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PRELIMINARY ASSESSMENT OF THE GROUNDWATER RESOURCES OF WESTERN COLLIER COUNTY, FLORIDA

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PRELIMINARY ASSESSMENT
OF THE
GROUNDWATER RESOURCES OF
WESTERN COLLIER COUNTY, FLORIDA

by

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EXECUTIVE SUMMARY

The major fresh water aquifers underlying Collier County are the water table, lower Tamiami, and Sandstone. The water table and lower Tamiami aquifers are the primary sources of water supply and occur within the Surficial Aquifer System. Vertical exchange of water between these aquifers occurs in varying degrees when leaky confining units are present. The Sandstone aquifer is separated from these two aquifers by low permeability sediments and is only present in the northern portion of Collier County. The Sandstone aquifer and the underlying mid-Hawthorn aquifer are part of the Intermediate Aquifer System.

Water flows through the Surficial Aquifer System in a southwesterly direction with potentiometric highs for both the water table and lower Tamiami aquifers occurring near Immokalee. The configuration of the potentiometric surface of both aquifers is similar, but water levels in the lower Tamiami aquifer are five to ten feet lower than those in the water table aquifer.

The primary source of recharge to the Surficial Aquifer System is rainfall. Downward movement of water through the leaky confining beds underlying the water table aquifer recharges the lower Tamiami aquifer. These confining beds are absent in some areas causing these aquifers to act as one unit. Hydrographs of selected wells show a rapid response to rainfall in the water table aquifer. Response to rainfall is not as dynamic in the lower Tamiami, which exhibits lag times of up to twenty days depending upon the degree of confinement.

Water levels within the Sandstone aquifer are highest in Hendry County and water flows radially from that area to the northwest and southwest. Water levels within this aquifer are lower than those of the Surficial Aquifer System indicating a downward hydraulic gradient. The primary source of recharge to the Sandstone aquifer is vertical leakance from adjacent aquifers. The aquifer is nearest to land surface in the Lehigh Acres area of Lee County where confining beds are thinner. The presence of numerous solution features that breach overlying confining beds in this area make this a region of significant recharge to the Sandstone aquifer.

The overall water quality within the Surficial Aquifer System and Sandstone aquifer is within potable standards. Localized areas do, however, contain waters that do not meet these standards. The Surficial Aquifer System contains nonpotable water in coastal areas where saltwater intrusion has occurred. The Sandstone aquifer contains water with moderately high chloride levels in an isolated area just south of the Lee and Collier County boundary. In addition, high iron levels in the water table aquifer sometimes make it undesirable for potable supply unless treated.

Municipal and agricultural withdrawals represent the major types of water use in Collier County. There are 12 permitted public water supply wellfields in the county with a combined annual allocation of 13.1 billion gallons. The U. S. Geological Survey estimated the 1980 agricultural consumptive groundwater use to be 83.5 million gallons per day (MGD) (Leach, 1982). Current maximum monthly allocation/projection for agricultural use in Collier County exceeds 32 billion gallons (1.08 billion gallons per day). However, no estimate can be made at the present on the actual quantity withdrawn due to lack of agricultural pumpage data.

Present and future water requirements for five municipal service areas, located along the coast, were evaluated based upon the information provided by the Collier County Utilities Department and the City of Naples. These service areas include North Naples, Naples, South Naples, and Marco Island.

The North Naples service area is presently served by both the City of Naples Coastal Ridge wellfield and the east Golden Gate wellfield, however, in the future this region will be serviced by its own wellfield.

Based on the present and projected water demands, it is estimated that the proposed north Naples regional wellfield may need to produce up to 1 million gallons per day (MGD) during the dry season by the year 2000. Average use for the year 2000 is estimated at 8 MGD for this area. A groundwater flow model indicates that a proposed wellfield site adjacent to the Cocohatchee Canal at C.R. 951 may supply this requirement from the water table aquifer if withdrawal does not generate adverse environmental impacts on the Cocohatchee Strand or adverse impacts on other users.

The Naples service area includes the City of Naples and major portions of east and central Naples.

Potable water for the Naples service area is provided by the Naples Coastal Ridge wellfield and the East Golden Gate wellfield, which both withdraw from the lower Tamiami aquifer. The projected daily requirements from both these wellfields by the year 2000 is approximately 20 MGD. Withdrawals from the Naples Coastal Ridge wellfield may exceed the safe yield of the lower Tamiami aquifer during prolonged periods of no recharge. Development of alternate sources of supply, proper management of the Coastal Ridge wellfield and/or expansion of the East Golden Gate wellfield will be needed to meet water demands for this area in the future.

The south Naples service area is supplied by the county wellfield in Golden Gate. Projected dry season requirements for the year 2000 may exceed 11 MGD. A model simulating the year 2000 projected dry season withdrawals for both the East Golden Gate and the county wellfields, indicates that with proper management the lower Tamiami aquifer will be capable of meeting the projected water requirements.

Water requirements for Marco Island were projected to exceed 11 MGD by the year 2000. At current demand, the existing Marco raw water source is threatened by salt-water intrusion during periods of prolonged drought. Therefore, it is recommended that an alternate source of freshwater be investigated and developed to meet future requirements.

In light of the recurring problems with the City of Naples Coastal Ridge wellfield during periods of prolonged drought, a first order estimate of the safe yield of the lower Tamiami aquifer for the Naples area was attempted. The estimates were based on conservative assumption of the saltwater/freshwater interface (Ghyben-Herzberg relation) and generalizations associated with a two-dimensional flow model. Depending on the criteria used, safe yield estimates for the modeled area range between 45 MGD and 84 MGD (under 1985 dry season conditions). Present permitted use may exceed the safe yield of the aquifer during extended drought especially in the area west of S.R. 31. During a normal rainfall year this should not result in significant saltwater intrusion. However, under a 1-in-3 year dry season drought, saltwater intrusion may occur which could result in voluntary or mandatory cutbacks.

A preliminary assessment of future groundwater development potential is presented in this report. Based on available information and results of a groundwater flow model, two areas in the water table aquifer may potentially be capable of supplying up to 30 MGD if the withdrawals do not generate adverse impacts. In addition, the lower Tamiami aquifer may be capable of supplying water in excess of 30 MGD in the Golden Gate area with proper management.

The data collected in this report should be added to regional data collected in Lee and Hendry Counties to develop a regional multi-layered groundwater flow model. The purpose of this model will be to determine the impacts of all major users and develop safe yield criteria for each aquifer. These results could then be utilized to develop regional groundwater management plans for the Lower West Coast.

ACKNOWLEDGEMENTS

This investigation was initiated by the South Florida Water Management District in response to its long range water resource planning responsibilities. The planning and data assimilation for this report was carried out under the direction and supervision of Nagendra Khanal, P.E., Director, Groundwater Division, Resource Planning Department, South Florida Water Management District. Dr. George Shih, P.E., Senior Professional, Resource Planning Department, also supervised various aspects of this study and wrote subroutines for the U. S. Geological Survey two-dimensional flow model that were used to determine safe yield. Their guidance during the preparation of this report is gratefully acknowledged. Dr. Leslie Wedderburn, Deputy Director, Resource Control Department, supervised the initial planning and aquifer testing phases of this project. His contributions are greatly appreciated. Stanley Hole, P. E., Chairman of the Board of the South Florida Water Management District, contributed freely of his time in the technical review process of this document. His guidance is gratefully acknowledged. Sharon Trost, Acting Director, Hydrogeology Division, contributed technical, logistical, and editorial assistance essential to the completion of this report. Dr. Pat Gleason, Director, Water Use Division and his staff are recognized for their editorial reviews. Dr. Carl Woehlcke, Director, Water Use Planning Division, provided editorial review and directed Ray Burgess, Bruce Adams, and Saleh Popalzai in the acquisition of pertinent water use data from the Naples area.

Recognition is given to Fred Vidzes, Administrator, Big Cypress Basin Board, and to Tom Crandall of the Collier County Utilities Division, for their assistance and contributions to this report.

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INTRODUCTION

Groundwater in Collier County and all of south Florida represents the largest percentage of available water for municipal and agricultural supply. Collier County is expected to double in population by the year 2000 and is becoming a prime area for agricultural development. Land use patterns are changing from predominately unimproved pasture to truck farming, citrus, and urbanization.

Numerous investigations have been conducted on various aspects of the hydrogeology of Collier County. Most have been localized and concentrated in population centers. The U. S. Geological Survey maintains a monitor well network in the area. This network was redesigned by the South Florida Water Management District and is currently being expanded by the Big Cypress Basin Board. The Basin Board has also initiated several studies to determine the limitations of the groundwater systems.

This study combines existing and generated hydrogeologic information to determine the areal extent and characteristics of the groundwater resources of the region. Water quality and future availability of the resource are also addressed.

It is hoped that this study will provide support to planners and decision makers concerning future land use changes in the county.

PURPOSE AND SCOPE

This study represents the second phase of a multi-county, multi-phase project to develop a comprehensive groundwater management plan based on safe sustained yield (the rate at which groundwater can be withdrawn over a long period of time without producing undesirable effects on "potentially permittable water") of the primary aquifers in the Lower West Coast of Florida. The first phase of this study was completed in 1984 and involved the evaluation and redesign of the regional monitoring network in Collier County and an approximation of the impacts of projected demands from the mid and lower Hawthorn aquifers around the Cape Coral area in Lee County. A preliminary groundwater resource assessment of Hendry and Glades Counties and a monitoring network redesign for Lee County are in progress.

This report presents the results of a compilation of the existing hydrogeologic data supplemented with data collected from extensive field investigations in Collier County. The data were assessed to determine aquifer characteristics, groundwater resource potential, and water use impacts in the region. The purposes of this study were to:

1. Review existing groundwater resource related literature on Collier County to determine gaps and ambiguities in the record.
2. Complete exploratory field drilling and hydraulic testing of wells to fill in data gaps.
3. Define areal extent of regionally continuous hydrogeologic data.
4. Determine regional flow patterns of major fresh water aquifers.
5. Determine regional water quality trends.
6. Assess future water requirements of municipal service areas.
7. Determine a first order estimate of safe yield for the Naples area and compare actual pumpage to this estimate to determine if over use is occurring along the coast.
8. Present a preliminary assessment of the future development potential of groundwater resources in recognition of the planned growth.

The final phase of the Lower West Coast project will assess the groundwater resource availability in terms of both technical and economic feasibility to derive a groundwater management plan.

LOCATION

Collier County is located on Florida's southwest coast (Figure 1) between latitude 26° 30' 56" and 25° 47' 10". It is bordered by Hendry, Lee, and Broward Counties and the Gulf of Mexico. The area of study is principally in Collier County with overlaps into adjoining Lee and Hendry Counties (Figure 2). The study area encompasses approximately 2500 sq miles. Land elevations vary from a high of near 40 ft. above National Geodetic Vertical Datum of 1929 (NGVD) in northern Collier and Hendry Counties to sea level along the coastline. Most of Collier County is at elevations less than 15 ft. above NGVD.

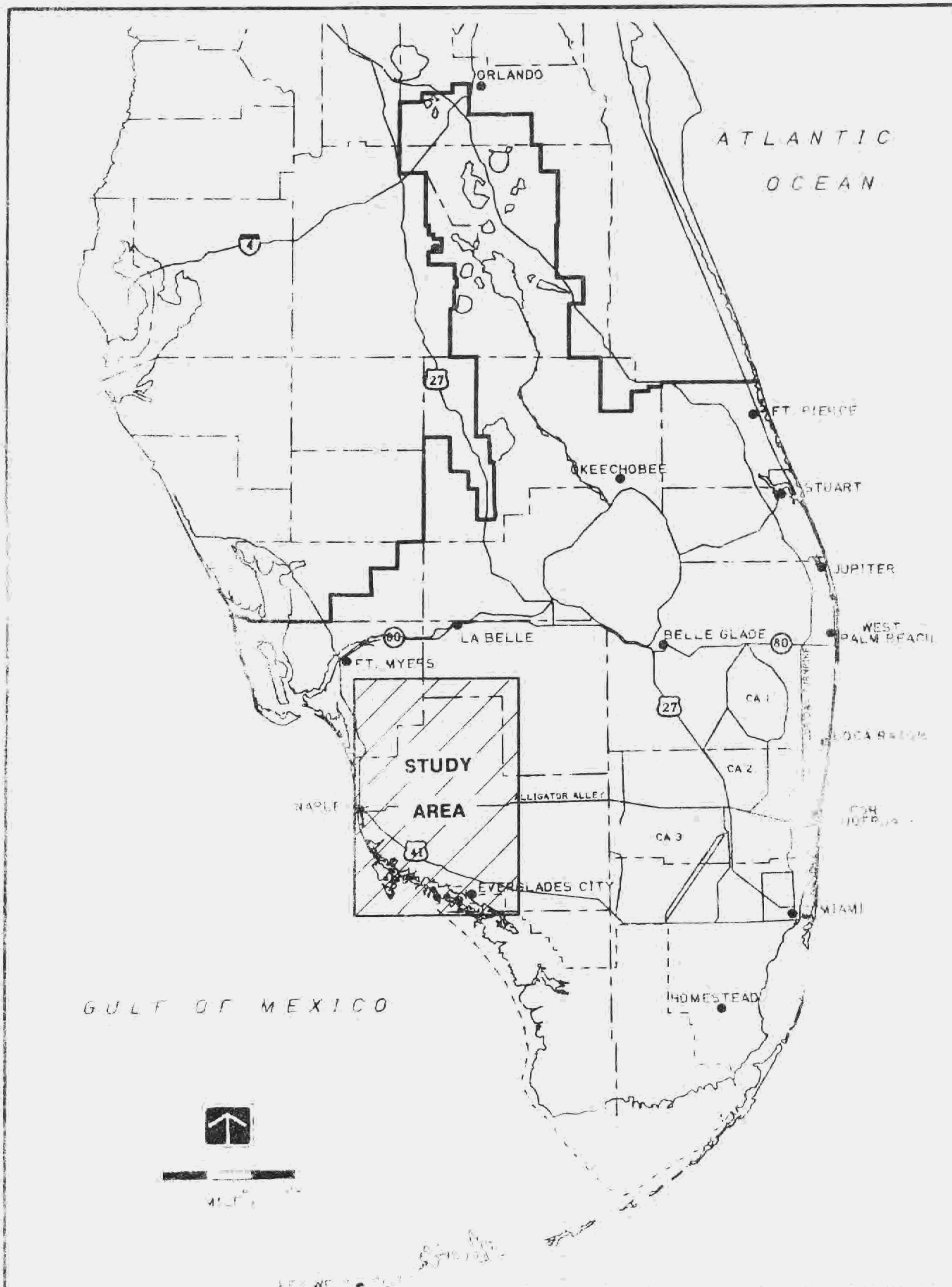


Figure 1 FLORIDA PENINSULA SHOWING LOCATION OF STUDY AREA

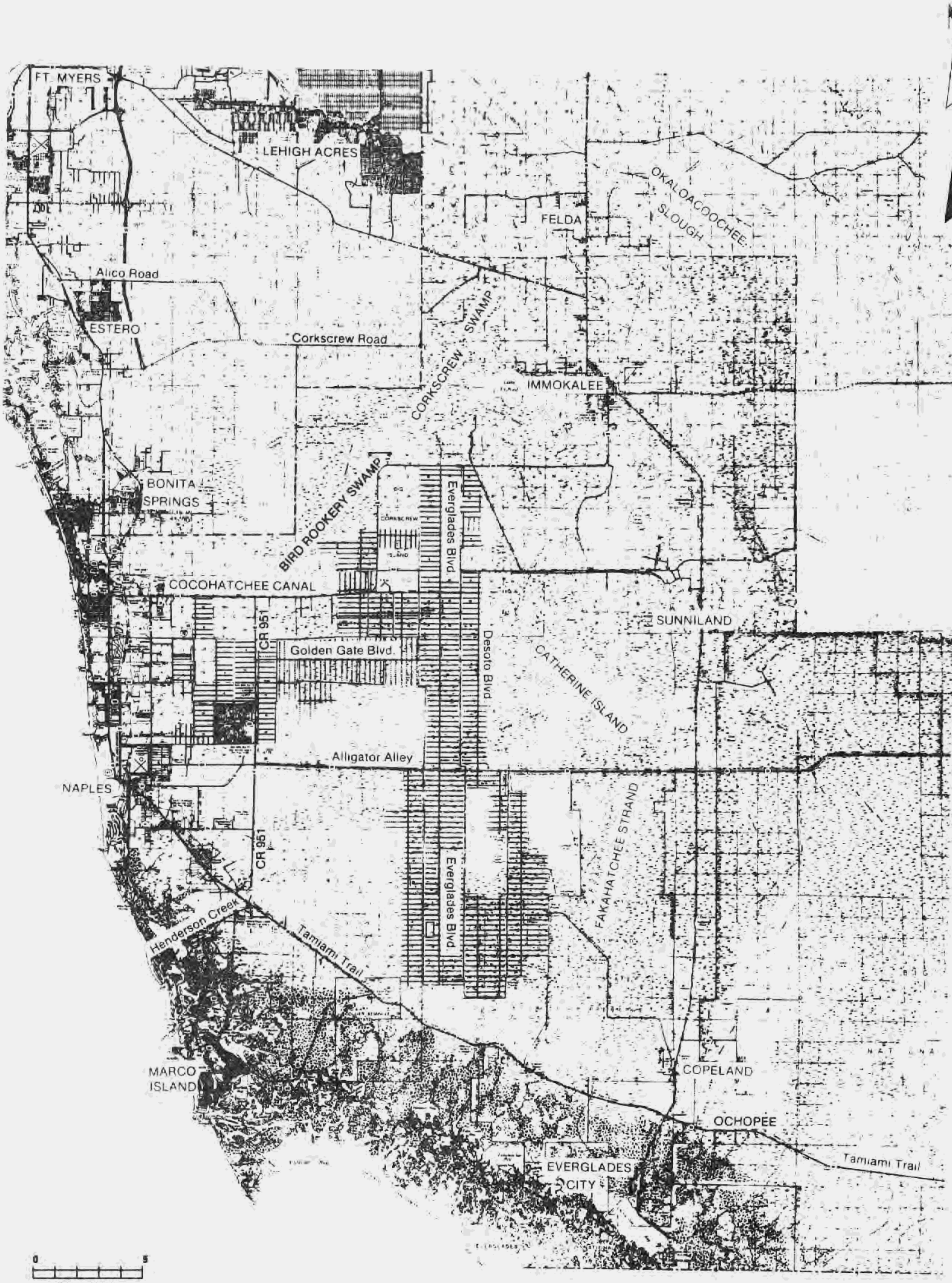


Figure 2 STUDY AREA

Collier County has been divided into three physiographic regions by Davis (1943). These regions are the Flatlands, the Big Cypress Swamp, and the Southwest Coast/Ten Thousand Islands region. The Flatlands occur in northern Collier and include such features as Corkscrew Swamp, Bird Rookery Swamp, Lake Trafford, and Big Corkscrew Island. This area is also referred to as the Immokalee Rise by White (1970). The Big Cypress Swamp encompasses most of central and eastern Collier County. It is poorly drained and characterized by wetlands containing cypress trees, pine forest islands, and large prairies. The Southwest Coast/Ten Thousand Islands region occurs along the coastline southward from Naples into Monroe County. Numerous tidal streams, bays, and lagoons are present in this area. Most of the islands present were formed by oyster shell and covered with mangroves. Major estuarines and drainageways in the region are the Cocohatchee, Gordon,and Barren Rivers, Okaloacoochee Slough, Fakahatchee Strand, Turner River, and various man-made canals.

METHODS

Seventy wells were analyzed and interpreted to construct the cross sections, structure, and isopach maps presented in this report. The wells are listed in Appendix I. All wells had lithologic descriptions and most were supplemented with geophysical surveys.

The lithologic descriptions available in the Appendix were made on a computer format that is stored on the Cyber System at the District. Two programs (LITHOLOG and STRATALOG), developed by the Florida Bureau of Geology in cooperation with Florida State University, were adapted to the District's Cyber to generate geologic logs and stratigraphic columns from the stored data.

Lithologies were identified using a binocular microscope and coded into the LITHOLOG program format. The data input criteria are standardized, making cor-relations between different wells more uniform. The major lithologies identified were limestone, dolomite, sandstone, shell, clay or dolosilt, sand, and phosphate. All are analyzed for color (GSA Munsell), estimated percent and type of porosity, relative permeability, grain size, degree of induration, cement or matrix components, sedimentary structures, accessory minerals, general fossils, and identifiable guide fossils. Modal grain size and grain size range were evaluated on most lithologies. Degree of alteration in dolomites and recrystallization in limestones were estimated. A second program (STRATALOG) was used to interface the stored data and plot geologic columns. The computer generated columns depict the major lithology, secondary minerals, induration, and accessory minerals. These data are presented in Appendix I.

Geophysical surveys were run in all of the District's exploratory wells and were also available from many of the other wells used in this report. Geophysical logs presented in Appendix I were obtained using one of the two Gearhart-Owens loggers owned and operated by the SFWMD. Each logger produces logs in analog and digital form. The information in digital form is stored on a cassette tape which is later read and stored on a seven track magnetic tape. Once on magnetic tape, the geophysical logs are ready for manipulation and final presentation using in-house computer programs.

The geophysical logs were used to assist in evaluating and correlating well cuttings from each site. Available logs included Natural Gamma, Neutron Porosity, Flowmeter, Caliper, 16 and 64 inch Normal Resistivity, 6 foot Lateral Resistivity, Temperature Gradient, Differential Temperature, Spontaneous Potential and Fluid Resistivity. Some of these logs are shown in this report and the remainder are on file at the District.

The geophysical logs most frequently used for evaluation and correlation of aquifer lithologic and fluid character-istics were: Natural Gamma, Neutron, 16 to 64 inch Normal Resistivity, and Caliper. The Natural Gamma log is a tool used to detect natural gamma radiation given off by the layers of sediment and rock present in the wall of a well. Geologic formations normally exhibit similar "signatures" within a given area. The Neutron Porosity log shows variation in the hydrogen content within formation pore space. It characteristically attenuates with increased hydrogen content, and, therefore, indicates the presence of water within pore spaces. Electric logs (16-64 inch, 6 foot Lateral and Spontaneous Potential) detect changes in the composition of the rock matrix and formation fluid. The Caliper log shows borehole diameter and helps locate competent and incompetent beds, solution cavities and possible fracture zones.

The Temperature Gradient, Differential Temperature and Flowmeter logs proved helpful in determining locations of major producing zones. Producing zones were indicated near abrupt temperature changes or where the flow contribution to the well increased in pumped or flowing wells.

Aquifer parameters were determined through specific capacity and duration aquifer pumping tests. A total of 18 aquifer tests were run in this study. Typical test sites consisted of a pumped well and one observation well. Step drawdown tests were completed on each production well prior to the duration aquifer pumping test. These specific capacity results were used to develop a regression equation to estimate transmissivity and for determining an acceptable discharge rate for the duration test.

Duration pumping tests were scheduled for 72 hours followed by 36 hours of recovery. Many of the tests, however, did not last more than 36 hours due to water level stabilization, equipment failure, meteorological events, or any combination of these. Constant discharge was measured through a discharge manometer. Water level data were collected throughout the test by an In-Situ, Inc. SE 200 Hydrologic Analysis System. The SE 200 is a portable computerized water level data aquisition system. Water levels were measured using Druck Ltd 160D transducers, which were corrected for temperature and barometric pressure fluctuations. Signals from the transducers were sampled and processed by a portable Hewlett-Packard HP-85F computer. Water level data were stored on magnetic tape and are retrievable in a variety of graphical and digital formats.

Regional water level data were obtained from the USGS and from recently drilled SFWMD wells throughout Collier County. Data were also obtained from USGS wells in adjoining areas. These data were contoured for both the end of the dry and wet seasons for water years 1984-85. Hydrographs were constructed from long term data available from several USGS wells. Rainfall and evapotranspiration data were accessed from the District's hydrologic data base, and bar graphs were plotted for the rainfall data. These are presented in Appendix II.

Water quality data are available from most of the USGS and District wells in the area. The USGS network is primarily sampled on a semi-annual basis. Complete major parameter analyses are available for some of the USGS wells, whereas chloride and conductivity values are measured on all sampled wells. The District wells were sampled during June 1984 with complete major parameter water quality analyses performed by the District's Water Chemistry LaboratoryMuch of this data is presented in Appendix III, and average chloride and conductivity trends are included in the text.

PREVIOUS INVESTIGATIONS

The geology and hydrology of Collier County and adjacent areas have been investigated by the U. S. Geological Survey, Florida Bureau of Geology, South Florida Water Management District, and private consultants for many years. Most studies have been on a localized scale or limited to individual topics.

The geology of Collier County and all of southern Florida has been investigated by many geologists since the turn of the twentieth century. Parker and Cooke (1944) give an excellent summary of the earlier studies. Cooke and Mossom (1929) and Cooke (1945) described outcrops along the Caloosahatchee River and near Alva in Lee County. They also summarized the geology of Florida on a county by county basis.

Significant regional stratigraphic studies have been conducted by Cole (1941), Applin and Applin (1944 and 1965), Dubar (1958 and 1962), Chen (1965), Puri and Winston (1974), Puri and Vernon (1964), and Peck et al. (1977 and 1979). Missimer (1984) summarized the geology of southern Florida and recommended establishing the Hawthorn Formation as a group in this area. Scott and Knapp (1985, in press) presented cross sections of the Hawthorn in peninsular Florida and informally raised this formation to group status. Peacock (1983) described the post-Eocene stratigraphy of southern Collier County. Evidence of faulting and folding has been presented by Tanner (1965), Sproul et al. (1972), Missimer and Gardner (1976), and Burns (1983).

The hydrogeology of the study area has been actively investigated by the U. S. Geological Survey since the early 1950's. Klein (1954), McCoy (1962), and Klein et al. (1964) performed some of the earlier studies. More recently, the South Florida Water Management District has sponsored several studies in the lower west coast region. These include: a regional hydrogeologic reconnaissance for Lee County (Wedderburn et al., 1982), direct current resistivity surveys and their application to water resource investigations in Collier County (Stewart et al., 1982), the hydrogeology of the shallow aquifer south of Naples (Jakob, 1983), an evaluation of the groundwater monitor network in Collier County (Burns and Shih, 1984), the hydrogeology of the East Naples area (Gee and Jensen, 1980), the groundwater resources of the Cocohatchee Watershed (Missimer and Associates, 1983a), and a preliminary assessment of the mid and lower Hawthorn aquifers in Cape Coral (Knapp et al., 1984). The regional Surficial Aquifer monitor network reevaluation, and the preliminary water resource assessment of Hendry and Glades Counties are in progress. In addition, there is a multitude of consultant's reports on various developments and wellfields.

GEOLOGY

GEOLOGIC OVERVIEW

Western Collier County lies on the eastern margin of a huge depositional feature known as the Gulf of Mexico Sedimentary Basin. Pressler (1947) divided the sediments on the eastern flank of this basin into the North Florida Province and the South Florida Province by a general line across north central Florida. Collier County lies within the South Florida Province, which is dominated by carbonate sedimentary rocks.

The major subsurface structural element in the region is the South Florida Shelf (Applin and Applin, 1965). This feature in the Comanchean strata of Cretaceous age is described as a relatively flat area which "trends S 45°E, extends nearly 200 miles across the peninsula from Charlotte County on the Gulf Coast to Key Largo, Monroe County on the Atlantic Coast."

The stratigraphic sequence is dominantly carbonates with clastic materials being present in Miocene and younger formations. The Cenozoic section is over 5,000 feet thick and contains close to 3,000 feet of Eocene limestone and dolomite. Oligocene and younger formations account for up to 1,200 feet of the section. The Mesozoic beds are over 8,000 feet thick with the Cretaceous system accounting for the major portion of that sequence.

The formations of primary concern in this study are of Miocene and younger age. They include the upper portion of the Hawthorn Group, Tamiami Formation, and undifferentiated terrace deposits.

INTRODUCTION TO STRATIGRAPHY

Well cuttings from 70 wells in Collier and adjacent counties (Figure 3) were examined to determine the regional significance of similar rock units. These rock units are grouped according to their relationship to previously defined stratigraphic units and by their hydraulic properties (Figure 4). The stratigraphic sequence described in this report ranges in age from Miocene to Recent. The Hawthorn is recognized as a "Group" in this report for discussion purposes. The Tamiami Formation overlies the Hawthorn Group and undifferentiated terrace deposits rest upon the Tamiami.

Miocene Series

Hawthorn Group

Dall and Harris (1892) first used the term "Hawthorn Beds" for phosphatic sediments being quarried near the Town of Hawthorne, Alachua County, Florida. These beds were designated the "Hawthorn Formation" by Matson and Clapp (1909). The formation was first described at Devil's Mill Hopper by L. C. Johnson (Dall and Harris, 1892). This site was later designated as the type location for the Hawthorn Formation by Puri and Vernon (1964). Scott (1981), in describing continuous cores through the Hawthorn, referred to the formation as consisting of "...various mixtures of clay, quartz sand, carbonate (dolomite to limestone), and phosphates...". In recent work by Scott and Knapp (1985, in press) the Hawthorn is described informally as a group and subdivided into several formations in peninsular Florida.

The Hawthorn has long been a confusing unit in southwest Florida. Parker et al. (1955) proposed a definition of the Hawthorn and overlying Tamiami strata in south Florida that included all of the middle and upper Miocene deposits within these two formations. In Collier County, McCoy (1962) recognized the gradational nature of the contact between these two formations and pointed out that lithologic differentiation was very difficult, if not impossible. Abstracts by Hunter and Wise (1980, 1980a) suggest that the top of the Hawthorn is properly placed beneath a redefined and restricted Tamiami Formation. They show the definition of the Tamiami Formation, presented by Parker et al. (1955), to be informal and not in compliance with the American Code of Stratigraphic Nomenclature (1970). Wedderburn et al. (1982), working in adjacent Lee County, used the Hunter and Wise redefinition of the Hawthorn to map it in that area. Peacock (1983) also used this concept to map and describe the Hawthorn in Collier County. Peacock recognized seven informal units within this formation in this area. Missimer (1984) discussed the geology of southern Florida and suggested combining many of the Hawthorn lithologies into one group and dividing the group into formations. Scott and Knapp (1985) divided the Hawthorn Group into two major lithologic units in southern Florida; an upper unit composed of predominantly clastic material and a lower unit that is principally carbonates.

Figure 3 LOCATION OF GEOLOGIC CONTROL WELLS AND HYDROGEOLOGIC CROSS SECTIONS

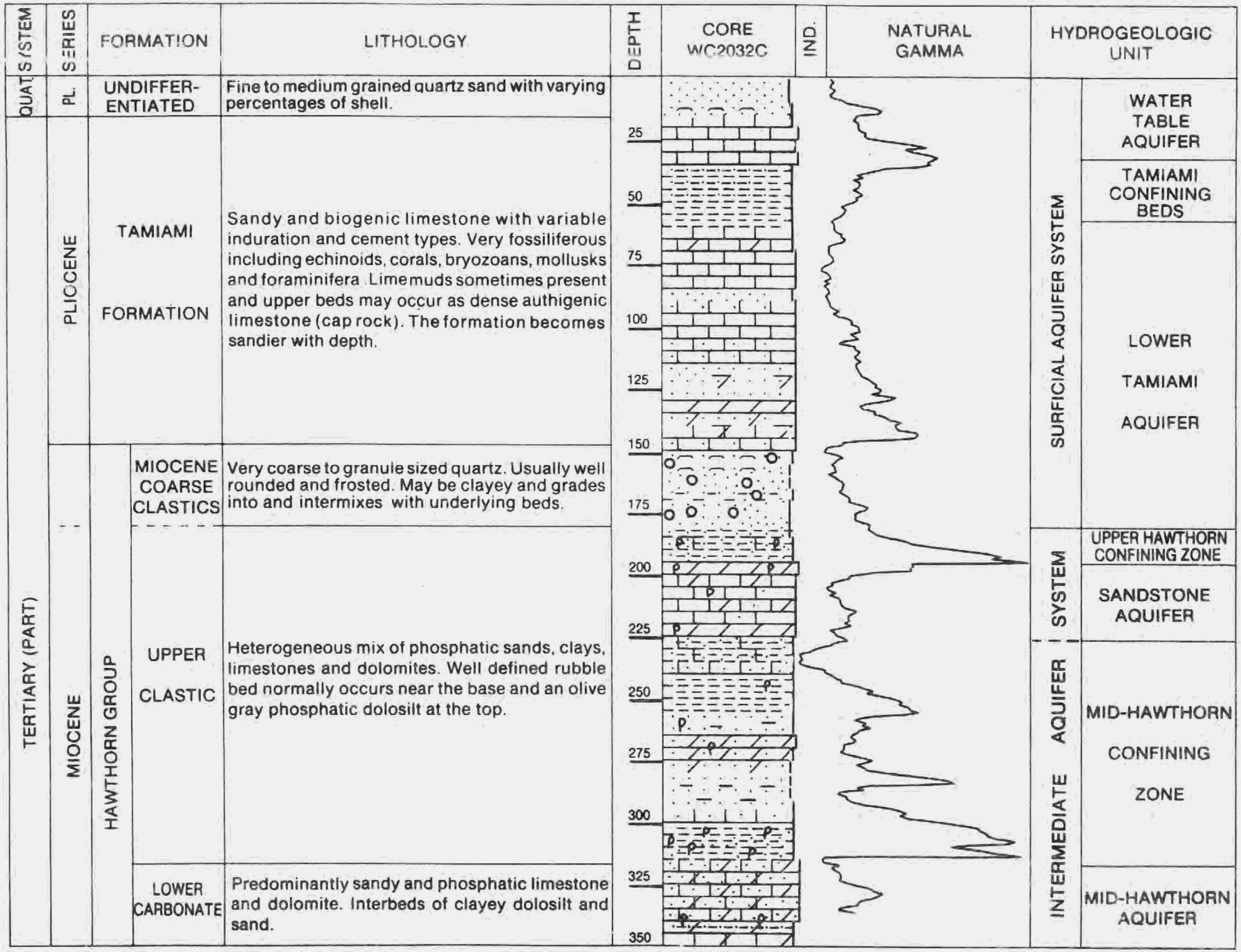


Figure 4 STRATIGRAPHIC COLUMN

The Hawthorn Group can be divided into two lithologic sequences; an upper clastic and lower carbonate, that are separated by a major regional disconformity. This contact is recognized as a rubble bed of quartz and phosphatic sand that gives a distinctive response on the natural gamma ray logs (Figure 4). The basal unit of the carbonate sequence of the Hawthorn Group is a sandy and slightly phosphatic carbonate equatable to the Tampa Formation of central Florida. Only a few wells analyzed for this study penetrated the "Tampa Formation". The reader desiring more detail on this unit is referred to Peacock, 1983.

The Hawthorn Group in the study area ranges in thickness from 680 to 900 feet. It is composed of a heterogeneous mixture of clay (calcareous and dolomitic), quartz sand, phosphate, and carbonates (limestone to dolomite). The uppermost bed in Hendry and Lee Counties is commonly an olive-gray (10 Y 4/2), phosphatic, sandy, slightly clayey dolosilt that lies below a sandy limestone (Tamiami). In central and eastern Collier County, a coarse sand sequence "Miocene coarse clastics" forms the uppermost portion of the group (Figure 4). This unit will be discussed as a separate lithologic unit.

The thickness of the upper clastic unit of the Hawthorn averages around 200 feet in the study area. It is predominantly composed of dolosilt and quartz sand with interbedded phosphatic limestones of varying degrees of induration. South of Alligator Alley (U. S. Hwy. 84), interfingering of the limestone with the clastics becomes less apparent and the unit becomes essentially uniform with dolosilt being the primary constituent. Coarse quartz sands commonly occur as stringers throughout the upper portion of the unit.

The configuration of the top of the upper clastic sequence of the Hawthorn is shown on Figure 5. The top of the sequence occurs from approximately 0 ft. NGVD to 50 ft. below NGVD along the Lee, Hendry, and Collier County border and dips in a southerly direction to near 150 ft. below NGVD along Tamiami Trail (U. S. Hwy. 41).

The top of the lower carbonate sequence of the Hawthorn Group is depicted on Figure 6. The unit dips to the east-southeast throughout Collier County. Highest elevations are apparent in northwestern Collier County where the top of the sequence occurs at 300 ft. below NGVD. Lowest elevations occur east of Hwy. 29 where the unit is consistently logged at 400 ft. below NGVD. Wells penetrating through the underlying "Tampa Formation" (Appendix I, WC2020, WC2024, WC2025, and WC2028) show the lower carbonate sequence of the Hawthorn to be over 650 feet thick. It consists principally of sandy, phosphatic dolomites and limestones interbedded with dolosilts of varying thicknesses.

"Miocene coarse clastics"

Beds of very coarse quartz sand are present in many wells logged for this and other studies of Collier County. Bishop (1956), working in Highlands County, placed this unit in the Hawthorn "Formation" and referred to it as a deltaic facies of that formation. Peacock (1983) also placed these beds within the Hawthorn "Formation" in Collier County. He recognized two units which contain coarse clastics in the upper section of the Hawthorn "Formation". In this study, the coarse clastics are recognized as a part of the Hawthorn Group.

Lithologically the unit is characterized by coarse to granule sized quartz sand that is usually frosted and poorly sorted. Olive gray dolosilts are commonly encountered and occasionally form a loose matrix for the sand. Additionally, very coarse phosphatic sand is sometimes present. In central and southern Collier County the unit contains localized, interbedded very sandy (greater than 30%) limestones and sandstones.

The top of the "Miocene coarse clastics" is shown on Figure 7. The unit is topographically high in northern Collier County, where it is sea level. It dips to the southwest from Immokalee and has been logged as deep as 150 ft. below NGVD in southern Collier County. In central and southeastern Collier the upper beds grade into the very sandy lower Tamiami limestones.

The thickness of the coarse clastic unit (Figure 8) is quite variable, ranging from 200 feet in parts of the Immokalee area, to an average of about 100 feet over most of Collier County. The unit thins and disappears north- westward into Lee County and thickens to the southeast from Immokalee.

Miocene/Pliocene Series

Tamiami Formation

Mansfield (1939) proposed the name "Tamiami Limestone" for a fossiliferous, sandy limestone approximately 25 feet thick, which was penetrated in shallow ditches along the Tamiami Trail (U. S. Route 41) in parts of Collier and Monroe Counties, Florida. Parker and Cooke (1944) combined the limestone with other sediments so that their unit included "... white to cream-colored calcareous sandstone, sandy limestone, and beds and pockets of quartz sand". Parker et al. (1955) redefined the formation to include all of the upper Miocene materials in southern Florida and estimated the maximum thickness to be 150 feet. As

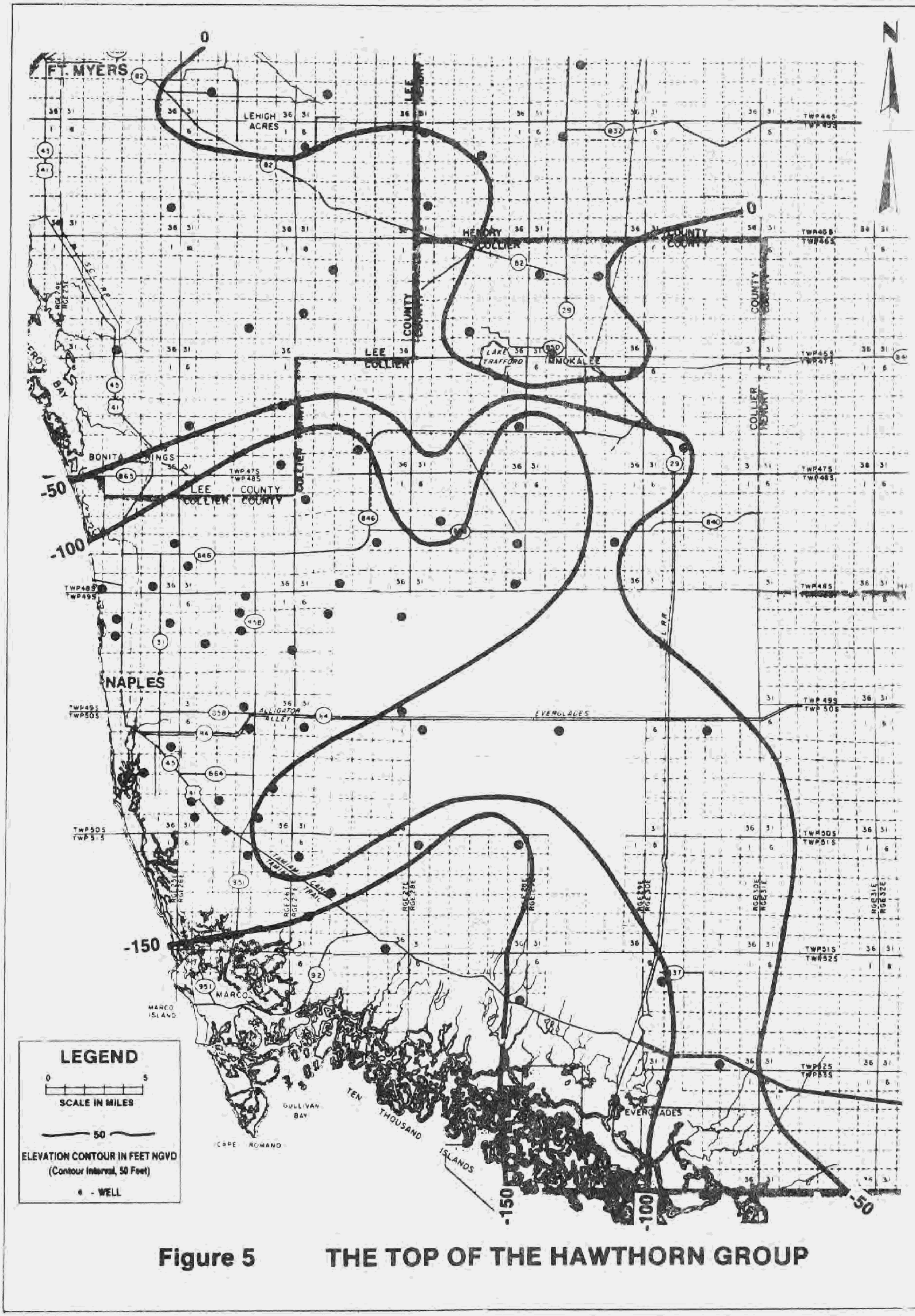


Figure 5 THE TOP OF THE HAWTHORN GROUP

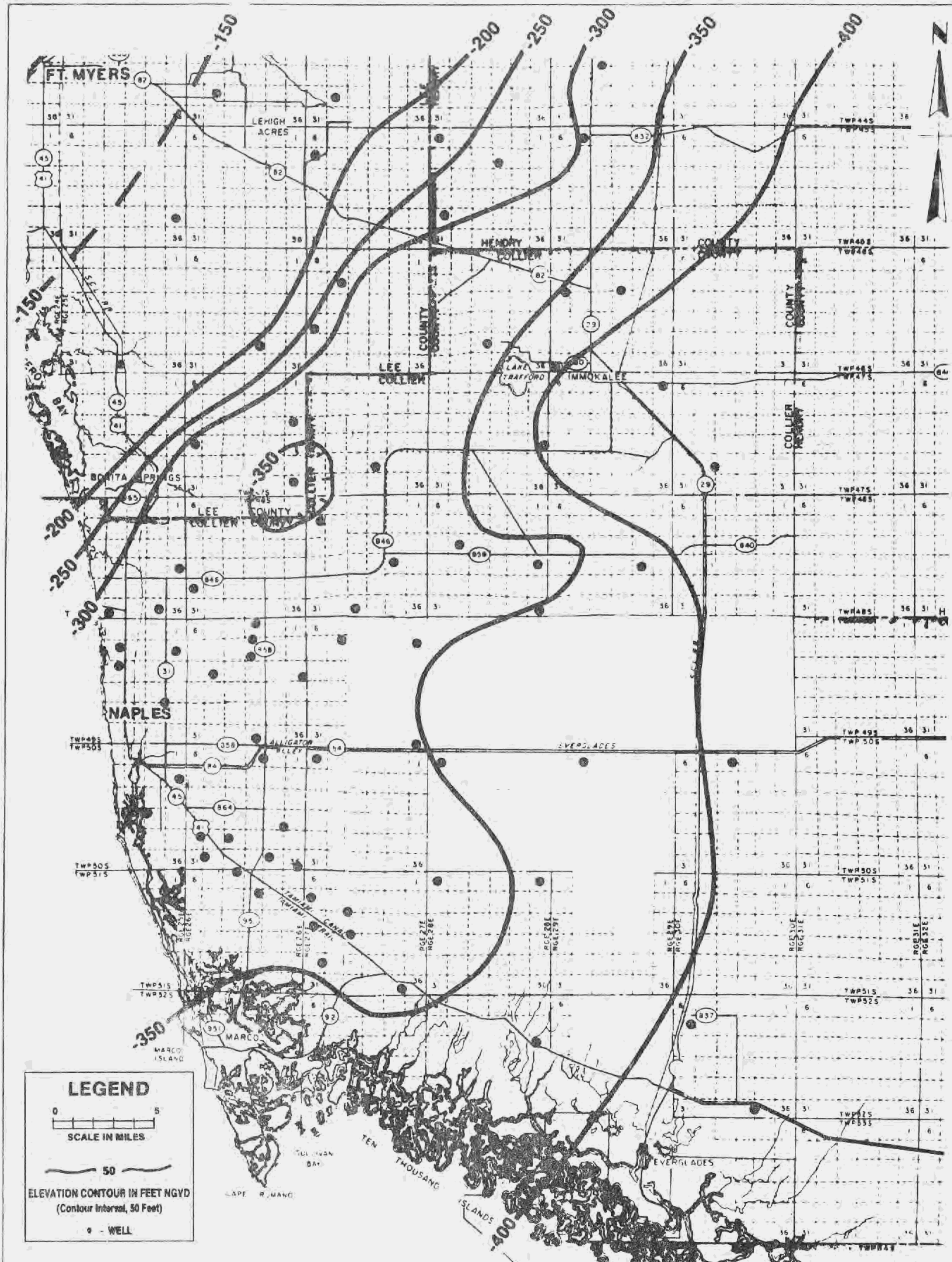


Figure 6 THE TOP OF THE LOWER CARBONATE SEQUENCE OF THE HAWTHORN GROUP

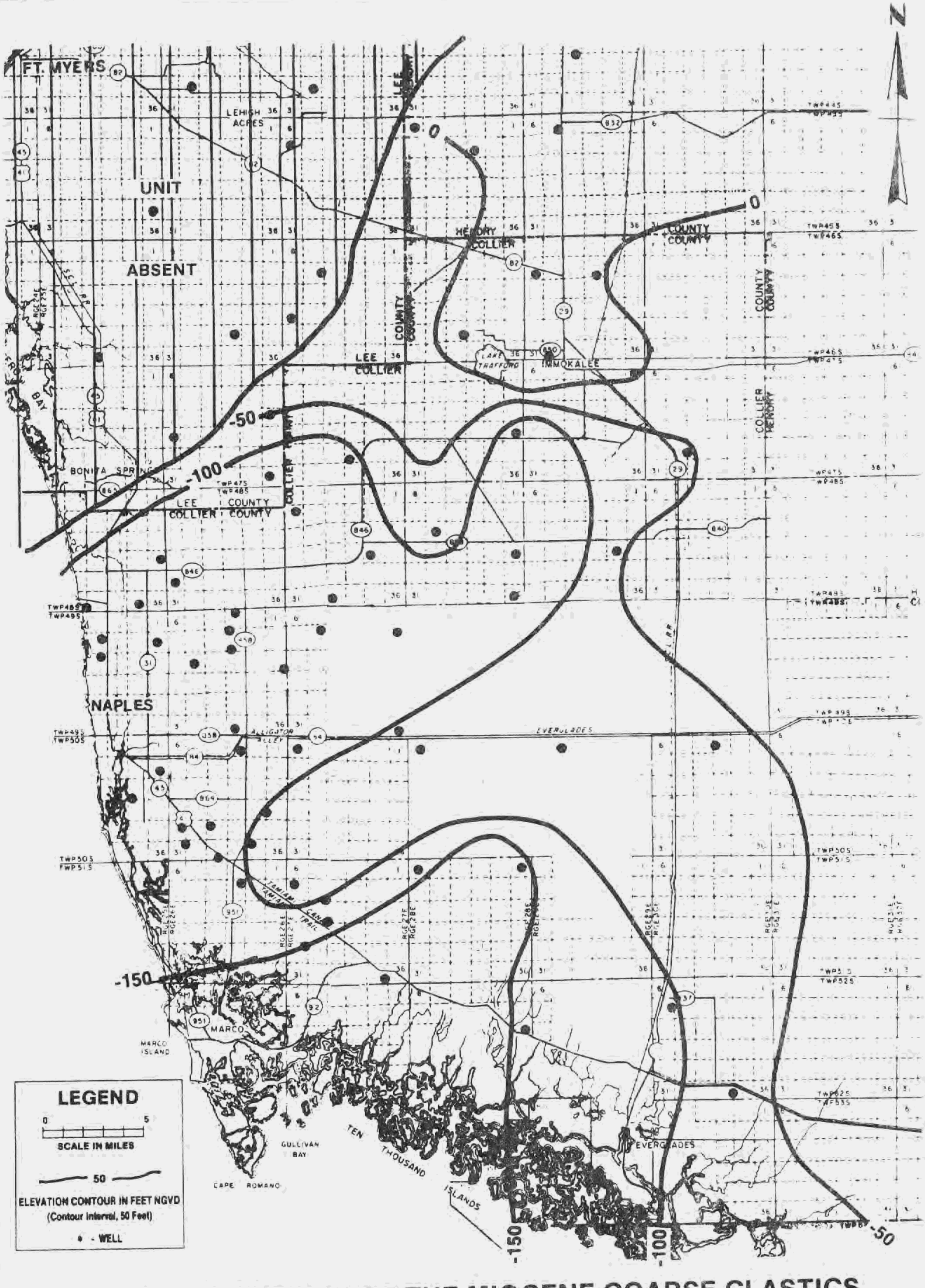


Figure 7 THE TOP OF THE MIOCENE COARSE CLASTICS

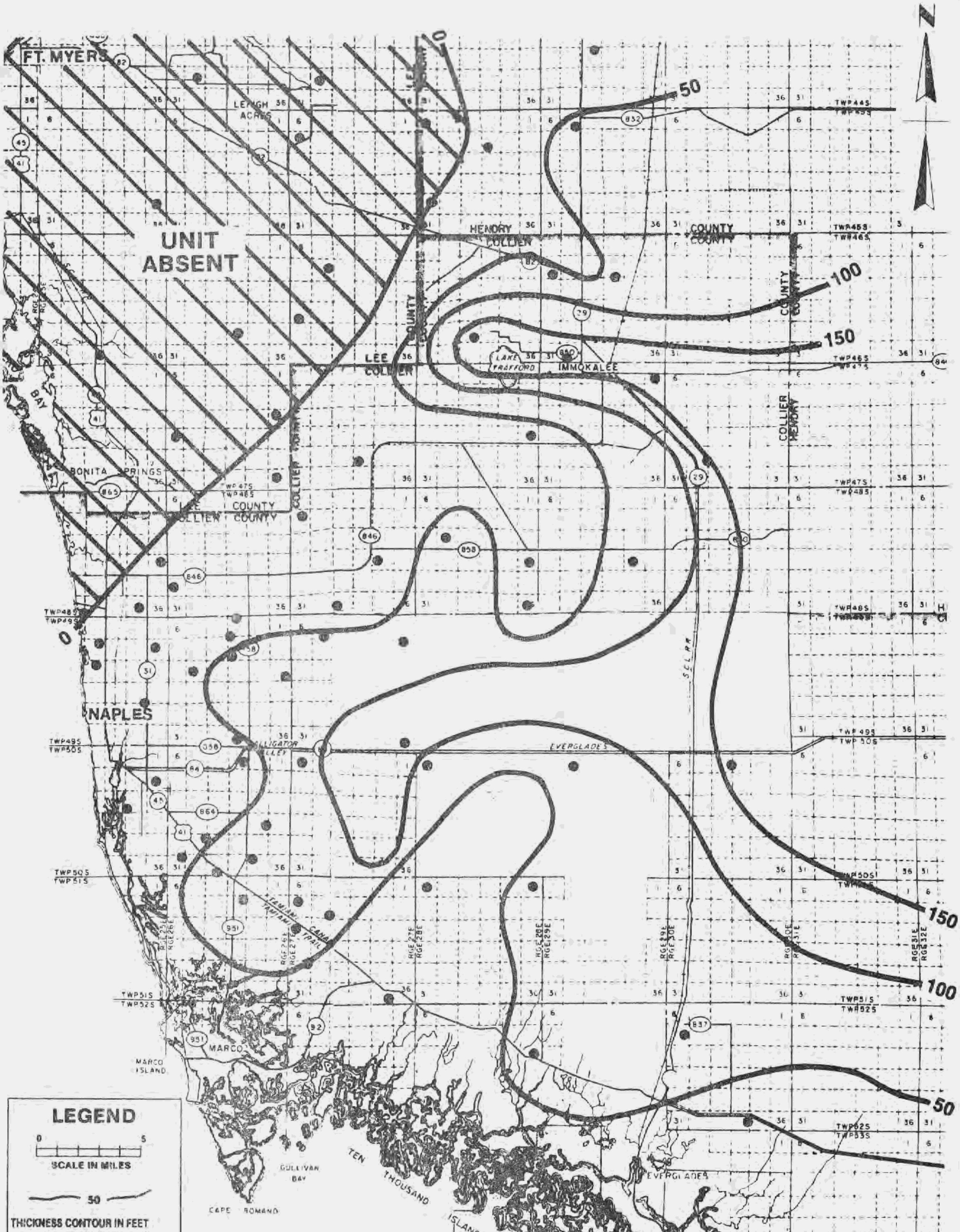


Figure 8 THE THICKNESS OF THE MIOCENE COARSE CLASTICS

previously discussed, Hunter and Wise (1980, 1980a) have shown this definition to be inconsistent with the American Code of Stratigraphic Nomenclature (1970). The literature pertaining to the Tamiami is extensive and the reader who desires more information on this unit in southwest Florida is referred to Wedderburn et al. (1982) or Peck et al. (1979) for more detail.

The Tamiami Formation in Collier County occurs as a moderately indurated, fossiliferous, medium grained, and usually micritic sandy limestone. The uppermost beds are commonly highly indurated and referred to as "cap rock". In many instances, these crusts are formed as a result of dissolution and reprecipitation of minerals. The crusts commonly occur as dense, laminated, crystalline calcite occupying solution cavities or vugs. A poorly indurated limestone is consistently found near the middle of the formation over much of the county. This unit in underlain by more well indurated limestone.

Figure 9 depicts the top of the Tamiami Formation in the study area. It occurs between sea level and 10 ft. above NGVD in the Collier County area. The unit has been logged as high as 20 ft. above NGVD in adjacent Hendry and Lee Counties, but it is very thin in these areas.

The thickness of the Tamiami Formation is quite variable (Figure 10) due to the gradational nature of the lower beds with the "Miocene coarse clastics". The Tamiami is absent around the Lake Trafford area and thins into Hendry County. This is due to the occurrence of the underlying Hawthorn Group at higher elevations and influx of the coarse clastics. In other areas of Collier County the Tamiami is generally greater than 100 feet in thickness.

Pleistocene-Holocene Series

Undifferentiated Terrace Deposits

Undifferentiated terrace deposits of varying thickness and lithology overlie the surface of the Tamiami Formation throughout Collier County. Parts of these deposits have been correlated with the Caloosahatchee and/or Fort Thompson Formations by some geologists (McCoy, 1962). Near the Gulf Coast and along the barrier islands much of this material may be of Holocene age.

The undifferentiated terrace deposits are primarily composed of quartz sands with minor percentages of shell and clay (Lane, 1981). The unit forms a thin veneer in central Collier County where the Tamiami Formation is near or at the surface. In northern Collier County, around the Immokalee area where the elevations are between 25 and 30 feet above NGVD, the terrace deposits are generally thicker (20-40 feet). This area is along the southern boundary of a physiographic feature named the Immokalee Rise by White (1970). He believed this feature to have originated as a submarine shoal during Pleistocene time.

The names "Fort Thompson" and "Caloosahatchee Marl" have been applied to some of the sediments (McCoy, 1962) here included in the undifferentiated terrace deposits. Recognition of these two formations is largely dependent upon differentiation of fossil assemblages present. While this may be done in large outcrop samples, the small quantity and size of well cuttings makes this distinction impractical for this study. In addition, the heterogeneous nature of the surficial deposits in this area makes detailed mapping infeasible. It was, therefore, decided to leave these sediments undifferentiated.

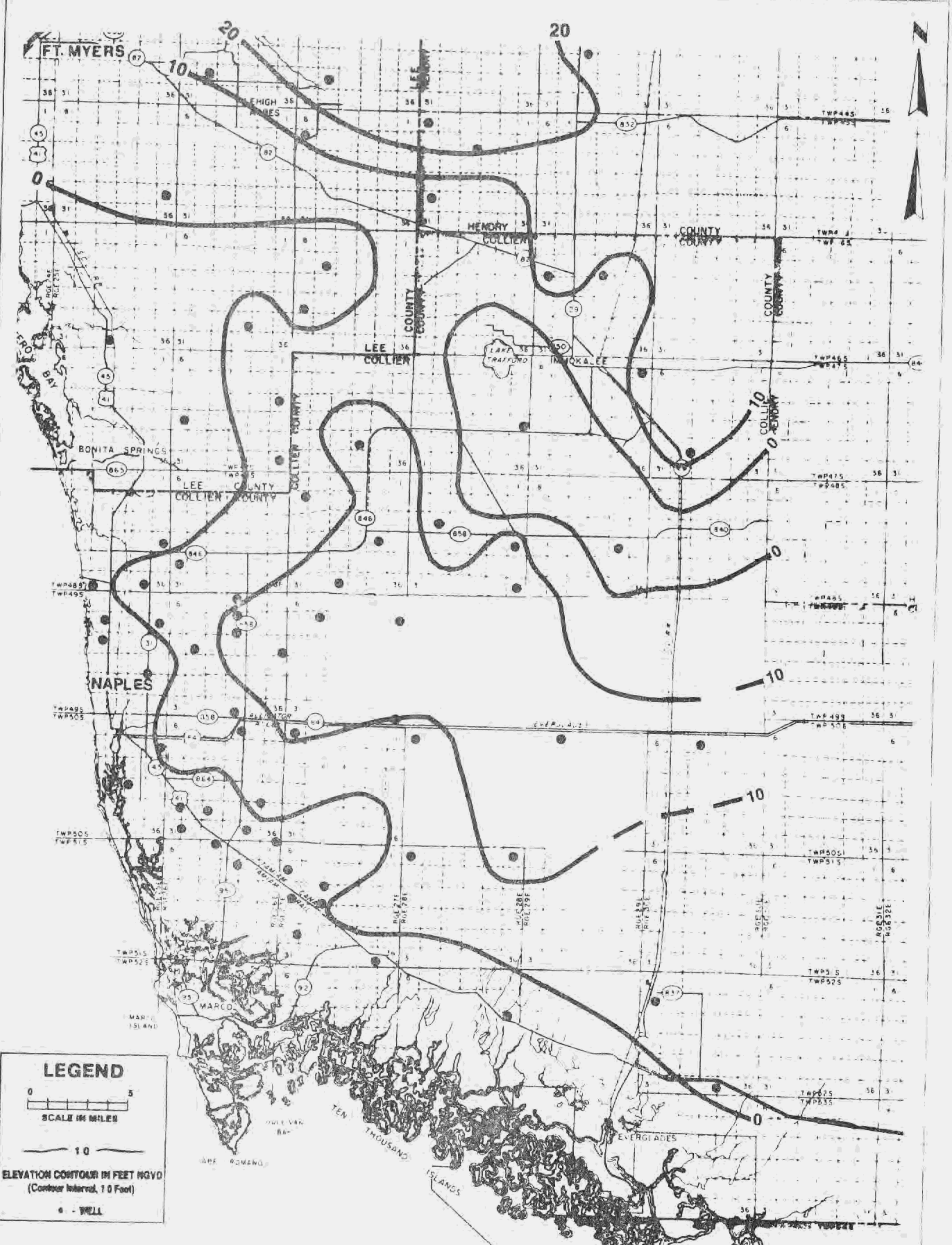


Figure 9 THE TOP OF THE TAMIAMI FORMATION

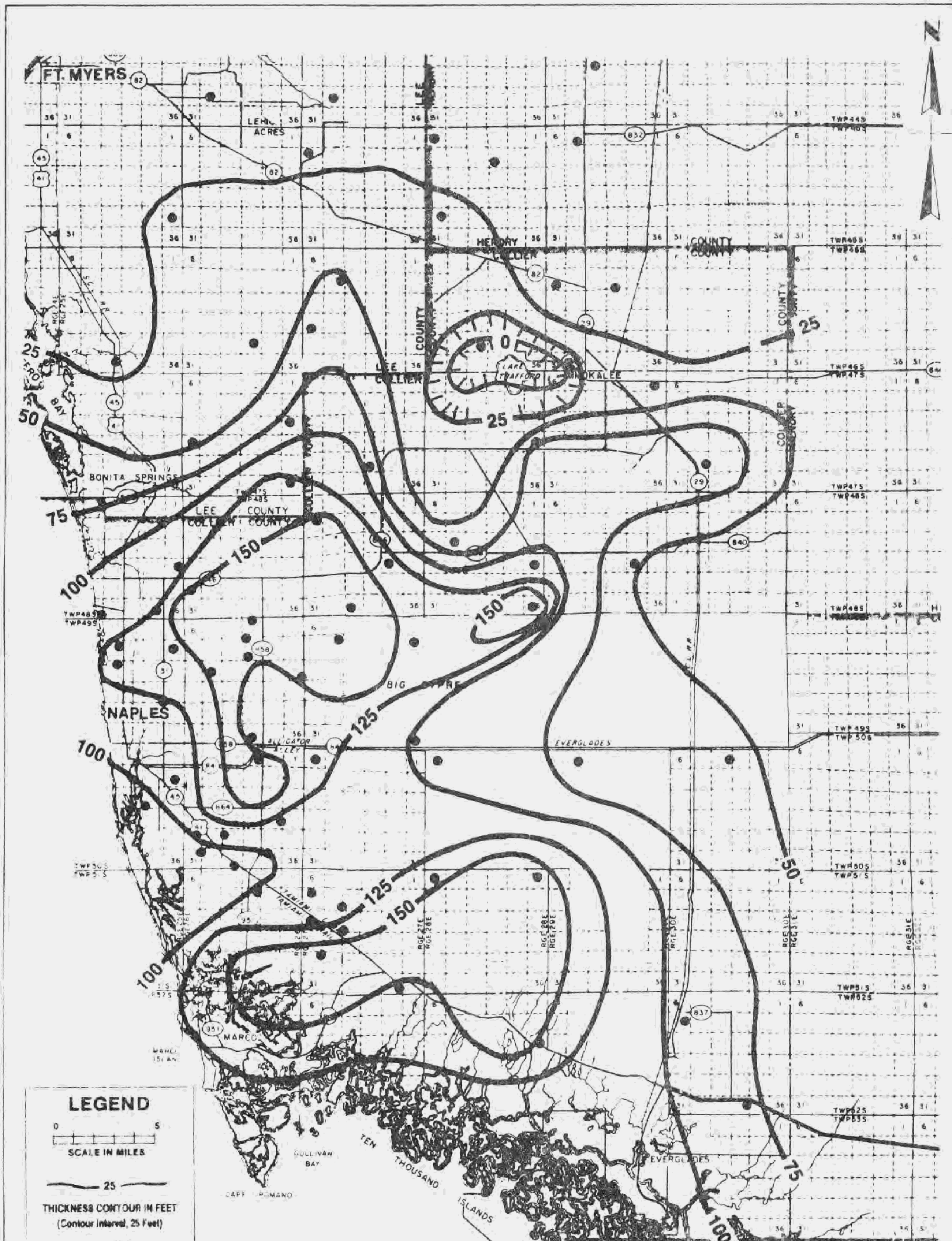


Figure 10 THE THICKNESS OF THE TAMIAMI FORMATION

HYDROGEOLOGY

INTRODUCTION

The geologic formations underlying the study area can be divided hydrogeologically into aquifers (those sediments which yield water in sufficient quantity to be valuable as a source of supply) and confining zones (low permeability rocks lying above, between, or below aquifers). The inclusion of a particular rock stratum within an aquifer is based upon substantial vertical and lateral hydraulic continuity within that stratum.

According to Kruseman and DeRidder (1970), there are four basic types of aquifers which occur in nature. These aquifer types are unconfined, confined, semi-confined, and semi-unconfined. Unconfined aquifers are composed of permeable material which may be partially or completely saturated with water. In an unconfined aquifer, water levels are in equilibrium with atmospheric pressure. The upper boundary is termed the water table or phreatic level. The lower boundary is formed by a relatively impermeable bed. A confined aquifer is completely saturated and is bounded at the top and bottom by relatively impermeable beds. The potentiometric surface (the imaginary level to which water rises in tightly cased wells which are open to the aquifer only) occurs above the top of the confined aquifer. As pointed out by Kruseman and DeRidder (1970), completely impervious beds rarely exist in nature and confined aquifers are less common than often recognized. A semi- confined or leaky aquifer is a completely saturated aquifer that is bounded above and below by low permeability beds. Water can move vertically through the semi-confining beds, the rate of movement being dependent on head differentials and permeabilities of the the confining beds. The semi-unconfined aquifer is one in which the horizontal flow in the adjacent semi- confining beds is great enough that it cannot be ignored. This type of aquifer is considered to be transitional between semi-confined and unconfined aquifers.

The aquifers described in this report exhibit characteristics of all of these aquifer types with the exception of the confined aquifer. The terminology used is largely based upon work done by Wedderburn et al. (1982) and recent writings by the Southeastern Geological Society Committee on Florida Hydrostratigraphy (SGSCFH). The relationship of this terminology and other aquifer nomenclature in Collier County is shown on Figure 11.

The hydrostratigraphy of four major aquifers (Figure 3) that occur within two regional aquifer systems is discussed in this section. The Surficial Aquifer System is the most important among the major aquifer systems in terms of public water supply, and is divided into two aquifers (the water table and the lower Tamiami) separated by the leaky Tamiami confining beds. The Intermediate Aquifer System underlies the Surficial Aquifer System and acts as a regional confining unit for the deeper Floridan Aquifer System. The Sandstone and mid-Hawthorn aquifers are contained within the Intermediate Aquifer System and will produce limited quantities of water. Both of these aquifers are under artesian pressure. The water levels and water quality of the Sandstone aquifer are similar to those of the Surficial Aquifer System and suggest hydraulic connection between this aquifer and the Surficial Aquifer System. Based on this hydraulic connection, some authors have grouped the Sandstone aquifer into the Surficial Aquifer System (Figure 11). However, based on criteria outlined by the SGSCFH, the placement of the Sandstone aquifer is here considered to be part of the Intermediate Aquifer System because it is located below the first regionally continuous confining bed. The Sandstone aquifer is separated from the Surficial Aquifer System by the upper Hawthorn confining zone and from the mid-Hawthorn aquifer by the mid-Hawthorn confining zone. The Floridan Aquifer System contains poor quality water (chlorides and sulfate concentrations are beyond potable standards) in this area and is not discussed in this report.

Figure 12 depicts the placement of the aquifer systems, lithologies, and associated geophysical signatures from a continuous core hole, WC2032, located near the Corkscrew Island area of Collier County. The electric logs (16", 64", 6' Lateral) show an overall high resistivity for the Surficial Aquifer System indicating well indurated lithologies and good quality water. The continuous core and water samples from this area correlate with the geophysical logs. Attenuations in resistivity (140 to 175 feet) identify the low permeability clayey dolosilts that form the top of the Intermediate Aquifer System. Resistivity in all the electric logs increases adjacent to the Sandstone and mid-Hawthorn aquifer limestones and dolomites. Exceptions occur in areas where the aquifers contain saline water. The natural gamma log shows increased radioactivity throughout the Intermediate Aquifer System due to the presence of phosphate. Gamma

<table>
<tr><th colspan="2">U.S. GEOLOGICAL SURVEY[1]</th><th colspan="2">CH_2M Hill[2]</th><th colspan="3">MISSIMER & ASSOCIATES[3]</th><th colspan="2">THIS REPORT</th></tr>
<tr><td rowspan="5">SURFICIAL AQUIFER SYSTEM</td><td>WATER TABLE</td><td rowspan="5">SURFICIAL AQUIFER SYSTEM</td><td>UNCONFINED ZONE</td><td rowspan="3">SURFICIAL AQUIFER SYSTEM</td><td colspan="2">WATER TABLE (Coral Reef Aquifer)</td><td rowspan="3">SURFICIAL AQUIFER SYSTEM</td><td>WATER TABLE AQUIFER</td></tr>
<tr><td>CONFINING BEDS</td><td>CONFINING BEDS</td><td colspan="2">CONFINING BEDS</td><td>TAMIAMI CONFINING BEDS</td></tr>
<tr><td rowspan="3">WATER BEARING UNITS OF THE LOWER SURFICIAL AQUIFER SYSTEM</td><td>SEMI-UNCONFINED ZONE</td><td colspan="2">TAMIAMI AQUIFER</td><td>LOWER TAMIAMI AQUIFER</td></tr>
<tr><td>CONFINING BEDS</td><td rowspan="4">INTERMEDIATE AQUIFER SYSTEM*</td><td rowspan="4">HAWTHORN AQUIFER GROUP</td><td>CONFINING BEDS</td><td rowspan="4">INTERMEDIATE AQUIFER SYSTEM*</td><td>UPPER HAWTHORN CONFINING ZONE</td></tr>
<tr><td>SEMI-CONFINED ZONE</td><td>SANDSTONE AQUIFER</td><td>SANDSTONE AQUIFER</td></tr>
<tr><td rowspan="2">INTERMEDIATE AQUIFER SYSTEM*</td><td>CONFINING BEDS</td><td rowspan="2">INTERMEDIATE AQUIFER SYSTEM*</td><td>CONFINING BEDS</td><td>CONFINING BEDS</td><td>MID-HAWTHORN CONFINING ZONE</td></tr>
<tr><td>UPPER INTERMEDIATE AQUIFER</td><td>UPPER HAWTHORN AQUIFER</td><td>ZONE 1</td><td>MID-HAWTHORN AQUIFER</td></tr>
</table>

Figure 11 RELATIONSHIP OF CURRENT HYDROSTRATIGRAPHIC NOMENCLATURE IN COLLIER COUNTY.

1- Henry LaRose - U.S. Geological Survey
2- Ross Sproul - CH^2M Hill
3- Tom Missimer - Missimer and Assoc.
*This system extends downward to the top of the Floridan

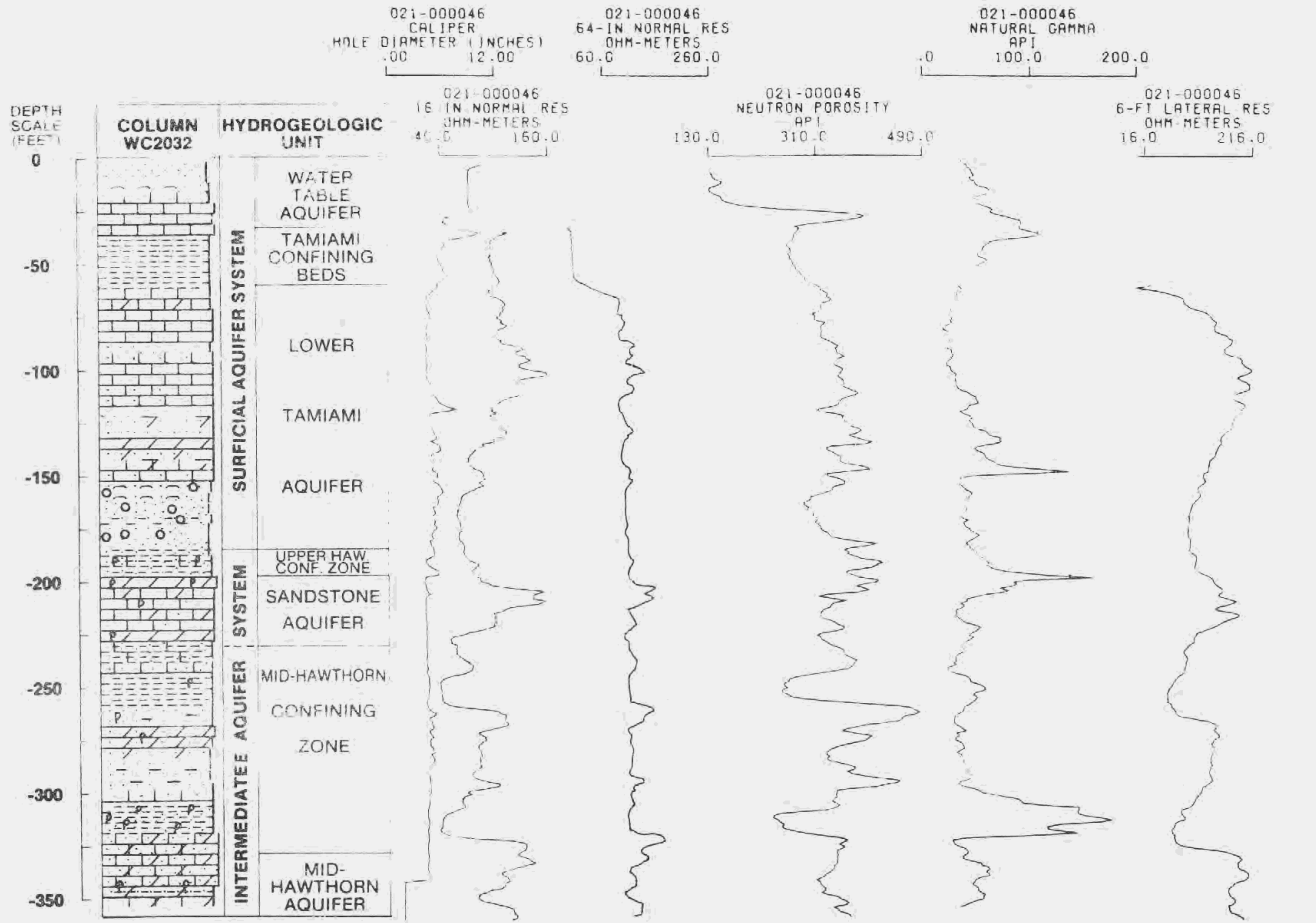


Figure 12 REPRESENTATIVE LITHOLOGIES AND BOREHOLE GEOPHYSICS FROM WELL C2032

activity is particularly strong adjacent to a rubble zone near the top of the mid-Hawthorn aquifer. The geophysical signatures and associated lithologies in this core hole are representative of the aquifer systems in most of Collier County north of Alligator Alley. In the area around Immokalee these geophysical signatures vary somewhat in the Surficial Aquifer System due to the thick sequence of Miocene coarse clastics. Local variations also occur in the electric logs where poor quality water is encountered.

Figure 13 depicts the lithology and borehole geophysics derived from well WC2044 in the Fakahatchee Strand Area of Collier County. This well is representative of the hydrogeology in southern and southeastern Collier. The electric logs (16",64") show high resistivity in the upper portion of the Surficial Aquifer System that correlates with the well indurated and porous limestones of the Tamiami Formation. Minor clay beds were lithologically described within the Surficial Aquifer System from 50 to 70 feet (Tamiami confining beds) and 135 to 150 feet below land surface. The Intermediate Aquifer System contains clayey dolosilts from 260 feet to the top of the mid- Hawthorn aquifer at 370 feet. These beds are shown as low resistivity zones on the electric logs. The natural gamma log shows little activity with the exception of a zone in the Surficial Aquifer System from 140 to 150 feet and another in the Intermediate from 320 to 370 feet. The upper zone (140 to 150) occurs as a very sandy calcareous clay with some phosphorite (probably reworked). The lower zone reflects high radioactivity associated with a rubble bed of coarse quartz and phosphate near the top of the lower carbonate horizon of the Hawthorn.

Hydrogeologic cross section A-A' (Figure 14) runs north-south from the Corkscrew Road area of Lee County to the Tamiami Trail on a line that parallels Highway 951 in Collier County (Figure 3). The Surficial Aquifer System is shown to be thickest around well WC2039 in the western Golden Gate area. The lower Tamiami aquifer is 200 feet thick in this well. The top of the underlying Intermediate Aquifer System dips gently to the south with local variations in the Golden Gate area. Within this system the beds composing the mid-Hawthorn aquifer correspond to the uppermost zone of the lower carbonate sequence of the Hawthorn Group. A structural low in the lower carbonate sequence occurs in southern Lee County in the vicinity of well LE-033.

Cross section B-B' (Figure 15) parallels and is east of A-A'. It coincides closely with the path of Everglades Boulevard to the Tamiami Trail (U. S. Highway 41). The Surficial Aquifer System maintains a thickness between 100 and 230 feet along this section line. The unit thins gradually to the north. Within the Intermediate System, the Sandstone aquifer pinches out near Alligator Alley. This aquifer is thickest in northern Collier County near well WC2038 where the unit may be receiving recharge from the underlying mid-Hawthorn aquifer as a result of upward leakance through relatively thin confining beds.

Cross section C-C' (Figure 16) follows a southerly route bordering Highway 29 from Hendry County through Immokalee to the Tamiami Trail. The confining beds within the Surficial System are locally absent around Immokalee allowing hydraulic connection between the water table and lower Tamiami aquifers. The lower Tamiami aquifer contains appreciable quantities of coarse clastic material in this area. The Sandstone aquifer pinches out as it approaches Alligator Alley.

SURFICIAL AQUIFER SYSTEM

Beds which are here placed within the Surficial Aquifer System in Collier County have in the past been included in the shallow aquifer (Klein, 1954 and McCoy, 1962). This terminology is used in light of recommendations by the Southeastern Geological Society Committee on Hydrostratigraphic Nomenclature that the term Surficial Aquifer System be used for the water table and hydraulically connected aquifers lying above the top of the laterally extensive and vertically persistent beds of lower permeability in the Hawthorn.

In the study area, the Surficial Aquifer System occurs within sediments of the Miocene coarse clastics, Tamiami Formation, and undifferentiated deposits. The aquifer system is divided into two aquifers (water table and lower Tamiami), separated by a leaky confining zone (Tamiami confining beds). The base of the aquifer system is formed by the low permeability, clayey dolosilts near the top of the Hawthorn. The thickness of the Surficial Aquifer System is shown on Figure 17. The system attains thicknesses up to 250 feet in central Collier County and thins to near 50 feet along the county's northern perimeter.

Water Table Aquifer

In Collier county the water table aquifer, extending from near land surface to the top of the Tamiami confining beds is ubiquitous. The uppermost beds within this aquifer are normally fine to medium grained, well-sorted, quartz sands with minor amounts of shell and organics. Below these beds, to the top of the Tamiami confining beds, are sandy, biogenic limestones of the Tamiami Formation that n

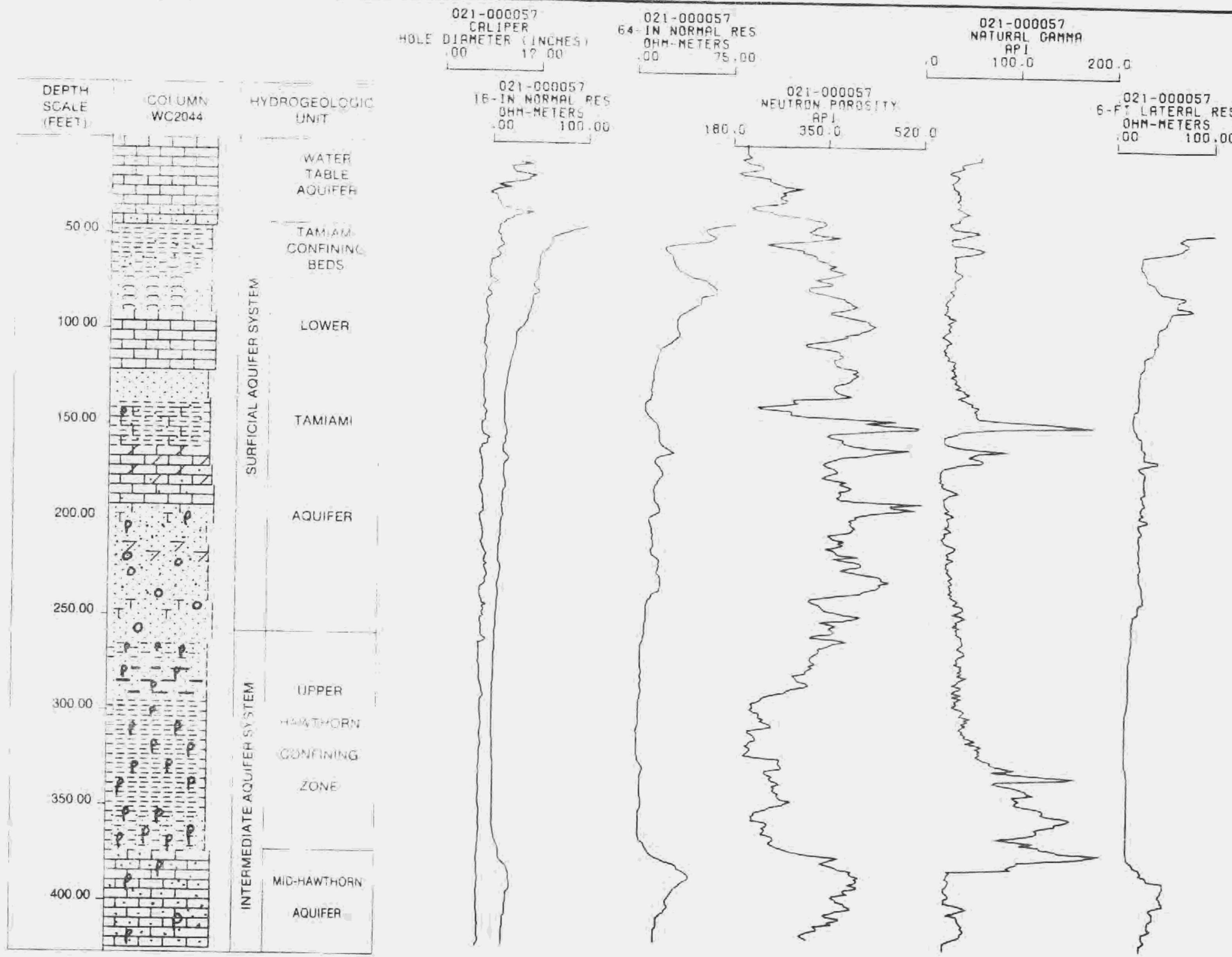


Figure 13 REPRESENTATIVE LITHOLOGIES AND BOREHOLE GEOPHYSICS FROM WELL C2044

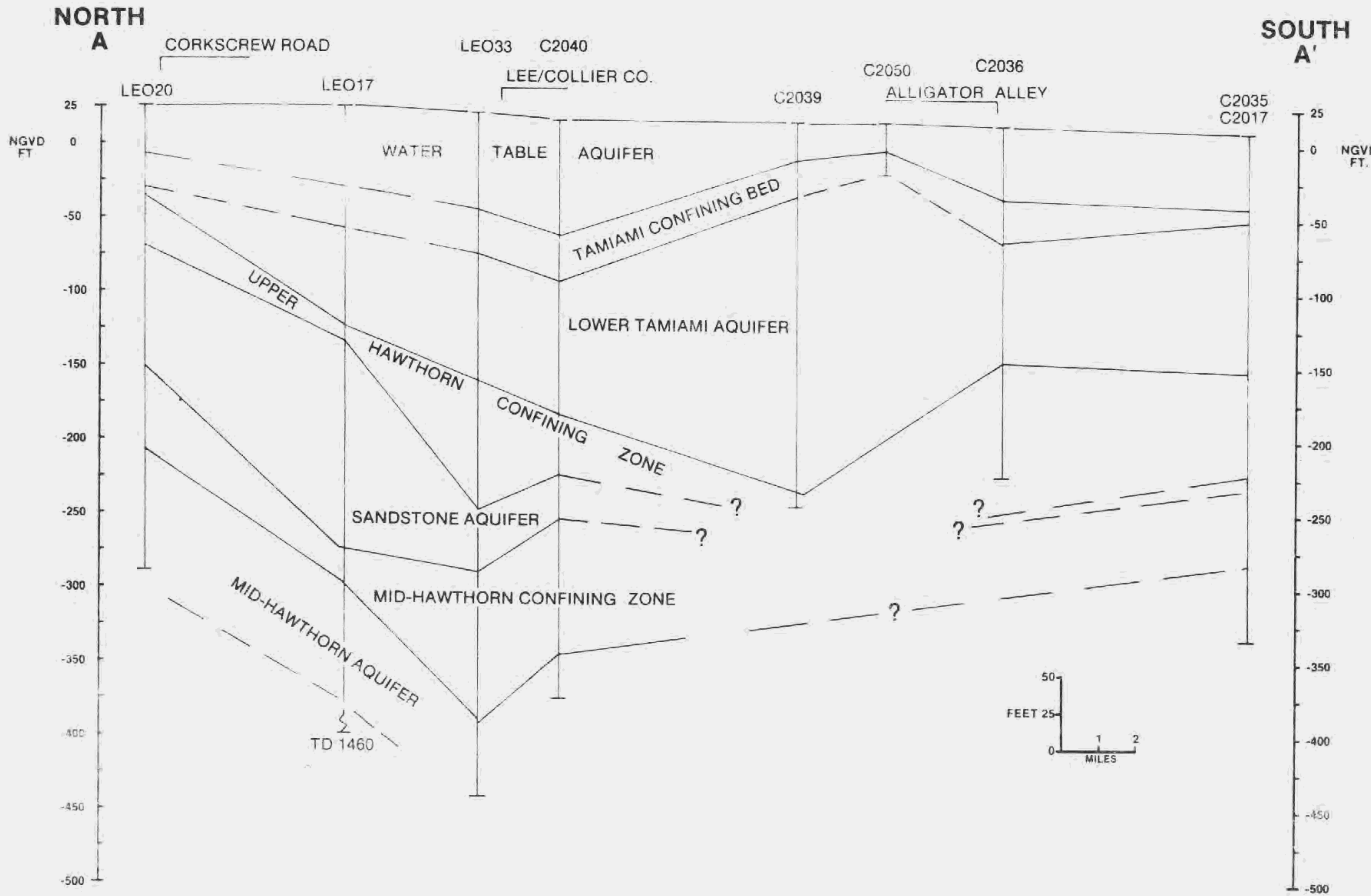


Figure 14 HYDROGEOLOGIC CROSS-SECTION A—A'

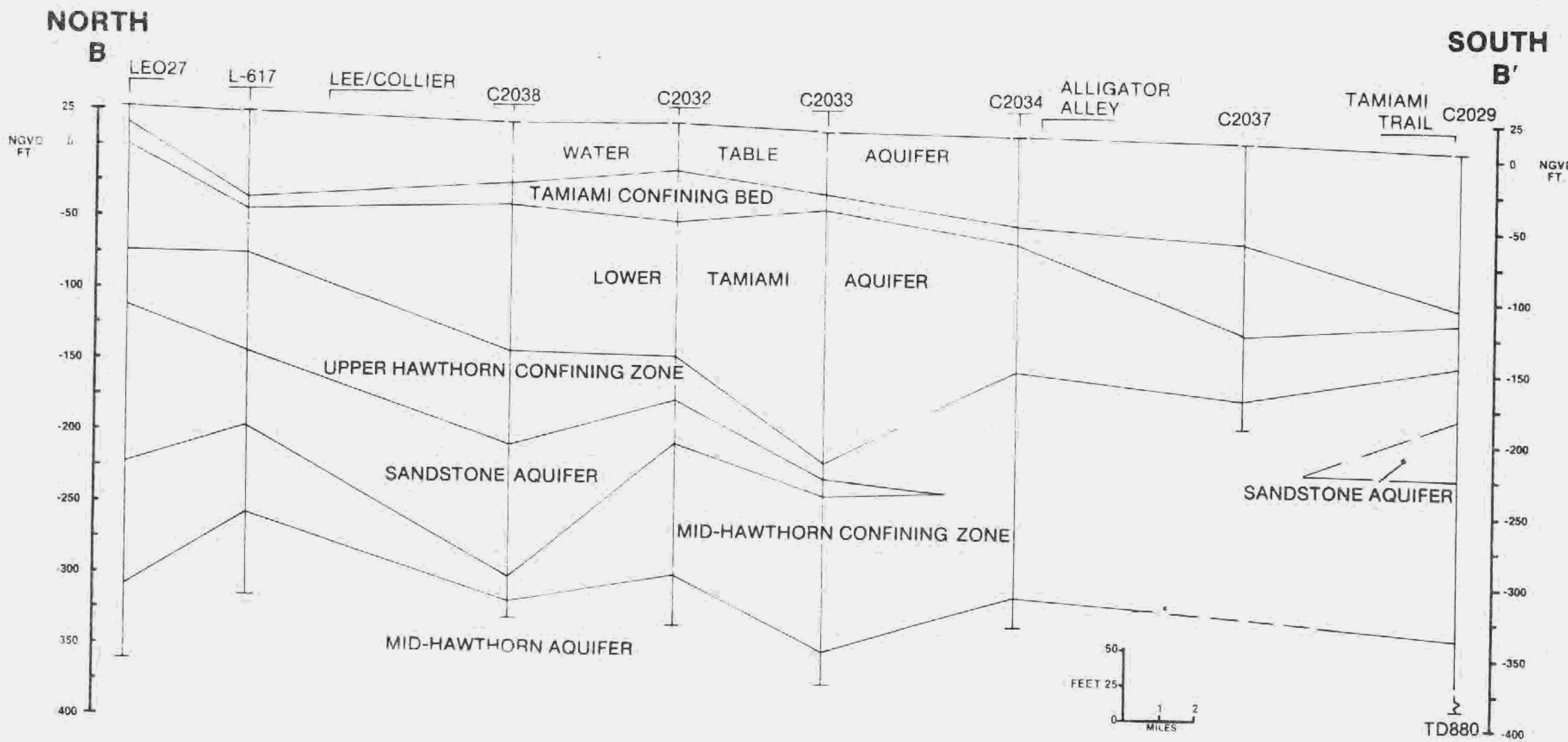


Figure 15 HYDROGEOLOGIC CROSS-SECTION B—B'

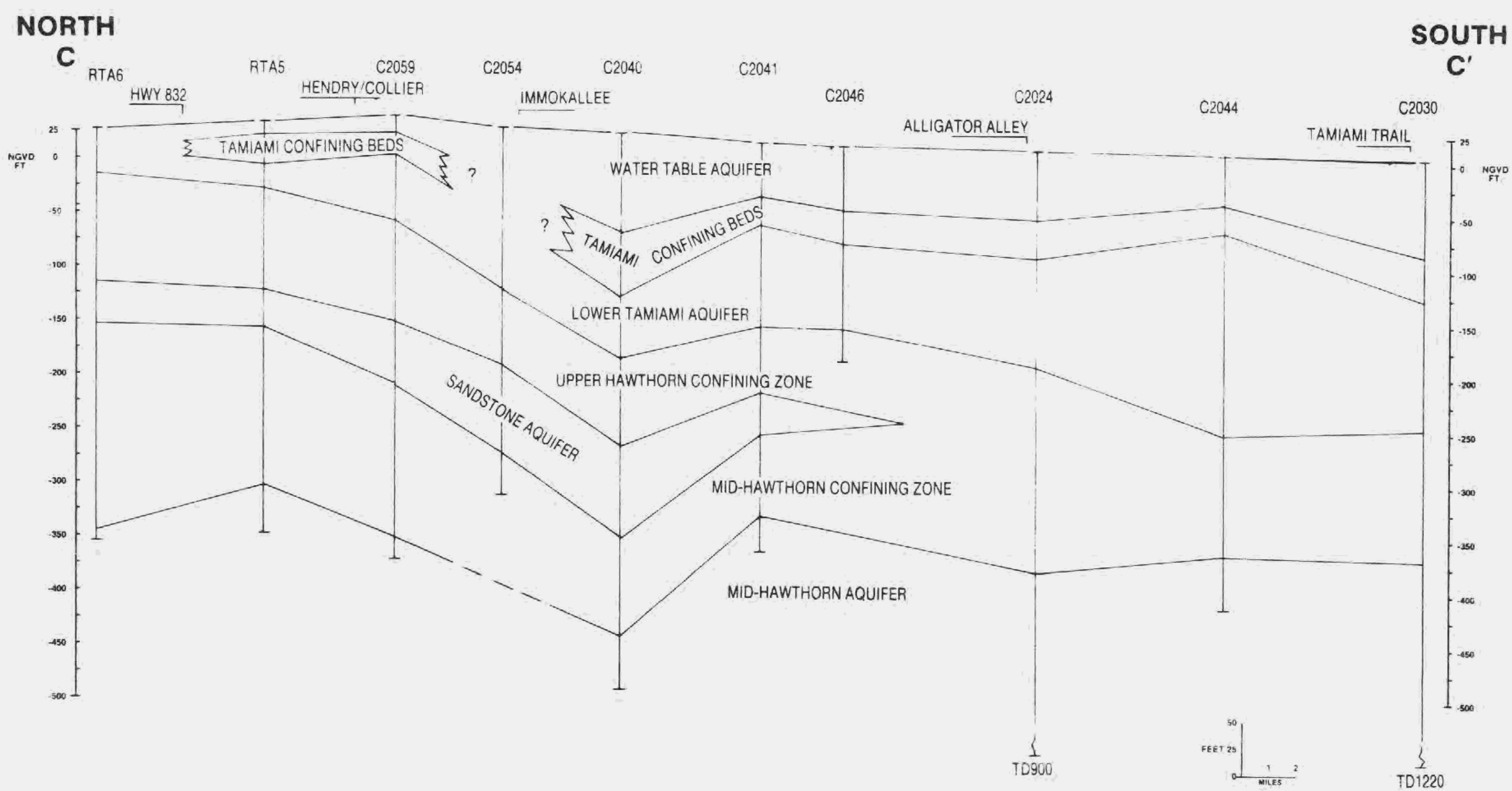


Figure 16 HYDROGEOLOGIC CROSS SECTION C-C′

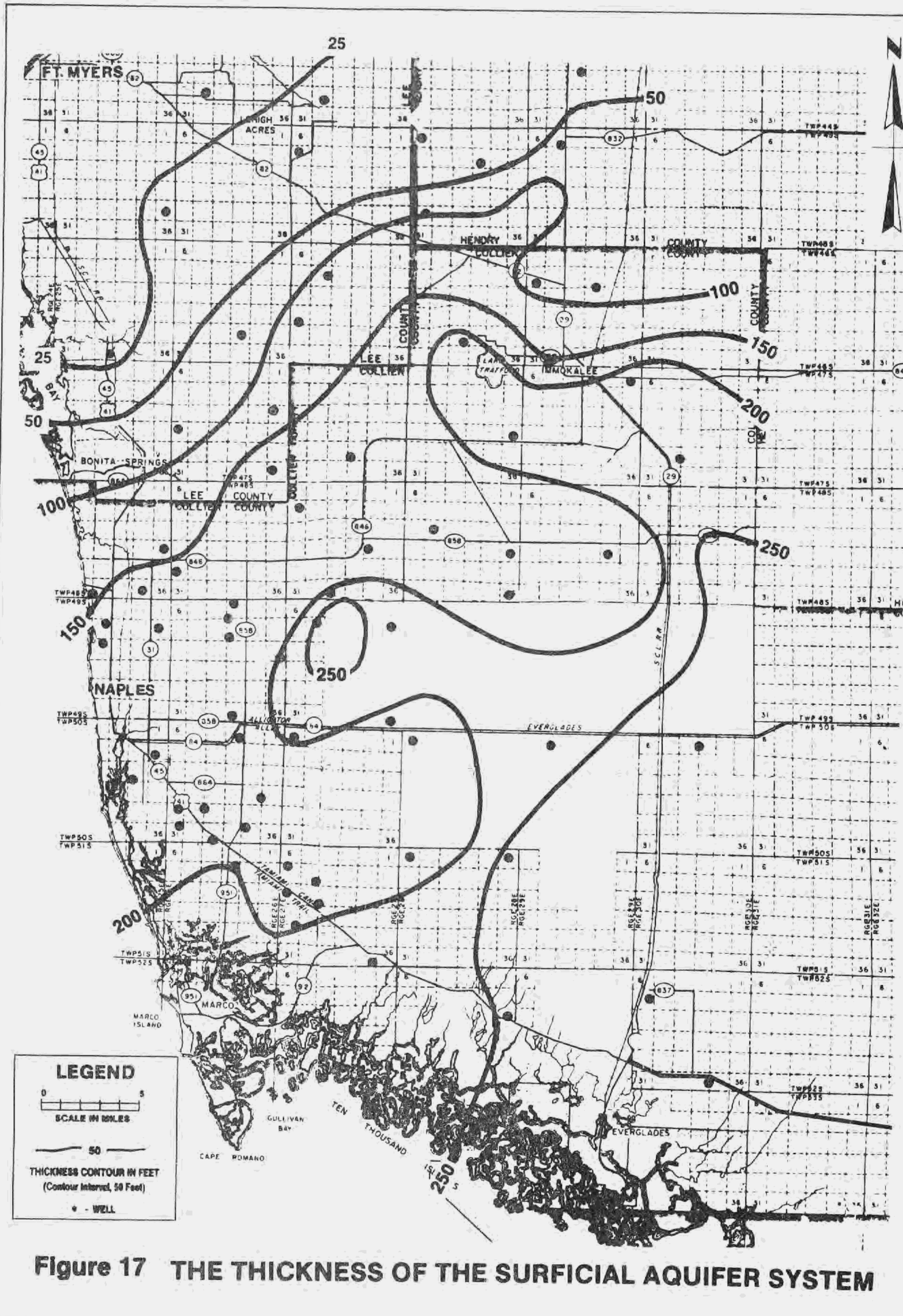


Figure 17 THE THICKNESS OF THE SURFICIAL AQUIFER SYSTEM

many areas are capable of producing large quantities of water. One such area north of the Cocohatchee Canal was investigated by Missimer (1982). He referred to the water table aquifer as the Coral Reef aquifer in this area in recognition of a coralline limestone facies in the Tamiami Formation and of the high permeabilities therein. Well cemented and low permeability limestone locally occurs as a crust (cap rock) over the Tamiami Formation. Where these crusts occur, they retard but do not prevent the vertical flow of water and cause sheet flow or ponding at the surface. The cap rocks are not continuous over great distances and are generally fractured and highly karstified, having little effect on recharge over large areas.

The water table aquifer is over 50 feet thick in the central portion of Collier County (Figure 18). It thins radially from this area and is less than 25 feet thick in central Lee and Hendry Counties. The thickest sequence of the aquifer was penetrated in well C2054 (Appendix I) near Lake Trafford, where the unit was 150 feet in thickness. In this area the underlying Tamiami confining beds have been breached and direct recharge occurs from the water table aquifer to the lower Tamiami aquifer.

Tamiami Confining Beds

The Tamiami confining beds are composed of low permeability, poorly indurated limestones, dolosilts, and calcareous sandy clays that are a part of the Tamiami Formation. These beds retard the vertical flow of water between the water table and lower Tamiami aquifers. The beds, however, are considered to be leaky with leakance values ranging from 1×10^{-4} to 1×10^{-1} day^{-1}. This is due in large part to their gradational nature and inherent rapid facies changes in the beds.

The thickness of the confining beds ranges between 25 and 50 feet over most of the county (Figure 19), normally averaging around 30 feet. The unit thins and thickens erratically and is absent in some areas. Where the confining beds are absent, the water table aquifer is in direct hydraulic connection with the lower Tamiami aquifer, and both units are under unconfined conditions.

Lower Tamiami Aquifer

The lower Tamiami aquifer is a major water producing unit in most of Collier County. The basal limestones of the Tamiami Formation and the quartz sands of the Miocene coarse clastics unit are the predominant lithologic constituents. This aquifer has been referred to as the Shallow aquifer and the Coastal Ridge aquifer by other workers (Klein, 1954 and McCoy, 1962). These designations, however, are inclusive of the water table, which is treated as a separate aquifer in this report.

The productivity of the lower Tamiami is related to the sand content of the different strata. The permeability decreases as the sand content increases towards the base of the unit. This is due to: a) the poorly sorted nature of the clastic facies, and b) the presence of silt and micrite matrix components which reduce the effective porosity. However, in localized areas where the coarse sands are better sorted, properly constructed wells are capable of producing large quantities of water. The limestone sequence in the lower Tamiami aquifer is thicker along the west coast and thins at the expense of the coarse clastics to the east. Coarse clastics predominate in the east central and north central parts (Figure 8) of the study area.

The top of the lower Tamiami aquifer occurs between sea level and 100 feet below NGVD throughout the study area (Figure 20). The only areas of exception are where the confining beds are absent and the lower Tamiami and water table act as one aquifer. The thickness of the lower Tamiami is presented on Figure 21. The unit is 200 feet thick in an area paralleling Alligator Alley (U.S. Highway 84) and more than 75 feet in most other areas of Collier County. Exploration wells (WC 2032, WC 2033, WC 2039, Appendix I) located near Golden Gate Blvd. and Corkscrew Island (Figure 3) penetrated highly permeable zones within this unit. In southern Collier, well C-2035 also contained zones of high permeability within this unit.

INTERMEDIATE AQUIFER SYSTEM

In general, the Intermediate Aquifer System acts to confine the underlying Floridan Aquifer System. The system is composed predominantly of low permeability clays, dolosilts, limestones, and mixtures of these lithologies. Highly permeable limestones and dolomites are present, and water within them is under artesian conditions. Two aquifers are delineated and discussed in this report. These are the Sandstone aquifer, which is relatively thin and discontinuous, and the mid-Hawthorn aquifer, which underlies all of the study area. These two aquifers are isolated from adjacent water bearing strata above and below by clayey dolosilts and low permeability limestones.

Upper Hawthorn Confining Zone

The upper Hawthorn confining zone was a term used by Wedderburn et al. (1982) to denote a bed of low

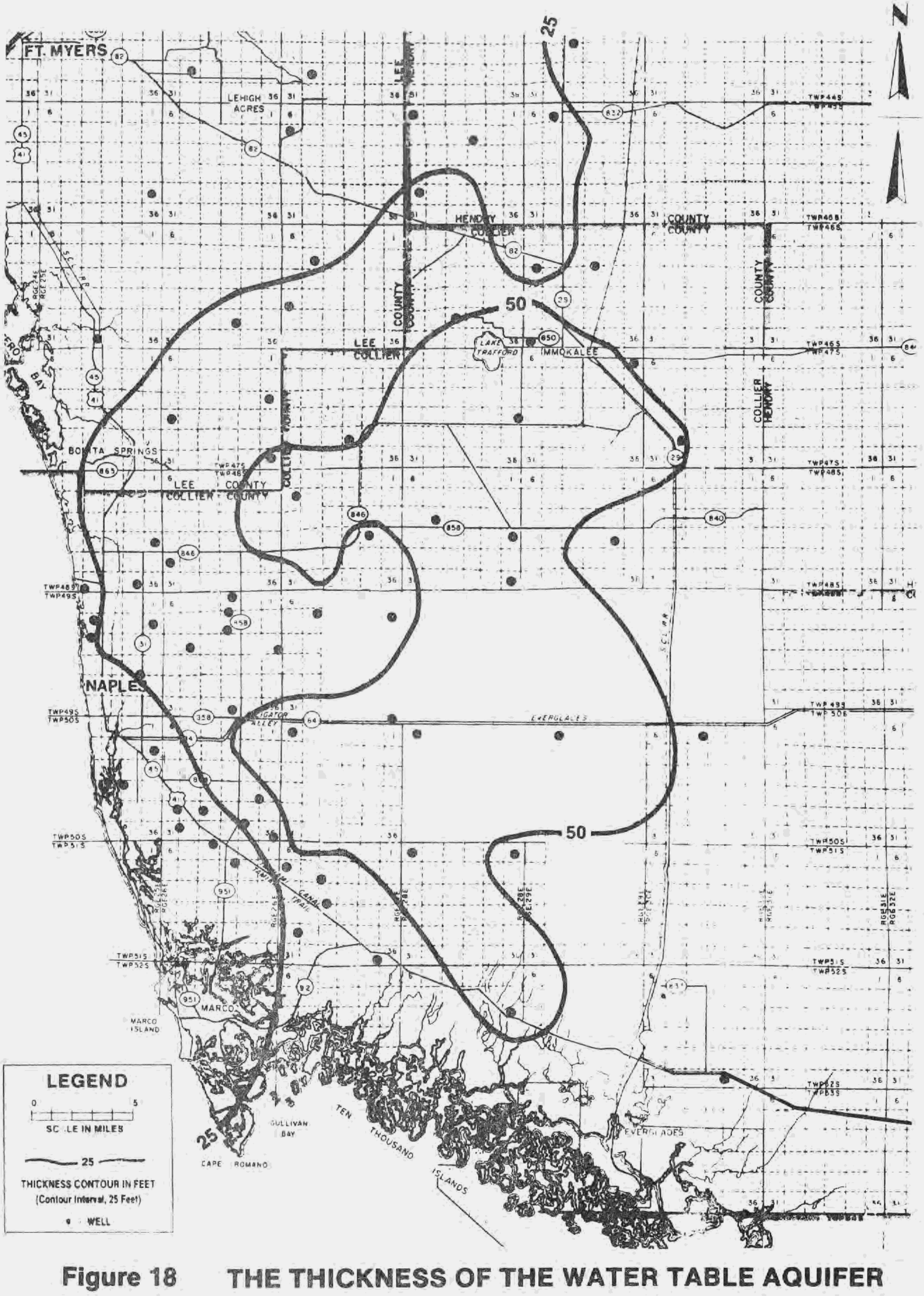


Figure 18 THE THICKNESS OF THE WATER TABLE AQUIFER

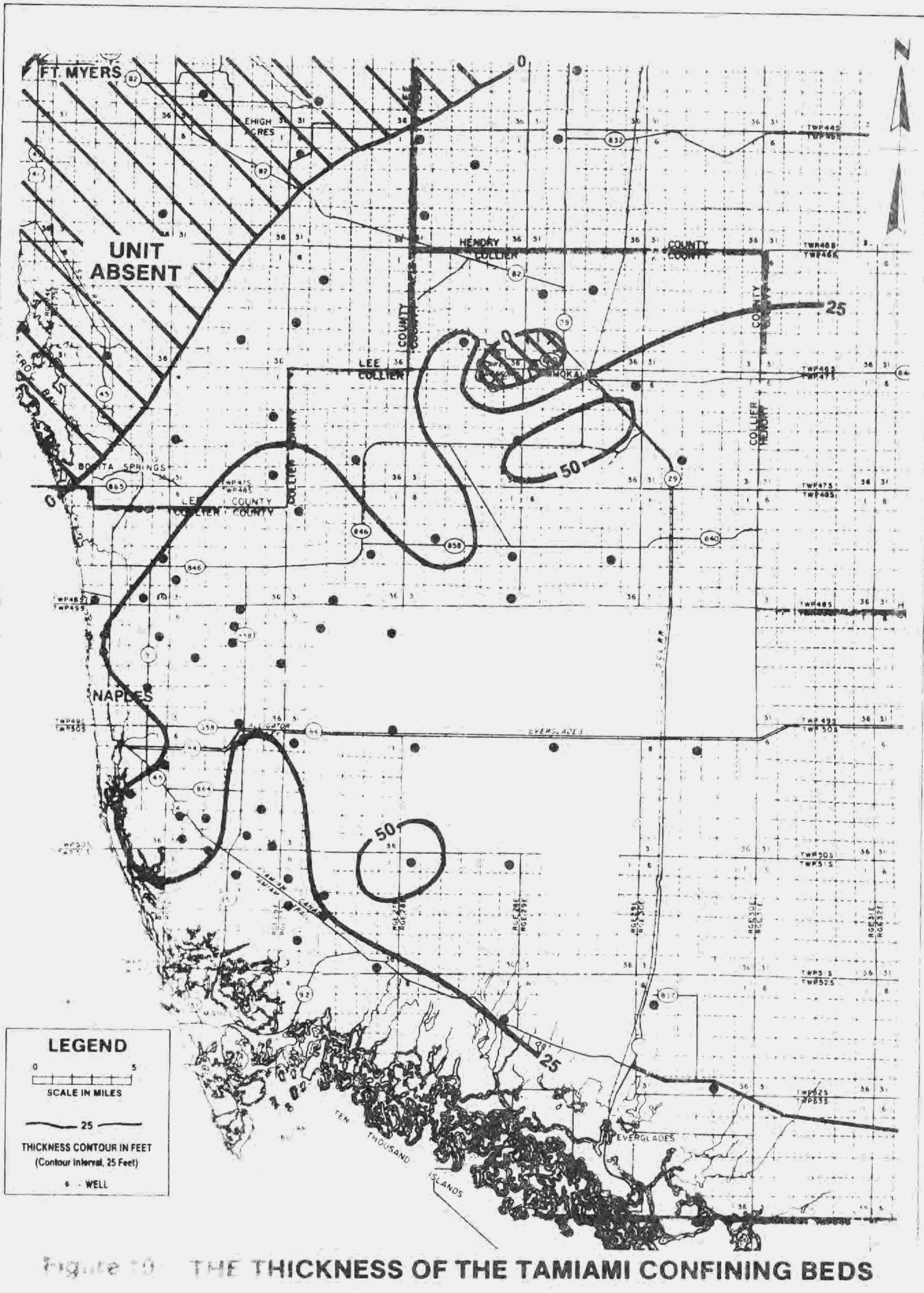


Figure 10 THE THICKNESS OF THE TAMIAMI CONFINING BEDS

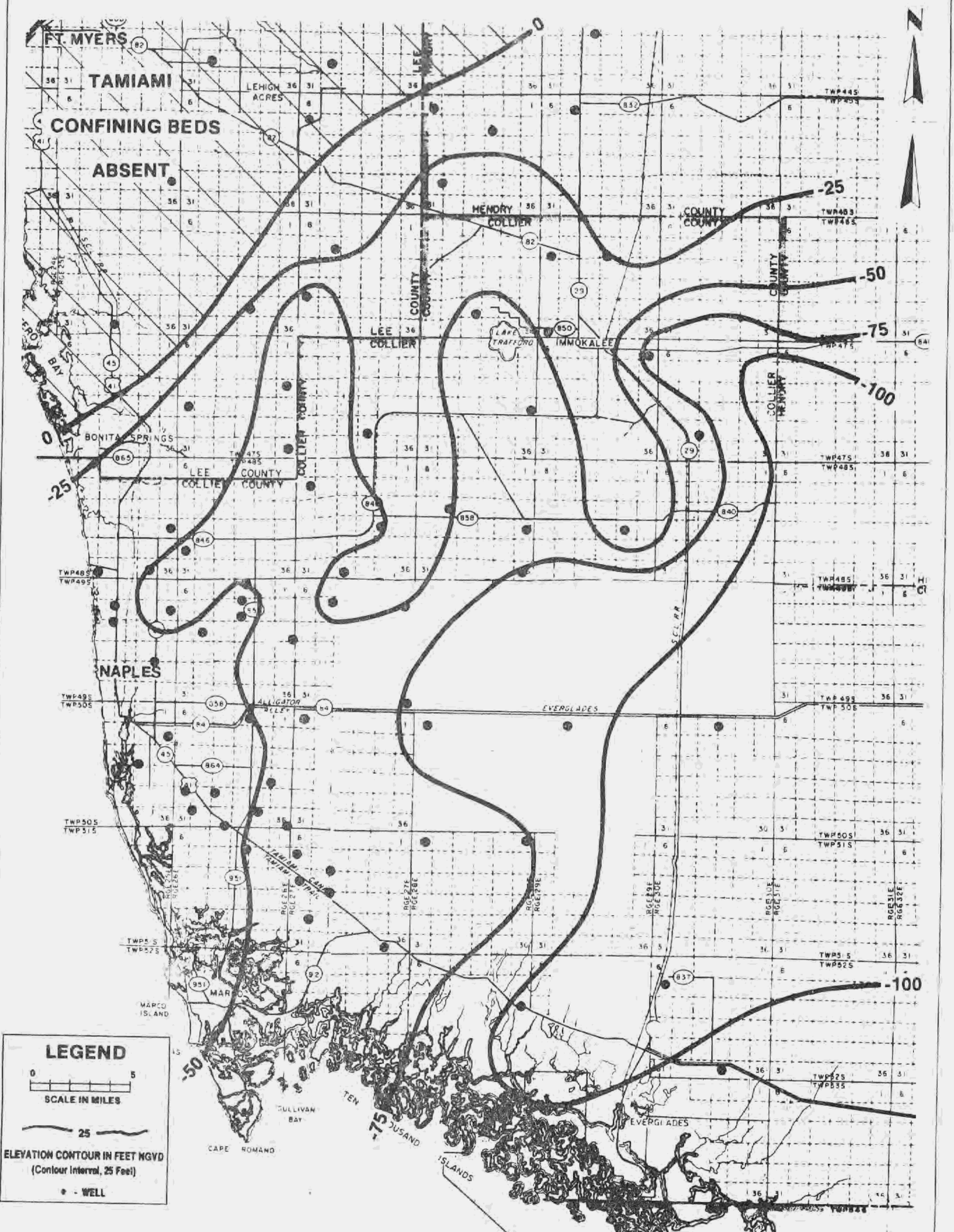


Figure 20 THE TOP OF THE LOWER TAMIAMI AQUIFER

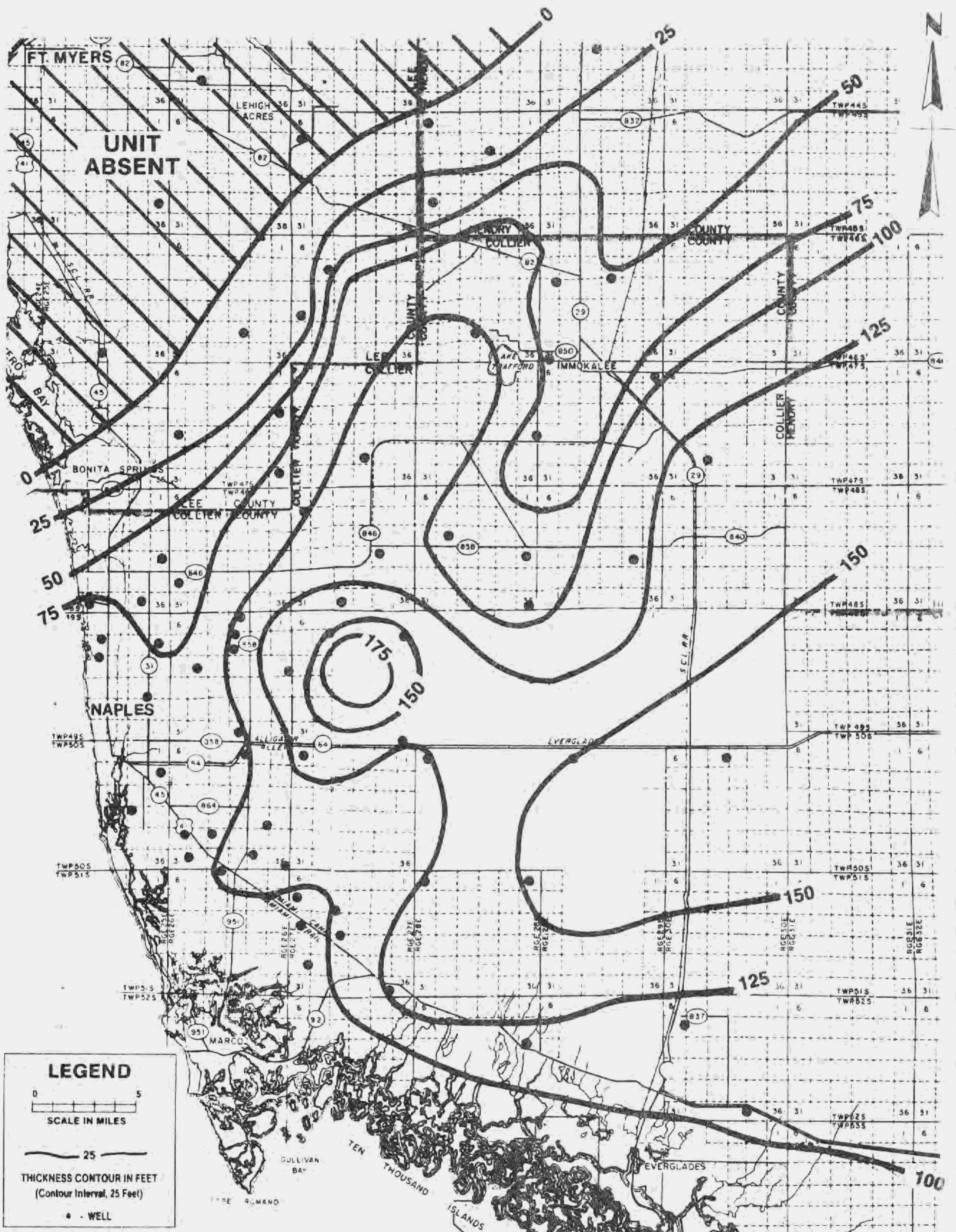


Figure 21 THE THICKNESS OF THE LOWER TAMIAMI AQUIFER

permeability in the uppermost part of the Hawthorn Formation in Lee County. In the study area this zone is composed of low permeability, phosphatic, clayey dolosilts, and sands (Figure 22). The zone separates the lower Tamiami aquifer from the Sandstone aquifer where the Sandstone aquifer is present. In some areas, especially north of Immokalee into Hendry County, the coarse clastics mix with the clays of the upper Hawthorn confining zone and effectively reduce the thickness of the lower Tamiami aquifer.

The upper Hawthorn confining zone averages 30 feet in thickness over most of Collier County, but can be as much as 80 feet. The underlying Sandstone aquifer pinches out in southern Collier County, and the upper Hawthorn confining zone lies directly upon the mid-Hawthorn confining zone, and the combined confining bed is termed the upper Hawthorn confining zone.

Sandstone Aquifer

The Sandstone aquifer underlies the upper Hawthorn confining zone in the northern portion of the study area. Boggess and Missimer (1975) used the term "Sandstone aquifer" when describing the sand, sandstone, and limestone members of the "Tamiami Formation" that are hydraulically interconnected in the Lehigh Acres area of Lee County. Wedderburn et al. (1982) mapped this unit in Lee County and included its strata within the Hawthorn "Formation".

Lithologically, this aquifer is composed of sandy limestone, sandstones, sandy dolomites, and calcareous sands confined above and below by clayey dolosilts. Individual beds of sandstone and limestone are highly permeable where intergranular and moldic porosities are well developed. The beds are sometimes interbedded with poorly indurated limestone and clayey dolosilt, creating several producing zones.

The top of the Sandstone aquifer is depicted on Figure 23. The aquifer dips gently to the southeast from the Lee-Collier County boundary and ranges from 100 ft. below NGVD in that area to 300 ft. below NGVD near Alligator Alley (U.S. Highway 84). As the unit dips to the southeast, it gradually thins (Figure 24), and is absent south of Alligator Alley and in western Collier County. The thickest sequences of the aquifer were identified in wells C2038 and C2040 (Figure 3) west of Immokalee and along Highway 846, respectively.

Mid-Hawthorn Confining Zone

The mid-Hawthorn confining zone is composed of a relatively thick sequence of clayey dolosilts locally interbedded with thin seams of porous limestone, sand, and dolomites. The unit effectively separates the mid-Hawthorn aquifer from overlying aquifers. Well C2038 (Figure 3) in the Corkscrew Island area penetrated a very thin sequence of this zone and the vertical transfer of water from the mid-Hawthorn aquifer into the Sandstone aquifer may be occurring in that area. In other areas, especially south of Highway 84, where the Sandstone aquifer is absent, the mid-Hawthorn confining zone merges with the upper Hawthorn confining zone. A rubble bed of very coarse phosphate and quartz sand that can be traced through characteristic geophysical signatures throughout most of the lower west coast is present at the base of this zone. Thin seams of limestone, sand, and dolomite are locally capable of producing small quantities of water under artesian pressure. They are, however, not considered a significant source and are cased off in wells tapping underlying aquifers.

Mid-Hawthorn Aquifer

The term "mid-Hawthorn aquifer" was applied by Wedderburn et al. (1982) to the phosphatic limestones and dolomites lying below a regional disconformity (Missimer, 1978) in Lee County, Florida. This aquifer has been referred to as the "upper Hawthorn aquifer" by the U. S. Geological Survey (e.g.; Sproul et al., 1972; Boggess, 1974) and as "Zone 1, Hawthorn Aquifer System" by Missimer and Associates (1979a). This aquifer is present throughout the lower west coast, and in many areas it is capable of producing significant quantities of water.

Lithologically, the unit consists of sandy and phosphatic limestones and dolomites which exhibit intergranular, moldic, and possible fracture and solution porosity. The reworked zone at the base of the overlying confining zone may in some areas be a part of the aquifer. The mid-Hawthorn aquifer is interbedded with lower permeability beds of dolosilt and poorly indurated limestone.

The top of the mid-Hawthorn aquifer is depicted on Figure 25. The aquifer dips to the east-southeast from a high of 150 ft. below NGVD in central Lee County. In Collier County the unit occurs between 300 and 400 ft. below NGVD. The aquifer averages about 100 ft. in thickness. The thickest sequence (130 feet) was observed in well C2044 (Figure 3) south of Alligator Alley.

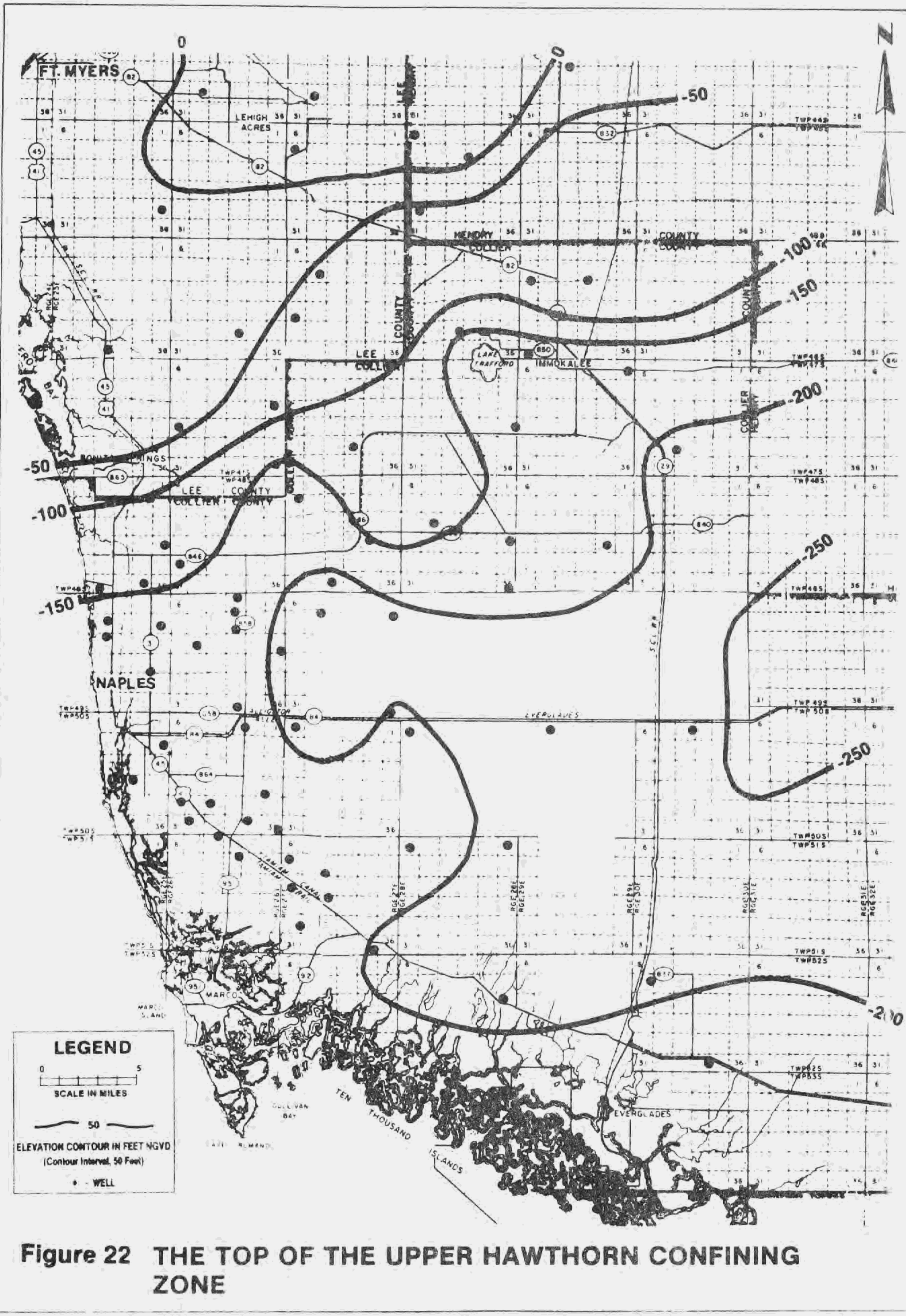


Figure 22 THE TOP OF THE UPPER HAWTHORN CONFINING ZONE

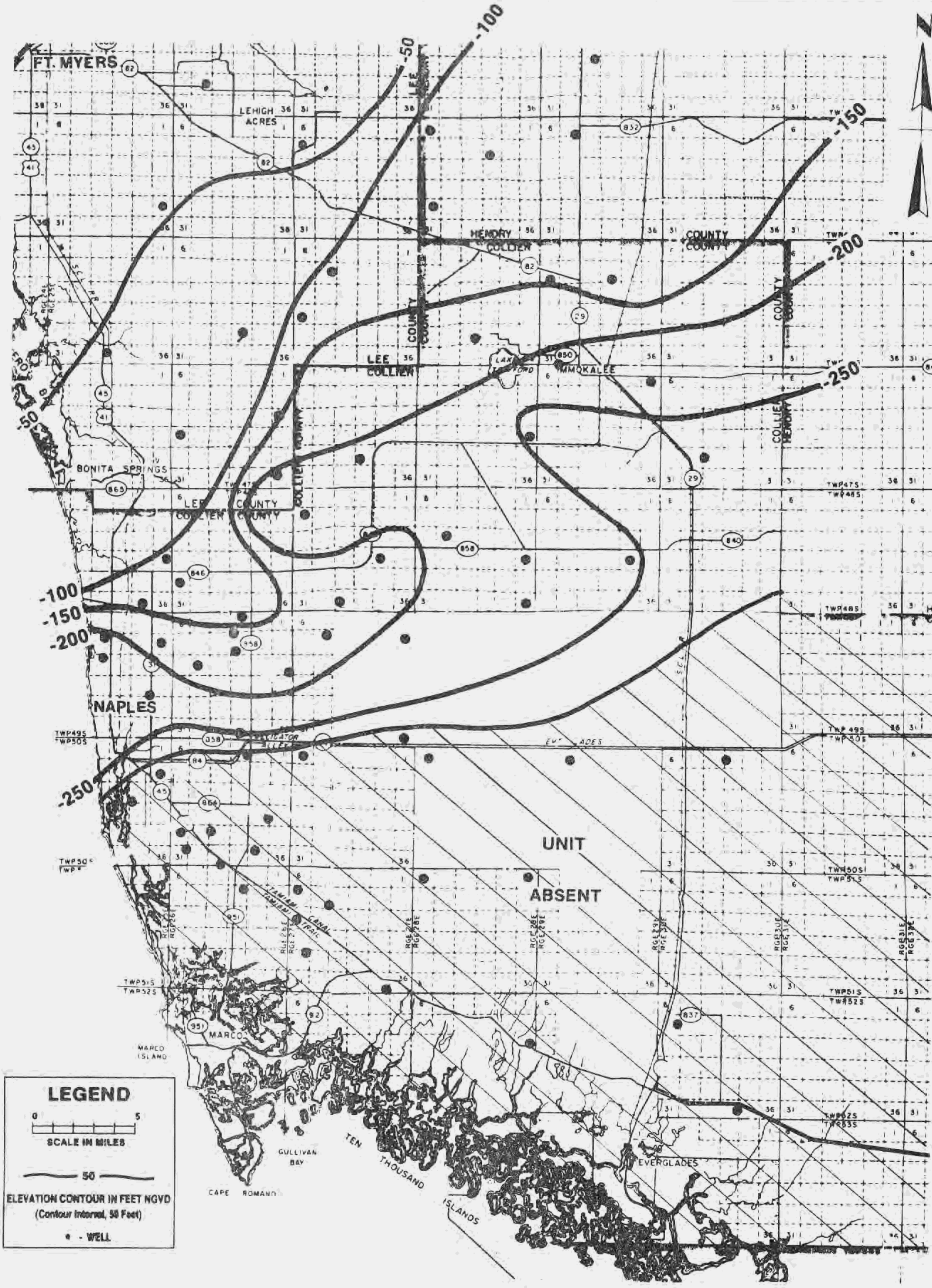


Figure 23 THE TOP OF THE SANDSTONE AQUIFER

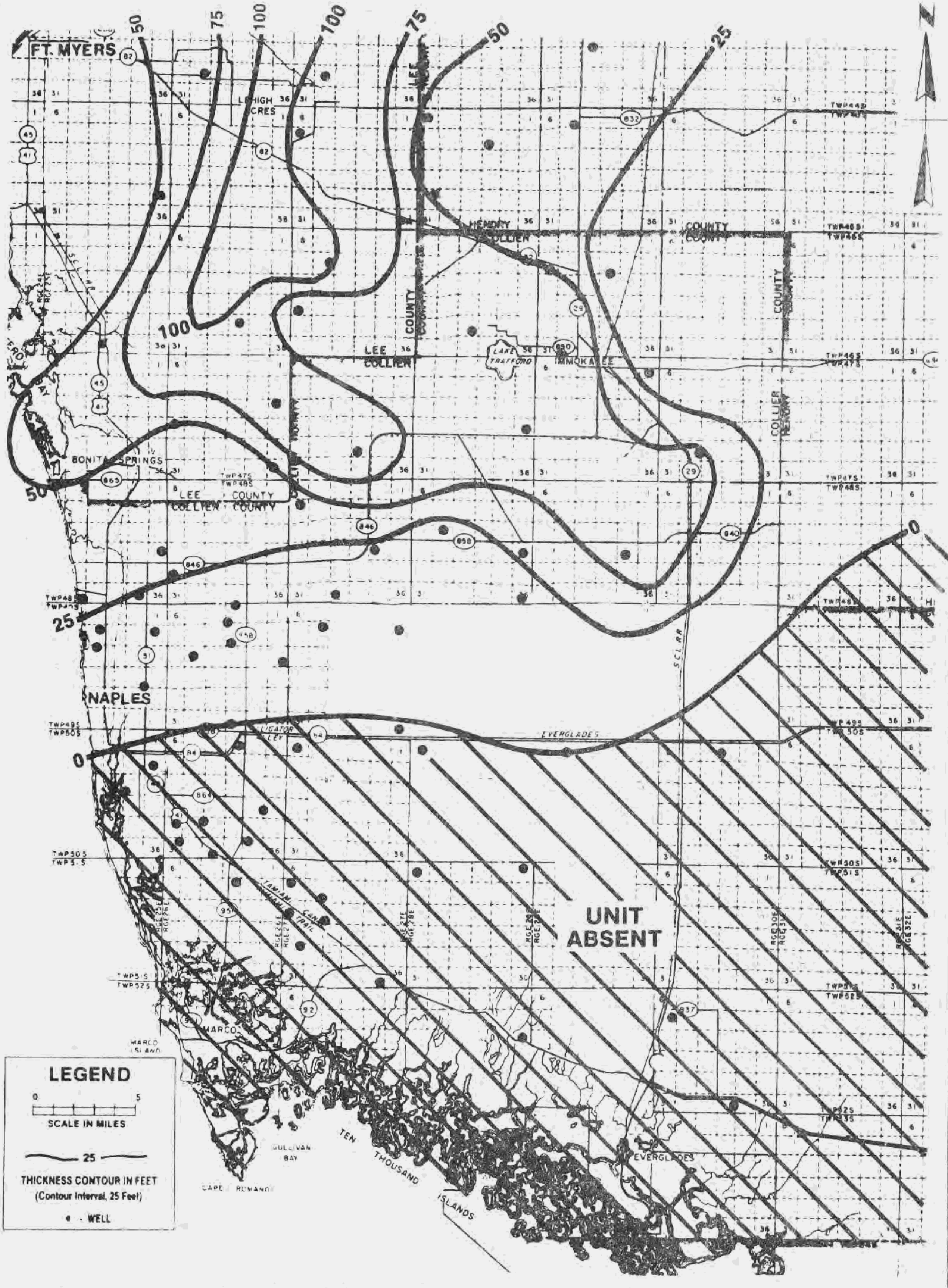


Figure 24 THE THICKNESS OF THE SANDSTONE AQUIFER

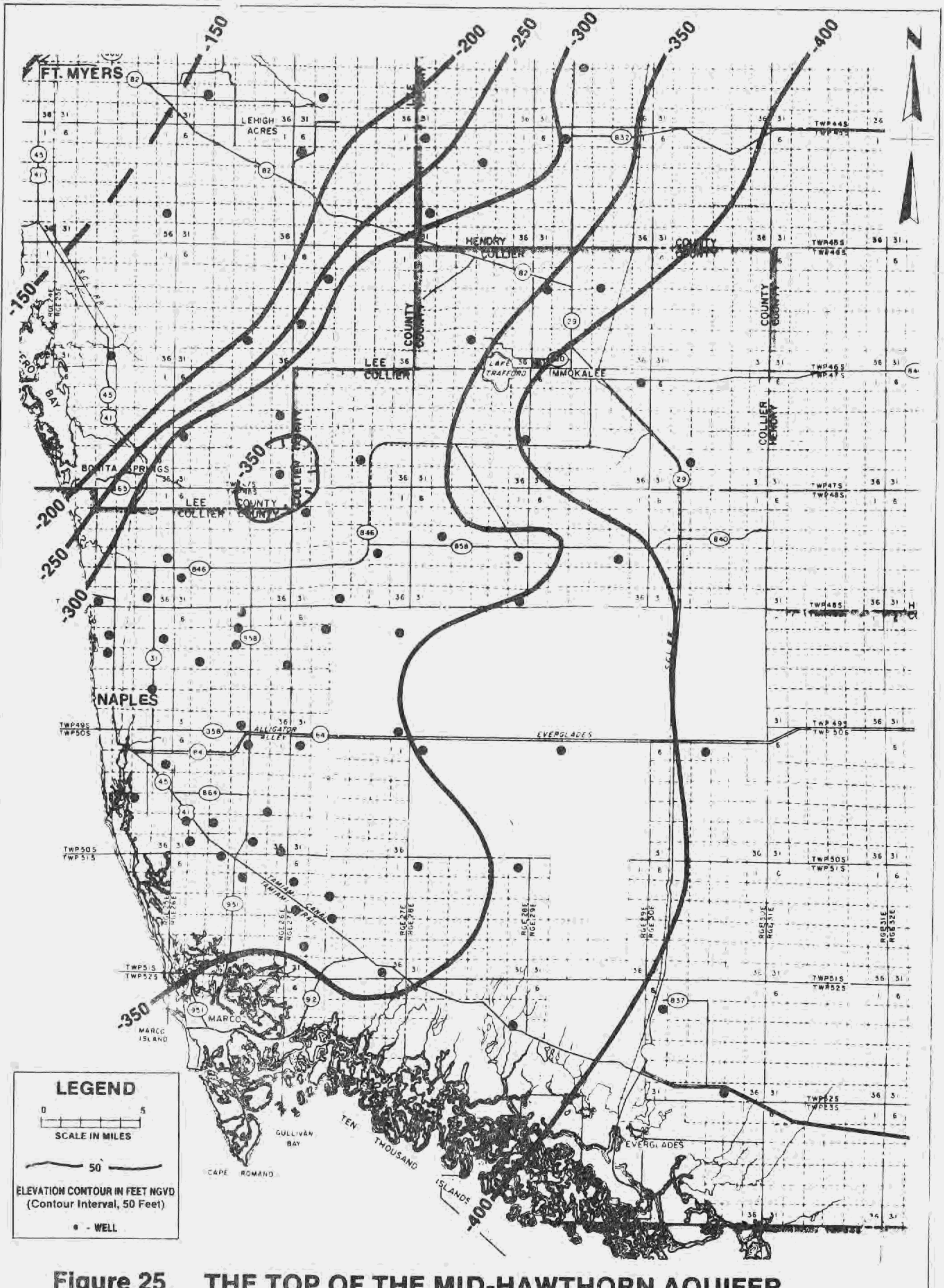


Figure 25 THE TOP OF THE MID-HAWTHORN AQUIFER

WATER LEVELS

INTRODUCTION

Water level data have been collected by the USGS from wells located throughout Collier County since the mid-1950's. While the construction details of the observation wells were known, the areal extent of individual aquifers was not known, making it difficult to determine regional trends in water levels. In 1984, the SFWMD completed a quantitative evaluation of the Collier County groundwater monitor network (Burns and Shih, 1984). In this study, the USGS wells were grouped by individual regional aquifer and statistically evaluated to determine areas of monitor well deficiency and redundancy. The additional 62 wells which were recommended for the USGS network have been constructed. Water level measurements for these wells began in October 1984.

Water level data from the end of the wet and dry seasons of 1984 are presented for the three primary aquifers. These data were chosen because they more accurately reflect water levels under near normal rainfall conditions. The 1985 data base contains more monitor wells; however, subnormal rainfall produced lower than normal water levels. The 1985 water level data is on file at the Ft. Myers USGS office for those interested. All water level data are referenced to feet NGVD unless otherwise specified.

SURFICIAL AQUIFER SYSTEM

Prior to 1984, most publications treated the Surficial Aquifer System as a single aquifer termed the "shallow aquifer" (Klein, 1954). Klein (1972) prepared the first regional water level map for Collier County (Figure 26). This map was generated using a limited number of USGS regional monitor wells and local wellfield data. Individual wells used to construct this map penetrated both the water table and the lower Tamimai aquifers. Water level maps for the "shallow aquifer" in the Naples area prior to 1972 have been published by McCoy (1962), Klein (1964), and more recently by Buckmiller (1982). In addition, localized water level maps have been developed by various consultants for public wellfields and residential development areas.

Water Table Aquifer

The water table aquifer is under unconfined conditions and responds chiefly to changes in recharge from rainfall or discharge from evapotranspiration, base flow to streams, or pumpage. In Collier County, the water table is relatively flat and follows the topography of the land. The highest water levels are in the northeastern portion of the study area, where land surface elevations are high, and the lowest levels occur along tidal streams or at the major outflow boundaries along the coastal margin.

Water Level Configuration

Figures 27 and 28 depict the configurations of the water table for the end of the 1984 dry and wet seasons. These figures were constructed using data from 28 groundwater monitor wells and 13 SFWMD surface water stage recorders (Figure 29). Water level data from 12 new monitor wells installed in October 1984 were added to the existing data to construct the 1984 wet season map.

The study area falls within the boundaries of five major drainage basins (Lin, 1984). These basins are the west Caloosahatchee, tidal Caloosahatchee, Estero Bay, and east and west Collier (Figure 30). Within each basin, surface water flow is controlled by drainage canals, estuaries, and topographically low sloughs and strands. Local water table flow patterns are also influenced by water levels within the drainage systems.

The two prominent canal systems in the county are the Golden Gate and the Faka Union (Figure 29). Construction on these systems was begun in the 1960's, and according to Lehman (1976) they have more than doubled the pre-canal surface water runoff. Browder (1974) calculated 162,115 million gallons as the mean annual surface water runoff from the Golden Gate Estates network. She reported that 50 percent of the observed runoff was through the Golden Gate Canal and 42 percent was through the Faka Union Canal. The effects of the canal systems can be seen on Figure 27 and 28 by the indenture of contours in the canal system areas.

The highest water table elevations in the study area occur approximately six to seven miles north of Immokalee where land elevations exceed 40 feet above NGVD. Water flows radially from this area. A regional groundwater divide (no flow boundary) trending east and west occurs south of Lehigh Acres. In this region groundwater flows north towards the Caloosahatchee River and south towards Collier County from the divide.

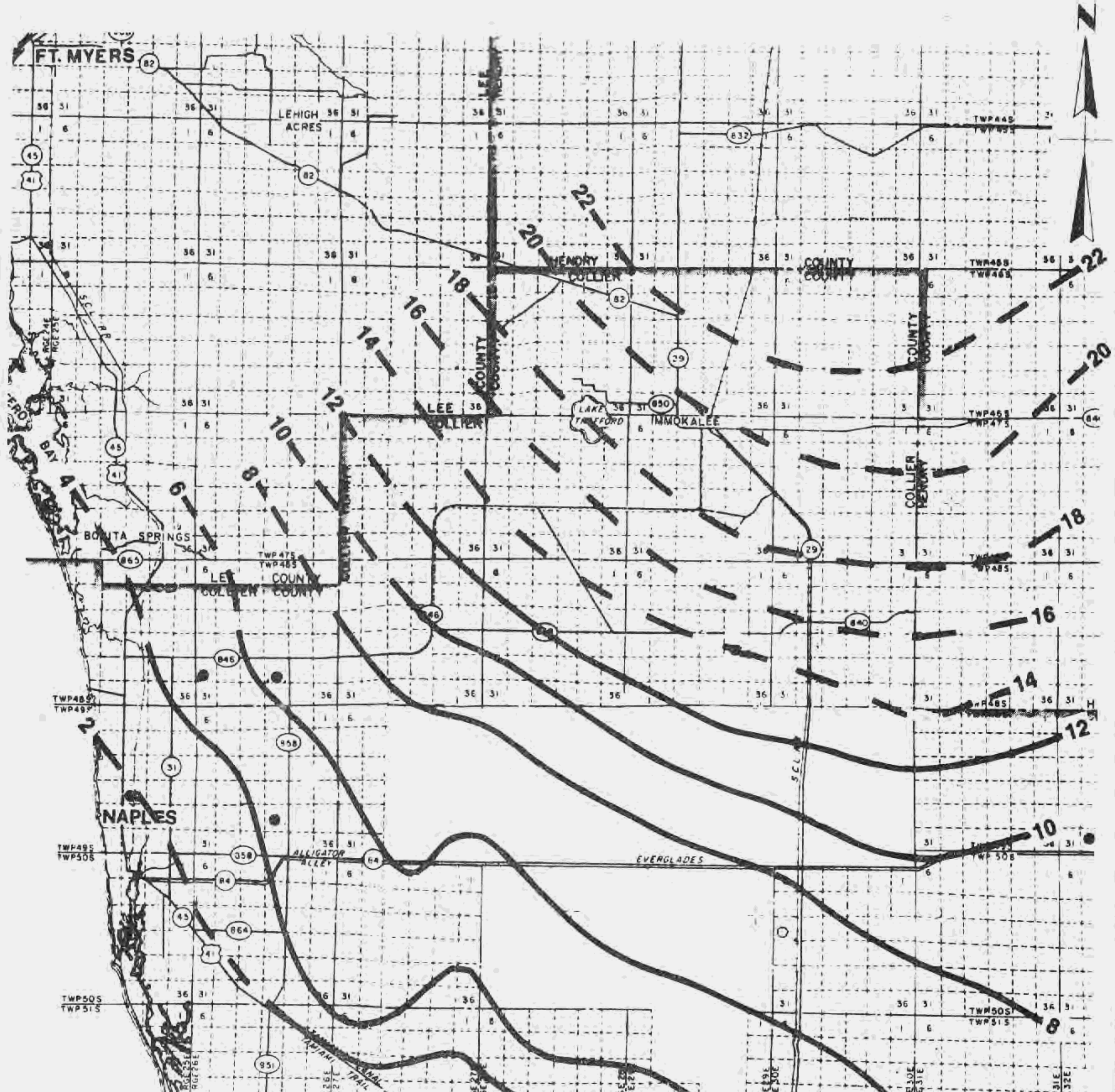


Figure 26 WATER LEVELS WITHIN THE SHALLOW AQUIFER OF SOUTHWEST FLORIDA, 1971 (Modified from Klein 1972)

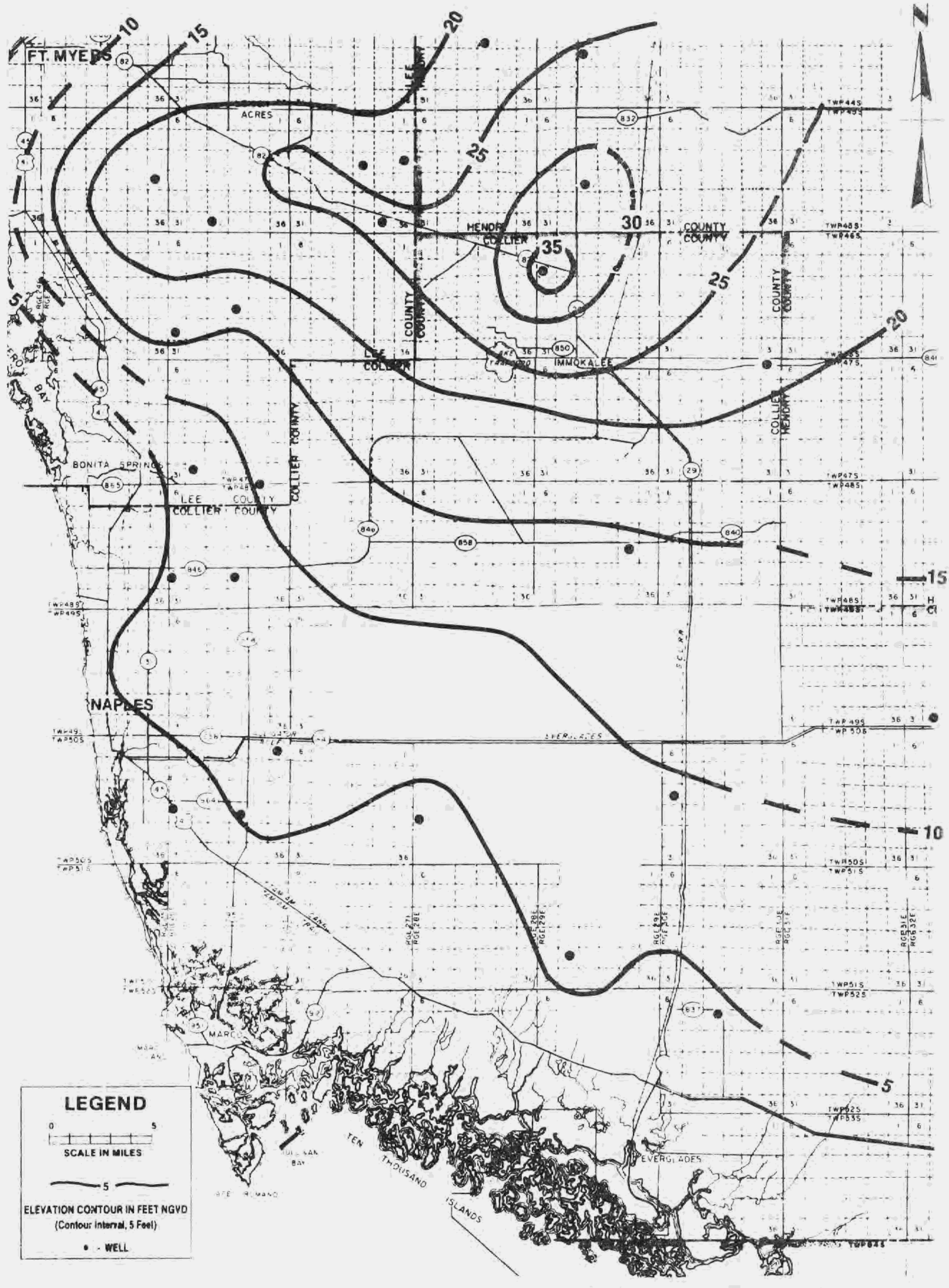


Figure 27 WATER LEVELS OF THE WATER TABLE AQUIFER APRIL 1984

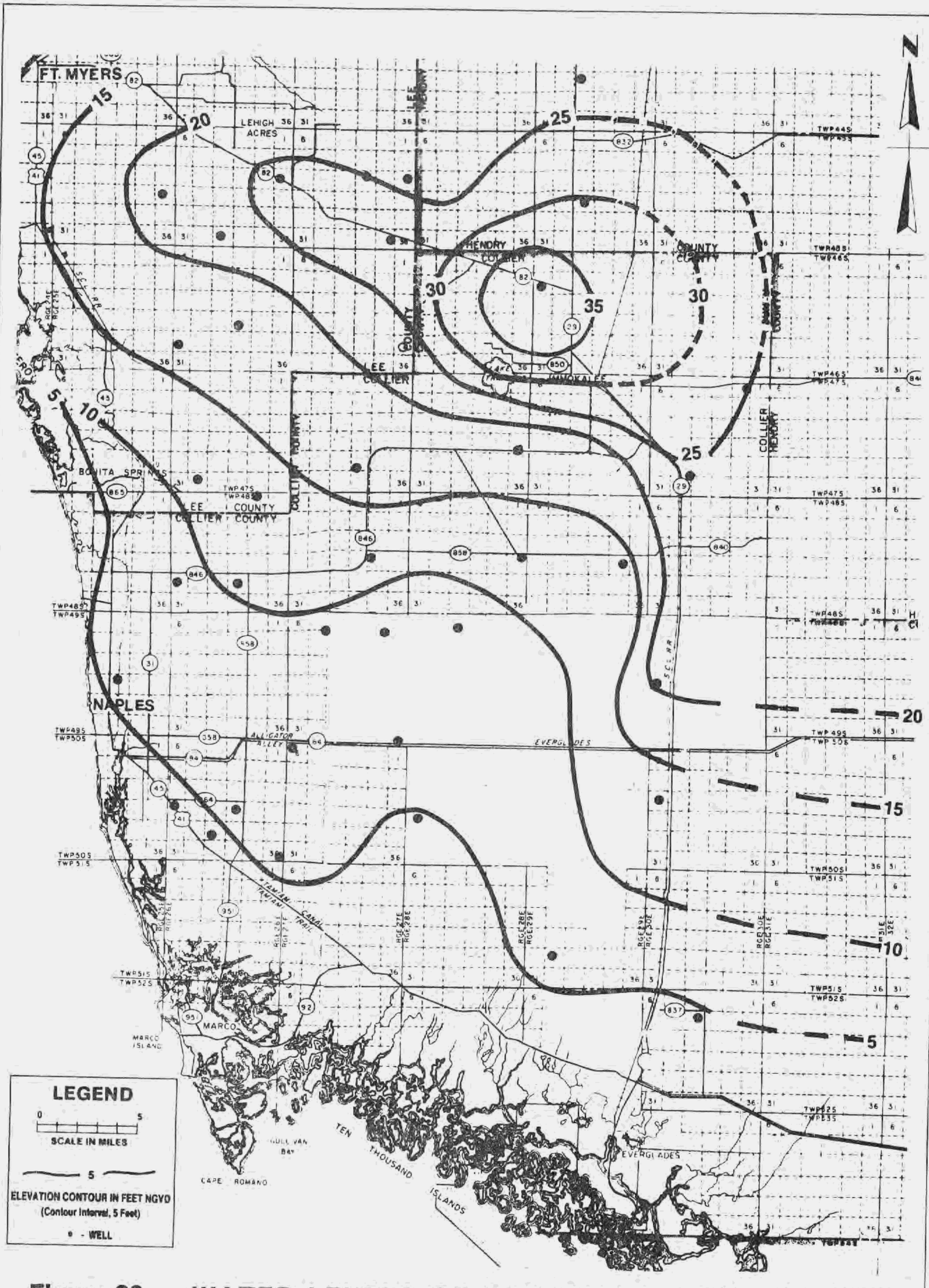


Figure 28 WATER LEVELS OF THE WATER TABLE AQUIFER OCTOBER, 1984

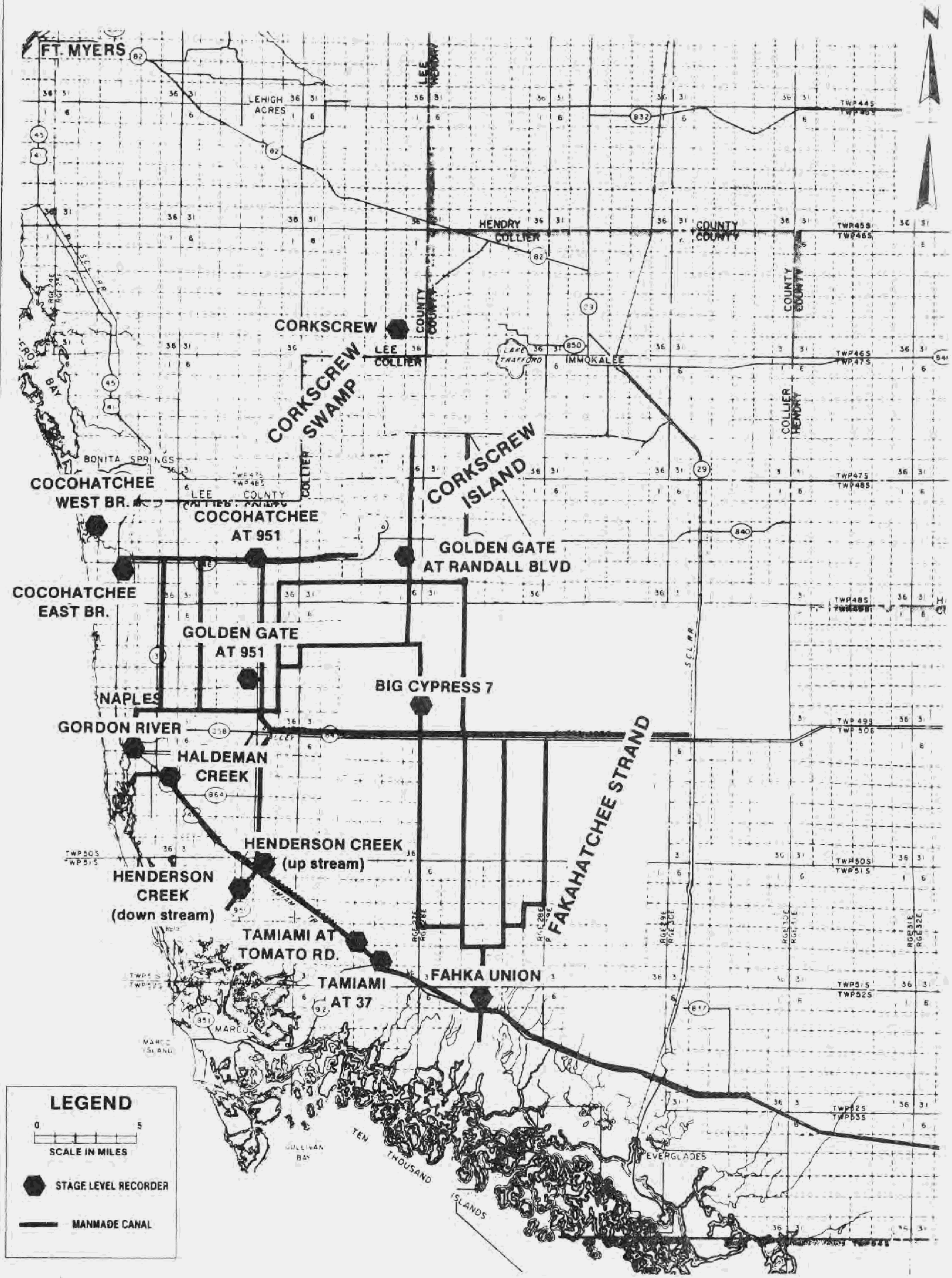


Figure 29 LOCATIONS OF SFWMD SURFACE WATER STAGE LEVEL RECORDERS

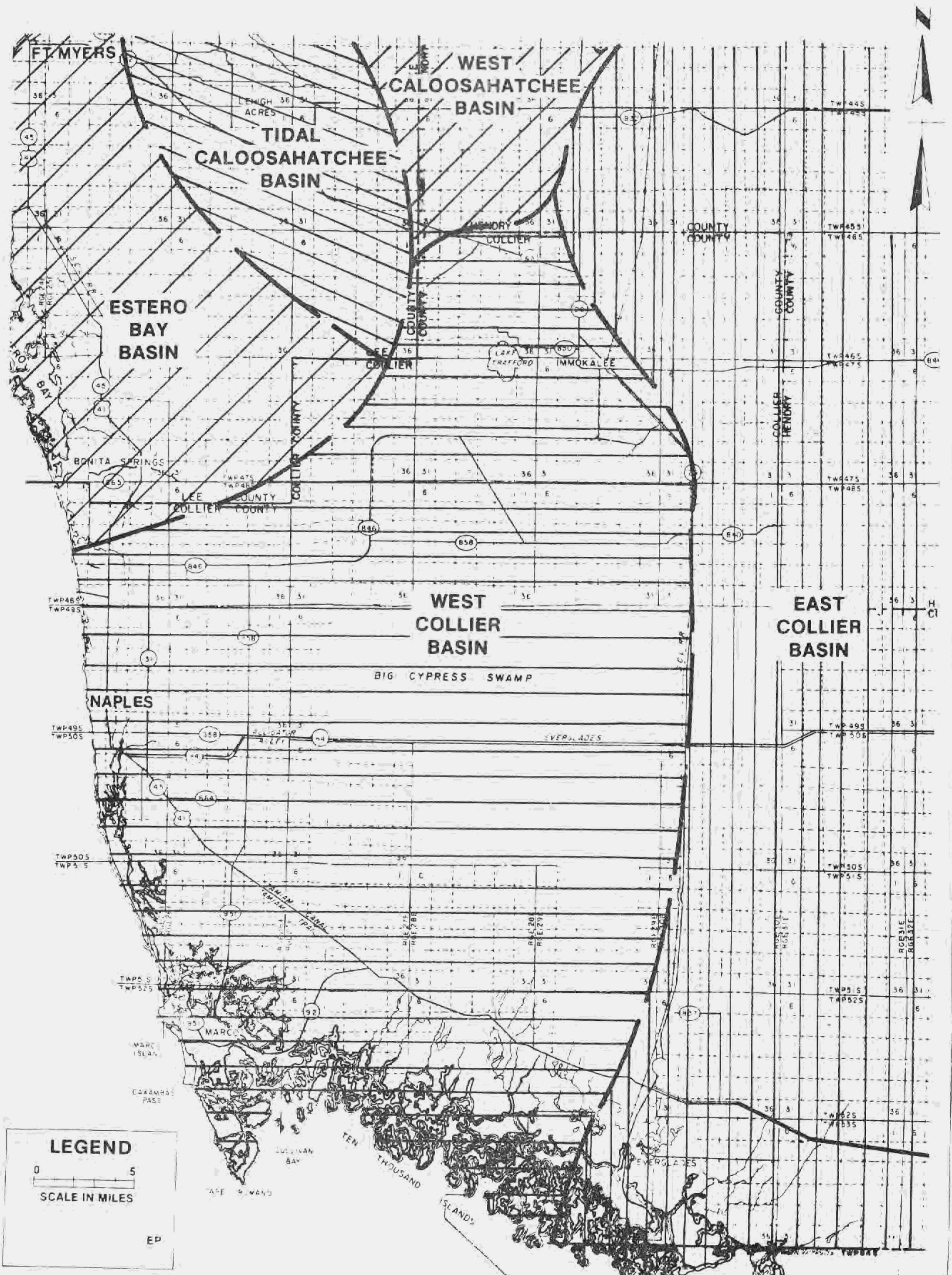


Figure 30 DRAINAGE BASIN BOUNDARIES (Modified From SFWMD Technical Publication 84-7)

The equipotential lines in most of Collier County tend to parallel the coastline (Figures 27 and 28). Deviations from this configuration occur around local wellfields withdrawing water from the water table aquifer (Figure 31). Equipotential contour lines are drawn inland near the Marco Island Utilities withdrawal pits, the Bonita Springs and Lee County Utilities wellfields, and to a lesser degree around the Everglades City and Copeland wellfield. The contours are also affected by the Golden Gate canal system.

The gradient of the water table varies from less than one foot per mile around Naples and the Estero Bay to five feet per mile just south of Immokalee near Lake Trafford. Groundwater gradients are primarily controlled by aquifer lithology, permeability, and the proximity to discharge and recharge areas.

The configuration of the water table aquifer shows little variation in the dry and wet season of 1984 (Figures 27 and 28). The contour lines are, however, "drawn inland" slightly during the dry season. In most of the study area seasonal water levels vary by less than two feet. These maps were constructed using single day values which are strongly influenced by short term weather patterns and probably do not accurately represent seasonal averages.

Water Level Fluctuations

Locations of selected water table wells with hydrographs are shown in Figure 32. Figures 33 and 34 are hydrographs of selected wells depicting water levels from October of 1976 through January of 1984. The lowest water levels commonly occur between March and May (end of the dry season), and the highest between August and October (end of the wet season). The seasonal differences vary about three feet in well C-392 (Figure 33) and eight feet in well C-503 (Appendix II).

The water table is open to the land surface and responds very quickly to changes in monthly rainfall. The decrease in rainfall (Figure 35) during the drought of 1980-1981 corresponds closely to water level declines in well C-495 (Figure 34). All water table hydrographs show similar declines during this period and can be found in Appendix II-1.

Recharge

Recharge to the water table aquifer in the study area comes from five principal sources: 1) direct infiltration through precipitation, 2) inflow from surface water bodies, 3) subsurface flow from adjacent areas, 4) upward leakage from semi-confined aquifers, and 5) infiltration from free-flowing artesian wells at the surface.

Direct infiltration from precipitation is the main source of recharge to the water table aquifer. Rainfall in excess of 60 inches per year, on the average, occurs in southern Collier County (Figure 36). Within the remainder of the study area, average annual rainfall ranges from 50 to 60 inches; however, only a portion of the total rainfall reaches the water table.

Recharge to the aquifer through inflow from surface water bodies occurs primarily from manmade canals and, to a lesser degree, rock quarries. Other sources include small lakes such as Lake Trafford near Immokalee and naturally low-lying areas. Generally, recharge from these sources is minimal and occurs after rainfall events when surface water runoff enters canals and lakes creating differential head toward the water table aquifer. Jakob (1983) indicates that the Tamiami Canal along SR 41, south of Naples, acts as a recharge canal for the aquifer. During the wet season recharge from the canals is greatest when canal levels immediately upstream from the weirs are higher than adjacent groundwater levels.

Subsurface flow from outside the study area occurs in a southerly direction from the Immokalee Rise to the coast. Subsurface inflow is important in localized areas where wellfields are pumping from the water table aquifer.

Recharge from upward leakage across semi-confining zones occurs when and where the potentiometric surface of the deeper aquifer is higher than the water levels in overlying aquifers. A potential source of leakance recharge for the water table is the lower Tamiami aquifer. Water levels in the water table, however, exceed levels of the lower Tamiami aquifer and recharge occurs around water table wellfields. In these areas, the water levels in the water table aquifer are lower than the lower Tamiami, and leakance recharge provides a substantial quantity of water to the wellfields.

Discharge

Discharge from the water table aquifer occurs through: 1) evapotranspiration, 2) groundwater flow to surface water bodies, 3) flow to the Gulf of Mexico, 4) subsurface outflow to adjacent areas, 5) downward movement through leaky confining beds, and 6) withdrawal from pumped wells. The portion of the rainfall that does not percolate down to the water table is either lost as runoff through canals and estuaries to the Gulf of Mexico, or through evaporation or transpiration. Pan evaporation data, collected by the SFWMD from seven stations located within the study area (Appendix 3) range from 52 to 67 inches per annum. The pan evaporation rates represent only water which lies on the surface. Once water enters the

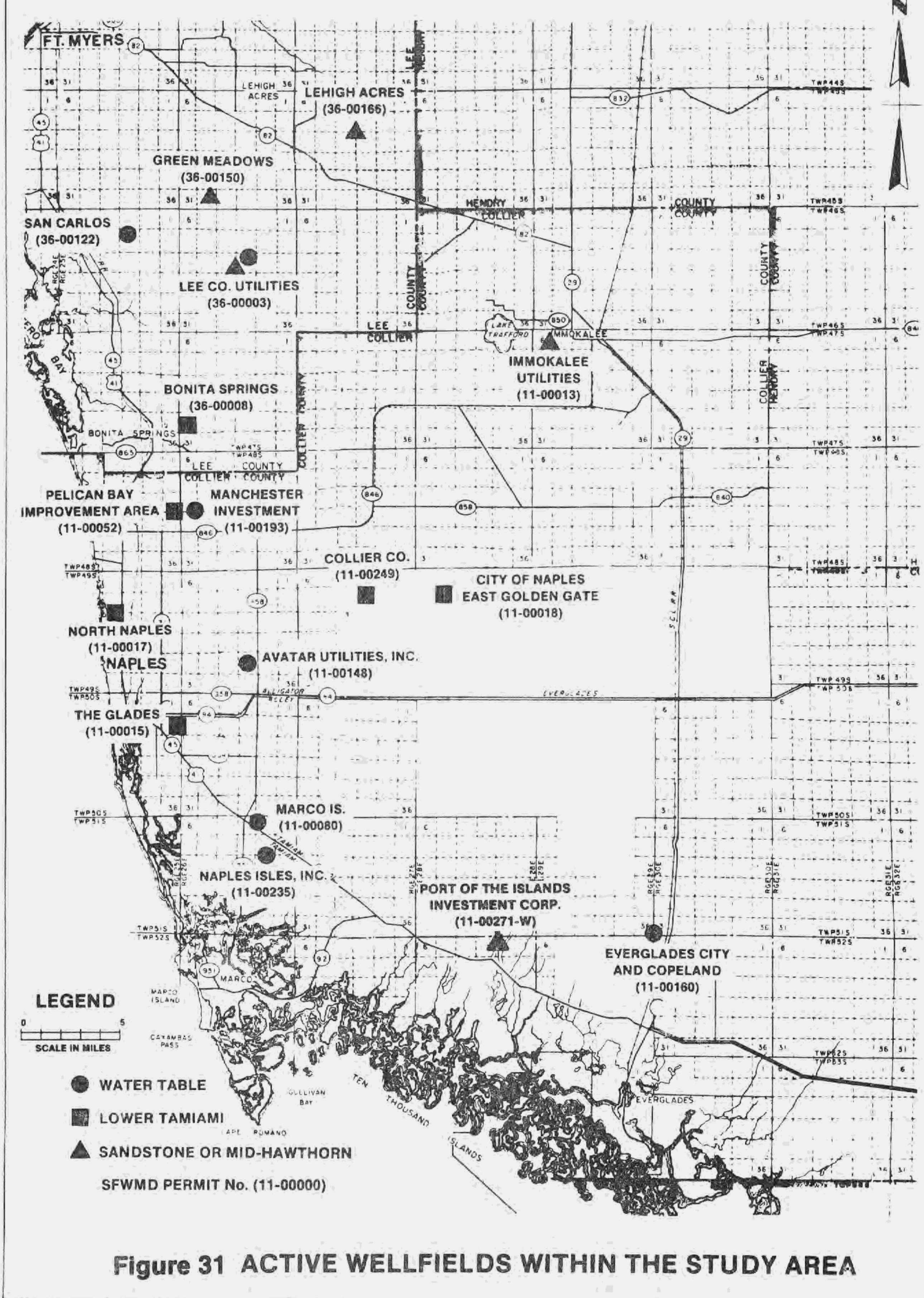


Figure 31 ACTIVE WELLFIELDS WITHIN THE STUDY AREA

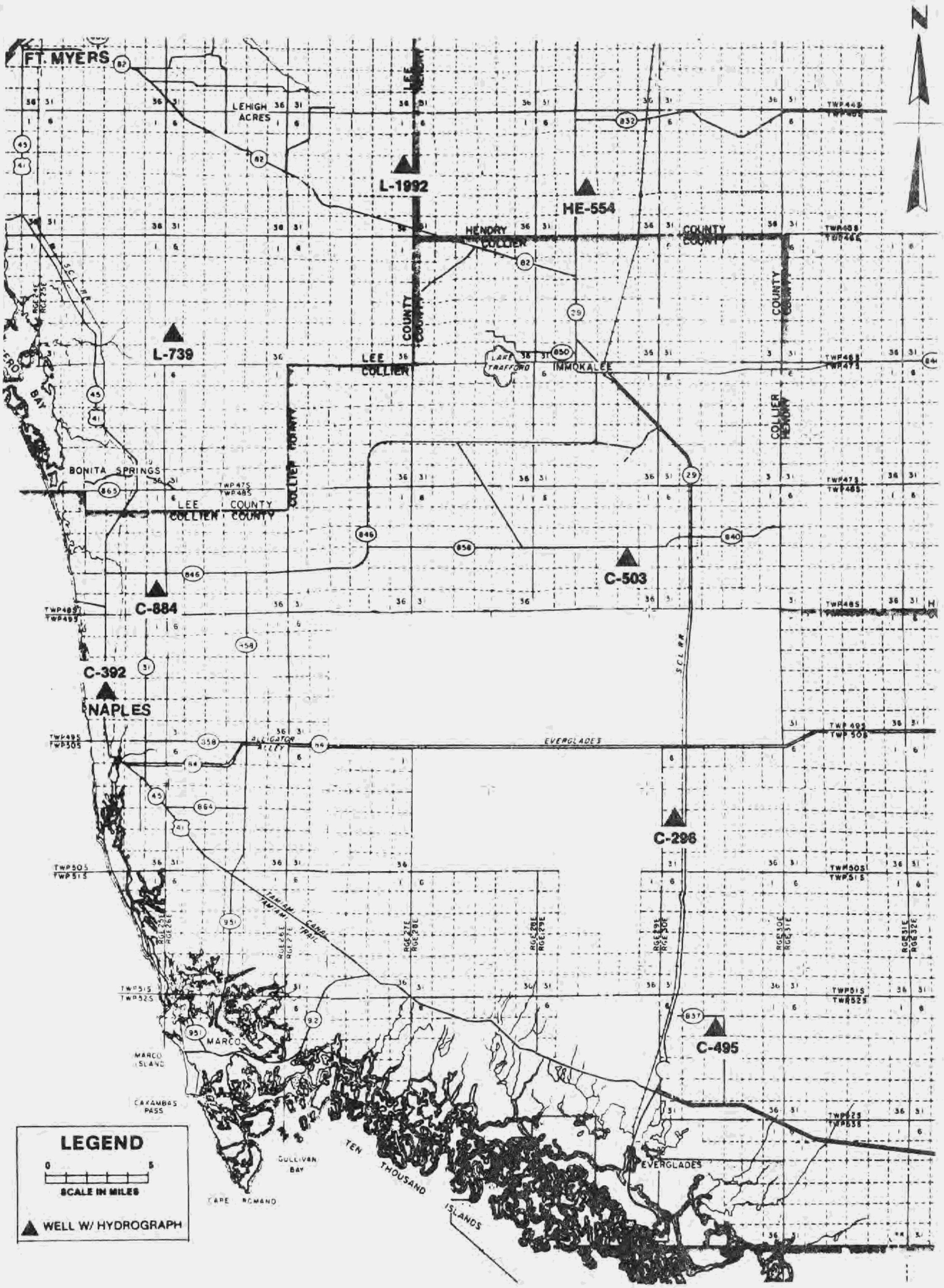


Figure 32 LOCATIONS OF SELECTED HYDROGRAPH STATIONS FROM THE WATER TABLE AQUIFER

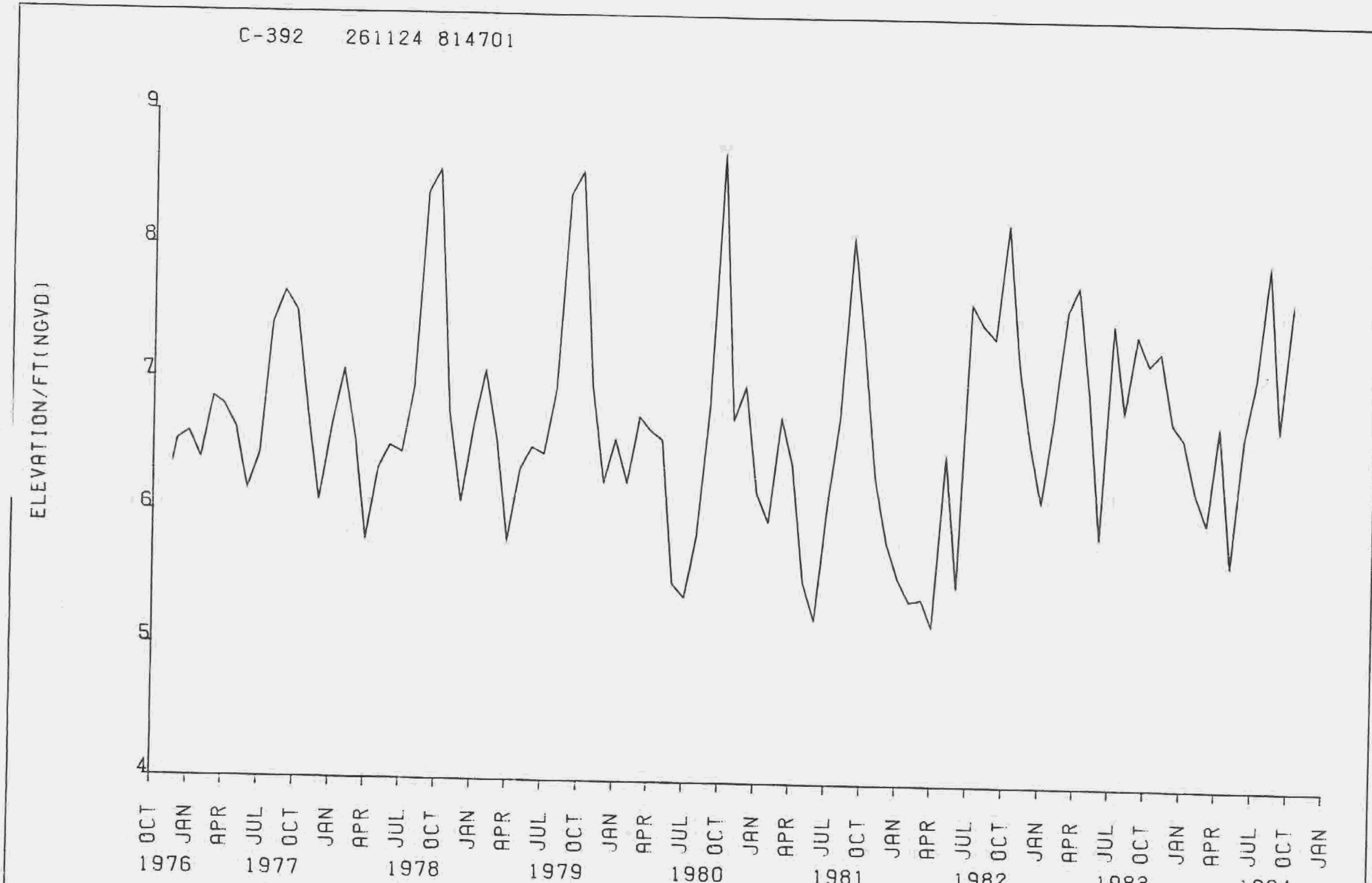


Figure 33 HYDROGRAPH OF THE WATER TABLE AQUIFER / COLLIER COUNTY 76-84

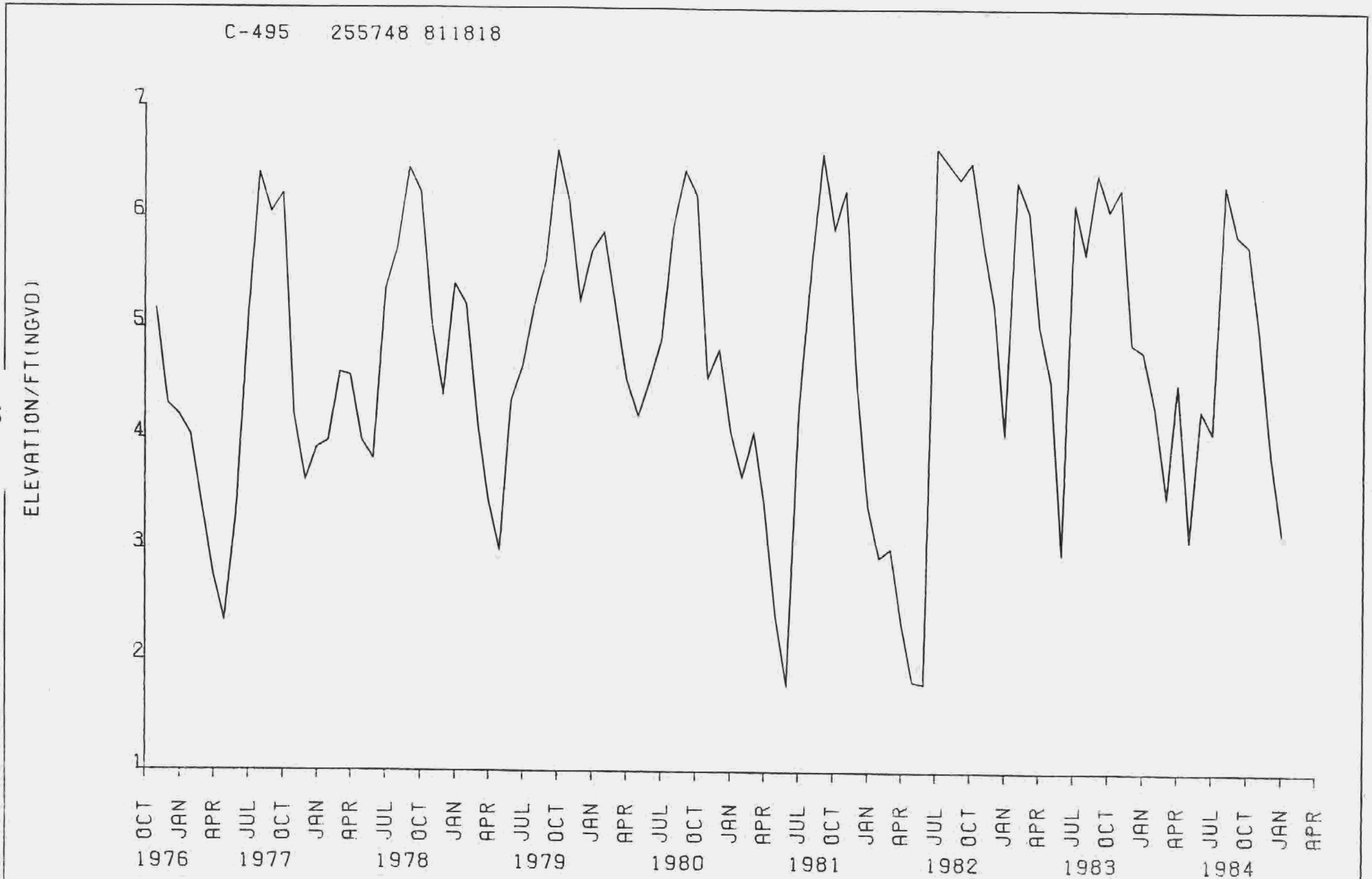


Figure 34 HYDROGRAPH OF THE WATER TABLE AQUIFER / COLLIER COUNTY 76-84

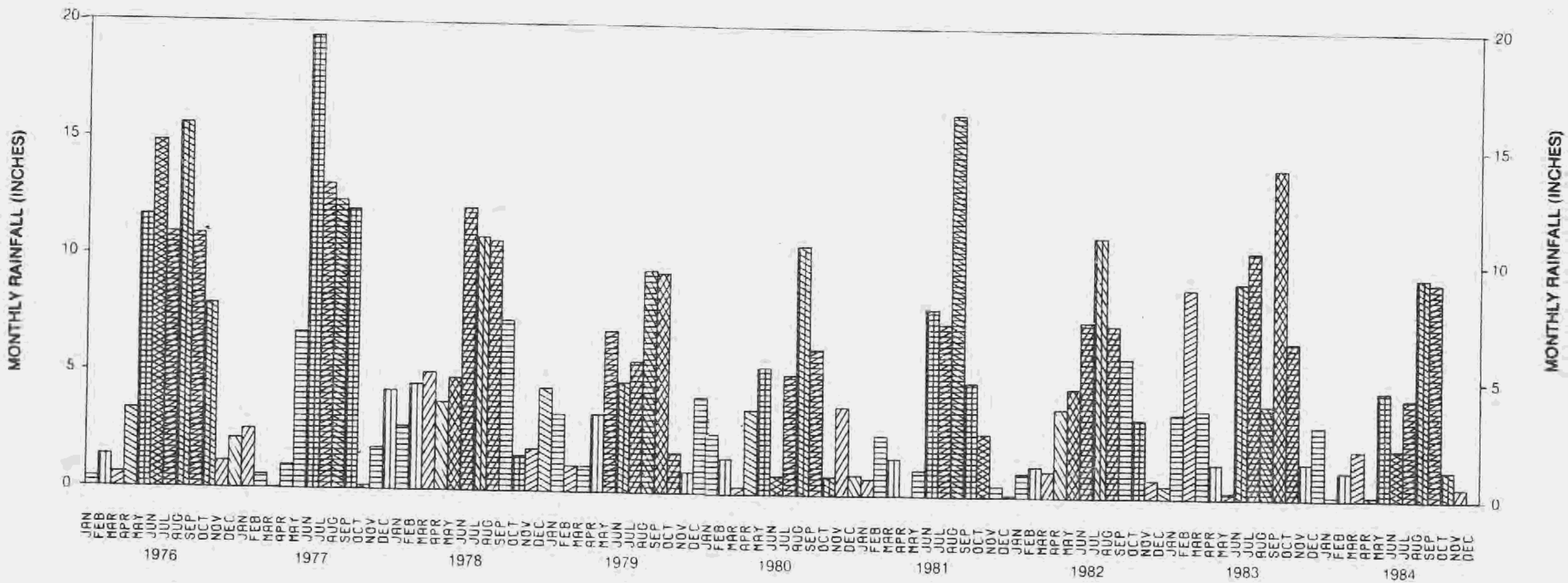


Figure 35 TOTAL MONTHLY RAINFALL MRF5014 / COLLIER COUNTY 1976-1984

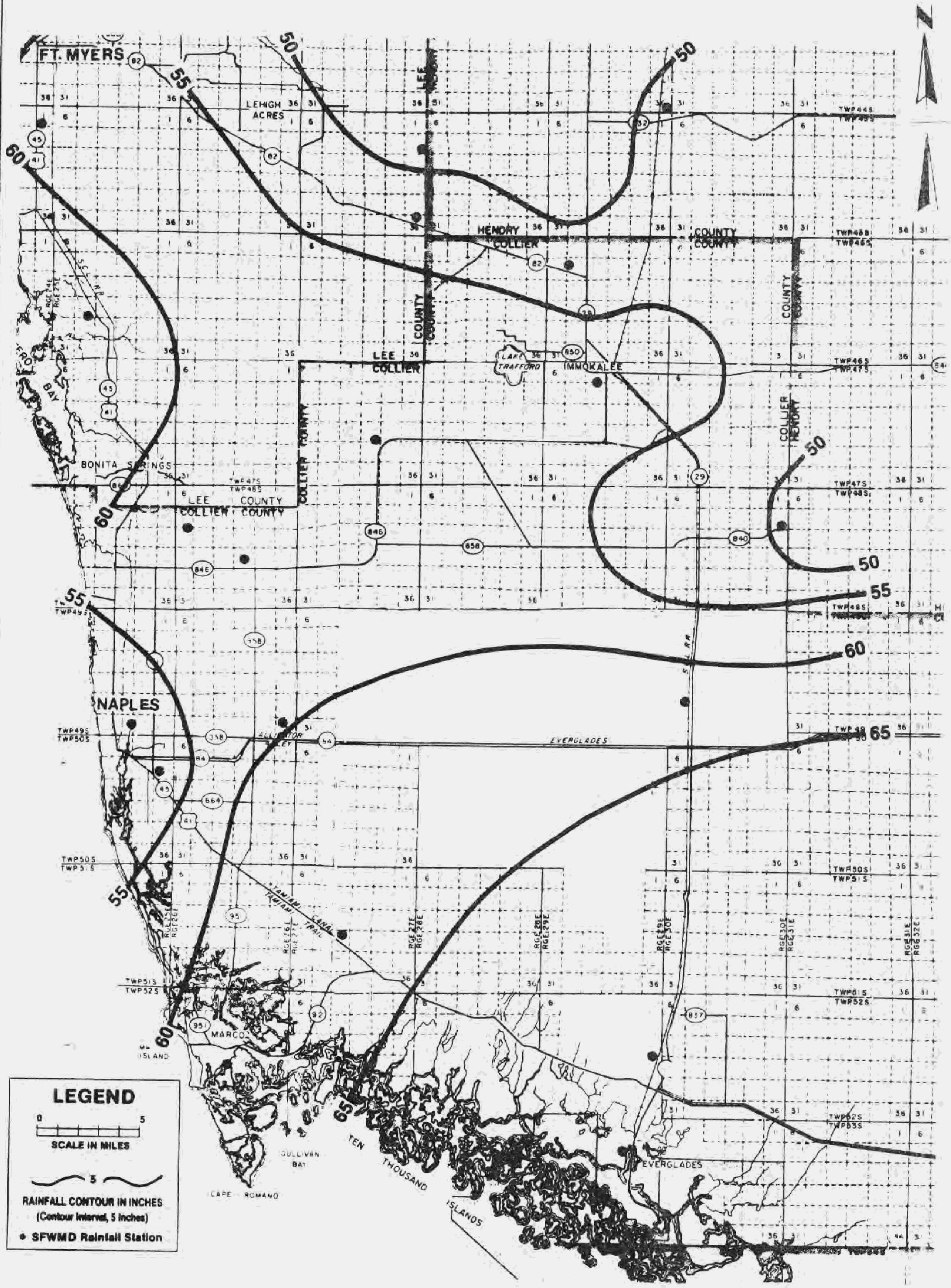


Figure 36 AVERAGE ANNUAL RAINFALL SINCE 1970

soil, evaporation rates drop rapidly; however, much of the water within the capillary fringe is consumed through plant transpiration.

Few data are available on evapotranspiration (ET) rates within the study area. Missimer (1981) determined ET rates in the Cocohatchee area to be 41 inches per year for an average annual rainfall of 55 inches. Gee and Jenson (1980), during a study of the Big Cypress Basin, calculated an ET rate of 27 inches per year. Evapotranspiration rates decline in a curvilinear manner with depth of water below land surface. The Missimer and Gee and Jenson studies indicate the ET cutoff depth to be between 6 and 7 feet below land surface. In order to quantify the recharge from rainfall to the water table aquifer, more ET data are needed.

Groundwater loss to surface water bodies is more pronounced during the dry season. Higher evaporation and discharge rates of canals cause a significant loss of water. Normally, water table levels are higher than surface water levels in the dry season and surface water bodies gain from groundwater base flow during this time.

The hydraulic gradient towards the coast of Collier County indicates a continuous groundwater discharge to the Gulf of Mexico. During the rainy season, discharge to the Gulf of Mexico is at a maximum; however, during the dry season, groundwater levels decline and the salt water begins to encroach inland beneath the fresh groundwater. Tidal fluctuations also cause minor changes in the magnitude of groundwater discharge.

Subsurface outflow to adjacent areas is controlled by the Immokalee Rise. Because of the radial flow from the Immokalee Rise, (Figure 28) much of the flow is retained in Collier County and subsurface outflow occurs mainly along the coast.

Discharge in the form of downward leakage from the water table aquifer to the lower Tamiami through leaky semi-confining beds varies throughout the study area. The rate of leakage is a function of the hydraulic gradient between adjacent aquifers, the hydraulic conductivity, and the thickness of the confining bed. The leakance is greatest in the vicinity of major wellfields which withdraw water from the lower Tamiami aquifer. Leakance accounts for a large portion of the natural discharge from the water table aquifer.

Withdrawal from wells also represents a major component of discharge from the water table aquifer. The majority of withdrawals are by agricultural users. Large scale pumpage takes place during the dry season. A portion of the pumped water is returned to the aquifer through seepage. Municipal and private wellfields (Figure 31) are scattered throughout the study area and withdraw water in variable quantities (Table 1) fron the water table aquifer. The amounts withdrawn from the aquifer are determined by local demand and permitted allocation.

Lower Tamiami Aquifer

Data from twenty-five monitor wells were used to generate potentiometric surface maps of the lower Tamiami aquifer. Figures 37 and 38 depict the potentiometric surface of the aquifer during the dry and wet seasons of 1984. Fourteen of these data points were taken from existing USGS wells and the remaining water level data is from monitor wells drilled in October of 1984.

Water Level Configuration

The lower Tamiami aquifer is under semi-confined to unconfined conditions. It is unconfined in portions of southern Lee County, western Hendry County, and in Collier County near Immokalee. The unit is separated from the water table aquifer by the Tamiami confining beds.

Water level configurations in the lower Tamiami normally correspond very closely to those of the water table aquifer due to the high degree of hydraulic connection between the aquifers. The regional flow pattern is toward the Gulf of Mexico (Figures 37 and 38). Regional water level contours reflect pumpages of local wellfields (Figure 30) withdrawing from the lower Tamiami aquifer. Hydraulic gradients of the lower Tamiami aquifer are about 1 foot per mile around the Immokalee area and flatten towards the Big Cypress Swamp. The steepest gradients occur adjacent to the municipal wellfields.

Water Level Fluctuations

The locations of selected lower Tamiami wells with accompanying hydrographs are depicted in Figure 39. Potentiometric levels in C-462 (Figure 40) range from 26 to 35 feet above NGVD. Seasonal water level differences seldom exceed five feet. Significant long term trends in well C- 462 are apparent from 1976 to 1979, from 1979 to 1981, and from 1981 to the present. Each trend reflects the effects of the rainfall that occurred in those periods.

A continuous, long term hydrograph of C-489 (north Naples) is shown on Figure 41. The seasonal fluctuation ranges between 2 and 8 feet above NGVD. A long term declining trend is shown from 1980 to the present that is attributed to increased water usage in the area.

TABLE 1. PUBLIC WATER SUPPLIES WITHIN STUDY AREA

PUBLIC WATER SUPPLIER	SFWMD PERMIT NUMBER	PUMPAGE PER ANNUM (MG)	AQUIFER	NUMBER OF WELLS	AVG. PUMPING RATE/WELL (GPM)
Avatar Utilities, Inc.	11-00148-W	223	Water Table	4	100
Bonita Bay*	36-00282-W	1200	Water Table	3	200
			Lower Tamiami	3	350
			Sandstone	1	350
Bonita Springs	36-00008-W	1131	Lower Tamiami	8	1270
Collier County	11-00249-W	1460	Lower Tamiami	13	200
Everglades City	11-00160-W	66	Water Table	2	**150
The Glades, Inc.	11-00015-W	131	Lower Tamiami	2	250
Green Meadows (Florida Cities)	36-00150-W	22815	Sandstone	23	1850
Immokalee Utilities	11-00013-W	730	Lower Tamiami	1	200
			Sandstone	3	200
				1	100
Lee County Utilities	36-00003-W	3650	Water Table	16	400
			Sandstone	6	
Lehigh Acres	36-00166-W	479	Sandstone	14	**200
Manchester Invest. (Quail Creek)	11-00193-W	110	Water Table	2	**200
Marco Is. Utilities	11-00080-W	2220	Water Table	3	1400
Naples, The City of (Coastal Ridge)	II-00017-W	2600	Lower Tamiami	42	120
Naples, The City of (East Golden Gate)	11-00018-W	4650	Lower Tamiami	18	700
Naples Isles, Inc.	11-00235-W	35	Water Table	1	65
Pelican Bay Improvement District	11-00052-W	756	Lower Tamiami	10	145
Port of the Islands Invest. Company	11-00271-W	105	Mid Hawthorn	2	100
San Carlos Utilities	36-00122-W	1110	Water Table	7	300

* Wellfield is presently being constructed and has yet to be at full capacity.

** Indicates capacity of each well, not the actual pumpage rates because not all the wells are utilized at one time.

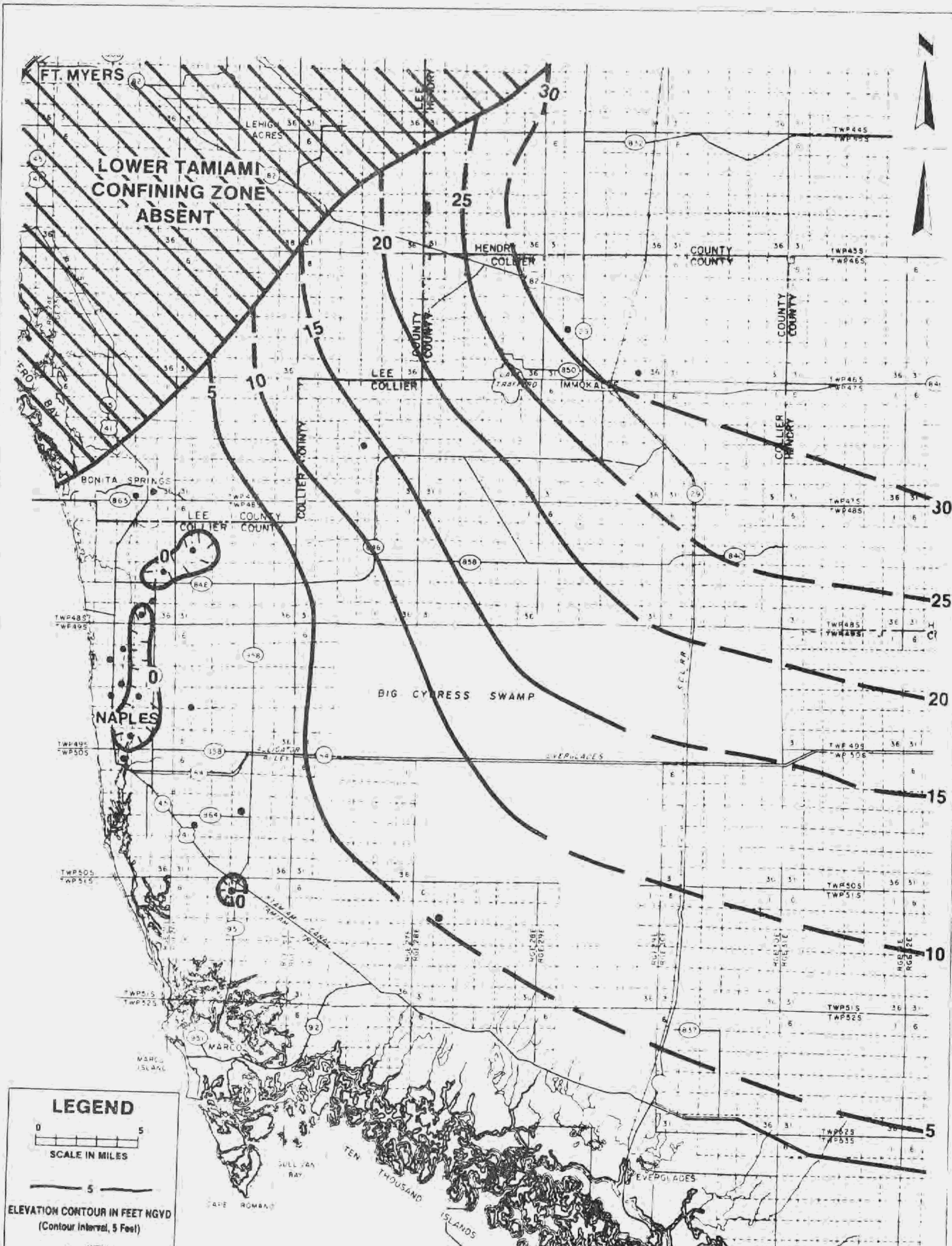


Figure 37 POTENTOMETRIC WATER LEVELS OF THE LOWER TAMIAMI AQUIFER APRIL 1984

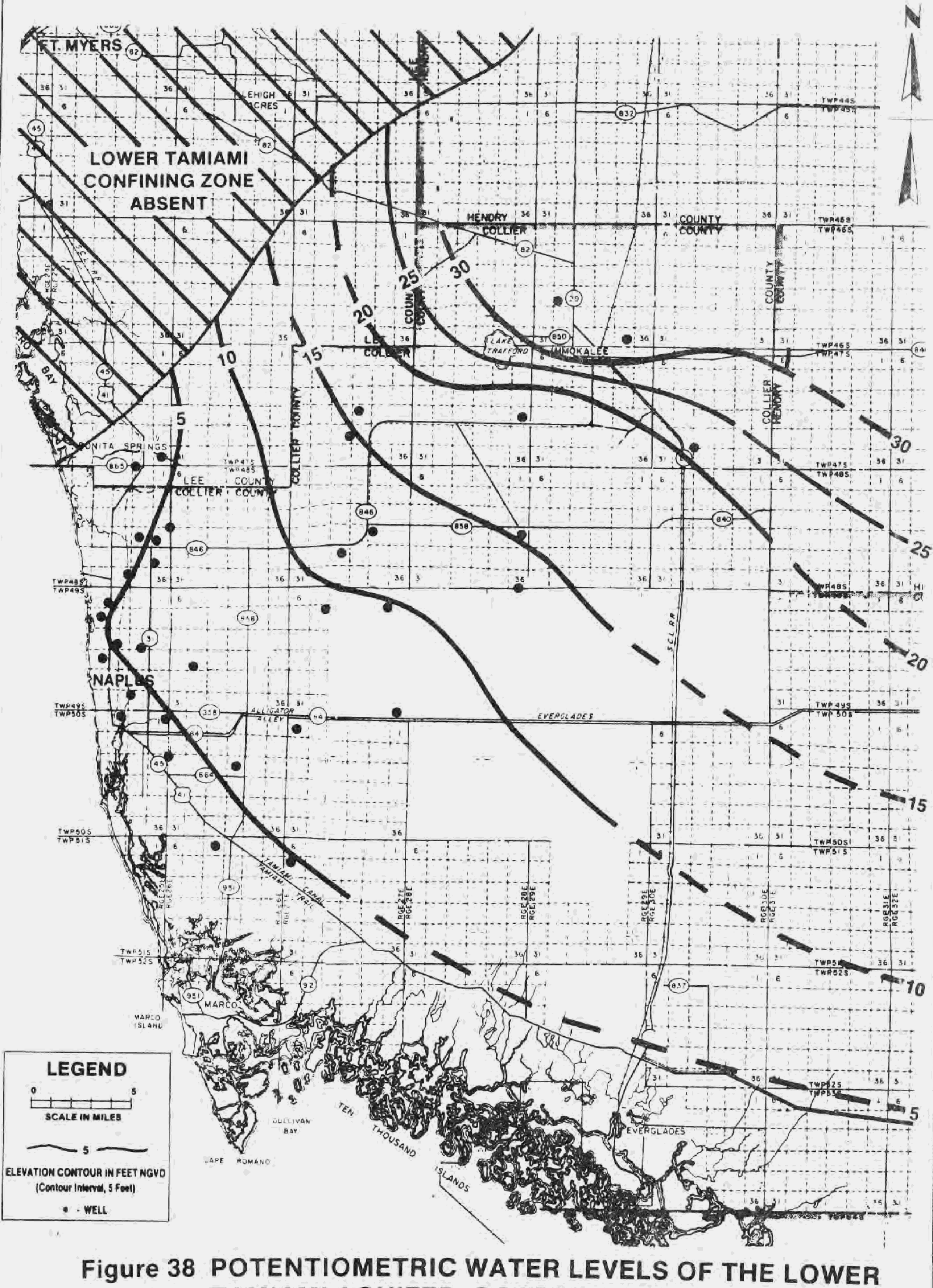


Figure 38 POTENTIOMETRIC WATER LEVELS OF THE LOWER TAMIAMI AQUIFER, OCTOBER, 1984

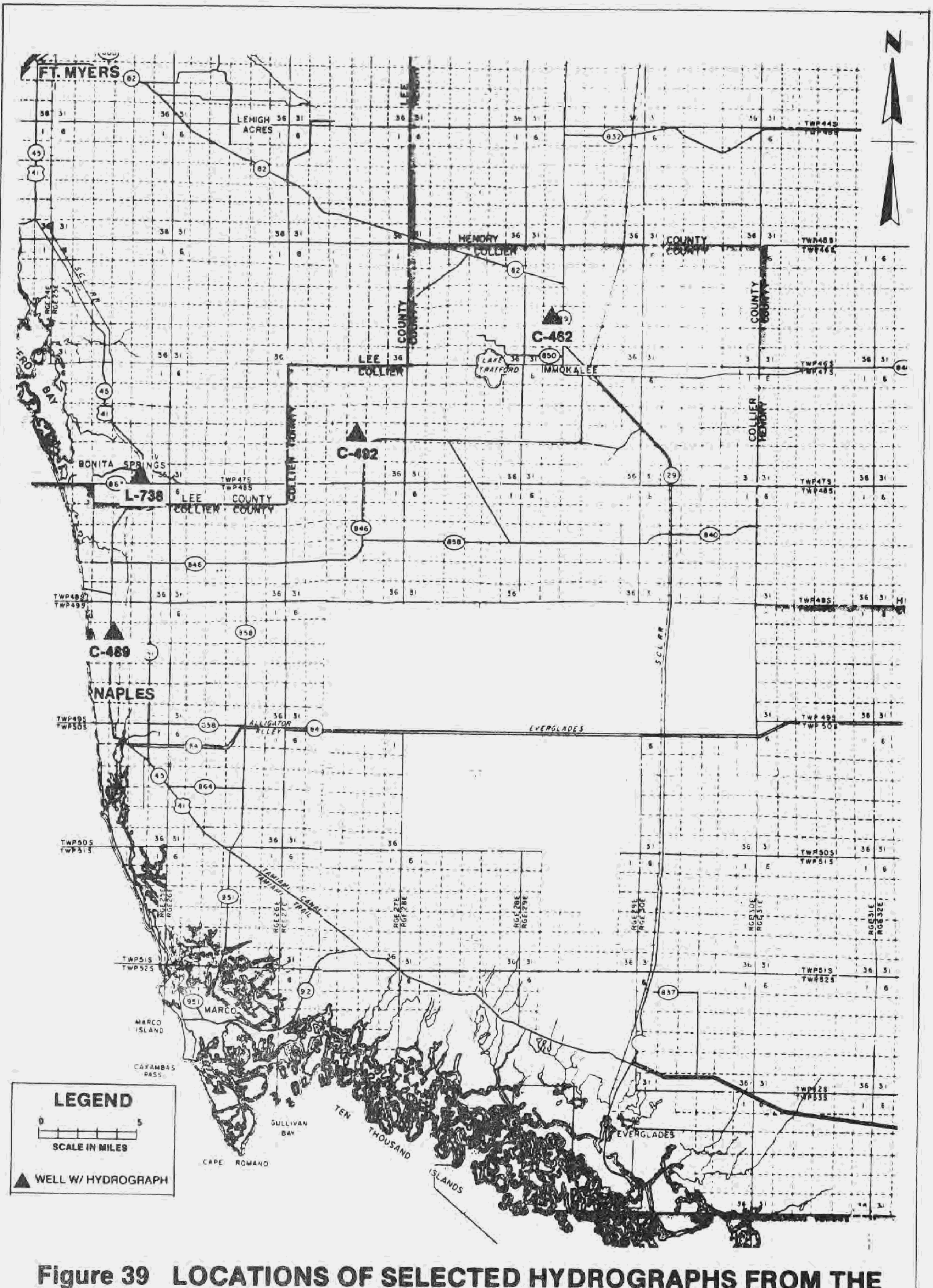


Figure 39 LOCATIONS OF SELECTED HYDROGRAPHS FROM THE LOWER TAMIAMI AQUIFER

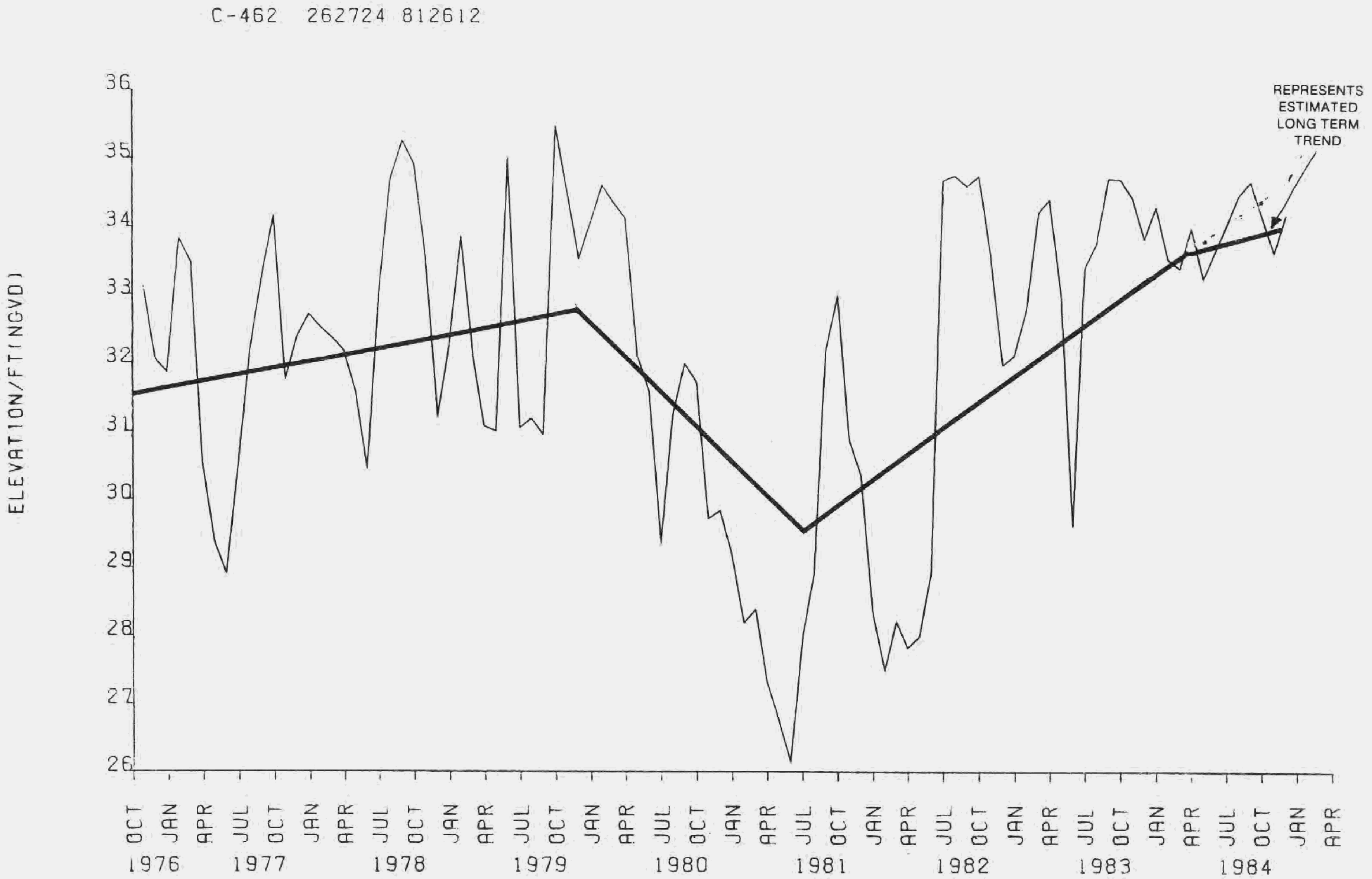


Figure 40 HYDROGRAPH OF THE LOWER TAMIAMI AQUIFER / COLLIER COUNTY 76-84

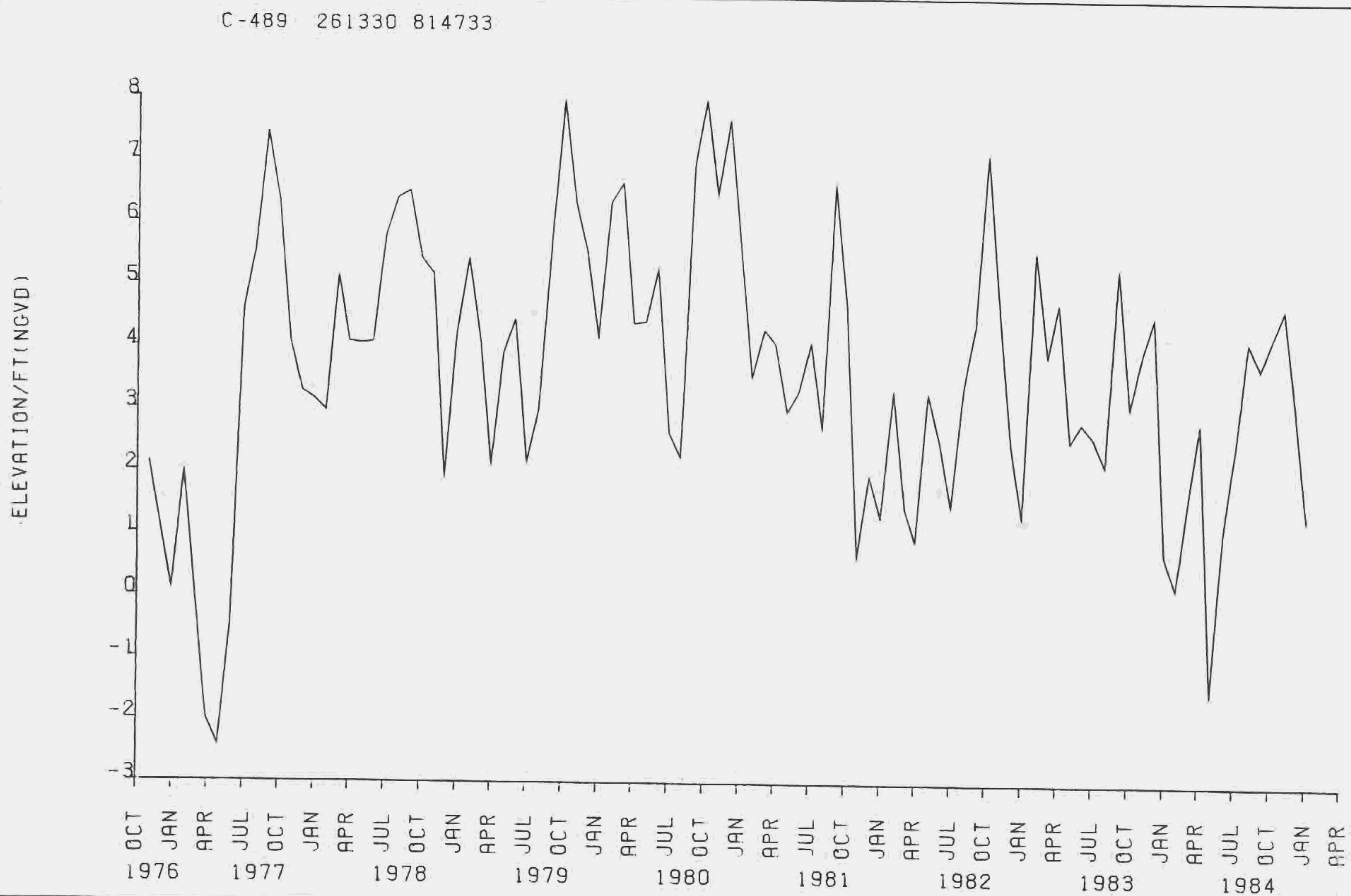


Figure 41 HYDROGRAPH OF THE LOWER TAMIAMI AQUIFER / COLLIER COUNTY 76-84

Hydrographs depicting fluctuations in water levels in other parts of the study area can be found in Appendix II-3. Fluctuations for the period of record in these hydrographs show seasonal fluctuations brought on by recharge (rainfall and leakance from the overlying, water table aquifer) and discharge (subsurface outflow and wellfield withdrawal).

Recharge

The lower Tamiami aquifer receives recharge from four possible sources: 1) direct recharge from precipitation where the aquifer in unconfined, 2) leakage from overlying or underlying aquifers, 3) inflow from interconnecting surface water bodies, and 4) subsurface inflow from outside the study area.

There are no known outcrops of the lower Tamiami aquifer within the study area. Therefore, the only known areas of possible direct recharge are where the overlying, confining beds are discontinuous. These conditions occur near Lake Trafford in Collier County and in southern Hendry and Lee Counties (Figure 19).

The primary source of leakance recharge to the lower Tamiami aquifer is the water table aquifer. Water level configurations of these two units are essentially the same and confining beds separating them are known to be very leaky.

It is doubtful that significant recharge is occurring through upward leakance from the underlying Intermediate Aquifer System because of the very thick and clayey nature of the upper Hawthorn confining zone. In the northern portion of the study area, where both the lower Tamiami and Sandstone aquifers exist, potentiometric levels of the underlying Sandstone aquifer are lower than those of the lower Tamiami aquifer. This would further prevent upward recharge into the lower Tamiami. Only in localized areas of heavy withdrawals (i.e. East Golden Gate wellfield, Figure 31) are lower Tamiami water levels lower than those in the Sandstone aquifer.

Subsurface inflow from outside the study area occurs from the east and the northeast. The aquifer, however, thins and disappears to the north and significant inflow is improbable.

Discharge

Discharge from the lower Tamiami aquifer occurs through: 1) submarine discharge into the Gulf of Mexico, 2) vertical leakance through confining beds, and 3) withdrawal from wells.

The configuration of the equipotential lines near the coast (Figures 37 and 38) indicates that the Gulf of Mexico is a major outflow boundary. The highest rate of discharge occurs under maximum hydraulic gradients during the months of highest precipitation. During the drier months, heavy withdrawal from wellfields lowers the potentiometric surface of the aquifer and decreases the discharge to the Gulf of Mexico.

Within a small portion of the study area, the lower Tamiami overlies the Sandstone aquifer, and small amounts of water may be vertically transferred across the confining beds to the Sandstone aquifer. Substantial amounts of outflow are doubtful due to the thickness of the confining beds and the low head differential between the two aquifers. Farther south, where the Sandstone aquifer pinches out, a very thick, underlying, confining zone effectively retards the vertical transfer of water to deeper aquifers. This, plus the higher potentiometric water levels of the mid-Hawthorn aquifer, prevents any downward leakance from the lower Tamiami in this area.

The lower Tamiami aquifer is the primary source for domestic water supplies in the area and pumpage represents a major source of discharge. During periods of stress in the dry season, the water levels sometimes drop to critical elevations in the City of Naples Coastal Ridge wellfield. During the dry season of 1984 (Figure 34), water levels in this aquifer were below sea level along the coast. Pumpage in coastal areas may reverse the normal hydraulic gradient toward the Gulf of Mexico, creating potential for saltwater intrusion.

INTERMEDIATE AQUIFER SYSTEM

The two regional aquifers within the Intermediate Aquifer System are the Sandstone and mid-Hawthorn aquifers. These aquifers produce water for agricultural and municipal supply. Low permeability beds within the Intermediate Aquifer System confine the deeper, artesian and highly saline Floridan Aquifer System.

Sandstone Aquifer

The Sandstone aquifer is a semi-confined aquifer, and potentiometric levels are well above the top of the aquifer. This aquifer is productive only within the northwestern portion of Collier County. The unit is absent south of S.R. 84 (Figure 23).

Water Level Configuration

The potentiometric surface maps of the Sandstone aquifer (Figures 42 and 43) were generated using water level data from 21 wells located in the

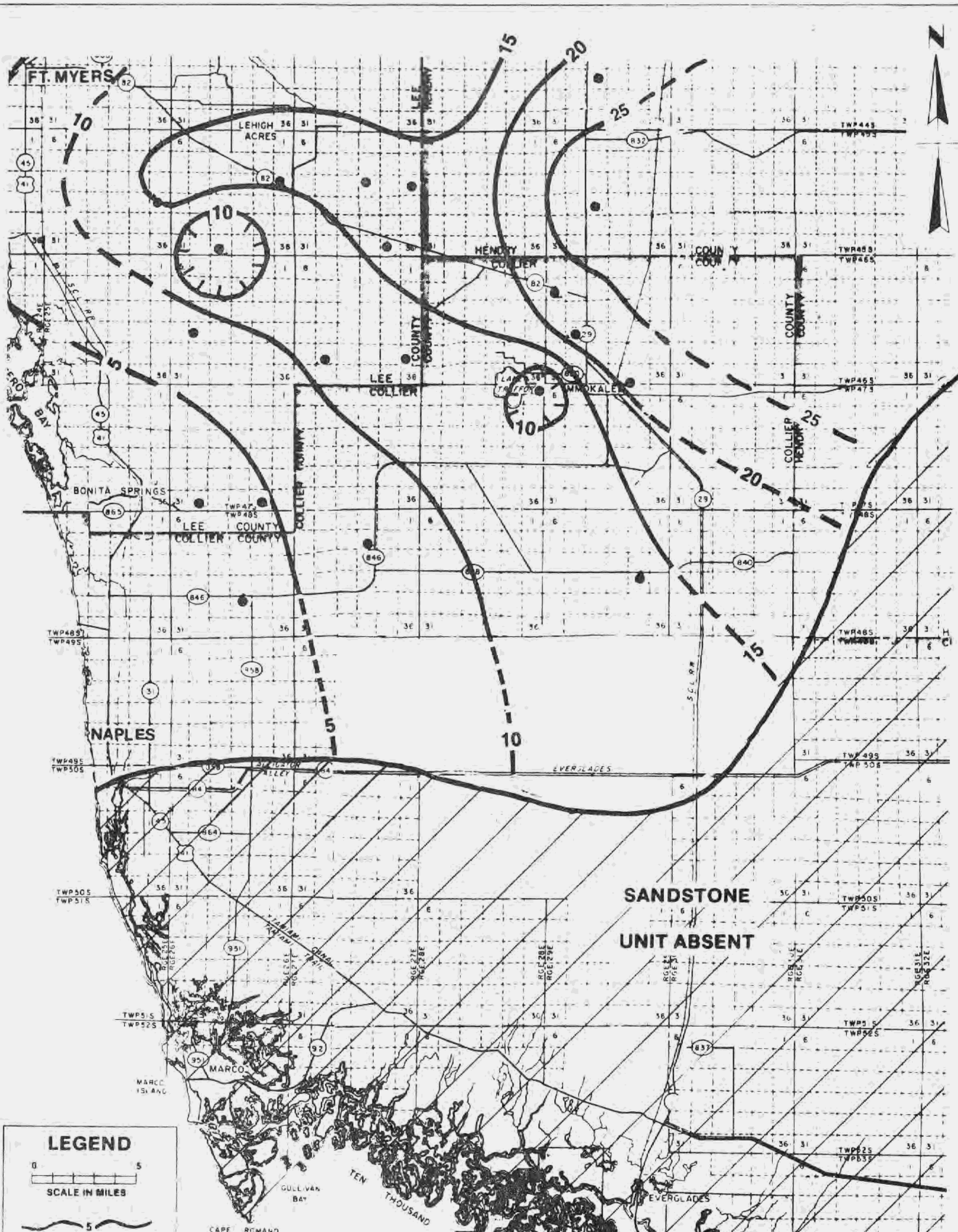


Figure 42 POTENTIOMETRIC WATER LEVELS OF THE SANDSTONE AQUIFER APRIL 1984

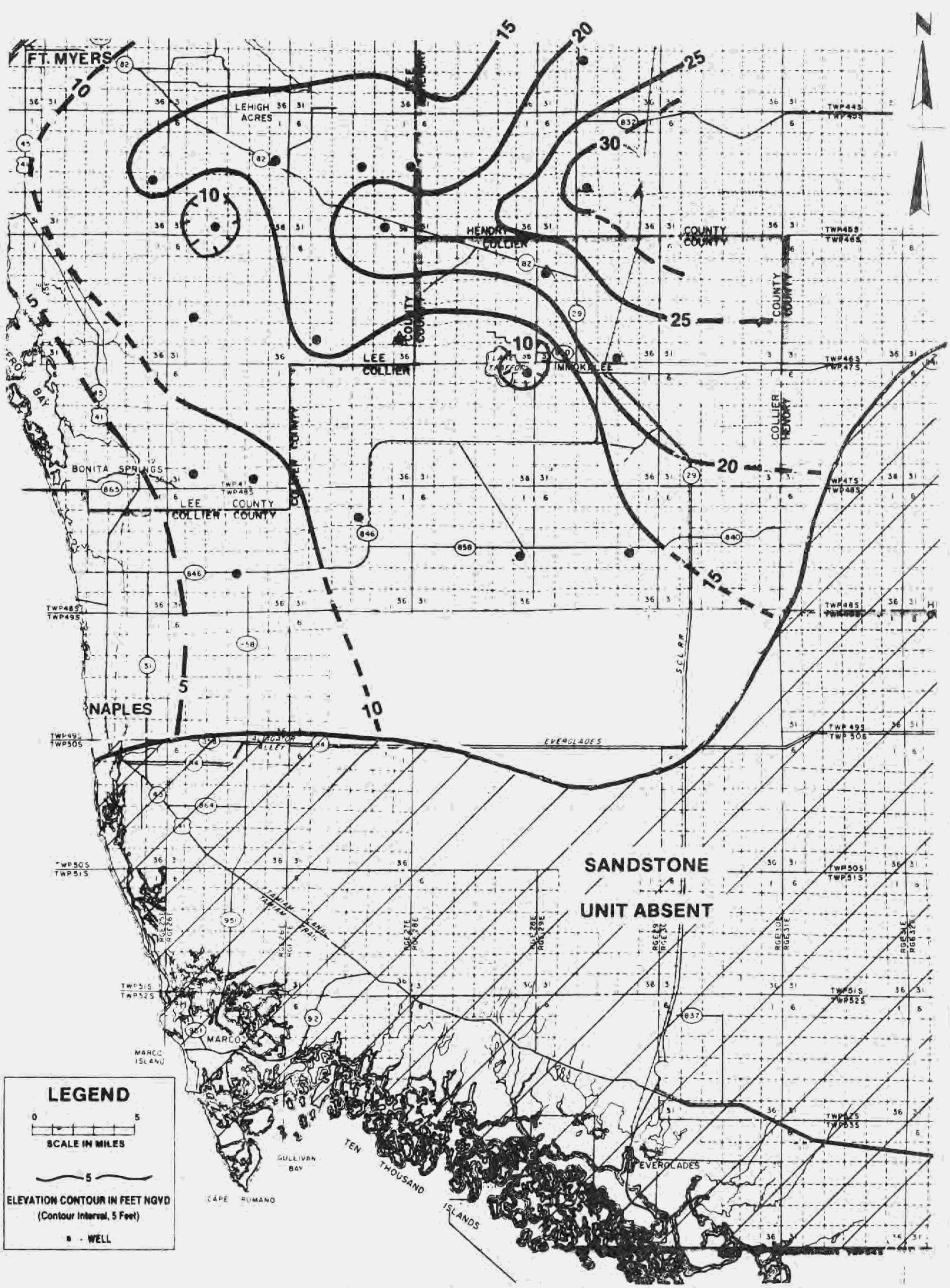


Figure 43 **POTENTIOMETRIC WATER LEVELS OF THE SANDSTONE AQUIFER OCTOBER 1984**

northern half of the study area. Contour lines are dashed in areas deficient in data.

The configuration of the potentiometric surface for the Sandstone aquifer resembles that of the lower Tamiami and water table aquifers. The highest water levels occur in Hendry County northeast of Immokalee where flow is in a radial direction toward the northwest and the southwest. The potentiometric surface of the Sandstone aquifer is below the water levels of the lower Tamiami and the water table aquifers, indicating a potential for downward leakage.

Deviations from the regional flow pattern occur near Immokalee and in eastern Lee County where water levels are below +10 ft. NGVD (Figure 42). Monitor wells near the Immokalee and Lee County wellfields report water levels as low as -13 ft. and -18 ft. NGVD, respectively. These values occur at the end of the dry season within the cones of depression created by municipal wellfields.

The hydraulic gradient in the Sandstone aquifer ranges from 0.5 feet per mile to 3.0 feet per mile throughout the study area. The steepest gradients of 5 feet per mile occur in areas near the wellfields. The hydraulic gradients gradually decrease with increasing distance away from the highest potentiometric water levels.

Water Level Fluctuations

Locations of selected Sandstone aquifer well hydrographs are shown in Figure 44. Figure 45 depicts groundwater levels within the Sandstone aquifer in well C-531, north of Immokalee. This hydrograph shows water levels have ranged from 18 feet to 32 feet above NGVD since October 1976. Since 1981 the difference between wet and dry season water levels is approximately ten feet.

In the past eight years there have been three long term trends. Annual rainfall accumulations measured at Station MRF 242 (Appendix II-4) indicates these trends can be partially explained by long term trends in rainfall. Seasonal fluctuations are due to short term rainfall patterns and local pumpage. The increased magnitude of the seasonal fluctuations in well C-531 (Figure 45) beginning in 1981 is due to increased withdrawals for citrus crops in the vicinity of this monitor well.

The hydrograph of well L-2194 (Figure 46), located near Bonita Springs, shows trends similar to those in well C-531. Water levels from this well range from less than one foot to over 12 feet since October 1976. Seasonal fluctuations often exceed ten feet.

Figure 47 depicts the hydrograph of well L-1994, located southwest of Lehigh Acres and near the Florida Cities Green Meadow wellfield (Figure 31). This hydrograph shows several trends, and water levels range from 10 to 23 feet above NGVD. Seasonal water level fluctuations range between 5 and 10 feet. Hydrographs for wells HE555, C-689, and L-2192 are shown in Appendix II-3.

Recharge

There are three possible ways in which the Sandstone aquifer receives recharge: 1) direct infiltration from precipitation in areas where the aquifer is at or near the surface, 2) vertical leakance from adjacent aquifers through semi-confining beds, and 3) subsurface inflow from outside the study area.

Since the aquifer does not crop out within the study area, direct infiltration does not occur. In areas where the confining beds separating the Sandstone aquifer from adjacent aquifers are leaky, the source of recharge is from overlying and underlying aquifers. Throughout most of the study area, the water levels in the Surficial Aquifer System are higher than those in the Sandstone aquifer. This, along with the similarities of the potentiometric level configurations of the lower Tamiami and Sandstone aquifers, suggests recharge occurs primarily from the Surficial Aquifer System. The underlying mid-Hawthorn aquifer also has higher potentiometric levels than the Sandstone aquifer, but upward leakance is considered minimal due to the better confining properties of the strata overlying the mid-Hawthorn (Wedderburn et al., 1982).

The configuration of the potentiometric surface (Figure 43) implies that subsurface inflow may occur from the northeastern section of the study area. However, there is not enough available information from the area to quantify the subsurface inflow, and it is assumed that recharge from this source is minimal.

Discharge

There are four modes of discharge from the Sandstone aquifer: 1) leakance to hydraulically connected aquifers, 2) subsurface outflow to adjacent areas, and 3) withdrawals from wells.

Because the potentiometric levels of the Sandstone aquifer are lower than the levels of the adjacent aquifers it is doubtful that water discharges from the Sandstone aquifer as leakance. The exceptions occur in areas where water levels in the adjacent aquifers have been lowered through pumpage.

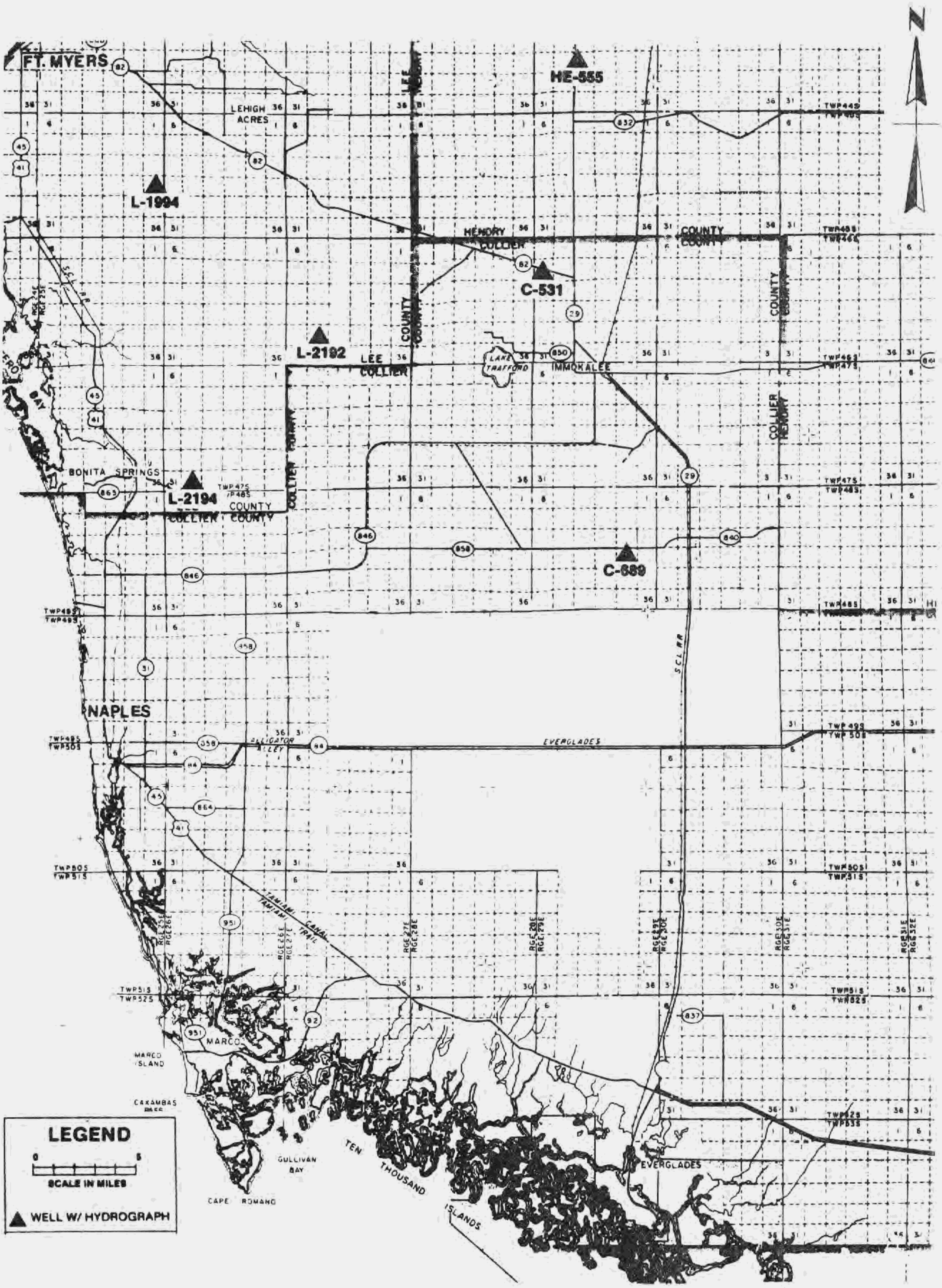


Figure 44 LOCATIONS OF SELECTED HYDROGRAPH STATIONS FROM THE SANDSTONE AQUIFER

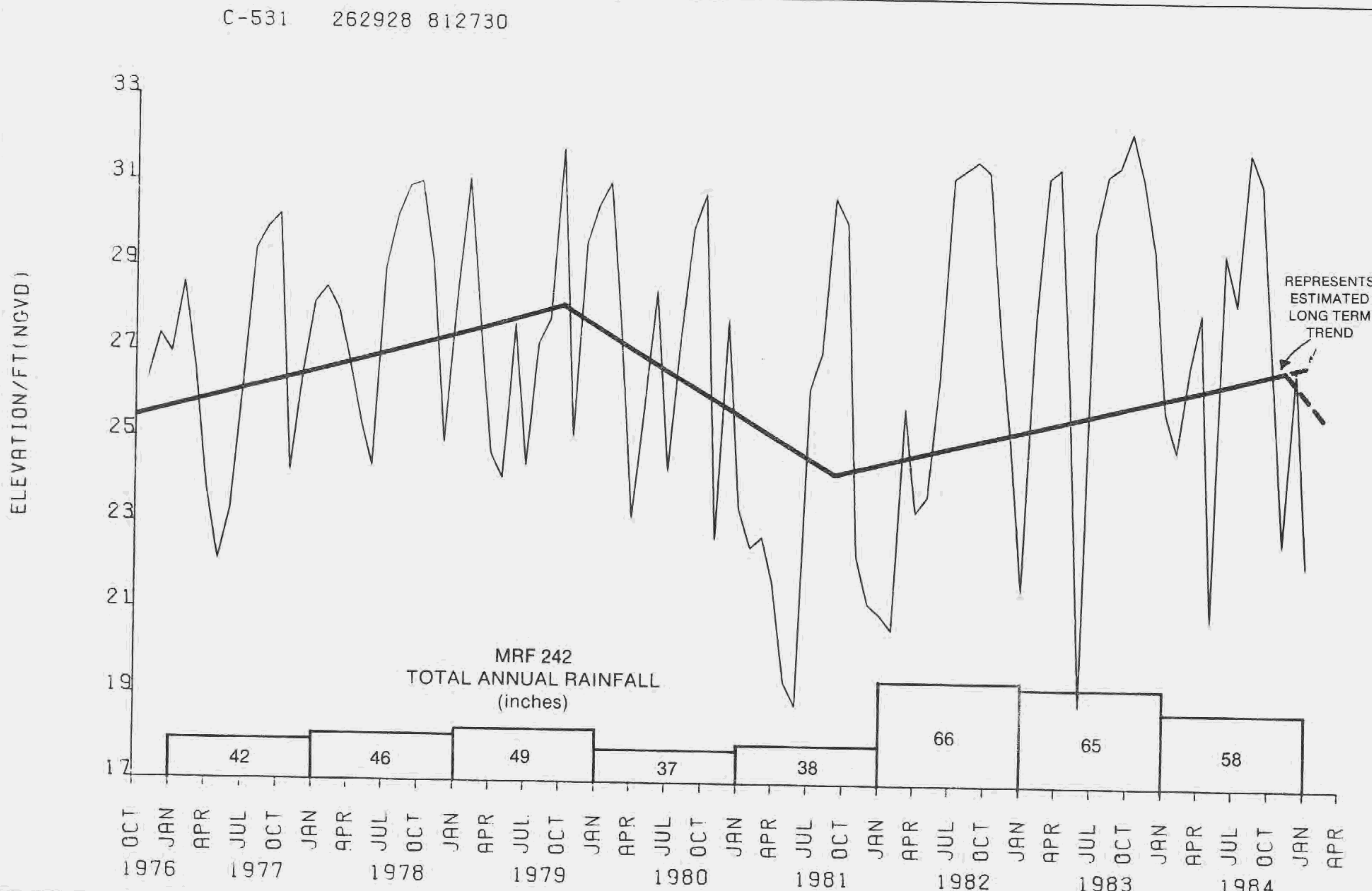


Figure 45 HYDROGRAPH OF THE SANDSTONE AQUIFER / COLLIER COUNTY 76-84

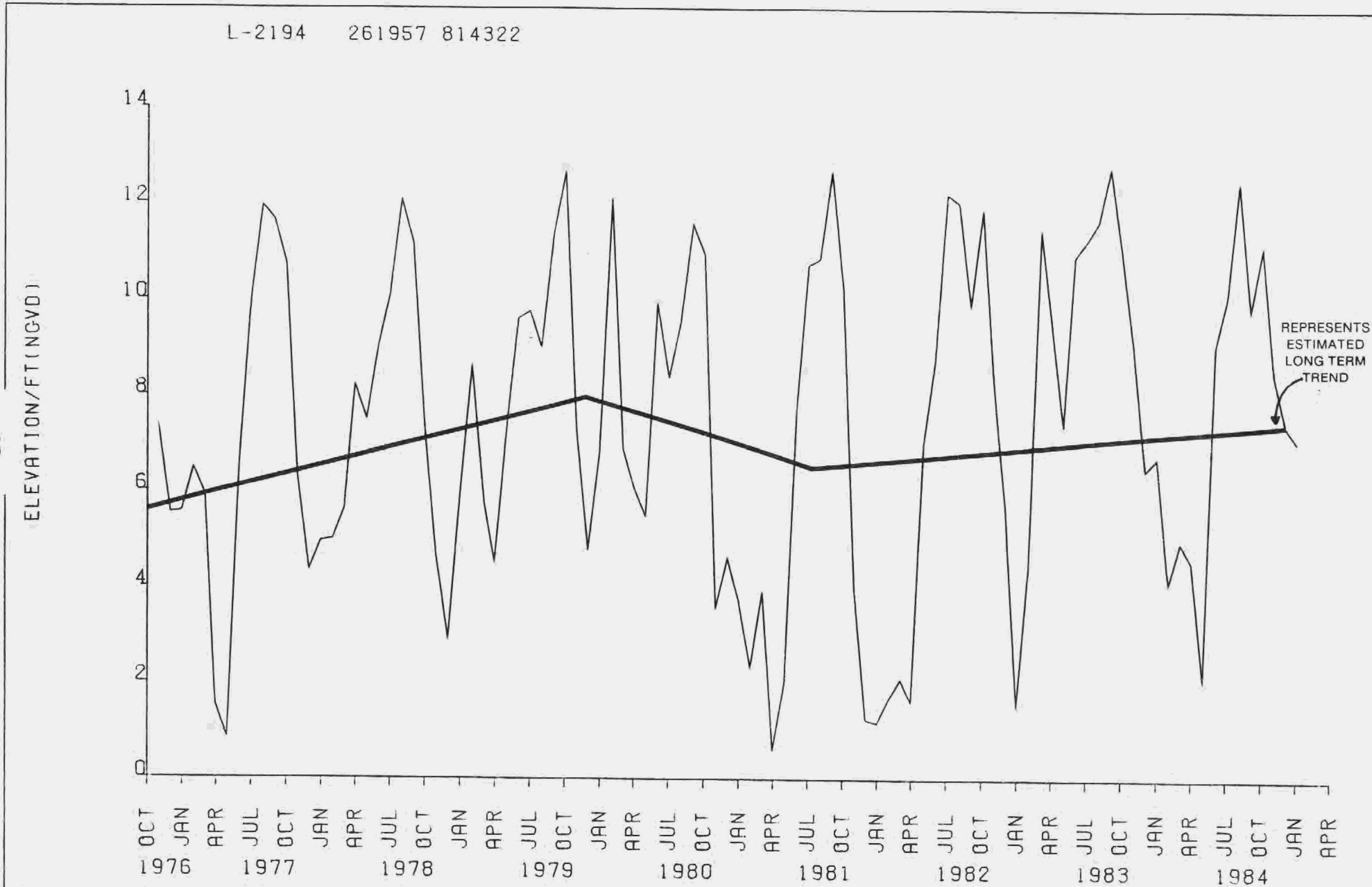


Figure 46 HYDROGRAPH OF THE SANDSTONE AQUIFER / LEE COUNTY 76-84

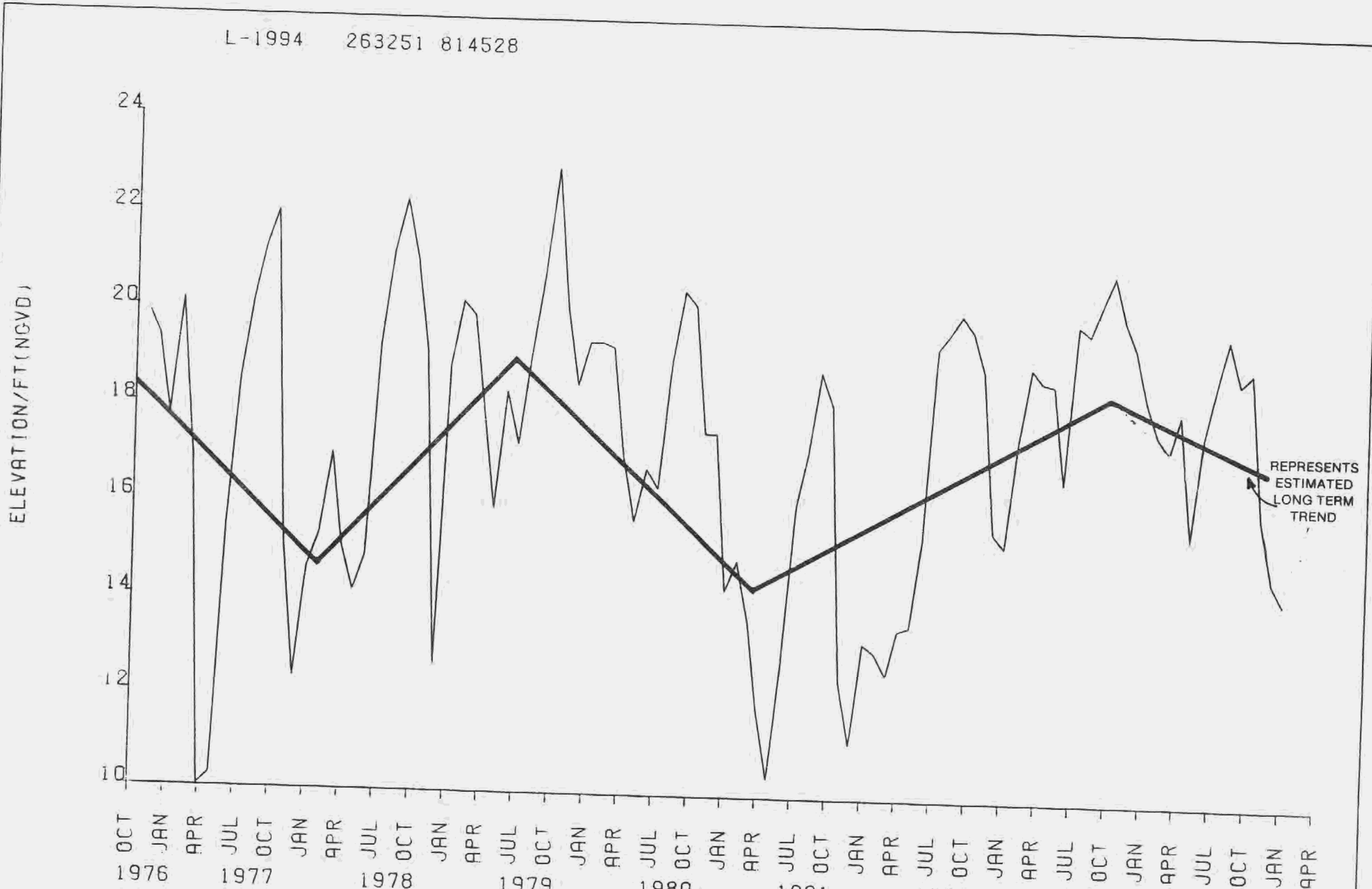


Figure 47 HYDROGRAPH OF THE SANDSTONE AQUIFER / LEE COUNTY 76-84

Subsurface outflow is also not considered to be a major source of discharge in western Collier County, because the potentiometric surface of the aquifer indicates that inflow occurs all along the Collier/Lee County line. The direction of subsurface flow for the Sandstone aquifer is not known along the Hendry/Collier County line east of Immokalee due to a lack of water level data. This is the only area where outflow may be occuring.

The equipotential lines suggest that outflow to the Gulf of Mexico may be occuring; however, Wedderburn et al. (1982) state that "... it is unlikely that significant outflow to the Gulf of Mexico (off of Lee County) occurs since the aquifer pinches out in western Lee County". Following this trend southward, it is believed that the Sandstone aquifer pinches out a few miles west of the Collier County coast, beneath the Gulf of Mexico. Therefore, outflow to the Gulf is probably minimal.

Water withdrawals by municipal and private users is a major source of discharge from the Sandstone aquifer. Figure 42 depicts the cones of depression surrounding the Florida Cities and Immokalee Utilities wellfields (Figure 31). These withdrawals have only a localized effect on the regional flow pattern. Heavy pumpage from agricultural activities north of Immokalee is responsible for attenuations of the potentiometric contour lines to the north in this area (Figure 43). This effect is most pronounced in the late fall and early winter months when citrus irrigation is most intense.

Mid-Hawthorn Aquifer

The mid-Hawthorn aquifer is a confined aquifer occurring between beds of low permeability. The potentiometric levels within the mid-Hawthorn aquifer are generally above land surface throughout the study area. This creates flowing, artesian conditions in wells which penetrate it. The principal recharge area for this aquifer is similar to that for the deeper artesian aquifers in southern Florida and may be located as far away as the Polk and Pasco County areas (Lichtler, 1960), and probably also in Sarasota, Manatee, and Hardee Counties (Wedderburn et al., 1982).

Since Collier County is over 150 miles from the recharge area, the groundwater flow moving through the mid-Hawthorn has a long residence time. By the time mid-Hawthorn water reaches Collier County, it has become for the most part highly mineralized making it unusable for most domestic purposes. Because there is a lack of sufficient data, and also because the aquifer is not presently being used, further discussion of the mid-Hawthorn potentiometric water levels will not be made in this report.

WATER QUALITY

INTRODUCTION

All groundwater contains dissolved minerals, the concentrations of which depend upon the lithology of the aquifer system and the residence time of the groundwater. In addition,.groundwater quality may be altered through mixing with water of different chemical properties. Groundwater can be contaminated by sewage, industrial discharge, agricultural wastes, animal wastes, fertilizers, pesticides, herbicides, and by salt water encroachment. The Department of Environmental Regulation has established standards for water quality based on the type of use. A list of primary and secondary drinking water quality standards are shown in Table 2.

Groundwater quality for the three primary aquifers is discussed here. In addition, salt water intrusion, the SFWMD's Salt water Intrusion Monitoring and Management program (SWIM), the county's waste disposal facilities, and the future goals of the Florida Water Quality Assurance Act will also be discusssed.

Water samples from selected monitor wells were analyzed by the SFWMD Chemistry Laboratory in June of 1984. In addition, data from the USGS were also reviewed. Measured parameters including chlorides (Cl), sulfate (SO_4), total dissolved solids (TDS), calcium (Ca), magnesium (Mg), sodium (Na), iron (Fe), alkalinity (ALK), and conductivity (COND).

Conductivity and chloride concentrations were chosen to depict the water quality of the three primary freshwater aquifers because these parameters are indicative of the most common type of water quality degradation. Conductivity is a measure of the ability of water to conduct electricity. The conductivity of water is directly related to the ion strength of the solution. Chloride levels are addressed because of concerns regarding salt water intrusion. A series of isochlor and isoconductance maps are presented for each of the primary aquifers. Data used to produce these maps are included in Appendix III.

Water Table Aquifer

Groundwater quality samples were collected and analyzed from 13 water table aquifer wells throughout the study area. Results of the analysis are presented in Table 3. Chlorides and conductivity data from an additional 24 wells are presented in Appendix III..

TABLE 2.
DER WATER QUALITY CLASSIFICATIONS AND STANDARDS FOR GROUNDWATER

Parameter	DER Standard
Arsenic	0.05 mg/l
Barium	1 mg/l
Cadmium	0.010 mg/l
Chlorides	250 mg/l
Chromium	6.05 mg/l
Color	15 color units
Copper	1 mg/l
Corrosivity	Noncorrosive
Dissolved Solid	500 mg/l
Foaming Agents	0.5 mg/l
Iron 0.3 mg/l	
Lead 0.5 mg/l	
Manganese	0.05 mg/l
Mercury	0.002 mg/l
Nitrate (as N)	10 mg/l
Odor	Threshold Odor 3
Pesticides:	
2,4-D	100 ug/l
2,4,5-TP	10 ug/l
Endrin	0.2 ug/l
Lindane	4 ug/l
Methoxy-Chlor	100 ug/l
Toxaphene	5 ug/l
pH	>6.5
Radioactive Subs.	Ra:5pCi/L
Selenium	0.01 mg/l
Silver	0.05 mg/l
Sodium	160 mg/l
Sulfates	250 mg/l
Trihalomethanes	0.01 mg/l
Zinc 5 mg/l	

Water quality ofthe water table aquifer is generally within potable standards. It is characteristically low in dissolved minerals, low to moderate in calcium hardness, and frequently exceeds DER standards for iron and color. Chloride concentrations measured for this report ranged from less than 5 mg/l to 215 mg/l. Conductivity values ranged from 300 umhos/cm to 1280 umhos/cm. The hardness of the water is determined by the concentration of calcium and magnesium ions. The combined concentration of

TABLE 3

WATER QUALITY DATA FROM THE WATER TABLE AQUIFER

USGS NO.	SFWMD NO.	Cl (mg/l)	SO_4 (mg/l)	TDS (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	T Fe (mg/l)	ALK (meq/l)	COND. (umhos/cm)	DATE
C-953	C-2033-S	31.7	8.3	434.0	84.30	14.20	24.80	0.04	6.37	608.0	6/8/84
C-966	C-2042-S	124.0	67.5	398.0	31.70	19.40	148.00	0.19	5.80	959.0	6/8/85
C-970	C-2032-S	7.5	9.8	322.0	103.70	2.30	14.20	2.99	3.16	521.0	4/4/84
C-972	C-2034-S	8.5	43.0	374.0	119.70	4.30	7.80	0.33	2.70	552.0	6/8/84
C-976	C-2036-S	29.1	91.9	598.0	124.90	10.00	17.50	0.37	6.64	745.0	6/8/84
C-978	C-2038-S	207.0	79.7	804.0	84.70	7.60	101.40	3.02	4.72	1182.0	6/8/84
C-980	C-2039-S	6.5	97.2	538.0	141.20	5.10	8.70	1.39	6.12	668.0	6/8/84
C-981	C-2040-S	32.7	4.5	634.0	92.10	5.00	18.40	3.11	5.68	543.0	6/8/84
C-984	C-2041-S	34.7	8.0	536.0	98.20	5.60	113.30	4.45	7.52	658.0	6/8/84
C-986	C-2043-S	35.1	4.7	3122.0	115.90	7.60	28.80	0.46	6.56	623.0	6/8/84
C-503	--	35.0	1.1	360.0	106.00	6.80	25.00	0.18	--	635.0	10/8/81
C-131	--	77.0	< .1	499.0	108.00	17.00	58.00	1.10	--	885.0	10/7/81
C-532	--	35.0	13.0	222.0	38.00	8.50	42.00	1.20	--	238.0	10/7/81

both of these ions were below 150 mg/l for the samples analyzed. Sulfate and sodium concentrations were within the DER groundwater quality standards. However, most of the wells sampled had iron concentrations that exceeded DER standards of 0.3 mg/l.

Isochlor and isoconductance maps of the water table aquifer are shown in Figures 48 and 49, respectively. These maps were drawn using 1984 data from 37 wells. An area of locally high chlorides occurs near S.R. 29, north of Copeland. This may be due to contamination from upward leakance of saline water from old abandoned Floridan wells or the presence of connate water. Another area of known high chlorides not shown on the map occurs along the intertidal fringe south of US 41. The lowest chloride concentrations were found in the western part of the Big Cypress Swamp and in the north section of the study area, where highest water levels for the aquifer occur.

The isoconductance map (Figure 49) also reflects the anomalously high chloride levels found near Copeland. In addition, an area north of the Marco Island rock pit has conductivities exceeding 900 umhos/cm. The range of conductivities over the rest of the study area is between 300 and 800 umhos/cm, with the lowest occurring in the north-northwestern section of the study area near the Hendry-Lee county line.

Lower Tamiami Aquifer

Water quality data from 14 wells penetrating the lower Tamiami aquifer are presented in Table 4. Chloride and conductivity data from ten additional wells are presented in Appendix III. The lower Tamiami aquifer is recharged from the overlying water table aquifer and water quality is similar for both aquifers. Iron concentrations are generally lower in the lower Tamiami aquifer as compared with the water table aquifer. This makes it more suitable for domestic supply and low volume irrigation systems.

Figure 50 is an isochlor map of the lower Tamiami aquifer. Measured chloride concentrations during 1984 ranged from less than 5 mg/l to over 10,000 mg/l, with the highest values occurring along the coast. A "trough" of low chlorides extending from Naples northeast to Immokalee. The chlorides increase to the northwest and southeast of the trough. Immediately south of Bonita Springs, chloride values range from 100 to 500 mg/l. The high chlorides in this area may be the result of saline intrusion from the Cocohatchee River. Chlorides in excess of 1000 mg/l have been identified in three USGS observation wells along the Naples coastline (C-527, C-524, and C-526). Water of this quality occuring less than 1.5 miles from the City of Naples Coastal Ridge wellfield is a concern to water managers. Another area of high chlorides occurs south of US 41 near SR 951. SWIMM data (not shown on map) indicate chloride levels exceed 500 mg/l in this area.

The isoconductance map (Figure 51) shows essentially the same configuration as the isochlor map. The lowest values (below 250 umnos/cm) occur around Immokalee in the area of highest groundwater levels. From that point the values increase to the south and the east where in some places the conductivity exceeds 1100 umhos/cm. The highest values occur north of the Naples wellfield (Coastal Ridge) at the mouth of the Cocohatchee River and along the southeast coastal area. The higher conductivity values within the southeastern area may be due to the flatter water level gradients and slower movement of the water in that area.

Sandstone Aquifer

Results of water quality analysis for eight Sandstone aquifer wells is depicted on Table 5. An additional nine wells were sampled for chloride and conductivity (Appendix III). Sulfate levels range from 8 to over 100 mg/l, and the calcium/magnesium hardness ranges from 48 to 144 mg/l. Iron concentrations range from 0.06 to 1.11 mg/l. The iron concentrations are lower than those in the Surficial Aquifer System making the Sandstone aquifer a better potential source of water for drip irrigation.

There appears to be a correlation between water quality and distance from the area with the highest water levels within the Sandstone aquifer. Water quality data from monitoring stations (C-561, L-201, L-203, L-204, L-205, Appendix III) located on an east to west transect from the Lee-Collier County line to Estero, respectively, shows an increase in hardness, magnesium, potassium, and alkalinity towards the west. This may be due in part to westward movement of water away from the areas of highest water levels combined with increased residence time within the Sandstone aquifer.

A contour map of chloride concentrations for the Sandstone aquifer is presented in Figure 52. The 1984 chloride concentrations ranged from 14 mg/l to 580 mg/l. The lowest concentrations occur in the Immokalee and Lehigh Acres areas. Values generally increase with distance from these areas. This coincides with the groundwater flow pattern of the Sandstone aquifer with the lowest chlorides occurring in the areas of highest potentiometric levels. As the flow moves south and southwest, the chloride levels increase.

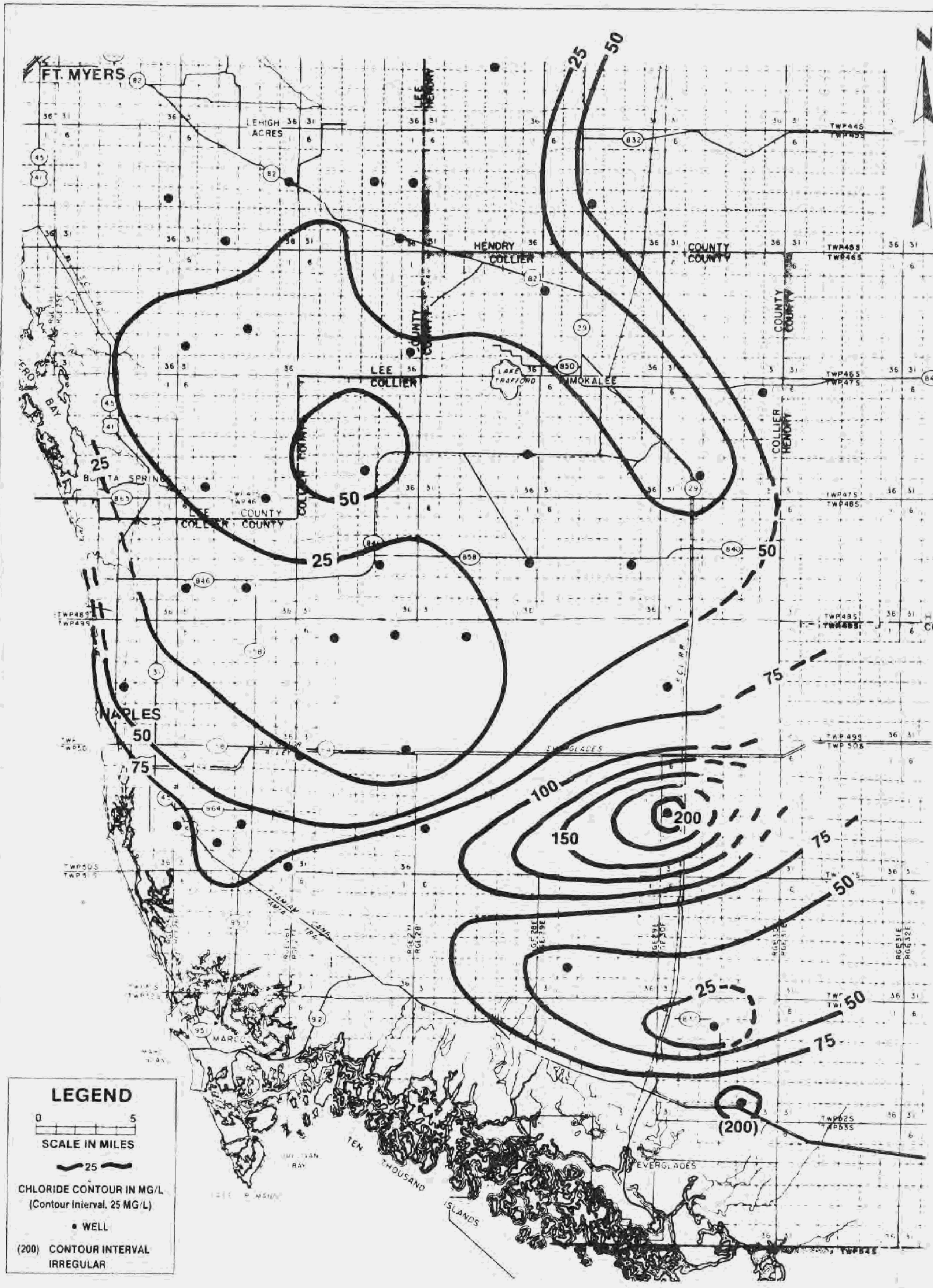


Figure 48 CHLORIDE CONCENTRATIONS WITHIN THE WATER TABLE AQUIFER

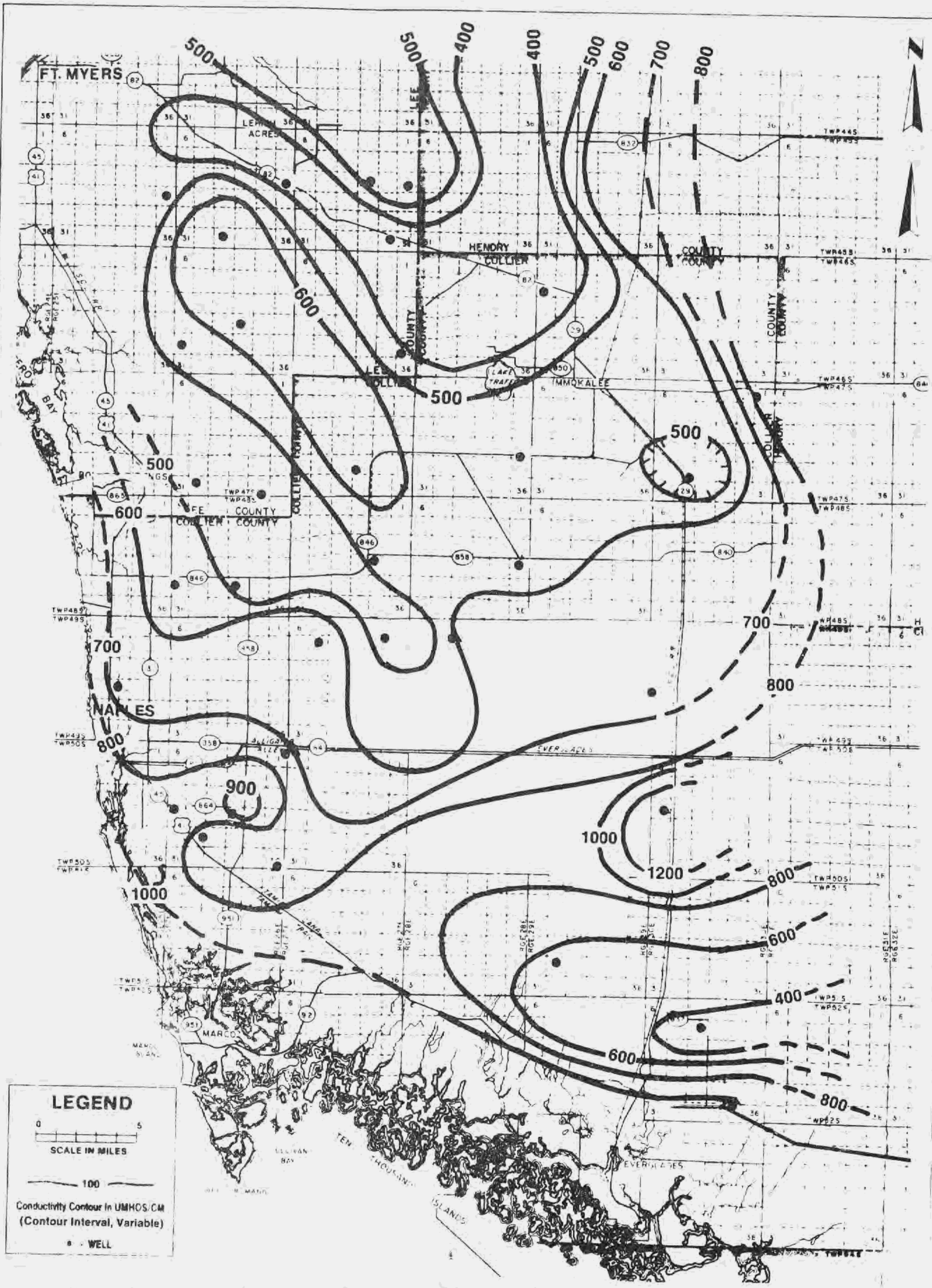


Figure 49 CONDUCTIVITY VALUES WITHIN THE WATER TABLE AQUIFER

TABLE 4

WATER QUALITY DATA FROM THE LOWER TAMIAMI AQUIFER

USGS NO.	SFWMD NO.	Cl (mg/l)	SO_4 (mg/l)	TDS (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	T Fe (mg/l)	ALK (meq/l)	COND. (umhos/cm)	DATE
C-951	C-2033-I	40.1	25.4	416.0	89.40	16.90	29.90	0.04	3.28	640.0	4/3/84
C-956	C-2039-I	15.4	55.2	408.0	132.40	5.30	9.30	0.13	7.24	662.0	4/3/84
C-965	C-2042-I	14.1	6.1	384.0	49.70	4.10	28.60	4.35	5.06	493.0	6/8/84
C-971	C-2032-I	51.5	18.5	474.0	108.50	17.80	45.40	0.07	4.00	795.0	4/3/84
C-973	C-2034-I	11.6	57.9	434.0	130.10	4.70	9.90	0.07	6.28	575.0	6/8/84
C-975	C-2035-I	113.0	9.6	646.0	131.30	33.00	196.00	0.18	3.70	861.0	6/8/84
C-977	C-2036-I	31.5	100.3	610.0	131.40	11.00	22.50	0.13	6.80	805.0	6/8/84
C-979	C-2038-I	38.8	36.7	426.0	55.70	13.60	37.90	0.14	4.76	570.0	6/8/84
C-982	C-2040-I	24.2	3.3	412.0	80.30	12.90	21.60	0.06	5.84	529.0	6/8/84
C-985	C-2041-I	38.3	26.8	450.0	67.80	15.90	45.50	4.69	6.08	605.0	6/8/84
C-988	C-2046-I	42.8	14.7	444.0	74.50	13.10	38.00	0.03	3.40	655.0	6/8/84
C-304	--	45.0	60.0	433.0	73.00	--	42.00	0.10	--	685.0	10/8/81
C-492	--	55.0	<.1	402.0	110.0	5.90	36.00	0.20	--	610.0	10/8/81
C-462	--	29.0	8.2	328.0	92.0	7.60	18.00	0.65	--	515.0	10/9/81

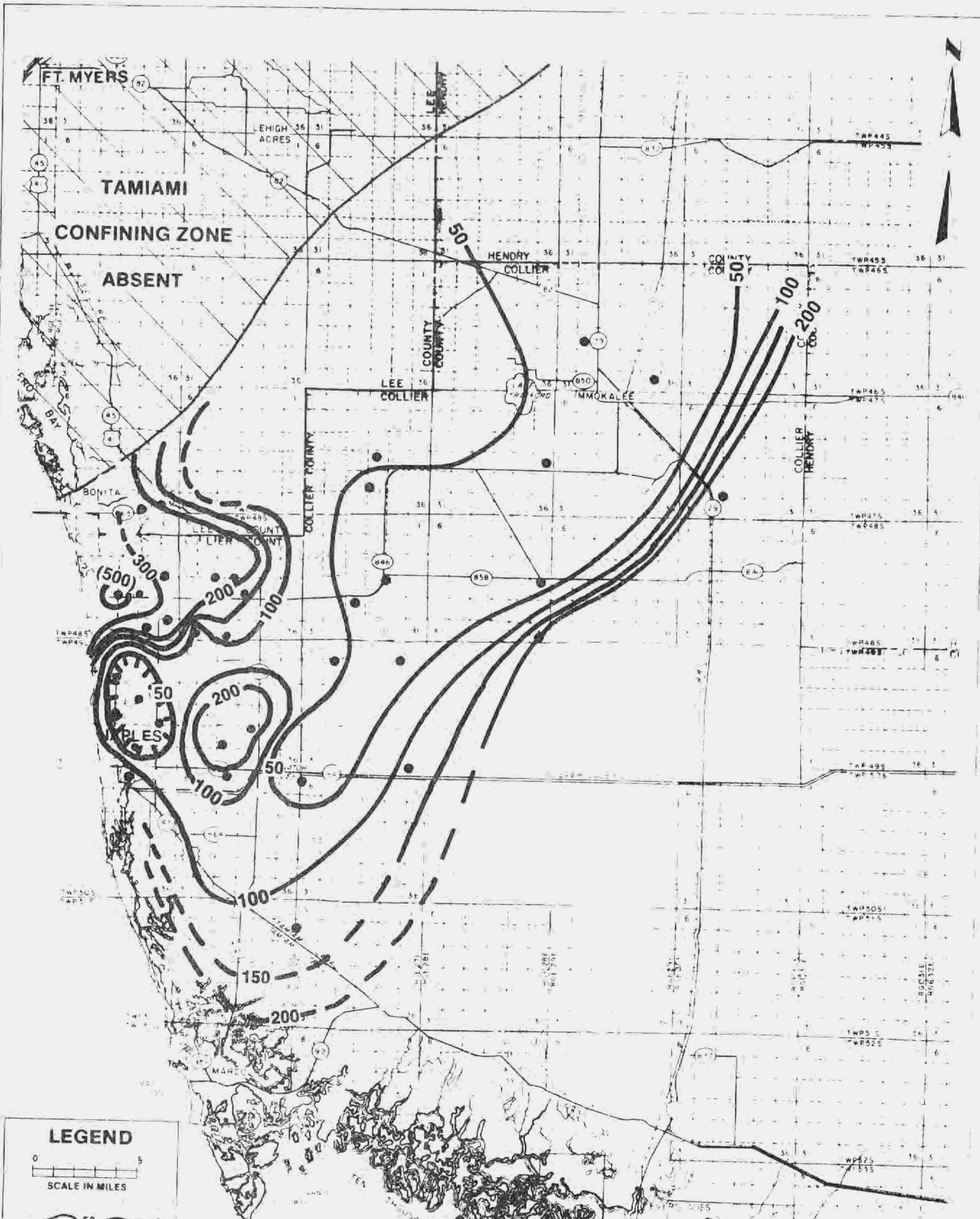


Figure 50 CHLORIDE CONCENTRATIONS WITHIN THE LOWER TAMIAMI AQUIFER

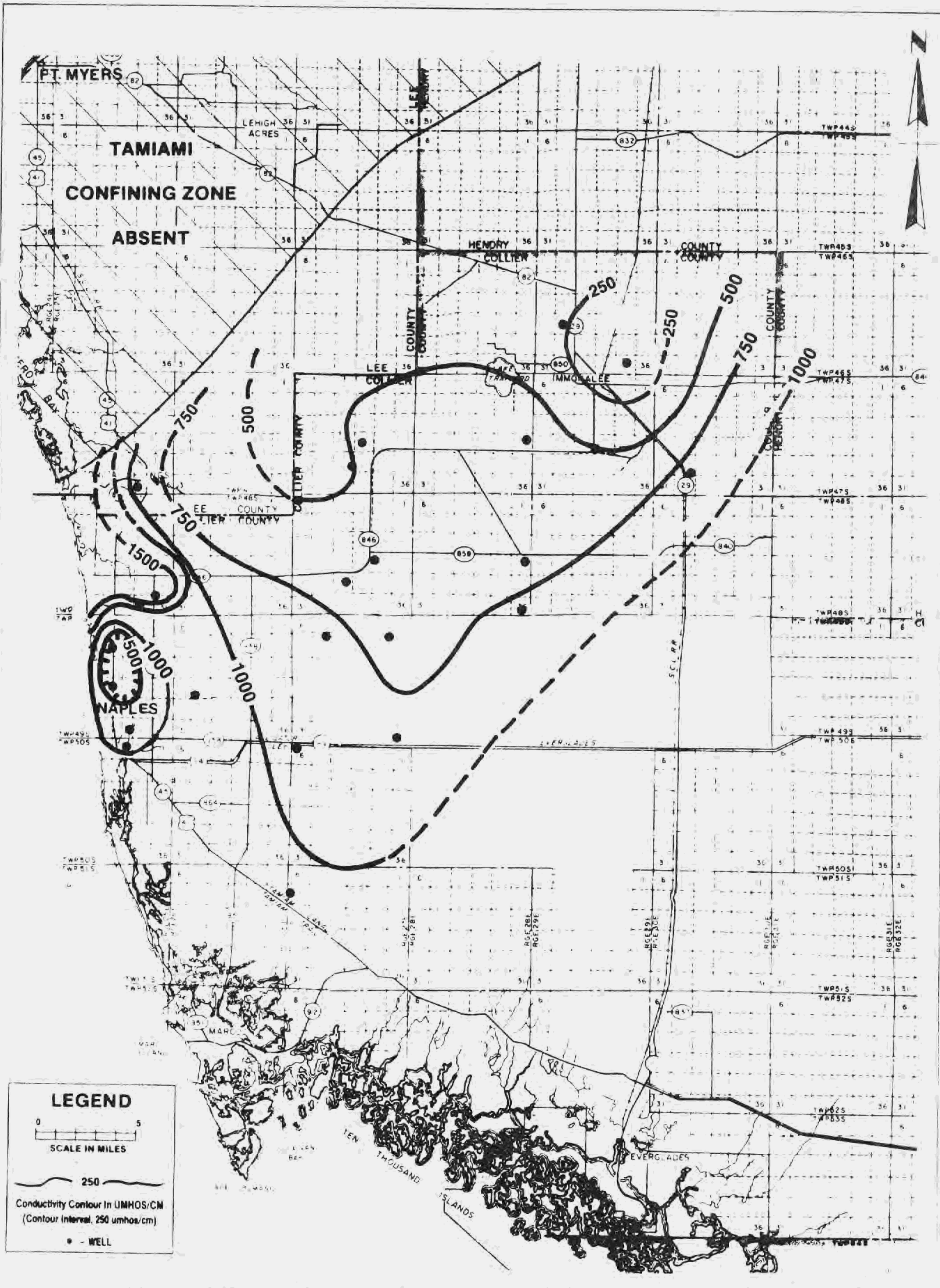


Figure 51 CONDUCTIVITY VALUES WITHIN THE LOWER TAMIAMI AQUIFER

TABLE 5

WATER QUALITY DATA FROM THE SANDSTONE AQUIFER

USGS NO.	SFWMD NO.	Cl (mg/l)	SO_4 (mg/l)	TDS (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	T Fe (mg/l)	ALK (meq/l)	COND. (umhos/cm)	DATE
C-969	C-2013-D	133.4	15.6	--	109.70	10.58	71.20	1.75	5.15	970.0	8/25/80
C-989	C-2041-D	192.0	111.5	812.0	30.00	18.40	207.50	0.47	4.76	1232.0	6/8/84
C-303	--	720.0	110.0	1458.0	81.00	63.00	310.00	1.10	--	3200.0	10/8/81
C-689	--	68.0	7.9	410.0	50.00	25.00	65.00	--	--	750.0	10/8/81
C-688	--	42.0	49.0	406.0	39.00	21.00	75.00	0.70	--	660.0	10/8/81
C-298	--	89.0	18.0	411.0	33.0	22.00	76.00	1.11	--	640.0	10/7/81
C-687	--	120.0	20.0	469.0	49.0	17.0	86.00	0.22	--	780.0	10/7/81
C-531	--	28.0	2.9	390.0	83.0	16.0	35.00	0.06	--	--	10/7/81

MID-HAWTHORN AQUIFER

USGS NO.	SFWMD NO.	Cl (mg/l)	SO_4 (mg/l)	TDS (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	T Fe (mg/l)	ALK (meq/l)	COND. (umhos/cm)	DATE
C-948	C-2033-M	164.0	322.9	1102.0	14.10	19.50	315.50	0.04	3.62	1740.0	4/4/84
C-955	C-2032-M	28.0	43.4	346.0	9.10	8.80	102.30	0.05	2.46	562.0	4/4/84
C-974	C-2034-M	2140.0	505.6	4332.0	99.50	141.50	654.00	<0.03	3.84	6790.0	6/8/84
C-983	C-2040-M	680.0	860.6	2774.0	6.90	21.60	749.00	--	5.74	4090.0	6/8/84
C-258	--	1000.0	570.0	402.0	110.00	5.90	36.00	0.20	--	--	10/7/81
C-684	--	130.0	2100.0	3287.0	270.00	230.0	360.00	0.019	--	--	10/8/81

Conductivity trends are presented in Figure 53. Conductivity values exceed 800 umhos/cm near the Lehigh Acres wellfield in Lee County. The chlorides in this area (Figure 52) are not anomolously high and the conductivity is probably being controlled by the presence of other ions. Two areas of anomalously high chloride and conductivity values occur near C-858 and C-846 in north-central Collier County (Figures 52 and 53). These high values suggest the presence of connate water or upward movement of saline water from abandoned artesian Floridan wells. Additional chloride and conductivity data need to be collected from these areas to determine the actual source and cause of the high values.

Mid-Hawthorn Aquifer

Water quality within the mid-Hawthorn aquifer in Collier County is variable. Generally, waters within this aquifer have high levels of calcium, magnesium, and sulfate, with moderate to high levels of dissolved chlorides (Table 5). There is not enough data to determine regional water quality trends for the mid-Hawthorn aquifer. Chloride data from three wells (C-2032, C-2033, and C-684) located along State Roads 846 and 858 in the center of the study area, indicate the water is within DER standards for this parameter. Water quality for well C-974 reflects the influence of a nearby short cased Floridan well. The Floridan well has been plugged and chloride levels had dropped in C-974 (C-2034) to just over 900 mg/l by June 1985. The mid-Hawthorn was also originally used for potable supply by the Everglades City wellfield until the wells became too salty for use. Additional information must be gathered to determine the development potential of this aquifer from a water quality standpoint.

SALTWATER INTRUSION

Saline water is found in the coastal portions of the Surficial Aquifer System throughout Florida. Salt water intrusion occurs when head levels are altered causing an imbalance along a fresh water/salt water interface. In Collier County there are three ways in which salt water occurs in groundwater:

1. lateral encroachment of salt water from the Gulf of Mexico,
2. vertical intrusion from abandoned artesian wells which tap the underlying saline aquifers, or
3. ancient sea water entrapped within sediments (connate water).

There are several theories concerning the coastal relationship between salt water and fresh water. The Ghyben-Herzberg theory (Herzberg, 1901) is based on an empirical relationship between salt water density and fresh water head. Generally, the theory states that in coastal areas for every foot of fresh ground water head above sea level, salt water occurs at 40 feet below sea level. This theory assumes the interface to be planar with no zone of diffusion and no discharge across the boundary.

Cooper (1959) proposed that the boundary was not an interface but a zone of diffusion. According to his theory, saltwater moves cyclically inland along the aquifer floor, upward into the zone of diffusion, and then returns to the sea. Glover (1964) addressed the shape of the interface and the general proximity of the boundary in terms of a dynamic interface. In this theory, the interface is a diffussed front, the orientation of which is based on outflow rates as well as differences in specific gravity.

Salt water intrusion occurs all along the coast line of the study area from Bonita Bay to the Ten Thousand Islands area. This process is further aided through open channels, rivers, and canals which allow salt water to migrate inland. Salt water control structures built by public agencies and private developers have limited salt water migration by keeping fresh water heads higher inland. Increased pumping by municipal and private wellfields during the dry months may also induce landward salt water migration. Monitor wells located between wellfields and the coast are used to detect salt water encroachment.

Deep, abandoned wells which tap the Floridan Aquifer System represent a possible source of salt water encroachment. Within the study area, potentiometric water levels in the Floridan Aquifer System exceed land surface elevations and water quality is known to be poor.

Many deep wells were constructed during the 1930's, 40's, and 50's by the agricultural and petroleum industries in this area. These wells were primarily constructed with steel casing which were driven and not grouted into place. With this type of construction, casing life expectancy is 20 to 25 years based on the mildly corrosive nature of the groundwater in the shallower aquifers (Burns, 1983). In addition, most of the old Floridan wells were short cased, with casings seldom extending beyond 200 feet below land surface. This results in more than one aquifer being exposed to open borehole flow (Figure 54).

Salt water contamination from abandoned Floridan wells in Collier County is not as widespread as in adjacent Lee and Hendry Counties. This problem

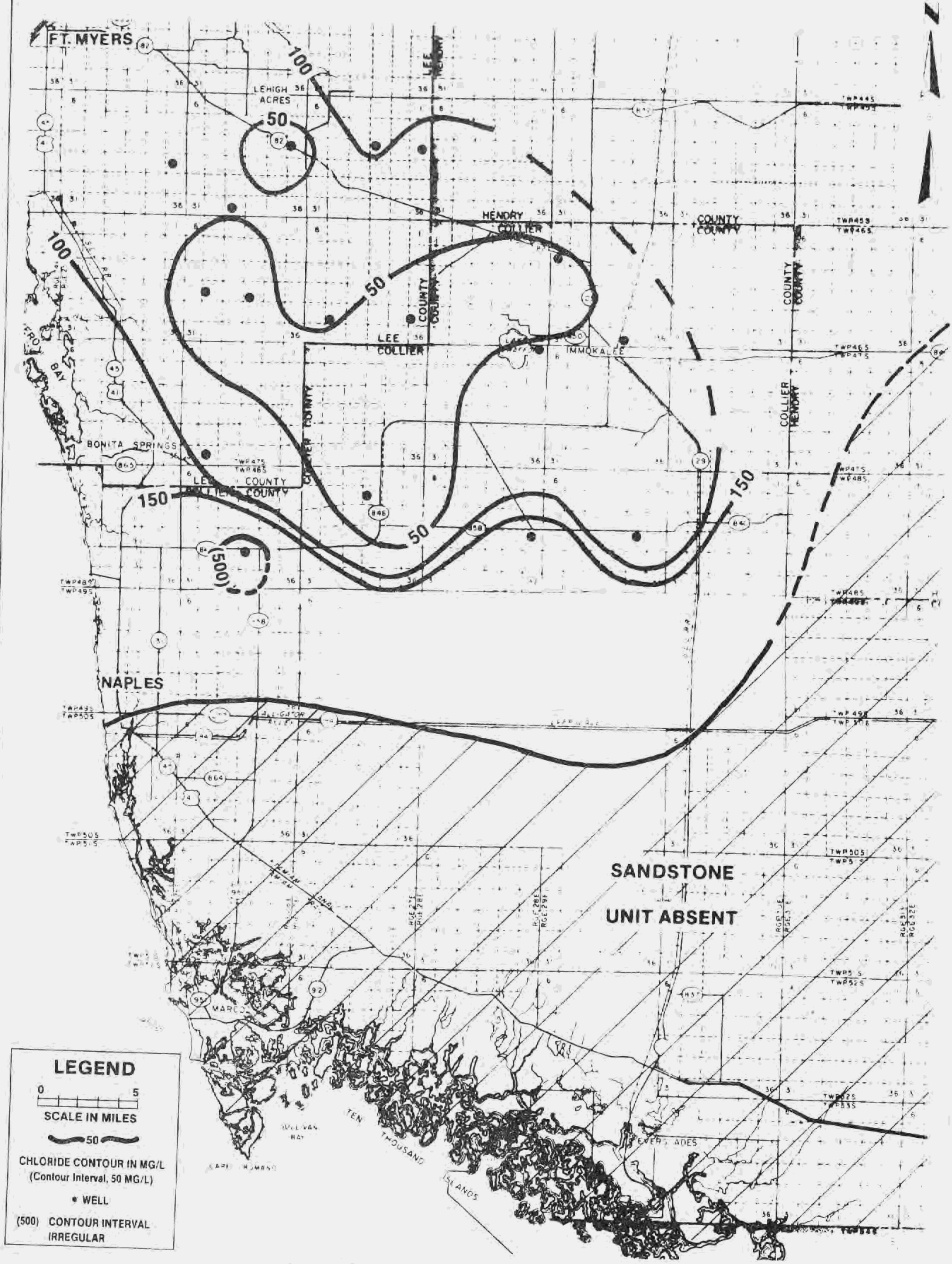


Figure 52 CHLORIDE CONCENTRATIONS WITHIN THE SANDSTONE AQUIFER

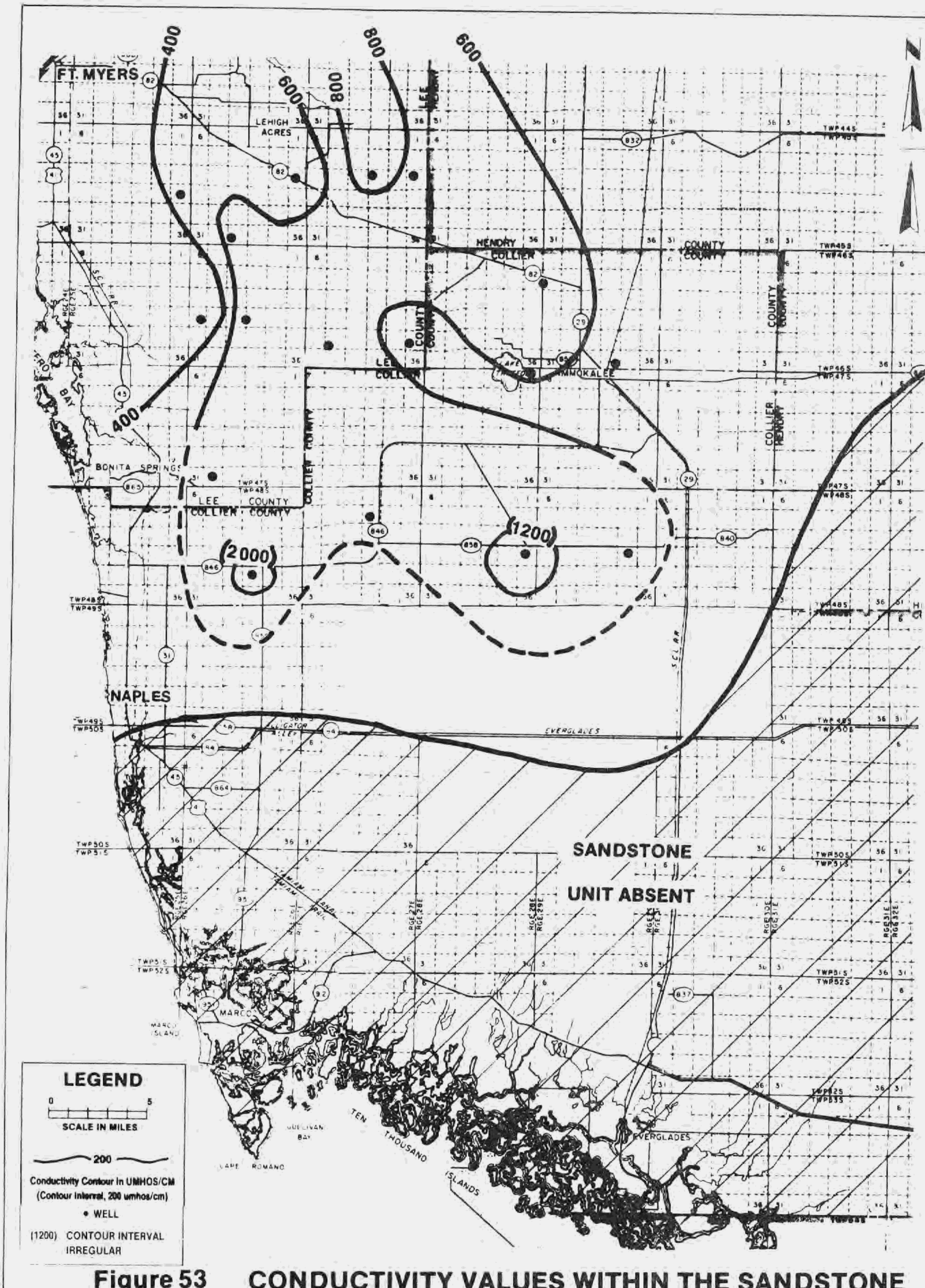


Figure 53 CONDUCTIVITY VALUES WITHIN THE SANDSTONE AQUIFER

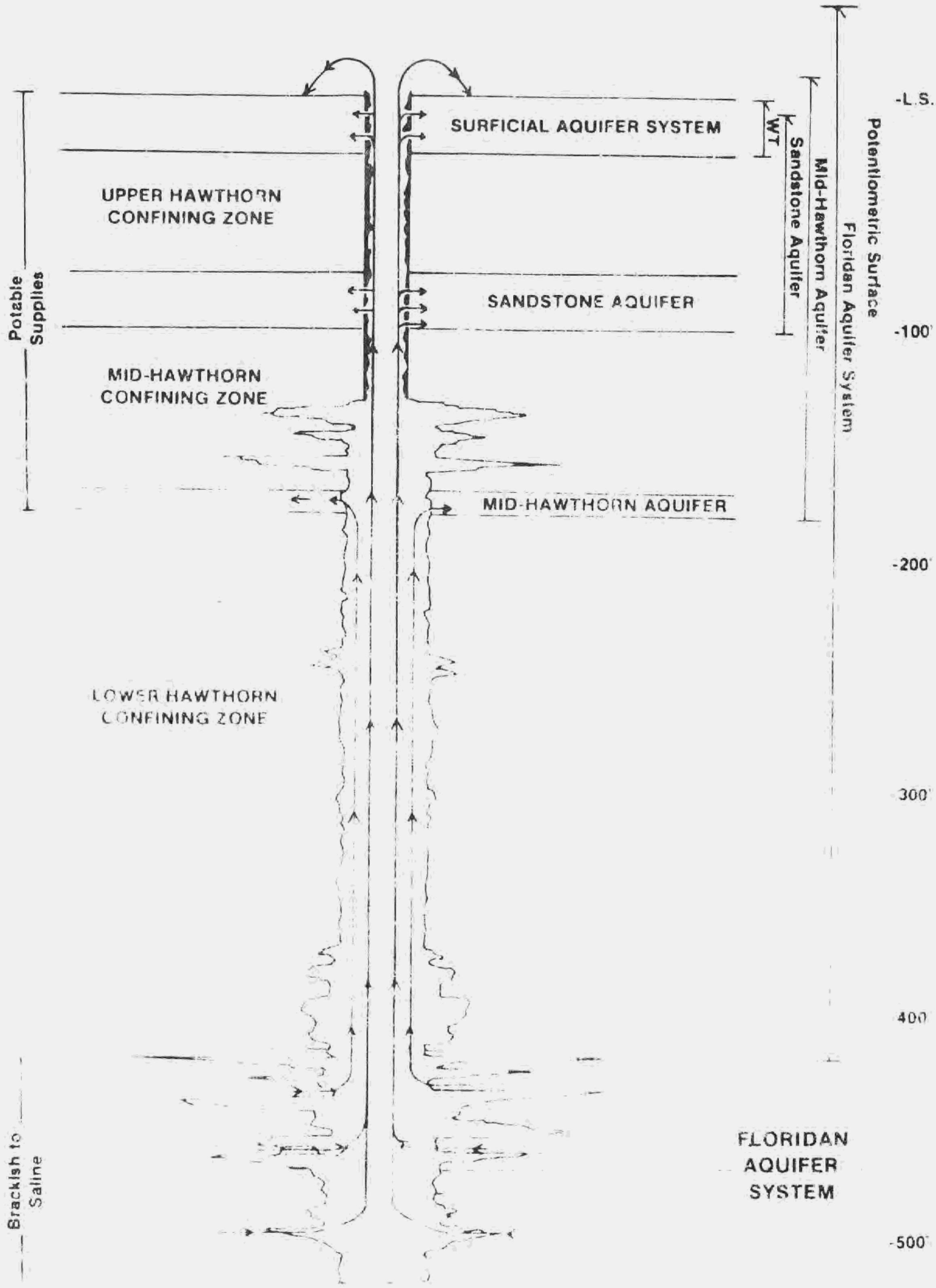


Figure 54 GENERALIZED CROSS SECTION DENOTING PATHS OF UPWARD SALINE MIGRATION (SFWMD Tech. Publication 83-8)

should be remedied by locating and cementing these wells which are sources of interaquifer contamination.

Little is known regarding the areas affected by connate water within the study area or water remaining from sea inundations during the Pleistocene interglacial stages. Localized areas of connate water are known to exist but their regional effect is considered minimal. Based on ambient groundwater flow and recharge rates, McCoy (1962) indicates it is likely that most of the sea water present in the shallow aquifers would have been flushed out since Pleistocene time.

SALTWATER INTRUSION MONITORING AND MANAGEMENT PROGRAM

To protect municipal wellfields from saline contamination the SFWMD, in cooperation with local municipalities and private utility owners, have set up a program called Saltwater Intrusion Monitoring and Management (SWIM). This program was initiated to monitor water levels and water quality for coastal wellfields.

Water quality and water levels are measured on a monthly basis except when droughts may warrant more frequent sampling. The monitoring wells are spaced between the wellfield and the salt water/fresh water interface such that, if a major increase in chlorides and conductivity is detected, corrective action can be taken before the saline water moves further landward into the wellfield.

The sampling of these monitor wells is the responsibility of the public utility or company that owns the wellfield. Water levels and water quality test results are sent to the SFWMD for further analysis and interpretation.

Eight SWIM programs are operational within Collier County (Figure 55). These are:

1. City of Naples (11-00017-W)
2. City of Naples, E. Golden Gate (11-00018-W)
3. Eagle Creek (11-00179-W)
4. Everglades City (11-00160-W)
5. The Glades (11-00015-W)
6. Marco Island Utilities (11-00080)
7. Pelican Bay Improvement Dist. (11-00052-W)
8. Quail Creek (11-00193-W)

Complete wellfield monitor well configurations can be found in Burns and Shih (1984). The tables in Appendix III shows parameters from each wellfield's monitor network (i.e., monitored aquifer, dry and wet season water levels, chlorides, and specific conductance).

WASTE DISPOSAL FACILITIES

The waste disposal facilities in Collier County consist of landfills, transfer stations, and incinerators. Collier County is relatively new to community solid waste disposal and thus has only a few known sites. The locations of these sites are shown in Figure 56. Most of these sites occur near populated areas. The landfills are classified by the Florida Department of Environmental Regulation (DER) as disposal facilities, and incinerators are classified under volume/resource recovery facilities as are transfer stations. Further classification is found in Table 6. Definitions of the facilities found in the study area follow Table 6.

TABLE 6. DESCRIPTIVE DIRECTORY OF SOLID WASTE FACILITIES

1.7 Class Codes for Type 3 Facilities (Solid Waste)

<u>Disposal Facilities</u>

100 Class I Landfill
200 Class II Landfill
300 Class III Landfill
  310 Trash/Yard Trash
  320 Trash Composting
400 Sludge Disposal Facility
500 Other Disposal Facility

<u>Volume Reduction/Resource Recovery Facilities</u>

600 Thermal Treatment Facility
  610 Incineration
    611 Incineration Only
    612 Waterwall Incinerator
  620 Pyrolysis
700 Volume Reduction/Transfer Station
  710 Baler/Compactor
  720 Shredder/Pulverizer
  730 Sludge Concentration
  740 Composting Plant
  750 Transfer Station
800 Resource Recovery Facility
  810 Material Recovery
  820 Energy Recovery
    821 Biomass Gas Production
900 Other Volume Reduction/Resource Recovery Facility
  999 Unknown

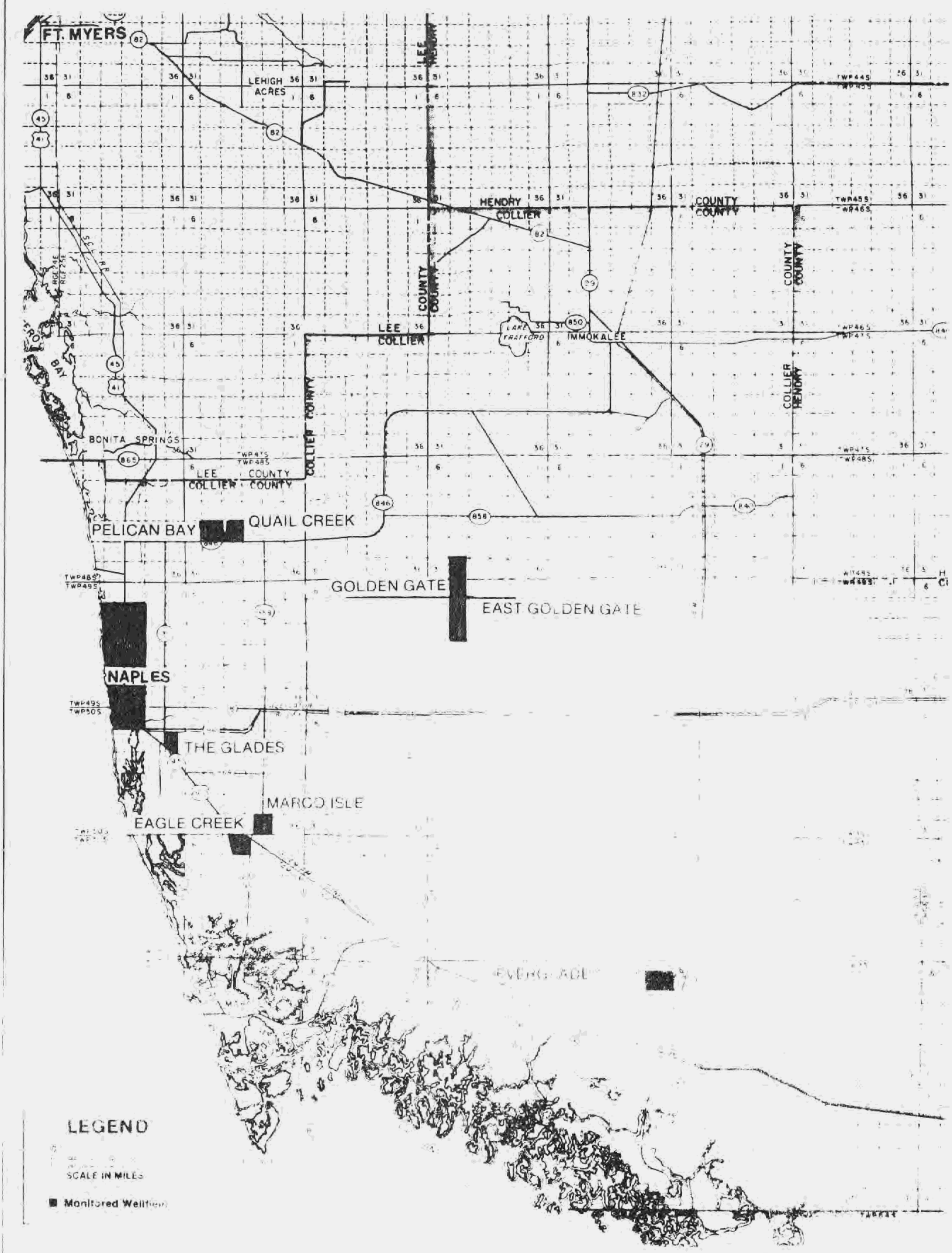


Figure 55 LOCATION OF SALINE WATER INTRUSION MONITOR & MANAGEMENT (SWIM) PROGRAMS (COLLIER COUNTY)

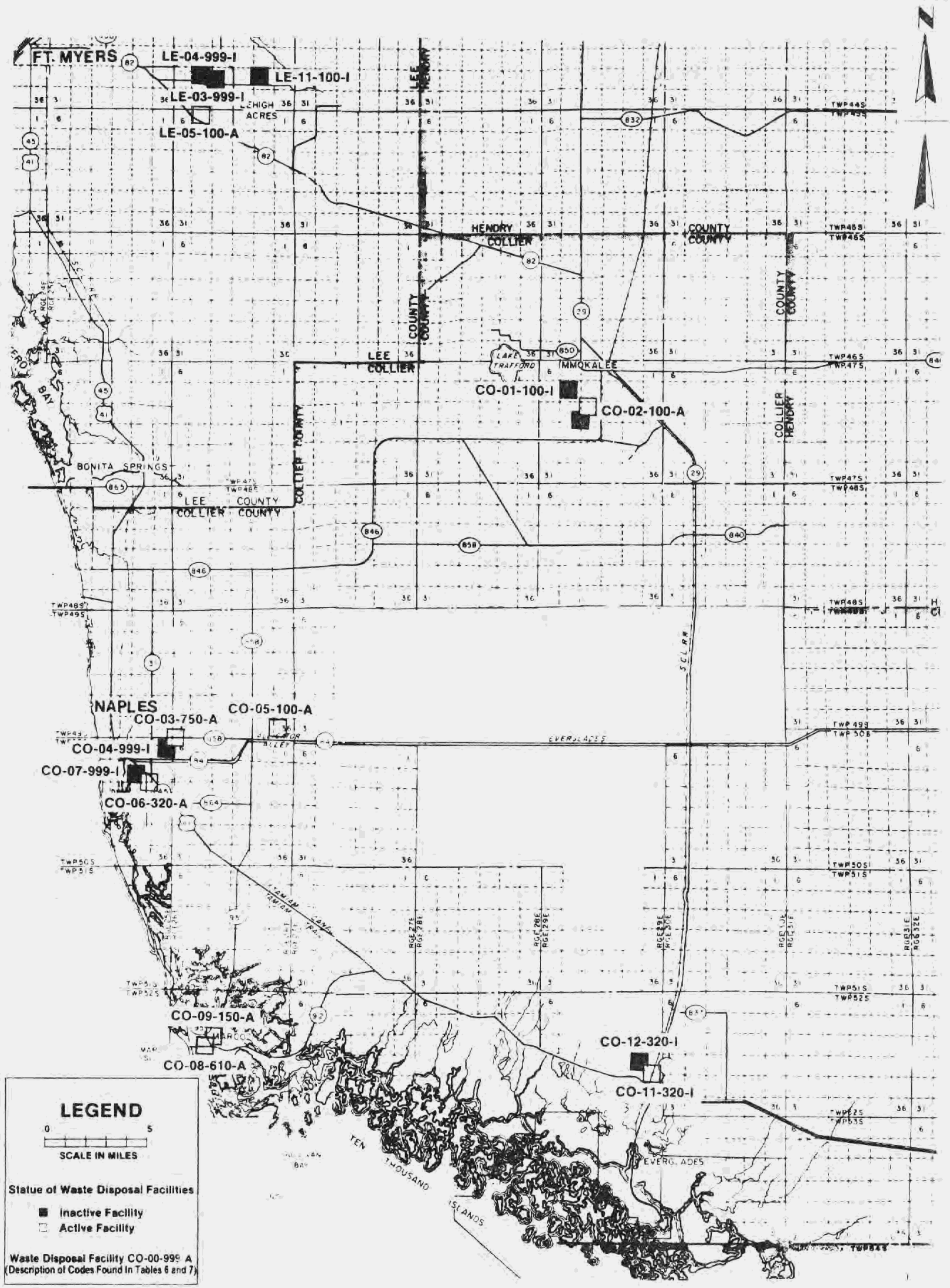


Figure 56 LOCATIONS OF ACTIVE AND INACTIVE WASTE DISPOSAL FACILITIES

Class Code	Facility	Description
100	Class I Landfill	Those which receive solid waste and which receive a monthly average of 20 tons or more or 50 cubic yards or more per day. These sites receive an initial cover at the end of each day.
320	Class III Landfill	Those which receive only trash or yard trash. These sites receive an initial cover only once a week, unless they are associated with composting facilities.
610	Thermal Treatment	The burning of trash shall be limited to incineration, handling wastes on a first come first serve basis. No waste will be allowed to remain unprocessed for more than 48 hours.
750	Transfer Station	A facility where solid waste from several relatively small vehicles is placed into a larger vehicle before being transferred to a solid waste processing or disposal facility.
999	Other Volume Reduction/Resource Recovery Facility	Use at the present time is unknown.

Of the eight existing sites in the study area, three are Class I landfills, two are incinerators, two are transfer stations, and one is a Class III landfill. In addition there are eight known inactive waste disposal facilities. Information on the types of facilities at most of these inactive sites is unavailable at this time.

The potential for groundwater contamination from waste disposal facilities increases because of improper disposal of the wastes, poor site selection for landfills, and improper design of the disposal facilities. Contamination of groundwater occurs when rain enters a landfill and percolates down through the waste picking up contaminants from organic and inorganic substances. After percolation through the waste, the contaminants may enter the groundwater through direct infiltration or through a semi-impervious liner. Once the contaminated water or leachate reaches the groundwater, it usually moves in the general direction of groundwater flow and creates a plume of contamination (Figure 57). Theoretically, after a period of time the plume expands, but the outside fringes become less concentrated with contaminants because of adsorption, dispersion and dilution.

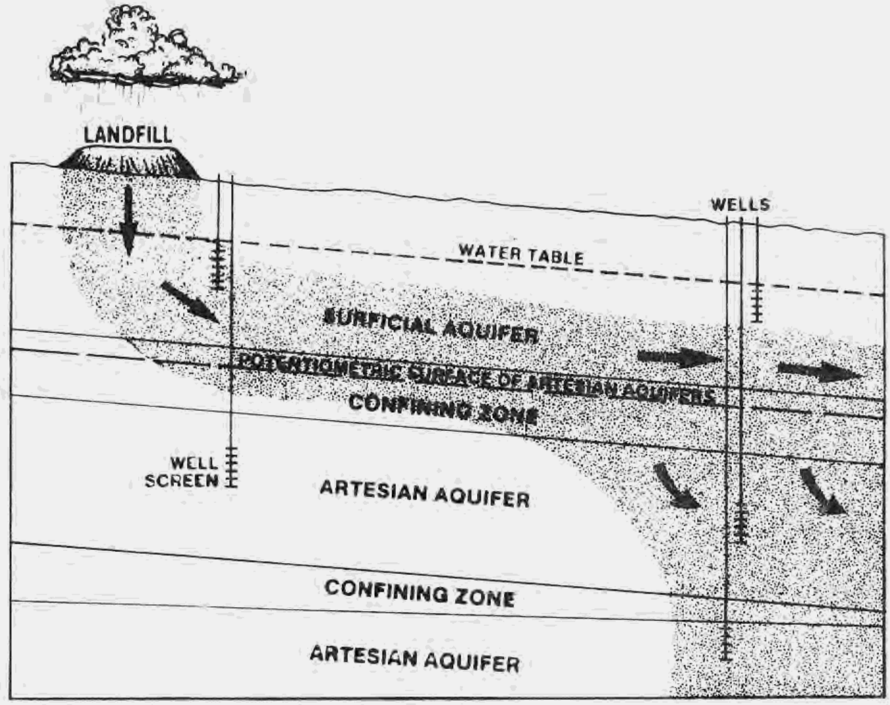
TABLE 7. STATUS OF SOLID WASTE FACILITIES WITHIN STUDY AREA

	ACTIVE	
LOCAL #	DESCRIPTION	CLASS CODES
Le-05	Gulf Coast Sanitary Landfill	100
CO-02	Immokalee Landfill #2	100
CO-03	Naples Transfer Station	750
CO-05	Naples Sanitary Landfill	100
CO-06	Naples Yard Trash Composite Site	320
CO-08	Marco Island Incinerator	610
CO-09	Marco Island Transfer Station	750
CO-11	Carnestown Yard Trash Composite Site	320

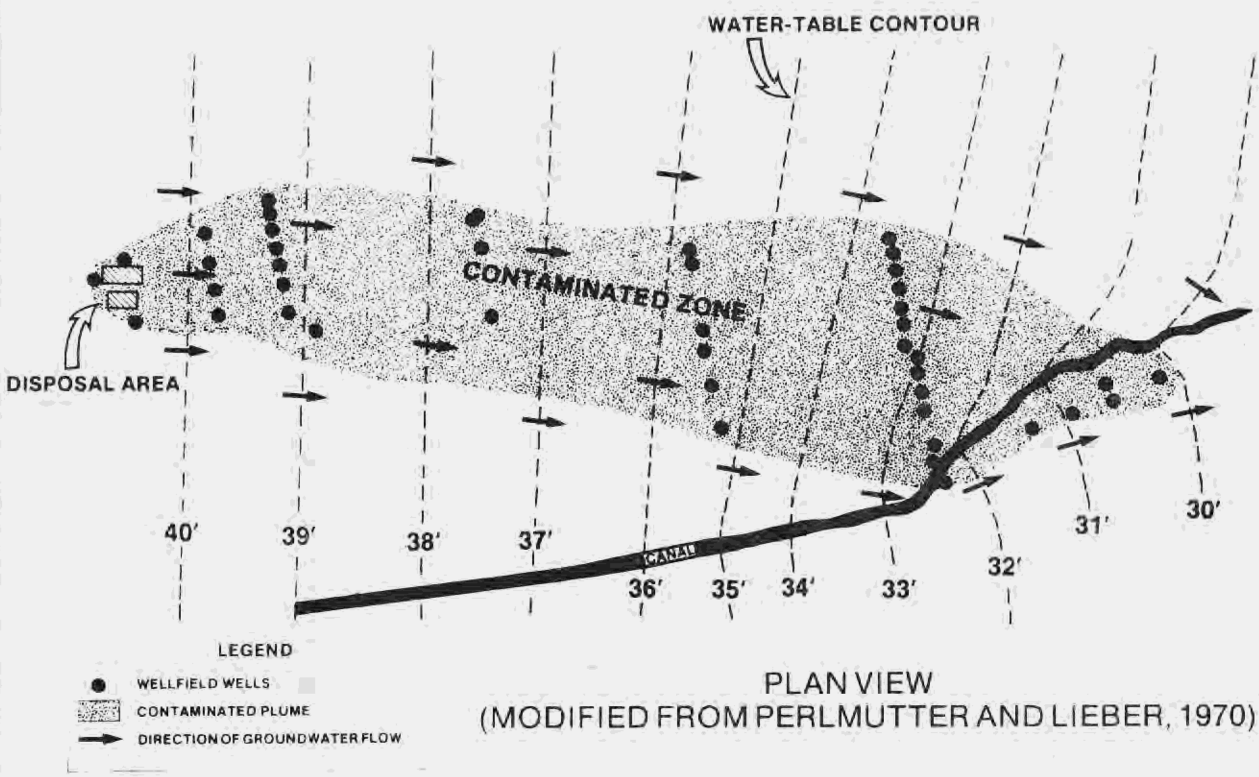
	INACTIVE	
LOCAL #	DESCRIPTION	CLASS CODES
CO-01	Immokalee Landfill #1	100
CO-04	Naples Dump	999
CO-07	Goodlette Road Landfill	999
CO-10	Carnestown Transfer Station	999
CO-12	Temple Drive Landfill	320
LE-03	Buckingham Landfill	999
LE-04	City of Fort Myers Landfill	999
LE-11	Old Lehigh Dump	100

The only known waste disposal facility monitor network was established around the Collier County Sanitary Landfill (Figure 56) by the USGS in 1982. Eight wells were drilled in order to monitor the groundwater for several organic and inorganic contaminants. Water quality data collected for these wells in 1982 is listed in Table 8. All of the presented values are within DER groundwater contaminant standards (Table 8). These parameters have been monitored since October 1980 and have not shown any noticeable increases (USGS Water Data Report, 1981).

The proper siting of landfills and other waste disposal facilities is an important aspect of groundwater management and is regulated by DER and SFWMD. Proper design, construction, and disposal



CROSS-SECTIONAL VIEW (MODIFIED FROM MILLER, 1980)



PLAN VIEW
(MODIFIED FROM PERLMUTTER AND LIEBER, 1970)

Figure 57 MOVEMENT OF LEACHATE PLUME WITHIN GROUNDWATER

TABLE 8

NUTRIENTS AND TRACE ELEMENTS (MG/L)

COLLIER COUNTY LANDFILL

USGS WELLS	LATITUDE	LONGITUDE	SAMPLE DATE	B.O.D.	TOTAL NITRATE	TOTAL NITRITE	TOTAL NO2 & NO3	TOTAL AMMONIA	ORGANIC NITROGEN
C-540	26 09 17	81 39 16	7/22/81	9.10	0.00	0.00	0.00	0.42	0.50
C-538	26 09 17	81 39 44	7/22/81	4.22	0.00	0.00	0.00	0.50	0.60
C-539	26 09 17	81 39 44	7/22/81	1.01	0.00	0.00	0.00	0.56	0.90
C-536	26 09 41	81 39 31	7/22/81	9.01	0.00	0.01	0.01	0.30	1.00
C-537	26 09 41	81 39 31	7/23/81	7.01	0.00	0.00	0.00	0.38	0.70
C-535	26 10 06	81 39 16	7/23/81	1.20	0.00	0.00	0.00	0.29	0.60
C-533	26 10 06	81 39 43	7/23/81	6.00	0.00	0.01	0.01	0.50	0.75
C-534	26 10 06	81 39 43	7/23/81	3.90	0.00	0.02	0.02	0.49	1.10
DER Groundwater Potable Standards	--	--	--	10	--	10	--	--	--

USGS WELLS	NITROGEN AMMONIA ORGANIC TOTAL	TOTAL NITROGEN	TOTAL PHOSPHORUS	PHOSPHORUS ORTHO TOTAL	DISSOLVED CADMIUM	DISSOLVED CHROMIUM	DISOLVED COPPER	DISSOLVED LEAD
C-540	0.90	1.00	0.01	0.01	0.02	0.02	0.00	0.03
C-538	1.20	1.20	0.09	0.08	0.00	0.01	0.03	0.00
C-539	0.20	1.05	0.05	0.05	0.03	0.02	0.01	0.03
C-536	1.30	1.30	0.05	0.03	0.01	0.03	0.01	0.00
C-537	1.00	1.10	0.08	0.03	0.01	0.00	0.03	0.01
C-535	0.90	0.90	0.05	0.01	0.01	0.02	0.00	0.01
C-533	1.00	1.00	0.10	0.09	0.01	0.04	0.01	0.01
C-534	1.60	1.60	0.12	0.01	0.01	0.00	0.01	0.02
DER Groundwater Potable Standards--	--	--	--	--	0.01	0.05	1.00	0.05

practices are the responsibility of the utility or company which owns the waste disposal facility. Locations of known waste disposal facilities within the study area in relation to the existing wellfields are shown in Figure 58. Most of the waste disposal facilities (active and inactive) are down gradient from existing wellfields. Most of the wellfields shown in this figure withdraw water from the water table and lower Tamiami aquifers. During periods of heavy pumpage, a wellfield's cone of influence may extend beneath a waste disposal sites in some cases. Monitoring of the groundwater near all of the waste disposal facilities (active and inactive) should be established to provide information on the existence or possible migration of contaminated groundwater into the wellfields.

WATER QUALITY ASSURANCE ACT

The Water Quality Assurance Act (WQAA) was established by the Florida Legislature in 1983. Funding was provided to all the water management districts to assist the DER in locating and accessing groundwater contamination sites.

Phase I of the Water Quality Assurance Act was devoted to a literature search and compilation of available data relative to the groundwater resources of the South Florida Water Management District. The types of data compiled for Collier County during Phase I include:

1. Compilation of data pertaining to areal continuity of water producing zones.
2. Location of public water supply wellfields and extent of cones of influence.
3. Identification of saltwater intrusion boundaries.
4. Location of active and abandoned landfills.
5. Delineation of various land uses which may affect water quality:
   a. commercial
   b. institutional
   c. agricultural
   d. industrial
   e. borrow or rock pits

The information for contour maps depicting the depth and areal continuity of producing zones and aquifers in Collier County was taken from preliminary data compiled and used for this report. The locations of public water supply wellfields and extent of cones of influence were taken from District permit files and DER files. The public water supplies were categorized into major and minor public water supply systems. The major public water supply systems are those that withdraw more than 100,000 gallons per day; the minor public water supply systems withdraw less than 100,000 gallons per day. The saltwater intrusion boundary was determined from information furnished by the District's SWIM (Salt Water Intrusion Monitoring and Management) program. Active and abandoned landfills in Collier County were located by using District information on file, the DER Groundwater Pollution Source Management System (GMS), and information supplied by individuals with long term knowledge of the area. The various land uses which may affect water quality were delineated using SFWMD Land Use and Land Cover Classification Codes.

Phase II of the WQAA program entails establishing a monitor well network designed to help determine the current (ambient) groundwater quality for all potable aquifers within the District. In Collier County the existing network of USGS wells supplies sufficient coverage for WQAA purposes. Thirty-eight of these wells will be sampled. The breakdown is as follows: 23 Surficial Aquifer System wells (17 water table and 6 lower Tamiami), 13 Intermediate Aquifer System wells (7 Sandstone and 6 mid-Hawthorn), and 2 Floridan Aquifer System wells. These wells will be sampled and analyzed once per year.

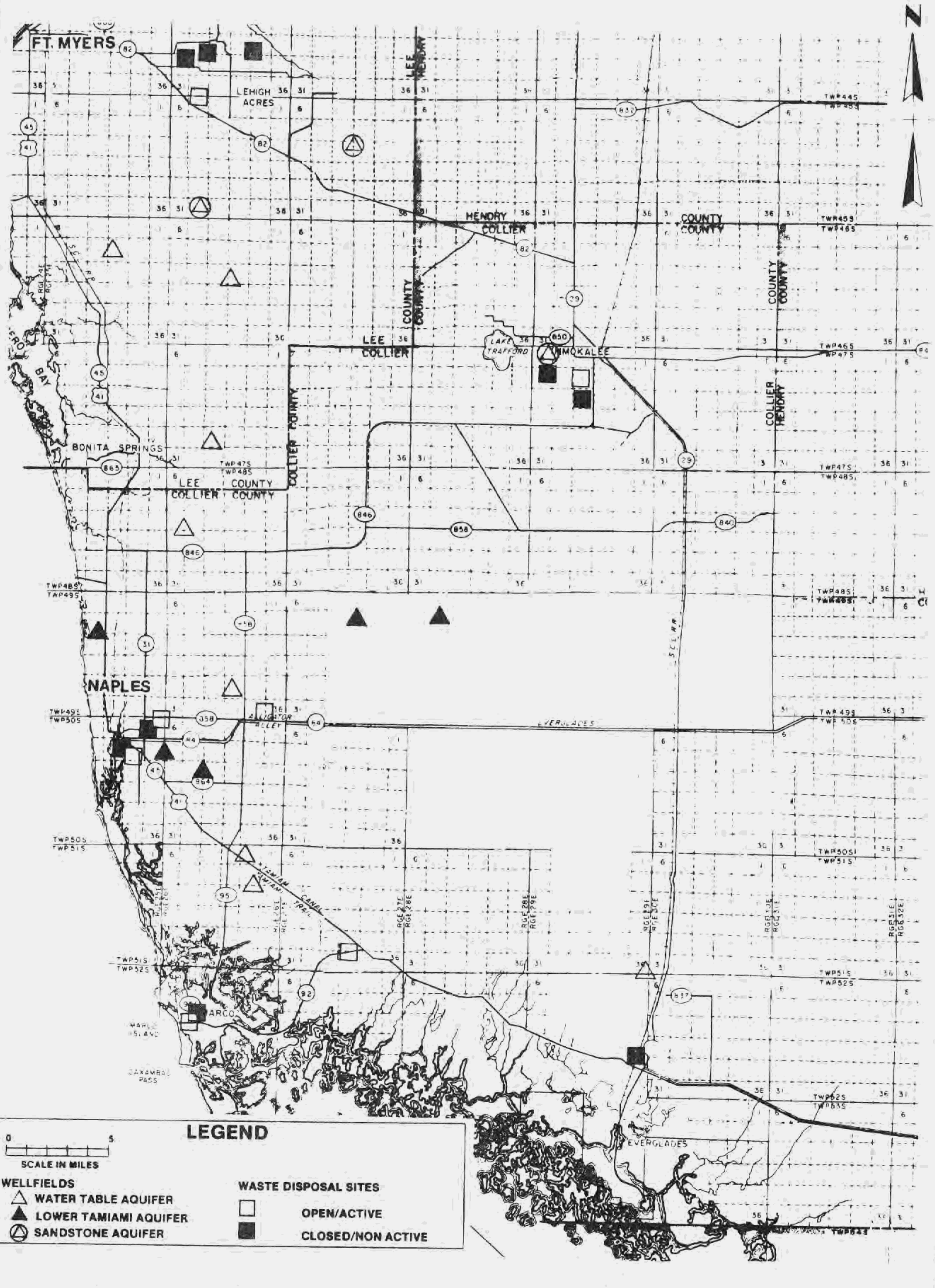


Figure 58 LOCATIONS OF WELLFIELDS AND WASTE DISPOSAL SITES

WATER USE

INTRODUCTION

The three major classifications of water users in Collier County are, in order of magnitude, agricultural, recreational/landscape, and public. Agricultural water use is concentrated in the northeastern quarter of the study area. Citrus, winter vegetables, and unimproved pasture comprise the majority of the agricultural industry in this area. Recreational water use is concentrated along the western coastal region. Golf courses and country clubs account for the majority of water used in this class. There are 12 permitted public supply wellfields which are located adjacent to major population centers.

Permitted allocations for agricultural properties are based on the type of crop, efficiency of the irrigation system, the amount of land to be irrigated, and water resource impacts of required withdrawals. Agricultural pumpage is seasonal and allocated withdrawals are based on maximum monthly and annual requirements. Few agricultural wells are metered, making it difficult to determine actual water withdrawn.

Recreational/landscape water users are in close competition with public supply wellfields in the Naples area. The majority of recreational users are located within five miles of the coast from the Lee-Collier County line south to Marco Island. Combined annual allocation for landscape and recreational users exceeds 15 billion gallons. Due to the proximity of municipal wellfields and coastal salt water, actual pumpage data are more closely monitored than is the case with agricultural users.

Permitted allocations for public supply wellfields are based on the needs of the population served, impacts on existing permitted users, and water quality considerations (salt water intrusion or groundwater contamination). Current annual allocations for the 12 utilities exceed 13.1 billion gallons. Water quality, local potentiometric elevations, and actual pumpage data are routinely monitored by the utility and submitted to the Water Management District for evaluation.

MUNICIPAL WATER SUPPLY

Three major wellfields supply nearly 70 percent of Collier residents with potable water. These include the City of Naples Coastal Ridge, East Golden Gate, and the Collier County Golden Gate wellfields. In addition, there are two smaller municipal service areas (Immokalee and Everglades) and seven private utilities (Figure 30).

Collier County has been divided into eleven planning areas by the Collier County Planning Department (Figure 59). Seventy-seven percent of the population resides in coastal planning areas 1 through 8. According to statistics provided by the county (Tom Crandall, written communication; Appendix IV), the population in this region is expected to rise from 84,500 (1984) to 125,300 by the year 1995. To accommodate this growth and provide efficient services, the county is regionalizing its wellfields with new facilities inland away from the coast. Four major service areas, denoted as regions A through D (Figure 59), are planned along the coastal region of the county. A preliminary evaluation of the future water requirements of these regions from a resource availability standpoint is presented here.

Region A: North Naples

Currently, regions A and B (Figure 59) are both serviced by the City of Naples Coastal Ridge and East Golden Gate wellfields. Under the Collier County Comprehensive Plan, region A (north Naples) will be served by its own wellfield in the near future. In order to determine the water requirements of region A alone, water use data from both wellfields were evaluated with respect to the populations in both regions A and B. Water used from February 1984 to January 1985 for each city wellfield is shown in Table 9. The combined average daily use for both wellfields is 15.97 million gallons (MG) with the dry season pumpage exceeding the yearly average by approximately 14%. According to population estimates (Appendix IV), in 1984 the combined population of regions A and B was 57,570 with a calculated per capita use of 277 gallons per person per day. Table 10 shows the projected population for region A from 1985 to 2000 along with estimated water requirements. It should be noted that the water quantity estimates shown here are for planning purposes only and may not have any bearing on the actual quantity used at a later date. According to Utilities Director Tom Crandall, the county is planning to construct an 8 MGD wellfield and treatment plant to service area A. Data provided in Table 10 shows that an 8 MGD capacity plant would provide sufficient quantities of water for average daily

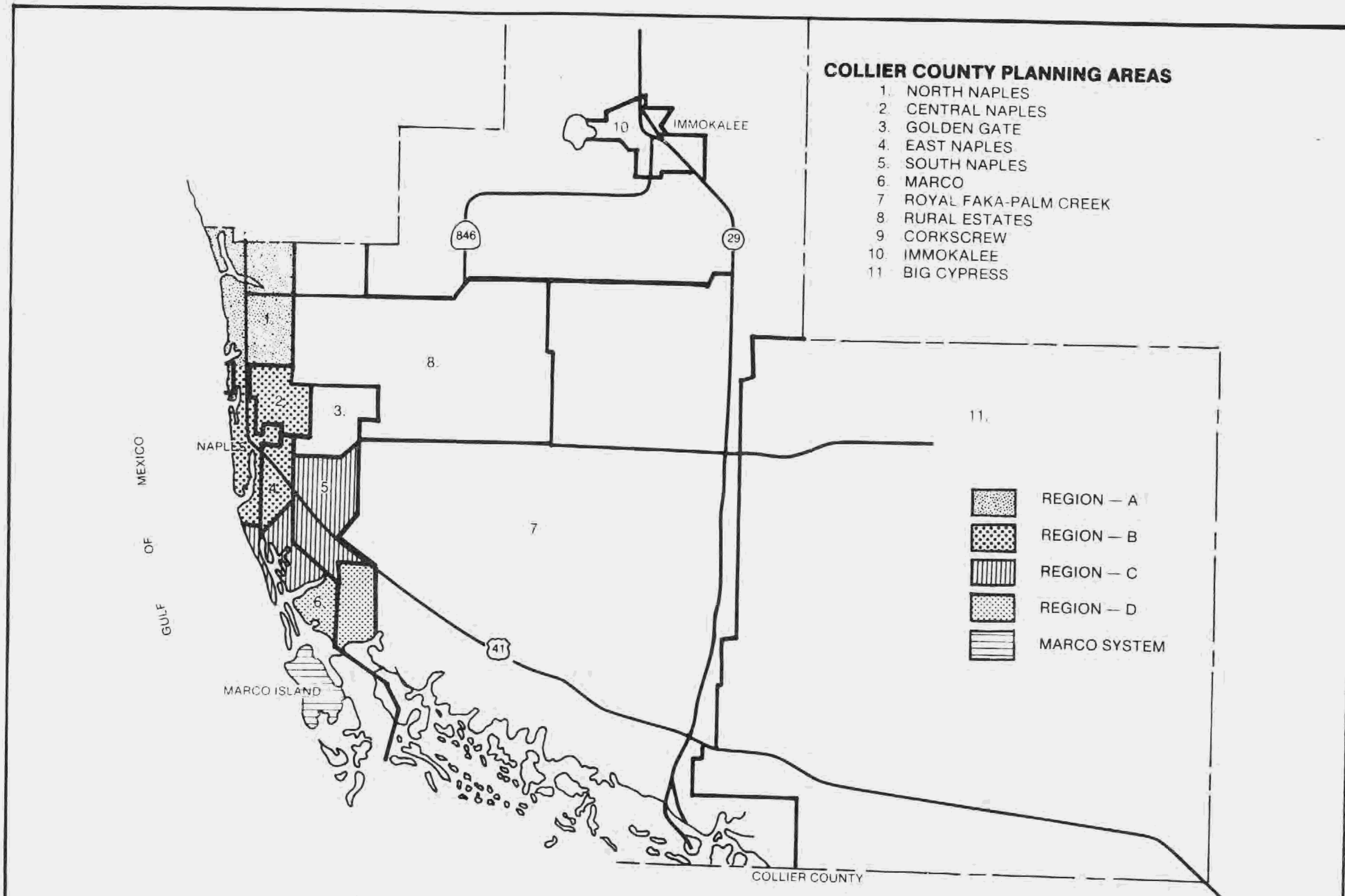


Figure 59 COLLIER COUNTY COMMUNITY PLANNING AREAS

TABLE 9. CITY OF NAPLES (11-00017 & 11-00018)* RAW WATER USE FROM FEBRUARY 1984 to JANUARY 1985

	COASTAL RIDGE		EAST GOLDEN GATE	
	MO. TOTAL (MG)	AVG. DAY (MG)	MO. TOTAL (MG)	AVG. DAY (MG)
January 1985	105.029	3.388	462.858	14.93
December 1984	190.534	6.146	373.500	12.048
November 1984	144.233	4.808	374.370	12.479
October 1984	216.648	6.989	271.398	8.755
September 1984	233.900	7.800	147.240	4.908
August 1984	255.341	8.237	137.640	4.44
July 1984	234.132	7.553	158.392	5.109
June 1984	132.133	4.404	320.516	10.684
May 1984	112.954	3.644	449.434	14.498
April 1984	218.412	7.280	332.076	11.06
March 1984	247.620	7.988	262.986	8.483
February 1984	247.520	8.535	217.709	7.507
12 Month Average	194.874	6.398	292.343	9.575
Allocation (MGD)		7.288		12.740
Percent of Allocation	88%		75%	

Gietz Pit (11-00016) has been discontinued

TABLE 10. PROJECTED MUNICIPAL WATER USE REQUIREMENTS FOR REGION A - NORTH NAPLES

YEAR	ESTIMATED POPULATION		AVERAGE DAILY[2] USE (MG)	DRY SEASON DEVIATION	AVERAGE DRY SEASON DEMAND (MGD)
1985	High	16815	4.66	14%	5.31
	Med.	16050	4.44		5.07
1990	High	22780	6.31	14%	7.19
	Med.	20840	5.77		6.58
1995	High	27890	7.72	14%	8.81
	Med.	24530	6.79		7.75
2000	High	33655	9.32	14%	10.62
	Med.	28530	7.90		9.01

1. Estimates provided by Tom Crandall (Appendix IV).
2. Based on consumptive use of 277 gpd/capita.

usage through 1990. By the year 2000 dry season demands may exceed 10 MGD and maximum day requirements could be significantly higher.

The principal area proposed for the wellfield site for region A is located along the Cocohatchee Canal.

A detailed investigation of the hydraulic characteristics of the Cocohatchee Watershed was completed for the Big Cypress Basin Board by Missimer and Associates and published in three volumes between 1981 and 1983. This study involved the collection and analysis of lithologic and hydraulic data from the surface and groundwater resources within a 12 sq. mile region north of CR 858 (Figure 60). The purpose of this study was to determine the availability of groundwater for large scale municipal development. Two regional aquifers were identified in the study area; the water table aquifer, termed the "Coral Reef Aquifer" by the consultant, and the lower Tamiami aquifer, referred to as the Tamiami Zone I Aquifer. Due to the highly transmissive nature of the reefal limestones in the water table aquifer, this system was studied intensively.

In order to determine the yield of the water table aquifer in this location, the consultant used an analytical model to simulate the effects of a 50 MGD withdrawal. This simulation involved a single transmissivity value of 500,000 gpd/ft. and a specific yield of 0.3. Ten production wells, spaced at 2500 foot intervals, were assigned 5 MGD pumping rates for a period of 120 days without recharge. Under these conditions the drawdowns in the vicinity of the production wells were about 21 feet. From these results, the consultant concluded that "... a 30 MGD capacity could be operated as shown in the computer diagram without any potential 'undesirable' effect." (Missimer, 1983a). Missimer also suggested that, due to limitations of the model he used, it would be premature to consider this projection fully accurate. The three major limitations in the consultant's model were: a) it over-simplified the detailed information developed in the study, b) the analytical model used cannot be calibrated to simulate the natural system, and c) the model is designed for artesian aquifer simulations.

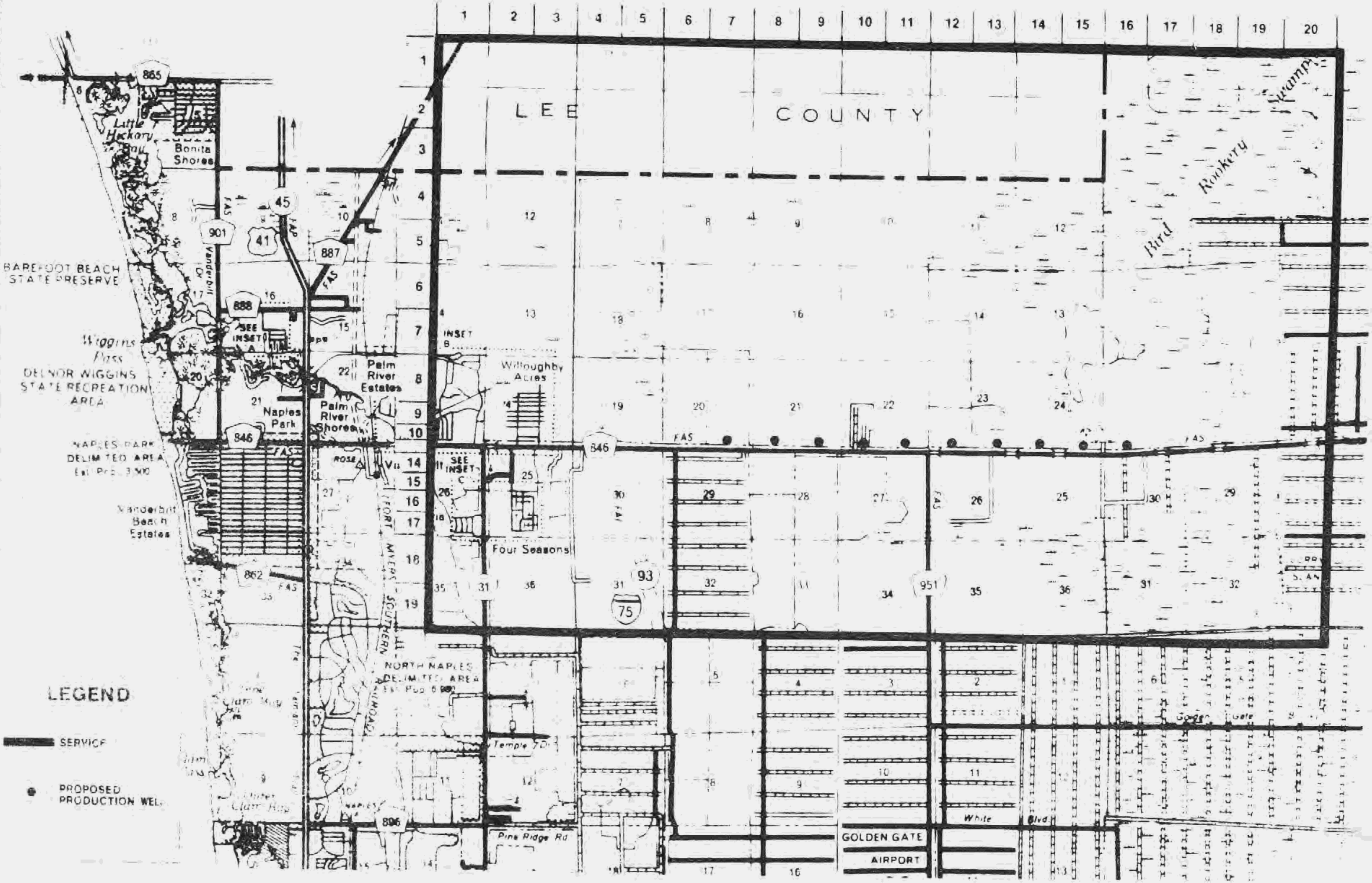


Figure 60 MODEL AREA FOR A PROPOSED WELLFIELD IN THE COCOHATCHEE WATERSHED

In water table aquifers, transmissivity is a function of the saturated thickness of the aquifer. As the water table drops in response to pumpage, the saturated thickness of the aquifer is reduced, which in turn, lowers the transmissivities and causes increased drawdowns..

In order to more accurately determien the impacts of pumpage in the Cocohatchee, the study areas was modeled by SFWMD using the USGS dimensional flow model developed by Trescott, Pinder, and Larson (1976). This model utilizes hydraulic conductivity data along with saturated aquifer thickness to recalculate transmissivity with each time step for unconfined aquifer simulation.

For the Cocohatchee simulation, the model area was expanded to cover 65 square miles in order to reduce the effects of the model boundaries on the drawdowns. A heterogeneous hydraulic conductivity matrix was derived from the transmissivity and aquifer thickness maps published by the consultant (Missimer, 1983). A constant specific yield value of .2 was used instead of the .3 value used by the consultant because it more accurately reflected the values derived from pumping tests within the study area. A specific yield of .9 was assigned to an area one mile long by 700 feet wide immediately north of the Cocohatchee Canal to simulate the water in storage at the Mule Penn quarry. A heterogeneous aquifer thickness map based on the consultants data was input to the model. A constant value of 4.6×10^{-8} ft/sec. was used as the hydraulic conductivity for the underlying confining bed. This is based on the average leakance value for the study area 1×10^{-3} gpd/ft^3 (Missimer, 1983a) divided by the average confining bed thickness of 30 ft. (Missimer, 1982). A constant flux boundary was used to simulate regional inflow from the northeast corner of the study area.

Inflow into the aquifer from the Cocohatchee Canal was not simulated in this model. Figure 61 shows stage level data for the Cocohatchee Canal at CR 951 and indicates that the canal is dry for much of the dry season. These data are different from measured discharge data taken downstream by the USGS at monitor station #02291393 as presented by Missimer (1981d). The average discharge at this station during the dry season was about 6 cfs from 1969 to 1979. However, the source of this water appears to occur downstream of CR 951.

The model was calibrated to water levels corresponding to the end of the wet season using an inflow of 6.5 MGD. This figure is larger than the 2 MGD value proposed by Missimer due to the increased model size. The simulated water table elevation correlated well with the consultant's water level map with the exception of an attenuation of the 9 ft. contour line to the north in the central portion of the model. This is due to the localized low transmissivities (59,000 gpd/ft.) which occur in this area.

The calibrated flow model was run to simulate 30 MGD withdrawal for 120 days without recharge. Ten production wells, spaced at 2600 ft. intervals, were located 1000 ft. north of the Cocohatchee Canal with the first well located in the southeast corner of section 20 (Figure 60) as proposed by the consultant. After simulating 10 days of pumpage, the three westernmost wells had run dry. This was due to the thinness of the aquifer (30 feet) in that area. The model was rerun changing the total thickness from 30 feet in section 20 and 21 to 40 feet. Under these conditions the wells were able to supply water for the entire 120 days. Drawdowns in these three western wells exceeded 25 feet. Water levels in the aquifer prior to pumping were five feet below land surface indicating that after pumping began there was only 10 feet of saturated thickness at the well. The model does not take into account well and formation losses which are a function of well construction techniques. These well efficiency losses will result in deeper drawdowns than predicted by the model and, depending on the magnitude, could result in reduced production. Therefore, it is recommended that production wells be located in areas where the water table aquifer total thickness exceeds 40 feet.

Analysis of the mass balance data indicates that 80 percent of the water pumped comes from aquifer storage, 19.5 percent comes from the constant flux boundary, and less than one percent is from leakance from the lower Tamiami aquifer. The contribution from the flux boundary indicates that the model area was not large enough for this simulation. The projected drawdowns of a 30 MGD wellfield in the Cocohatchee Watershed are shown in Figure 62. The model indicates a drawdown of approximately one foot at the Lee-Collier County line, however, the cone of influence is being affected by the model boundaries at this point. The actual drawdown in this area will probably be between two and three feet based upon trends in the cone of depression. The model was run again using an evapotranspiration rate of 41 inches per year and cutoff depth of 7.5 feet (Missimer, 1981d). Under these conditions, drawdown at the county line was four to five feet.

Additional water table aquifer withdrawals in the area were not included in the model. Missimer identifies several irrigation wells within the study area and a number of wells in Lee County at the Lee County line. Irrigation use intensifies during the dry

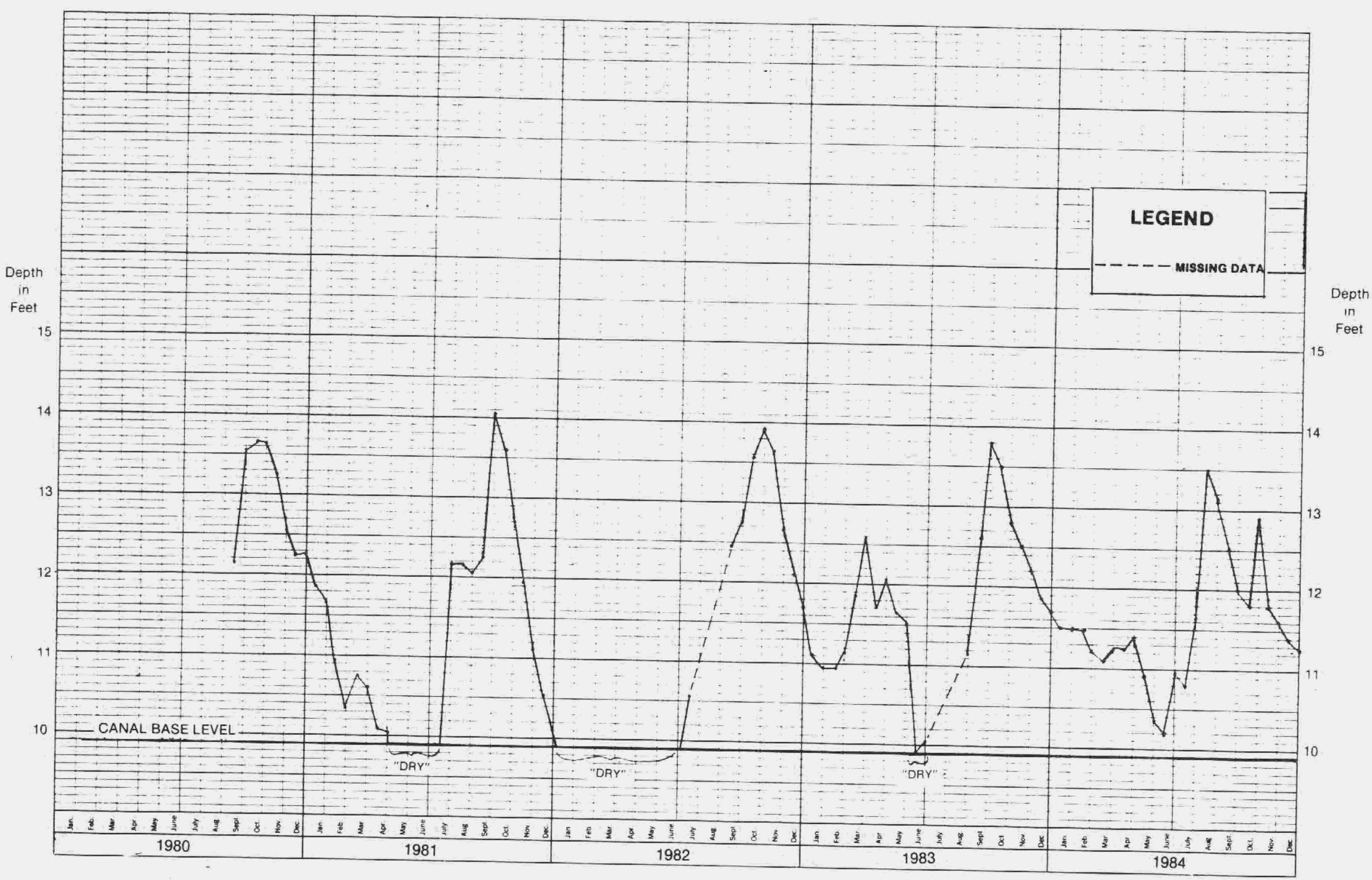


Figure 61 STAGE DATA FOR THE COCOHATCHEE CANAL AT CR951, 1980-1984

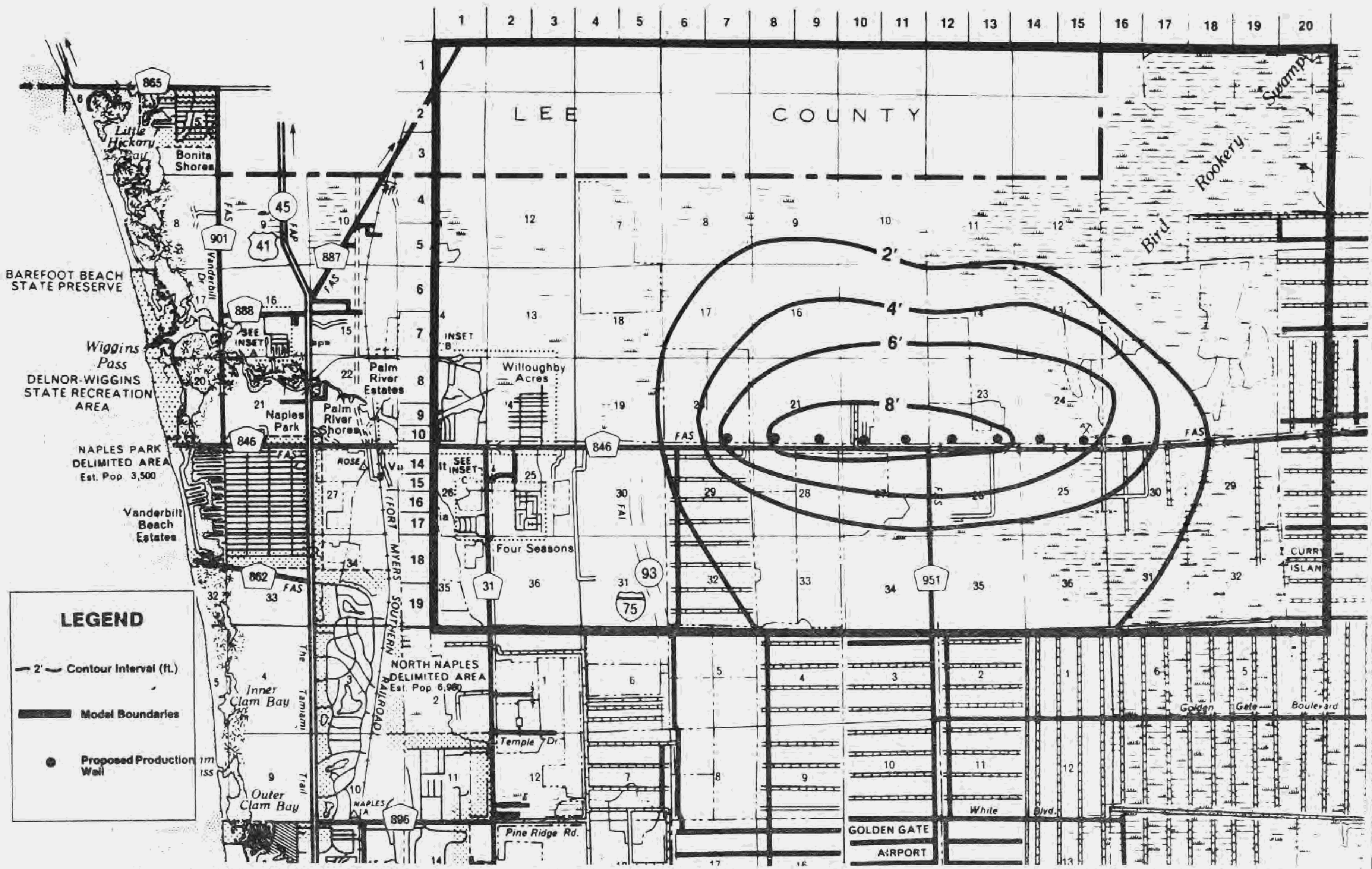


Figure 62 PROJECTED WATER LEVEL DRAWDOWNS OF A 30 MGD WELLFIELD IN THE COCOHATCHEE WATERSHED

season and, while some of the water returns to the aquifer through seepage, a major portion is lost to evapotranspiration. The concentration of agricultural activities in Lee County are located to the northwest of the proposed wellfield, and any drawdowns associated with their use should not significantly impact the wellfield. However, reduced levels resulting from the combined effects of irrigational and municipal usage may have significant environmental impacts on the native vegetation located in the northeastern portion of the study area. Additional investigations are needed to assess these impacts.

Another consideration of this proposed wellfield is surface water quality. The model was rerun using a constant head at the Cocohatchee Canal to simulate a constant source of water as could be expected during the wet season. Under these conditions over 70 percent of the water pumped would be from the canal. In reality this value would be less because the hydraulic conductivity of the canal bed is lower than that of the aquifer due to siltation effects. In addition, Missimer (1981) notes that a major source of recharge into the study area is agricultural discharge from Lee County. Therefore, careful analysis of surface water quality for fertilizer and pesticides is recommended prior to the development of a wellfield in this region.

The final yield of the wellfield in this area is more dependent on production well construction and water quality than groundwater availability. Therefore, the final design and construction of the wellfield should be carefully planned with the assistance of professional hydrogeologists. The following considerations should be addressed in designing the wellfield:

1. The environmental impact associated with wellfield withdrawal needs to be assessed.
2. Production wells should be located where the aquifer thickness exceeds 40 feet.
3. Special consideration to maximizing well efficiency should be incorporated into production well designs.
4. The wellfield should incorporate an adequate number of wells so that localized drawdown effects are minimized.
5. Routine well testing and maintenance schedules should be established.
6. A monitoring network to routinely test for nutrients, fertilizers, pesticides, and other organic contaminants should be developed, especially around proposed wellfields.
7. Wellfield protection ordinances for the buildout cone of influence should be enacted.

Locating the wells where the aquifer is thickest has some limitations in this area. Except for a narrow trough located to the west through sections 16 and 20, the aquifer thins to less than 30 feet to the north of the Cocohatchee Canal. The aquifer appears to thicken to the east. Resistivity data collected by Stewart (1982) indicate that a thick sequence of non reefal limestones exists along the Cocohatchee at Wilson Boulevard. However, shifting pumpage to the west may result in adverse environmental impacts.

Production well design should include special consideration to screen selection and gravel pack design. Wire wound screen should be selected over underbar or slotted screen in order to maximize the amount of open area which will in turn reduce wellpoint drawdowns. The wells should be extensively developed before and after setting the screens. When air rotary is not feasible, polymer drilling fluid should be substituted for drill mud, because it is more easily broken down and removed from the well than bentonite mud.

Because portions of the well screens will be exposed to alternating oxidizing and reducing environments, screens and gravel packs may become clogged with calcium carbonate, bacteria, and oxidized iron. Periodic well efficiency tests should be undertaken yearly to establish a maintenance schedule.

The water quality monitoring network should be designed with respect to the existing agricultural properties and the regional flow patterns induced after pumpage begins. The monitor wells should be designed in accordance to DER construction standards for organic contaminant monitoring wells. In addition, water quality data should be collected in the Cocohatchee Canal and at the surface and bottom of the Mule Penn Quarry.

Wellfield protection ordinances similar to those drafted by Dade and Broward Counties should be enacted. The area protected under this ordinance should be assessed using the ultimate projected capacity of the wellfield. The model run indicates the cone of influence for a 30 MGD withdrawal will extend into Lee County. Therefore, coordination with Lee County officials is advised.

In conclusion, the aquifer as modeled may be capable of producing 30 MGD during an average dry season; however, water quality limitations and environmental impacts should be carefully assessed prior to developing a wellfield of this size. During periods of prolonged drought, production capacity will be significantly less. As the water requirements for region A will not exceed 15 MGD by the year 2000, it may be safe to assume that environmental impacts will be more localized, however, the potential for surface water contamination and environmental impact should be carefully assessed before any wellfield development in the area.

Region B: Naples

Region B (Figure 59) is comprised of three planning areas, the city of Naples, east Naples, and central Naples. This region is serviced by two wellfields, the city of Naples Coastal Ridge and East Golden Gate wellfields. The combined population for region B in 1984 is reported to be 42,195 (Appen-dix IV). Based on growth projections from the county and using a calculated per capita use rate of 277 gallons per day, the future water requirements are calculated as shown on Table 11. Assuming region A would produce water from its own wellfield, the combined daily requirements from both City of Naples wellfields by the year 2000 would be approximately 20 MGD.

The yield of the lower Tamiami aquifer in the Naples area is limited. Future production of the Coastal Ridge wellfield is dependent on proper management, including reduction in pumpage by competing uses. Therefore, it is difficult to estimate what percent of the future demand will be furnished by this wellfield. Assuming by the year 2000 the Coastal Ridge wellfield would be operating at its current permitted capacity of 7 MGD, the East Golden Gate wellfield would need to produce approximately 14 MGD during the dry season.

To simulate a worst case scenario, where all the potable water would be produced by the East Golden Gate wellfield, a simple numerical flow model was run for the lower Tamiami aquifer to determine the general impact of a sustained 20 MGD withdrawal. The modeled area covered 225 square miles (30 by 30 half mile grid). A constant head boundary was inserted along the perimeter of the modeled area. A single transmissivity of 150,000 gpd/ft and a storage value of 5×10^{-4} were used in the simulation. The hydraulic conductivity of the confining bed used in the model was 2×10^{-7} ft/sec. and the average confining bed thickness was 30 feet. Pumpage was distributed over a four mile line corresponding to the current wellfield configuration. Additional pumpage of 11 MGD was input at the location of the county's Golden Gate wellfield to reflect maximum water use requirements for the dry season in the year 2000. Other users were not input to the model due to uncertainty of future demands. Therefore, the model results yielded higher water elevations than might actually occur.

Under these conditions, projected drawdowns, excluding the influence of other users, are shown on Figure 63. Water levels in the vicinity of both wellfields will be below sea level with the 0 NGVD contour occurring approximately one mile away from the center of pumpage. Drawdowns in the production

TABLE 11. PROJECTED MUNICIPAL WATER USE REQUIREMENTS FOR REGION B - CITY OF NAPLES

YEAR	ESTIMATED POPULATION	AVERAGE DAILY[2] USE (MG)	DRY SEASON DEVIATION	AVERAGE DRY SEASON DEMAND (MGD)
1985	High 44625	12.36	14%	14.01
	Med. 43420	12.03		13.71
1990	High 54530	15.10	14%	17.22
	Med. 51470	14.26		16.25
1995	High 63090	17.47	14%	19.92
	Med 57770	16.00		18.24
2000	High 72640	20.12	14%	22.94
	Med 64540	17.88		20.38

1. Estimates provided by Tom Crandall (Appendix IV).
2. Based on a per capita use rate of 277 gallons per day.
3. Average daily use for 1985 excludes water produced for the North Naples Area.

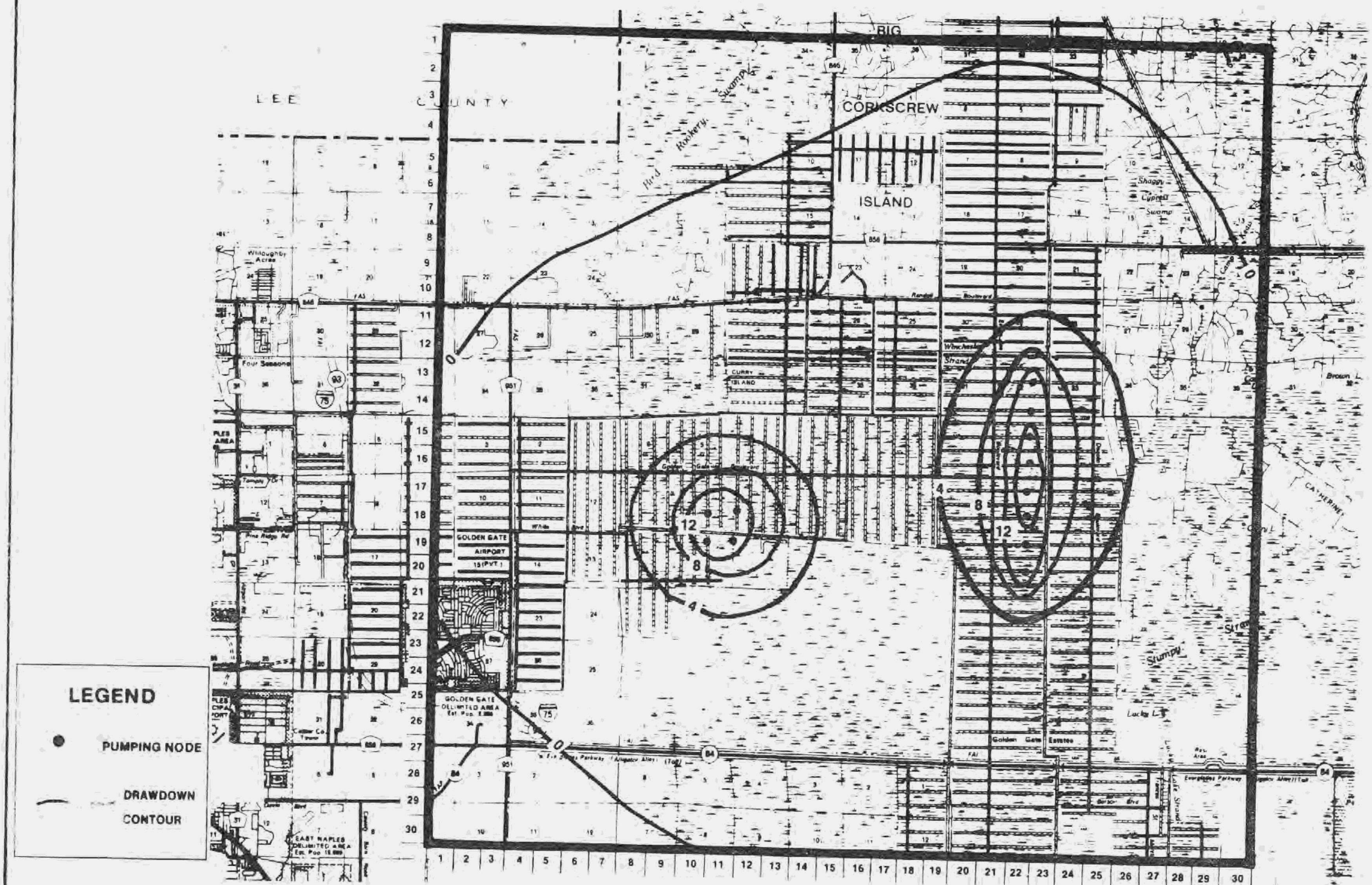


Figure 63 PROJECTED WATER LEVEL DRAWDOWNS OF A COMBINED PUMPAGE RATE OF 31 MGD FROM TWO MUNICIPAL WELLFIELDS IN GOLDEN GATE

wells will exceed 25 feet, but water levels will be above the top of the aquifer. The final determination regarding the acceptability of these drawdowns will require quantification of the impacts on environmentally sensitive areas, other local issues, and on the regional surface and groundwater flow system.

The major source of water (90%) under these conditions is downward leakance from the water table aquifer. Stewart (1982) identified a widespread reefal limestone facies within the water table aquifer in the Golden Gate area. Well cuttings analyzed for this report also identify reefal limestones in this area. These highly porous limestones contain large amounts of water in storage. Therefore, it is expected that the large amount of water required by leakage could be obtainable in the future.

Impact of agricultural users to the east may cause further drawdowns in the Golden Gate area during the dry season. Because the Golden Gate wellfields are upgradient of the coastal outflow areas, withdrawals of this size may affect water levels in the Coastal Ridge wellfield. As the model indicates, however, the vast majority of water pumped will be from localized leakance from the water table aquifer. The extent of impacts of all major users will be quantified in a later study, but the future potable supply for the Naples area will be dependent upon a reduction of pumpage from other competing users near the Coastal Ridge wellfield or shifting all pumpage to the East Golden Gate wellfield during the dry season.

Regions C and D: South Naples

Regions C and D (Figure 59) include south Naples and portions of the Marco planning areas. Combined population in these areas in 1984 was approximately 11,065 (Appendix IV). Beginning in July 1984, municipal water for the area was being supplied by the new Golden Gate wellfield. Pumpage data for this wellfield through August 1985 are shown on Table 12. Based on the existing data, an average daily withdrawal rate of 3 MGD was used to determine an average per capita day consumption rate of 253 gallons.

Estimates of future population and metered connections were not provided by the county for region D. In order to determine water requirements for this area, the population in region D was assumed to grow at the same rate as in region C. Projected water requirements for both areas combined are shown on Table 13. Based on these data, dry season requirements for the county wellfield may exceed 6 MGD by the year 2000. Based on preliminary modeling results, the county's Golden Gate wellfield will be capable of producing 11 MGD from a water quantity standpoint. Wellfield expansion designs should space production wells over as large an area as possible to minimize wellpoint drawdowns.

TABLE 12. COLLIER COUNTY UTILITIES (11-00249) RAW WATER USE FROM 7/84* to 1/85

	MONTHLY TOTAL (MG)	AVERAGE DAILY (MG)
July*	5.538	.176
August	32.826	1.563
September	62.398	2.080
October	90.315	2.913
November	95.996	3.199
December	93.588	3.019
January	94.811	3.058
Six Month Average (excluding July)	78.322	2.639
Allocation (MGD)		4.000
Percent Allocation		66%

*Plant first began production

Marco Island

Marco Island is not currently incorporated into any county supplied water use regions. It is supplied by a private utility which withdraws water from two abandoned rock pits which are recharged by groundwater baseflow, surface water runoff, and rainfall. The raw water pumpage facility is located in the vicinity of CR 951 and U.S. 41 (Figure 30). Marco Island also operates a wastewater treatment facility which was constructed in 1964. The plant furnishes effluent to two golf courses with a total of 310 acres. The design capacity of the water treatment plant is 1 MGD.

Due to the proximity of seawater, the main factor influencing safe yield is saltwater intrusion. Lithologic data indicate that the Tamiami confining beds are discontinuous or absent in this region. The location of the saltwater interface is determined by the fresh water head. In karstic, carbonate environments the position of the saltwater front is difficult to approximate. Stewart (1982), using DC resistivity methods, identified substantial deviations from the classical saltwater wedge described in the Ghyben-Herzberg interface model (Figure 64). Both Missimer (1980b) and Jakob (1983) reported water containing

TABLE 13. PROJECTED MUNICIPAL WATER USE REQUIREMENTS FOR REGIONS C & D - SOUTH NAPLES

YEAR	ESTIMATED POPULATION	AVERAGE DAILY[2] USE (MG)	DRY SEASON DEVIATION	AVERAGE DRY SEASON DEMAND (MGD)
1985	High 11855	3.00	14%	3.42
	Med. 11315	2.86		3.26
1990	High 16060	4.06	14%	4.63
	Med. 14695	3.72		4.24
1995	High 19665	4.97	14%	5.66
	Med. 17300	4.38		4.99
2000	High 23725	6.00	14%	6.84
	Med. 19715	4.99		5.69

I. Estimates based on figures provided by Tom Crandall.

2. Based on consumptive use of 253 gallons per capita day.

dissolved chlorides in excess of 250 mg/l beginning at 50 ft. below land surface in the vicinity of Marco Pit. A salinity control structure was added to Henderson Creek just north of U. S. Highway 41 to reduce landward, salt water movement. The effect of this structure is shown in Stewart's study and in water quality data from shallow monitor wells adjacent to Marco Pit. A water resource assessment study undertaken in 1980 (Missimer, 1980b) indicates a safe yield of the utility at 14 MGD. This yield was contingent upon the construction of a proposed wellfield (dewatering trough) north of the existing pits. The remaining 8 MGD was considered as the safe yield of the two pits.

According to estimates provided by the County, the 1984 population of Marco Island was 8,439 (Appendix IV). During 1984, the average pumpage was 4.15 MGD (Table 14), which equals a per capita consumption rate of 492 gpd. Projected growth and projected water requirements figures through the year 2000 are shown in Table 15. The reason for this high per capita water use figure is individual property irrigational requirements on the island. Based on these projections, Marco Utility may need to produce as much as 10.4 MGD during the year 2000 dry season.

While data provided by the utilities' consultant indicate that this yield is attainable, conditions of the wellfield area during the 1985 drought have raised questions of the safe yield from this area during drought periods. Beginning in December 1984, the utility produced water at an average rate of 4.15 MGD. By the beginning of March 1985 water levels in the lakes dropped below 0 ft. NGVD (plus one foot NGVD is considered to be the lowest safe operational elevation in the lakes). The depressed water levels were caused by a lack of recharge. Rainfall during the 1984 wet season was normal for the lower west coast. For the 1984-85 dry season up to March, rainfall was only 25 percent of normal.

In addition to rainfall, the Henderson Creek Canal provides recharge to the Marco Utility. In Missimer's study it was assumed that the Henderson Creek Canal would provide 2 MGD of recharge to the water table aquifer during the dry season and that water levels in the lake would stay .5 feet above NGVD. By the first week of March 1985 Henderson Creek had gone dry adjacent to the pits, and water levels in the lakes dropped below 0 ft. NGVD. Therefore, during periods of sustained drought, Henderson Creek may not be capable of providing recharge to the wellfield as anticipated for in the consultant's report. As of March 1985, there had been no apparent increase in chlorides in the wellfield or lakes, but sustained operation under these conditions could result in vertical and horizontal movement of saltwater.

If water demand in Marco Island is doubled by the year 2000 as estimated, the existing facilities can

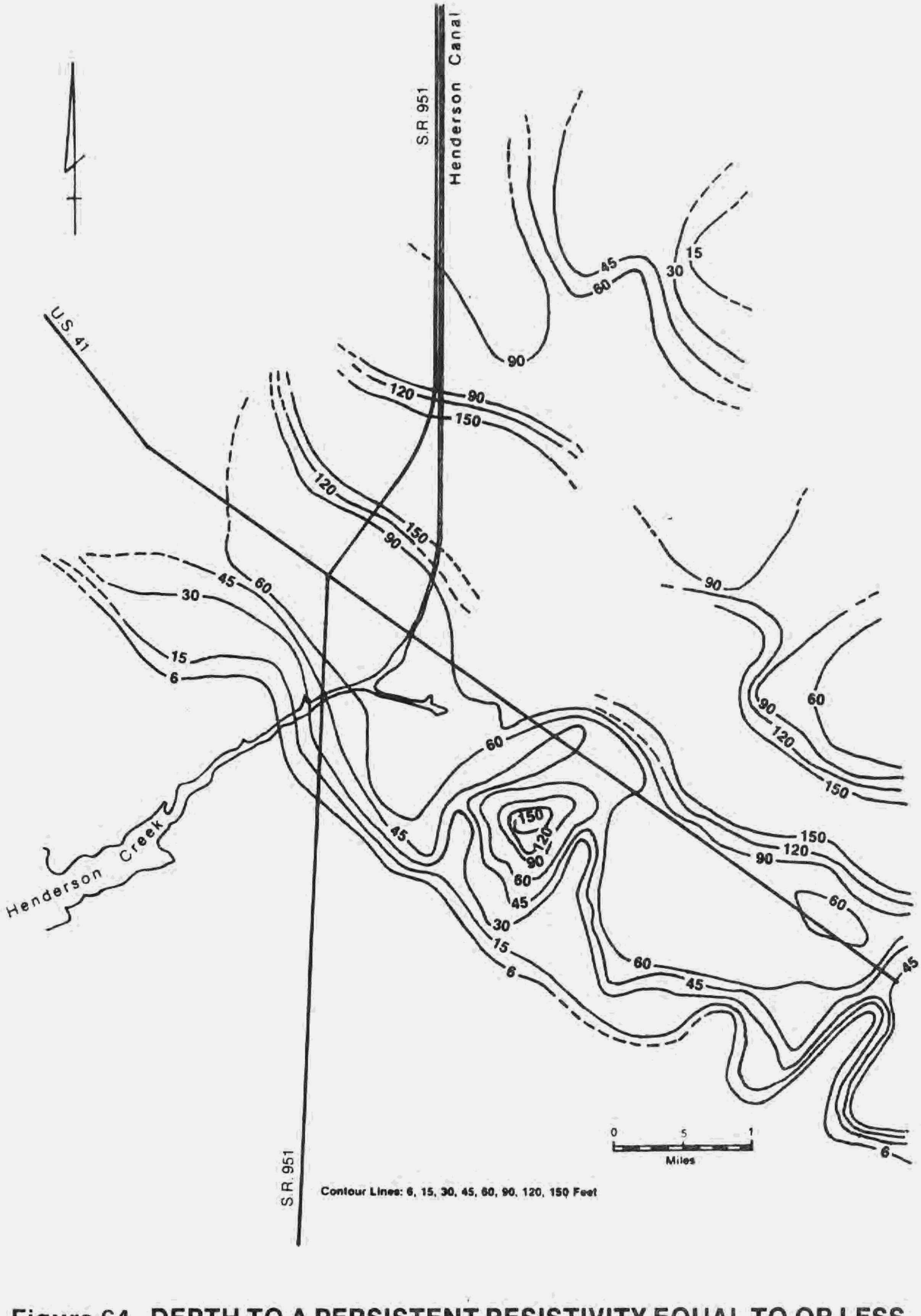


Figure 64 DEPTH TO A PERSISTENT RESISTIVITY EQUAL TO OR LESS THAN 30 OHM-M (~250 mg/l isochlor) after Stewart, 1982

TABLE 14. PUMPAGE DATA FOR MARCO ISLAND UTILITIES (11-00080) FROM 2/84 to 1/85

	MONTHLY TOTAL(MG)	AVERAGE DAILY(MG)
February	122.430	4.222
March	129.900	4.190
April	143.650	4.788
May	146.240	4.717
June	108.850	3.628
July	85.3900	2.755
August	105.280	3.396
September	101.570	3.386
October	129.177	4.186
November	137.010	4.582
December	134.822	4.349
January	142.574	4.599
12 Month Average		4.15
Daily Allocation		6.082
% of Allocation		68%

not be expected to meet demand under a sustained drought such as 1984-85. It is recommended that the Marco area be reevaluated using a coastal saltwater interface model to determine safe operating levels under various drought simulations. In addition, the utility should examine developing an alternative supply for use during future droughts. Such alternatives should include: a) developing an inland wellfield, b) ability to hook up to county distribution systems, or c) development of a reverse osmosis plant.

AGRICULTURAL WATER USE

Agricultural activities represent the largest users of groundwater in the county. The highest density of agricultural properties occurs in the north and central portion of the county. According to Leach (1982), 39,500 acres were under agricultural development in Collier County in 1980. Leach subdivided this acreage by crop type with 7,000 acres for citrus, 16,000 for truck farming, 12,000 for pasture, and 4,500 for other uses (primarily nurseries).

By selectively metering several different types of agricultural activities, Leach estimated that the 1980 agricultural groundwater use for Collier County was 83.5 MGD. These data are broken down to monthly use in Table 16, which indicates that 60 percent of the total water use occurs over a four month period during the dry season (February through May). The majority of the groundwater used comes from the Sandstone aquifer in northern Collier County south of Immokalee, where the Sandstone aquifer begins to pinch out, water is withdrawn from the water table and the lower Tamiami aquifers.

Water use permits are issued by the District to agricultural properties in Collier County. Table 17 shows all county agricultural permits with maximum monthly allocations in excess of 100 million gallons per month (MGM). There are an additional 55 permittees for water uses below 100 MGM. The total maximum monthly groundwater allocation or projected use for Collier County agricultural properties is 32.3 billion gallons or 1.1 billion gallons per day. This figure is substantially larger than estimated by Leach. There are several reasons for this discrepancy. The major reason is that actual water use over the year is much lower than the maximum monthly allocation. During the dry season, most users pump near the permitted maximum monthly allocation. In addition, a large number of properties have recently changed from unimproved pasture which are not irrigated to truck farm or citrus which have greater water requirements. Despite this, the magnitude of the allocation and the deficiency of actual use data suggests the need to more accurately assess the water consumption of agricultural users.

TABLE 15. PROJECTED POTABLE WATER REQUIREMENTS OF MARCO ISLAND

YEAR	POPULATION[1]	AVERAGE DAILY[2] USE (MG)	DRY SEASON DEVIATION	AVERAGE DRY SEASON DEMAND (MGD)
1985	8,439	4.15	14%	4.73
1990	12,505	6.15	14%	7.01
1995	15,314	7.53	14%	8.58
2000	18,478	9.09	14%	10.36

1 Estimates provided by the County (Appendix IV).

2 Based on a daily, per capita consumption rate of 492 gallons.

TABLE 16. COLLIER COUNTY ESTIMATED IRRIGATION USE FOR 1980
(from Leach, 1982)

	SURFACE WATER (MGD)	GROUNDWATER (MGD)
January	2.900	69.604
February	4.205	100.939
March	7.284	174.824
April	7.284	174.824
May	6.316	151.605
June	1.305	31.315
July	0.983	23.600
August	0.616	14.783
September	1.044	25.070
October	4.326	103.840
November	2.632	63.185
December	2.838	68.123

Actual water use data are necessary prior to any future regional modeling of resource quantification.

In order to properly manage the groundwater resourcs of the lower west coast, a program should be undertaken to accurately monitor and assess actual water use by large agricultural properties. This study should develop cost effective methods for determining pumpage using statistical techniques. Because some of the water used returns to the water table aquifer through seepage, detailed crop specific evapotranspiration data should be developed to determine the amount of water lost from the system.

Due to the current lack of reliable agricultural water use data, it is difficult to project or model future water requirements. County planning documents indicate the majority of growth will continue along the coastal regions and will not encroach on the major agricultural areas to the north and east. In light of the hard freezes of 1983 and 1984, much of the state's citrus industry is moving southward. In Collier County this will occur at the expense of pasture land. Therefore, agricultural water use can be expected to increase in Collier County in the future years. Because much of this growth will occur adjacent to inland municipal wellfields, detailed management criteria must be developed to reduce impacts along the southwestern portions of the ocunty.

TABLE 17. PERMITTED AGRICULTURAL GROUNDWATER USERS OVER 100 MGM

PERMIT NO.	MAXIMUM MONTHLY ALLOCATION(MG)	PERMITTEE
11-00033	632	W. J. Piper
11-00034	130	J. E. Price Jr.
11-00034	847	J. E. Price Jr.
11-00036	151	D. C. Brown
11-00040	156	I. C. Read
11-00042	200	Collier Company-Grove Division
11-00043	104	Lely Estates
11-00044	104	Lely Estates
11-00055	152	J. Johnson
11-00062	254	Johnson Farms
11-00069	173	R. Smith
11-00071	181	Manatee Fruit Company
11-00074	163	M. C. Hall
11-00075	261	J & N Farms, Inc.
11-00077	138	W. Sills
11-00084	2,821	Turner Corporation
11-00089	129	M. R. Collier
11-00090	252	NF & V Corporation
11-00094	576	Turner Corporation
11-00095	633	A. Duda & Sons, Inc.
11-00097	384	A. Duda & Sons, Inc.
11-00100	1,237	Barron Collier Company
11-00102	137	Collier Company
11-00105	829	Collier Development Corporation
11-00106	274	Collier Company
11-00I07	657	Collier Company
Total Maximum Monthly Allocation	11,575	

FIRST ORDER ESTIMATE OF SAFE YIELD FOR THE NAPLES AREA

INTRODUCTION

Since the 1950's, salt water intrusion into the City of Naples Coastal Ridge wellfield has been a concern of water managers. In addition to the wellfield, the area supports a diverse group of competing water users along the front of a dynamic salt water interface. In light of the 1985 water shortage and continuing requests for additional groundwater allocations in the area, a first order attempt to define and quantify safe yield is presented here.

In order to determine the existing and potential impacts of existing users, a two-dimensional aquifer simulation was developed using the Trescott, Pinder, and Larson flow model. To relate present use and allocations to the supply capability of the lower Tamiami aquifer, a first order attempt is made to determine safe yield figures for the aquifer. These estimates are compared to current allocation and estimated wet and dry season pumpage to determine areas where additional groundwater use should be allowed or restricted. The safe yield estimates are based on conservative assumptions and generalizations associated with a two-dimensional flow model, and, therefore, should be considered preliminary until a more detailed and specific model can be developed for the area.

BACKGROUND

The primary source of groundwater in the Naples area is from the lower Tamiami aquifer. Wells penetrating this zone are characteristically 40 to 80 feet deep. The aquifer is semi-confined and receives leakance recharge from the overlying water table aquifer. The aquifer is very transmissive, however, water quality represents the limitation of its development potential.

The lower Tamiami aquifer contains saline water along the coastal regions and beneath the southern edge of the City of Naples Coastal Ridge wellfield. Water level and chloride concentration data for observation wells located in and near Naples indicate chloride levels fluctuate seasonally in relation to water levels, suggesting a dynamic salt water front. Long term trends in chloride levels have been noted in several observation wells since the late 1970's (Appendix II). Data from two wells, C-430 and C-161 located east of the coastal ridge wellfield, indicate a downward trend in chloride levels. This is possibly due to the flushing of connate water from the aquifer by nearby pumpage. Connate water is reported to occur east of the coastal ridge between Golden Gate and Airport Road (SR 31). A long term increase in chloride levels may be occuring in wells C-474A, C-409A, C-355, C-525, C-527, and A-2D (SFWMD monitor well). These wells are located west of the coastal ridge wellfield near the coast. Coastal saline intrusion in response to pumpage is a possible explanation for this trend. These trends, coupled with seasonal quality fluctuations, cause landward saline migration to become a concern (Figure 65).

In December 1985, chloride levels in the three coastal monitor wells located within one mile of production wells in the southern portion of the Coastal Ridge wellfield rose to extreme levels. Pumpage was reduced and shifted to the north in the wellfield to prevent further inland migration of the saltwater front. This action was effective in reducing the saltwater advancement; however, by March 8, 1985 chloride concentrations in wells C-524, C-526, and C-527 were 4700, 3030, and 16,400 mg/l, respectively.

Despite pumpage reductions in the Coastal Ridge wellfield, regional water levels have not significantly changed over the last ten years. Figure 66 shows the cone of influence for the Coastal Ridge wellfield for May 1975 and February 1985. The drawdowns are similar, but the municipal pumpage rates are markedly different. During May 1974, when the Coastal Ridge wellfield was the sole supplier of water to the area, average daily pumpage was 13.5 MGD (USGS Water Level Report, 1975). The 1984-85 pumpage at the Coastal Ridge wellfield averaged 6.4 MGD and the February, 1985 pumpage averaged 3.87 MGD. The Coastal Ridge wellfield has reduced its pumpage since 1975 due to the construction of the City of Naples East Golden Gate wellfield. Despite these reductions, drawdowns within the Coastal Ridge wellfield have remained essentially the same due to the influence of additional users in the area.

These additional competing water users have coexisted for several years. During drought periods, however, the Coastal Ridge wellfield has had to reduce pumpage to avoid salt water intrusion. At the same

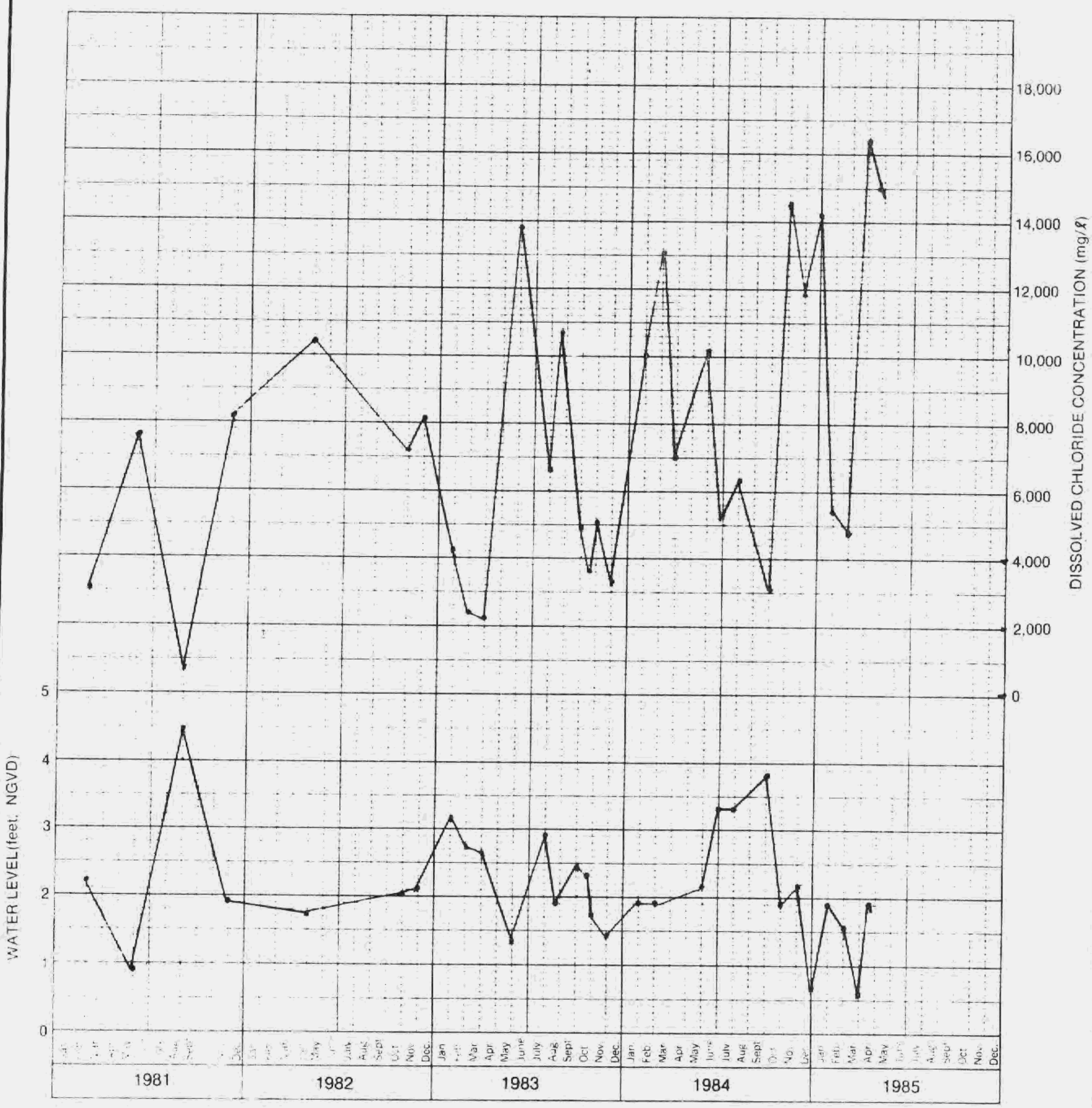


Figure 65 WATER LEVEL AND CHLORIDE CONCENTRATION FOR WELL C-527

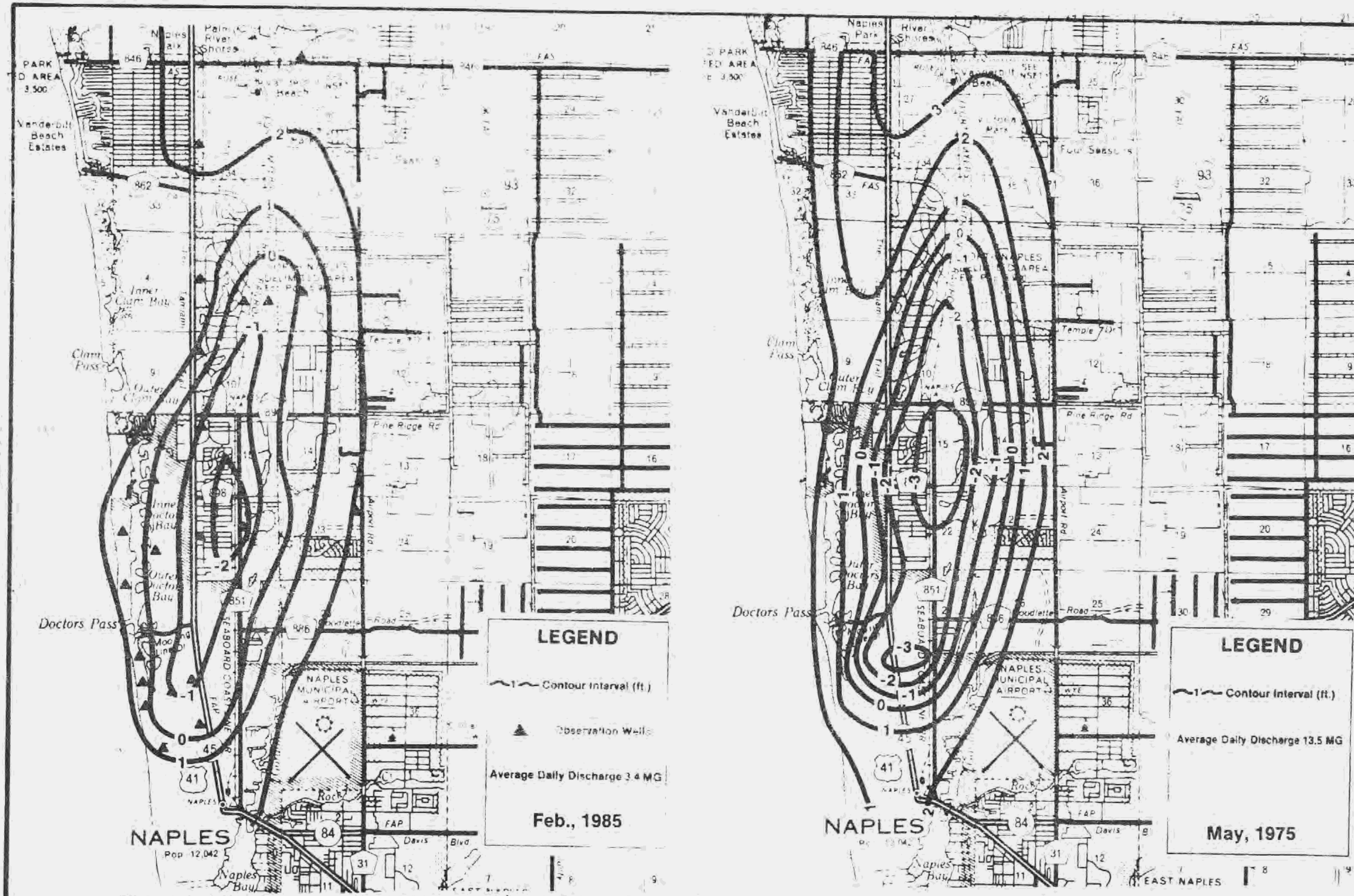


Figure 66 COMPARISON OF THE CONE OF INFLUENCE FOR THE COASTAL RIDGE WELLFIELD (May 1975, Feb. 1985)

time, the other permitted users in the area have been allowed to continue full use of water within their permitted guidelines unless a water shortage was declared. Rainfall deficiencies, combined with extensive pumpages, have resulted in voluntary and mandatory water cutbacks in three of the past five years.

HYDROGEOLOGIC ASSUMPTIONS

A number of assumptions were made in developing the aquifer simulation discussed here. Most of these assumptions were made due to a lack of detailed information on the hydrogeologic conditions of the area. While it is physically and financially impossible to obtain all of the data needed to establish an exact aquifer system simulation, the assumptions made reflect the general characteristics of the area based on the available data. A detailed understanding of the assumptions made, and how they affect the results, is necessary prior to using the model as a management tool. The following is a discussion of the major assumptions used and the possible impacts on the results.

Two-Dimensional Groundwater Flow Model

A two-dimensional model was chosen over a three-dimensional model due to deficiencies in water level data and aquifer characteristics (transmissivity, storage, aquifer thickness, etc.) for the overlying water table aquifer. These made it impossible to accurately calibrate a data intensive three- dimensional model. There is a high degree of hydraulic connection between the water table and the underlying lower Tamiami aquifer due to the leaky nature of the semi-confining beds separating the aquifers. As a result, the use of a two-dimensional model to simulate a three-dimensional flow regime represents the most significant assumption of this exercise. While the model does simulate recharge and discharge from leakance across a single semi-confining layer, the water levels opposite the semi-confining bed (leakance source beds) must remain fixed throughout each pumping period. Therefore, for a given pumping period, the head in the leakance source bed (water table aquifer) is treated as a constant head boundary. This assumption becomes invalid if applied for long (seasonal) time increments, because water levels in the water table aquifer water levels fluctuate widely in response to rainfall and drainage.

Water levels in the water table aquifer that were used in the validation and predictive model runs were based on data collected on a single day at the end of a month. This data does not accurately reflect the water table elevations throughout the month and affects calculated water levels in the lower Tamiami aquifer when the model is run to steady state. A sensitivity analysis of the model indicated that a one foot change in head in the water table aquifer throughout the model resulted in a corresponding change in head in the lower Tamiami aquifer of up to .7 foot of steady state. However, a one foot change in water levels for the water table aquifer on local levels (one- one half mile grid) generally resulted in corresponding changes in the lower Tamiami aquifer of 0.2 feet or less.

Isotropic Aquifer

The aquifer is assumed to be isotropic in this simulation. This means that water will flow through the rock-matrix without directional preference, and the cone of influence formed due to withdrawals from an individual well will be circular in shape rather than oblate. In solutioned limestones, such as those encountered in the study area, this assumption is invalid on a small scale (cone of influence) over short periods of time; however, on a regional scale these effects are considered inconsequential.

Model Area and Grid Spacing

A homogeneous finite difference $\frac{1}{2}$ mile grid consisting of 26 columns and 32 rows was superimposed over a 208 square mile area of western Collier County and the Gulf of Mexico (Figure 67). The model calculates the average water level for each one-half mile square (node). Well point drawdowns, which will be greater than the average drawdown over the entire node, can be calculated at each node assuming only one well exists there. In the case where two or more wells occur within a node, the total pumpage is treated as though it is from one well located at the center of the block. A one-half mile grid spacing was chosen because it allows most permitted properties to be isolated within an individual node.

Boundary Conditions

Lateral inflow and outflow within the lower Tamiami aquifer were simulated using both constant flux and constant head boundaries. The flux nodes used to simulate the natural groundwater inflow were located along the northern and eastern margins of the model area. The total inflow used was 1.9 MGD. This apparent low inflow rate is due to the relative flatness of the potentiometric surface outside the influence of pumpage. The outflow flux nodes were located along the southern margin of the model.

Normally, the use of a flux boundary with low rates of inflow and outflow in a well-confined aquifer would cause large drawdowns. Due to the high degree

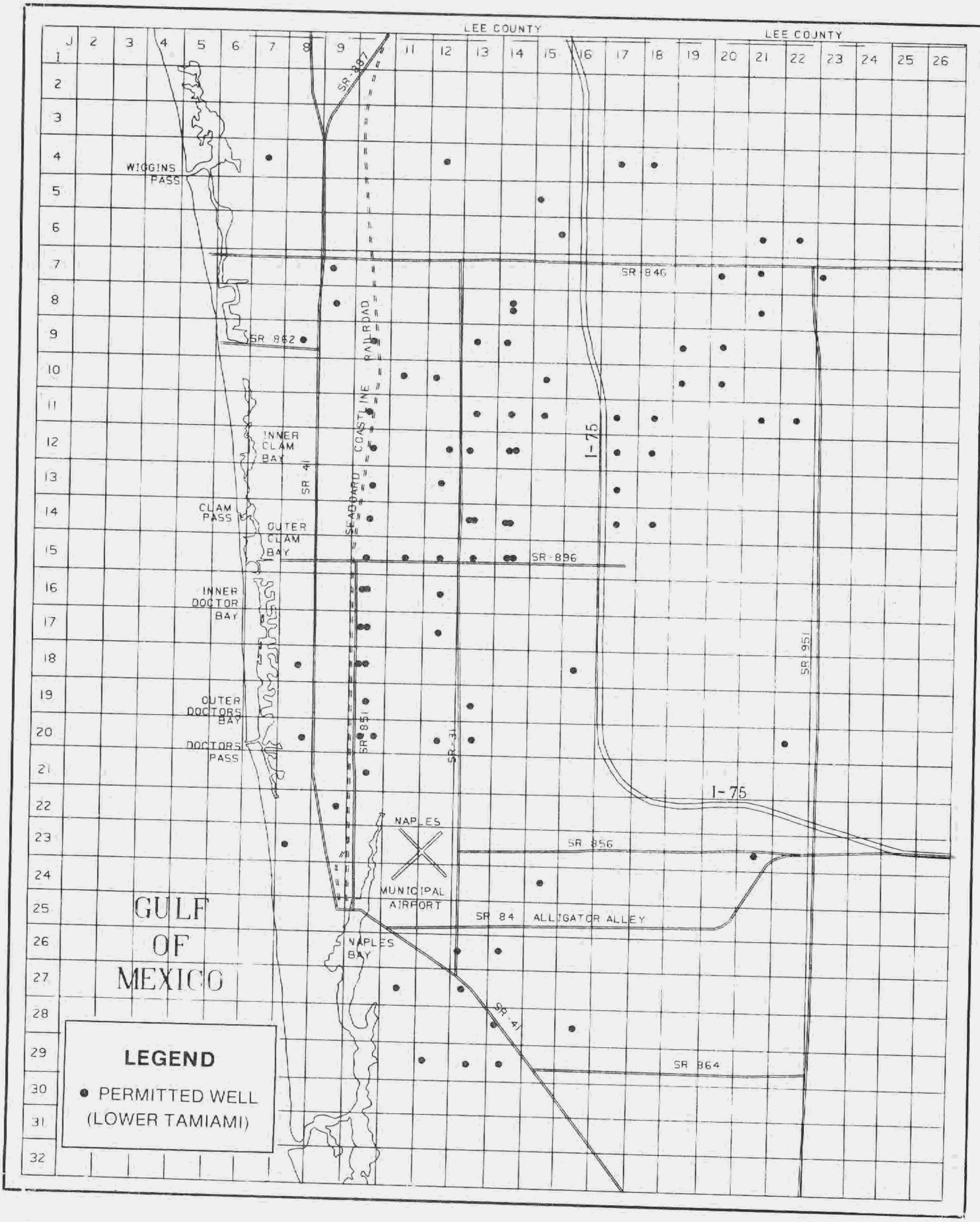


Figure 67 **FINITE DIFFERENCE GRID USED IN 2 DIMENSIONAL MODELING OF WESTERN COLLIER COUNTY**

of leakance and the distance between the model boundaries and the areas of greatest pumpage, the calculated drawdowns were acceptable and the flux boundaries were considered valid. Water levels calculated very close to the flux boundaries (2 to 3 nodes from this boundary) were considered to be influenced by the boundary.

The western boundary was assigned a constant head value of 0 ft. NGVD. The use of the constant head boundary was based on the assumption that where the depth of the Gulf of Mexico exceeds 40 feet (depth to the top of the lower Tamiami aquifer along the coast) the aquifer would outcrop and be directly recharged by the Gulf. This criteria is met approximately three miles offshore.

The flux boundaries are assumed not to change with time. This assumption is not met in nature because of seasonal recharge patterns; however, in this simulation the water levels in the water table aquifer (leakance source bed) had a greater impact on the model than the flux boundaries. The water levels in the water table aquifer were varied during validation runs to simulate seasonal fluctuation in recharge.

Steady-State vs Transient Conditions

Running the model under steady-state versus transient conditions will produce different results over small time frames. In steady-state simulations all the sources and sinks are fixed and the model runs to equilibrium. In transient simulations, aquifer storage is added to the simulation. This more accurately reflects the physical system and normally increases the simulation time required for the system to reach equilibrium. In transient simulations, pumpage can be changed for individual pumping periods.

The average storage coefficient of the lower Tamiami aquifer is 1×10^{-3}. This indicates that the volume of water derived from storage for each nodal area per foot of drawdown is 52,000 gallons. This volume of water is small compared with the volume of water derived from leakance and inflow. In the study area, the small degree of storage combined with the large magnitude of leakance cause this system to reach equilibrium very quickly. Aquifer test data indicate that equilibrium occurs within several hours after pumping begins. Under these conditions, transient solutions will virtually duplicate steady-state solutions in all but very short time simulations. Therefore, the steady-state assumption is valid for pumping periods which exceed more than a few days. In addition, to perform accurate transient simulations for a semi-confined aquifer, detailed information on pumpage and water levels in the leakance source bed is required for each pumping period. Without sufficient data to accurately map the water table aquifer throughout the model area on a monthly basis, and without a 3-D model to calculate water table fluctuations from rainfall data, it was not possible to accurately run transient scenarios.

Therefore, the validation and predictive scenarios were run to steady-state conditions. This, combined with the assumption that all pumped wells discharge continuously at rates averaged over the length of the pumping period, will result in computed water levels at or slightly below those that would occur under natural conditions where pumping is intermittent.

PHYSICAL PARAMETERS

Values of various physical parameters are required for every node of the model in order to solve the partial differential equations used to calculate water levels. Input data used in the model were derived from measured values which were intuitively regionalized through standard contour mapping techniques. The physical parameters required are classified as those which always remain fixed (time invariant) and those that vary with respect to time (time variant).

The time invariant parameters used in the model include transmissivity, storage, hydraulic conductivity of the confining beds, and confining bed thickness. Eleven transmissivity values were measured in the Naples area by different investigators. The values used in the model ranged from 100,000 gpd/ft to 500,000 gpd/ft. The highest values of transmissivity occurred in the northeast and the southeast, with lowest values occurring along the coast. Eleven storage coefficients were measured in the modeled area, however, due to the low degree of variance between the values, a single value of 1×10^{-3} was used throughout the modeled area for the test transient simulation. Hydraulic conductivity of the confining beds was calculated from eight leakance values. The values of the hydraulic conductivity of the confining beds used in the model ranged from 5×10^{-6} to 5×10^{-5} ft/sec, with the lowest values occurring in the northeast and the highest values occurring along the southwestern coastal area. The thickness of the confining bed was uniformly set at 30 feet.

The time variant parameters included water levels of the leakance source bed and pumpage. Water table elevations were available from 20 stations sampled monthly and two stations sampled continuously. An additional nine surface water gaging stations were used to approximate water table elevations. Water levels ranged from + 14 to 0 ft. NGVD in an area extending less than 1.5 miles inland from the coast.

Pumpage data from wells within the modeled area (Appendix IV) were estimated for the months of September and October 1984 and April and May 1985 by members of Water Resources Division (SFWMD) staff. The estimates were based on pump capacity multiplied by the hours the pump was used as reported by the owner. The total water pumped was then averaged over the month for input to the model. In addition to permitted use, estimates were made for individual home irrigation requirements assuming that 50 percent of the homes irrigated for two hours during the dry season at a rate of 15 gpm. A distribution of the private irrigation use was based on interpretation of the 1985 Mark Hurd Aerial photographs. These numbers were halved to estimate wet season demands.

CALIBRATION/VALIDATION

It was not possible to calibrate the model to an observed or measured set of pre-development conditions, because groundwater monitoring did not begin in the Naples area until much of it had already been significantly developed. Earliest data for the lower Tamiamí aquifer outside the influence of major pumpage indicated a regional gradient of approximately one foot per mile trending from the northeast to the southwest. These conditions were simulated using flux boundaries and assuming the aquifer was fully confined (Figure 68). Once the one foot per mile gradient was established for the confined simulation, the May 1985 water level matrix for the water table aquifer was input to the model along with a heterogeneous confining bed hydraulic conductivity matrix to simulate leakance inflow. The 1985 water table levels reflect moderate drought conditions and the calculated pre-development water levels are considered to represent below average water level conditions for the lower Tamiami aquifer. Calculated water levels compared favorably with earliest measured values outside the influence of pumpage (City of Naples wellfield). Calculated values were generally lower (within one foot) of actual values indicating the effects of the lower than average water table levels.

Sufficient data was not available to validate the pre-development simulations. Therefore, the model was validated using pumpage data from the 1984 wet and 1985 dry season. The model was run to steady-state conditions for September and October 1984 and April and May 1985 and calculated water levels were compared with measured values collected from 22 monitor wells. The results were compared with measured head values from the monitor data. Physical parameters were changed in the areas where all four simulations showed consistent errors in calculated water levels. Final adjustments were made by adjusting the pumpage estimates. The final comparison of measured values to calculated values for the validation runs are shown on Table 18.

There are a number of reasons for the difference between actual and computed water level values. The foremost is due to node centering where all the pumpage within each ½ mile grid block is simulated by a single well located at the center of the node. In addition, the calculated head at a given node is affected by the assumption of continuous discharge and the procedure of averaging the pumpage over the length of the withdrawal period. In reality, pumpage probably occurs at a higher rate for shorter durations. This is a possible explanation for the consistently low calculated water levels for the months of September and October when pumping is most variable. Therefore, both the spatial error introduced from node centering and the averaging errors associated with pumpage can cause significant problems in matching water levels. The effects of variation in pumpage and rainfall (a third variable) are demonstrated in monitor wells where daily measurements were made. For the month of April 1985 water levels along the coast varied over 2.25 ft. During the same time period, well C-430, located in north Naples varied 1.4 ft. in just three days. Considering these problems, an acceptable error band between measured and calculated water levels appeared to be plus or minus one foot.

Based on the results from the final validation runs, the total pumpage during the months of September and October 1984 was 21 MGD and 33 MGD respectively. The calculated dry season pumpage for April and May 1985 was 38 MGD and 20 MGD, respectively. Of these totals, leakance provides approximately 95 percent of the water pumped and the remainder came from the flux boundaries. While storage was not included in these simulations, its contribution to the total volume pumped would represent approximately 5% of the total discharge.

The high contribution of downward leakance into the lower Tamiami aquifer represents a limitation on the development potential for the water table aquifer. Water levels in the water table aquifer reflect the impacts of rainfall, surface drainage, direct withdrawals due to pumping, and indirect withdrawals due to leakance outflow. Since the water table aquifer is the leakance source bed and leakance rates are high, activities which affect water levels

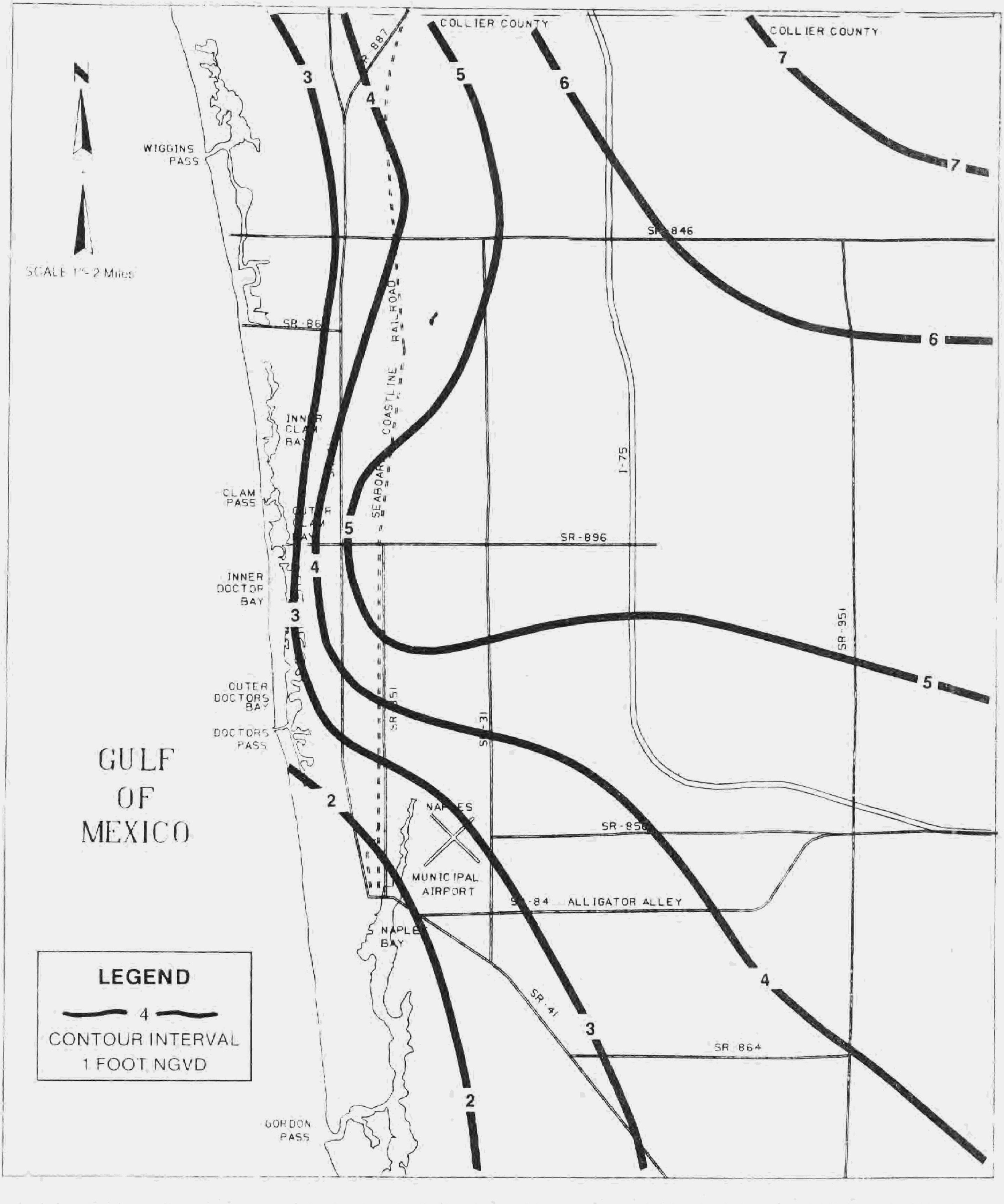


Figure 68 ESTIMATED PREDEVELOPMENT WATER LEVELS FOR THE LOWER TAMIAMI AQUIFER SIMULATING A 1 IN 3 YEAR DROUGHT

TABLE 18

COMPARISON OF CALCULATED VS. MEASURED VALUES FROM THE 1984 WET SEASON AND THE 1985 DRY SEASON VALIDATION RUNS

(Elevation in Feet MSL, Actual Values Rounded to Nearest 0.1 ft.)

	September		October		April		May	
Well #	Actual	Calc.	Actual	Calc.	Actual	Calc.	Actual	Calc.
C-123	-	0.6	-	0.7	-0.3	0.2	0.5	0.9
C-130	2.6	1.8	-1.3	-0.8	1.2	0.6	1.2	0.6
C-161	2.2	2.0	1.9	1.5	0.5	1.1	0.9	1.5
C-175	-	6.2	7.5	6.8	4.1	3.6	3.6	3.9
C-353	4.9	4.3	2.0	2.8	-	2.2	-	2.2
C-391	3.0	2.5	0.7	0.9	1.0	0.9	0.2	0.5
C-430	6.3	4.5	5.3	4.5	4.3	2.3	2.3	2.7
C-459	-	4.4	5.6	4.2	1.1	1.0	0.8	1.6
C-460	7.0	6.6	5.7	4.2	0.9	1.0	0.8	1.6
C-474	1.7	2.3	0.8	1.3	1.9	1.4	0.8	1.4
C-489	3.7	3.1	4.7	4.0	2.8	2.2	1.6	2.5
C-490	3.7	3.9	5.4	4.8	3.1	2.6	2.7	2.8
C-506	5.1	4.3	4.9	5.2	2.7	2.3	2.5	2.6
C-516	-	3.8	3.9	3.2	2.1	1.4	1.5	1.9
C-524	2.2	1.6	-0.2	-0.1	1.4	1.3	0.3	0.7
C-525	3.3	2.5	1.1	0.6	1.9	1.5	1.5	1.1
C-526	3.4	2.7	1.2	1.1	2.2	1.6	1.3	1.2
C-527	3.8	2.9	1.9	1.5	2.6	1.7	1.6	1.4
C-528	3.4	2.7	1.4	2.1	1.9	1.6	1.1	1.8
C-956	-	8.5	7.5	8.0	4.6	5.3	4.8	4.7
C-977	-	8.0	8.0	8.4	4.8	4.6	5.3	5.6
CO-29	4.9	4.3	3.7	3.3	2.8	2.5	2.5	2.3

near land surface will indirectly impact water levels in the lower Tamiami aquifer.

ESTIMATION OF SAFE YIELD

Criteria

The determination of the safe yield of an aquifer is contingent upon the criteria used to define this yield. Todd (1959) defines safe yield as the amount of water which can be withdrawn without undesired effects. Undesired effects may include depletion of groundwater reserves, inducing intrusion of undesirable quality water, infringing on the rights of existing users, and deteriorating the available economic advantages of pumping (Domenico, 1972; paraphased by Freeze and Cherry, 1979). A commonly applied technique to estimate safe yield is to limit withdrawals to annual groundwater recharge rates. This method, however, ignores the dynamics of aquifer recharge capabilities under pumping conditions. Sources of induced recharge include increased leakance, evapotranspiration capture, and increased lateral inflow in response to increased gradients. Therefore, improved estimations of safe yield should be made using models which take these dynamics into account.

In this study, safe yield estimates were based on the review of the following four criteria:

1. Drawdowns should not reach the base of the producing unit of the water table aquifer or the top of the unit of the artesian aquifers.
2. Pumpage should not induce an "excessive" degree of saltwater intrusion landward.
3. Drawdowns should not result in adverse impacts in environmentally sensitive areas.
4. Pumpage should not cause adverse impacts on existing legal users.

Of these criteria, two were not directly evaluated for the lower Tamiami aquifer in this study. Because the aquifer is semi-confined, pumpage normally will not directly affect water levels in the environmentally sensitive areas. Normally, these conditions would eliminate this criteria from consideration, however, due to the large volume of water derived from leakance, measurable impacts on water table elevations in these areas may be occurring. This impact could be assessed in the future using a three-dimensional model. The second criteria not addressed in this study is the assessment of adverse impacts on existing legal users. Historically, adverse impacts are defined as "a decrease of ten percent or more in the withdrawal capability of any presently existing legal user" (SFWMD, 1985). Adverse impacts are addressed through the District's water use permitting system. Such impacts are determined on a localized level with mitigation being the responsibility of the permit applicant.

The remaining two criteria addressed in this study are the prevention of excessive saltwater intrusion and excessive drawdowns. The mechanisms of saltwater intrusion are quite complex, but for this simulation the Ghyben-Herzberg theory is used to identify the theorized plane of the saltwater/fresh water interface. This theory generally states that each foot of freshwater head displaces 40 feet of saltwater. In coastal regions, this theory would describe a wedge shaped plane with the toe of the salt water occurring inland and broadening in towards the coast. The Ghyben-Herzberg theory has two major limitations inherent to it. The first assumption is that the interface is planar. Field data contradicts this and indicates the interface is actually a diffused zone. The second assumption is that the interface is static and groundwater flow does not move across it. This is also unsupported by field data. Despite these contradictions, the Ghyben-Herzberg theory is frequently used for conservative approximations of the salt water interface in coastal areas.

The depth to the base of the lower Tamiami along the coast is 140 to 160 below NGVD. Assuming one foot of fresh water head will displace 40 feet of salt water, four feet of fresh water head would be required along the coast to prevent salt water intrusion from the Gulf of Mexico. Topographically, this condition could occur along localized areas of the coastal ridge where predevelopment water levels appeared to exceed +4 ft. NGVD. However, in low lying coastal areas where water levels in the lower Tamiami are normally +1 to +3 ft. NGVD, salt water intrusion has already occurred. This is illustrated in well C-527 which indicates good correlation between water levels and chloride concentrations (Figure 65). This well is 72 feet deep and has water levels ranging between one and three feet above NGVD. Assuming an average water level of two feet, the location of the fresh water/salt water interface should be about 80 feet below NGVD. Figure 65 indicates that when water levels drop below +2 ft. NGVD, chloride levels approach or exceed 10,000 mg/l. The Ghyben-Herzberg relationship is not so well demonstrated by many other monitor wells in the area. This is attributed to well construction (partial penetration of the aquifer) combined with the inland location of the remaining observation wells. Until a calibrated, dynamic salt water interface model can be developed for this area, the Ghyben-Herzberg relationship will be used to relate water levels to coastal salt water intrusion.

Methodology

Under these criteria two methods were developed to estimate available water in the Naples area. The first approach assumes that all users bear equal responsibility for the limitation of salt water intrusion. The second method assumes that all withdrawals will occur inland and are restricted by the constraints of maintaining a fresh water head "barrier" near the coast and limiting drawdowns to the top of the aquifer.

Both simulations employed the aquifer system characteristics depicting the conditions which occurred at the end of the 1985 dry season. Cumulative rainfall data from November 1984 to April 1985 were used to determine the theoretical recurrence frequency of the 1984-85 dry season conditions (Lin, 1981). Rainfall in Naples for the months of November through March totaled 2.39 inches which is classified by Lin as having a return frequency of 1-in-5 years. Near normal rainfall occurred during the last two months of the dry season. The total rainfall for November through May was 7.06 inches which is equivalent to a 1-in-3 year drought. Therefore, the estimates presented by both methods represent the maximum amount of water that can be "safely" withdrawn at present levels of development for an extended period of slightly less than normal rainfall.

The first method utilized an iterative subroutine written by Dr. George Shih (SFWMD) to determine the amount of water which can be removed from each node to areally lower the potentiometric surface at every node to a uniform specified depth. Because aquifer properties differ spatially, each half mile square node is pumped at a different rate.

In this exercise, two final head levels (one and two feet above NGVD) were used to determine the available yield of the area. Since drawdown is directly proportional to pumpage, the initial estimate of pumpage at any node, q_{ij}^o, is assumed to be proportional to the residual head. The residual head is defined as the initial predevelopment head, h_{ij}^o, minus the target head, h_c, at every node, where:

$$q_{ij}^o \propto h_{ij}^o - h_c \qquad (1)$$

An initial estimate of the total pumpage, Q_o, for the modeled area was made and distributed among each node (q_{ij}^o) proportionately to the magnitude of the residual head, as shown in the following equation:

$$q_{ij}^o = \frac{Q_o}{\Sigma(h_{ij}^o - h_c)} (h_{ij}^o - h_c) \qquad (2)$$

An initial estimate of q_{ij}^o for every node was input to the USGS 2-D model and an initial estimate of head at every node, $h^{n=1}$, (where n is an iterative number) was then calculated and compared to the final target head h_c. Once a good estimation and distribution of Q_o was found, an iterative automatic correction scheme was applied that adjusted each estimate of q_{ij} so the calculated head levels in the modeled area would approximate the target head. This procedure involved calculating a dimensionless adjustment factor, F, for each estimate of $q_{ij}^{n=1}$, based on the residual head such that:

$$F_{ij}^{n=1} = \frac{h_{ij}^{n=1} - h_c}{h_{ij}^{n=1}} \qquad (3)$$

Therefore, the next estimation of pumpage $q_{ij}^{n=2}$ is calculated as:

$$q_{ij}^{n=2} = q_{ij}^{n=1} \text{ X } (1 + F_{ij}^{n=1}) \qquad (4)$$

To avoid over adjustment and to help the solution converge more rapidly, the absolute value of F was limited to a range such that:

$$|F_{ij}^n| \leq U^k \qquad (5)$$

where the starting value of U^k of 0.5 was gradually reduced to 0.01 as head levels converged to the target level, h_c. After each set of pumping values was calculated, they were input to the USGS 2-D model to determine regional head levels. When the computed head distribution closely approximated the target heads (where every $h_{ij} \cong h_c$), the solution was considered complete and the basin yield was calculated as:

$$Q^n = \Sigma q_{ij}^n \qquad (6)$$

This type of problem does not have a unique solution in terms of q_{ij}^n. Different distributions of q_{ij} can be attained by using different Q_o and U^k values. However, the total possible pumpage, Q^n, was observed to vary by less than 5%.

The second technique used to determine a safe yield for the study area limited drawdowns to the top of the lower Tamiami aquifer while maintaining a fresh water "barrier" near the coast to prevent saltwater intrusion. The USGS 2-D model was used to estimate the westernmost extent of the +4 ft NGVD contour under predevelopment conditions when simulating a 1-in-3 year drought (Figure 68). The four feet of fresh water head was chosen to assure fresh water throughout the entire thickness of the aquifer which would prevent coastal salt water intrusion past the barrier. East of the 4 ft. above NGVD head contour, regularly spaced discharge nodes were selected and pumped at increased rates until well point drawdown reached the top of the aquifer, and water levels along the western fresh water head boundary dropped below four feet NGVD. This solution does not represent a unique distribution scheme for pumpage and is only meant to give an approximation of total pumpage available.

Results

The total volume of water which can be withdrawn from the lower Tamiami aquifer to uniformly lower the potentiometric head to +1 foot NGVD elevation is approximately 65 MGD. Figure 69 shows the possible distribution of this pumpage. Under these conditions, landward saltwater intrusion would be quite extensive. During the 1985 water shortage emergency, water levels along the coast exceeded +1 ft but salinities in several observation wells reached the highest recorded levels. Therefore, the +1 foot criteria is not considered acceptable along the coastal area.

A subsequent simulation was performed to determine Q^n using a +2 ft NGVD criteria. This minimum water level was chosen because the majority of the wells along the coast do not exceed depths of 80 feet. While salt water intrusion would occur at the base of the aquifer, the partially penetrating wells would be able to "skim" fresh water off the top of the aquifer. The total amount of water available under this criteria is approximately 45 MGD for the modeled area. The approximate distribution of this pumpage is shown on Figure 70. While this distribution is not unique, it does represent an accurate spatial distribution scheme for pumpage. It is felt that the 45 MGD withdrawal distributed generally as shown, especially along the coastal area, would provide protection from substantial salt water intrusion during a 1-in-3 year drought. However, when water levels drop below +2 ft NGVD inland from the coast for extended periods of time, salt water intrusion may result in temporary cutbacks in pumpage.

The second method of examining safe yield based on maintaining a fresh water barrier against salt water intrusion indicates that a total volume of approximately 84 MGD is available in the modeled area. Figure 71 shows the calculated potentiometric levels based on this pumpage rate. This is not a unique solution. Magnitudes of pumpage and potentiometric levels will vary somewhat based on the distribution of the pumping wells.

Using a lower fresh water head along the coast would increase the available yield; however, if salt water intrudes along the base of the aquifer, lower heads east of the +4 ft. NGVD fresh water head barrier will induce salt water to flow inland past the barrier, possibly resulting in extensive intrusion. Therefore, maintaining four feet of fresh water head is recommended under this scenario. It should be noted, however, that the four foot criteria will not prevent upconing of connate salt water east of the barrier.

Maintaining a fresh water head four feet above NGVD in this area would be difficult. Existing users have substantially altered the potentiometric levels as compared with predevelopment levels. Using water levels calculated for May 1985, the first occurrence of the four foot contour is much further inland than shown on Figure 72. Under 1985 conditions, considerably less water could be withdrawn using the four foot criteria. In addition, the four foot criteria does not protect users from salt water intrusion west of the barrier. Therefore, this method may not be applicable to this study area.

Existing Users

The present permitted users developing the lower Tamiami aquifer are listed in Table 19. In addition to the individual permits, other users in the area include general permits, small uses with little potential for adverse impacts, and exempt users such as individual home wells. General permits were not addressed in this study due to the minor withdrawals and the scattered distribution of the small number of permittees. Exempt uses were estimated at 6 MGD during the dry season, however, this number has a low reliability.

The criteria for issuing agricultural and recreational water use permits have changed over the years. As a result, District water use allocations have been issued either on an annual basis, a maximum monthly basis, or daily basis. This makes it difficult to accurately summarize allocation with respect to a single time frame. Most of the agricultural permits issued in the study area were based on average annual allocations. Maximum projected monthly water use based on accepted criteria of the day were calculated in the staff reports but were not included on the permit itself. Present agricultural water use permits include maximum monthly allocations as well as permits based on annual and maximum day allocations. Using

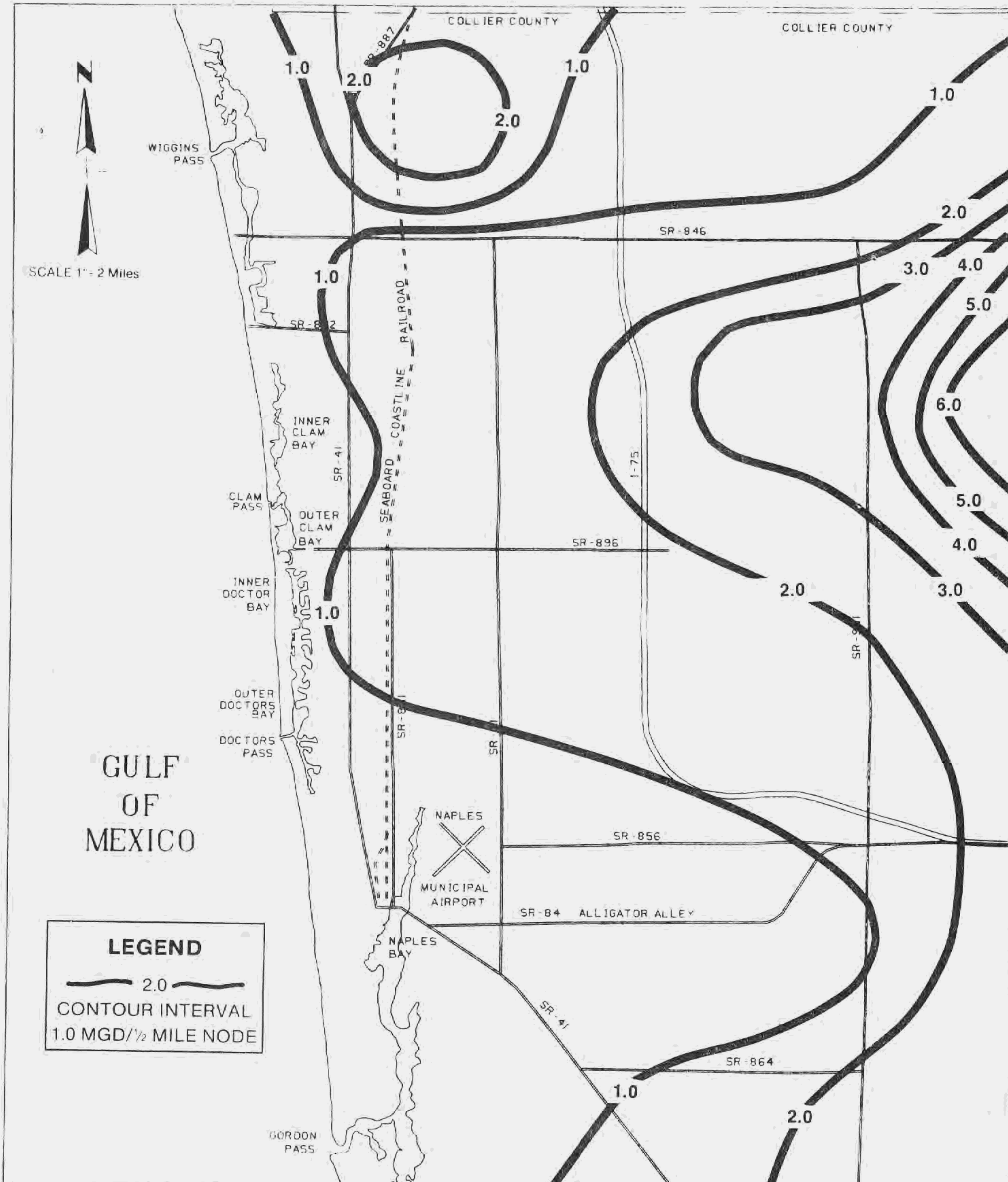


Figure 69 DISTRIBUTION OF PUMPAGE (65 MGD) FOR THE LOWER TAMIAMI AQUIFER USING A + 1 FT. FRESH WATER LEVEL

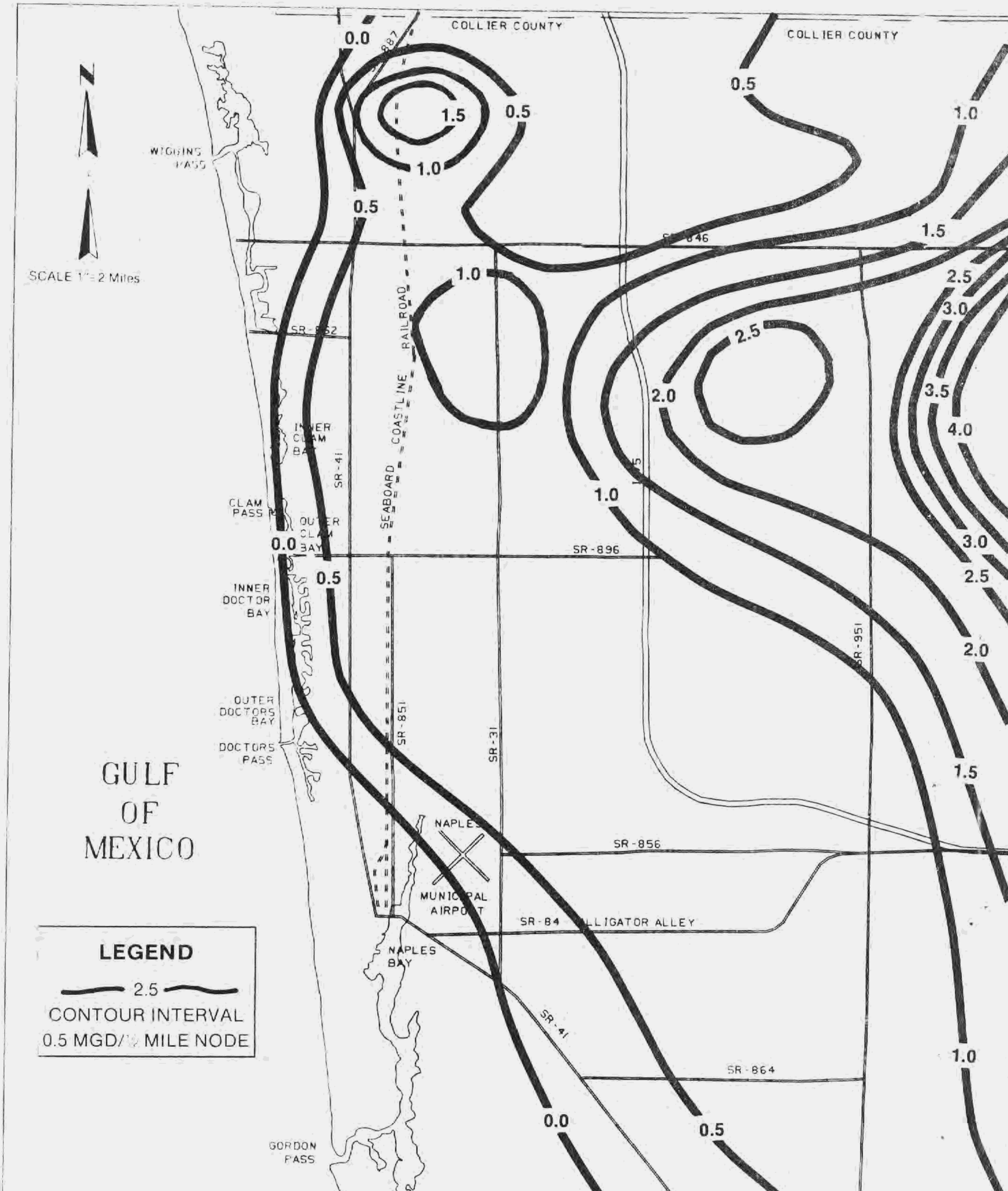


Figure 70 DISTRIBUTION OF PUMPAGE (45 MGD) FOR THE LOWER TAMIAMI AQUIFER USING A + 2 FT. WATER LEVEL

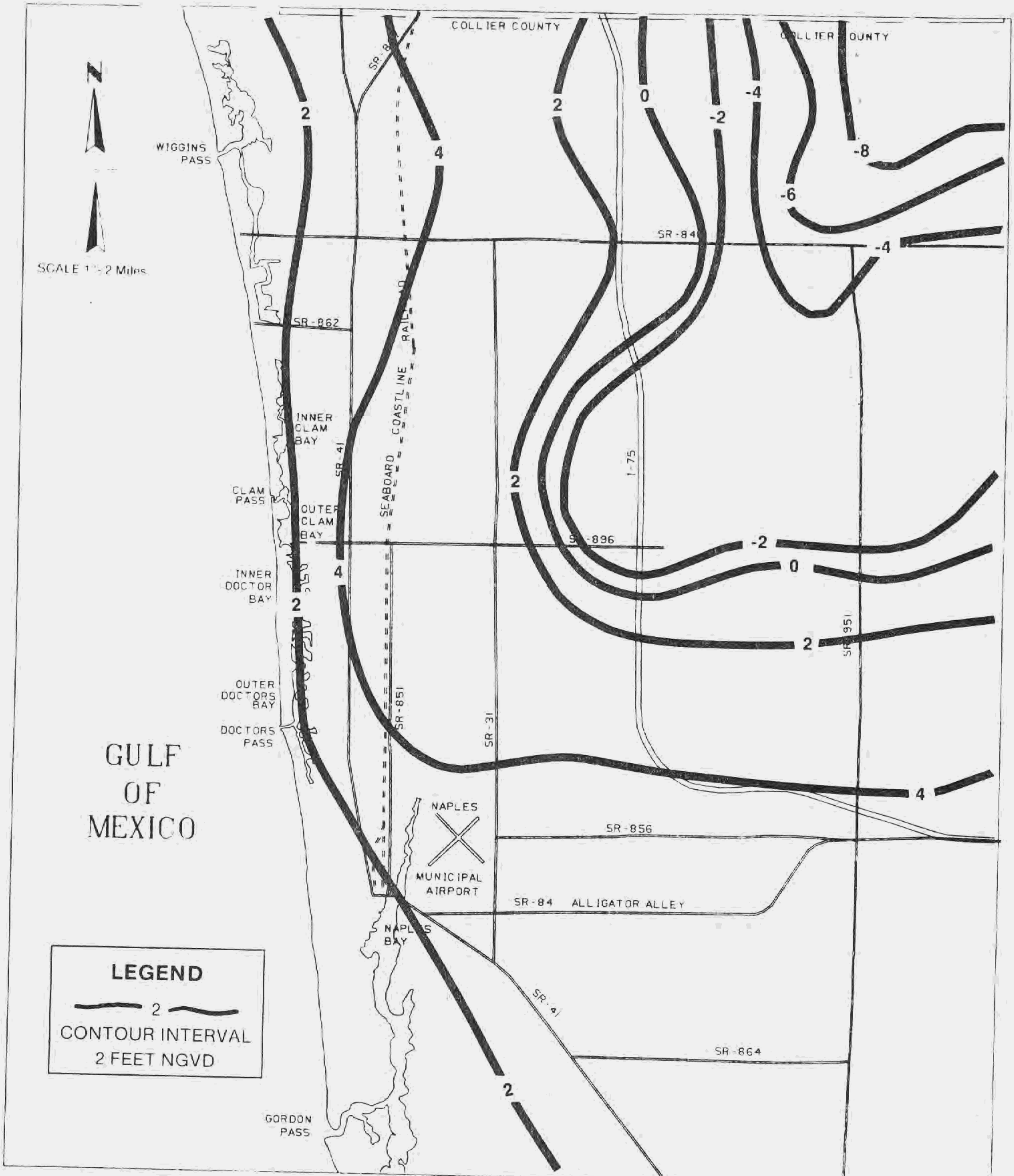


Figure 71 SIMULATED WATER LEVELS OF THE LOWER TAMIAMI AQUIFER MAINTAINING A FRESH WATER BARRIER AND PUMPING 84 MGD

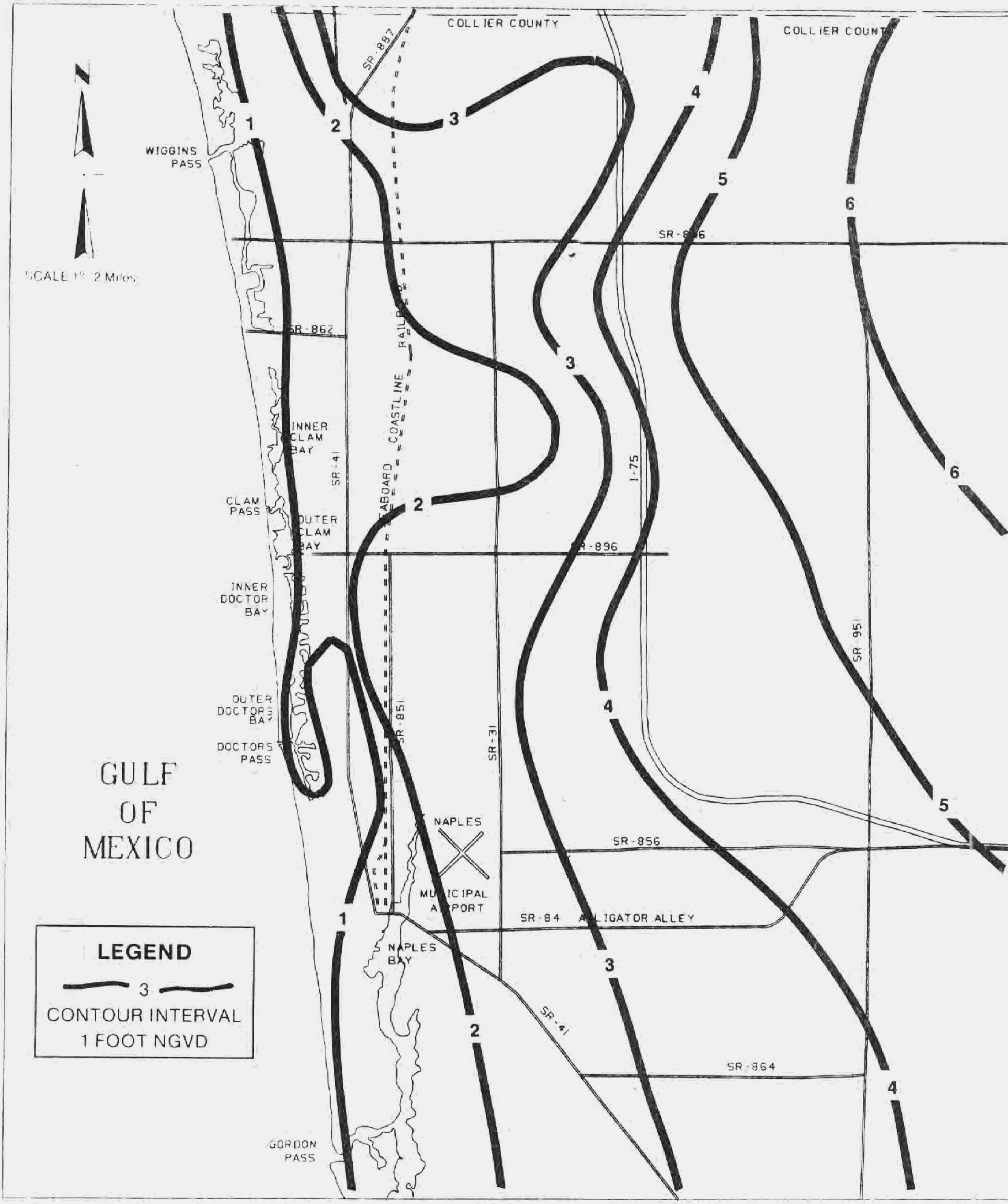


Figure 72 LOWER TAMIAMI AQUIFER WATER LEVEL SIMULATION FOR MAY, 1985

TABLE 19. ACTUAL AND ALLOCATED PUMPAGE FROM THE LOWER TAMIAMI AQUIFER IN THE NAPLES AREA

PERMIT NO.	OWNER	WATER USE	ACTUAL MONTHLY PUMPAGE (MG) SEP. 84	OCT. 84	APR. 85	MAY 85
11-00008	Naples Bath & Tennis	LAN	1.3	1.3	2.7	2.7
11-00015	The Glades, Inc.	PWS	7.7	9.3	10.7	9.8
11-00017	City of Naples	PWS	147.3	262.7	25.9	44.8
11-00019	High Point Country Club	REC	<0.1	<0.1	<0.1	<0.1
11-00020	The Glades	LAN	2.5	4.8	5.8	10.1
11-00030	Hole in the Wall Golf Course	REC	23.3	34.8	17.5	20.0
11-00052	Pelican Bay Impr. District	PWS	5.8	6.4	6.5	6.2
11-00053	Riviera Golf Club	LAN	7.5	8.3	5.2	10.8
11-00054	Moorings Golf Club	REC	0.0	7.0	7.3	5.6
11-00057	Wilderness Country Club	LAN	25.2	39.2	5.9	9.4
11-00058	Imperial Golf Course	LAN	13.0	13.0	13.0	13.0
11-00063	Naples Golf & Beach Club	LAN	21.0	23.2	9.7	16.3
11-00064	Country Club of Naples	LAN	17.4	29.3	15.1	15.3
11-00070	Manatee Fruit Company	AGR	0.0	14.4	14.4	0.0
11-00071	Manatee Fruit Company	AGR	83.9	108.0	120.0	84.0
11-00078*	Exotic Foliage Nursery	AGR	0.0	0.0	0.0	0.0
11-00086	Eden Island Nursery	AGR	0.0	0.0	3.6	0.0
11-00087	Eden Island Nursery	AGR	0.0	19.2	4.8	0.0
11-00089	Eden Island Nursery	AGR	2.4	2.9	18.0	9.0
11-00092	Sproul Trust	AGR	0.0	8.8	15.1	10.0
11-00096	Pinewood Development	LAN	1.4	1.4	2.8	2.8
11-00117	N.F.V. Corporation	AGR	0.0	60.5	47.2	23.0
11-00118	P.B.A. Temple Grove	AGR	20.9	37.7	37.7	37.7
11-00125	Royce O. Stallings	AGR	11.5	8.6	17.3	5.8
11-00126	D.T. Farms	AGR	0.0	11.9	0.0	0.0
11-00150	Lakewood Country Club	LAN	0.0	0.0	11.4	0.0
11-00157	Manatee Fruit (D.T. Farms)	AGR	35.7	70.2	23.4	0.0
11-00164	Harvey Brothers Farms	AGR	64.8	103.8	388.7	4.3
11-00167*	Wyndemere Holdings	LAN	0.0	0.0	0.0	0.0
11-00170	Pelican Nursery	AGR	5.9	7.4	9.1	10.2
11-00175	Pelican Nursery	AGR	9.0	9.0	0.0	0.0
11-00176	Stoney's Citrus Grove	AGR	1.4	0.8	30.2	30.2
11-00180	A.L. Leinweber	AGR	0.0	0.0	2.1	2.1
11-00183	D.R.H., Inc.	AGR	0.0	0.0	2.1	2.1
11-00192	Manchester Invest. Inc.	REC	0.0	0.0	27.6	35.7
11-00193	Manchester Invest. Inc.	PWS	1.3	2.4	2.6	2.4
11-00196*	Manchester Invest. Inc.	REC	0.0	0.0	0.0	0.0
11-00199	Manchester Invest. Inc.	AGR	12.0	12.0	12.0	12.0
11-00200	The Moorings, Inc.	LAN	1.1	1.3	4.3	3.5
11-00210	Whispering Pines	LAN	1.2	1.5	0.0	0.0
11-00221*	U.S. Homes Corp.	LAN	0.0	0.0	0.0	0.0
11-00222	Stahlman Properties	AGR	<0.1	<0.1	<0.1	<0.1
11-00243	GMC Development Corp.	LAN	0.6	0.6	0.8	0.8
11-00245	Smallwood Landscaping	LAN	0.2	0.2	0.4	0.4
11-00257*	Tree Plateau Co., Inc.	AGR	0.0	0.0	0.0	0.0
11-00260*	Community School of Naples	PWS	0.0	0.0	0.0	0.0
11-00265	Development Corp. of America	LAN	2.4	2.4	2.4	2.4
11-00270*	Wiggins Bay Association	LAN	0.0	0.0	0.0	0.0
11-00312	Naples Yacht Harbor	LAN	0.0	0.0	3.6	3.4
11-00319	H.M. Buckley & Sons	AGR	0.3	0.3	0.6	0.6

*Not developed or in operation yet.

WATER USE ABBREVIATIONS:
AGR - Agriculture
LAN - Landscaping
PWS - Public Water Supply
REC - Recreation

the maximum monthly requirements as estimated in the staff reports for the existing permits, demand would be 3.24 billion gallons (108 MGD). By reevaluating the old permits using present allocated criteria, the maximum monthly use is estimated at 1095 MG or 74 MGD. This latter figure is believed to be more realistic.

The total maximum monthly allocation, however, is never actually withdrawn at any specific time for several reasons. The first reason is that virtually every agricultural and recreational permit includes surface water sources as well as groundwater sources. The second is that demands do not occur simultaneously. Vegetable farms require their greatest quantities of water in the late fall and winter during the growing season. In addition, not all the permitted land is planted every year. Recreational users and public supplies require the greatest quantities of water at the end of the dry season (April and May).

Existing pumpage data for individual permit users are not sufficient to quantify actual use. Early permits required property owners to submit pumpage reports twice each year. After the Naples area was designated a "Reduced Threshold Area" water use permits required daily pumpage records to be submitted on a monthly basis. Despite the regulations, very few users have complied. The actual pumpage estimates listed on Table 19 indicate the actual pumpage was below maximum monthly allocations for most users during the four months in which actual pumpage was measured. Actual pumpage from users located west of S.R. 31 for the month of April 1985 was approximately 12.7 MGD. By comparison, the estimated safe yield for this same area using the +1 and +2 feet criteria is 11.3 and 6.9 MGD, respectively. These data suggest water use from the lower Tamiami aquifer exceeds the safe yield of this area.

Summary

Based on a comparison of the results of the one and two foot drawdown criteria for safe yield with the existing maximum monthly allocations and the actual pumpage data, the lower Tamiami aquifer is considered to be over-allocated in most of the western portion of the modeled area and over-developed west of the S.R. 31. Under these conditions, water use at present rates during a normal rainfall year should not result in significant salt water intrusion. However, under a 1-in-3 year dry season drought, salt water intrusion caused by excessive drawdowns will occur west of US 41 and south of Doctors Pass, resulting in voluntary and possible mandatory cutbacks. Under a 1-in-5 year dry season drought, mandatory cutbacks will be required.

In addition, due to the amount of water derived from the water table aquifer as leakance, efforts should be made to maintain highest possible water levels in this aquifer during the dry season. This can be accomplished where feasible by maintaining high crest elevations on major canals during the dry season, sharply limiting pumpage from the water table west of I-75, and continuing to require on-site retention lakes where possible.

Future Outlook

If future allocations are restricted in the Naples area, there are two factors which will reduce present withdrawal rates in the future. The first is the development of wastewater reuse facilities by both the City of Naples and Collier County. Naples is presently developing (1985) a large-scale, wastewater-reuse system. The city operates a 6 MGD treatment system which discharges treated effluent into the Gordon River. An expansion of the existing facility, along with a pressurized distribution system, is planned to be completed by October 1986. The upgraded plant will have a design capacity of 8.5 MGD (Florida Atlantic University, 1984). The average daily effluent output is anticipated to be 6.8 MGD with the maximum flow (8.5 MGD) occurring between February and March and the minimum flow (5.0 MGD) occurring in September and October. It is estimated that 75 percent of the effluent will be used for golf course irrigation (nine users with an average daily demand of 5.0 MGD) and the remaining 25 percent (1.8 MGD) will be discharged into the Gordon River in accordance to the city's DER permit.

Collier County is in the planning phase of developing a wastewater reuse facility. The plant being considered would have a design capacity of 2.5 MGD and would supply irrigation water primarily to golf courses. The plant should be operational by 1986.

In addition to the City of Naples wastewater reuse system, the Pelican Bay Improvement District also uses treated effluent. The Pelican Bay facility was built in 1979 and supplies irrigation water to a 110 acre golf course located in Section 4, Township 49S, Range 25E. The design capacity of the plant is 0.5 MGD; however, the current average daily flow is 0.145 MGD.

The current and future utilization of waste water reuse systems will reduce withdrawal problems from the lower Tamiami aquifer. This water management practice should continue to be encouraged within this area.

Management Options

In order to protect existing legal users and preserve the water quality in the lower Tamiami aquifer along coastal Collier County, actions should be taken to minimize withdrawals during extended periods of drought. The following is a list of short and long term management options which may be considered in formulating strategies for protecting the resources of this aquifer.

Short Term:

1. Pumpage from the city of Naples Coastal Ridge Wellfield should cease during most of the dry season except during emergencies. Under these conditions water supply for the utility's service area would be provided by the East Golden Gates wellfield. The period during which withdrawals from the Coastal Ridge Wellfield should be restricted would be determined by rainfall and water level data. A model which will be used to predict various levels of drought is currently being developed by the SFWMD and could be used to determine when the Coastal Ridge Wellfield should restrict pumpage.

2. The District should work with local government to promote the implementation of acceptable water conservation measures throughout the Naples area.

3. The District should adopt appropriate regulatory strategies for the lower Tamiami aquifer in the study area. There are three regulatory options available to the District. The first is to continue the current permitting approach, based on a site by site evaluation of each application. This option, if chosen, could result in further lowering of water levels along the coastal areas, and, consequently, a higher probability of water restrictions will result in order to protect the aquifer during prolonged droughts. Therefore, based on the hydrologic data and the District's commitment to protecting the resources, this option may not be feasible for much of the western coastal portion of the modeled area.

   The second option is to place restrictions on the issuance of permits for the lower Tamiami aquifer in the study area. Restrictions on significant usages (those in excess of 10,000 gpd) should be strongly considered in the area west of S.R. 31. Salt water intrusion is a concern under present withdrawals during a one-in-three year drought, and continued increases in pumpage can lead to more frequent mandatory water use cutbacks.

   The third option is to temporarily discontinue the issuance of general and/or individual water use permits for the lower Tamiami aquifer in all or part of the study area. The area of greatest concern is west of S.R. 31. Although this option would provide the greatest margin of safety of the three presented, it could result in significant hardships. However, even under this option, water use restrictions may be necessary for dry season drought frequencies in excess of a one-in-three year condition.

Long Term:

1. The District should reevaluate current groundwater allocation criteria for coastal Collier County with respect to the temporal relationship between peak demand and the type of water use. Attempts should be made to limit the number of long duration, high volume users which are active during the dry season. Consideration of permit issuance should favor users which require water primarily during the wet season.

2. The District should continue to support county and city efforts in investigating the feasibility and implementation of active water conservation measures such as fresh water storage and waste water reclamation.

3. The District should work with the county in the comprehensive planning process to provide appropriate technical input on land use designations in order to minimize water demands.

4. The city and county should plan to develop and expand future public supply wellfields east of the modelled area to supply users located along coastal Collier County.

FUTURE GROUNDWATER POTENTIAL

INTRODUCTION

A basic assessment of the future groundwater development potential for the water table, lower Tamiami and Sandstone aquifers is presented to assist the county in making planning decisions. Four factors were evaluated in determining the development potential for each aquifer. These factors include: a) water quality, b) degree of resource development, c) proximity of undesirable land uses, and d) aquifer characteristics.

In Collier County the major adverse water quality component is salt water. Salt water may originate from landward movement of the coastal salt water interface, from localized areas of relict seawater, or from vertical migration across semi-confining beds. In addition to salinity, other undesirable groundwater constituents can affect water usage. Waters with high levels of iron, for instance, can be treated for potable supply by aeration but cannot be successfully used for drip irrigation systems. Other water quality parameters limiting water use include color, nutrient levels, organics, hardness, and sulfate levels.

Degree of resource development is limited in areas where users are approaching or exceeding the producing capacity of an aquifer. These types of assessments are subject to debate and require detailed quantification. They have not been completed for the county but will be applied to regions near specific municipal wellfields discussed earlier.

Proximity of undesirable land uses acts to limit the location of potable supply sources. In Collier County these are mainly landfill sites because industrial activities are not well established at this time.

The aquifer characteristics assessed in this study include transmissivity, aquifer storage, and leakance of confining beds. These data have been collected from consultant reports and grouped by aquifer. In addition, the SFWMD conducted fourteen duration pump tests in the county. In order to fill in data gaps and work within existing time constraints, another 18 transmissivity values were estimated using specific capacity data.

The relationship between transmissivity and specific capacity is dubious. This is mostly due to head losses within a pumped well caused by friction in the well itself (well losses), and pressure deviations between laminar and turbulent flow in the formation immediately adjacent to the well (formation losses). Walton (1970) proposed the following equation to estimate transmissivity from specific capacity data, assuming no well losses, full penetration, and homogeneous and isotropic conditions. The equation is:

$$\frac{Q}{s} = \frac{T}{264 \log\left(\frac{Tt}{2693\, r_w^2 S}\right) - 65.5} \qquad (7)$$

Where: $\frac{Q}{s}$ = Specific Capacity gpm/ft,
Q = Discharge (gpm)
s = Drawdown (ft)
T = Transmissivity (gpd/ft),
S = Storage coefficient (dimensionless fraction)
r_w = Nominal radius of well (ft),
t = Time in minutes after pumping starts.

In this study, an attempt was made to develop an empirical relationship between transmissivity values calculated from duration pump tests in Collier County and specific capacity data. The advantage of this equation is its basis in actual measured physical response and the ability to quantify the estimated error. Regression analysis was performed on sets of data comparing duration pump test results with specific capacity data. The specific capacity data consisted of both single and multi-step tests of fixed duration (15 minutes) and constant discharge per step. The results of this exercise indicate that multi-step specific capacity data have a high degree of correlation with calculated transmissivity data. The correlation coefficient is 86 percent. Single step specific capacity data did not correlate well with transmissivity data (R^2 = 40 percent), and yields minor improvements in accuracy over Walton's equation.

The equation used to calculate transmissivity from a three step specific capacity test is:

$$\frac{T}{10{,}000} = -1.20147 + .33536(S_3) + .163(S_2) - .1549(S_1) \qquad (8)$$

Where: T = Transmissivity (gpd/ft), and
S = Specific Capacity (gpm/ft) at the i^{th} step.

S_1, S_2, S_3 indicate the sequence of steps with S_1 calculated for the lowest pumping rate and S_3 for the highest pumping rate. The equation used to calculate transmissivity from a single step test is:

$$\frac{T}{10{,}000} = 19.83037 + .15852\,(S_1) \qquad (9)$$

The final transmissivity data were mapped as shown in the text (Figures 73 and 74). No attempts were made to quantitatively regionalize these data at this time. If a regional flow model is to be used as a management tool in the future, these data should be regionalized using the kriging technique.

The final assessment of development potential for each aquifer is categorized as good, moderate, or poor in this study. It should be noted that this categorization is completely subjective at this point. The next phase of developing a resource management plan should be the production of a verified three dimensional numerical flow model. The model should be capable of quantitatively addressing the physical system including flow boundaries, inflow and outflow, recharge evapotranspiration, and consumptive use. This model would allow water managers to more accurately assess the degree of influence of existing users and determine the safe yield of components of the actual groundwater system.

AVAILABILITY OF WATER FROM THE WATER TABLE AQUIFER

Aquifer Characteristics

The hydraulic characteristics from the water table aquifer are presented in Table 20 and Figure 73. Generally the aquifer is extremely productive throughout the western half of the county. Transmissivity values range from 30,000 gallon per day/ft (gpd/ft) along the west coast to over 1,000,000 gpd/ft in the southeastern portion of the study area. The transmissivities are lower to the north and along the west coast because the aquifer is composed mostly of fine grained clastics. In the central portion of the county the aquifer contains highly porous and karstic carbonate facies. Transmissivities in these areas range between 100,000 to 300,000 gpd/ft. In several localized areas where hard cap rock is present, karstic vuggy porosity yields transmissivities from 500,000 to over 1,000,000. Specific yield for the aquifer ranges from .01 to .3.

Water quality is generally good in the water table aquifer. Chloride concentrations are low, except in coastal areas, as are most other dissolved ions. The exception is iron, which may exceed 4 mg/l in some areas in the county. High iron levels occur sporadically throughout the county, but are consistently high to the northeast. In addition to iron, the water table aquifer contains variable amounts of organic constituents that color the water and make it difficult to treat for potable supply. Color increases near cypress swamp areas where tannic acids are produced. As water enters the aquifer through seepage, the possibility of pesticides and fertilizers entering the aquifer exists in the vicinity of agricultural properties and landfills. Septic tanks are located primarily in the eastern rural areas of the county that are sparsely populated. Therefore, septic tanks are considered a localized concern only.

Potential for Water Supply

Figure 74 is a relative assessment of the development potential for the water table aquifer. There are two regions shown which offer good potential for future fresh water supply. The northernmost area (Ia) is the region which was studied for the Big Cypress Basin Board by Missimer and Associates (1982). As previously discussed, this region may be capable of yielding up to 30 MGD during an average dry season. The only questionable land uses from a water quality standpoint are an active quarry (Mule Penn) and several agricultural operations. Region Ib occurs in a thick sequence of highly transmissive limestones beneath the Fakahatchee Strand. Water in the eastern portion of this region is high in color suggesting the presence of organics. In the western portion water quality is very good. Two pump tests conducted along Everglades Boulevard south of SR 84 yielded transmissivities over 900,000 gpd/ft.

Stewart (1982) ran a DC resistivity profile along the southern extent of Everglades Boulevard. Stewart attributed a low resistivity zone, which occurred at 60 to 80 feet below land surface, to be saltwater. However, test drilling and borehole geophysical data collected along the same transect determined that the low resistivity layer was the lower Tamiami confining zone and not saltwater. A wellfield along the southern end of Everglades Boulevard should be capable of producing water in larger quantities than in the Cocohatchee Watershed area. This is due to the increased areal thickness of the unit combined with the proximity of two major, fresh water canals which act as a source of recharge to the wellfield in the dry season.

Region II is considered a zone of moderate development potential. While the aquifer is very transmissive in most areas, the principal factors which limit its potential are it relative thinness and several competing users. Along the southwest coast, large scale withdrawals could cause inward saltwater movement; however, the potential for this is considered low and moderate aquifer development canbe achieved. Little information is available in this region and new users should develop site specific data.

In the central portion of Region II, the water table is very productive but is locally thin, which limits its yield during periods of drought. In addition,

TABLE 20. AQUIFER PARAMETERS FOR THE WATER TABLE AQUIFER

WELL	TWP	RGE	SEC	LATITUDE	LONGITUDE	Total DEPTH	Casing DEPTH	Transmissivity (gpd/ft)	Storage (Dimensionless)	Leakance (day-1)	Source
C-01	49	25	09	26 12 59	81 48 45	30		3.0E4			Missimer 1979
L-02	47	25	28	26 21 05	81 47 56	33	19	6.5E4	5.0E-2		Missimer 1981B
C-03	48	29	26	26 16 42	81 23 39	50		1.5E6	3.0E-3	1.5E-4	Missimer 1983
C-04	48	26	17	26 46 26	81 43 20	35	20	1.0E6	2.0E-1a		Missimer 1980B
C-05	49	28	05	26 12 15	81 34 10	25	20	2.1E5	1.0E-2		CH2M Hill 1980
C-06	51	26	04	26 03 50	81 44 32	45		4.0E5	2.8E-4	6.3E-3	Missimer 1980C
C-07	50	26	26	26 05 25	81 42 26	50	11	8.6E5	2.0E-2		Missimer 1980D
C-08	52	29	12	25 57 28	81 21 57	25	15	1.2E6	1.2E-1a		Missimer 1981C
C-09	50	26	16	26 06 40	81 44 32	60	5	5.0E5	3.0E-1a		Gee & Jenson 1980
L-10	46	25	36	26 25 15	81 45 24	38	20	3.3E5	1.6E-1a	1.1E-1	Missimer 1980E
L-11	46	25	25	26 26 32	81 45 25	28	20	1.4E5	4.0E-3	5.1E-1	Missimer 1980E
L-12	46	25	10	26 29 04	81 47 50	20	38	1.9E5	2.0E-1a	1.3E-3	Missimer 1979C
L-13	47	26	28	25 56 21	81 19 55	20		2.2E5	2.0E-4	6.7E-4	Missimer 1981D
H-14	47	31	06	26 25 42	81 15 47	40		9.6E5	3.1E-4	1.9E-6	Klein 1964
H-15	45	31	19	26 32 40	81 15 28	34		1.2E3	1.2E-3	4.2E-7	Klein 1964
C-16	46	28	08	26 29 32	81 27 02	29		6.0E4	2.5E-4	1.1E-4	McCoy 1962
C-17	48	26	09	26 18 33	81 42 26	30	13	2.7E5	2.0E-2		Missimer 1983B
C-18	48	26	22	26 16 27	81 42 15	43	14	1.0E6	2.7E-2		Missimer 1983B
C-19	48	26	14	26 18 02	81 41 18	21	10	5.9E4	1.2E-2		Missimer 1983B
C-20	48	26	23	26 16 53	81 40 25	30		2.2E5	1.2E-1a		Missimer 1983B
C-21	48	26	13	26 18 17	81 39 32	33	12	6.2E5	1.0E-1a		Missimer 1983B
C-22	48	27	23	26 17 17	81 35 12	40	10	2.5E5	1.7E-3	6.2E-2	SFWMD
C-23	50	28	06	26 04 56	81 33 41	70	20	1.0E6	3.0E-4		SFWMD
C-24	51	27	06	26 03 13	81 38 02	42	20	2.0E6	1.0E-2a		SFWMD
C-25	51	28	06	26 04 31	81 33 15	50	10	9.3E5	7.0E-2a		SFWMD
C-26	47	27	27	26 21 05	81 36 15	50	20	7.0E4	6.5E-4		SFWMD
C-27	49	28	02	26 14 49	81 29 10	50	10	8.4E4	1.0E-2a		SFWMD
C-28	49	30	18	26 12 00	81 20 48	39	10	9.2E5b			SFWMD
C-29	50	27	06	26 08 42	81 38 11	45	10	3.9E5b			SFWMD
C-30	52	30	34	26 54 03	81 18 12	40	12	7.2E5b			SFWMD
C-31	48	28	23	26 17 34	81 31 09	45	20	9.4E4b			SFWMD
C-32	49	27	11	26 13 46	81 35 28	35	10	2.6E5b			SFWMD
C-33	47	28	24	26 22 41	81 28 15	80	20	3.4E5b			SFWMD
C-34	49	30	32	26 09 28	81 50 25	53	0	9.4E5b			SFWMD
C-35	49	29	34	26 09 28	81 23 31	82	0	1.1E6b			SFWMD
C-36	50	29	06	26 09 27	81 26 20	60	0	1.1E6b			SFWMD
C-37	49	28	34	26 09 28	81 29 58	70	0	2.7E5b			SFWMD
C-38	49	26	30	26 05 17	81 46 30	63	30	8.7E5b			SFWMD
C-39	49	28	19	26 11 32	81 33 01	80	0	2.6E5b			SFWMD
C-40	47	25	17	26 23 28	81 51 25			8.6E3b	7.7E-3	3.1E-2	Missimer 1980F

a. Specific yield value
b. Estimated from specific capacity data

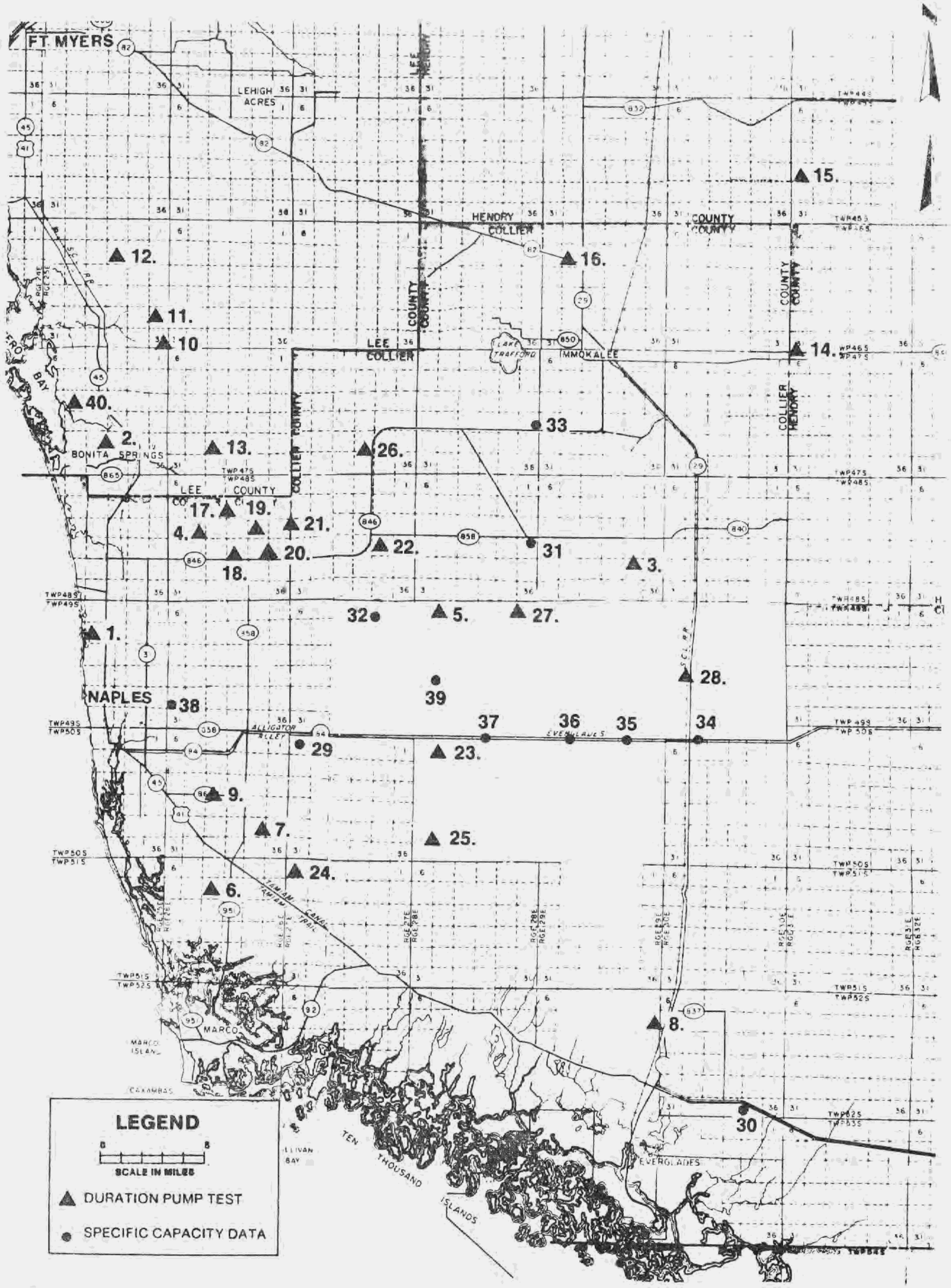


Figure 73 AQUIFER PARAMETER BASE MAP FOR THE WATER TABLE AQUIFER

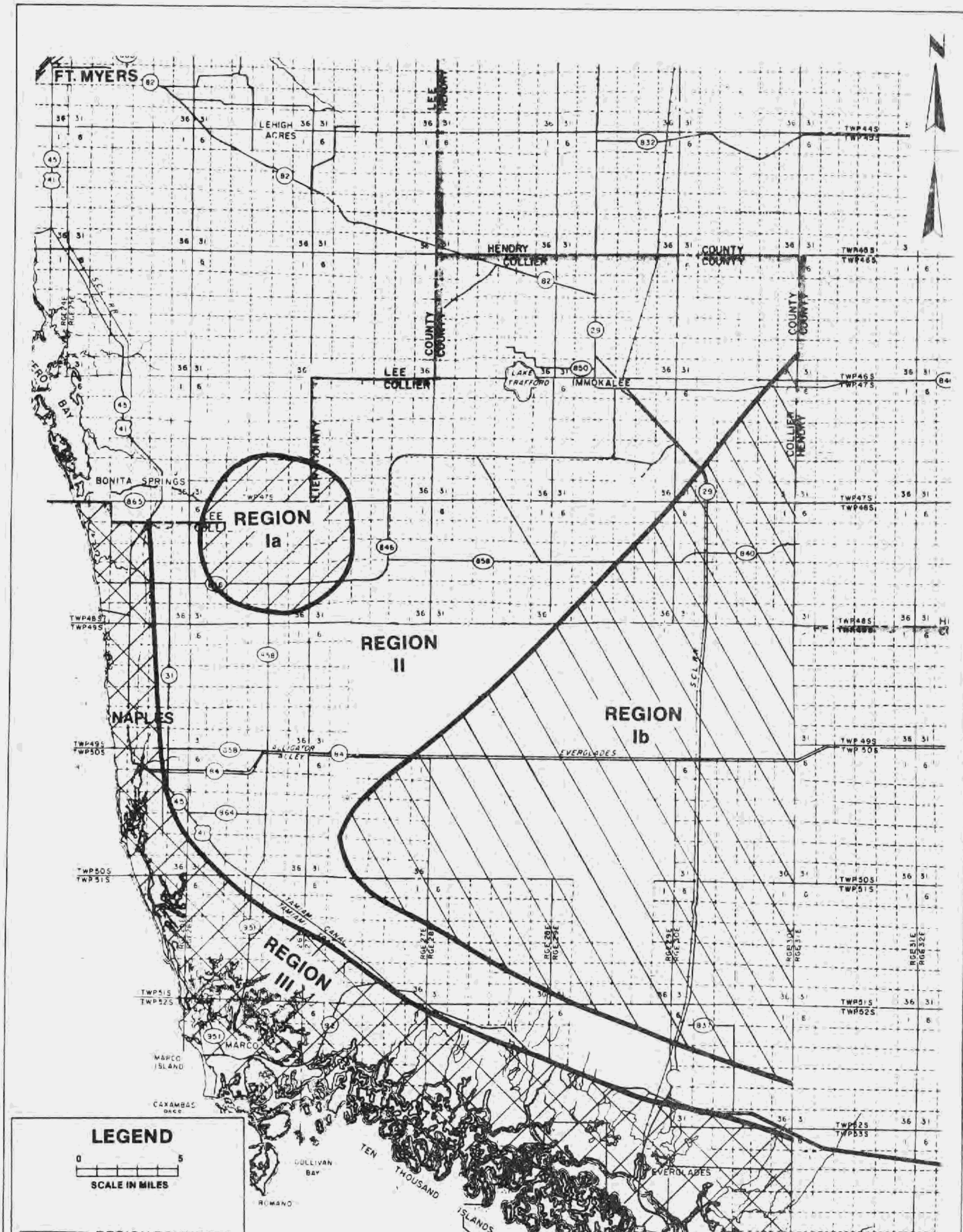


Figure 74 DEVELOPMENT POTENTIAL FOR THE WATER TABLE AQUIFER

the water table aquifer provides recharge to the lower Tamiami aquifer through downward leakance in the vicinity of the East Golden Gate and the County Municipal wellfields. Large scale development of the water table in this area could affect the yield of the lower Tamiami aquifer in this area. In the northern portions of Region II, transmissivities are lower and dissolved iron levels are high. Principal water users in this region are agricultural. Moderate development of the water table can be accomplished where iron levels and well yields are acceptable.

Region III denotes regions of poor development potential. This is mainly due to the proximity of coastal salt water. Transmissivities are less than 50,000 gpd/ft along the western coastal regions, where the aquifer is composed of fine, grained sands and sandy micrites. Along the southwestern portion of the county, transmissivities increase, and the inland extent of the salt water front acts to limit development potential. The Tamiami Trail (U.S. 41) generally acts as a salt water barrier by building up fresh water head in certain areas on the north side of the road. The proximity of the Marco Island Pit to this region of low development potential represents a limitation of this water source in the future.

While Region III is denoted as an area of poor potential, small scale withdrawals are often capable of yielding acceptable water quality and quantity to meet demands. Other localized areas of poor potential correspond to the location of landfill sites. This does not necessarily mean ground water has been contaminated in these regions but indicates some potential for contamination.

AVAILABILITY OF WATER FROM THE LOWER TAMIAMI AQUIFER

Aquifer Characteristics

Hydraulic characteristics of the lower Tamiami aquifer are listed on Table 21 and located on Figure 75. The hydraulic properties are variable depending on facies changes within the unit. To the west the aquifer is primarily composed of biogenic limestones with highly developed secondary porosity. To the east the limestone thins at the expense of increasing thicknesses of poorly sorted clastic material at the base of the aquifer (Miocene coarse clastics). Transmissivities for the limestone facies characteristically range between 100,000 and 300,000 gpd/ft but have been found to exceed 1,000,000 gpd/ft at two sites in Golden Gate. Transmissivities are generally below 100,000 gpd/ft in the clastic facies of the aquifer. The aquifer is semi confined above by the Tamiami confining beds and to a greater degree from below by the upper Hawthorn confining beds. Exceptions occur in Immokalee and in the south-western coastal reaches. Storage coefficients in areas where the aquifer is semi-confined range between 2×10^{-2} and 3×10^{-5}. In areas where the aquifer is unconfined specific yield values may exceed 0.1. Leakance for the aquifer is also quite variable depending on the thickness and hydraulic characteristics of the confining beds. Leakance values range from a high of 0.6 day^{-1} in northern Collier, where the Tamiami confining beds are almost absent, to a low of 1.3×10^{-4}/day.

Water quality is generally good for all uses. Chloride levels im most areas are below 250 mg/l. Along the southwestern coastal region where Tamiami confining beds are absent, salt water occurs for several miles inland. In addition, high chloride levels have been identified in localized areas east of the coastal ridge. The source of these chloride levels is not fully known but localized concentrations range between 300 and 900 mg/l along this north-south trending area. Elsewhere in the county the water is characterized by low conductivity and total dissolved solids, low iron levels, and good color, making it ideal for public supply and agriculture. Sulfate levels are higher than in the water table, but this can be treated through aeration.

Competition for this water source has been growing rapidly in the western coastal areas. In central Collier County the lower Tamiami is being increasingly developed by agricultural interests because the water quality is suitable for drip and spray irrigation needs. In the future, these users may be competing with the city of Naples and the county regional wellfields in the Golden Gate area.

Hazards from undesirable land usages are minimized due to the Tamiami confining beds which act to filter out some groundwater contaminants. The areas of concern occur in areas where the confining beds are absent.

Potential for Water Supply

Region I (Figure 76) is considered to be a region of good potential for future development. Transmissivities range from 100,000 to over 1,000,000 gpd/ft. Currently, there are two large scale users in this area. The county and city wellfields are located in Golden Gate and are currently withdrawing approximately 12.5 MGD. To the north are several large scale truck farms and citrus properties. Water use information is not quantified in this region. More indepth data on the safe yield of this aquifer is needed.

TABLE 21. AQUIFER PARAMETERS FOR THE LOWER TAMIAMI AQUIFER

WELL	TWP	RGE	SEC	LATITUDE	LONGITUDE	Total DEPTH	Casing DEPTH	Transmissivity (gpd/ft)	Storage (Dimensionless)	Leakance (day^{-1})	Source
L-01	46	26	22	26 27 13	81 41 47	80	67	2.0E5	1.7E-1	1.1E-2	Post, Buck 1978A
C-02	48	29	17	26 18 10	81 26 32	75	--	2.5E5	2.0E-4	1.3E-3	Missimer 1981A
C-03	48	26	19	26 16 23	81 45 21	90	53	1.2E5	4.0E-5	1.3E-3	Post, Buck 1978A
L-04	47	25	28	26 21 05	81 47 55	120	74	6.0E4	1.0E-4	1.7E-4	Missimer 1981B
C-05	49	26	34	26 09 27	81 42 02	60	42	5.5E5	3.3E-5	5.5E-4	Missimer 1980A
C-06	48	26	27	26 46 25	81 43 45	100	65	6.0E5	2.0E-4	1.3E-4	Missimer 1980B
C-07	49	28	05	26 12 38	81 34 09	80	40	2.8E5	1.0E-4		CH2M Hill 1980
C-08	49	25	12	26 12 57	81 46 04	90	65	1.4E5	1.4E-4		Gee & Jenson 1980
C-09	49	26	03	26 14 16	81 47 49	100	65	1.6E5	2.4E-2		Gee & Jenson 1980
C-10	50	25	12	26 08 12	81 45 14	55	38	2.2E5	3.2E-4	4.3E-2	Missimer 1978C
C-11	49	25	04	26 13 30	81 48 47	90	57	1.0E5	2.0E-4	2.7E-3	Missimer 1979A
C-12	48	26	08	26 18 55	81 43 22	83	63	2.2E5	2.0E-4	1.3E-4	Missimer 1979B
C-13	50	25	04	26 08 26	81 50 20	70	--	9.8E4	6.0E-4		Klein 1954
C-14	49	25	27	26 10 07	81 49 58	96	--	1.8E5	4.0E-4	1.1E-3	Sherwood 1961
C-15	48	27	23	26 17 17	81 35 12	160	50	7.5E4	1.1E-3	1.5E-1	SFWMD
C-16	48	27	23	26 17 17	81 35 12	185	120	1.5E6	1.8E-1		SFWMD
C-17	50	28	06	26 04 58	81 33 40	150	90	4.0E4			SFWMD
C-18	51	27	06	26 03 13	81 38 03	170	64	1.6E5	1.0E-3	6.1E-1	SFWMD
C-19	47	27	27	26 21 05	81 36 15	120	65	3.8E5	1.1E-2	9.0E-2	SFWMD
C-20	49	28	02	26 14 52	81 29 02	150	80	1.8E5	1.0E-4	4.0E-3	SFWMD
C-21	50	27	06	26 08 42	81 38 12	140	70	3.0E5			SFWMD
C-22	49	27	07	26 13 43	81 38 55	200	60	1.1E6			SFWMD
C-23	48	28	23	26 17 33	81 31 07	160	80	6.4E5			SFWMD
C-24	47	28	24	26 22 40	81 28 16	205	150	1.8E5			SFWMD
C-25	49	28	14	26 11 56	81 29 02	85	65	2.7E5			SFWMD
C-26	50	26	28	26 05 27	81 43 02	140	20	2.9E5	3.0E-3	7.6E-1	SFWMD 1983

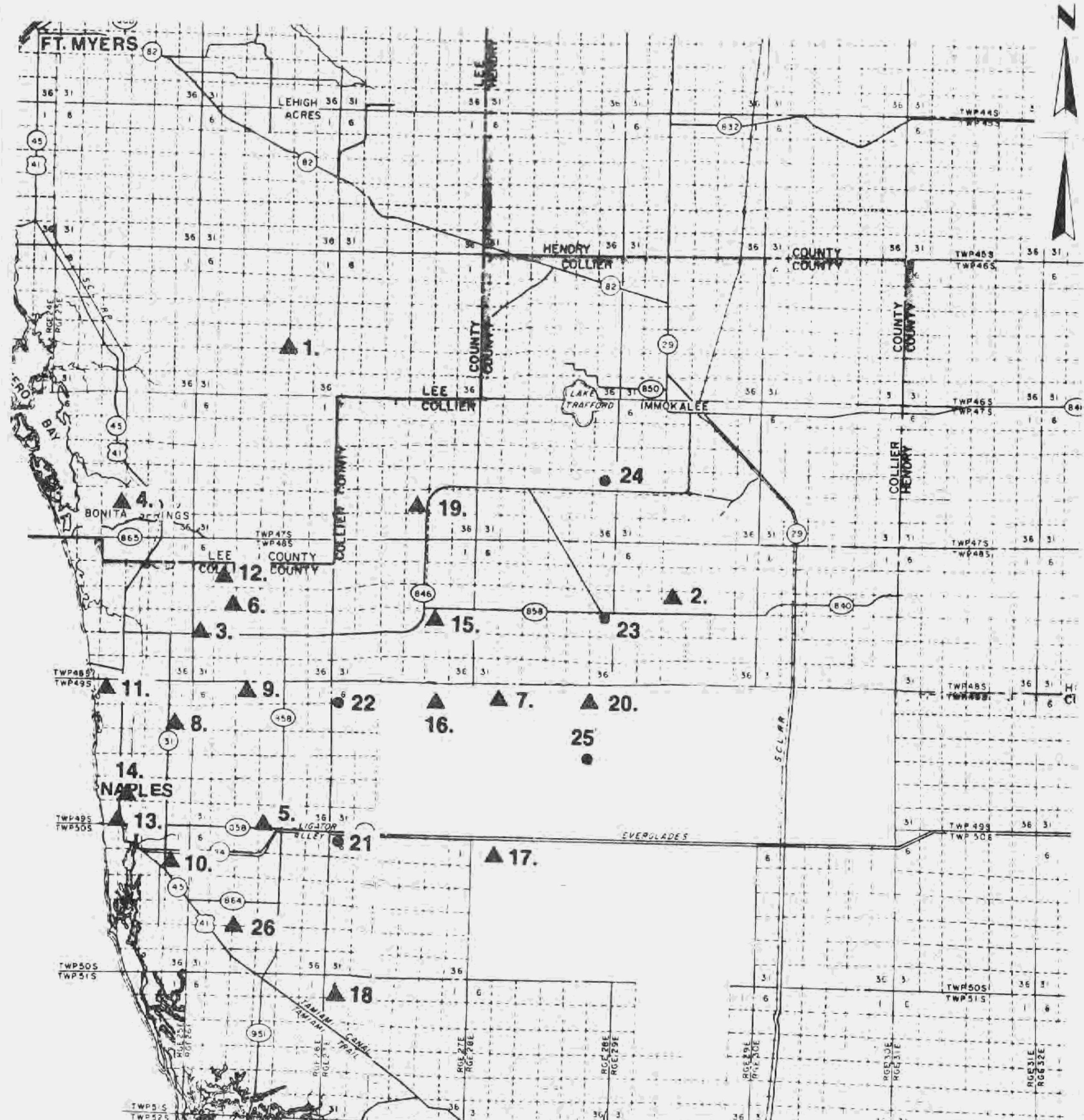


Figure 75 AQUIFER PARAMETER BASE MAP FOR THE LOWER TAMIAMI AQUIFER

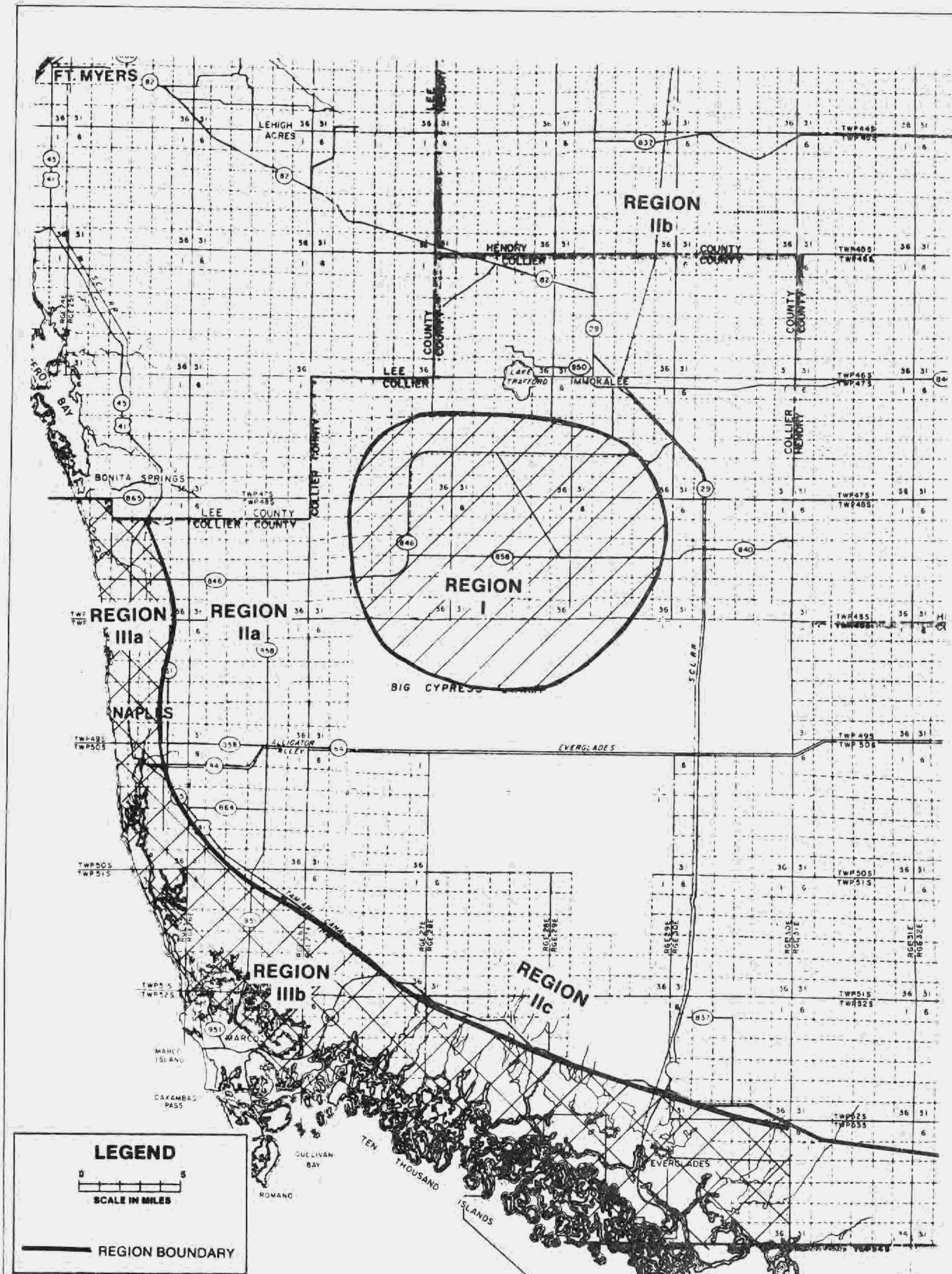


Figure 76 DEVELOPMENT POTENTIAL FOR THE LOWER TAMIAMI AQUIFER

Region II is broken down into three areas, IIa, IIb, and IIc. Region IIa trends north-south and roughly parallels the coastal ridge. Aquifer parameters are favorable for large scale development, however, the local presence of salt water make large scale development in this area unpredictable. The aquifer thins to the north of area IIb and contains large amounts of lower permeability clastic material. In addition, the aquifer thins to the north which further reduces the development potential. Region IIc is located in southwest Collier County. Few data are available in this region. Test drilling along U.S. 41 indicates salt water occurs towards the base of the aquifer. Inland, the high yielding carbonate facies thins and the majority of the aquifer is composed of low yielding coarse clastics. A pump test into the sand facies of this aquifer at S.R. 84 and Everglades Boulevard yielded a transmissivity of 40,000 gpd/ft.

Region III represents regions of low development potential. It occurs throughout coastal Collier County and is divided into two different zones. In zone IIIa the lower Tamiami is considered to be near the supply capacity of the aquifer. During periods of drought the combined impacts of all users in the Naples area causes landward movement of salt water and water use restrictions are required. During normal years, the aquifer can safely supply water to all users. In region IIIb the limiting factor is strictly water quality. However, small scale users withdrawing from the top of the aquifer may find fresh water year round.

WATER AVAILABILITY IN THE SANDSTONE AND MID-HAWTHORN AQUIFERS

Aquifer Characteristics

The Sandstone aquifer occurs only in the northern portion of Collier County. The aquifer ranges in thickness between 0 and 75 feet and occurs at depths ranging from 150 ft below NGVD in the north, to 300 ft below NGVD to the south. Although few data are available for this unit (Figure 77), transmissivities for the aquifer appear to be less than 100,000 gpd/ft (Table 22). The Sandstone aquifer is developed by agricultural interests north of Immokalee and by the City of Immokalee for its potable supply. Large scale withdrawals from an aquifer with low transmissivities produces deep cones of influence of small areal extent. Water for the Sandstone aquifer is characteristically high in sulfate and calcium hardness. Chloride concentrations are generally within potable water standards except on the western edge of the aquifer, along the Cocohatchee Canal, where chloride levels in excess of 500 mg/l have been measured.

The mid-Hawthorn aquifer occurs throughout the study area. The average thickness is 100 ft and the top of the aquifer occurs at depths ranging from 300 to 400 ft below NGVD. Transmissivity data are scarce, but the available values correlate with those measured in Lee County that range between 10,000 and 30,000 gpd/ft (Table 23). Water quality is also fair. The water is mineralized, high in sulfate, and generally low in chlorides. Exceptions occur along the Lee/Collier County line where chlorides may exceed 1000 mg/l. Water levels in the mid-Hawthorn are above land surface through most of Collier County, except the very northernmost areas. This makes the mid-Hawthorn a good source of water for pasture land.

Potential for Water Supply

Due to low yield, both the Sandstone and the mid-Hawthorn aquifers have been considered to have little potential for large scale development. However, where water quality is sufficient, these aquifers can provide an alternate source of water for moderate development. Because of their depth, it is possible to pump sufficient quantities of water for agricultural use with turbine or submersible pumps. For this reason, combined with the undesirable qualities of the shallower aquifers, the Sandstone aquifer is extensively used north of Immokalee. Additional data on water use must be collected to determine the future potential of the Sandstone and mid-Hawthorn aquifers.

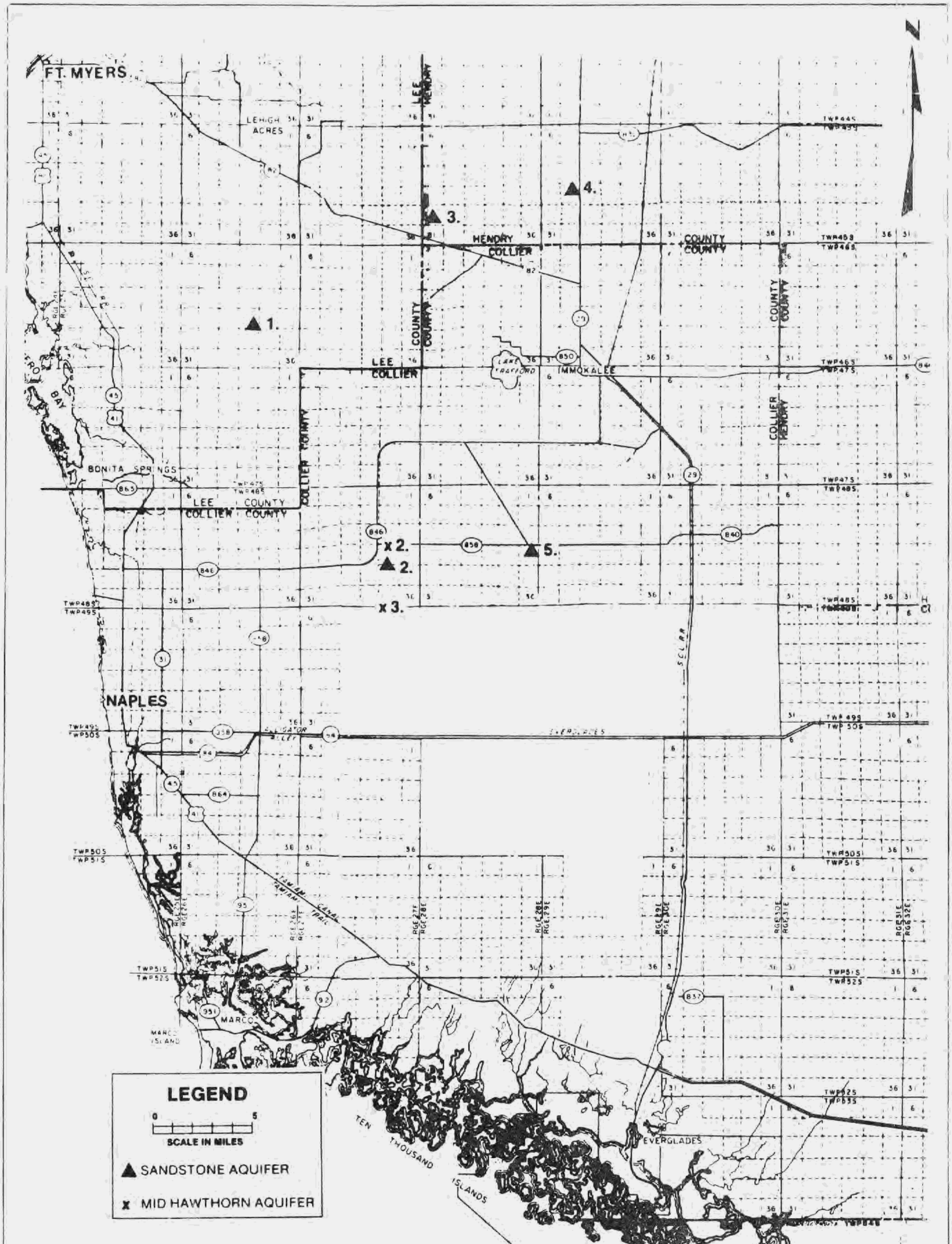


Figure 77 AQUIFER PARAMETER BASE MAP FOR THE SANDSTONE AND MID-HAWTHORN AQUIFERS

TABLE 22. AQUIFER PARAMETERS FOR THE SANDSTONE AQUIFER

WELL	TWP	RGE	SEC	LATITUDE	LONGITUDE	Total DEPTH	Casing DEPTH	Transmissivity (gpd/ft)	Storage (Dimensionless)	Leakance (day^{-1})	Source
L-01	46	26	22	26 27 13	81 41 46	300	200	2.0E4	3.0E-5	6.3E-5	Post, Buck 1978A
C-02	48	27	23	26 17 17	81 35 12	225	200	1.0E4	1.5E-4	1.2E-2	SFWMD
H-03	45	28	20	26 38 40	81 20 45	160	120	1.1E5	1.4E-4	1.0E-5	Missimer
H-04	45	29	20	26 33 32	81 26 10	200	150	6.0E3	3.6E-5	8.0E-5	SFWMd
C-05	48	28	26	26 17 33	81 31 06	265	230	9.8E4			SFWMD

TABLE 23. AQUIFER PARAMETERS FOR THE MID-HAWTHORN AQUIFER

WELL	TWP	RGE	SEC	LATITUDE	LONGITUDE	Total DEPTH	Casing DEPTH	Transmissivity (gpd/ft)	Storage (Dimensionless)	Leakance (day^{-1})	Source
L-01	47	25	28	26 21 09	81 48 00	255	235	7.0E4	5.0E-5	1.3E-6	Missimer 1981B
C-02	48	27	23	26 17 17	81 35 12	420	350	1.8E4	7.0E-5	1.7E-4	SFWMD
C-03	49	27	11	26 13 46	81 35 28	420	360	3.0E4	9.0E-3		SFWMD

CONCLUSIONS

1. The Surficial Aquifer System is regionally extensive throughout Collier County. The system is composed of two aquifers, the water table and lower Tamiami, which are separated by beds of lower permeability. The water table aquifer ranges between 20 and 60 feet in thickness. The aquifer is capable of producing large quantities of fresh water and transmissivities range from 100,000 to over 1,000,000 gallons per day per foot (gpd/ft).

   The Tamiami confining beds vary in thickness from 0 to 50 feet in Collier County, and they are regionally discontinuous. These strata are a semi- confining unit and leakance coefficients range from 1×10^{-1} to 1×10^{-4} per day.

   The lower Tamiami aquifer occurs throughout the county and ranges in thickness between 75 and 100 feet. The basal portion of the aquifer is characterized by a lower permeability sand facies, which is thin along the coast and thickens to the east. The lower Tamiami is extensively developed by municipal and agricultural interests. Transmissivities range between 100,000 and 500,000 gpd/ft. The top of the underlying upper-Hawthorn confining zone marks the base of the Surficial Aquifer System.

2. The Intermediate Aquifer System has limited potential for large scale development. The principal aquifers within the system are the Sandstone and mid-Hawthorn. The Sandstone aquifer occurs in the northern half of the county and pinches out along SR 84. The aquifer is used primarily by agricultural interests north of Immokalee. It ranges in thickness between 0 and 100 feet and has transmissivities below 100,000 gpd/ft. The mid-Hawthorn aquifer occurs throughout western Collier County. The aquifer is capable of producing small quantities of fresh water but is not used extensively in Collier County. It ranges in thickness between 40 and 100 feet and transmissivities are below 50,000 gpd/ft.

3. The water table aquifer receives direct recharge from infiltration of rainfall. Annual rainfall ranges from 55 to 65 inches per year throughout the study area. Evapotranspiration accounts for the majority of recharge loss. Highest water levels occur north of Immokalee and decrease towards the coast. The regional flow patterns of the lower Tamiami and Sandstone aquifers are similar. The lower Tamiami aquifer receives direct recharge in the Immokalee area where the Tamiami confining beds are absent. Elsewhere in the county, the lower Tamiami aquifer receives recharge through downward leakance from the water table aquifer. The Sandstone aquifer receives recharge through downward leakance from the lower Tamiami aquifer in the study area.

4. Water quality is generally within Florida DER drinking water standards for potable supply. Water within the Surficial aquifer is characteristically low in calcium, chlorides, TDS, sulfate, and locally high in dissolved iron, color, nutrients, and organics. Water within the Sandstone aquifer is generally higher in dissolved solids with increased distance from the Immokalee area.

5. Salt water intrusion from the Gulf of Mexico continues to be a problem all along the Collier County coast. The city of Naples has experienced problems with salt water encroachment within the Coastal Ridge and the Marco Island utilities wellfields. Other wellfields in the area have not experienced problems with salt water intrusion.

6. There are eight landfill sites in Collier County. Water quality monitoring around the existing county landfill has not detected any groundwater contamination as of 1980. The remaining seven sites are not being monitored at this time.

7. Municipal pumpage along the west coast is divided into four regions. Region A (north Naples) will be serviced by a new proposed wellfield. Water requirements for this region will exceed 11 mgd by the year 2000. Region B (central and east Naples) will be serviced by the Coastal Ridge and East Golden Gate wellfields. Projected water requirement for this region will exceed 20 MGD by the year 2000. Regions C and D include south Naples. Water requirements for the year 2000 will exceed 11 MGD and will be supplied by the county wellfield at Golden Gate. Marco Island will continue to be supplied by the Marco wellfield (private utility) and from the Marco pit; however, increased demands may exceed safe yields for the water table aquifer in this area and wellfield relocation may be imminent.

8. The water table aquifer along the Cocohatchee Canal east of CR 951 is capable of yielding 30 mgd throughout the average dry season. However, water quality and environmental impacts may represent significant limitations on wellfield development under these conditions. Yield will be substantially lower during periods of prolonged drought.

9. During periods of prolonged drought, Marco Island Utilities may have to reduce pumpage to prevent vertical and horizontal movement of salt water into the wellfield/lakes. This was the case during the 1985 dry season which represented a 1-in-3 year rainfall drought.

10. Agricultural pumpage is heaviest during the months of February through May. The current maximum monthly allocation/projected use for the county exceeds 32 billion gallons. The actual agricultural pumpage and use is not known at this time due to the lack of data.

11. Two criteria were used to determine safe yield from the lower Tamiami aquifer in the Naples are. The first was based on limiting salt water intrusion using the Ghyben-Herzberg coastal saltwater interface theory. The second was based on limiting drawdowns to the top of the aquifer while maintaining a fresh water head barrier along the coast. A total of 45 MGD can be safely withdrawn from the modeled area during a 1-in-3 year dry season drought without inducing significant inland saltwater intrusion, based on the results of the Ghyben-Herzberg model. A total of 84 MGD can be withdrawn from the area using the fresh water barrier model. The fresh water barrier model requires all users to pump several miles inland. Therefore, this criteria may not be feasible because it would require an eastward relocation of existing permitted users.

The safe yield estimate presented here should be considered preliminary, based on conservative assumptions and generalizations associated with a two-dimension flow model. The conclusion of this work stresses caution in allocating any additional water from the lower Tamiami aquifer in the area west of S.R. 951. Other sources of water should be closely evaluated as alternatives to the continued development of the lower Tamiami aquifer with the modeled area.

Maximum demand estimates derived from existing permits may be as high as 108 MGD. However, it is considered unlikely that users would withdraw the maximum quantities of water originally estimated by these permits. Under current regulatory criteria, the maximum daily demand for existing legal users is estimated at 74 MGD. This figure is considered to represent a more realistic assessment of a maximum withdrawal assuming full usage by all legal users. Because irrigation systems are not completely efficient, there will be some return flow to the aquifers. Based on a review of irrigation efficiencies of the permitted systems in the area, it is estimated that as much as 26 MGD out the 74 MGD may represent excess irrigation water, some of which recharges the lower Tamiami aquifer.

Estimates of actual water use derived from data furnished by the permittees indicates pumpage for the months of September, October 1984 and April, May 1985 were 21, 33, 38, and 20 MGD, respectively.

Based on current water consumption data versus safe yield estimates, present usage could result in significant salt water intrusion leading to voluntary and/or mandatory cutbacks during 1-in-3 year dry season drought conditions. The completion of the City of Naples and Collier County wastewater reuse systems will reduce recreational pumpage along the Coastal Ridge by 11 MGD during the dry season. The completion of this facility will lessen the demands placed on the lower Tamiami aquifer. Until actual and permitted use is significantly reduced, steps should be taken to limit additional development of the lower Tamiami aquifer in the study area.

12. Good development potential for exploitation of the water table aquifer exists in two areas of the study. The first region occurs north of County Road 951 along the Cocohatchee Canal. The second region occurs principally south of Alligator Alley and west of County Road 951. While the aquifer is thick and very transmissive, the actual permittable yield will be based on the assessment of environmental impacts and water quality considerations.

13. The lower Tamiami aquifer has good development potential with respect to water quality and aquifer yield throughout the west-central portion of the study area. Two municipal wellfields occur within this region and preliminary modeling indicates the aquifer could meet projected demands for the year 2000; however, environmental impacts and influences of other users which could act to limit the development of the aquifer to a lesser extent in the area were not addressed in this assessment.

RECOMMENDATIONS

1. The county should consider the water table aquifer in the vicinity of the Cocohatchee Canal east of SR951 as a potential location for a wellfield to serve the north Naples planning area. Prior to constructing a wellfield in this area, however, water quality and environmental impacts should be studied in detail. The county should also consider the implementation of a wellfield protection ordinance similar to those enacted in other counties. The area included in the wellfield protection ordinance should be based on the ultimate planned buildout capacity of the wellfield, rather than the initial permitted amount.

2. Water use interaction by all competing users should be quantified on a regional level. A regional groundwater model should be developed from information presented in this report and from agricultural consumption data. The results of such a study would provide the basis for a future water management plan for Collier County.

3. The existing water level monitor network should be sampled for common groundwater constituents on an annual basis. The parameters tested should include: chloride, sulfate, TDS, calcium, magnesium, sodium, potassium, conductivity, total iron, color, silica, and organic and inorganic carbon.

4. A comprehensive groundwater monitor system should be established in the vicinity of the existing landfill sites. The monitor wells should be constructed in accordance with EPA guidelines to assure the integrity of the water samples. These networks should be sampled a minimum of once per year.

5. Marco Island Utilities should develop an inland source for potable water to be used during extended droughts. Such a source may consist of a new wellfield or a hookup to the south county distribution system. Expansion of existing facilities at the present site should be carefully reevaluated in light of the 1985 drought prior to any additional construction.

6. A study is needed to quantify actual agricultural water use from both surface and groundwater sources. The results of such a study is required in order to develop a three-dimensional flow model which will be used to manage the groundwater resources of the county.

7. Additional stresses on the lower Tamiami aquifer in the Naples area should be prevented to assure continued development of fresh water from this source throughout the years. In order to minimize the impacts of extended droughts and protect existing legal users, the District should work with county and city officials to develop short and long term strategies to limit adverse impacts on this source.

8. In order to protect an area possessing high development potential for potable quality water, the boundaries of the existing Reduced Threshold Areas should be expanded as shown on Figure 78. This action is not meant to restrict usage in the area but will require small scale users to obtain an individual permit. This action is necessary in order to assess cumulative impacts in the area.

9. Feasible actions should be taken to maintain high groundwater levels in the water table aquifer throughout the dry season in the Naples area. This could include limiting canal system discharge, maintaining on-site retention lakes, and/or limiting pumpage from the water table aquifer.

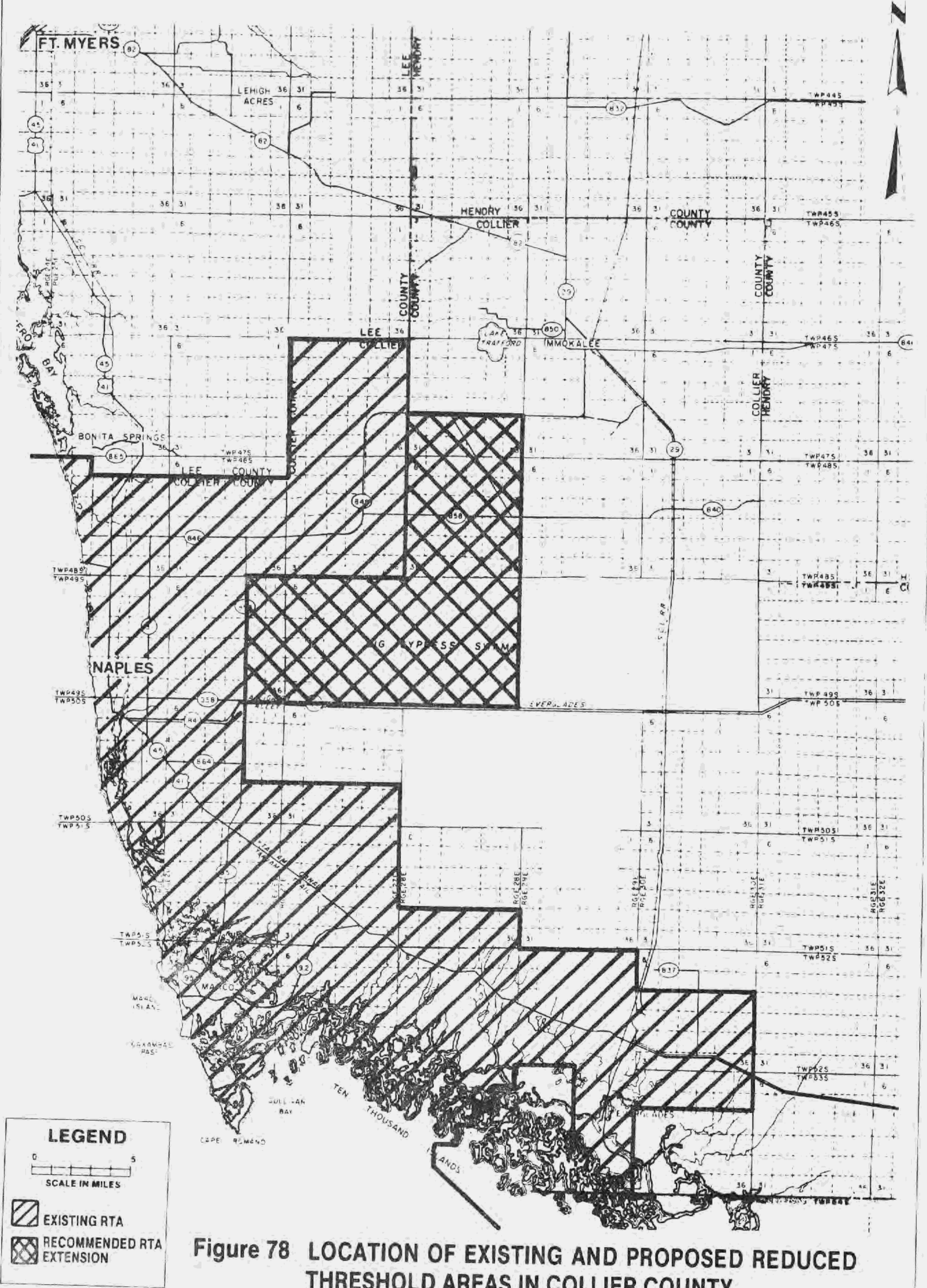


Figure 78 LOCATION OF EXISTING AND PROPOSED REDUCED THRESHOLD AREAS IN COLLIER COUNTY

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