequate for precise model calibration and predictions. (Data from only two tests were representative of an isolated lower Hawthorn aquifer.)

C. Based upon the limited existing data, the model indicates that as much as 10.5 MGD may be withdrawn by Cape Coral with minimal impact upon this aquifer. However, even this withdrawal will necessitate a monitor system, because of uncertainties in the model results caused by deficiencies in the existing areal hydraulic parameters.

D. When lower transmissivity values, which may be more representative of the isolated lower Hawthorn aquifer are used in the models, the regional potentiometric decline is substantial.

RECOMMENDATIONS

I. MID-HAWTHORN

A. The present excessive demand placed upon this aquifer is adversely affecting its water levels. If additional stress is placed on the aquifer, it could possibly cause permanent deterioration of this resource in the future. Alternative sources of irrigation supply such as, fresh canal water, Surficial Aquifer System, wastewater reuse, or any combination of these should be implemented immediately to minimize the adverse effects on this already overstressed resource. In addition, alternative sources for municipal supply should also be investigated and developed as soon as possible.

B. A study should be undertaken to determine the source(s) and quality of leakance water entering the mid-Hawthorn aquifer.

C. A feasibility study of artificially recharging this aquifer despite the possible unsuitability due to low hydraulic properties should be investigated.

II. LOWER HAWTHORN

A. Consideration of further withdrawals from the lower Hawthorn aquifer should be made in phases based upon detailed investigation of previous withdrawal impacts. One alternative for future consideration may be to distribute future pumpage beyond 10.5 MGD in new wellfield locations. This might minimize the localized steep cone of depression.

B. Further investigation needs to be conducted to ascertain the actual aquifer parameter values (transmissivity, storage and leakance) that are representative of the lower Hawthorn aquifer.

C. Deep wells should be drilled to determine the exact nature of the water quality in the lower Floridan Aquifer System.

D. Aquifer tests should be conducted on any new wells drilled in the study area and hydrogeologic zones identified.

E. A monitor network that is approved by the District should be developed for the lower Hawthorn aquifer to monitor the impact of additional withdrawal from this resource.

F. A feasibility study of artificially recharging this aquifer in conjunction with the mid-Hawthorn should be investigated.

G. The underlying Suwannee aquifer should also be investigated to determine its potential for water supply purposes after desalination.

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