TECHNICAL PUBLICATION 82-1

January, 1982

HYDROGEOLOGIC RECONNAISSANCE OF LEE COUNTY, FLORIDA

PART 1 : TEXT

TECHNICAL PUBLICATION 82-1

January 1982

PART 1 - TEXT

HYDROGEOLOGIC RECONNAISSANCE OF LEE COUNTY, FLORIDA

By

Leslie A. Wedderburn, Michael S. Knapp,
Daniel P. Waltz, and Wm. Scott Burns

This publication was produced at an annual cost of $787.50 or $1.58 per copy to inform the public.
500 390

Groundwater Division
Resource Planning Department
SOUTH FLORIDA WATER MANAGEMENT DISTRICT

TABLE OF CONTENTS

Page

Page

LIST OF FIGURES

LIST OF FIGURES (Continued)

Page

LIST OF FIGURES (Continued)

LIST OF TABLES

ABSTRACT

The stratigraphy and lithology of the upper 1500 to 2000 feet of rocks in Lee County is complex. The sequence of rocks consists of sands, sandstones, shell beds, limestone, and dolomite. The ages of these rocks range from Eocene to Recent and the stratigraphic sequence includes the Lake City Limestone, Avon Park Limestone, Williston Formation, Crystal River Formation, Suwannee Limestone, Hawthorn Formation, Tamiami Formation and Undifferentiated deposits. The Lake City Limestone is only tentatively suggested as a separate formation. The Hawthorn Formation as defined in this report includes beds previously placed in the Tamiami and Tampa Formations.

Five major aquifers or producing zones have been identified within this sequence of rocks. The upper Surficial aquifer consists of sands, shells, and limestones, and in some areas consists of two water producing zones separated by a semi-permeable bed. This aquifer occurs within sediments of the Tamiami Formation and Undifferentiated deposits.

The Sandstone aquifer underlies the Surficial aquifer and is separated from it by a semi-confining bed. It occurs within sandstones and sandy limestones of the Hawthorn Formation. The mid-Hawthorn aquifer is semi-confined and consists mainly of limestones and dolomitic limestones which occurs below the Sandstone aquifer. The lower Hawthorn/Tampa producing zone (which includes the basal part of the lower Hawthorn aquifer of Sproul et al., 1972) and the Suwannee aquifer are considered parts of the Floridan Aquifer System. These consist mainly of limestones and dolomitic limestones.

The aquifers in Lee County are hydrogeologically complex. In these aquifers, intergranular, moldic, fracture, and solution porosities are

developed. The water bearing properties of the aquifers vary both vertically and horizontally. Reported transmissivities in the area in specific aquifers range from 2,100 gpd/ft. to 350,000 gpd/ft. Storage coefficient values range from 0.05 in the unconfined parts of the Surficial aquifer to 0.00003 in the confined aquifers.

Water quality varies both vertically and horizontally in the aquifers. The Surficial aquifer and Sandstone aquifer both contain mainly potable water, except in localized areas. The mid-Hawthorn aquifer contains both potable and non-potable quality water. Most of the aquifers and producing zones in the Floridan Aquifer System contain mainly non-potable quality water.

Based on water quality, water levels, lithology, and aquifer characteristics, it is concluded that in all the aquifers discussed, potential exists for withdrawal of additional groundwater. However, some areas in each aquifer have a higher potential for groundwater supply. The available groundwater resources should be protected from quality deterioration by controls on groundwater withdrawal in sensitive areas, proper well and wellfield design, plugging of derelict abandoned wells, and controls on surface drainage.

ACKNOWLEDGEMENTS

This investigation was initiated by the South Florida Water Management District in response to its long range planning responsibilities in water management and an awareness of the acute groundwater problems within the Lower West Coast Planning Area. The preparation of this report was carried out under the direction and supervision of Abe Kreitman, Director, Groundwater Division, Resource Planning Department, South Florida Water Management District. His guidance in all aspects of this study is gratefully acknowledged. Appreciation is also extended to Vince Faraone (SFWMD) for modifying and adapting certain computer programs into the Water Management District's Cyber computer system. These programs were essential to the completion of this report.

The U. S. Geological Survey in Fort Myers contributed geologic and hydrologic information essential to this report. Frank Watkins and Henry LaRose of that office were especially helpful.

The Bureau of Geology provided drill cuttings and geophysical logs of deep wells in Lee County. In particular, the assistance of Ed Lane, Supervising Geologist of that organization, is gratefully acknowledged.

Frank Green of Green's Citrus Groves near Alva made his property available for exploratory drilling. His patience and generosity are greatly appreciated.

The authors are grateful to the staff of Missimer and Associates, Inc., who supplied geophysical logs and well cuttings, and who shared freely their knowledge of the complex hydrogeology of this area.

Muriel E. Hunter reviewed and made suggestions on the stratigraphy portion of this report. The authors gratefully acknowledge her assistance.

INTRODUCTION

The purpose of this study is to comprehensively define the geologic and hydrostratigraphic framework of the aquifers in Lee County, Florida, and to assess water level and water quality variations in these aquifers. A preliminary assessment of the groundwater potentials of the area is made based upon the available hydrogeologic data. A specific objective of this report is to provide a basis for the optimal development and management of the groundwater resources in the area.

The study was motivated by the increasing concern for adequate groundwater supply sources in Lee County to meet the needs generated by rapid urbanization and population growth. A number of hydrogeologic problems have been identified in this area which significantly affect the availability of groundwater. These include water quality problems associated with saline intrusion from coastal areas, from other saline water bodies, and from deeper saline aquifers. In addition, due to the complexity of the hydrogeologic systems, it is often difficult to identify zones of high production within the aquifers and to design wells so that producing zones or aquifers of different water quality are properly protected. Because of the relatively low transmissivities in some of the aquifers, withdrawal of groundwater has caused significant lowering of water levels in some areas. Although some of these problems have been addressed in previous reports on a site-specific basis, the need existed for a comprehensive hydrogeologic assessment and reevaluation of the county.

This report consists of three parts. Part 1 is an interpretive text which describes in detail all of the major elements of the study. These include: discussions of aquifer potentials, geology, hydrostratigraphy, water quality trends within each of the aquifers, hydrologic implications associated with potentiometric heads, methods of investigations and major conclusions and recommendations.

Part 2 is a hydrogeologic atlas consisting of 28 plates. It presents in map form depths and thicknesses of the various stratigraphic and hydrogeologic units and associated potentiometric heads and numerous geologic cross-sections illustrating the relationships that exist between the various units and the water bearing formations.

The final portion of this report (Part 3) contains appendices which give relevant data used in the preparation of the maps or referred to in the text.

The report is designed as a user's document. It attempts to answer all the major questions that may be raised by those professionals and laymen interested in or responsible for planning, regulating, developing, and meeting Lee County's future water demands.

LOCATION

Lee County, Florida is located on the southwest coast of the Florida Peninsula between Latitude 26° 19' 04"N and 26° 47' 23"N and Longitude 81° 33' 50"E and 82° 16' 24"E (Figure 1). It encompasses an area of approximately 786 square miles. Land elevations range from 0 feet NGVD near the Gulf coast to over 30 feet NGVD inland, increasing to the north and east. A major drainageway, the Caloosahatchee River, flows in a northeast to southwest direction across the county to the Gulf of Mexico. Other rivers include the Orange, Estero, and Imperial. Numerous canals have also been constructed throughout the area.

The population of Lee County (1980 census) is 205,266. Approximately 90 percent of the people in the area live within 10 miles of the Gulf Coast. This area has undergone rapid population growth between 1960 and 1980. Between 1960 and 1970 the population increased almost 90 percent and between 1970 and 1980 over 100 percent. The areas of greatest population density are the Fort Myers urban area and the City of Cape Coral.

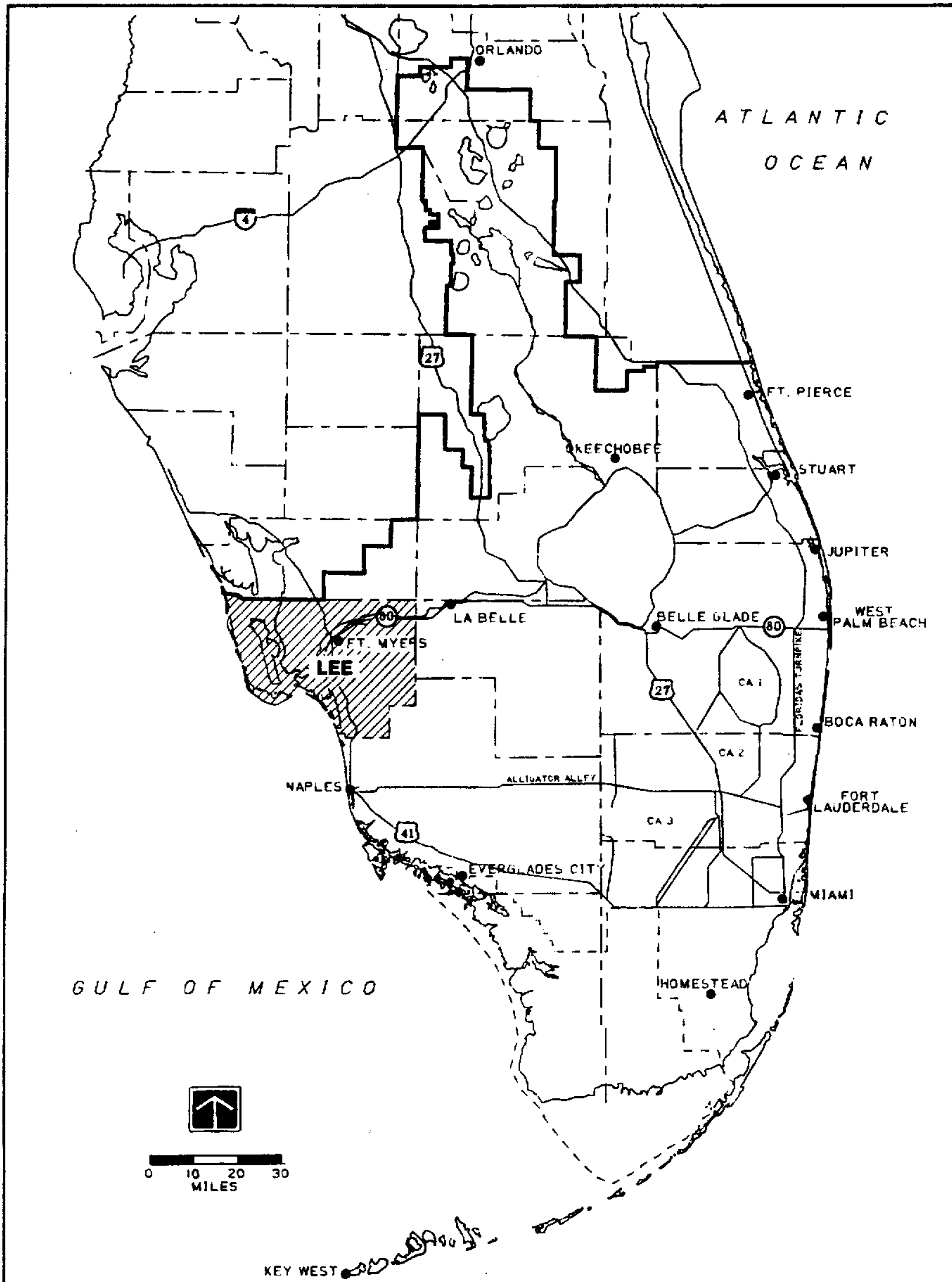


Figure 1. FLORIDA PENINSULA SHOWING LOCATION OF LEE COUNTY.

WELL LOCATIONS AND NUMBERING

Geologic control wells, shown on plates 1 and 13 of the map atlas, are numbered consecutively from 1 to 81, west to east by range, and north to south by township. This system was used because control data were obtained from several sources, each with its own numbering system, and use of the different numbers associated with these systems was considered to be confusing to the reader. The control well number for each well is cross-referenced (in Appendix 1-1) with numbers used by the U. S. Geological Survey, the Florida Bureau of Geology, and the South Florida Water Management District. Appendix 1-1 also gives latitude and longitude, and section, township, and range for individual control wells.

The system used for determining section, township, and range conforms to Florida Bureau of Geology usage (see Yon, 1966, pp. 5-6 and Figure 1). The basic rectangle is the township which is 6 miles square. It is divided equally into 36 square miles called sections, which are numbered 1 through 36. Each section is divided into quarters labeled "a" - "d" (east to west and north to south) (see Figure 3, pp. 6, Yon, 1966). In turn each of these 1/4 sections are divided into quarters and labeled "a" - "d" in the same manner.

The U. S. Geological Survey numbering system is used to identify those wells incorporated in the water quality and water level monitoring network. Appendices 3 and 4 give the locations of these wells by latitude and longitude.

METHODS

Geologic and hydrogeologic data discussed in this report, mostly in the form of lithologic descriptions of drill cuttings and core samples, geophysical logs, and water quality and level data, were obtained from the U. S. Geological Survey, Florida Bureau of Geology, private drilling contractors, geological consultants, and supplemented by data developed by the South Florida Water Management District. The existing literature on the geology and hydrogeology of Lee County was evaluated and is briefly summarized in the previous investigations section.

Cuttings from 26 wells were examined with the aid of a binocular microscope and were described as to color (using the GSA, Munsell, chart), estimated porosity, type of porosity, estimated relative permeability, induration, cement type, percent and type of accessory minerals, and fossil content. For quartz sand or sandstone, the modal grain size was estimated by use of a printed scale and/or micrometer. Observations were also made concerning grain size range, roundness of grains, sphericity and, if applicable, cement type. Hydrochloric acid and Alazarin Red solutions were used to estimate the calcium carbonate or dolomite content of carbonate rocks. The description of limestones essentially follows the classification proposed by Folk (1968). Where applicable, the limestone grain type, modal grain size, grain size range, and percentage of grains with a size greater than 0.062 mm were noted. Descriptions of dolomite include an estimated percentage of alteration, crystallinity, modal grain size, and grain size range. Observations were made on standardized sample description forms developed by the Florida Bureau of Geology for computer storage and retrieval of lithologic data. The Florida Bureau of

Geology computer data base program was adapted to the computer system at the South Florida Water Management District and used in this study. X-ray diffractograms were completed on samples from selected intervals to determine major "d" spacings and minerals present. These data are provided in Appendix 1-2.

More than 100 suites of borehole geophysical logs were evaluated and correlated in the preparation of this report. 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. However, not all of these surveys were run in each borehole. In addition, Acoustic Amplitude and Sonic Travel Time logs were available for one well (Well 12, Atlas).

Most of the geophysical surveys were done using two District-owned and operated Gearhart-Owens loggers, one of which has been modified for digital data capture. Additional logs were obtained from the U. S. Geological Survey or private sources. Data were stored, manipulated, and displayed using the South Florida Water Management District's computerized Well Log Analysis System. This system accepts digital borehole geophysical data from cards, paper tapes, or magnetic cassette tape. The system allows for a number of adjustments to the data and a variety of display options which facilitate correlation between different logs in a suite, or single logs for a number of wells. Both the accurately calibrated logs which were available from the South Florida Water Management District's geophysical surveys and the availability of a computerized well log analysis system were important assets in carrying out this study.

Borehole geophysical logs are records of variation with depth of various properties of the rocks, borehole fluid, or formation fluid in or adjacent to the borehole. These records, used in conjunction with other available data, provided important lithologic and hydrogeologic information. A particular asset of the geophysical data is that they allow for more reliable depth control as compared to lithologic data from drill cuttings.

For lithologic and regional stratigraphic correlation, the Natural Gamma log provided the most valuable information. Increases in gamma ray activity were found to relate to the presence of phosphate and, to a lesser extent, dolomite in the rocks. Intervals within the borehole which show similar gamma signatures were successfully correlated in most wells. The Neutron Porosity logs which mainly show variations in the water content of the rocks, and electric logs (16 and 64 inch Normal Resistivity, 6 foot Lateral Resistivity and Spontaneous Potential logs) which show variations in the composition of the rock matrix, borehole fluid or formation fluid, were also useful for lithologic and stratigraphic correlation. Variations in borehole diameter are shown on the Caliper logs and give indications of relative competence of the beds or the presence of fractures and solution openings.

Both Temperature and Flowmeter logs gave valuable information on the movement of water in the aquifers. Producing zones were indicated where abrupt temperature changes took place or where flow contribution to the well increased in pumped or flowing wells.

Information on water quality in the aquifers was derived in part from the Fluid Resistivity and Electric logs, particularly the 6 foot Lateral or 64 inch Normal Resistivity logs as these are less influenced by the quality of the borehole fluid. These logs were valuable in identifying producing zones and aquifers with different water quality, and in evaluating intra-aquifer water quality variations. Correlations were made between geophysical characteristics and lithologic characteristics of the strata. Geologic and hydrogeologic interpretations were based on all available data, but special weight was given to the geophysical interpretations where other data were scarce or unreliable. Structure contour maps, isopach maps, and cross sections were constructed to outline the major geologic and hydrostratigraphic features in the area.

Water level and water quality maps were prepared using data published by the U. S. Geological Survey. Wells were assigned to aquifers on the basis of depth and uncased intervals, compared with lithologic and stratigraphic data in the vicinity of the well.

Exploration and monitor wells were constructed in the northeast corner of Lee County near Alva. The scarcity of reliable data in this area and the need to determine and evaluate the long term effects on near surface aquifers as a consequence of plugging upward leaking saline wells were the criteria for site selection. The exploratory site is located close to a deep (1100 feet) abandoned well which is a likely source of contamination of potable water in the shallower aquifers. This well is currently being plugged. Future monitoring and testing of these wells will be conducted to further evaluate the efficacy and effect of plugging a deep saline well which is under higher hydrostatic pressure than the overlying aquifers.

The well network consists of seven wells which penetrate and monitor the Surficial aquifer, Sandstone aquifer, and the upper part of the Floridan Aquifer System. Three of the wells monitor the Surficial aquifer. These are cased with two inch diameter PVC tubing to an average depth of eight feet and are open from this depth to the top of a thick confining bed at the base of the aquifer (approximately 20 feet). There are three wells monitoring the Sandstone aquifer, one of which has a six inch PVC casing to allow for pump testing. The other two monitor wells are cased with two inch PVC. The three wells are cased to an average depth below land surface of 90 feet and are open from this depth to the confining bed at the base of this aquifer. All of the wells were drilled using reverse air techniques. Cuttings were taken every five feet and at lithologic changes. Water samples were taken through the drill stem at 20 foot intervals. A pump test was conducted on the Sandstone aquifer in order to determine aquifer parameters and water quality.

A 1,200 foot deep exploration well (Well 17, Atlas) was also constructed and 346 feet of eight inch PVC casing was installed. This well was plugged back from a depth of 1,200 to 670 feet and a piezometer was placed at 600 feet to monitor the lower Hawthorn/Tampa producing zone. A lithologic description of this well (LE022) and a full suite of geophysical logs are given in Appendix 1-2 and Appendix 2, respectively.

PREVIOUS INVESTIGATIONS

Lee County, Florida, has been an area of intensive geologic and hydrologic research by the U. S. Geological Survey, Florida Bureau of Geology, and private consultants for many years. Most of these studies have been on a localized and/or site specific level.

The geology of Lee County and all of southern Florida has been investigated by many geologists since the turn of the twentieth century. A good synopsis of these investigations is given by Parker and Cooke (1944). Cooke (1929 and 1945) described outcrops along the Caloosahatchee River and in the vicinity of Alva, Lee County. Dubar (1958, 1962) described the Neogene stratigraphy in the vicinity of the Caloosahatchee River and Charlotte Harbor. Chen (1965), Puri and Winston (1974), and Applin and Applin (1944 and 1965) all described the stratigraphy of the late Cenozoic beds in this area. In other reports by Sproul, et al. (1972) and Sutcliffe (1975), Oligocene and younger beds were described. Hunter (1968) described molluscan guide fossils from, and the lithostratigraphy of, the Tamiami Formation in southern Florida. Peck, et al. (1977 and 1979) described the Tamiami Formation in Lee and Hendry Counties. Missimer (1978) found evidence for a regional disconformity between the Tamiami and Hawthorn Formations in this area. Missimer and Banks (1981) described cyclic sedimentation patterns in early and middle Miocene rocks in western Lee County. Evidence of faulting in or near this area has been presented by Tanner (1965) and Sproul, et al. (1972).

The hydrogeology of Lee County has been the subject of a number of studies by the U. S. Geological Survey and numerous consultants. The reader is referred to the Water Use and Supply Development Plan (SFWMD, 1980) for a comprehensive review of these references.

The U. S. Geological Survey maintains a hydrogeologic network in Lee County for the acquisition of water level and water quality data. Data from this network have been published in summary form since 1975 (U. S. Geological Survey, 1976, 1977, 1978, 1979, 1980). A series of reports discussing fluctuations in water levels in Lee County have been published by the U. S. Geological Survey since 1974 (Missimer and Boggess, 1974; Missimer and O'Donnell, 1975; O'Donnell, 1977; LaRose, 1977).

A number of local and site specific studies have been carried out in Lee County by the U. S. Geological Survey and many private consultants. These include studies by the U. S. Geological Survey on saline water resources (Boggess, 1974); saline water intrusion (Sproul, Boggess and Woodard, 1972; Boggess, Missimer and O'Donnell, 1977); freshwater resources on Sanibel Island (Boggess, 1974); and the hydrogeology of Lehigh Acres (Boggess and Missimer, 1975).

Most of the consultant reports have been detailed studies of local areas in connection with wellfield development. Examples of these are Black, Crow and Eidsness, Inc. (1976, City of Cape Coral); Geraghty and Miller, Inc. (1978, Sanibel Island); Missimer and Associates, Inc. (1978, south Lee County wellfields, Sanibel Island, and Indian Pines); and Nuzman and Waltz (1977) Cape Coral.

None of these reports have dealt comprehensively with the hydrogeology of the entire county, but each has added valuable data and information to this study.

GEOLOGIC SETTING AND STRUCTURE

Lee County, Florida, lies on the eastern margin of a large depositional feature referred to 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 South Florida Province by a general line running from Levy County, Florida, northeast to Nassau County, Florida. The North Florida Province is composed predominantly of terrigenous clastic sedimentary rocks, and the South Florida Province by carbonate sedimentary rocks. The region of Florida in which the study area is located is within the South Florida Province.

The major subsurface structural element in the region, as described by Applin and Applin (1965), is named the South Florida Shelf. Applin and Applin proposed this term for a relatively flat area in the Comanchee Rocks (Cretaceous) 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 elevation of the top of this feature is approximately -8500 NGVD throughout Lee County (Applin and Applin, 1965).

Missimer and Gardner (1976) interpreted seismic profiles to represent apparent concentric folds in middle and upper Miocene sediments along the Caloosahatchee River near Ft. Myers and Cape Coral. They attributed the formations of these folds to possible "differential subsidence caused by tensional basal displacement". A structure contour map on the top of the associated beds (Plate 8), an isopach map of this unit (Plate 11), and a structure contour map of the underlying Suwannee Limestone (Plate 12) are presented in the Atlas. The regional high in the Lower Carbonate Member of the Hawthorn Formation (Plates 8 and 11) could probably be attributed to a thickening of the unit in the Fort Myers and Cape Coral areas.

Sproul, et al. (1972) presented evidence for a series of faults thought to extend from the Hawthorn Formation (Miocene) at least through the Ocala Group (Eocene) in the McGregor Isles area of Lee County. Although apparent fracturing is evidenced, the presence of major faults in this area is questionable because older beds (Oligocene to Cretaceous) do not reflect any noticeable offset. Chen (1965) and Puri and Winston (1974) both show the Eocene and Upper Cretaceous beds to be gently dipping to the southwest throughout the area. Plate 12 (Atlas) depicts the top of the Suwannee Limestone in Lee County to be an undulatory surface more easily attributed to differential subsidence and erosion than structural movements.

PHYSIOGRAPHY

White (1970) divided the Florida peninsula into three zones; the southern or distal zone, the central or mid-peninsular zone, and the northern or proximal zone. Segments of the southern and central zones are present in Lee County, and are separated by a boundary that crosses the State along a line extending roughly from Fort Myers on the Gulf coast to Stuart on the Atlantic coast. The boundary between the two zones in Lee County is loosely interpreted as following the course of the Caloosahatchee River.

Two physiographic features of the southern zone, the Immokalee Rise and the Southwestern Slope (Figure 2), occupy the southern part of the county. According to White (1970), the Immokalee Rise (Immokalee Island of Parker, et al., 1955) appears to have formed during one of the interglacial episodes of the Pleistocene as a submarine shoal that developed offshore from higher land masses directly to the north. Lane (1981) described the surficial deposits of the Immokalee Rise as consisting predominantly of medium to fine sand and silt. The numerous small lakes and ponds that surround the Immokalee Rise are discussed by White (1970) as follows: "...as in other areas where sand overlies limestone (White, 1958), a line of lakes has developed along the feather edge of the sand-covered area, to the extent that the sandy Immokalee Rise is ringed with small solution lakes. The occurrence of these peripheral lakes is so characteristic that the edge of the sand-covered area can be delineated by drawing a line on the map connecting the lakes." The Southwestern Slope borders the Immokalee Rise on the southwest and slopes gently from a high elevation near 25 feet at its eastern edge to sea level at the Gulf coast. The

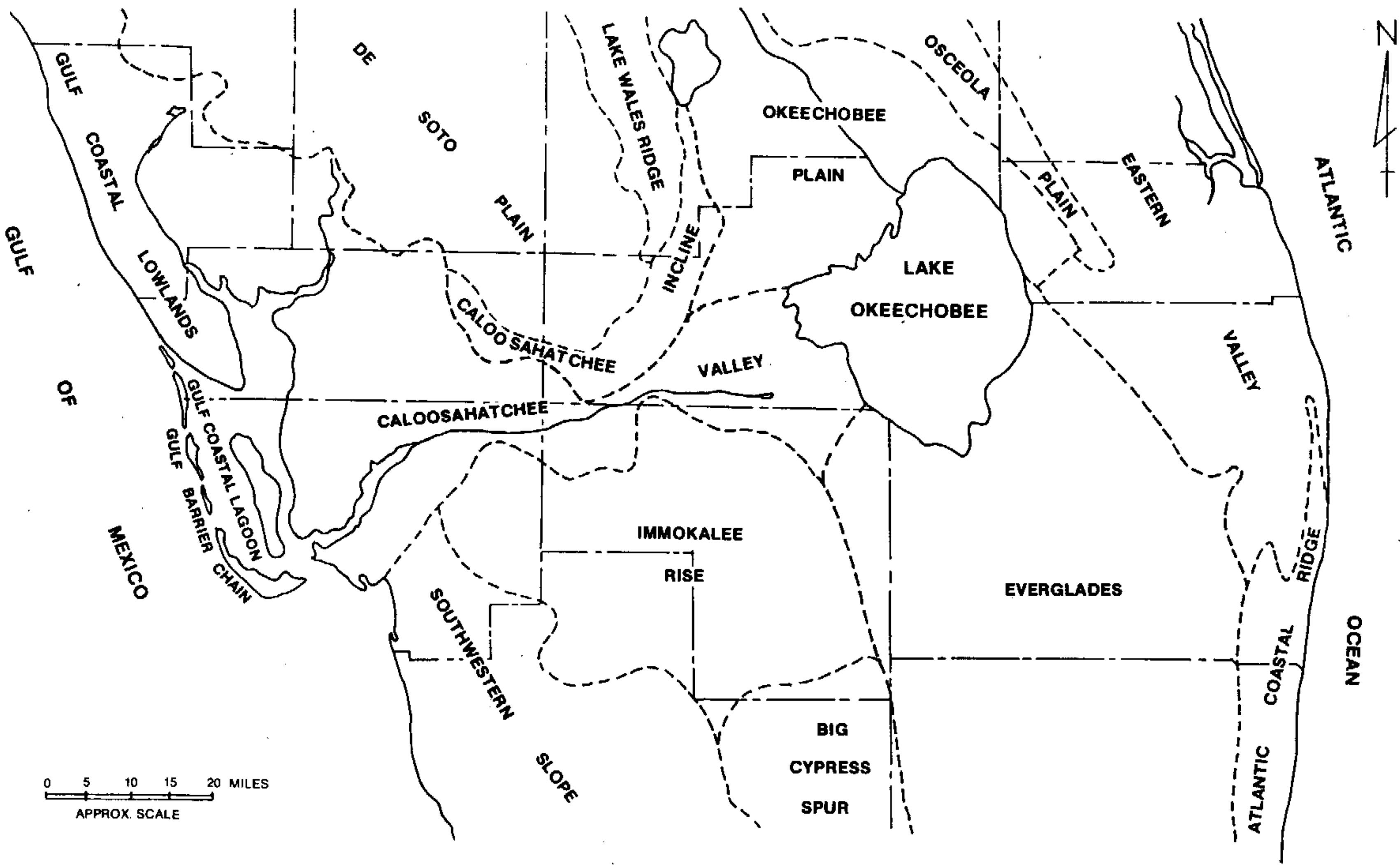


Figure 2. PHYSIOGRAPHIC MAP OF SOUTH CENTRAL FLORIDA (MODIFIED FROM WHITE, 1970)

Caloosahatchee Valley, a comparatively low-lying area of varying width, occurs to the north of these two features and lies astride the boundary between the southern and central zones. It is bounded by Lake Okeechobee on the east, and grades into the Gulf Coastal Lowlands on the west. According to Lane (1981), the near-surface sediments of both the Southwestern Slope and the Caloosahatchee Valley are predominantly sand, shell, and limestone.

The Gulf Coastal Lowlands (Puri and Vernon, 1964) is a gently sloping plain that extends along the western edge of the central zone parallel to the Gulf Coast. Only a small part of this feature occurs in Lee County, north of the Caloosahatchee River, where it merges indistinctly with the Caloosahatchee Valley. In Lee County, the surficial deposits of this plain consist of sand, shell, and clay (Knapp, 1980; Lane, 1981) that range from lithified coquinas to poorly indurated or semi-consolidated sandy shell beds, sand, and clay beds.

The entire coastline of Lee County is bordered by islands of the Gulf Barrier Chain which are separated from the mainland by Gulf Coastal Lagoons. White (1970) suggested that these barrier islands may have been formed by sand locally derived from erosion of headlands.

STRATIGRAPHY

INTRODUCTION

Figure 3 shows the major stratigraphic units in the study area. The stratigraphic sequence described in this report ranges in age from Eocene to Recent. Eocene rock units include the Ocala Group, the Avon Park Limestone, and the Lake City Limestone. The Lake City Limestone and Avon Park Limestone are quite similar; thus the recognition of the Lake City Limestone as a separate formation is questionable. An Oligocene rock unit, the Suwannee Limestone, is described from several sets of well cuttings in the area. The contact between the Suwannee Limestone and Ocala Group is lithologically distinct. Rubble beds are sometimes present at the base of the Suwannee Limestone. The Miocene age Hawthorn Formation overlies the Suwannee Limestone throughout Lee County. The lowermost beds of the Hawthorn Formation are somewhat similar to lithologies that define the Tampa Formation in other parts of Florida. The phosphatic nature of these beds, however, precludes this usage in Lee County. Younger formations range in age from late Miocene/early Pliocene to Recent and are represented by the Tamiami Formation, the undifferentiated Fort Preston/Caloosahatchee Formation and the terrace deposits.

CENOZOIC ERATHEM

Eocene Series

Lake City Limestone and Avon Park Limestone

Applin and Applin (1944) proposed the names Lake City Limestone and Avon Park Limestone to describe rocks of early Middle Eocene and late Middle Eocene age respectively that occur in northern and peninsular Florida. They identified the rocks primarily as faunizones, but did give brief lithologic

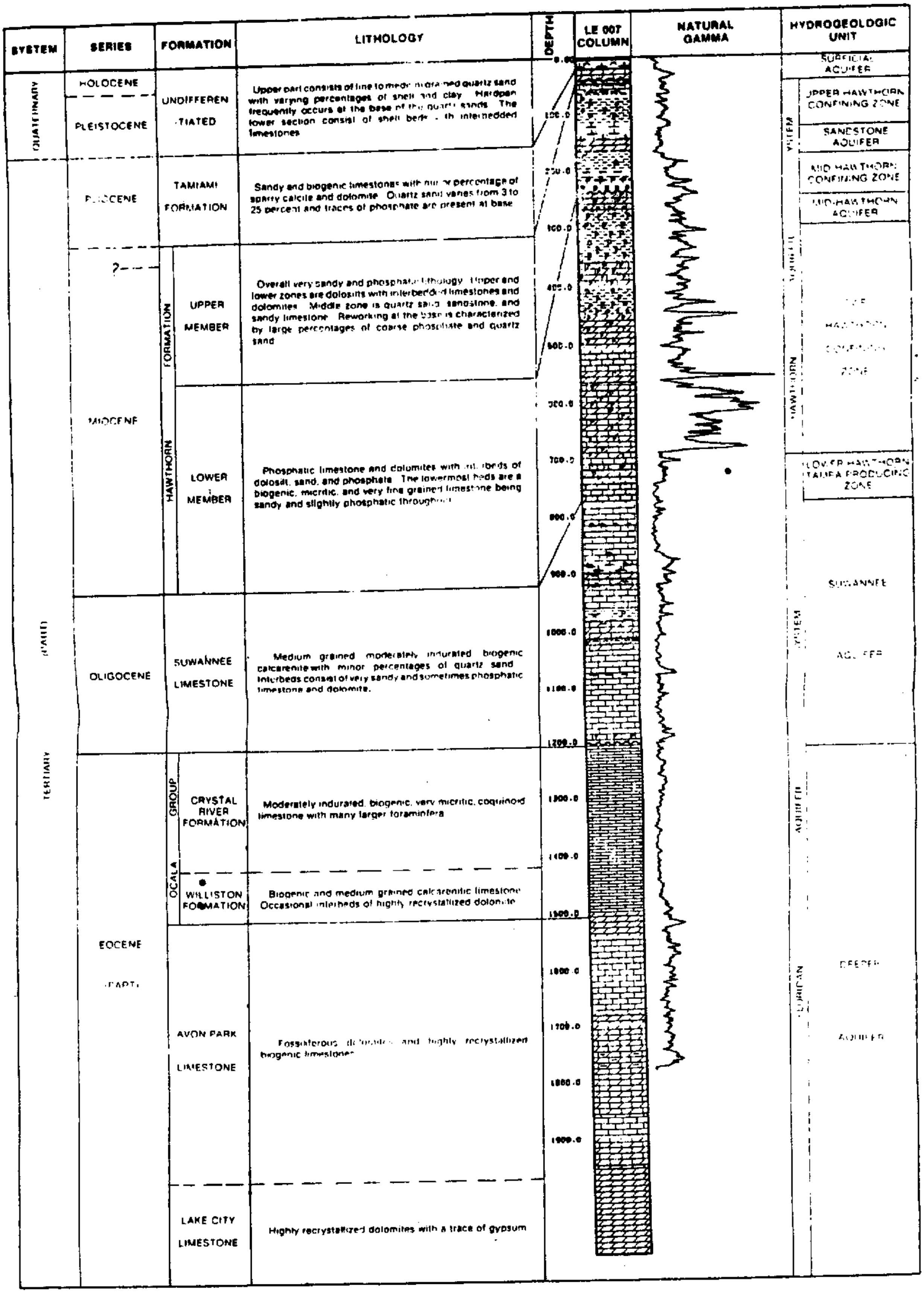


Figure 3 STRATIGRAPHIC CHART

descriptions of both units. They described the Lake City Limestone as a chalky limestone interbedded with dark brown dolomite containing gypsum, occasional chert, and near the top of the unit in a well in Marion County, a bed of lignite about 25 feet thick. They described the Avon Park Limestone from a few wells in the Tallahassee area as mainly a cream-colored, highly microfossiliferous chalky limestone, with gypsum and chert. Some authors have described the boundary between the Avon Park and Lake City Limestones as unconformable, but others have regarded the boundary as conformable with some tendency to be locally unconformable. In addition, dolomitization frequently obscures any possible lithologic boundary and destroys any fossils that might otherwise assist in distinguishing the two formations. These factors have been discussed by a number of authors, including Chen (1965) and Vernon (1951). The reader is referred to their comments for further insight into these two units.

In the Lee County study, the Avon Park Limestone and possibly the Lake City Limestone were identified only in the deepest well (well 12, Atlas and LE007, Appendix 1-2). At total depth, the well had penetrated 610 feet of these carbonates, with an unknown thickness remaining undrilled. A distinct lithologic change marks the boundary between the fossiliferous dolomite of the Avon Park Limestone and the overlying calcarenite of the Williston Formation of the Ocala Group. Fossils present in the Avon Park Limestone include echinoids, foraminifera (especially miliolids), mollusks, and other fossil fragments. The lithologic change is sharp and abrupt, and is accompanied by a faunal discontinuity. This combination suggests the possibility of an unconformity at the contact between these two formations. The upper dolomite beds of the Avon Park Limestone grade downward into a highly recrystallized biogenic limestone containing numerous foraminifera at a depth of 1545 feet below land surface (-1519 feet NGVD). Interbedded dolomites and limestones continue downward to a depth of 1950 feet below land surface (-1924 feet NGVD). At this point, there is a change in the texture of the dolomite and the appearance of a trace (1%) of gypsum. This new lithology continues to the total depth of the well at 2105 feet below land surface (-2079 feet NGVD). The lower dolomite is tentatively identified as being a part of the Lake City Limestone. This conclusion is based largely on the appearance of gypsum in the samples, and a report of the Lake City Limestone at an elevation of approximately -1860 feet NGVD in southwestern Charlotte County, just a short distance to the northwest (Puri and Winston, 1974).

Ocala Group

The term "Ocala limestone" was first used by Dall and Harris (1892) in a discussion of limestones being quarried near the town of Ocala in Marion County, Florida. The age and relative stratigraphic position of the limestones remained controversial until 1915, when Cooke was able to demonstrate that the "Ocala limestone" is actually of Eocene age and underlies the Marianna Limestone (Oligocene) in Jackson County, Florida. Cooke and Mossom (1929) defined the Ocala limestone as a formation that included "...all the rock of Eocene age exposed in Florida." Later in a study of the subsurface stratigraphy of Florida, Applin and Applin (1944) identified an upper and a lower member within the "Ocala limestone." This usage is still followed by the U. S. Geological Survey and many others. Puri (1953) followed Vernon (1951) in recognizing three distinct units that he believed were present within the strata of the "Ocala limestone." He proposed for his units the names Crystal River Formation, Williston Formation, and Inglis Formation (in descending order of depth) and suggested that the new formations should be included in the Ocala Group. This usage is followed in this publication.

In the present study of Lee County, the Crystal River and Williston Formations were recognized in one well (Well 12, Atlas; LE007, Appendix 1-2) and the Crystal River Formation alone was recognized in four others (Well 54, LE001; Well 29, LE008; Well 81, LE023; and Well 34, LE025). The Inglis Formation was not identified in any well. The total thickness of the Ocala Group was observed in only one well in the Lee County study. This well (LE007) penetrated 70 feet of Williston Formation and 220 feet of Crystal River Formation, indicating a total thickness of 290 feet for the Ocala Group at the well site.

As seen in LE007, the Williston Formation is a medium-grained calcarenitic limestone. The unit is fossiliferous but not coquinoid, and the fossils are usually small in size. Large foraminifera present in the wells, especially Operculinoides sp. and Amphistegina ap. are small for their types and are poorly preserved.

In the wells in which the Crystal River Formation is present, the unit is a very pale orange to very light gray, moderately indurated, biogenic, very micritic, coquinoid limestone with a fauna that includes abundant larger foraminifera, especially Lepidocyclina sp. and Heterostegina sp.

The boundary between the Williston and the underlying Avon Park Formation is marked by an abrupt lithologic change and dolomitization of the upper part of the Avon Park strata, combined with a change in the fossil fauna. The contact between the Williston Formation and the overlying Crystal River Formation is also marked by an abrupt lithologic and paleontologic change. The presence of unconformities (or diastems) at both boundaries is suggested by the differences.

Oligocene Series

Suwannee Limestone

Cooke and Mansfield (1936) introduced the name Suwannee Limestone to describe an interval of yellowish limestones exposed in the banks of the Suwannee River from Ellaville to White Springs. These beds contain numerous echinoids, especially *Rhyncholampas* (formerly "*Cassidulus*") *gouldii*, Bouve. Mansfield (1937) also described this formation and included in this original description additional limestones exposed near Live Oak in Suwannee County, Florida, and near Brooksville in Hernando County, Florida. He discussed the lithology and part of the fauna of the Suwannee Limestone, and demonstrated the differences between the Suwannee Limestone and the Tampa Formation in which the strata of the Suwannee had formerly been included. The definition of the Suwannee Limestone was later expanded by popular usage to include "all sediments of Oligocene age" in peninsular Florida (Vernon, 1951; and Yon, 1966).

In the type area, the Suwannee Limestone is normally a very pale orange, moderately indurated, very porous calcarenite that contains numerous fossil foraminifera, mollusks, and echinoids (Ceryak, et al., in press). Another major lithology within the type area is described by Colton (1978) as "...a dense, hard, resonate limestone composed of foraminiferal tests completely embedded in dense crystalline calcite...." Locally the limestone may contain minor percentages of quartz sand (Mansfield, 1937; Vernon, 1951; and Yon, 1966). Away from the type area, the limestones may be locally and erratically dolomitized.

The lithologic features described above are present in the Suwannee Limestone in Lee County, and the characteristic beds are sometimes interbedded with sandy phosphatic limestone and dolomite. Sproul, et al. (1972), working in the McGregor Isles area of west central Lee County described the Suwannee Limestone as a pale yellowish brown nodular limestone with no phosphorite. In the Lee County wells included in this study, the dominant lithology is very light orange to tan (brown) medium grained, moderately indurated, biogenic limestone (calcarenite) with minor percentages of quartz sand. Dolomite and sandstone interbeds of varying thickness occur erratically through the formation. The lower part of the Suwannee locally contains rubble zones, calcareous clay beds, and chert. The lithologic logs (see Appendix 1-2) describe some intervals within the Suwannee Limestone that contain quartz sand and phosphate embedded in the matrix of the rocks. Geophysical logs (see Appendix 2 and Plates 14-20, Atlas) indicate intervals of high gamma activity which do not appear to be associated with fracture zones or solution features. It is therefore concluded that much of this material has been deposited in the matrix of the rock. However, it is possible that some material of this type could represent cavings from above, material recirculated in the drilling fluid, or leaked sediment from younger strata that has travelled downwards along solution cracks into cavities.

The thickness of the Suwannee Limestone is variable and was logged at 360 feet in LE023, 485 feet in LE001, 370 feet in LE008, 350 in LE025, 425 feet in LE007. At total drilled depth, Well LE017 was still in Suwannee Limestone after penetrating 620 feet of the unit. The lower boundary of the Suwannee Limestone is easily identified in Lee County by an abrupt change from the typical granular and sometimes slightly sandy limestones of the Suwannee Limestone to the micritic coquinoid limestone of the Crystal River Formation of the Ocala Group. At the same point, in some wells, there is an abrupt change in the fossil assemblages that suggests the possibility of a faunal discontinuity. These features combine to suggest that this boundary may be unconformable.

The upper boundary of the Suwannee Limestone occurs at the contact between the slightly sandy carbonates of the Suwannee Limestone and the phosphatic and sandy sediments of the Hawthorn Formation. This boundary is usually fairly clear lithologically, and is also useful when comparing geophysical logs. The contact between the Suwannee Limestone and the Hawthorn Formation is marked on the Natural Gamma logs by a characteristic gamma ray attenuation, followed upward by medium to strong gamma activity throughout the Hawthorn interval. The boundary appears lithologically gradational in samples from a number of the wells in Lee County, but in other wells the lithologic change is sufficiently abrupt to suggest an unconformity. The usually abrupt change in gamma ray activity at the boundary also tends to support an abrupt change in lithology. The Hawthorn Formation is known to be a transgressive unit that elsewhere in Florida overlies sediments ranging in age from middle to late Eocene and Oligocene, often with many feet of the older beds missing at the contact. Therefore, despite the gradational appearance of the contact in some wells, an unconformity at the boundary is suggested.

Miocene Series

Beds associated with the Hawthorn Formation are present in many wells in Lee County. As identified here, the Hawthorn Formation in most of the county is a very distinctive unit that is marked at the top by a green phosphatic dolo-silt, and remains phosphatic, sandy, dolomitic, calcareous, and more or less heterogeneous throughout. An interval of sandy phosphatic limestone is present in Lee County, and has been identified as "Tampa Limestone" by many authors. This unit is distinctive, and has been identified on the lithologic logs (Appendix 1-2). However, it is considered to be part of the Hawthorn Formation in this report because of the high percentages of phosphate present in many beds. In the section on hydrostratigraphy, the uppermost producing zone of the Floridan Aquifer System has been called the lower Hawthorn/Tampa producing zone, to indicate that this unit is included. For these reasons, a discussion of this unit is included here, even though it is not recognized as a separate stratigraphic formation in this report.

Tampa Formation

The name "Tampa formation" was first used by L. C. Johnson in 1888 for limestones that crop out in and near the city of Tampa in Hillsborough County, Florida. In the following years, the rocks were referred to as the "Tampa formation" by some authors and the "Tampa limestone" by others, and the name "Tampa" was applied to supposedly contemporaneous limestones that are present in much of central and northern peninsular Florida. Cooke and Mossom (1929) used the name "Tampa limestone", including in their interpretation the original limestones in the Tampa area, the limestones in the central and northern peninsula, and the "Chattahoochee formation" of northern Florida east of the Apalachicola River. Cooke and Mansfield (1936) and Mansfield (1937) restricted the "Tampa limestone" by removing from it the limestones in central and northern peninsular Florida that are now included in the Suwannee Limestone. Cooke further redefined the Tampa Limestone to include the original limestones near Tampa and also in nearby Pinellas and southern Pasco counties, and the "Chattahoochee formation" of northern Florida. Cooke's interpretation is currently used by the U. S. Geological Survey.

King and Wright (1979) proposed a formal definition of the Tampa Formation in accordance with the American Code of Stratigraphic Nomenclature (1970). They restricted the formation to its original area of occurrence in eastern Hillsborough and Pinellas Counties and excluded the "Chattahoochee formation" of northern Florida. Their Tampa Formation generally consists of limestone with a content of at least 10 percent fine quartz sand and less than 1 percent phosphate, and is bounded at the top and bottom by unconformities.

Puri proposed a time stratigraphic term, the Tampa Stage, in his study of the Miocene of the Florida Panhandle (1954), and discussed two lithofacies within the stage; an updip, silty, clayey lithology (Chattahoochee lithofacies), and a downdip calcareous lithology (St. Marks lithofacies). He proposed the outcrops near Tampa in Hillsborough County as the type area of the stage, with special reference to those on Six Mile Creek near Orient and at Ballast Point on Tampa Bay. Puri and Vernon (1964) reinstated the Chattahoochee Formation as a name for the Chattahoochee lithofacies of Puri (1954), and informally referred to the St. Marks lithofacies as the St. Marks Formation. The St. Marks Formation was later described in Leon County by Hendry and Sproul (1966) and in Jefferson County by Yon (1966). Puri and Vernon (1964) suggested the name St. Marks Formation as a replacement for the name Tampa Formation in the Tampa area, but this usage has never gained popular acceptance.

In the Lee County area, Sproul et al. (1972), described as "Tampa Limestone" a "...grayish yellow sandy limestone with some black phosphorite..." In Charlotte County, Sutcliffe (1975) applied the name "Tampa Limestone" to "...interbedded gray to tan sandy limestone and gray to white clay; less phosphorite than above." Missimer and Banks (1981) did not recognize the Tampa Formation in the Sanibel Island area of Lee County. They did, however, describe the lower 75 to 100 feet of the Hawthorn Formation as "...a relatively uniform sequence of white biomicrite and biomicruditic limestone. These limestones contain between 5 and 10 percent fine, well rounded quartz sand. Micro-phosphorite nodules with a characteristically black color occur abundantly in isolated beds which are separated by beds containing little visible phosphorite." The unit which Missimer and Banks included in the Hawthorn Formation appears to be the same as that referred to as the Tampa Formation or "Tampa Limestone" by previous authors in southwest Florida.

A rock interval similar to that described by Missimer and Banks is present in many of the wells studied for this report. Because of the quantities of phosphate present in the strata (trace to 2 percent generally, with some beds containing as much 15 percent), this author concurs with Missimer and Banks, and has also included this rock interval in the Hawthorn Formation.

Hawthorn Formation

Dall and Harris (1892) first used the term "Hawthorne beds" for phosphatic sediments being quarried for fertilizer near the town of Hawthorne, Alachua County, Florida. Matson and Clapp (1909) designated these beds the "Hawthorne formation" and described them as clays, sands, and phosphatic limestones. Vaughan and Cooke (1914) recommended that the "Hawthorne formation" be abandoned and the sediments be included in the "Alum Bluff formation." Later, in 1929, Cooke and Mossom reinstated the Hawthorn Formation. The literature concerning this formation is voluminous, and the reader is referred to the publications listed in this paper for additional detail.

L. C. Johnson first described the section exposed at the Devil's Mill Hopper in Alachua County (in Dall and Harris, 1892), and Pirkle (1956, 1958,

1965) published detailed geologic sections at this sinkhole and also at Brooks Sink in Bradford County. Puri and Vernon (1964) designated the Devil's Mill Hopper as the type locality for the Hawthorn Formation and Brooks Sink as a co-type locality. They pointed out that these localities should be used as the basis for later correlation of outcrops of the Hawthorn Formation. Scott (1981) discussed three continuous cores penetrating the entire unit in the type area that were correlated with the type and co-type sections. He described the sediments of the Hawthorn Formation as consisting of "...various mixtures of clay, quartz sand, carbonate (dolomite to limestone), and phosphates."

In Lee County, the Hawthorn Formation has been identified by several authors including Sproul et al. (1972), Boggess and Missimer (1975), Missimer (1978), and Peck, et al. (1979). These authors all followed Parker, et al. (1955) and included in the Tamiami Formation beds that in this report are considered part of the Hawthorn Formation. Abstracts by Hunter and Wise (1980, 1980a) suggest that the top of the Hawthorn Formation is properly placed beneath a redefined and restricted Tamiami Formation. They show Parker's (1955) definition of the Tamiami Formation to be informal and not conformable to the U. S. Code of Stratigraphic Nomenclature (1970). In recent work by Missimer and Banks (1981), the upper boundary of the Hawthorn Formation in western Lee County was identified at the base of the Ochopee Limestone Member of the Tamiami Formation as a matter of preference.

As defined in this report, the Hawthorn Formation in Lee County, Florida, is a heterogeneous sequence of phosphatic, sandy, clayey, calcareous and dolomitic sediments of which the uppermost bed is frequently a green to gray phosphatic, sandy, slightly clayey dolo-silt. The elevation of the top of this unit is shown on Plate 3 (Atlas). The formation is divided into an upper predominantly clastic member and a lower predominantly carbonate member. The combined thickness of these two members varies from 443 feet to 780 feet, with an average thickness of approximately 550 feet (see Plate 10, Atlas). In northeastern Lee County and south of the Caloosahatchee River, a thinning of the Hawthorn Formation is apparent. This may be due to a structural high in the Suwannee Limestone in this area (Plate 12, Atlas).

The Hawthorn Formation overlies the Suwannee Limestone unconformably as discussed under the section dealing with the Suwannee Limestone. Throughout the county, the Hawthorn Formation is overlain by the Tamiami Formation. The contact between these two units is not always distinct, but the local absence of the uppermost Hawthorn sediments suggests that the contact is actually unconformable. The Hawthorn Formation and its boundaries are usually easily recognizable on Gamma Ray logs. The upper boundary is marked by a sudden attenuation in gamma activity, while the lower boundary is marked by a more or less abrupt decrease at the contact with the normally non-radioactive limestones of the Suwannee. Between these two points, the log indicates medium to high radioactivity for the Hawthorn Formation.

The lower predominantly carbonate member is divided into three zones with a total thickness that varies from 250 feet to 656 feet as shown on Plate 11 (Atlas). The lowest zone analogous to the Tampa Formation or Tampa Limestone, is present in many of the wells included in this report, and generally may be described as a very light orange to white, biogenic, micritic, very fine grained limestone that contains up to 10 percent quartz sand and has a phosphate content that usually varies from a trace to 2 percent, but in some intervals may be as high as 15 percent. Echinoid fragments, mollusks, corals and benthonic foraminifera (especially *Sorites* sp. and *Archaias* sp.) are abundant in some beds. A characteristic attenuation in the Natural Gamma log profiles occurs at the top of this unit. A second characteristic attenuation of gamma activity at the base of this unit normally marks the contact with the Suwannee Limestone. A structure contour map representing the top of this zone is shown on Plate 9 (Atlas).

The overlying middle zone of the lower member is characterized by a series of interbedded clayey phosphatic dolo-silts and phosphatic sandy dolomites and limestones. This zone is distinguished from the overlying and underlying zones by the extreme heterogeneity of the sediments within it. Shell beds are present in some intervals and phosphorite content varies from 1 to 15 percent. The occurrence of lenses of concentrated sand and gravel phosphorite causes this zone to give characteristically high peaks on Natural Gamma logs (see Plates 14-20, Atlas). It is marked at the top by a phosphatic dolo-silt and at the bottom by the less sandy, phosphatic and micritic limestones of the lower zone.

The upper zone of the lower member is a slightly sandy, dolomitic, phosphatic limestone with a maximum thickness of 150 feet. There is a distinct break between this lithology and the overlying predominantly clastic and clayey lithologies within the upper member of the Hawthorn Formation. The top of this bed (Plate 8, Atlas) is shown as being a structural high at approximately -100 feet NGVD in the Cape Coral area. It dips in all directions from this locality and is more than 300 feet deep in some areas.

The upper predominantly clastic member is also divided into three lithic zones, all of which contain intermixed and varying percentages of phosphate, quartz sand and clayey dolo-silts. This member varies in thickness from 90 feet to more than 350 feet in Lee County. The lower zone of the upper member is composed of sandy and phosphatic dolo-silts with thin interbeds of sandy phosphatic limestone and dolomite. The interval is marked at the bottom by a rubble zone, or reworked interval, that has been regarded as evidence for a regional disconformity (Missimer, 1978). A phosphatic dolo-silt that occurs at the top of this interval in Lee County produces a characteristic gamma signature on geophysical logs (see Plates 14-20, Atlas). Plate 7 (Atlas) is a structure contour map representing the top of this zone.

The middle zone of the upper member normally occurs as very sandy, phosphatic limestones and dolomites. The zone may be phosphatic at the top and bottom, and may sometimes include a sandstone or sand with a carbonate matrix. It was named the Lehigh Acres Member, and together with the overlying upper zone and underlying lower zone, was included in the Tamiami Formation by Peck, et al. (1979). The top of this zone and its thickness are shown on Plates 5 and 6 (Atlas), respectively. The middle zone is non-existent in the Cape Coral area and thicknes only slightly to the west. However, east and south of Cape Coral the zone thickens and is in many areas over 100 feet thick. Plate 6 (Atlas) shows a linear northeast-southwest trend of 100 feet or more of thickness for this unit in eastern Lee County. In the southern portion of the county, the overlying upper zone is frequently thin, or may be missing, with the middle zone being directly overlain by sediments of the Tamiami Formation. Where this occurs, it is very difficult to distinguish the boundary between the Hawthorn Formation and the Tamiami Formation.

The upper zone of the upper member is composed predominantly of phosphatic dolo-silts interbedded with poorly indurated limestones, shell beds, and green clays, with the most phosphatic sediments occurring in the lower part of the zone. The thickness of this zone varies from less than 25 feet to over 100 feet as shown on Plate 4 (Atlas). West of the Caloosahatchee River and east of Pine Island, the zone thickens at the expense of the underlying middle zone (Plate 6, Atlas). Where the middle zone is absent in the Cape Coral area, differentiation of the upper zone from the lower zone is difficult. East of Interstate Route 75, and in the central portion of Lee County, the middle zone thickens and the upper zone thins. The thickness of the upper zone in Well 78 (Plate 1, Atlas) near Bonita Springs is 30 feet, and the top of the zone has an elevation of -45 feet NGVD. In Well 79 (Plate 1, Atlas) located approximately 5 miles due east of well 78, the thickness of the upper zone is only 10 feet and the top occurs at an elevation of -110 feet NGVD. These relationships are also illustrated on Plates 14 and 20 (Atlas). The top of the upper zone dips to the south from central Lee County.

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. He tentatively correlated the limestone with the "Caloosahatchee marl" which was at that time thought to be of Pliocene age. 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." They preferred the name "Tamiami formation" for this unit because of the predominance of quartz sand. Later, in 1955, Parker, et al., redefined the Tamiami Formation to include Mansfield's original thin limestone and a thick section (approximately 125 feet thick) that had previously been included in the Hawthorn. According to Parker, et al. (1955); "The formation includes all the upper Miocene materials in southern Florida and has a maximum thickness of about 150 feet." The new age designation of "upper Miocene" was based on the molluscan fauna, in which they had discovered *Ecphora quadricostata umbilicata*, Wagner. In 1968, Hunter described five lithologic members present in surface exposures of the Tamiami Formation: the Ochopee Limestone Member (Mansfield's original limestone), the Buckingham Limestone Member, and the Pinecrest Sand Member, which were believed to be three laterally-equivalent, interfingering facies, and the underlying Murdock Station Member and Bayshore Clay Member. Missimer (1978) suggested that the base of the Tamiami Formation occurred at a major disconformity that he recognized through much of Lee and Charlotte Counties. Peck, et al. (1979), recognized eight lithologic units within a thick Tamiami Formation in Lee and Hendry Counties and proposed one as a formal member. Abstracts by Hunter and Wise (1980, 1980a) indicate that the Tamiami Formation as established by Parker, et al. (1955), is actually a time stratigraphic unit that lacks formal lithologic description and firm boundaries, and does not conform to the American Code of Stratigraphic Nomenclature. They proposed redefining the formation to include only the original limestone of Mansfield (the Ochopee Limestone Member) and its lateral equivalents.

Hunter (1968) proposed three molluscan biostratigraphic zones based on guide fossils present in the various members. She suggested that the zones are useful for local correlation, and accepted the late Miocene age assigned to the strata by Parker, et al. (1955). Akers (1974) examined samples from the Pinecrest Sand Member of the Tamiami exposed in Sarasota County and reported that they contained calcareous nanoplankton of Neogene Zone 20 (Blow, 1969), indicating a middle Pliocene age for the Pinecrest Sand. A similar age would, of course, apply to the other laterally equivalent members of the Tamiami. In Lee and Hendry Counites, Peck, et al. (1979), followed Parker, et al. (1955), and included a subsurface section approximately 400 feet thick within the Tamiami Formation. From their samples they reported diatoms, nanoplankton and planktonic foraminifera that together suggest an age ranging from late Miocene to middle Pliocene (Neogene zones N.17 to N.20 of Blow, 1969). It is now generally accepted that the Pinecrest, Ochopee and Buckingham members of the Tamiami are of middle Pliocene age, and that part, if not all, of the section added by Parker, et al., is of late Miocene age.

The reader who desires more detail of the history of the Tamiami Formation is referred to the references shown above, and especially to Peck, et al. (1979), for an excellent synopsis. In this report, the Tamiami Formation of Lee County is restricted to include only the Ochopee and Buckingham Limestone Members. The Pinecrest Sand Member was not identified in any sample. In effect, this action follows the restructing proposed by Hunter and Wise (1980, 1980a). Actually, the most consistently recognizable lithologic boundary in this part of the section occurs between these two members and the underlying sediments which have here been included in the Hawthorn Formation.

The Ochopee Limestone Member underlies most of Lee County. It is a well indurated, biogenic, medium grain, fossiliferous, sandy, calcarenitic limestone with good moldic and intergranular porosity. It varies in thickness from less than 10 feet to more than 100 feet, thickening to the south. The Buckingham Limestone Member is a poorly indurated, slightly sandy, locally somewhat phosphatic, fossiliferous, micritic (calcilutitic) limestone with overall low porosity. This member is thin (usually not more than 15 feet) and has been identified only in the northeastern part of Lee County in the vicinity of Buckingham and Alva. The two members appear to represent laterally equivalent facies. The Buckingham Limestone exists in other areas but could not be identified on the basis of the available data.

The boundary between the Hawthorn and the Tamiami Foramtions is recognized at the contact between the limestones of the Tamiami and the phosphatic, very sandy, clayey dolo-silts that usually comprise the upper member of the Hawthorn Formation as discussed previously. The Tamiami is overlain by undifferentiated sediments thought to be of Pleistocene to Holocene age, as discussed below.

Pleistocene-Holocene Series

Undifferentiated

Undifferentiated deposits of varying thickness and lithology overlie the surface of the Tamiami Formation throughout Lee County. A part of these deposits, particularly in the interior of the county, has long been thought to be of late Pleistocene age, and possibly correlatable with strata of the Caloosahatchee and/or Fort Thompson Formations that are typically exposed along the Callosahatchee River in Hendry County. Near the

Gulf Coast, and particularly on the barrier islands, an undetermined percentage of the Undifferentiated material may be of Holocene age.

A large part of the undifferentiated deposits is composed predominantly of quartz sand with minor percentages of shell and clay (Knapp, 1980; Lane, 1981). The sand is subangular with medium sphericity and is sometimes frosted. Occasionally very low percentages of sand-size phosphate grains and a trace of opaque heavy minerals are present. As elevations increase, the sand becomes thicker and less calcareous. It is not known if calcareous material was once present at the higher elevations but has been leached from the sand since deposition, or if the calcareous material was never present. In addition to the sand, numerous interfingering limestones, sandstones, and shell beds are present locally.

The names "Fort Thompson" and "Caloosahatchee Marl" have been applied to some of these sediments in the past (Dubar, 1958, 1962). However, due to lithologic dissimilarity between the Lee County sediments and these two formations in their type area in Hendry County, it seems inadvisable to extend the two names into the study area. Also, recognition of these two formations is partly dependent on differentiation between the two fossil assemblages present in the formations. While this may be done with large outcrop samples, the small size and quantity of well cuttings make such distinction impractical, if not impossible. In addition, the heterogeneous nature of the Lee County surficial sediments and the erratic occurrence of interbedded lithologies make detailed mapping, except at very large scale, essentially infeasible. It was therefore decided to leave these sediments Undifferentiated.

HYDROSTRATIGRAPHY

INTRODUCTION

The sequence of rocks which underlie Lee County can be grouped hydrogeologically into aquifers (those rocks which will yield water in sufficient quantity to be valuable as a source of supply) and confining zones (low permeability rocks which lie above, between or below aquifers). The basic criteria for including a section of rock strata within a particular aquifer designation are substantial vertical and lateral hydraulic continuity within the rock strata.

The hydrostratigraphy of five major aquifers or producing zones of particular importance for water supply in Lee County is discussed in this section. These are; the Surficial aquifer, the Sandstone aquifer, the mid-Hawthorn aquifer, the lower Hawthorn/Tampa producing zone, and the Suwannee aquifer. Figure 4 shows the relationship between these designations and existing aquifer nomenclature in Lee County. The lower Hawthorn/Tampa producing zone is actually part of the "Floridan aquifer" as defined by Parker (1955) and as the term is commonly used by the U. S. Geological Survey. In this report the term "Floridan Aquifer System" is substituted for the "Floridan aquifer" of Parker (1955) in recognition of the fact that a number of discrete producing zones which have themselves been designated as aquifers (eg. Sproul, et al., 1972 and Boggess, 1974) are embraced within this definition. In subsequent sections of the report, dealing with water levels and water quality, the designation "lower Hawthorn aquifer" is used when referring to data obtained from the U. S. Geological Survey's "lower Hawthorn" aquifer monitoring network. The wells in this network monitor zones ranging from the lower Hawthorn Confining

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

Figure 4 RELATIONSHIPS OF AQUIFER NOMENCLATURE IN LEE COUNTY, FLORIDA.

Zone to the Suwannee aquifer, and for the most part include the lower Hawthorn/Tampa producing zone of this report. For completeness, the Floridan aquifers are also briefly discussed. Brief mention is also made of the "Boulder Zone" of the Oldsmar Limestone, which lies below the Floridan Aquifer System.

There are four basic types of aquifers which occur in nature. These aquifer types are (according to Kruseman and DeRidder, 1970) 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 across the confining bed, and the permeability of the confining bed. 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. In general, the Sandstone, mid-Hawthorn, and the individual aquifers within the Floridan Aquifer System are of the semi-confined type. The Surficial aquifer displays properties of the unconfined "water table", semi-confined, and semi-unconfined aquifer types.

SURFICIAL AQUIFER

The Surficial aquifer occurs within sediments of the Tamiami Formation and the Undifferentiated deposits. The Tamiami Formation is composed principally of sandy biogenic limestones, while the Undifferentiated deposits consist of quartz sand, shell beds, and calcareous clays occasionally interbedded with thin seams of limestones. The calcareous clays, where present in sufficient thickness, act as semi-confining beds, dividing the aquifer into the water table and the Tamiami producing zones. The base of the Surficial aquifer is formed by the clayey dolo-silts at the top of the Hawthorn Formation.

The thickness of the Surficial aquifer varies between 25 and 50 feet in central Lee County (Plate 2, Atlas). The aquifer thickens west of Cape Coral, and in the southeastern part of the county. It is very thin in an area just south of the Caloosahatchee River in northeastern and central Lee County.

The Surficial aquifer is hydrogeologically complex, due to lateral facies changes in the strata and variations in thickness of the beds. Over much of the area the sands, shell beds, and limestones exhibit sufficient hydraulic continuity to be considered a single producing zone. In areas where the aquifer is relatively thick, interbedded clayey beds create semi-confined or semi-unconfined conditions within the aquifer. In southern Lee County a coral reef facies (Meeder, 1979) extends into the area at shallow depths from northern Collier County. This tract has been termed the Coral Reef aquifer by Missimer and Associates (1981), but is included within the Surficial aquifer in this report. In some parts of southern Lee County, the underlying upper Hawthorn confining zone is thin or absent, and the Surficial aquifer is in direct hydraulic communication with the Sandstone aquifer.

Within the Surficial aquifer porosities and permeabilities vary vertically and laterally, depending mainly on lithologies. In areas of similar lithologies, the transmissivity of the aquifer is dependent on the thickness of permeable rocks. Where sand is the dominant lithology permeability is intergranular, due to the lack of cementation of the grains. The sands vary in grain size from fine to medium, and based on Lohman (1972) would be expected to have relatively low permeabilities of 15-50 feet per day. Shell beds have variable permeabilities depending on matrix materials present. Porosities are normally intergranular and occasionally moldic. Reef tracts have mainly moldic porosity with some solution porosity and would be expected to have relatively higher permeabilities. The highest permeabilities in the Surficial aquifer are expected in the corraline reef limestone facies. The calcareous clays are apparently of low permeability, due to the fine grained nature and cohesiveness of the material.

HAWTHORN AQUIFER SYSTEM

The Hawthorn Aquifer System consists of five zones, as shown on Figures 3 and 4. All of these zones tend to be sandy, phosphatic, calcareous, and dolomitic. The confining zones are predominantly clayey dolo-silts usually interbedded with shell beds or poorly indurated limestones. The water producing zones are formed by limestone, calcareous quartz sand, sandstone, and dolomite. Each zone will be discussed individually below.

Upper Hawthorn Confining Zone

The upper Hawthorn confining zone separates the Surficial aquifer from the Sandstone aquifer in most of Lee County. The beds associated with this zone have very low permeabilities owing to the silt size and dense packing arrangement of matrix components. The dominance of the green gray clayey dolo-silts and minor presence of interbedded lithologies make this zone easily recognizable throughout the area. The Natural Gamma log reflects the lower percentages of phosphate in the upper section of this zone, and the increase in phosphate content with depth. Wells 17, 12, and 20 (Appendix 1-2 and 2) are examples of this relationship. Electrical logs are characteristically attenuated in this zone. Some vertical permeability does exist and this zone is considered to be semi-confining.

This zone is equated with the uppermost beds of the Hawthorn Formation and the elevation of the top of this unit is shown on Plate 3 (Atlas). It occurs between 0 and -25 feet NGVD over most of central Lee County. The unit dips gently to the west from Cape Coral and occurs at elevations between -50 feet and -75 feet NGVD in the Sanibel Island area. In the southeastern segment of the County an apparent area of subsidence in the lower part of the Hawthorn Formation (see Plates 3, 15, Atlas) causes this zone and most other zones in the Hawthorn Formation to be structurally low. The thickness of this zone varies between 10 and 100 feet in Lee County as depicted on Plate 4 (Atlas). The zone thins and is absent in the extreme southern portion of the county near Bonita Springs. In the Cape Coral area it directly overlies the mid-Hawthorn confining zone and due to the similarities between them differentiation of these two units is difficult in this area.

Sandstone Aquifer

The Sandstone aquifer underlies the upper Hawthorn confining zone in nearly all of Lee County. 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. In this report the Sandstone aquifer is considered to be within the Hawthorn Formation because of the overall phosphatic and dolomitic nature of these and overlying beds.

Lithologically this aquifer is composed of sandy limestones, sandstones, sandy dolomites, and calcareous sands confined above and below by clayey dolo-silts. The high gamma activity at the base of the upper Hawthorn confining zone helps to define the top of this unit. The Sandstone aquifer also tends to be more phosphatic at the base, resulting in characteristic Natural Gamma signatures in this section. 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 dolo-silt, creating several producing zones. Lithologic logs of wells LE017, LE009, and LE025 (Appendix 1-2) illustrate these features.

The top of the Sandstone aquifer is depicted on Plate 5 (Atlas) and the thickness on Plate 6 (Atlas). The top of this unit occurs between -21 feet and -167 feet NGVD in Lee County. It is structurally high in Lehigh Acres and adjoining areas where it is encountered between -25 feet and -50 feet NGVD. It dips in a southerly direction from this area and occurs at -150 feet NGVD in the southeastern portion of the county. A linear NE-SW trend in the thickness of this unit (Plate 6, Atlas) exists in the eastern portion of the county. The highest transmissivities found in the Sandstone aquifer occur in beds associated with this trend. In the southeastern portion of the county the sandstone thickens to over 200 feet and the overlying confining zone is thin or absent. Within a large portion of this area the Surficial aquifer directly overlies and is in hydraulic communication with the Sandstone aquifer.

Mid-Hawthorn Confining Zone

The mid-Hawthorn confining zone is composed of a relatively thick sequence of clayey dolo-silts locally interbedded with thin seams of porous limestone, sand, and dolomites. The elevation of the top of this zone is shown on Plate 7 (Atlas). It occurs between -75 and -150 NGVD over most of the central and northern portions of the county dipping to the southeast from the vicinity of Corkscrew Road and to the west from Pine Island. Although there is both vertical and horizontal movement of water in this zone the permeability contrast with the overlying and underlying aquifers is considered sufficient for it to be designated as a semi-confining bed. The thickness of this unit varies from approximately 20 feet to more than 180 feet. The unit is consistently thin in the Cape Coral area (less than 50 feet thick) due to a structural high in the lower Hawthorn carbonate member. A rubble bed of very coarse phosphorite and medium fine sands is present at the base resulting in a distinctive Natural Gamma Log signature throughout most of the county.

The thin seams of limestone, sand, and dolomite are locally capable of producing small quantities of water under artesian pressure. However, due to the random occurrence of these beds, they are not considered as a significant groundwater source and are normally cased off in wells which tap the underlying aquifers.

Mid-Hawthorn Aquifer

The water producing limestones, sandstones, and dolomites that lie below a regional disconformity (Missimer, 1978) within the Hawthorn aquifer are referred to in this report as the mid-Hawthorn aquifer. This unit is also referred to as the "upper Hawthorn aquifer" by the U. S. Geological Survey (eg. Sproul, et al., 1972; Boggess, 1974) and as "Zone 1, Hawthorn Aquifer System" by Missimer and Associates (1979) (Figure 4). The term "mid-Hawthorn aquifer" has been used in this report in recognition of the position of the aquifer in the stratigraphic column as well as the fact that the Sandstone aquifer is included in the Hawthorn Formation and is therefore the uppermost aquifer in this formation.

Lithologically, the mid-Hawthorn aquifer is composed primarily of limestone, dolomite, and sandstone which exhibit intergranular, moldic, and possible fracture and solution porosity. A reworked zone at the base of the mid-Hawthorn confining zone consisting of quartz and phosphatic sand may also act as part of the aquifer. This zone shows characteristic high natural gamma activity and is a good geophysical marker bed for the top of the aquifer. Phosphatic sand, quartz sands, and fossiliferous clayey dolo-silts are also interbedded with the major lithologies in the aquifer. These interbeds are normally of lower permeability than the limestones, dolomites, and sandstones.

The elevation of the top of the mid-Hawthorn aquifer is shown on Plate 8 (Atlas). A structural high occurs in the vicinity of Cape Coral and Fort Myers, and the unit dips radially from this area. The thickness of the aquifer (see Plates 14-20, Atlas) is variable, but rarely exceeds 80 feet. The relatively thin section of aquifer coupled with the interbedding of low permeability beds results in an overall low transmissivity of the aquifer.

The base of this aquifer is often difficult to identify because the interbedded dolo-silts occur erratically throughout the unit. Where they occur close to the base of the aquifer the distinction between these and the lithologies in the underlying lower Hawthorn confining zone is not clear. There is, however, a characteristic gamma peak at the base of this unit (see Figure 3) that is associated with a phosphatic dolo-silt.

Lower Hawthorn Confining Zone

The lower Hawthorn confining zone lies below the mid-Hawthorn aquifer, and consists principally of sandy, phosphatic, poorly indurated limestones interbedded with phosphatic dolo-silts. The low permeability of this zone results from the fine-grained nature of the rocks. The lithology of this zone is, however, not uniform and there are several well-indurated porous limestone, dolomite, and sandstone beds within it. Locally these beds may produce water under artesian pressure. In western coastal Lee County, Missimer (1979) identified two relatively thick zones (Zones 2, 3, Figure 4) which could yield significant quantities of water.

In most of Lee County, the thickness of the lower Hawthorn confining zone varies between 180 and 350 feet. It is significantly thinner in the northern Pine Island area, as a result of a structural high in the Suwannee Limestone in this area.

FLORIDAN AQUIFER SYSTEM

The term "Floridan aquifer" was established by Parker (1955) for water bearing rocks associated with the Lake City Limestone, Avon Park Limestone, Ocala Limestone, Suwannee Limestone, Tampa Limestone, and the lower permeable parts of the Hawthorn Formation in hydrologic contact with underlying units. The terms "Ocala Limestone" and "Tampa Limestone" are used by the U. S. Geological Survey. Stringfield (1966) referred to Parker's (1955) Floridan aquifer as the "principal artesian aquifer" in his study on the artesian water of the Southeastern United States. The top of the Floridan aquifer has been mapped regionally in northern and central Florida by several workers in the recent past (Kwader and Schmidt, 1978; Knapp, 1978; Buono and Rutledge, 1979; Brown, 1980; and Scott and Hadishafie, 1980). These authors all place the top of the Floridan aquifer in the porous beds referred to by Parker (1955). The top of this unit has not been mapped regionally in south Florida.

In Lee County the water producing beds that can be correlated with the upper section of the "Floridan aquifer" as defined by Parker (1955) have been referred to as the lower Hawthorn aquifer and the Suwannee aquifer (Sproul, et al., 1972; and Boggess, 1974). These workers indicate that these aquifers should be treated as individual hydrologic units that are separated above and below by confining beds. In later work by Black, Crow, and Eidsness (1976) the lower Hawthorn and Suwannee aquifers were placed in the Floridan aquifer.

In this report, Parker's "Floridan aquifer" (1955) is referred to as the Floridan Aquifer System. It consists of an areally thick sequence of interbedded limestones and dolomites of Eocene to lower Miocene age, which show differences in vertical and horizontal porosity and permeability. This system is divided into three zones; the lower Hawthorn/Tampa producing zone, the Suwannee aquifer, and the Deeper aquifer. Permeability differences exist within each of these zones, such that some intervals produce significantly more water than others. The top of the Floridan Aquifer System is equated with beds assocaited with the lower Hawthorn Formation and by some geologists to the Tampa Formation. The major producing zones within this system normally occur near the contacts of the geologic formations. These zones have higher porosities and permeabilities due to the reworking or dissolution of the carbonate rocks in these intervals.

Lower Hawthorn/Tampa Producing Zone

In this report the term "lower Hawthorn/Tampa producing zone" is used to describe those water bearing units within the base of the lower Hawthorn Formation, including those beds referred to by previous authors as the Tampa Limestone. It includes the lowermost part of the "Lower Hawthorn Aquifer" as defined by Sproul, et al. (1972), and extends to near the top of the Suwannee Limestone. This extension is justified on the basis of recent data which has shown that major water producing zones consistently occur below the base of Sproul's lower Hawthorn aquifer and above the Suwannee aquifer.

Lithologically this unit is composed of sandy and phosphatic biogenic limestones with intergranular and moldic porosity. It is interbedded with well indurated crystalline dolomites and phosphatic clayey dolo-silts. The variability of the porosity within the limestones and the presence of lower permeability dolomites and dolo-silts cause the water producing zones to be isolated into intervals of different productivity. The zone of major production within this unit occurs near its top in a well-indurated, sandy limestone. This interval is easily located by a marked attenuation in gamma activity which follows a large zone of high activity associated with the overlying lower Hawthorn confining zone. This characteristic gamma signature is found in wells throughout Lee County and is useful in locating the top of the producing zone. Temperature and Flowmeter logs show changes at this interval which indicate an increase in flow in the well bore and differences in groundwater temperature between this zone and the overlying lower Hawthorn confining zone. Geophysical log suites (Appendix 2) show some characteristic signatures of this zone. The Temperature Differential log (Well 41, Appendix 2) shows large-order fluctuations in this zone at 585 feet. These fluctuations, coupled with the gamma attenuation at the top of this zone, are diagnostic. Although the majority of the water produced from the lower Hawthorn/Tampa producing zone comes from the top of the unit, several smaller producing intervals occur elsewhere in the unit.

Beds of lower permeability are present at the base of the lower Hawthorn/Tampa producing zone. The low permeability beds are composed of compact micrites which act as semi-confining beds to the underlying Suwannee aquifer.

The top of the lower Hawthorn/Tampa producing zone is depicted on Plate 9 (Atlas). It is an undulatory surface that ranges from -350 feet NGVD in northwestern Lee County to -700 feet NGVD in the southern portion of the county. The thickness of this unit varies from 80 to 275 feet and regional highs occur in the Cape Coral and east Fort Myers areas. Plates 14-20 (Atlas) show the unit as gently dipping to the east and south.

Suwannee Aquifer

The Suwannee aquifer occurs within beds that are assigned to the Suwannee Limestone. The lithology of the Suwannee Limestone in this area is complex due to the interbedding of poorly indurated micrite, slightly phosphatic dolo-silt, sand, and sandstone. A major attenuation in the gamma profiles (see Appendix 2 and Plates 14-20, Atlas) mark the top of this aquifer in Lee County. The major producing zones within the Suwannee aquifer occur in isolated beds of relatively high porosity and permeability that are normally composed of calcarenitic limestones and occasionally sandstones.

The elevation of the top of the Suwannee aquifer is depicted on Plate 12 (Atlas). The top occurs between -500 feet NGVD in northwestern Lee County and 850 feet NGVD in the extreme southern and northeastern Lee County. The thickness of the aquifer is consistently more than 350 feet and in Well LE017 (Appendix 1-2), located in southern Lee County, was more than 620 feet. The major producing intervals in this aquifer are located near the top, normally occurring about 30 feet below the attenuation in the gamma log profiles. Large-order fluctuations in Flowmeter and Temperature logs occur in these intervals. Several other producing intervals occur at greater depths, including a major producing interval detected at -1060 feet NGVD in Well LE022.

Deeper Aquifers

The deeper aquifers are associated with porous beds of limestones and dolomites that occur in the Ocala Group, Avon Park Limestone, and Lake City Limestone. Puri and Winston (1974) described several zones of high permeability occurring within these strata.

Five wells described in Appendix 1-2 penetrate deeper aquifers (Ocala Group) between -1100 and -1200 feet NGVD. Another well (LE017) in southeastern Lee County was logged to a depth of -1439 feet NGVD without encountering strata of the Ocala Group. Plates 14, 19, and 20 (Atlas) show the top of the deeper aquifers to be dipping to the south and east. Well 12 (LE007) was drilled through the Ocala Group into the Avon Park and/or Lake City Limestones. A suite of geophysical logs for this well is presented in Appendix 2. The lithology of the Ocala Group is characterized by very micritic coquinoid limestones with intergranular and moldic porosities. The Avon Park Limestone and/or Lake City Limestone is commonly dolomitized with correspondingly lower intracrystalline and vugular porosities. The

Flowmeter log on Well LE007 shows a major producing zone present at the contact between the Ocala Group and Suwannee Limestone. Another producing zone occurs at the base of the Ocala Group.

Zones of high transmissivity, commonly called "Boulder Zones" typically occur at several horizons within the lower parts of the Lake City Limestone and parts of the Oldsmar Limestone. The high transmissivities are the result of diagenetic changes related to dolomitization and/or carbonate dissolution.

WATER LEVELS AND POTENTIOMETRIC SURFACES

INTRODUCTION

Water table elevation maps and potentiometric surface maps of the Surficial, Sandstone, mid-Hawthorn, and lower Hawthorn aquifers were prepared, using published 1979 data from the U. S. Geological Survey (U. S. Geological Survey, 1980). To illustrate seasonal variations, dry season maps based on end of March data and wet season maps based on end of September data were made. Rainfall data (South Florida Water Management District, 1980) indicate that these periods represent approximately the end of the dry season and the end of the wet season, respectively.

Elevations were referenced to National Geodetic Vertical Datum (NGVD)of 1929. Data displayed are either end of month measurements or maximum monthly values from continuous records. Consequently, the values do not necessarily represent the highest levels during the month, nor are they necessarily representative of annual maxima or minima. The maps do, however, present a general picture of water levels and potentiometric surfaces during periods of high levels and periods of low levels.

A series of maps showing differences in water levels or potentiometric levels between wet and dry seasons is also presented. All data on which the maps are based are presented in Appendix 3.

Detailed short term and long term variations in water levels and potentiometric levels are illustrated by four (4) sets of hydrographs for each aquifer. The wells for which hydrographs are presented were chosen to be representative, as far as possible, of different areas within each aquifer. Each set of hydrographs consists of a long term record (incorporating the entire available period of record for the well) and an annual hydrograph showing monthly or short term variations. The long term hydrographs were constructed using annual maximum and minimum values with occasional additional values where necessary to preserve the trend. One of two types of annual hydrographs is shown; the first type is a plot of end of month data; the second plots averages of daily maxima and minima.

The effects of recharge and discharge on the water level and potentiometric surfaces of the aquifers are discussed in this section. Further quantitative discussion of these factors is deferred to the section on groundwater potentials. Figure 5 shows the locations of municipal wellfields in the area. Discharges from these wellfields significantly affect water levels in many of the aquifers.

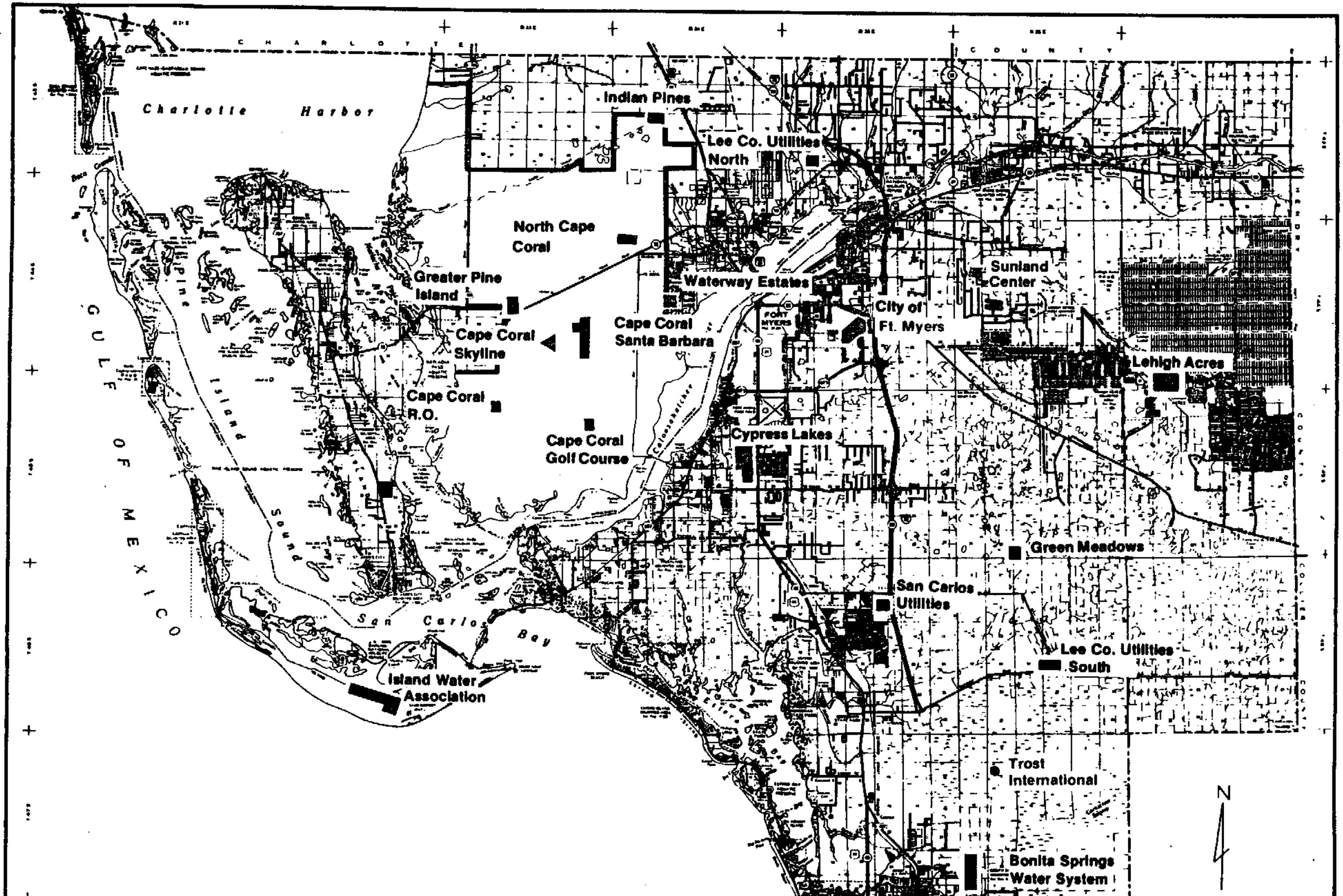
WATER LEVELS IN THE SURFICIAL AQUIFER

Plates 21 and 22 (Atlas) depict the water table elevations in the Surficial aquifer. The water table in an unconfined aquifer represents the upper limit of the zone of saturation. These maps were constructed using 28 data points distributed over an area of 786 square miles. This low density, and the uneven distribution of the points, did not allow for exact definition of the water table in all areas. In areas of sparse data, the contour lines are dashed to indicate uncertainty. Since the aquifer is largely unconfined and assumed to be in direct communication with surface water bodies, both the Caloosahatchee River and the Gulf of Mexico were treated as regional flow boundaries.

Configuration of Water Table

Both dry season and wet season water table maps exhibit similar patterns. The water table is an undulating surface generally conforming to the topography of the land. Thus, water level elevations are higher beneath areas of higher land elevation, and lower below areas of low elevation.

The Caloosahatchee River, which divides the area from northeast to southwest, and the Gulf of Mexico on the western side of the area, act principally



MUNICIPAL WELLFIELDS, LEE CO., FLORIDA

as regional groundwater discharge points. There are two major areas of high groundwater levels. One is in the north-central part of the county, in the vicinity of Telegraph Swamp, and the other is located in the east-central part of the county south of Lehigh Acres. From the north-central high, the water table slopes south and southwest towards discharge points in the Caloosahatchee River and the Gulf of Mexico. The slope of the water table from the east-central high is radially towards the Caloosahatchee River on the north and northwest and towards the Gulf of Mexico on the west and southwest.

Water level gradients are flattest in the east-central and southeastern parts of the area, and in the vicinity of Cape Coral. In these areas the gradient is between 0.5 and 1 foot per mile. Steeper gradients are found adjacent to Estero Bay. The steepest gradients are of the order of 20 feet per mile north of the Caloosahatchee River.

The changes in gradient may be a reflection of changes in thickness, and consequently, transmissivity of the aquifer. The aquifer thins south of the Caloosahatchee River in the Fort Myers area and south of Fort Myers between Fort Myers and Estero (See Plate 2, Atlas). This area coincides approximately with the area of steepest water table gradients. In areas where the aquifer is thicker, such as in the southeastern part of the county, groundwater gradients are significantly flatter.

The differences in levels during wet and dry seasons is illustrated on Figure 6. In the east-central part of the area, water levels were more than three (3) feet higher in the wet season than in the dry season during 1979. Around well L-954, northwest of Fort Myers, and well L-2195 in the Bonita Springs area, differences of 7.05 and 4.03 feet, respectively, occur. These are probably the result of higher pumpages during the dry season. Over most of the rest of the area the differences are between two and three feet and are fairly consistent.

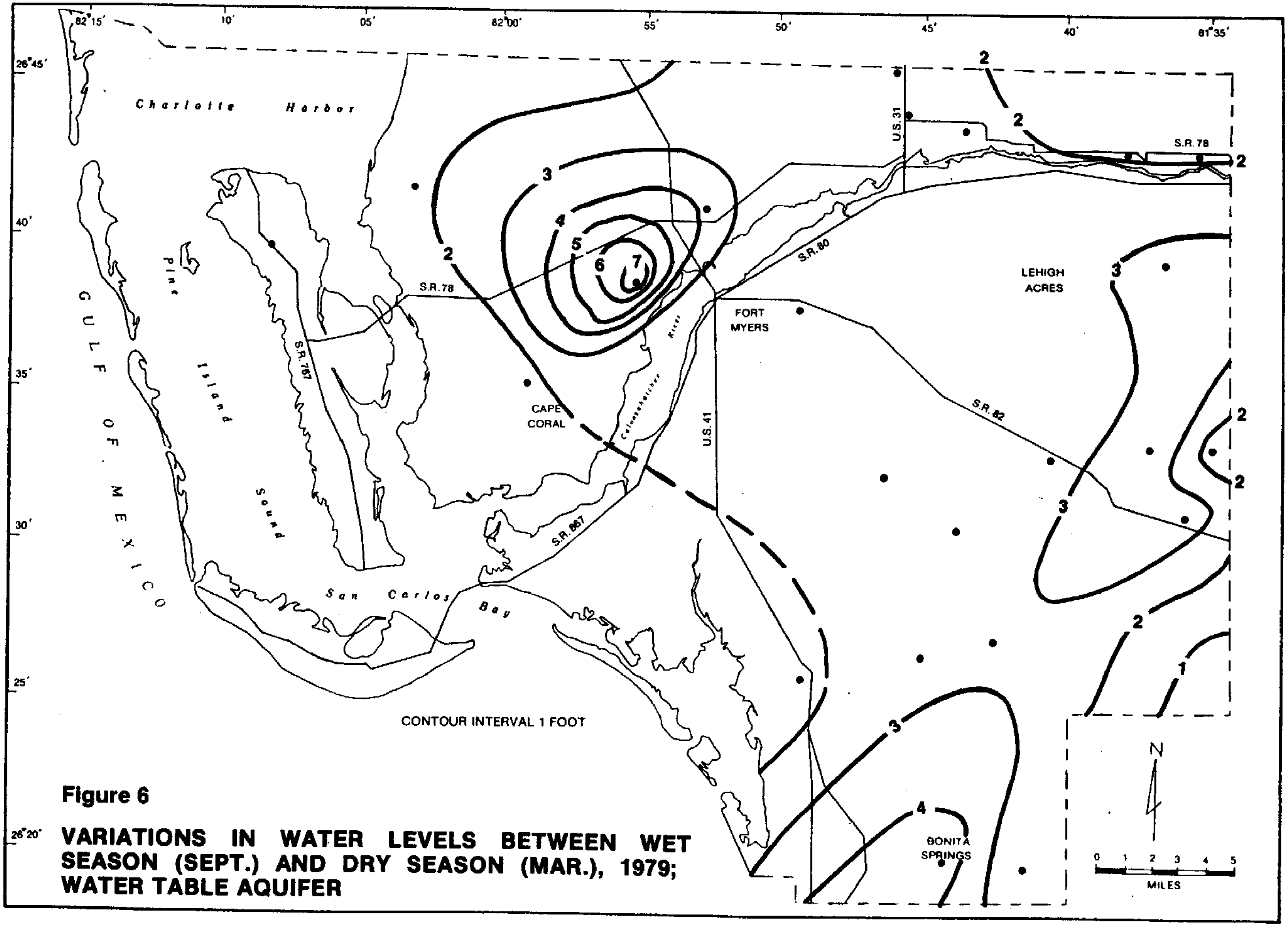


Figure 6

VARIATIONS IN WATER LEVELS BETWEEN WET SEASON (SEPT.) AND DRY SEASON (MAR.), 1979; WATER TABLE AQUIFER

Water Level Fluctuations

Figures 7, 8, 9, and 10 show hydrographs of wells L-730, L-1137, L-726, and L-954, respectively. In the Surficial aquifer, well L-730 is located in the area of high groundwater levels south of Lehigh Acres in the east-central part of the county. The hydrograph indicates water levels close to land surface (about 1-3 feet below land surface) during the wet season, and levels as much as eight (8) feet below land surface during some dry seasons. The pattern of high and low water levels is repeated fairly consistently each year. The water level in this well responds rapidly to rainfall. During the period October 1980 to February 1981, high water level conditions existed, followed by a gradual recession which terminated in July 1981. During August 1981, water levels rose rapidly and reached maximum levels which were essentially maintained through September 1981.

Well L-1137 is located about 12 miles north of well L-730. Its hydrographs are generally similar to those of well L-730 except for a generally smaller range of fluctuations and the slower groundwater recession with the onset of the dry season in February. Both the smaller range of fluctuations and the slower recession are probably due to close proximity to the Caloosahatchee River which acts as a regional boundary in the groundwater flow field and, consequently, tends to moderate changes in levels adjacent to it.

Well L-726 is located north of the Caloosahatchee River, nine miles northeast of Fort Myers. The long term hydrograph is similar to that of well L-1137. Annual water level fluctuations are similar in range to those in well L-1137, probably also reflecting the influence of the Caloosahatchee River. The annual hydrograph gives only end of month data, but indicates a narrow range of fluctuation (about 3 feet).

Well L-954 is located about four (4) miles northwest of Fort Myers, north of the Caloosahatchee River. The long term hydrograph shows a

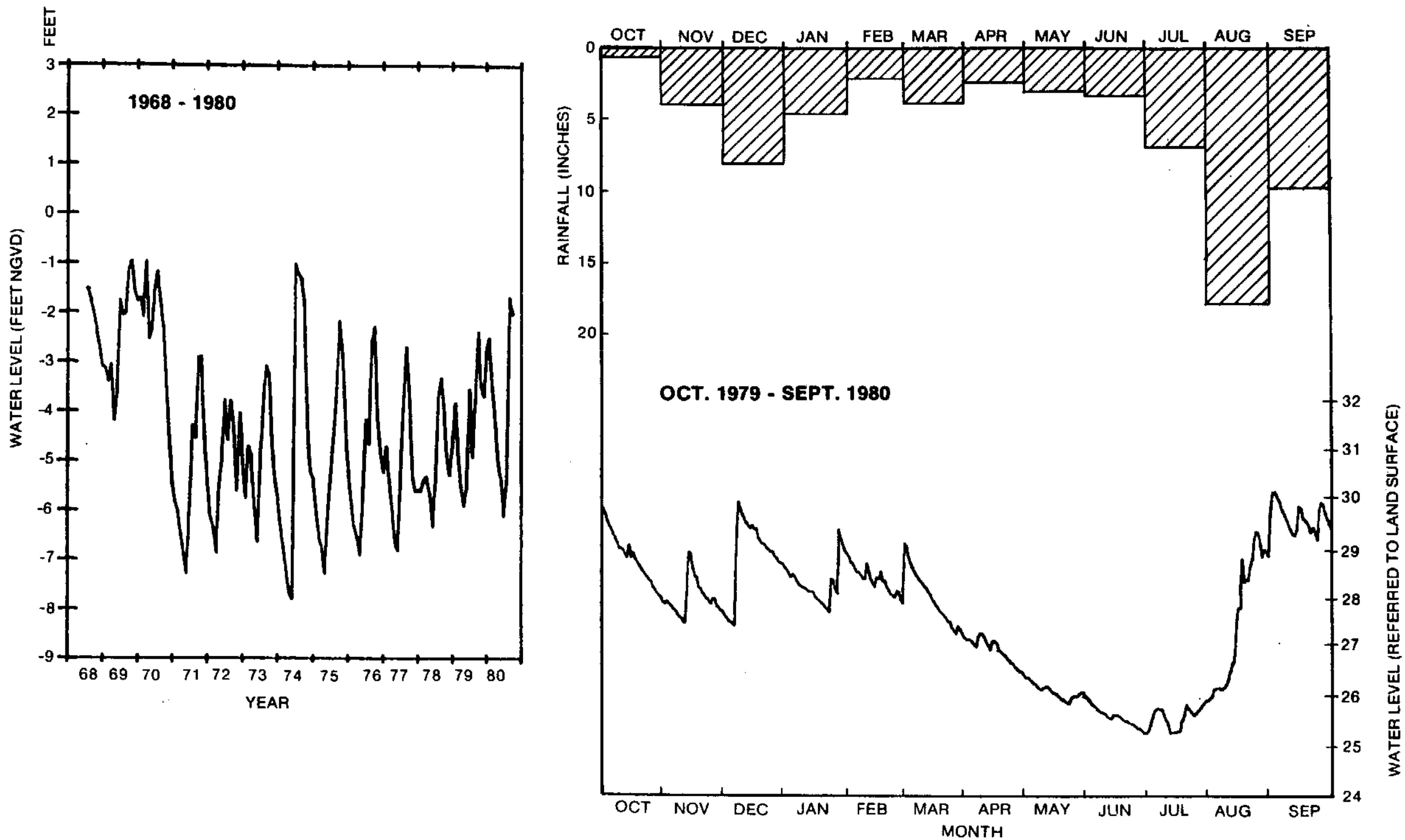


Figure 7 HYDROGRAPHS OF WELL L-730, SURFICIAL AQUIFER (COURTESY OF U.S. GEOLOGICAL SURVEY), AND MONTHLY RAINFALL AT STATION MRF 5001, LEE COUNTY

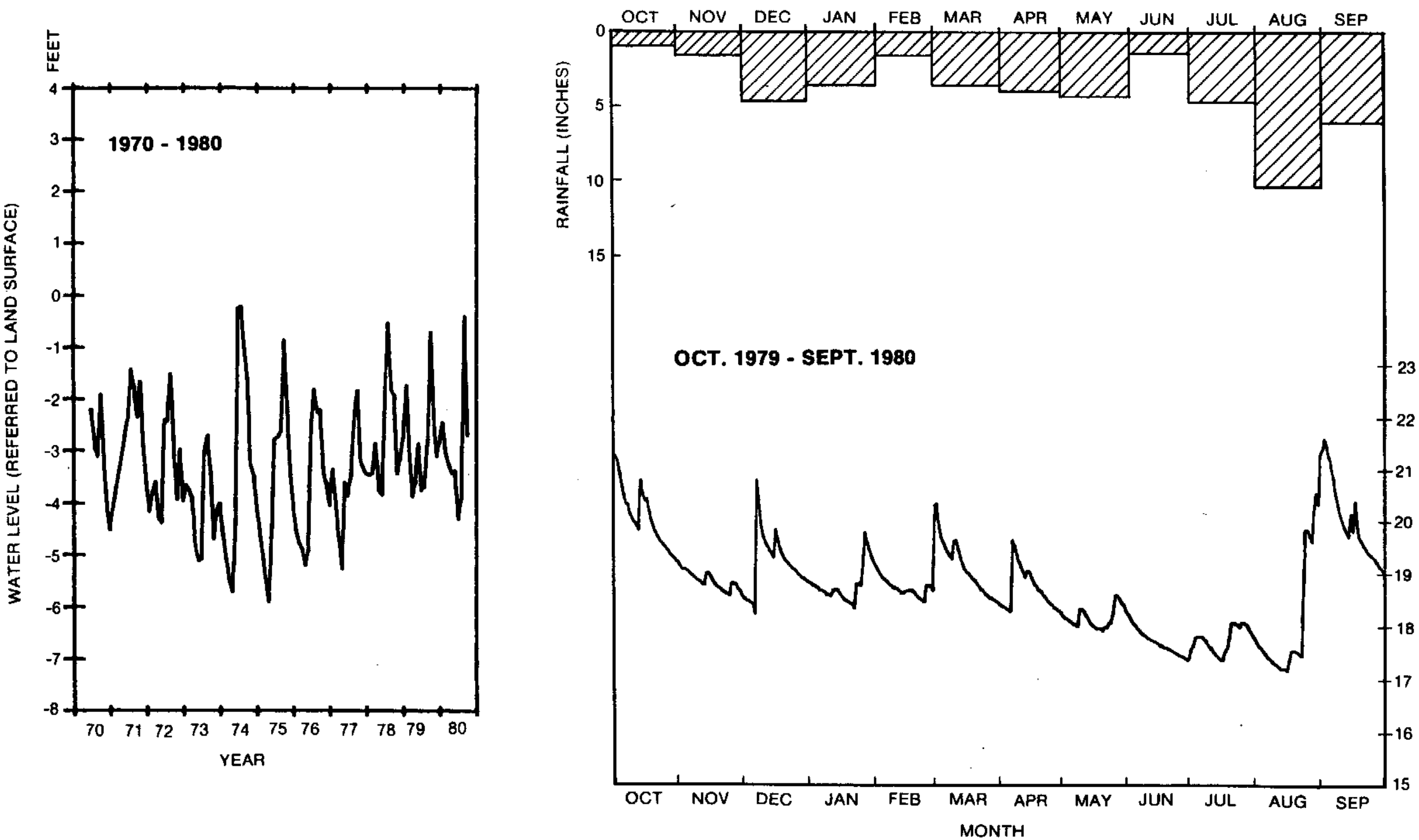


Figure 8 HYDROGRAPHS OF WELL L-1137, SURFICIAL AQUIFER (COURTESY OF U.S. GEOLOGICAL SURVEY) AND MONTHLY RAINFALL AT STATION MRF 206, LEE COUNTY.

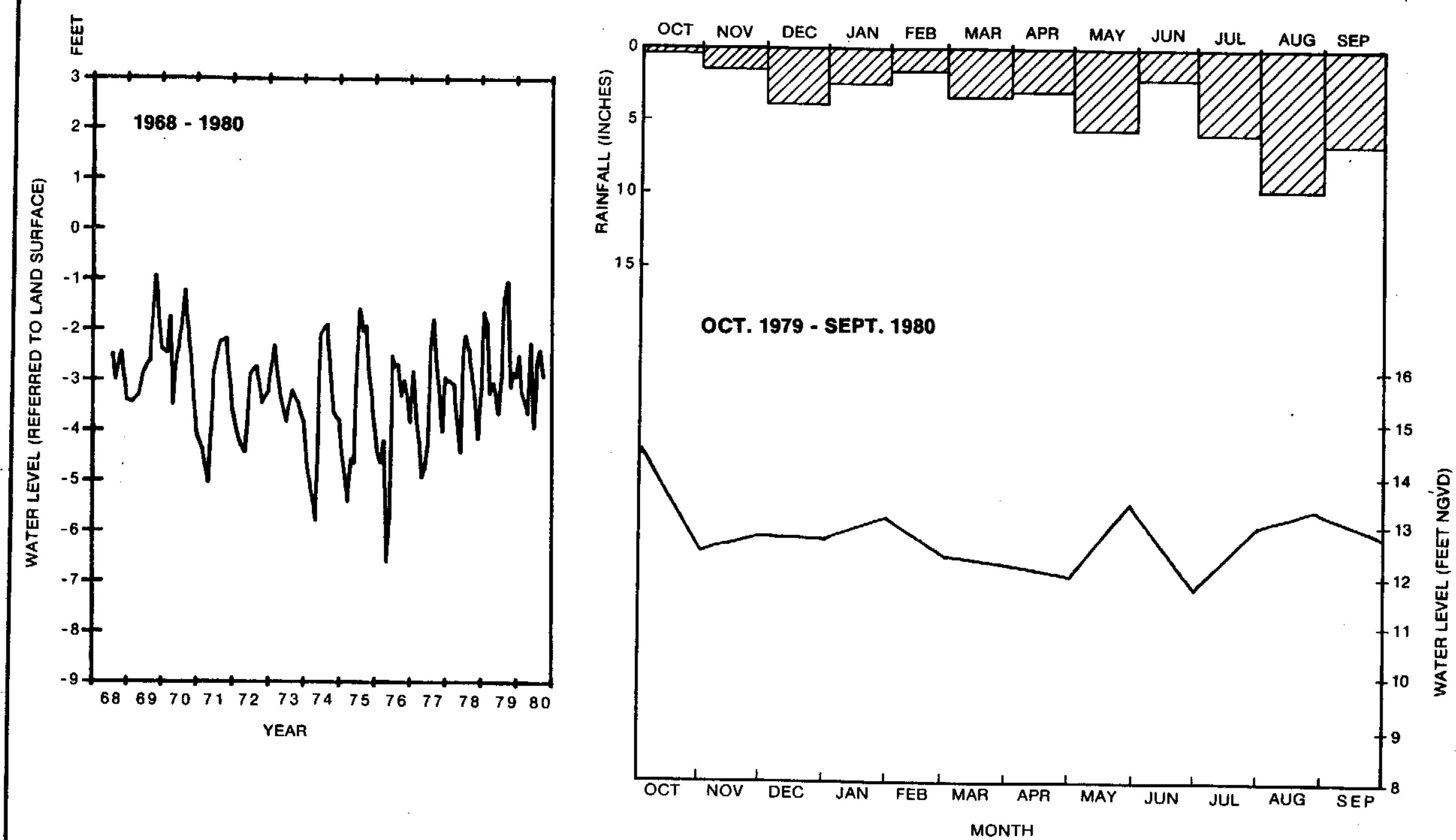


Figure 9 HYDROGRAPHS OF WELL L-726, SURFICIAL AQUIFER (COURTESY OF U.S. GEOLOGICAL SURVEY), AND MONTHLY RAINFALL AT STATION MRF 5004, LEE COUNTY

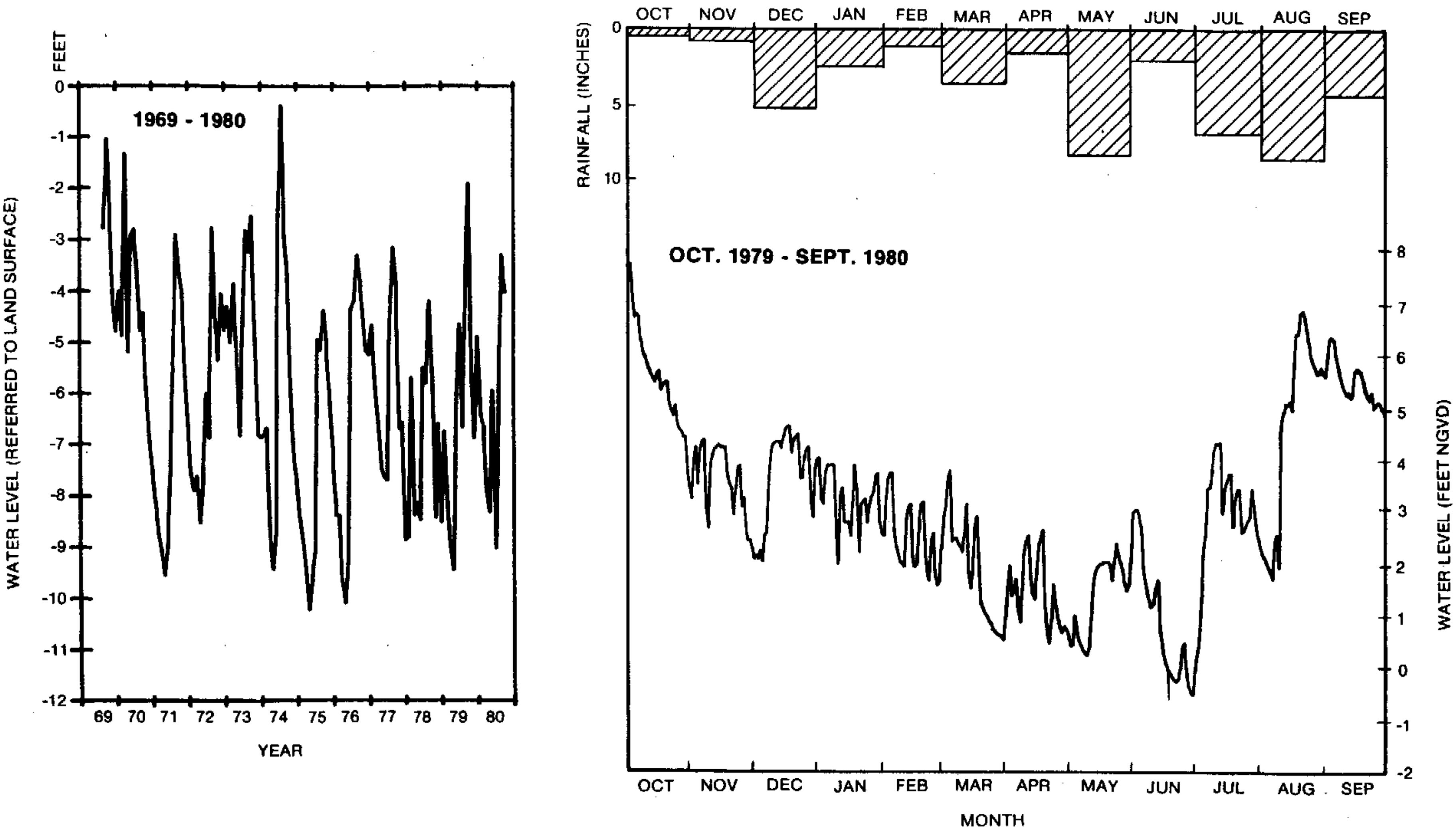


Figure 10 HYDROGRAPHS OF WELL L-954, SURFICIAL AQUIFER (COURTESY OF U.S. GEOLOGICAL SURVEY), AND MONTHLY RAINFALL AT STATION MRF 6093, LEE COUNTY

relatively wide range of annual fluctuations of water levels, the maximum shown being about 11 feet. The serrated appearance of the annual hydrograph is probably due to the effects of local pumpage.

The hydrographs indicate that wet season water levels in the Surficial aquifer are generally within 1 to 3 feet of the land surface. During the dry season, levels generally fall to 5 to 13 feet below land surface. While some of this fluctuation may be caused by pumpage, the greater portion is probably the result of natural recharge and discharge processes, including rainfall and evapotranspiration.

Long term water level trends as shown by the long term hydrographs are generally similar throughout the aquifer. All the hydrographs show relatively high average water levels prior to 1969, a general decline in water levels between 1970 and 1974, and a gradual recovery of water levels thereafter. The 1970 to 1971 drought is clearly shown on all hydrographs except that of well L-1137. All four hydrographs show a rapid rise in water levels in mid-1974 as a result of high rainfall (34 inches) in May, June, and July of 1974 following a period of low rainfall during the early part of the rainy season (Boggess and Missimer, 1976; Missimer and O'Donnell, 1976). The long term trends shown on these hydrographs are therefore mainly a reflection of rainfall conditions during this period, with differences reflecting local effects such as pumpage or location of the wells in the hydrologic system.

Recharge

There are four likely modes of recharge to the Surficial aquifer in Lee County. These are: (a) direct infiltration of precipitation; (b) inflow from surface water bodies; (c) subsurface inflow from adjacent areas; and (d) upward leakage of water from underlying semi-confined aquifers.

Direct infiltration of precipitation is believed to be the major source of recharge to the aquifer. Evidence for this is given by the generally higher water levels throughout the area during the wet season (when rainfall is highest) and by the rapid response of the hydrographs to rainfall. The surficial material comprising the aquifer consists of medium to fine quartz sands associated with terrace deposits. This type of material allows free infiltration of water. The absence of a well developed surface drainage network indicates that direct runoff is low, and that much of the rainfall over the area is available for infiltration and percolation to the water table.

Average annual rainfall over Lee County varies from less than 48 inches in the northwest to more than 68 inches in the southwest (Figure 11). Approximately 70% of the total annual rainfall occurs during the wet season (June to September) (Missimer and Boggess, 1974). Much of this water is lost by direct evaporation and transpiration by plants.

Although recharge through infiltration takes place throughout the county, an area in the east central part (see Plates 21 and 22, Atlas) bordering SR 82, is of particular significance. This is the area of highest water levels, from which flow originates to much of central and southern Lee County and is characterized by shallow lakes and swamps which pond water and increase infiltration potential. It is suggested that development in Lee County should be planned to preserve portions of this area as a natural regional recharge area for the aquifer.

The Surficial aquifer in Lee County also receives recharge through inflow from adjacent areas. South of the Caloosahatchee River, the shape of the groundwater elevation contour lines indicates that there is little subsurface inflow to the aquifer. The 25 foot elevation contour, which is almost closed, indicates flow away from this area. North of the river, however, the contours

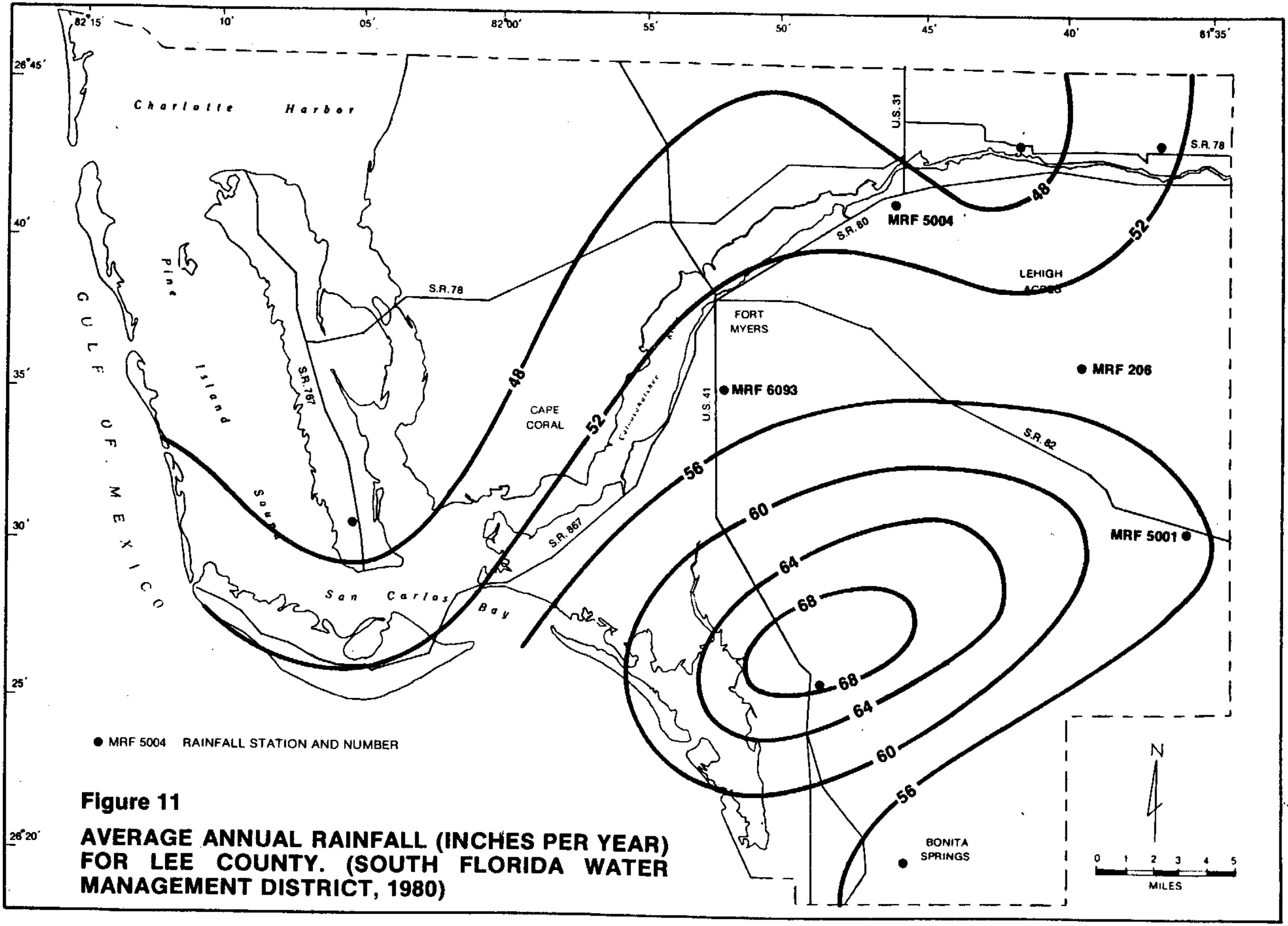


Figure 11

AVERAGE ANNUAL RAINFALL (INCHES PER YEAR) FOR LEE COUNTY. (SOUTH FLORIDA WATER MANAGEMENT DISTRICT, 1980)

run sub-parallel to the county line, indicating movement of water from the north (Telegraph Swamp) into Lee County.

A third source of recharge to the Surficial aquifer is surface water bodies such as canals, lakes, rockpits, the Caloosahatchee River and the Gulf of Mexico. While these surface water bodies may act as recharge sources when their water levels exceed the groundwater levels, the generally high groundwater levels compared to ground surface elevation suggest that the opposite effect is more frequent.

Aquifer hydraulic gradients, both during the dry season and during the wet season, are toward the major surface water bodies (the Caloosahatchee River and the Gulf of Mexico), which act as regional base levels. However, during high tides, hurricanes, or other high rainfall events, the possibility of gradient reversals from these surface water bodies exists.

Where the aquifer is in contact with saline water sources (bays, estuaries, sounds, or the Gulf) a saltwater/freshwater interface exists inland within the aquifer. The penetration of saline water into the aquifer is due to the higher density of the saline water. A dynamic equilibrium is maintained between the fresh water and the saline water. The interface changes position depending on the head difference between the waters of different densities. In addition to the natural variations due to rainfall, tidal movement, and natural groundwater losses, changes in the interface may also be induced by local or regional pumpage.

Upward leakage of water to the Surficial aquifer may occur where an underlying aquifer, separated by a leaky confining bed exists, and the potentiometric level in this aquifer is higher than the water table elevation in the Surficial aquifer. Over most of the county the Surficial aquifer is underlain by the Sandstone aquifer or the mid-Hawthorn aquifer, and separated from these by semi-confining strata. Although the mid-Hawthorn aquifer in the area has higher potentiometric levels than the water table elevation, the confining beds separating the two are usually of very low permeability and upward leakage is considered minimal. The water table has generally higher elevations than the Sandstone aquifer, and although the confining beds are more permeable, the downward hydraulic gradient generally prevents recharge from this source. However, local recharge may occur when pumpage lowers the water level below the potentiometric level of the Sandstone aquifer. Near the Caloosahatchee River, the Sandstone aquifer potentiometric levels are higher than the water table, indicating the possibility of recharge from the Sandstone aquifer.

Discharge

Groundwater is discharged from the Surficial aquifer in Lee County by flow into streams, springs, and lakes; by direct flow into the Gulf of Mexico or the various bays and sounds; by evapotranspiration; by downward leakage into underlying semi-confined aquifers; by subsurface outflow to adjacent areas; and by pumping from wells.

The Caloosahatchee River is a major discharge area for groundwater. The water table elevation maps (Plates 21 and 22, Atlas) indicate gradients toward the river from the north, northwest, south, and east during both wet and dry seasons. The groundwater discharged to the river is lost either through outflow to San Carlos Bay or through evaporation. Since the longest section of contour lines parallel the river, it is assumed that this is the major source of outflow from the aquifer.

In the northwest and southwest parts of the county, contour lines parallel the coast and the groundwater gradient indicates outflow to the Bays and the Gulf of Mexico. Groundwater which flows towards these salt water bodies is expected to entrain saline water along the saltwater/freshwater interface, thus creating a zone of mixing or a zone of brackish water (Cooper, et al., 1964).

Evapotranspiration is a major source of water loss from the aquifer. Evapotranspiration losses are a combination of losses due to evaporation and losses due to transpiration of water by plants. In Lee County, annual average potential evaporation rates from open water bodies exceed average annual rainfall. This is because south Florida has a sub-tropical climate with a large number of cloudless days and relatively high temperatures. Lee County and adjacent areas lose from 2 to 4 inches of water per month due to evaporation (South Florida Water Management District, 1980).

Downward leakage of water from the Surficial aquifer occurs when a semi-confining bed separates the aquifer from underlying aquifers, and the water table elevation is higher than the potentiometric surface in the underlying aquifer. In some parts of Lee County, notably in the east-central area, this condition exists where the Surficial aquifer overlies the Sandstone aquifer. The differences in hydraulic heads between the two aquifers do not exceed 5 feet, and although the intervening confining strata are considered moderately permeable, losses due to downward leakage are probably of less importance than other losses from the aquifer.

Subsurface discharge from the study area to adjacent areas occurs where flow lines (drawn at right angles to elevation contours) cross the boundary of the study area. Only two possible areas of subsurface outflow are shown on the water table maps. These are located along the Collier County/Lee County boundary south and southeast of the area. Since flow towards these areas originated from only a small section of Lee County, it is concluded that subsurface outflow to adjacent areas is not a significant factor in losses from the Surficial aquifer.

Water is withdrawn from the Surficial aquifer in Lee County for municipal, agricultural, recreational, mining, dewatering, and industrial uses. Some of this water is returned to the aquifer after use. No reliable estimate of withdrawal for consumptive use of water from this aquifer is available. The water table contour maps show noticeable effects of pumpage northeast of Fort Myers in the vicinity of the Florida Cities Water Company's Waterway Estates wellfield, and in the Bonita Springs area.

POTENTIOMETRIC LEVELS IN THE SANDSTONE AQUIFER

Plates 23 and 24 (Atlas) show the potentiometric surface in the Sandstone aquifer. This aquifer is semi-confined, and the potentiometric levels represent the levels to which water would rise in tightly cased wells which are open to this aquifer only. The maps were constructed using 27 data points distributed throughout the central and eastern portions of the aquifer. The areal extent of the aquifer is about 1/3 less than the total area of the county, as the aquifer is absent in some areas. Data coverage along the western edge of the aquifer was inadequate to complete the five foot contour line in this area.

Configuration of the Potentiometric Surface

In most parts of the county, the potentiometric surface of the Sandstone aquifer is at a lower elevation than the water table in the Surficial aquifer indicating a downward hydraulic gradient. The potentiometric surface contours generally follow the configuration of the water table elevation contours. Highest elevations occur in the east-central part of the county, south of Lehigh Acres, and in the north-central portion of the county along the Charlotte County boundary. From the east-central high, the gradient is radially toward the Caloosahatchee River and the Gulf of Mexico. From the northeastern high the gradient is south and southwest toward the river and Charlotte Harbour.

An area of low potentiometric levels parallels the Caloosahatchee River and corresponds with a similar low in the water table elevations. Since the Sandstone aquifer does not discharge directly to the river, it is likely that this low is created by upward leakage of water from the Sandstone aquifer to the Surficial aquifer. In this area the potentiometric surface of the Sandstone aquifer is higher than the water table elevation. While the water table contours in this area parallel the river, the 10 foot potentiometric surface contour crosses the river east of Fort Myers. The higher levels in this area are probably due to the fact that the Sandstone aquifer pinches out in the western part of Lee County (see Plate 6, Atlas), and thus a barrier to groundwater flow is created. The Sandstone aquifer probably does not discharge significant quantities of water into the Gulf of Mexico.

Gradients are relatively low in the Sandstone aquifer compared to the Surficial aquifer. South of the Caloosahatchee River the average gradients are approximately 1 foot per mile. North of the river the average gradients are about 2.5 feet per mile. The difference in gradients probably reflects lower transmissivities north of the river.

The major differences between the potentiometric surface elevations during the wet season as compared to the dry season are the generally higher levels during the wet season, and the presence of pumping depressions during the dry season east of Estero and in the vicinity of Bonita Springs. The first depression in the vicinity of wells L-1988 and L-1853 is located near the Florida Cities Water Company's Green Meadows wellfield which withdraws water from both the Sandstone and mid-Hawthorn aquifers. The lower levels in the Bonita Springs area are probably also related to pumpage from the Bonita Springs wellfield.

Figure 12 presents the variations in potentiometric levels between wet and dry seasons during 1979 in greater detail. The general pattern is one of higher fluctuations (about 5 feet) in the eastern and southeastern parts of the county, gradually declining to about 1 foot in the vicinity of the Caloosahatchee River or close to the edge of the aquifer. Four areas of major changes which depart from this pattern are shown. The maximum variation of 20.92 feet occurs at well L-1998. This well is located in the vicinity of the Florida Cities Water Company's wellfield at Green Meadows. Another large variation of 8.76 feet occurs around well L-2194. This depression is influenced by pumpage from the Bonita Springs wellfield which withdraws water from this aquifer. A potentiometric level variation of 10.05 feet occurs on the southeastern border of the county in the vicinity of well L-731. This variation is probably related to agricultural pumpage. The fourth major variation (4.96 feet) occurs north of Fort Myers around well L-2190. This appears to be related to pumpages from the Surficial aquifer in the nearby Florida Cities Water Company's Waterway Estates wellfield. Lowering of the water table in the Surficial aquifer, by pumpage, increases the head differential between this aquifer and the Sandstone aquifer, thus increasing upward leakage and consequently increasing drawdowns in the Sandstone aquifer.

Water Level Fluctuations

The potentiometric surface in a confined or semi-confined aquifer fluctuates in response to recharge, discharge from wells, variations in barometric pressure, and other short term factors such as earthquakes, tides, and passing trains (Parker and Stringfield, 1950, pp 441-460). The changes due to barometric pressure, earthquakes, tides, and passing trains are of short duration and consequently of minor interest in regional groundwater assessments.

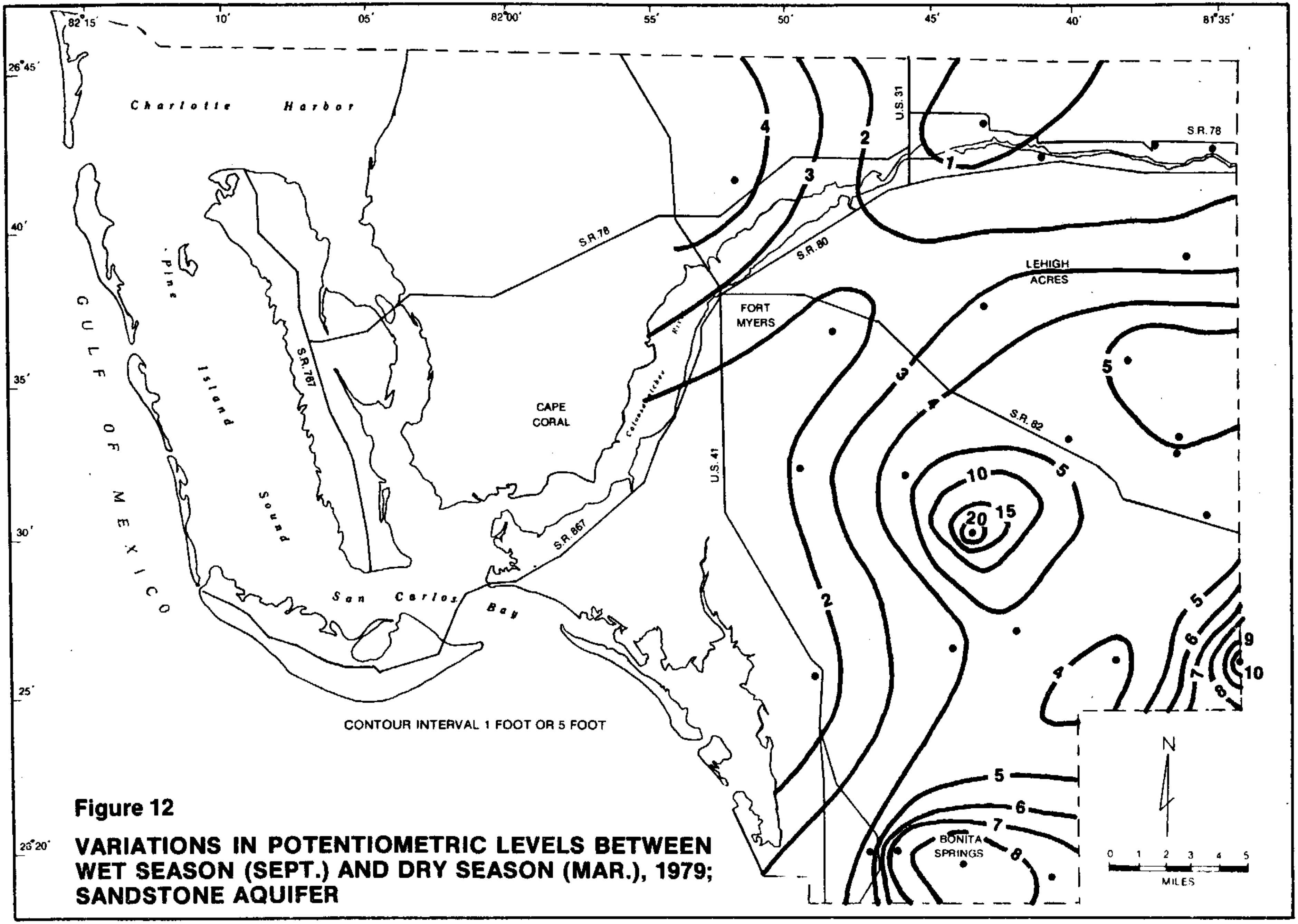


Figure 12

VARIATIONS IN POTENTIOMETRIC LEVELS BETWEEN WET SEASON (SEPT.) AND DRY SEASON (MAR.), 1979; SANDSTONE AQUIFER

Figures 13, 14, 15, and 16 show hydrographs of wells L-729, L-1975, L-738, and L-1853, respectively, in the Sandstone aquifer.

Well L-729 is located in the area of high potentiometric levels in the east-central part of the county. The long term hydrograph shows maximum levels of approximately 3 feet below land surface, and minimum levels of about 11 feet below land surface during the period of record (1968-1980). A well defined pattern of potentiometric level fluctuation between dry and wet seasons of each year is also indicated. The short term hydrograph (October 1980 to September 1981) shows high water levels during the months of high rainfall and a gradual recession of water levels to the end of the dry season. Overall, there is a great deal of similarity between these hydrographs and those for well L-730 located in the same general area in the Surficial aquifer.

The long term hydrograph of well L-1975, which is located in the area of low potentiometric levels adjacent to the Caloosahatchee River, shows relatively small seasonal variations compared to the hydrographs of well L-730. Potentiometric levels in this well are generally above land surface except during extremely dry periods. The levels are also generally above the water table elevation in this area, as is shown by a comparison with the hydrograph of well L-726. The short term hydrograph (October 1980 to September 1981) of well L-1975 is constructed from end-of-month data and does not show much detail. However, it confirms the generally small range of annual fluctuation and the seasonal pattern of high and low water levels.

Well L-1853 is located in the south-central part of the county between the area of high water levels and the coast. It is within the potentiometric surface depression shown on Plate 23 (Atlas). The long term hydrograph of this well shows wide variations in levels between wet and dry seasons. Some

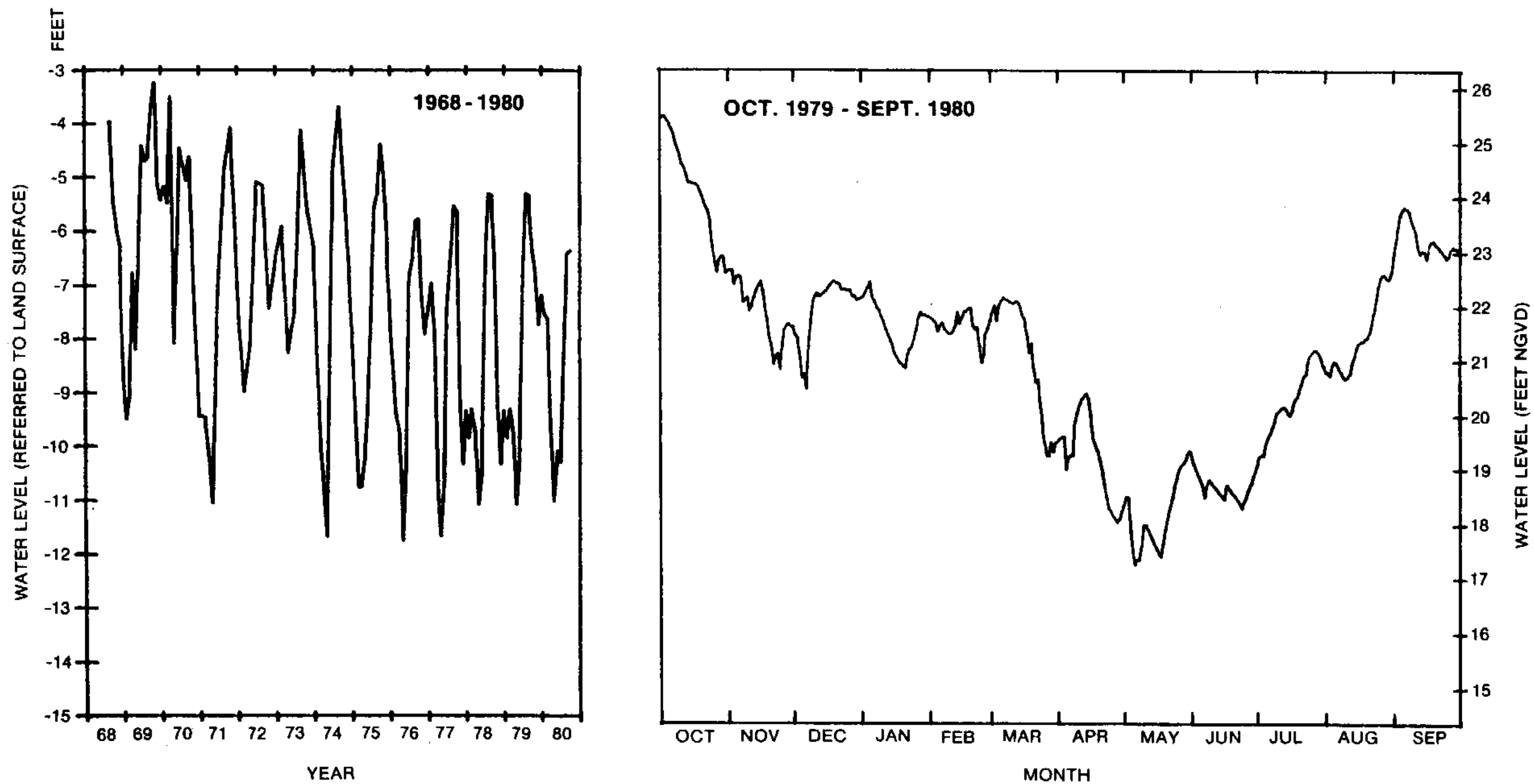


Figure 13 HYDROGRAPHS OF WELL L-729, SANDSTONE AQUIFER, LEE COUNTY (COURTESY OF U.S. GEOLOGICAL SURVEY)

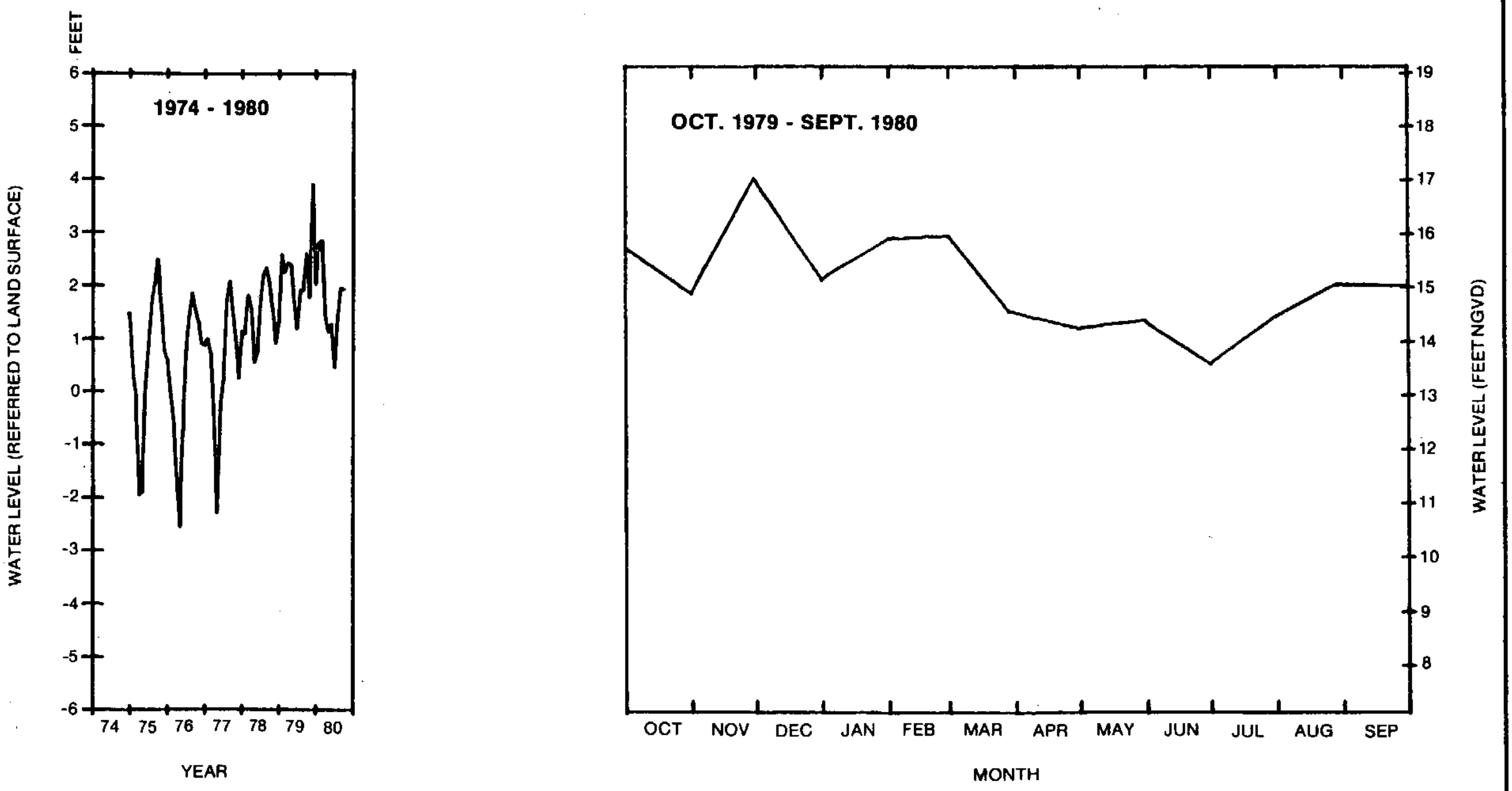


Figure 14 HYDROGRAPHS OF WELL L-1975, SANDSTONE AQUIFER, LEE COUNTY (COURTESY OF U.S. GEOLOGICAL SURVEY)

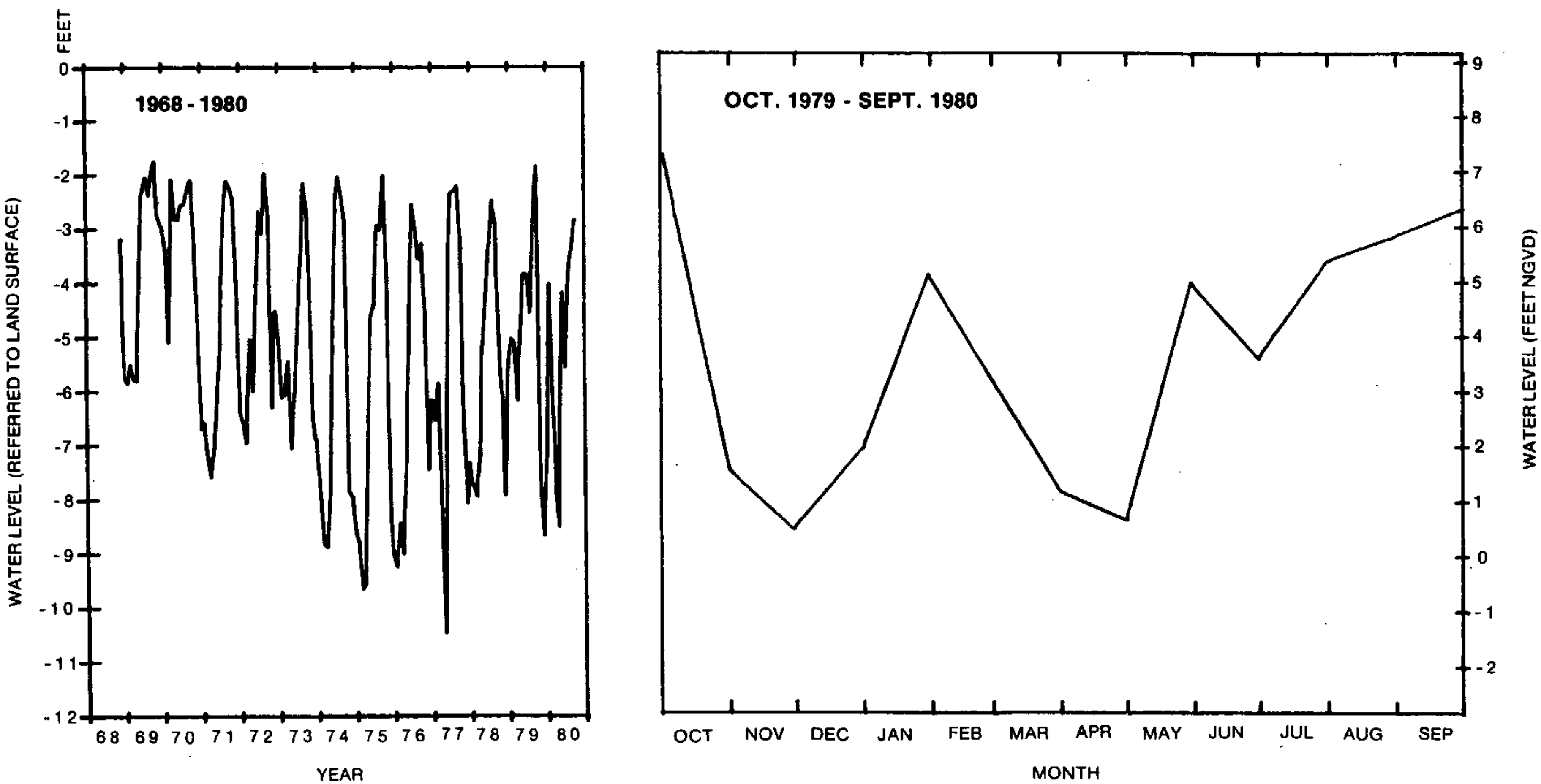


Figure 15 HYDROGRAPHS OF WELL L-738, SANDSTONE AQUIFER, LEE COUNTY (COURTESY OF U.S. GEOLOGICAL SURVEY)

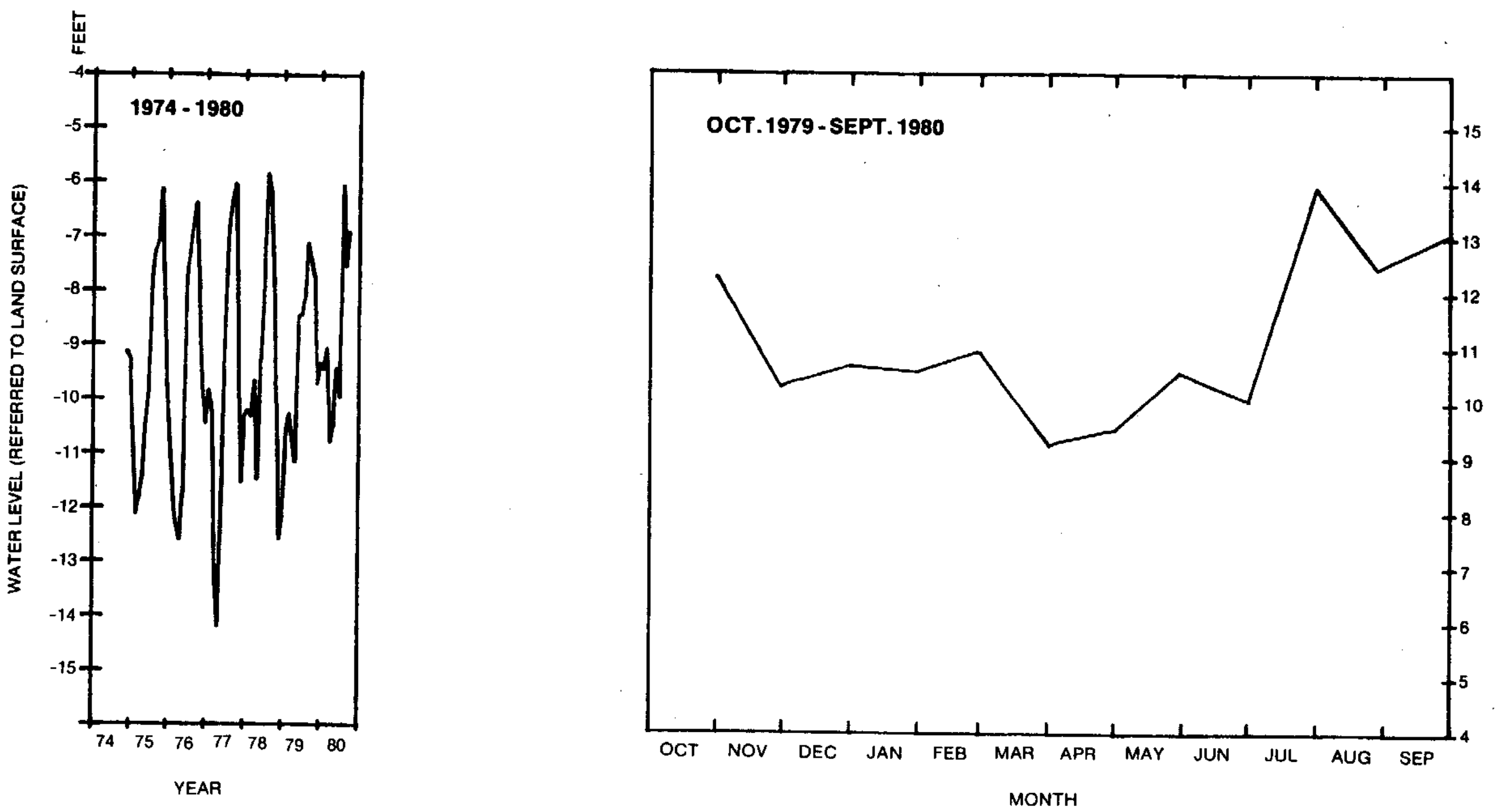


Figure 16 HYDROGRAPHS OF WELL L-1853, SANDSTONE AQUIFER, LEE COUNTY (COURTESY OF U.S. GEOLOGICAL SURVEY)

of this variation is probably a reflection of nearby pumping patterns. The water levels are generally at greater depth below the surface during both wet and dry seasons, compared to the other wells. The hydrograph for the water year October 1979 to September 1980 shows relatively high levels in August and September, but relatively low levels during the period November to February when water levels would normally be expected to be high. This is probably a reflection of pumpages in nearby wells tapping the Sandstone aquifer.

The long term hydrograph of well L-738, which is located in southern Lee County in the vicinity of Bonita Springs, shows relatively wide seasonal variations in potentiometric levels (a maximum of about 9 feet in 1977). Potentiometric levels remain fairly constant at about 2 feet below land surface during maximum levels, but minimum levels vary from 6 feet below land surface to 11 feet below land surface. The levels in the Sandstone aquifer are approximately the same as those of the Surficial aquifer at the end of the wet season, but the dry season levels are substantially lower, indicating greater effects of pumpage during that time.

The short term hydrograph (October 1980 to September 1981) for this well shows significant drawdowns during November and December 1980 and February and March 1981. This is probably a reflection of pumping patterns in adjacent sandstone wells. These drawdowns modify the usual pattern of a gradual recession during the period October to May.

Long term water level trends are generally similar for all 4 hydrographs. They indicate a period of relatively high average potentiometric levels between 1968 and 1973, followed by a period of lower average water levels between 1974 and 1977,and a gradual recovery subsequent to 1977. During the periods 1968 to 1973 and subsequent to 1977, the annual range of fluctuation is signficantly less than during the period 1974 to 1977. Minimum levels over the period of record are consistently shown in 1977. This general pattern reflects variations in levels in the overlying Surficial aquifer which are a result of rainfall patterns.

Based on these hydrographs, it may be concluded that no significant regional potentiometric level changes have taken place in the aquifer over the last decade as a result of withdrawals from the aquifer.

Recharge

Recharge to the Sandstone aquifer in Lee County may occur where the permeable rocks that constitute the aquifer are at or near the surface; where the aquifer is overlain or underlain by aquifers with higher water levels or potentiometric levels and is separated from these by semi-permeable confining beds; or by subsurface inflow from adjacent areas.

The Sandstone aquifer does not crop out in Lee County (see Plate 5, Atlas), consequently no direct recharge from rainfall occurs in the study area. The major recharge to the aquifer comes from downward leakage from the Surficial aquifer. Except for the area bordering the Caloosahatchee River, water levels in the Surficial aquifer are generally higher than potentiometric levels in the Sandstone aquifer. The intervening confining bed between these two aquifers is considered to have sufficient permeability to allow leakage. This conclusion is supported by the general correspondence in shape between hydrographs in adjacent wells in both aquifers. Head differences between the two aquifers are moderate (generally less than 5 feet) indicating that some hydraulic communication does exist between the two aquifers.

The major area of recharge to the Sandstone aquifer is in the east-central part of the county, south of Lehigh Acres. This area corresponds to the area of high water levels in the Surficial aquifer.

Although the underlying mid-Hawthorn aquifer also has higher potentiometric levels than the Sandstone aquifer, upward leakage from this aquifer is considered to be minimal due to the better confining properties of the rocks overlying the mid-Hawthorn aquifer.

Subsurface inflow to the Sandstone aquifer in Lee County mainly occurs along the northeastern boundary of the area. In this area the potentiometric surface contours parallel the county line. The source of this water which flows into Lee County may be leakage from the Surficial aquifer outside of the county or direct rainfall recharge originating in areas north of Lee County where the aquifer crops out.

Discharge

Discharge from the Sandstone aquifer in Lee County may occur through leakage to overlying or underlying aquifers where the potentiometric levels in the aquifer are higher than the water levels or potentiometric levels in the adjacent aquifer, and the aquifer is separated from the adjacent aquifers by a semi-confining bed. Discharge may also take place through subsurface outflow or pumpage.

Water is discharged from the aquifer through upward leakage to the Surficial aquifer in the area adjacent to the Caloosahatchee River. In this area, potentiometric levels in the Sandstone aquifer may be as much as 10 feet higher than water levels in the Surficial aquifer. The Sandstone aquifer is separated from the Caloosahatchee River by a semi-confining bed and the Surficial aquifer, thus there is no direct discharge of water from the aquifer to the river.

Although there is a potentiometric gradient toward the west, it is unlikely that significant outflow to the Gulf of Mexico occurs since the aquifer pinches out in western Lee County (see Plate 6, Atlas). The potentiometric contours also indicate that there are no significant areas of subsurface outflow to adjacent areas.

Pumpage represents an important source of discharge from the aquifer. The dry season potentiometric contour map shows two depressions in the southern and south-central parts of the county. The depression around wells L-1998 and L-1852 is related principally to pumpages from the Florida Cities Water Company's Green Meadows wellfield which withdraws water from both the Sandstone and the mid-Hawthorn aquifers. The second depression around wells L-738, L-1691, and L-2194 is probably related to pumpages from the Bonita Springs wellfield.

POTENTIOMETRIC LEVELS IN THE MID-HAWTHORN AQUIFER

Potentiometric surfaces at the end of the dry season and at the end of the wet season for the mid-Hawthorn aquifer are depicted on Plates 25 and 26 (Atlas). The mid-Hawthorn aquifer is confined above and below by low permeability beds, and the potentiometric levels represent the levels to which water would rise in tightly cased wells open to this aquifer only. Thirty-one (31) data points over an area of 786 square miles were used to construct these maps. However, the data points are concentrated in the western part of the county (Cape Coral area) and coverage in other areas is generally poor. In areas of sparse data, the contour lines are broken to indicate uncertainty. In the eastern and northeastern sections of the county, no contours were drawn due to lack of data, although the aquifer is present in these areas.

Configuration of the Potentiometric Surface

Over most of the county, the potentiometric surface of the mid-Hawthorn aquifer is above the land surface, creating flowing artesian conditions in wells which penetrate it. In areas where the potentiometric surface is below land elevation, the decline in levels is generally caused by pumpage from the aquifer.

The contours indicate that the natural potentiometric gradient is from east to west or from northeast to southwest. The natural gradient appears to be about 2.5 - 3 feet per mile.

Highest potentiometric levels are found in the eastern and northeastern parts of the county. In these areas the levels may be as much as 10-15 feet above land elevation. The direction of slope of the potentiometric surface of this aquifer differs from that of the previously discussed aquifers (the Surficial and Sandstone aquifers). The difference appears to be related mainly to the direct or indirect effects of the Caloosahatchee River on the flow regimes in the Surficial and Sandstone aquifers, and also possibly to the source of recharge to the aquifers. The flexure of the contour lines across and to the north of the river may be caused by withdrawals from the aquifer in the north Cape Coral region. The regional potentiometric surface gradient is towards the Gulf of Mexico.

A major feature of the potentiometric surface maps is the large depression in the Cape Coral area. Potentiometric levels in this area may be more than 20 feet below NGVD (National Geodetic Vertical Datum of 1929). This depression encompasses the Greater Pine Island, Cape Coral, Skyline, Santa Barbara, and Florida Cities Water Company's Waterway Estates wellfields (Figure 5), all of which produce water from the mid-Hawthorn aquifer. In addition, hundreds of wells for golf courses and domestic (lawn sprinkling) irrigation purposes which withdraw water from this aquifer are located within this depression.

Another deeper depression in the potentiometric surface is located around well L-742 in south Fort Myers, south and east of the Caloosahatchee River. In this depression the potentiometric level is below -60 NGVD. This depression is near the Florida Cities Water Company's Cypress Lake wellfield. The two depressions have coalesced, indicating overlapping drawdowns.

Reconstruction of the contour lines to omit the effects of these depressions would suggest that the contour lines ran in a northwest to southeast direction, prior to initiation of pumpage. For example, the 10 foot contour line probably paralleled the coast south of the depression and continued west of Pine Island. The contours have been shifted a considerable distance to the east in the Cape Coral/Fort Myers area, due to pumpage.

The main difference between the potentiometric surface for wet and dry seasons is the deepening of the depressions during the dry season. Outside of the depressions (approximately the 10 foot contour line) variations in potentiometric levels between wet and dry seasons are slight. Figure 17 shows in greater detail the variations in potentiometric levels between wet and dry season. The large variations in the Cape Coral, Fort Myers, and south Fort Myers areas are clearly shown. These represent higher pumpages from the mid-Hawthorn aquifer for municipal and irrigation use during the dry season.

Potentiometric Level Fluctuations

Long term and short term fluctuations in potentiometric levels in the mid-Hawthorn aquifer are illustrated in Figures 18, 19, 20, and 21. Wells L-735 and L-1059 are located outside the main pumping depressions, in the southwest and northwest parts of the area, respectively. Well L-742 is located in the center of the deepest depresseion.

Well L-1059 probably most clearly represents non-pumping conditions in the aquifer, as it is located about 7 miles from the pumping depression. The long term hydrograph (1970-1980) shows maximum water levels of about 7 feet above land surface, and relatively small seasonal variations of 1 to 3 feet. The annual hydrograph (October 1979 to September 1980) shows a relatively constant water level throughout the year.

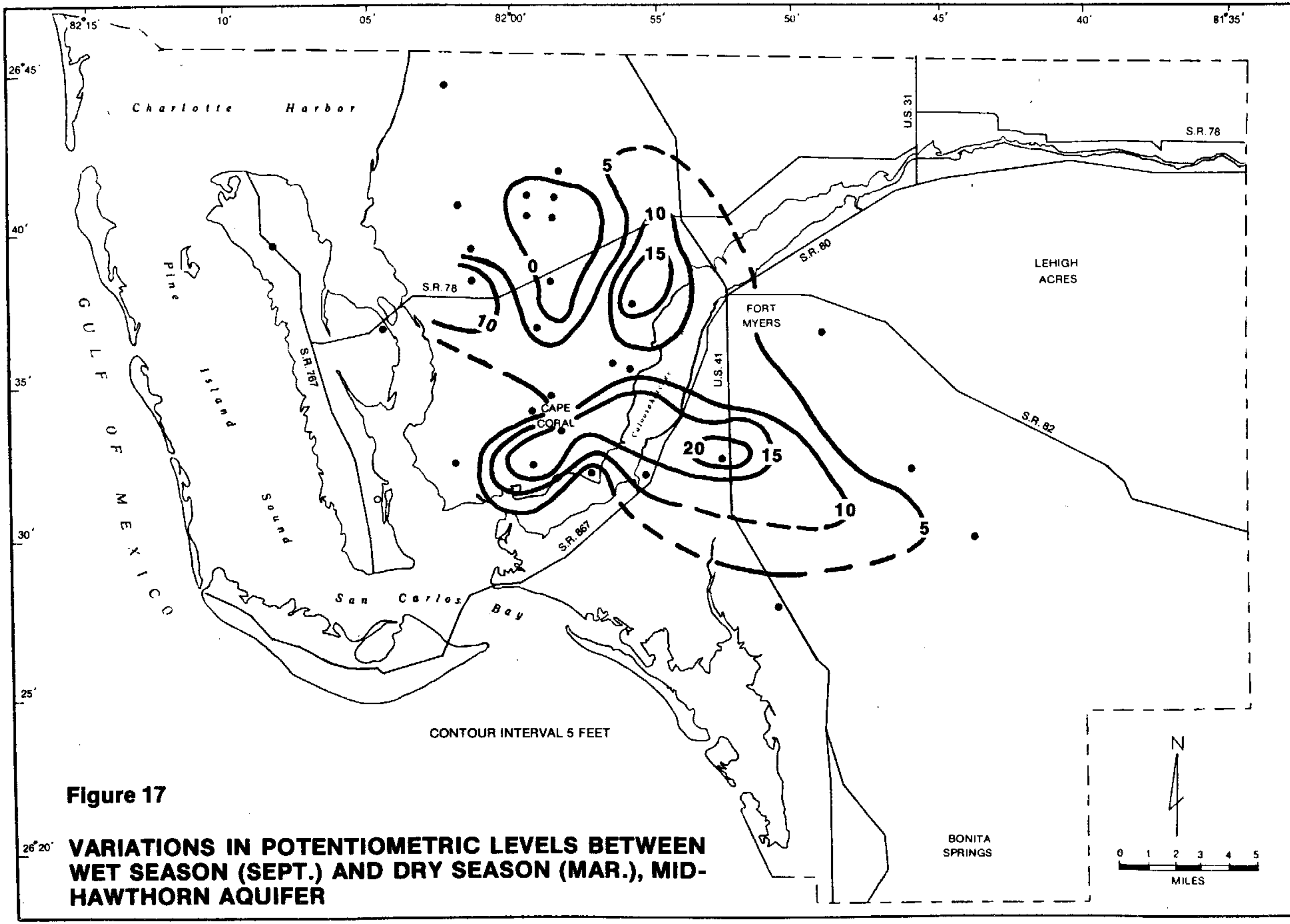


Figure 17

VARIATIONS IN POTENTIOMETRIC LEVELS BETWEEN WET SEASON (SEPT.) AND DRY SEASON (MAR.), MID-HAWTHORN AQUIFER

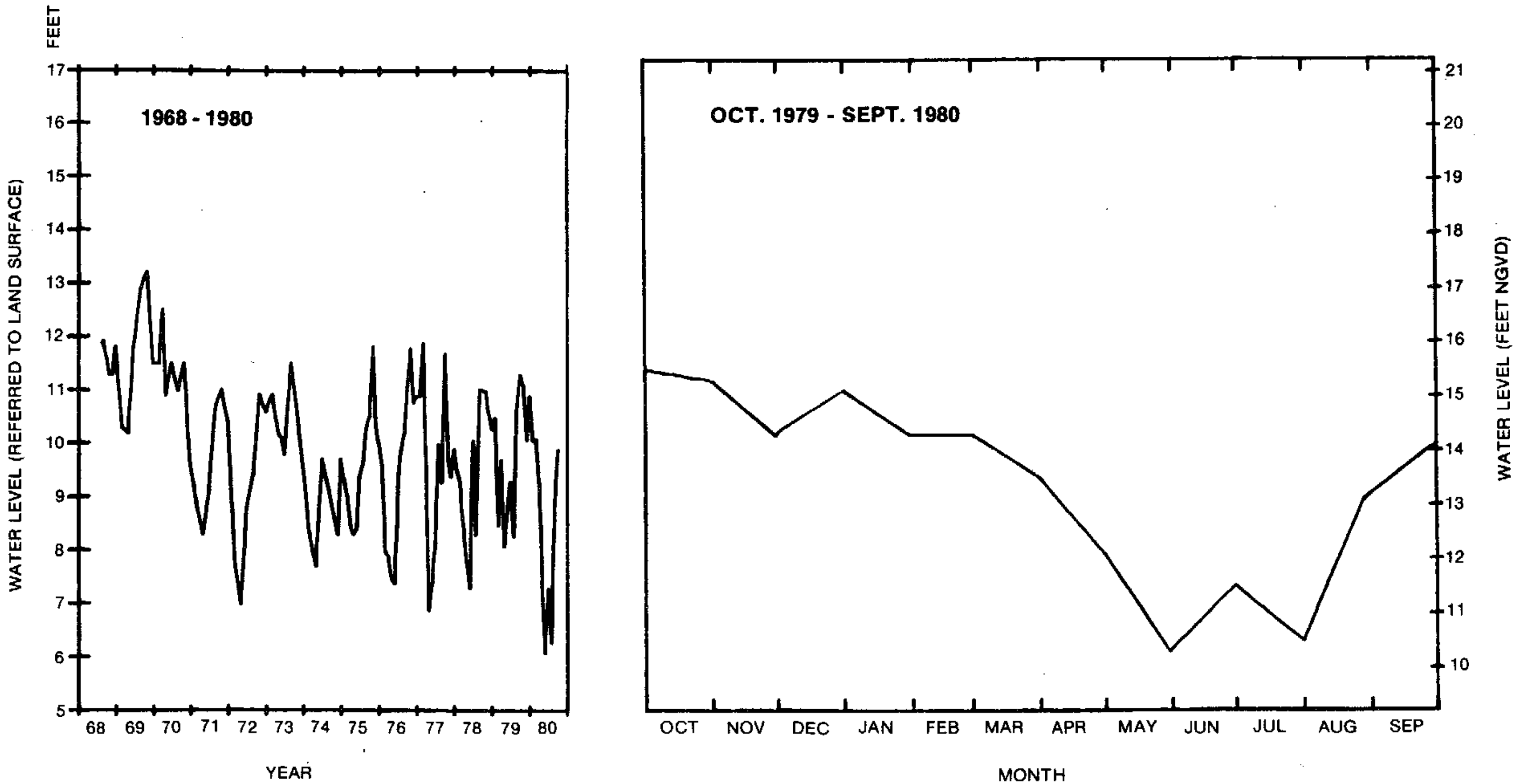


Figure 18 HYDROGRAPHS OF WELL L-735, MID-HAWTHORN AQUIFER, LEE COUNTY (COURTESY OF U.S. GEOLOGICAL SURVEY)

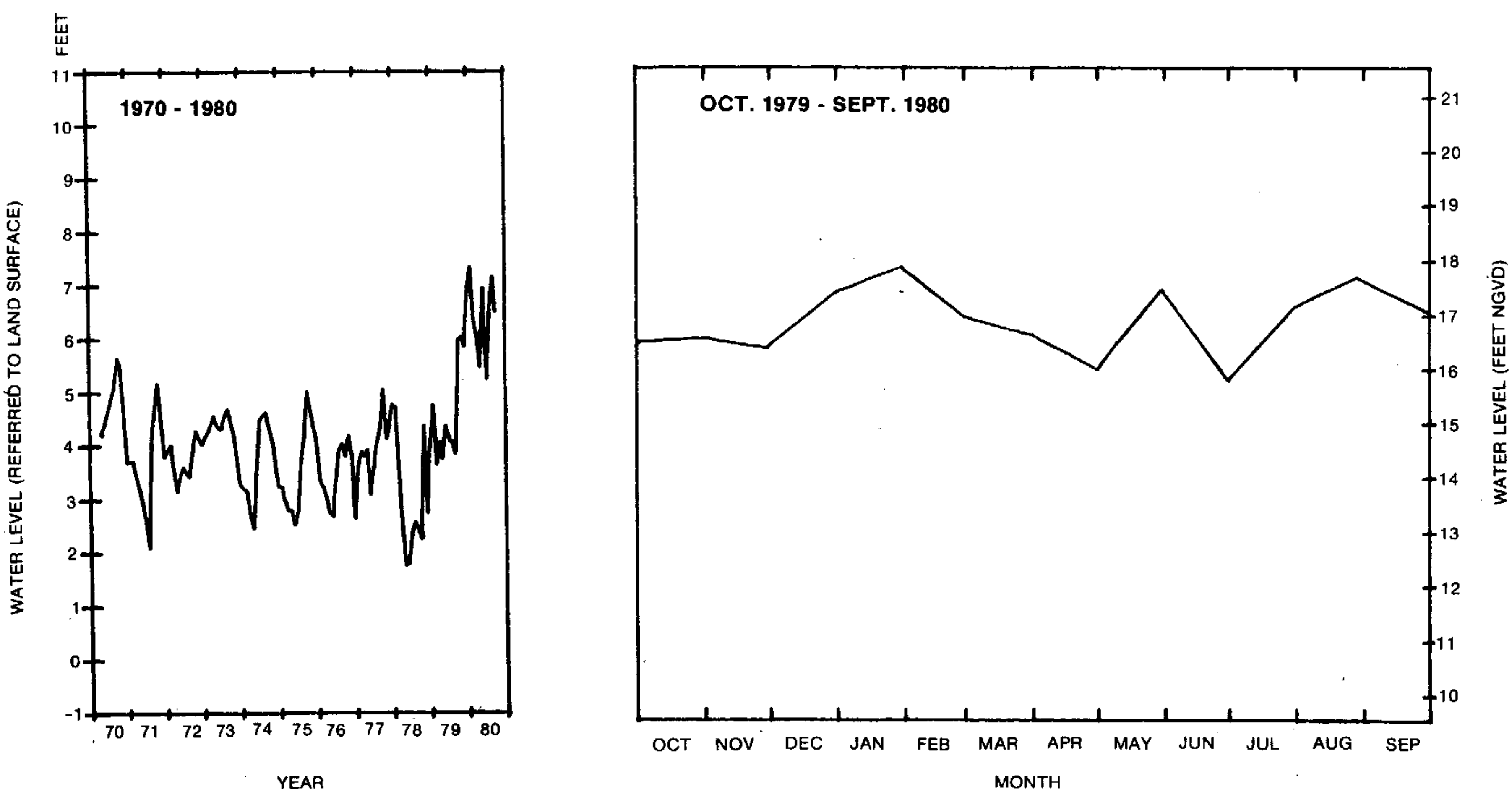


Figure 19 HYDROGRAPHS OF WELL L-1059, MID-HAWTHORN AQUIFER, LEE COUNTY (COURTESY OF U.S. GEOLOGICAL SURVEY)

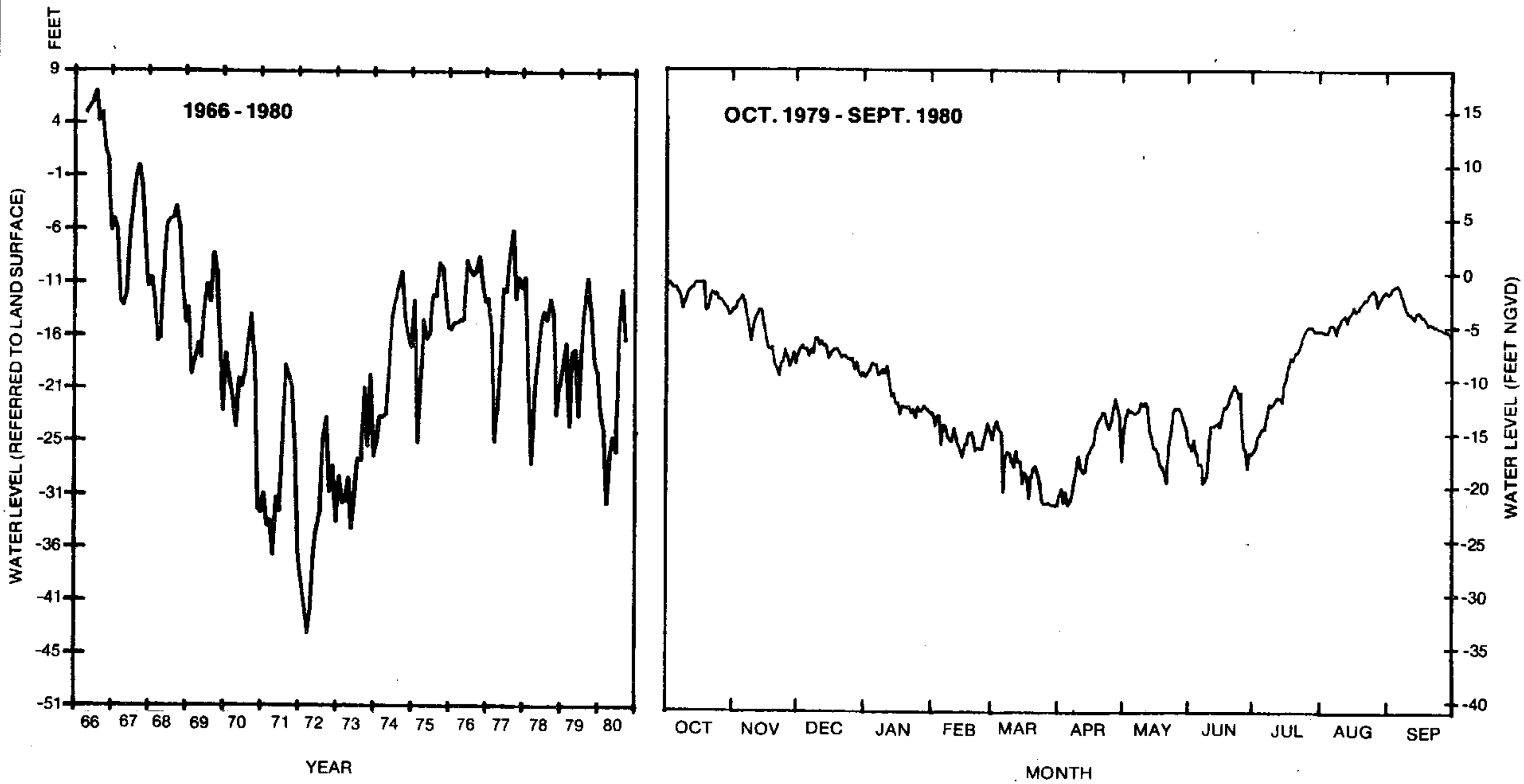


Figure 20 HYDROGRAPHS OF WELL L-781, MID-HAWTHORN AQUIFER, LEE COUNTY (COURTESY OF U.S. GEOLOGICAL SURVEY)

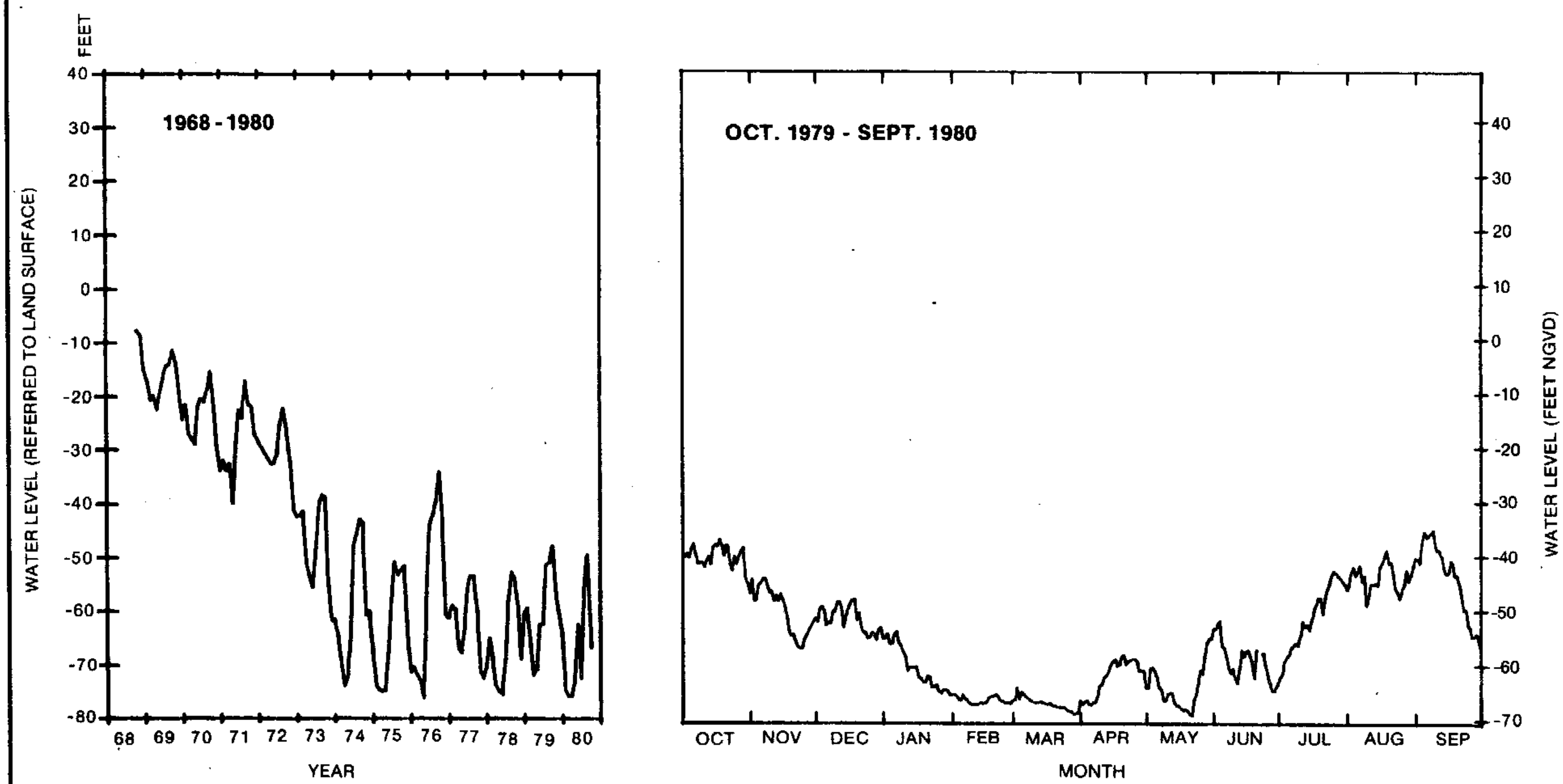


Figure 21 HYDROGRAPHS OF WELL L-742, MID-HAWTHORN AQUIFER, LEE COUNTY (COURTESY OF U.S. GEOLOGICAL SURVEY)

The hydrographs of well L-735 show relatively larger seasonal fluctuations and a pronounced recession in levels from the end of the wet season to the end of the dry season. Potentiometric surface levels at this well vary from a maximum of more than 13 feet above land surface to a minimum of about 6 feet above land surface - a historical range of approximately 7 feet.

Well L-781 shows the effects of pumpage in the Cape Coral area. Seasonal variations shown on the long term hydrograph are very pronounced, attaining a maximum of over 20 feet in some years. The annual hydrograph shows a recession from about 1 foot NGVD to below 23 feet NGVD. The hydrographs of well L-742, which is located in the center of the deepest depression shown on the potentiometric map, show even more pronounced effects of pumpage. Maximum season variations shown on the long term hydrograph exceed 40 feet. Potentiometric levels have fallen historically to more than 80 feet below land surface. The annual hydrograph shows a recession during the dry season from about -37 feet NGVD to almost -70 feet NGVD.

Long term patterns of potentiometric levels in the aquifer, as illustrated by the hydrographs, are distorted by the effects of pumpage. The long term hydrograph of well L-1059 gives probably the closest picture of a "natural" trend in the aquifer. Average levels have been relatively stable since 1970 with a trend towards rising water levels since 1978. Potentiometric levels appear to have leveled off in 1979 to 1980. The hydrograph of well L-735 shows a gradual but continuous downward trend in average potentiometric levels. The downward trend was steeper between 1968 and 1971, and appears to have stabilized somewhat between 1971 and 1980.

The hydrograph of well L-781 shows a much steeper downward trend between 1966 and 1971, an upward trend between 1971 and 1974, relatively stable levels between 1974 and 1976, followed by a slight downward trend between 1976 and 1980. The steepest long term decline in potentiometric levels is seen on the hydrograph for well L-742. There has been a continuous decline in levels in this well between 1968 and 1974. Since 1974, however, levels have remained essentially stable.

All the long term hydrographs, with the exception of that for well L-1059, indicate that over the past 20 years or longer water levels have declined drastically from previous levels in the areas represented by these hydrographs. Flowing artesian conditions no longer exist in these parts of the county and, in some areas, levels may fall below -70 feet NGVD.

Recharge

For direct recharge by precipitation to take place in the mid-Hawthorn aquifer, the permeable beds must crop out at an elevation above the potentiometric level. This does not occur within Lee County. The major source of recharge to the aquifer in Lee County appears to be from inflow from adjacent areas. The potentiometric surface gradient indicates that this recharge originates in the north. The principal recharge area for this aquifer is similar to that for the deep artesian aquifers in southern Florida and is located in the Polk and Pasco County areas (Lichtler, 1960, page 41), and probably also in Manatee and Hardee Counties. Because Lee County is approximately 100 miles from the recharge areas, fluctuations of the potentiometric surface due to seasonal rainfall in the recharge area are relatively small.

The mid-Hawthorn aquifer has higher potentiometric levels than the overlying Sandstone aquifer except where the levels have been lowered by pumpage. Due to the relatively impermeable strata separating these aquifers, it is not expected that any significant recharge takes place through leakage from above. The confining strata are composed of as much as 150 feet of clayey dolo-silts interbedded with sandy phosphatic limestones with an overall low permeability. Evidence that very little leakage is taking place is shown by the lack of correspondence between the potentiometric surface contour patterns of the two aquifers. The underlying lower Hawthorn aquifer has higher potentiometric heads than the mid-Hawthorn aquifer. Some leakage may occur from this aquifer, especially in areas where the head difference is substantial.

Discharge

Discharge from wells causes the greatest changes in the potentiometric surface in the mid-Hawthorn aquifer. Continuous discharge of water from a number of wells over a period of more than 20 years causes a wide cone of depression to form, as shown on Plate 25, Atlas.

The potentiometric surface of the mid-Hawthorn aquifer slopes toward the Gulf of Mexico, where this pattern is not interrupted by pumping depressions. Artesian water could, therefore, discharge into the Gulf, where the aquifer crops out or confining beds are absent. Lichtler (1960, p 44) considers that subsea outcrop areas on the east coast could probably be covered by somewhat impermeable sediments of relatively recent origin, which could restrict such discharge. This condition could also exist on the west coast.

Discharge by upward leakage through the confining beds which separate the mid-Hawthorn aquifer from the Sandstone aquifer is probably small in Lee County.

POTENTIOMETRIC LEVELS IN THE LOWER HAWTHORN AQUIFER

Plates 27 and 28 (Atlas) depict the potentiometric surface of the lower Hawthorn aquifer during March and September of 1979. These levels are considered representative of levels in the upper part of the Floridan Aquifer System. The maps were constructed using 24 data points which are fairly evenly distributed over the area. A number of factors affect the accurate determination of potentiometric levels in this aquifer. These include the length and condition of casing and water quality. Where casings are too short, an interconnection may exist between this aquifer and overlying aquifers, and the measured head will represent a composite of pressures existing within the borehole. If the specific gravity of the water varies significantly from that of fresh water, the greater weight of the water column will also affect the accuracy of the measurements. The field measurements under these conditions will indicate a slightly lower artesian head than actually exists.

Configuration of the Potentiometric Surface

The potentiometric surface of the lower Hawthorn aquifer is generally approximately 20 feet higher than that of the mid-Hawthorn aquifer. Levels in some areas are more than 20 feet above land surface, and flowing artesian conditions exist in most parts of the county.

The configuration of the lower Hawthorn aquifer potentiometric surface is similar to that of the mid-Hawthorn aquifer except where pumping depressions occur. The general shape of the contour lines for this aquifer can therefore be used as a guide to reconstruct pre-pumpage potentiometric contours of the mid-Hawthorn aquifer.

The potentiometric surface gradient is oriented from northeast to southwest, with a pronounced "bulge" where the lines cross the Caloosahatchee River. Boggess (1974) suggests that this bulge may be caused by discharge from wells in the lower Hawthorn aquifer, although other factors such as increased leakage to the overstressed mid-Hawthorn aquifer may be contributary. The areas of highest potentiometric levels are to the east and northeast of the county, with a fairly low regional gradient of approximately 1 to 2 feet per mile. At the coastline with the Gulf of Mexico, potentiometric levels are still approximately 20 feet above NGVD.

Undulations in the potentiometric surface appear to be mainly caused by groundwater withdrawals. The eastward displacement of the contour lines where they cross the Caloosahatchee River is the major regional feature shown on the maps. In addition, local depressions are shown around wells L-2434 and L-588. Well L-2434 is near the Cape Coral Reverse Osmosis Plant wellfield which withdraws water from the lower Hawthorn aquifer, and the depression is probably a result of this withdrawal. The depression on Sanibel Island around well L-588 is a result of pumping from this aquifer by the nearby Island Water Association wellfield. The eastward shift of the 20 foot contour line around well L-1635, located on Estero Island, may also be attributed to pumpage. The relatively high levels on Pine Island indicate that the effects of groundwater withdrawal on the mainland have had little effect on this area.

In general, potentiometric levels are only slightly higher during the wet season than during the dry season. Figure 22 shows that over most of the area the range of seasonal fluctuation is less than 3 feet. In the eastern Cape Coral area, around well L-2434, water levels are actually higher in the dry season than in the wet season. This may be explained by the fact that the Cape Coral Reverse Osmosis Plant Wellfield in this area is used principally as a back-up system and withdrawals are not consistent. Since only once-monthly data are available, it is possible that readings were taken during the dry season at a time when withdrawals were not being

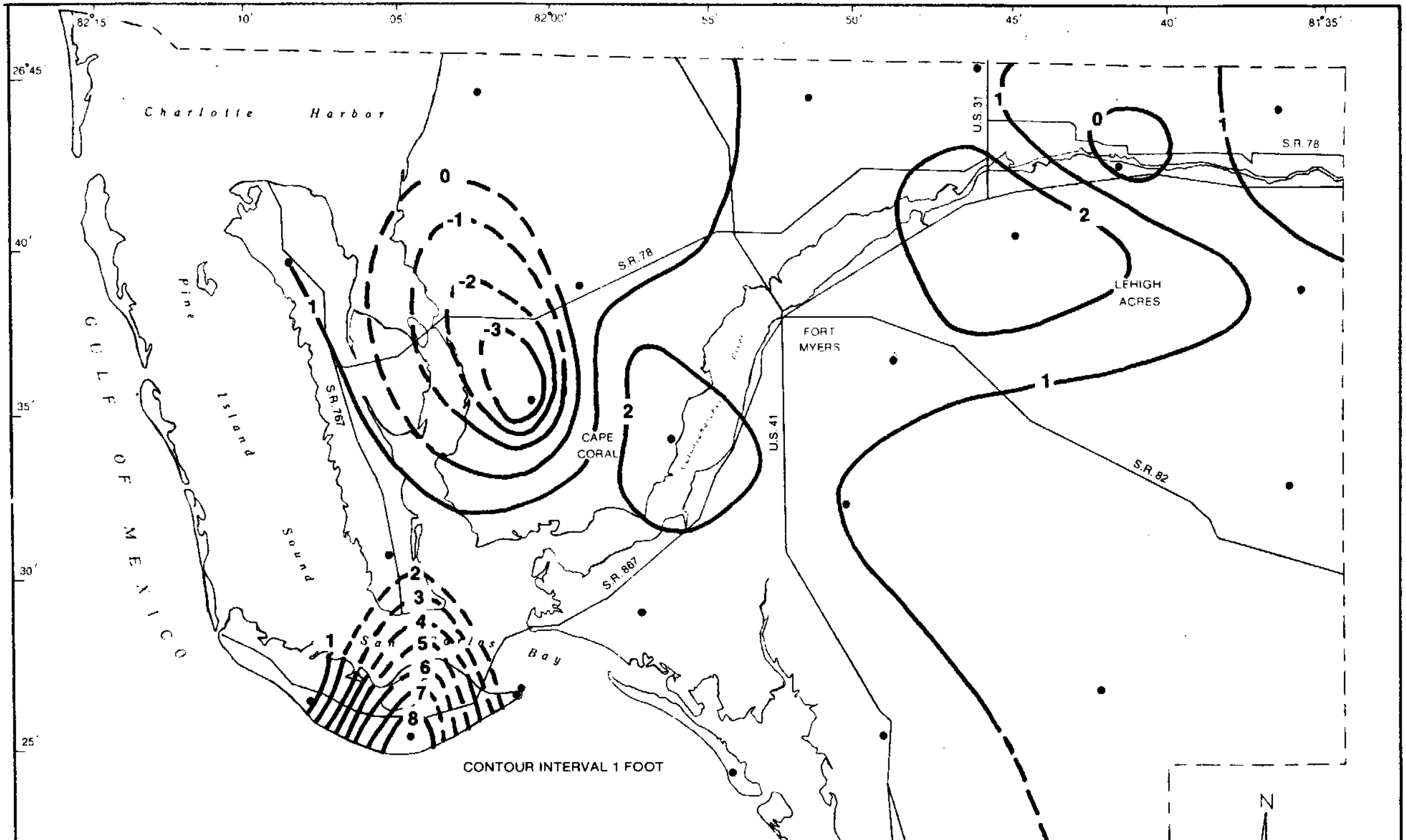


Figure 22

VARIATIONS IN POTENTIOMETRIC LEVELS BETWEEN WET SEASON (SEPT.) AND DRY SEASON (MAR.), 1979; LOWER HAWTHORN AQUIFER

made from the wellfield. The largest variation is on Sanibel Island (up to 8 feet lower in the dry season) reflecting differences in withdrawals during wet and dry seasons.

Potentiometric Level Fluctuations

Figures 23, 24, 25, and 26 show hydrographs of wells L-588, L-706, L-2293, and L-2341, in the lower Hawthorn aquifer. All of the long term hydrographs show seasonal fluctuations in potentiometric levels, varying from less than 1 foot to about 5 feet. The short term hydrographs show relatively high water levels during August and September which are probably the result of increased subsurface inflow and reduced withdrawals due to reduced water demand during the fall. A recession in potentiometric levels begins in October and continues through June when water levels recover.

Long term trends, as shown by the hydrographs, vary from well to well. The hydrograph of well L-706, which is located close to the eastern edge of the area, shows a period of low average potentiometric levels and wider fluctuations in levels between 1974 and 1978. This would indicate either a period of below normal dry season rainfall, or greater withdrawals. Maximum levels show a slight, but relatively uniform, downward trend. The hydrographs of wells L-2293 and L-2341 show a slight upward trend between 1976 and 1980 with seasonal fluctuations of 2 to 3 feet. These wells are located relatively far from areas of heavy pumpage. The hydrograph of well L-588, which is located in a pumping depression on Sanibel Island, shows an unexpected upward trend between 1976 and 1980. However, the period of record is probably too short to fully show the effects of withdrawals in this area.

Figure 27 (from Boggess, 1974), shows potentiometric levels from 1944 to 1950 and from 1966 to 1973. This figure indicates long term changes in water levels which have taken place in the aquifer.

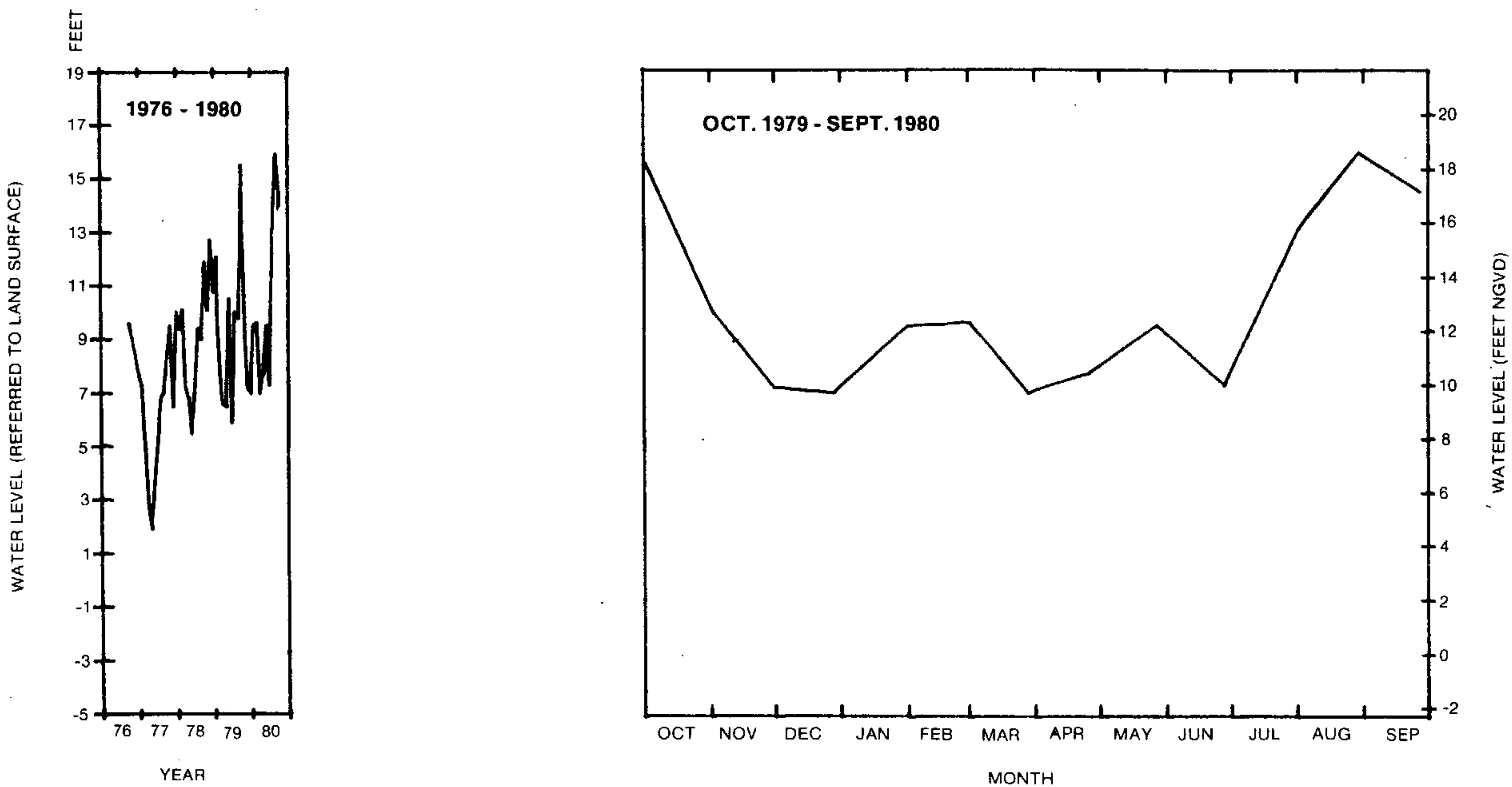


Figure 23 HYDROGRAPHS OF WELL L-588, LOWER HAWTHORN AQUIFER, LEE COUNTY (COURTESY OF U.S. GEOLOGICAL SURVEY)

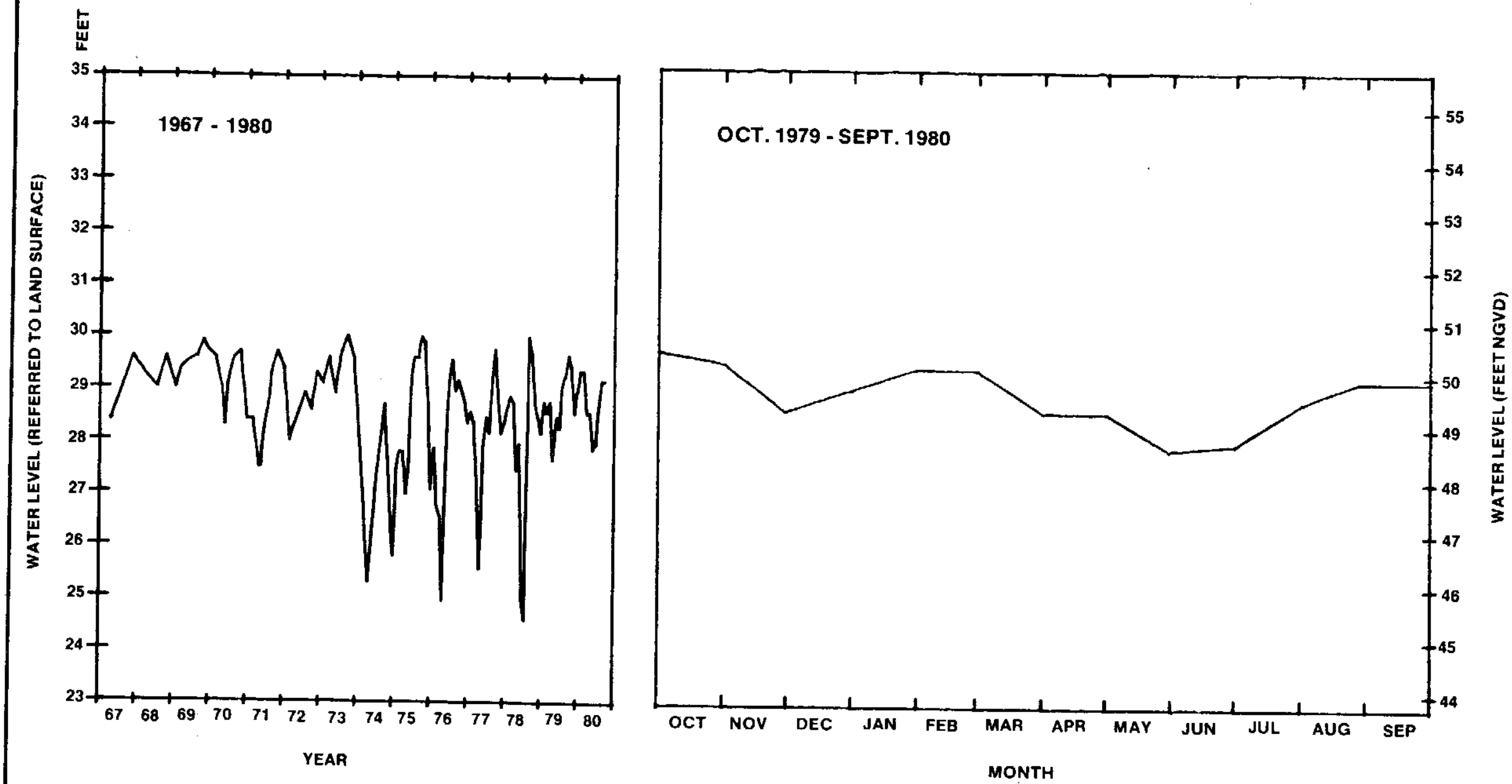
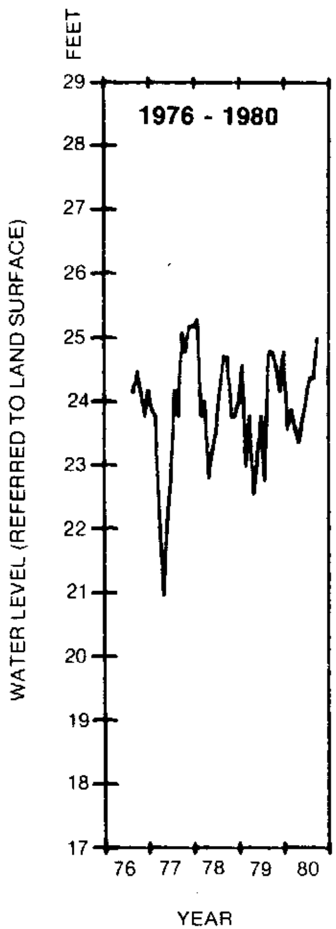


Figure 24 HYDROGRAPHS OF WELL L-706, LOWER HAWTHORN AQUIFER, LEE COUNTY (COURTESY OF U.S. GEOLOGICAL SURVEY)



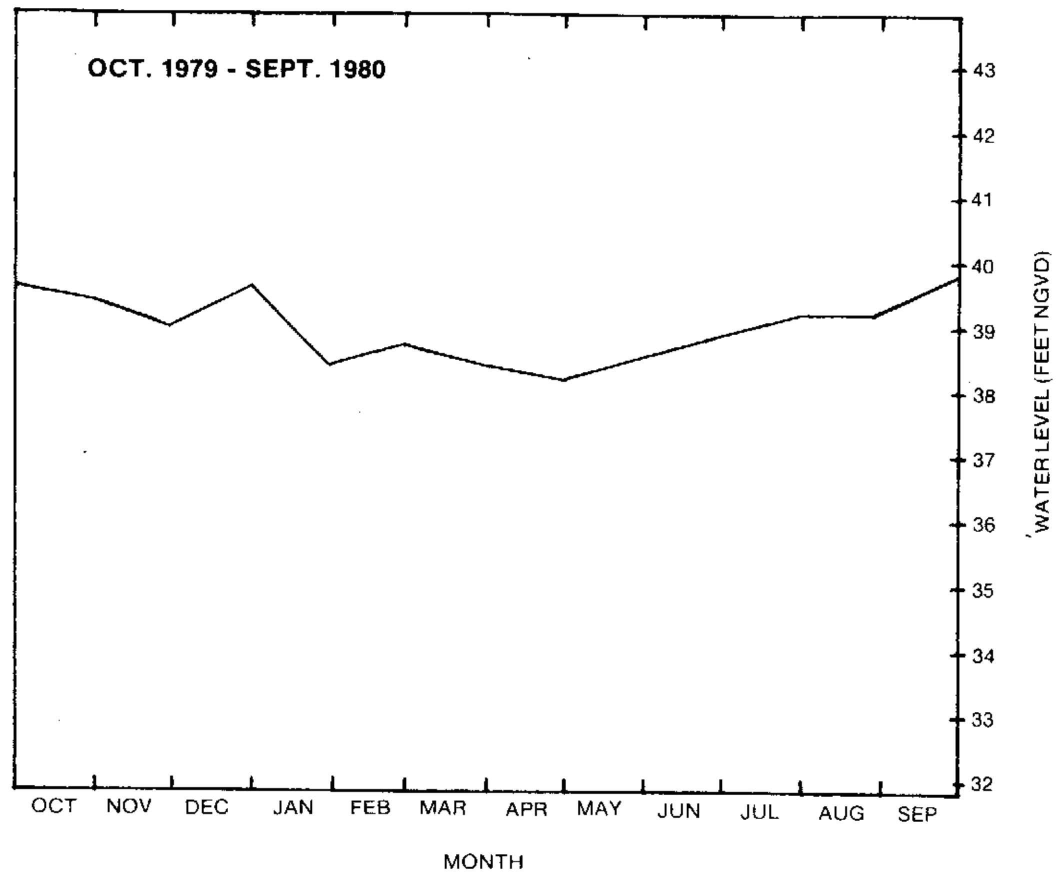


Figure 25 HYDROGRAPHS OF WELL L-2293, LOWER HAWTHORN AQUIFER, LEE COUNTY (COURTESY OF U.S. GEOLOGICAL SURVEY)

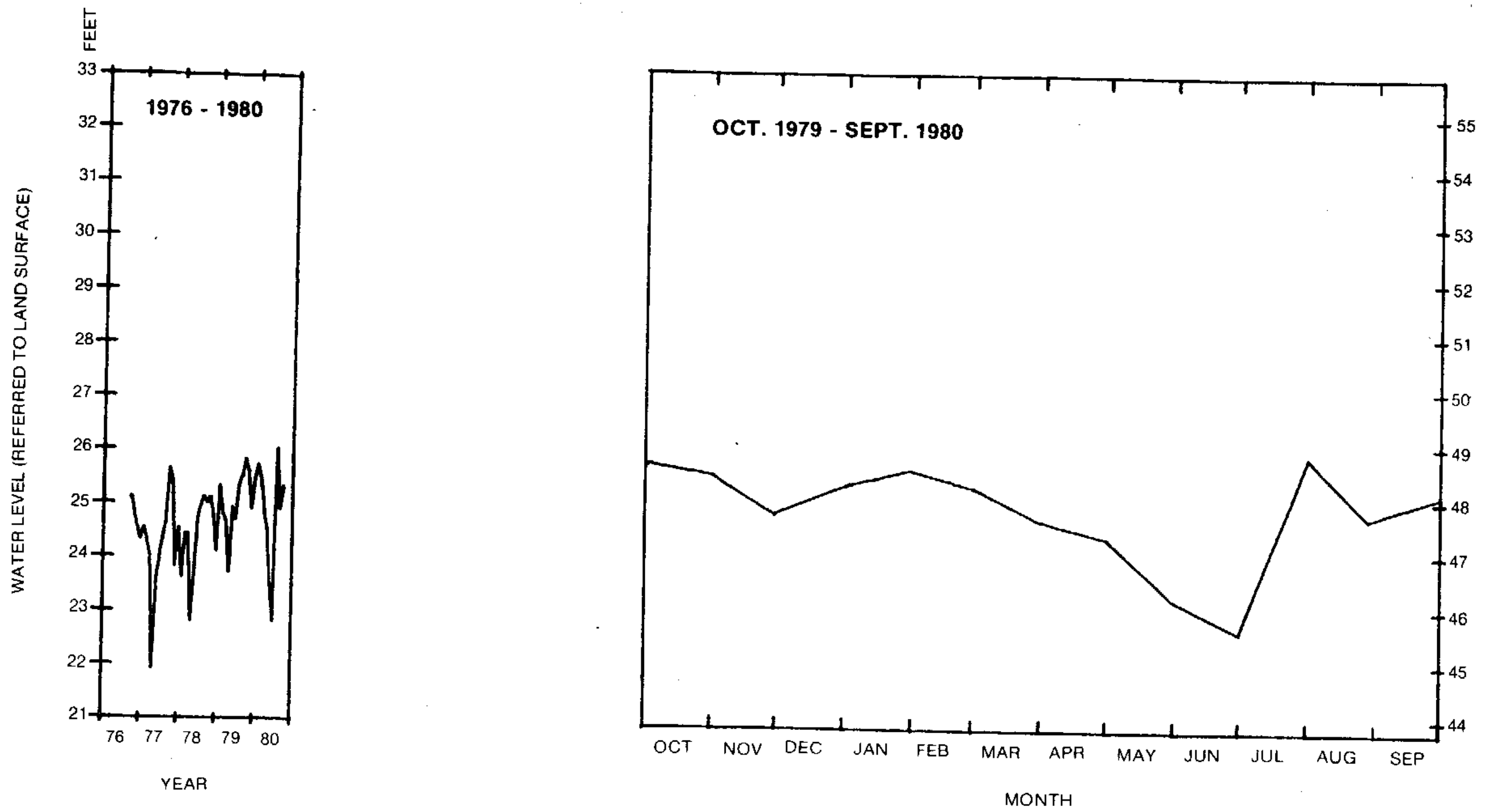


Figure 26 HYDROGRAPHS OF WELL L-2341, LOWER HAWTHORN AQUIFER, LEE COUNTY (COURTESY OF U.S. GEOLOGICAL SURVEY)

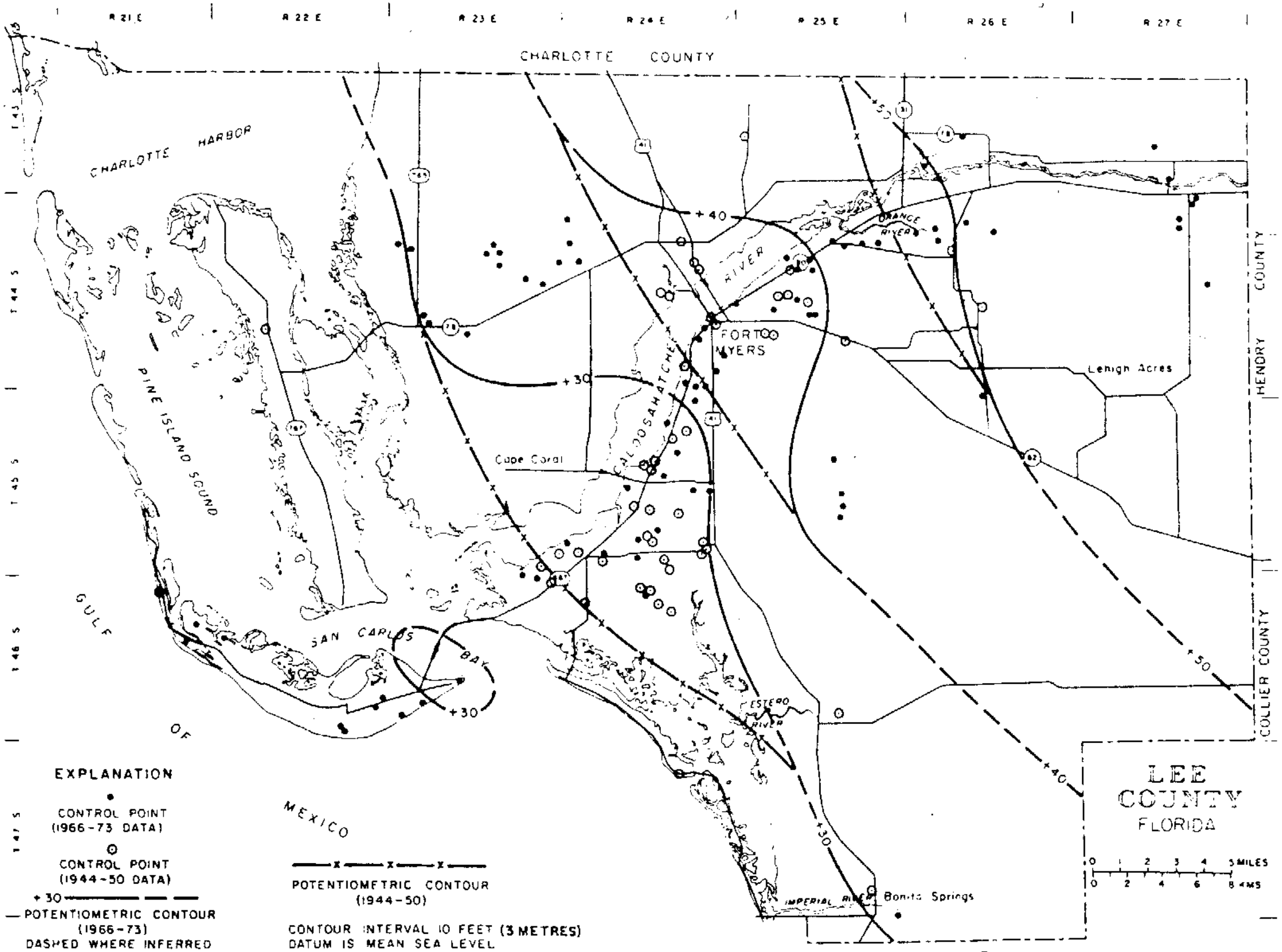


Figure 27 POTENTIOMETRIC SURFACE OF THE LOWER HAWTHORN AND SUWANNEE AQUIFERS IN 1966-73 AND 1944-50 (BOGGESS, 1974)

Recharge

Most of the recharge to the lower Hawthorn aquifer originates from outside of the area, probably in the Polk County highlands and adjacent areas where the aquifer crops out at higher elevations. The subsurface inflow enters the county on its northern and eastern borders.

Because of the high potentiometric levels in this aquifer, recharge by leakage through the confining beds does not occur under natural conditions. However, if heads in the aquifer are lowered through withdrawals, recharge from this source is possible. Direct sea water intrusion inland from the coast is also not possible due to the high potentiometric levels offshore.

Discharge

The hydraulic gradient of the lower Hawthorn aquifer is toward the Gulf of Mexico which serves as the major point of discharge. Discharge by upward leakage through the confining bed is probably small in Lee County since both the water quality and the difference in hydraulic heads between this aquifer and the overlying aquifer indicate good confinement. The major discharge from this aquifer within Lee County is from irrigation wells which flow unabated or from wells which have inadequate or leaky casings. It has been estimated that there may be as many as 3000 derelict abandoned wells penetrating the lower Hawthorn aquifer in the county. The absence or poor condition of the casings of these wells allows interaquifer flow of water, resulting in water quality deterioration in the upper aquifers and may also reduce potentiometric heads regionally. The South Florida Water Management District has initiated cooperative programs with various municipalities and other agencies in the county to identify and plug these derelict wells.

The effects of municipal withdrawals on the potentiometric surface are also shown on Plates 27 and 28 (Atlas). Pumping depressions are located close to wellfields operated by the Island Water Association on Sanibel Island, on Sanibel Island, and in the vicinity of the wellfield for the Cape Coral Reverse Osmosis Plant.

GROUNDWATER QUALITY IN LEE COUNTY

INTRODUCTION

The quality of groundwater is largely determined by the chemical or physical changes which take place as water falls through the atmosphere and flows through the rocks. Mixing of waters of different chemical or physical properties may also take place, and groundwater quality may be affected by pollution from activities of man, or animal wastes. Although groundwater quality includes many chemical and physical parameters, only four were chosen for detailed discussion in this report. These are dissolved sulfates, chlorides, iron, and total dissolved solids. The choice of these four parameters was based on relevance of these parameters to use of the water for a variety of purposes (domestic, irrigation, industrial), existence of potable drinking water standards for these parameters, regional groundwater flow implications, and data availability.

Chloride content of water is regarded as a good indication of saltwater contamination. The secondary drinking water standard for chloride is set at 250 mg/l (PL 93-523), although the taste threshold is about 500 mg/l. Water with chloride concentrations in excess of 750 mg/l may cause damage to most cultivated plants if used over a long period of time. A high chloride content also makes water more corrosive, resulting in rusting of certain metals.

Sulfate concentrations of about 750 mg/l or greater in potable water may have a laxative effect. The drinking water standard for this constituent is 250 mg/l. For industrial uses, water with high sulfate concentrations (especially in conjunction with high calcium and magnesium concentrations) is considered objectionable because of scaling problems in boilers.

Iron, at concentrations of only a few tenths of a milligram per litre, imparts a disagreeable taste to water and causes staining of fixtures, laundry or buildings. The recommended drinking water standard for this constituent is 0.3 mg/l.

The recommended drinking water standard for total dissolved solids is 500 mg/1. Water having concentrations greater than 1000 mg/1 would have a noticeable taste and be unsuitable for many industrial uses.

A series of maps is presented showing regional distribution of these parameters within the Surficial, Sandstone, mid-Hawthorn, and lower Hawthorn aquifers. These maps are based on data published by the U. S. Geological Survey (Water Resources Data for Florida, 1975, 1976, 1977, 1978, and 1979). Of the 194 data points used for these maps, 52 represented samples from the Surficial aquifer, 39 were from the Sandstone aquifer, 52 were from the mid-Hawthorn aquifer, and 51 were from the lower Hawthorn aquifer. A summary of the data on which these maps are based is given in Appendix 4. To provide reasonable coverage of the area, data from a number of years between 1975 and 1979 were used since wells were not consistently sampled in any one year. Consequently, the maps should be considered as presenting a general, regional picture only and the possibility exists that local variations in water quality may not be fully addressed on the maps. The overall patterns are, however, considered to be reasonably accurate as examination of the data shows no drastic regional changes in water quality over these years, except in a few localized areas.

A more serious problem relates to the construction of wells from which samples were taken, and the methods of sampling these wells. This problem was particularly evident in the case of aquifers in the Hawthorn and Floridan aquifer systems. Water quality stratification appears to exist in these aquifers, and wells relatively close together which are finished at different levels in the same aquifer may show different water qualities. Where wells have been improperly cased for water sampling purposes, the samples may represent a combination of waters of different quality from different zones within the same aquifer, or even from two or more aquifers.

For any particular use of groundwater, a number of other parameters may be relevant. For example, for potable water use physical properties (color, temperature, pH, turbidity), metals (arsenic, barium, cadmium, chromium, lead, copper, mercury, selenium, silver, zinc), pesticides (endrin, lindane, methoxychlor, toxaphene, 2-4-D, 2-4-5-TP, etc.), nutrients (nitrate, phosphate), and radionuclide concentrations are of importance. The scope of this report does not allow for detailed discussion of these constituents.

WATER QUALITY IN THE SURFICIAL AQUIFER

Figures 28 , 29 , 30 , and 31 show regional distribution patterns for chlorides, sulfates, iron, and total dissolved solids in the Surficial aquifer. The data points used in constructing the maps are identified on Figure 32.

Chlorides

Chloride concentrations in groundwater from wells sampled in the Surficial aquifer range from less than 5 milligrams per litre (mg/l) to more than 300 mg/l on the mainland. Concentrations of up to 30,000 milligrams per litre are found on Sanibel Island. Although data are not available in near coastal areas or on some islands, it is to be expected that these areas would have high chloride concentrations. Wells placed close to the tidal reaches of the Caloosahatchee River and whose cone of depression intersect the river would also be expected to show abnormally high concentrations.

Over most of Lee County, except for localized pockets and close to saline surface water sources (bays, tidal rivers and creeks, the Gulf of Mexico), chloride concentrations are within potable limits (less than 250 mg/l). The general pattern of chloride distribution is one of low concentrations (less than 50 mg/l) in the major recharge areas, especially in the east-central and southeastern parts of the county, with concentrations increasing as the water moves down gradient (see Plates 21 and 23, Atlas). Localized pockets of more saline water (>250 mg/l) are found in Cape Coral and in two areas close to the

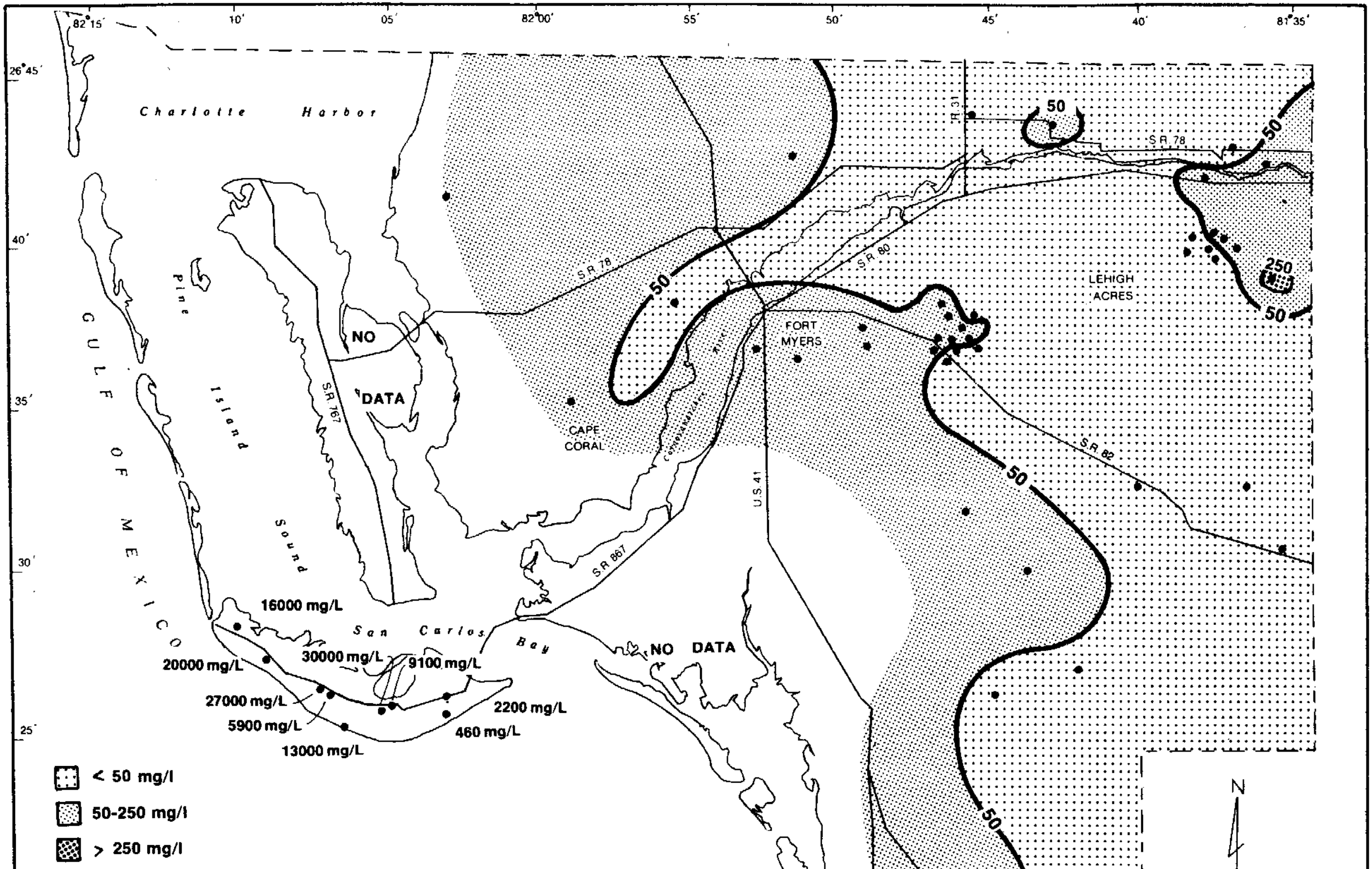


Figure 28
CHLORIDE CONCENTRATIONS IN THE SURFICIAL AQUIFER (MOST RECENT DATA)

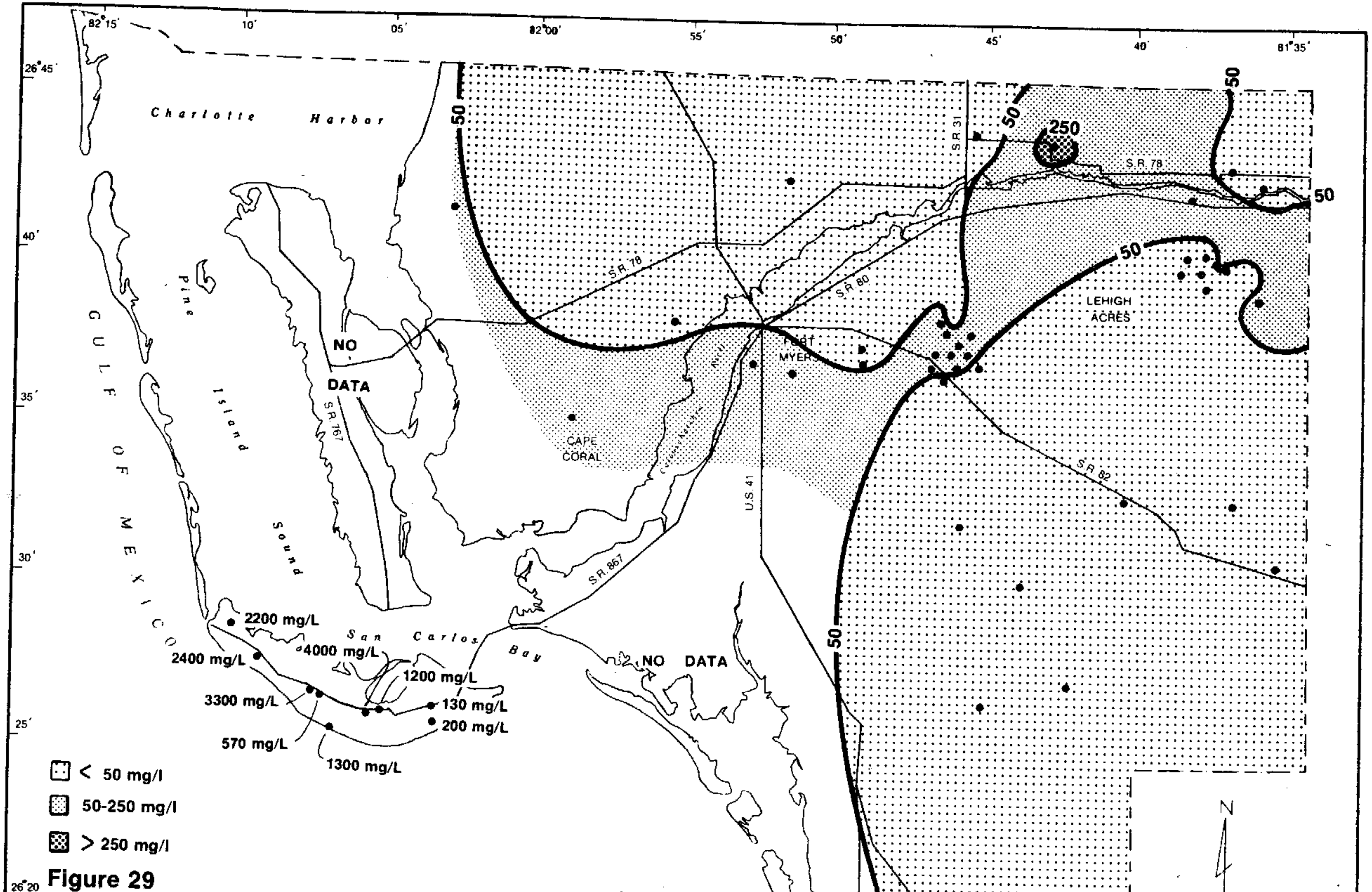


Figure 29

SULFATE CONCENTRATIONS IN THE SURFICIAL AQUIFER (MOST RECENT DATA)

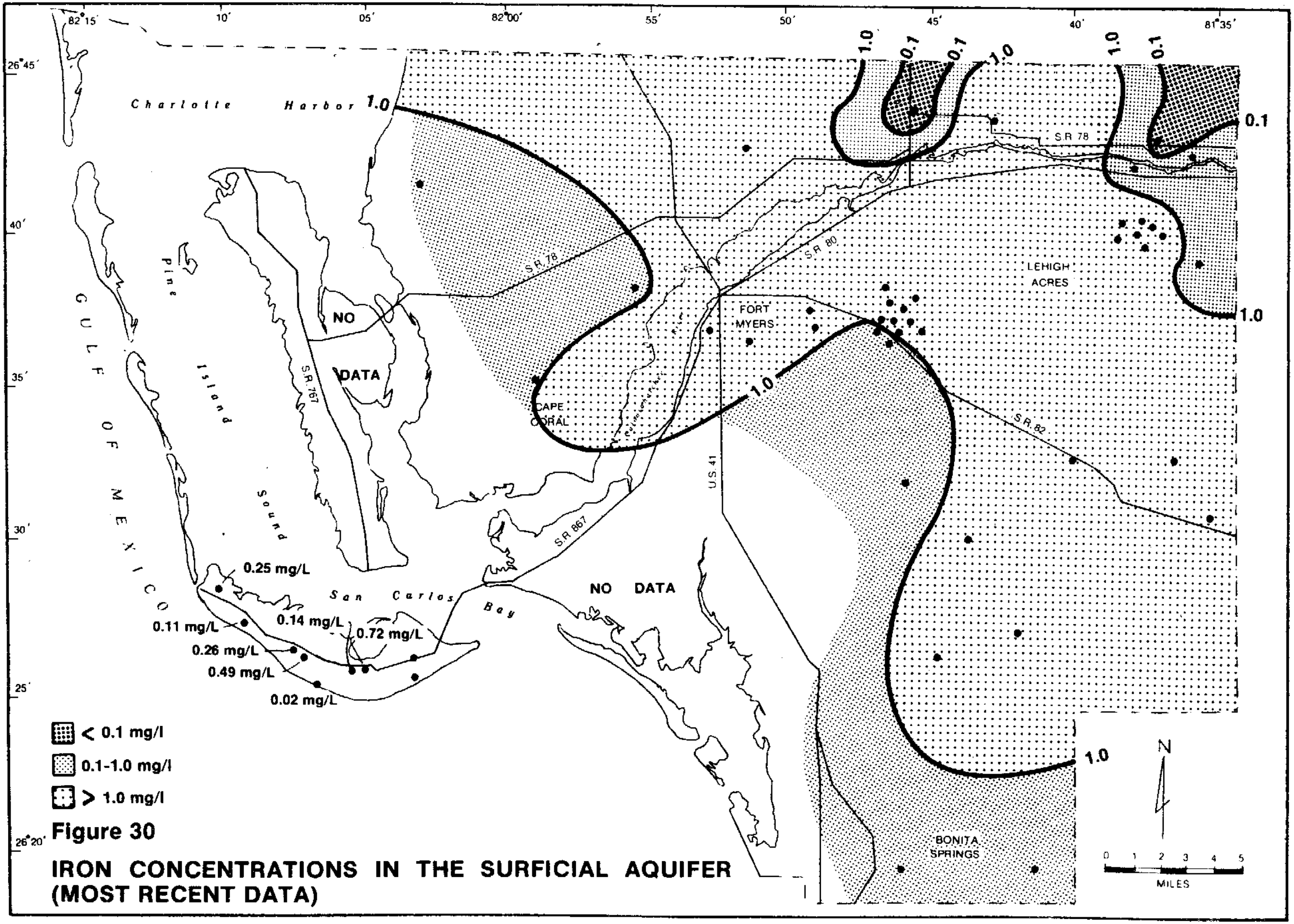


Figure 30

IRON CONCENTRATIONS IN THE SURFICIAL AQUIFER (MOST RECENT DATA)

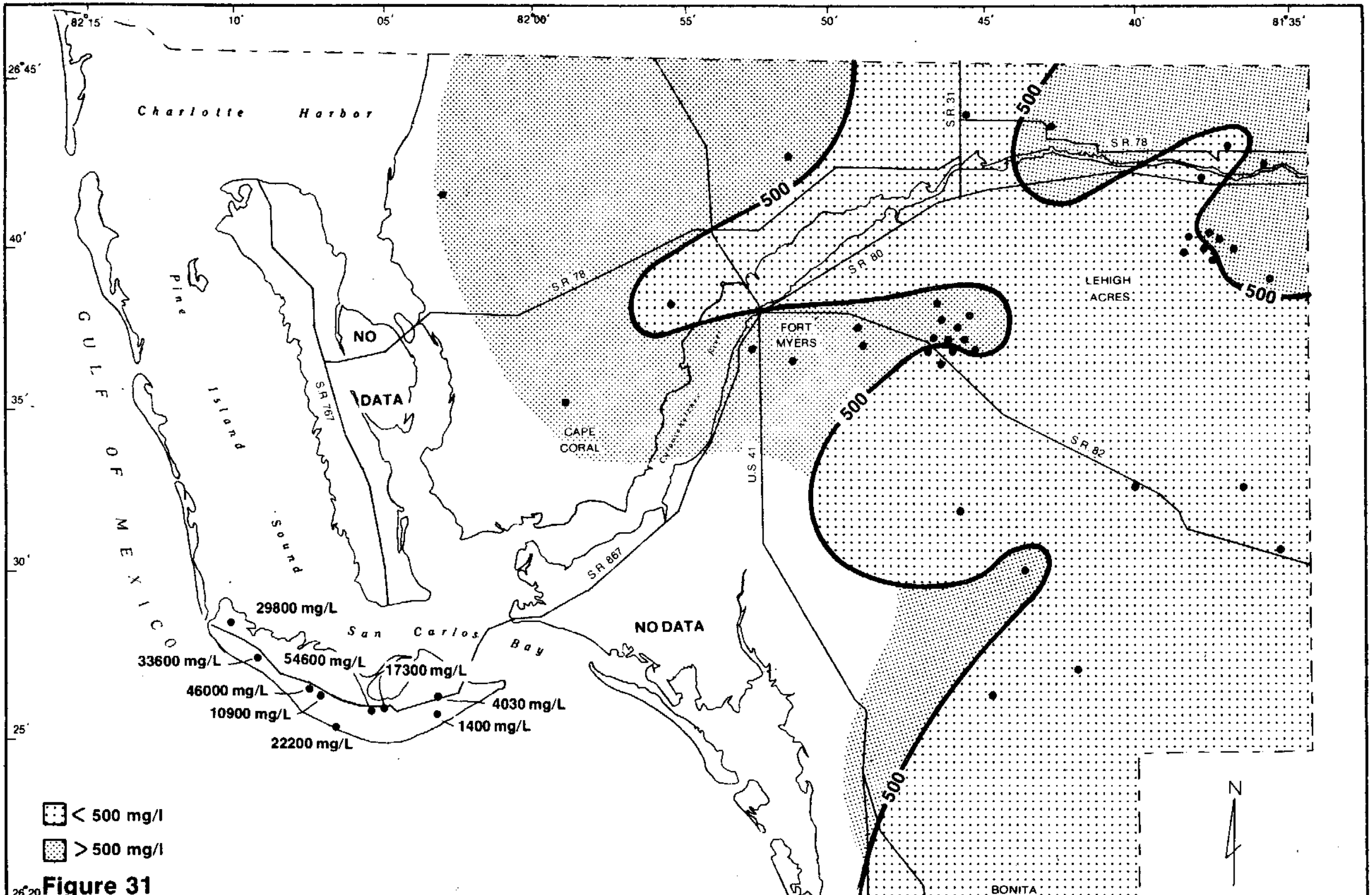


Figure 31

TOTAL DISSOLVED SOLIDS CONCENTRATIONS IN THE SURFICIAL AQUIFER (MOST RECENT DATA)

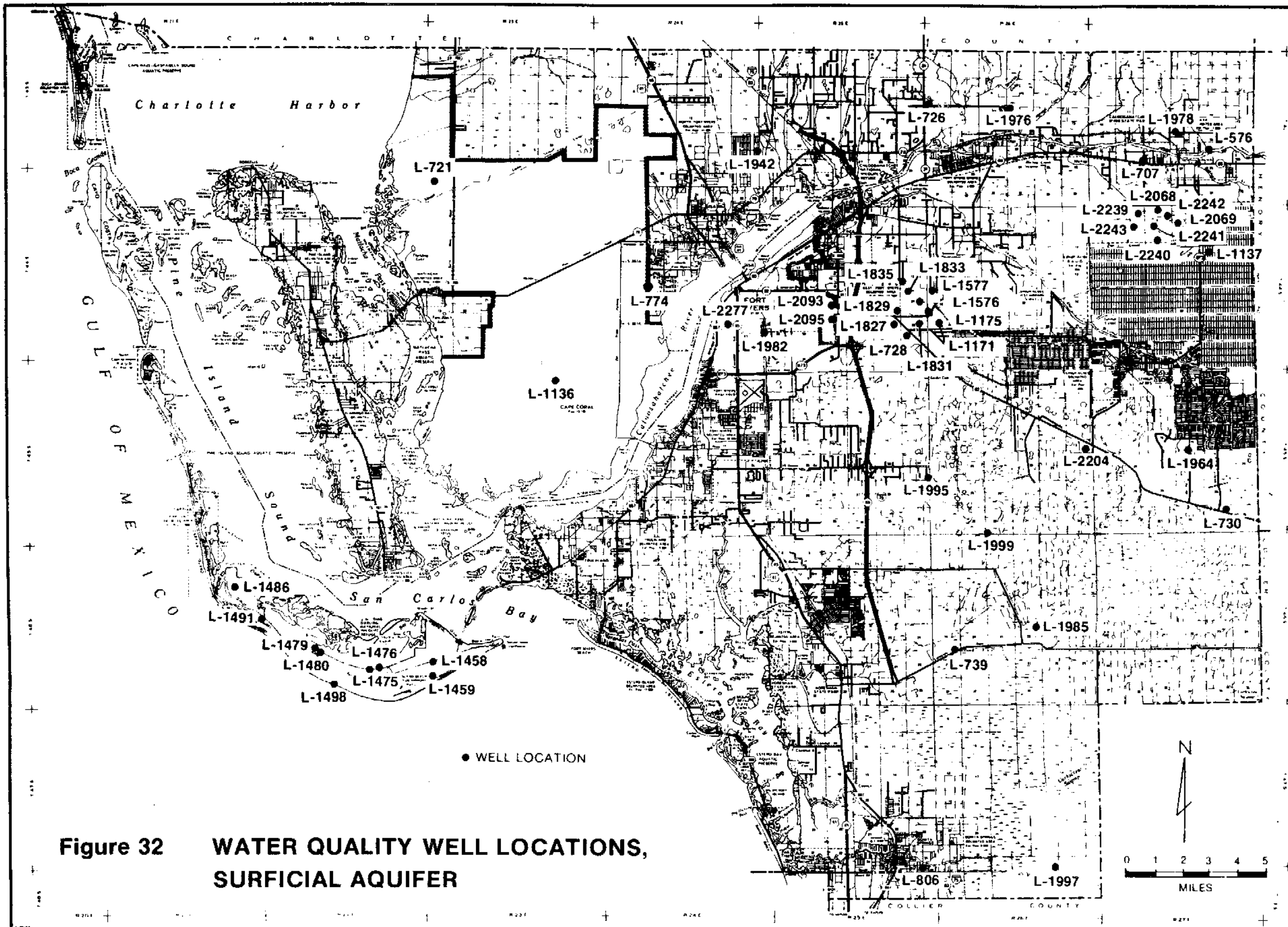


Figure 32 WATER QUALITY WELL LOCATIONS, SURFICIAL AQUIFER

Caloosahatchee River. These are probably the result of movement of more saline water from underlying aquifers in response to pumping stresses, or the use of saline water from deeper aquifers for lawn sprinkling in Cape Coral.

Groundwater from one well on Sanibel Island (L-1459) shows abnormally low chloride concentrations (460 mg/l) compared to other wells on the island. The reason for this has not been investigated but may be due either to skimming of fresh water from a thin lens which floats on the saline water or direct hydraulic connection between the well and a fresh surface water source.

Long term changes in chloride concentrations could not be determined in detail because of lack of historical data. Of the five wells shown on Table 1, only one (L-1137) shows significant changes in chloride concentrations.

Table 1. WATER QUALITY CHANGES, SURFICIAL AQUIFER

Well No.	Date	Cl	SO_4	Fe	T.D.S.
L-721	Jul-68	109	0.07	-	523
	Apr-74	88	35	1.7	526
	Oct-76	67	52	0.84	502
L-1137	Apr-74	21	7.7	1.7	316
	Jun-76	340	140	0.03	1,090
L-1976	Nov-74	200	240	7.4	1,070
	Oct-75	200	280	21.6	1,170
L-1995	Nov-74	47	1.6	0.01	340
	Nov-75	59	3	0.53	388
L-739	Aug-68	21	4.0	-	320
	Mar-75	25	0.7	0.66	312
	Nov-75	23	0.7	1.8	326

Between April 1974 and June 1976 the chloride concentration of water from this well increased from 21 mg/l to 340 mg/l. This well is located in Lehigh Acres and the increase in chlorides is probably related to pumpages in the area which have caused upconing of poorer quality water, or to contamination by abandoned flowing wells.

Sulfates

The distribution of sulfates in the Surficial aquifer is similar to that of chlorides in a number of respects. Sulfates are lowest (<50 mg/l) in the recharge area in the eastern, southeastern, and northern parts of the county and appear to increase towards the Gulf of Mexico. Localized areas of higher sulfate concentrations are found in the Fort Myers area and north of the Caloosahatchee River (well L-1976) where concentrations exceed the potable limit of 250 mg/l. Sulfates greatly exceed these limits on Sanibel Island (up to 4,000 mg/l) although three of the sampled wells on the island have concentrations of 250 mg/l or less. It is believed that, as with chlorides, sulfate concentrations are high in near coastal areas and over most of the Barrier Islands due to salt water intrusion.

In general therefore, most of the water from the Surficial aquifer meets potable water standards, except in a few local areas inland and in near coastal areas. Table 1 shows only one well where significant change in sulfate concentrations have taken place (well L-1137).

Iron

The iron content of water from the Surficial aquifer ranges from undetectable to more than 8 mg/l. The occurrence of this constituent is unpredictable and concentrations may vary with depth as well as location. Relatively low concentrations are found on Sanibel Island. This may be due to shorter residence time of the water in the aquifer in these areas, the relative thinness of the aquifer, or mixture with sea water of low iron content.

In general, iron concentrations of waters in the Surficial aquifer in most of Lee County do not meet secondary drinking water standards.

Total Dissolved Solids

Total dissolved solids concentrations of waters in the Surficial aquifer in Lee County range from about 200 mg/l to more than 700 mg/l except in near coastal areas such as Sanibel Island. The lowest concentrations are found in the eastern and southeastern parts of the county in the recharge areas. Concentrations increase toward the sea and are higher in localized areas where contamination by disposal of saline water from deeper aquifers (mainly for irrigation) or leakage from abandoned flowing wells may be the cause. The major areas which show anomalously high concentrations are the Cape Coral area and the northeastern corner of the county. As expected, very high total dissolved solids concentrations are found on Sanibel Island (up to 54,600 mg/l).

Summary

Much of the groundwater in the shallow aquifer in Lee County, although not of exceptionally good quality, is suitable for most domestic, agricultural, and industrial purposes. Generally the north-central, central, and south-central areas have relatively good quality water while the western, south-western, and northeastern areas have relatively poor quality water. Better quality water is found near the recharge areas, indicating that as the water travels through the aquifer it dissolves more minerals and may mix with more highly mineralized water near the coastline and tidal portions of rivers, creeks, and canals. On Sanibel Island, a thin layer of fresher water (1000 to 10,000 mg/l total dissolved solids) appears to exist above very saline waters (20,000 to 54,600 mg/l total dissolved solids) in the Surficial aquifer. The indications are that this represents a lens of fresher water which floats on the more saline water. The saline water has probably become more concentrated by evaporation in tidal lagoons or other enclosed water bodies that received sea water during storms (Stringfield, 1966).

As shown in Table 1 , there is no evidence of regional changes in water quality in the aquifer in the recent past. However, the water quality changes in well L-1976 indicate that in localized areas, significant changes may have taken place. At this well, over a two year period (April 1974 to June 1976) the total dissolved solids increased over 300 percent, the sulfates increased over 2,000 percent, and the chlorides increased over 1,500 percent. A long term monitoring network for water quality is, however, required to document historic water quality changes.

WATER QUALITY IN THE SANDSTONE AQUIFER

The regional distribution of chlorides, sulfate, iron, and total dissolved solids in the Sandstone aquifer is shown on Figures 33, 34, 35, and 36. Data points are identified on Figure 37, and data on which the maps are based are reproduced in Appendix 4-2.

Chloride

Chloride concentrations in groundwater from the Sandstone aquifer range from 1,000 mg/l to less than 40 mg/l. On a regional scale, concentrations rarely exceed 250 mg/l. The areas with concentrations greater than 250 mg/l (as shown on Figure 33) are located in the northeast, east-central, and south central parts of the county. It is possible that these concentrations may be exceeded in some areas for which no data is available. The best quality water with respect to chlorides (less than 50 mg/l) is found in the southeastern part of the county in an area which corresponds approximately with the area of highest potentiometric levels. Over most of the county chloride concentrations are between 50 mg/l and 250 mg/l.

Two of the sampled wells showed chloride concentrations which were significantly higher than normal. Well L-2200 and well L-1977, both located in the northeastern section of the county, showed concentrations of 970 and 1,000 mg/l respectively. These wells are located in an area where flowing

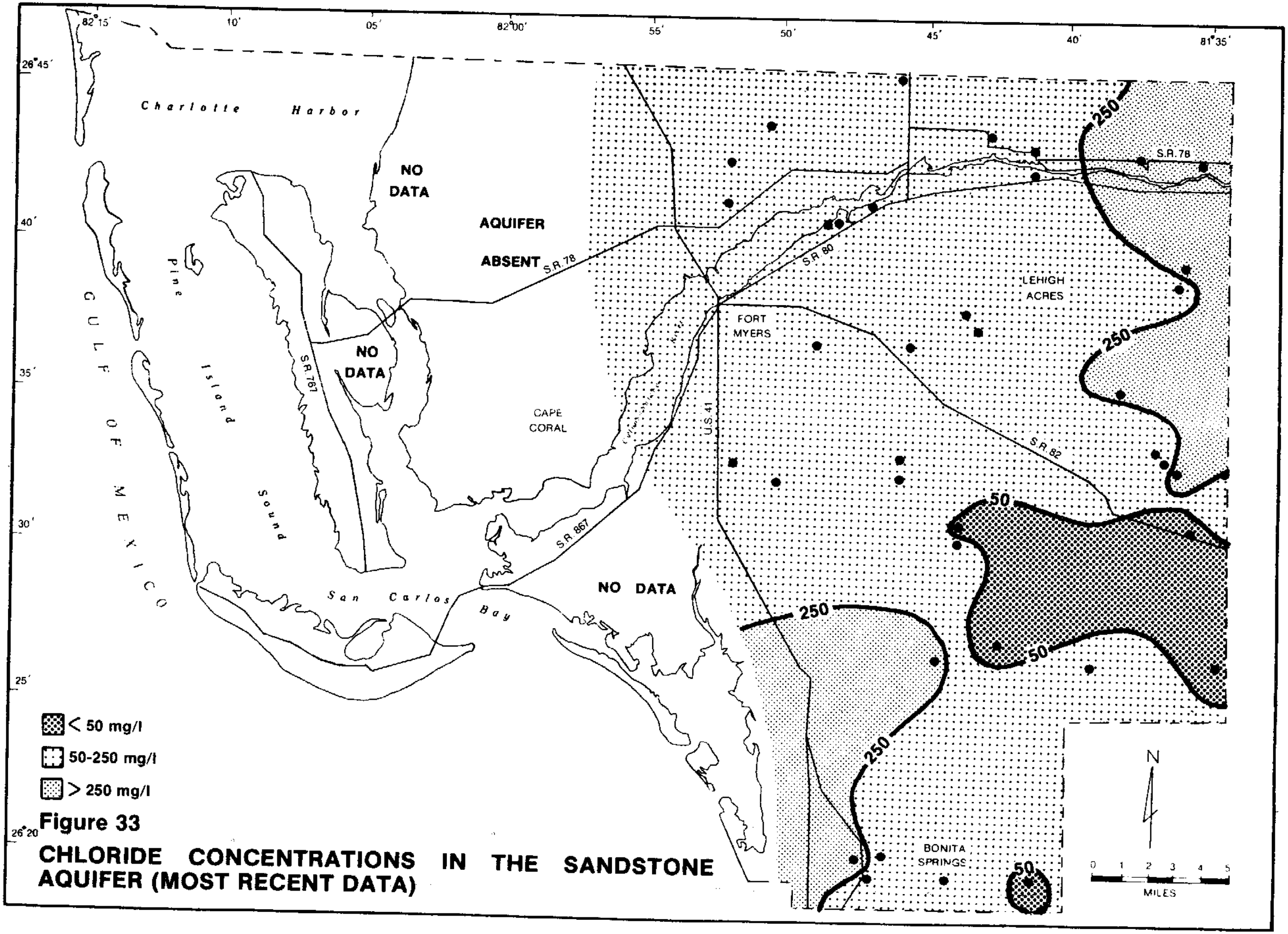


Figure 33

CHLORIDE CONCENTRATIONS IN THE SANDSTONE AQUIFER (MOST RECENT DATA)

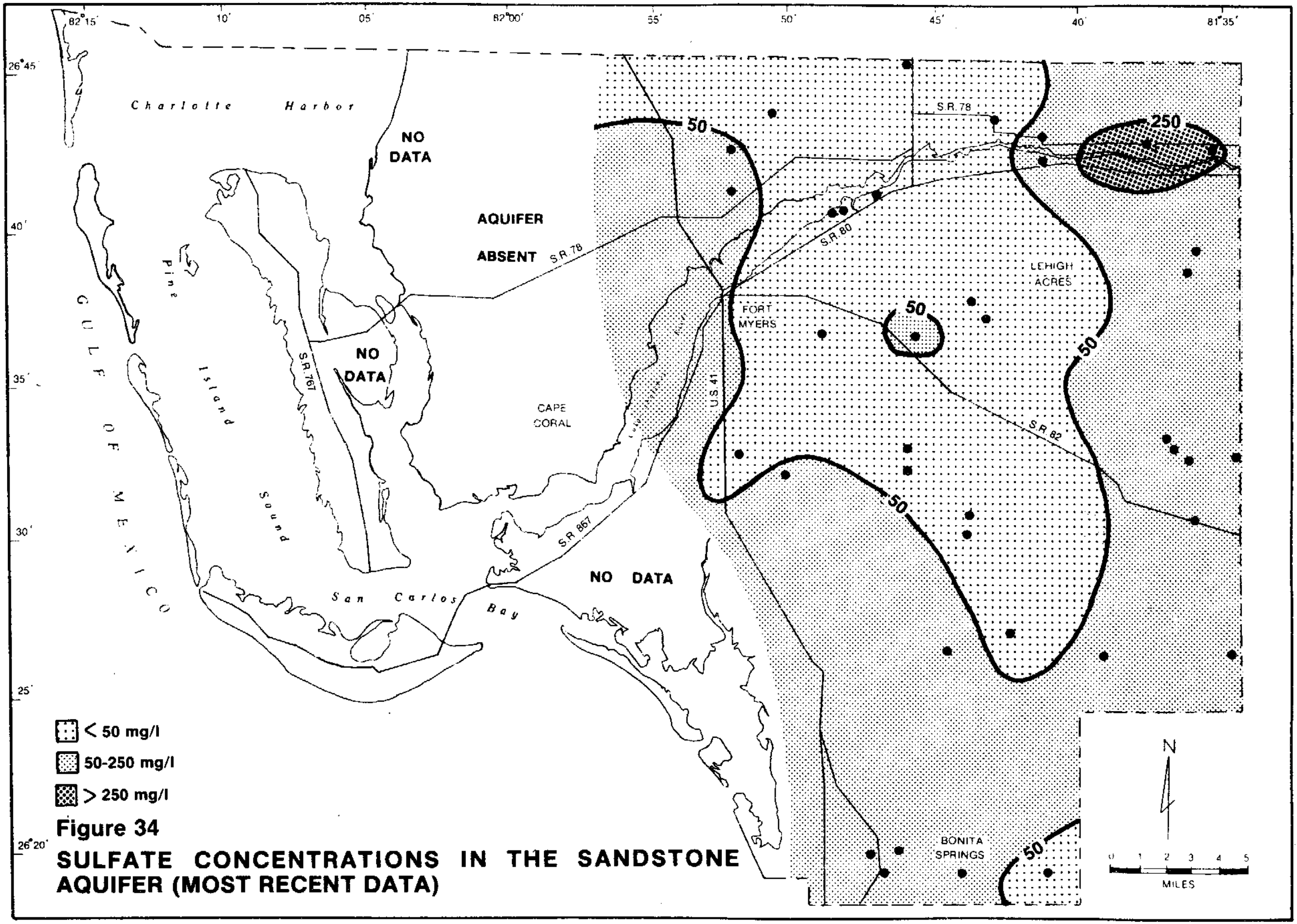


Figure 34
SULFATE CONCENTRATIONS IN THE SANDSTONE AQUIFER (MOST RECENT DATA)

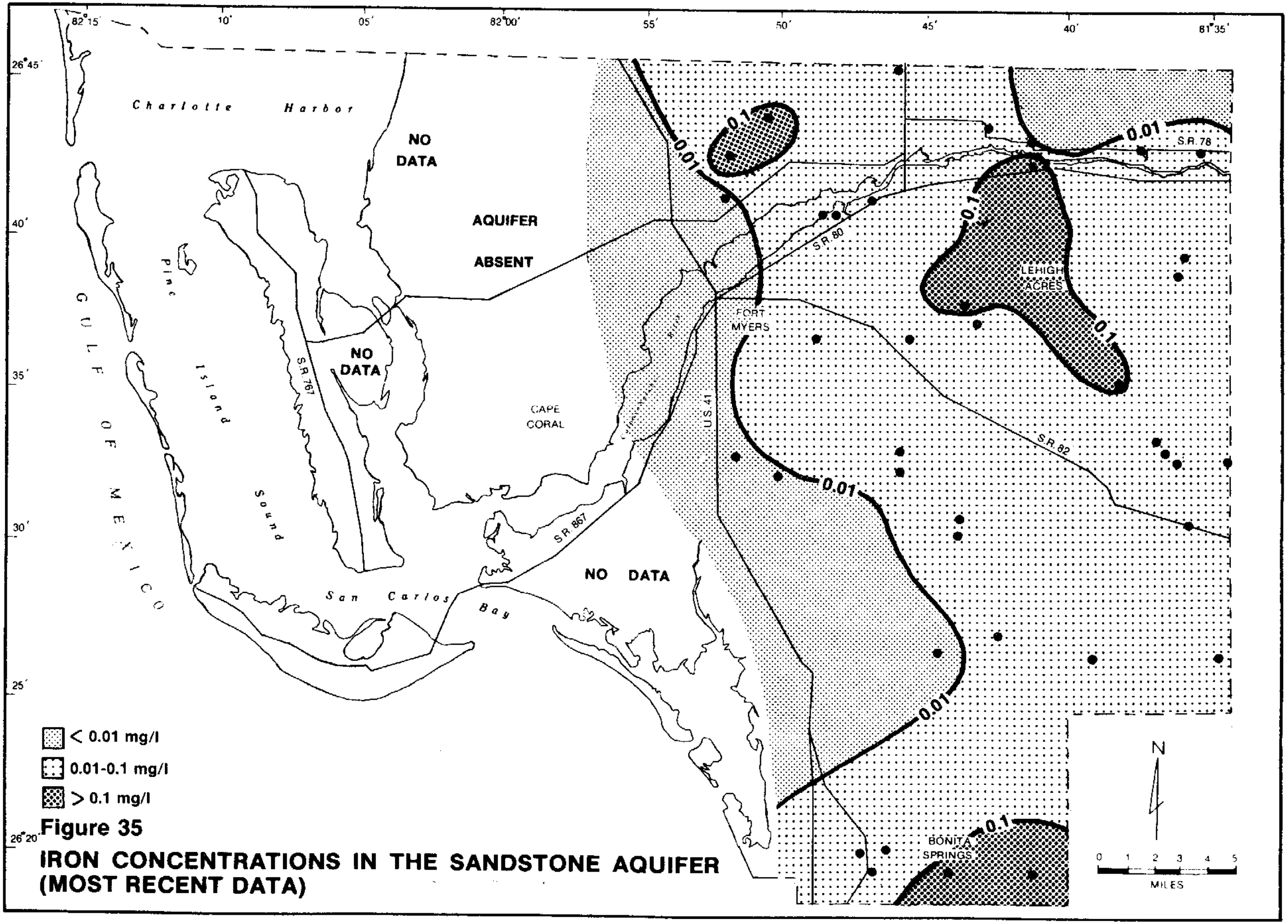


Figure 35

IRON CONCENTRATIONS IN THE SANDSTONE AQUIFER (MOST RECENT DATA)

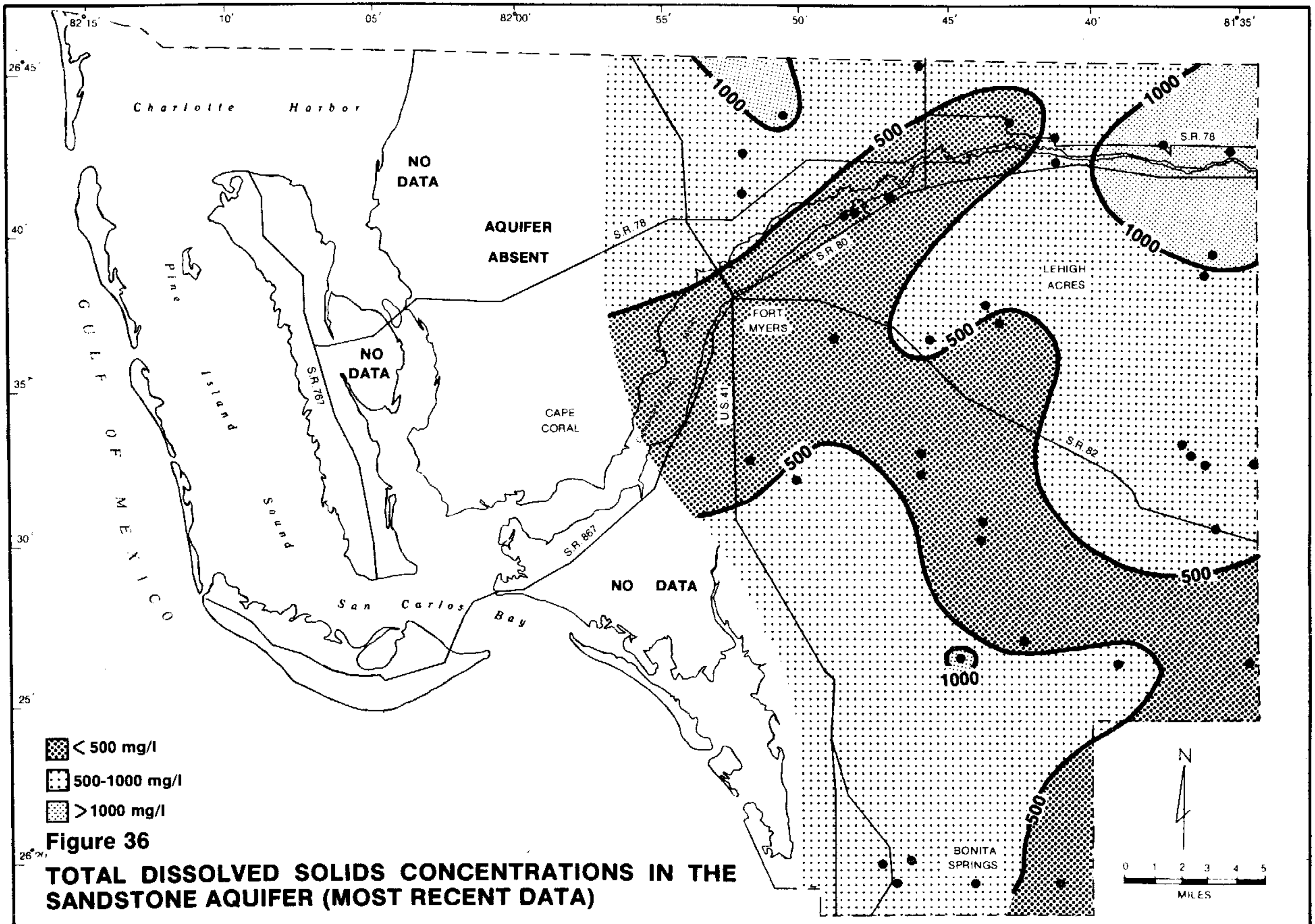


Figure 36
TOTAL DISSOLVED SOLIDS CONCENTRATIONS IN THE SANDSTONE AQUIFER (MOST RECENT DATA)

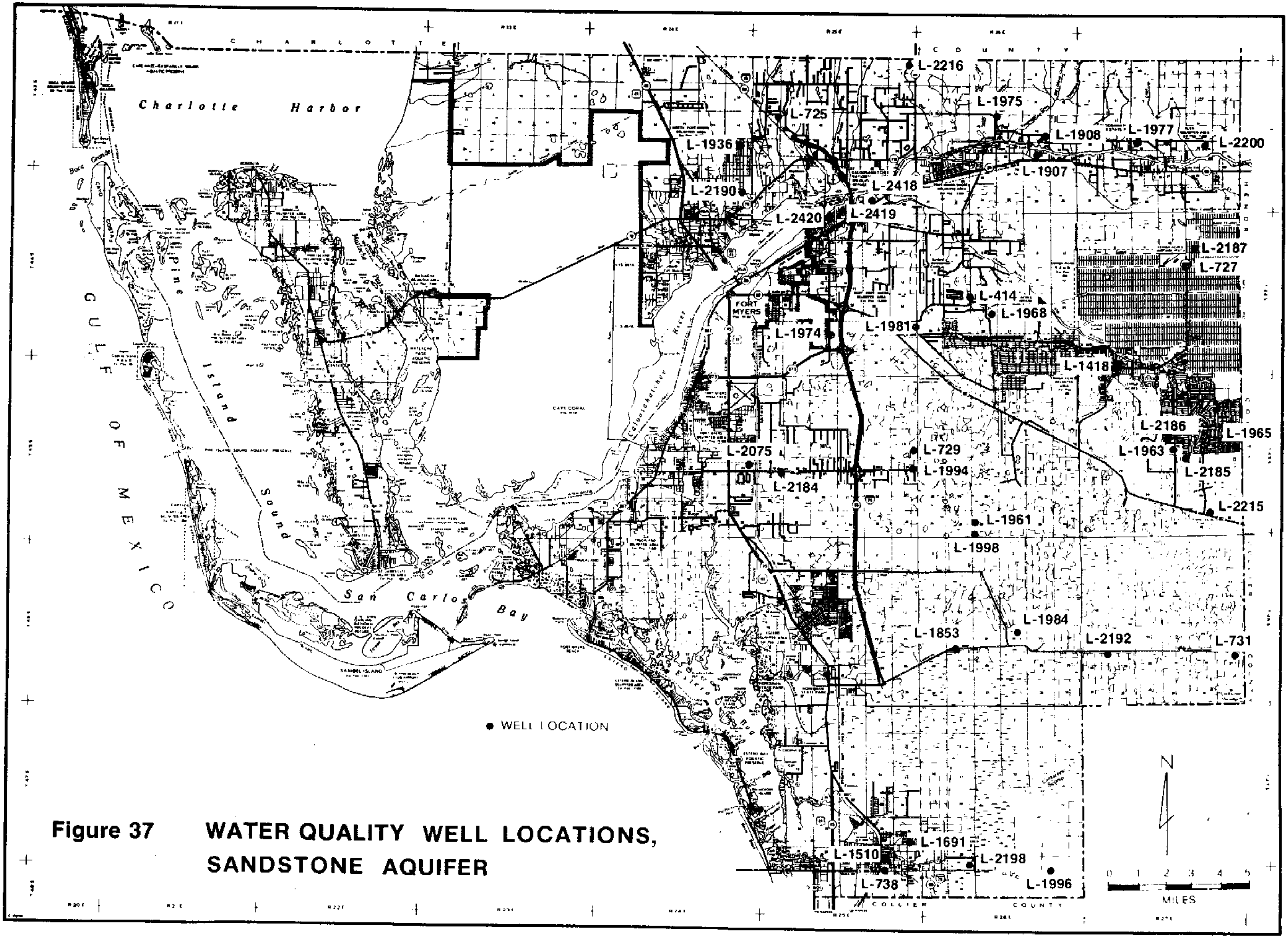


Figure 37 WATER QUALITY WELL LOCATIONS, SANDSTONE AQUIFER

abandoned wells with saline water have been located, and it is believed that the high chlorides in the Sandstone aquifer in this area originate from this source.

On a regional scale, the chloride levels are probably related to the quality of water which recharges the Sandstone aquifer from the Surficial aquifer. Local variations in chloride content may be due to contamination from flowing wells or leakage from lower aquifers. In parts of southern Lee County (west and north of Bonita Springs) where the upper Hawthorn confining zone is thin or absent, more saline groundwater from the mid-Hawthorn aquifer may mix with fresher water in the Sandstone aquifer and result in relatively poorer water quality (e.g., at well L-1853).

Sulfate

Sulfate concentrations in groundwater of the Sandstone aquifer in Lee County are generally below 250 mg/l with concentrations below 50 mg/l over a substantial part of the aquifer. Concentrations in excess of 250 mg/l are found in the northeastern part of the county in the vicinity of wells L-2200 and L-1977. These higher concentrations are probably the result of contamination by more mineralized deeper waters through abandoned wells.

Iron

Iron concentrations range from undetectable to 2.6 mg/l. Some areas show less than 0.01 mg/l while a few isolated areas have concentrations which exceed 0.1 mg/l. Over most of the area, however, concentrations are between 0.01 and 0.1 mg/l.

Total Dissolved Solids

Total dissolved solids of sampled wells in Lee County range from 360 mg/l to more than 2200 mg/l. A northwest to southeast trending band contains water of less than 500 mg/l. Over much of the rest of the area concentrations are between 500 mg/l and 1,000 mg/l. The most extensive area with total dissolved solids exceeding 1,000 mg/l is located in the northeast of the county where leakage of saline water from deep abandoned wells affect the Sandstone aquifer. In this area concentrations of 2,250 mg/l (L-1977), 1,020 mg/l (L-2187), and 2,260 mg/l (L-2200) were recorded. Only two other sampled wells showed concentrations exceeding 1,000 mg/l. These were well L-1853 located in the southern part of the county (1,010 mg/l) and well L-725 located close to the northern county line (1,170 mg/l). Well L-1510, located in the southwestern part of the county, showed a total dissolved solids content close to 1,000 mg/l (976 mg/l).

Water Quality Changes

Table 2 gives variations in concentrations of the 4 constituents discussed in this report. Most of the variations appear to be relatively minor, and may be explainable as seasonal variations or differences in the accuracy of the measurements, and may not be representative of long term trends. However, some significant variations are noted - such as at well L-725 where total dissolved solids were 717 mg/l in July 1968, 736 mg/l in April 1974, and increased to 1,170 mg/l in June 1976. In well L-1691, total dissolved solids increased from 127 mg/l in March 1974 to 502 mg/l in June 1976. The data are, however, inadequate to predict water quality trends, but indicate that long term monitoring of water quality in selected wells would be advantageous.

Table 2. WATER QUALITY CHANGES, SANDSTONE AQUIFER

Well No.	Date	Cl	SO_4	Fe	T.D.S.
L-725	Jul-68	222	31	-	717
	Apr-74	200	34	0.1	736
	Jun-76	200	35	0.15	1,170
L-727	Jul-68	208	124	-	841
	Apr-74	170	0.8	0.06	340
	Jun-76	200	130	0.03	834
L-1691	Mar-74	26	0.4	0.01	127
	Jun-76	76	53	0.15	502
L-1974	Dec-74	81	7.9	0.13	350
	Apr-76	87	11	0.04	360

Summary

Over large parts of the county water from the Sandstone aquifer meets potable water standards and is suitable for most other purposes. Although having generally higher chloride, sulfate, and total dissolved solids content than water from the Surficial aquifer, it has the advantage of having lower iron concentrations which makes it more desirable for most domestic purposes. While total dissolved solids exceed recommended limits over about 50% of the area, the water would still be acceptable for most uses. Generally, the central part of the county has the best quality water.

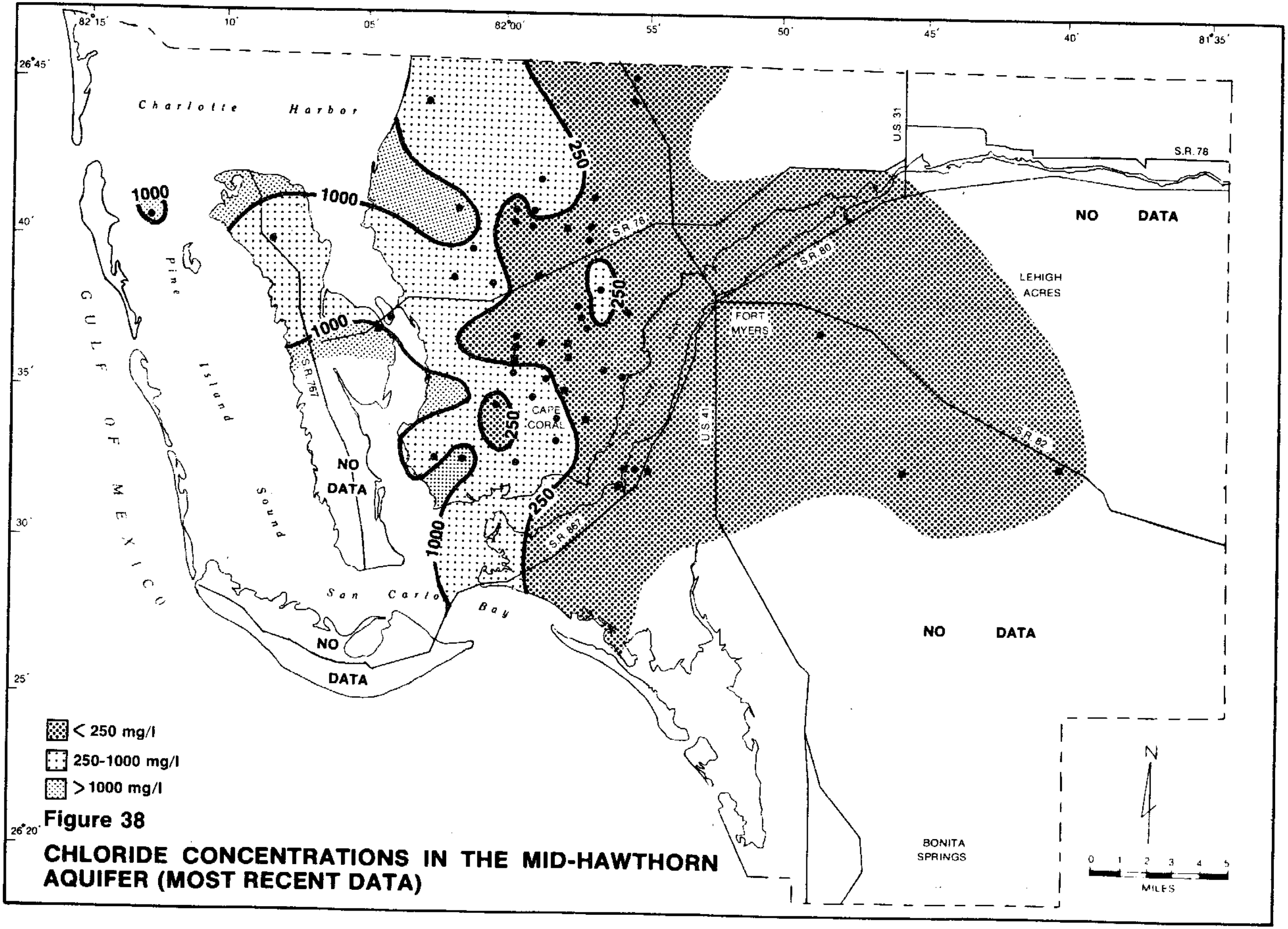
WATER QUALITY IN THE MID-HAWTHORN AQUIFER

The regional patterns of chloride, sulfate, iron, and total dissolved solids concentrations in the mid-Hawthorn aquifer are shown on Figures 38, 39, 40, and 41. Figure 42 identifies the data points used in constructing the maps. The data on which the maps are based are given in Appendix 4-3. Most of the data points are located in the western part of the county and there are substantial parts of the area for which no data were available.

Chlorides

Chloride concentrations from the sampled wells ranged from 50 mg/l to 2,500 mg/l. Generally, chlorides are lower in the central and eastern parts of the county and increase westward towards the Gulf. Figure 38 indicates noticeably higher concentrations in the Cape Coral area which corresponds to the pumping depression shown on Plates 25 and 26 (Atlas).

The highest chloride concentration of 2,500 mg/l was found in well L-2180 which is located on Mondongo Island. It is possible that chlorides are high in the mid-Hawthorn aquifer in all the Barrier Islands, although the available data are inadequate to confirm this. Lower chloride concentrations (1,000 mg/l and 650 mg/l) were recorded from wells L-434 and L-2820 on Pine Island.



< 250 mg/l

250-1000 mg/l

> 1000 mg/l

Figure 38

CHLORIDE CONCENTRATIONS IN THE MID-HAWTHORN AQUIFER (MOST RECENT DATA)

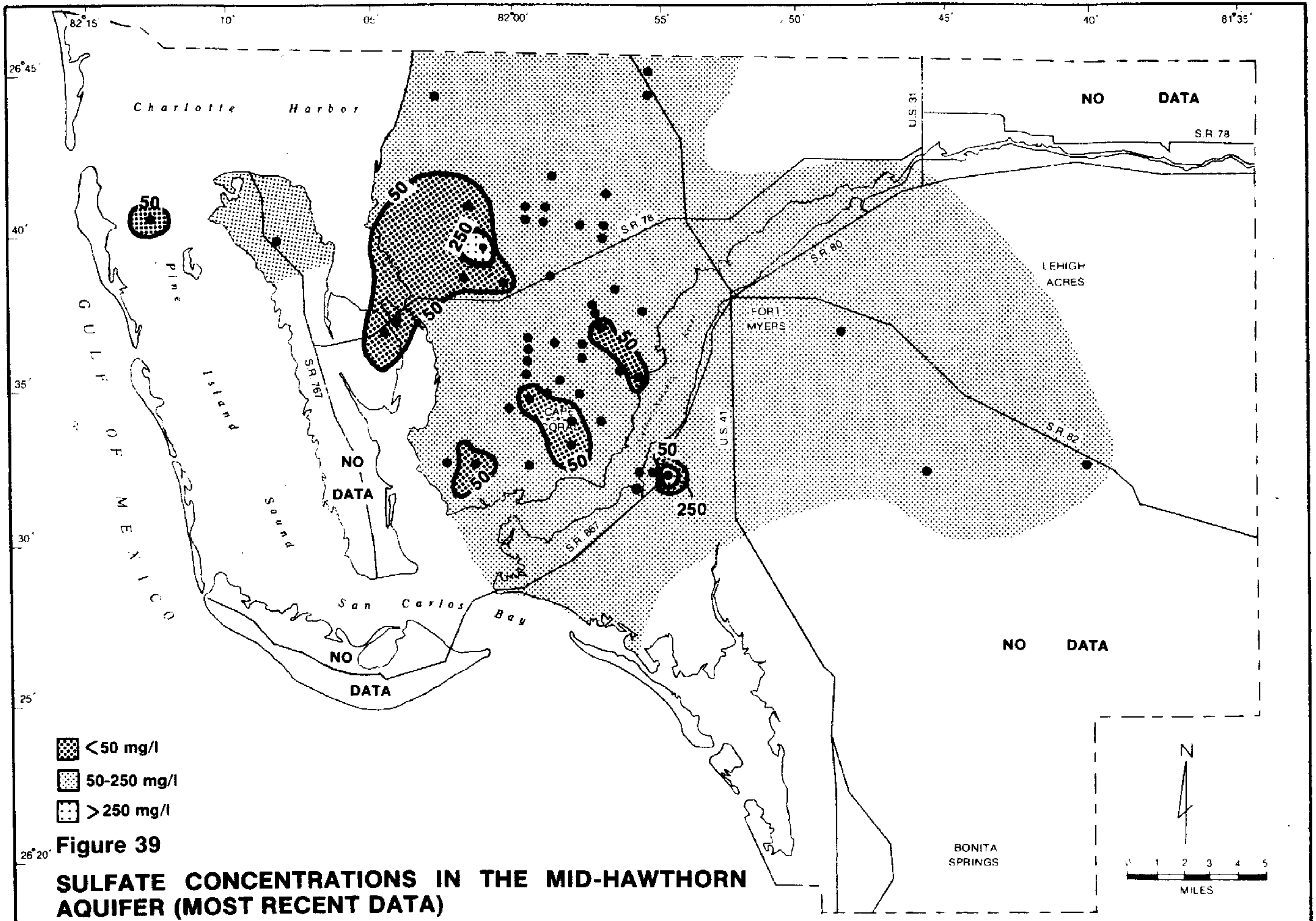


Figure 39

SULFATE CONCENTRATIONS IN THE MID-HAWTHORN AQUIFER (MOST RECENT DATA)

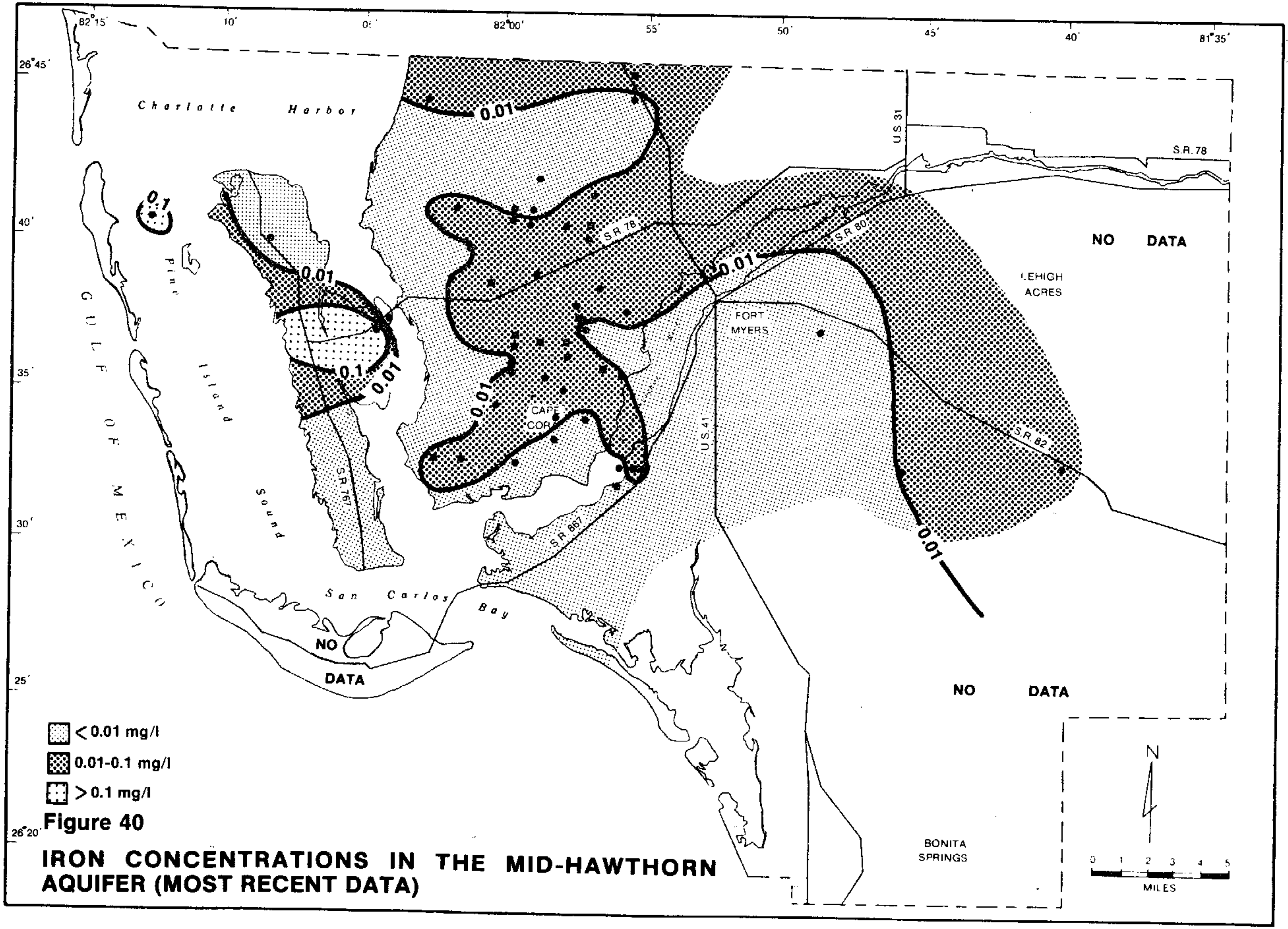


Figure 40

IRON CONCENTRATIONS IN THE MID-HAWTHORN AQUIFER (MOST RECENT DATA)

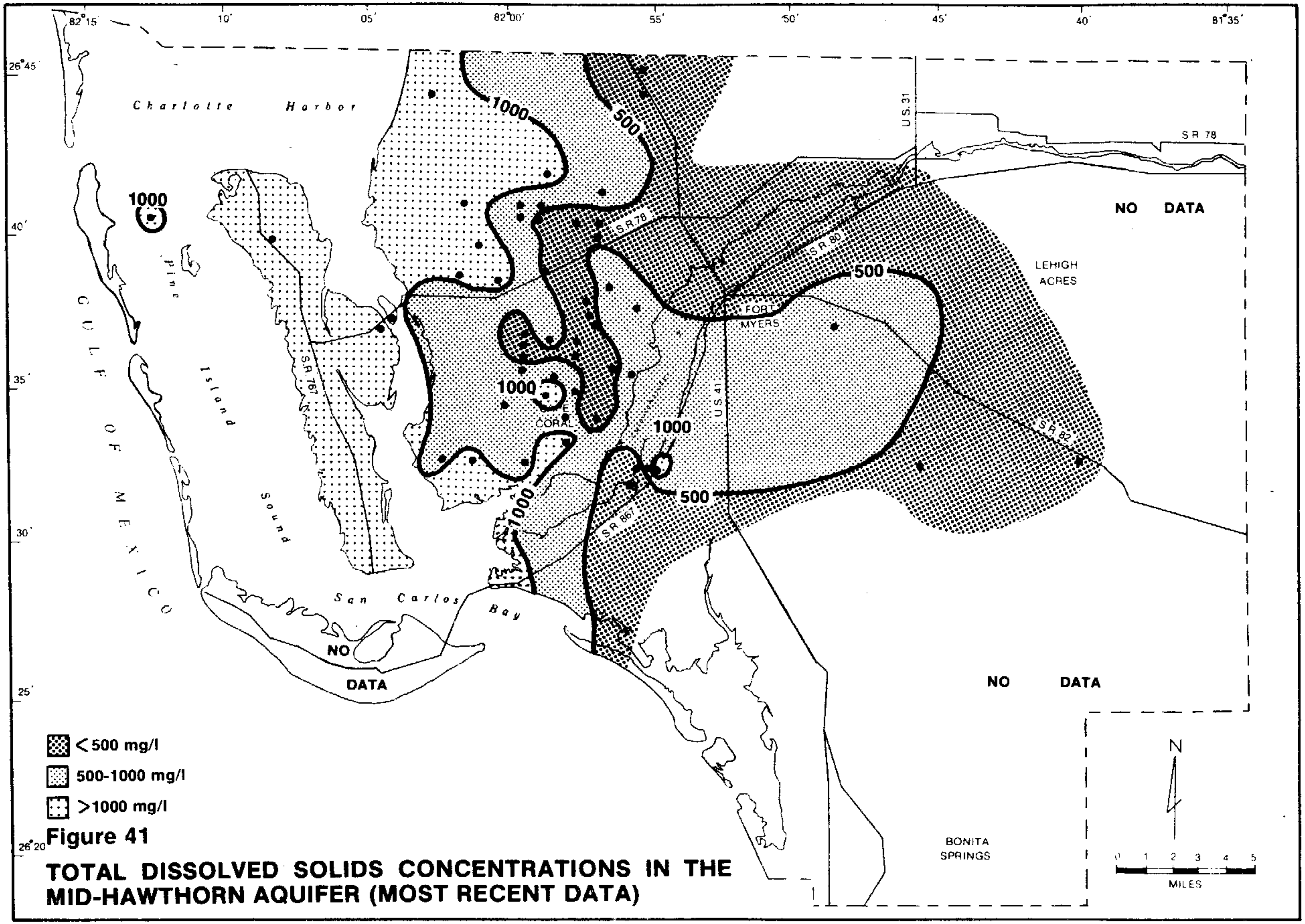


Figure 41

TOTAL DISSOLVED SOLIDS CONCENTRATIONS IN THE MID-HAWTHORN AQUIFER (MOST RECENT DATA)

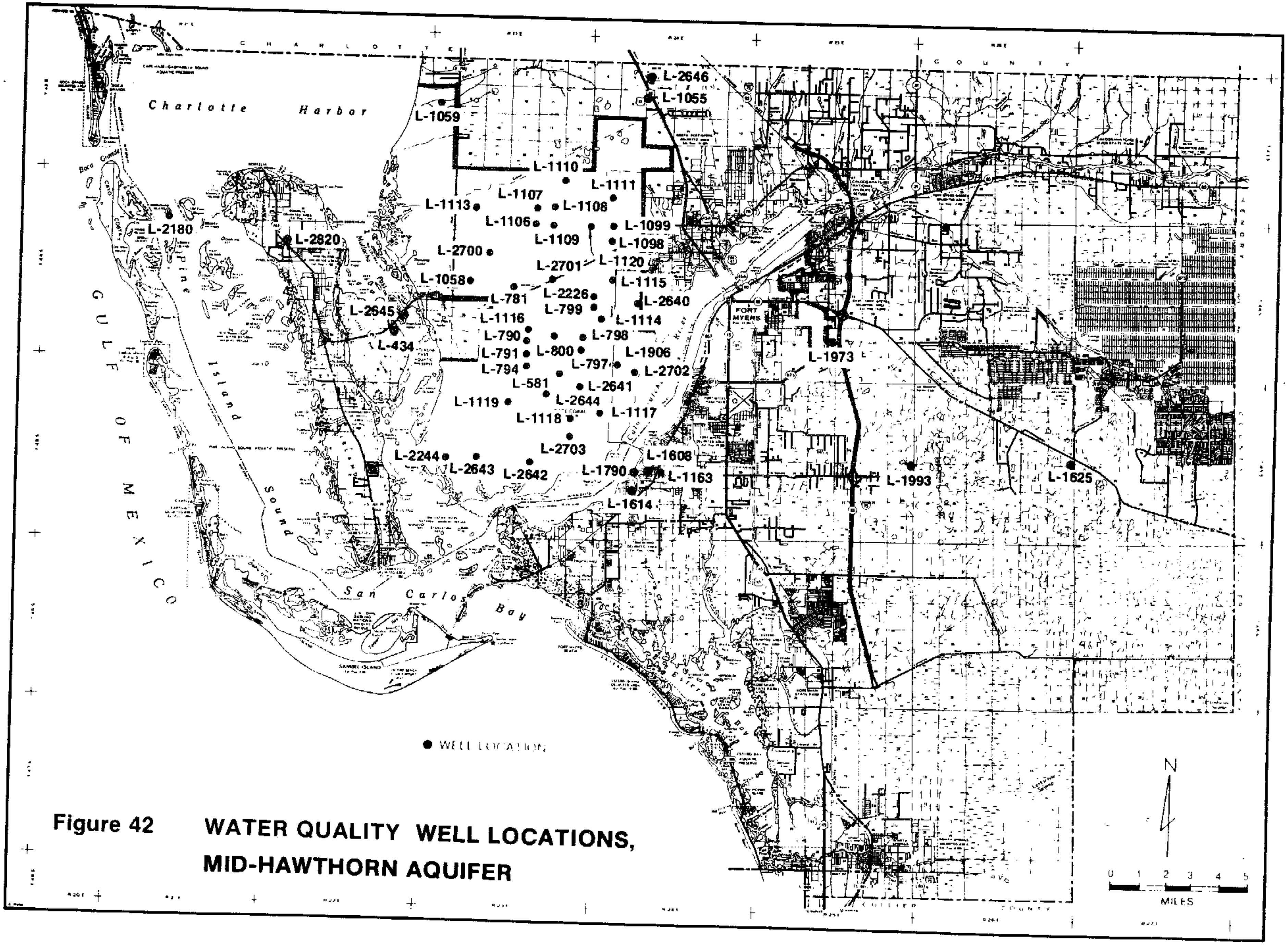


Figure 42 WATER QUALITY WELL LOCATIONS, MID-HAWTHORN AQUIFER

Chloride concentrations exceeded 500 mg/l at six other locations (wells L-1058, L-1113, L-1163, L-2643, L-2644, and L-2700). At three of these six locations (L-1113, L-1163, and L-2643) chlorides exceeded 1,000 mg/l. Well L-1163 is located within a deep depression in the potentiometric surface, and probably reflects the effects of local overpumping. Wells L-1113 and L-2643 are located westward toward the Gulf and probably indicate lateral movement of saline water due to regional overpumping.

A substantial part of the aquifer has water with chloride concentrations less than 250 mg/l. Although data coverage is not complete, it is expected that the aquifer in most of the area east of the 250 mg/l contour line has water of similar or better quality, except in local areas where saline artesian wells have contaminated the aquifer.

Sulfate

Sulfate concentrations range from 10 mg/l to 380 mg/l, but most of the area for which data was available showed concentrations less than 250 mg/l. Two wells showed concentrations above 250 mg/l (L-2700 and L-1163). The high sulfates are related to the presence of high chloride waters at these locations, although sulfates are not noticeably high at other locations which show high chlorides. It is concluded that these high sulfate concentrations result from upward movement of deeper groundwater probably through abandoned wells.

Iron

Iron concentrations are consistently low in the mid-Hawthorn aquifer in the area for which data is available. Concentrations range from undetectable to 1.6 mg/l. The highest value (1.6 mg/l) is found on Pine Island. However, apart from this one sample, all other concentrations are less than 0.1 mg/l, and in a large part of western and southern Lee County, concentrations appear to be less than 0.01 mg/l.

Total Dissolved Solids

Total dissolved solids concentrations in the mid-Hawthorn aquifer range from 4,960 mg/1 to 309 mg/1. Lowest concentrations are found in the eastern portion of the county, with concentrations increasing to the west. The highest value (4,960 mg/1) is found in well L-2180 located on Mondongo Island, and it is expected that groundwater from this aquifer as in all the barrier islands also has high concentrations of total dissolved solids. Concentrations in groundwater from this aquifer on Pine Island and West Island (east of Pine Island) exceed 1,000 mg/1. Wells L-1113, L-1163, L-2643, L-2644, and L-2700 (located on the mainland) show concentrations in excess of 2,000 mg/1. Two isolated areas with concentrations in excess of 1,000 mg/1 are located in Cape Coral (well L-2644 with 2,240 mg/1) and southeast of Cape Coral (well L-1163 with 2,890 mg/1). These highly mineralized waters probably reflect the effect of over-withdrawals in these areas.

Water Quality Trends

The limited historical data available (Table 3) indicate some deterioration of water quality with time. For example, well L-581 showed an increase in total dissolved solids from 580 mg/1 in April 1978 to 717 mg/1 in May 1979. Well L-1099 showed an increase in total dissolved solids from 393 mg/1 in June 1975 to 568 mg/1 in April 1978. More detailed monitoring of long term variations in water quality in this aquifer is required.

TABLE 3. WATER QUALITY CHANGES, MID-HAWTHORN AQUIFER

Well No.	Date	Cl	SO_4	Fe	T.D.S.
L-581	Apr-78	250	15	-	580
	May-79	250	14	0.03	717
L-1059	Aug-75	440	13	0.01	1,028
	Apr-78	450	17	-	1,050
	May-79	440	15	0.01	1,110
L-1099	Jun-75	72	12	0.03	393
	Apr-78	150	45	-	568
L-1973	Dec-74	180	31	0.0	603
	Mar-76	190	38	0.02	607

Summary

The mid-Hawthorn aquifer has generally poorer water quality than either the Surficial or the Sandstone aquifers. Water of acceptable quality for most uses is, however, available in the central and eastern parts of the county, east of Cape Coral. In the areas of heavy groundwater withdrawals such as Cape Coral and adjacent areas, the evidence indicates that water quality has deteriorated. Based on the trends shown on the water quality maps, it may be assumed that relatively good quality water exists in the aquifer towards the east, in areas for which no data was available. The barrier islands may, however, be assumed to have poor quality water in this aquifer.

WATER QUALITY IN THE FLORIDAN AQUIFER SYSTEM

The lithologic and stratigraphic complexity of the Floridan Aquifer System in Lee County is reflected in the lateral and vertical variability of water quality within the system. Groundwater in this system tends to become more mineralized as distance from the primary recharge areas increases. In Lee County, which is located more than 100 miles from the principal recharge area, water quality in the Floridan Aquifer System is poor. Generally, water quality deteriorates with depth in the Floridan Aquifer System. However, local variations in quality may be caused by variations in the rate of groundwater movement in different layers, or by interchange of water between aquifers and producing zones.

Data specific to individual aquifers and producing zones within the Floridan Aquifer System are limited. Most of the wells which penetrate these units are open to more than one unit, and consequently wellhead samples represent a mixture of waters from various zones. The scope of this study did not allow for the construction of properly cased monitoring wells or the use of packers to isolate specific zones. Some data on water quality at various depths were, however, obtained from borehole geophysical surveys and point sampling in existing deep wells. In wells which penetrated more than one aquifer or producing zone, corrected flow log data and point sample data were used to estimate some water quality parameters in each zone. Specific conductance data were obtained from Fluid Resistivity surveys which were accurately calibrated against a conductivity bridge. Chloride is the most commonly identified and abundant chemical constituent in waters of the Floridan Aquifer System, and it is the chloride concentration that largely determines the conductivity of the water. For most direct uses, and for domestic treatment processes such as reverse osmosis, chloride and total dissolved solids concentrations are of particular interest. Both chloride concentrations and conductivity are relatively easy to determine in the field. Total dissolved solid concentrations can be estimated from specific conductance data using the empirical relationship shown on Figure 43. For these reasons, a discussion of specific conductance data from the Floridan Aquifer System is included in this section.

Water quality data shown on Figures 44 through 47 were derived from the U. S. Geological Survey's water quality monitoring network. Almost all of the 51 wells represented are cased into the lower Hawthorn confining zone (Plates 14-20, Atlas) and are open hole for the remainder of the total depth of the well. The wells vary as to the producing zones they monitor and include producing beds within the lower Hawthorn confining zone, the Tampa Limestone of Sproul, et al. (1972), and the top of the Suwannee aquifer. All of these wells are, to varying degrees, open to Sproul's lower Hawthorn aquifer and this designation is used on these water quality maps. As previously explained, the most productive part of Sproul's lower Hawthorn aquifer is considered to be a part of the Floridan Aquifer System.

Figures 44, 45, 46, and 47 show the gross distribution of chloride, sulfate, iron, and total dissolved solid concentrations. Data points used to prepare these maps are identified on Figure 48. The data on which the maps are based are given in Appendix 5.

Chlorides

Chloride concentrations vary from 200 mg/l to 4300 mg/l. Only 11 of the 51 wells sampled had chloride concentrations less than 500 mg/l. The wells which show low chloride values are scattered throughout the county and do not appear to represent any regional trend. They may, however, indicate vertical variations in water quality within the aquifer or poor isolation of the lower Hawthorn aquifer within the well bore.

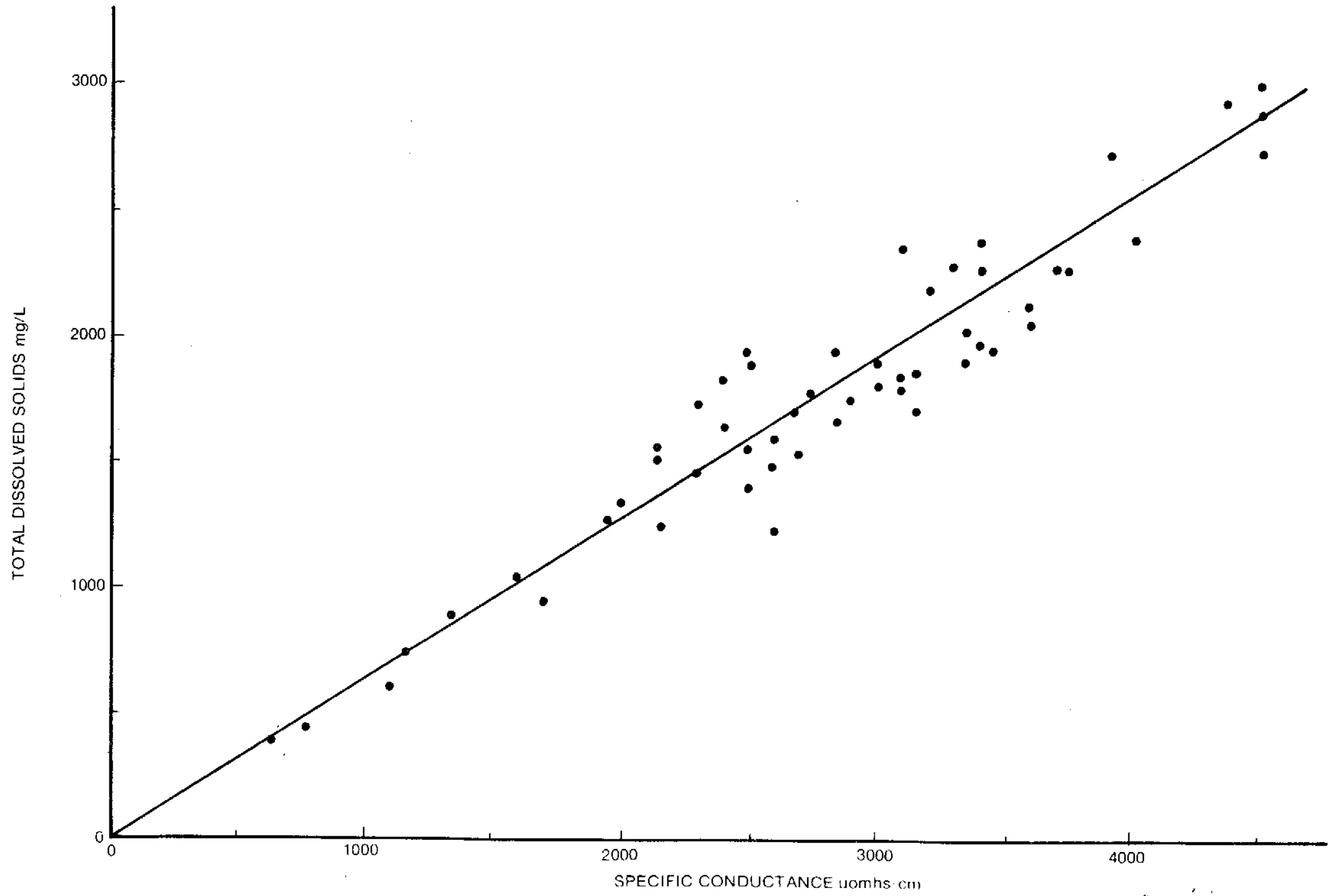


Figure 43 SPECIFIC CONDUCTANCE AS RELATED TO TOTAL DISSOLVED SOLIDS. COMPILED FROM LOWER HAWTHORN/TAMPA AND SUWANNEE AQUIFER DATA IN LEE COUNTY

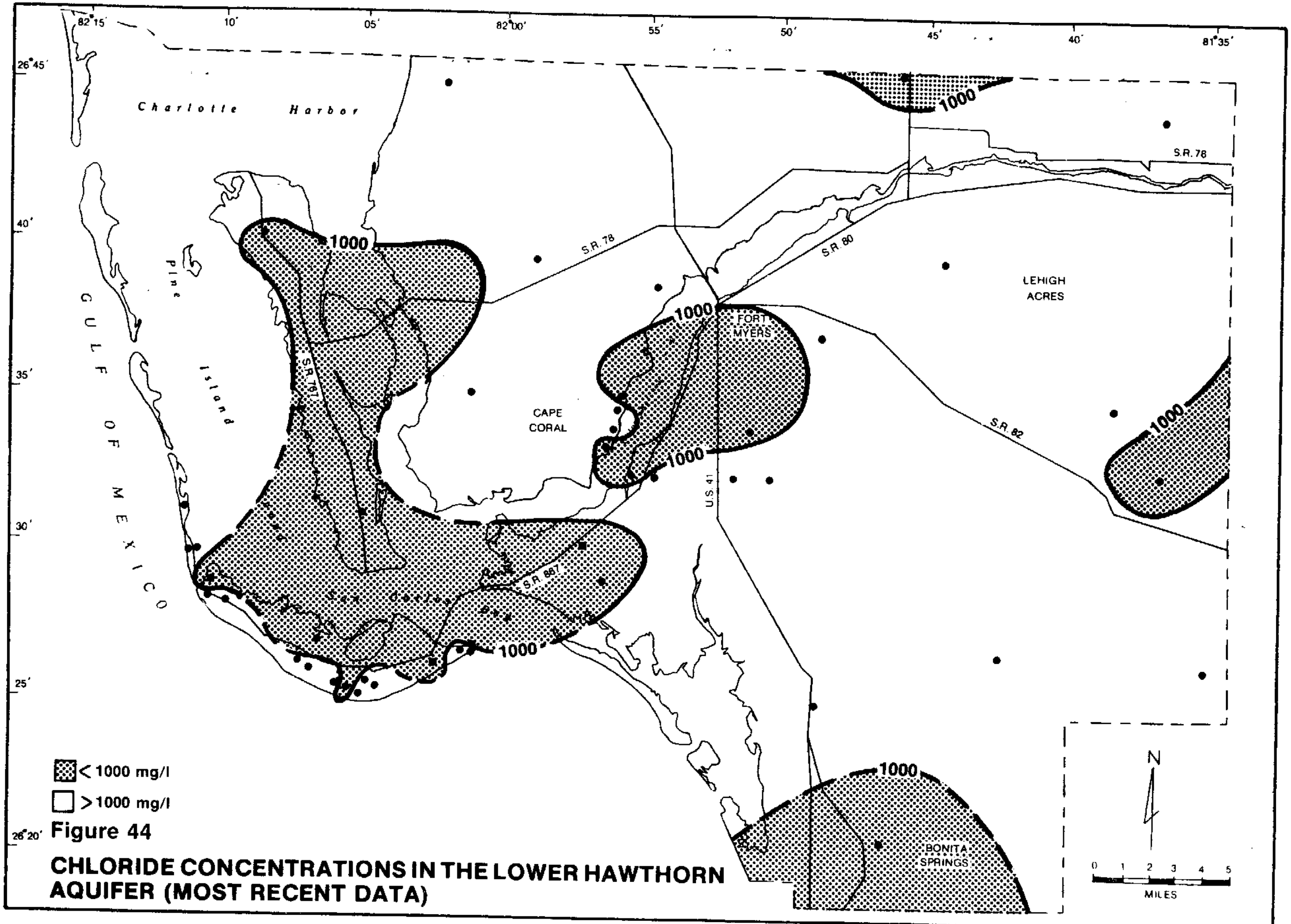


Figure 44

CHLORIDE CONCENTRATIONS IN THE LOWER HAWTHORN AQUIFER (MOST RECENT DATA)

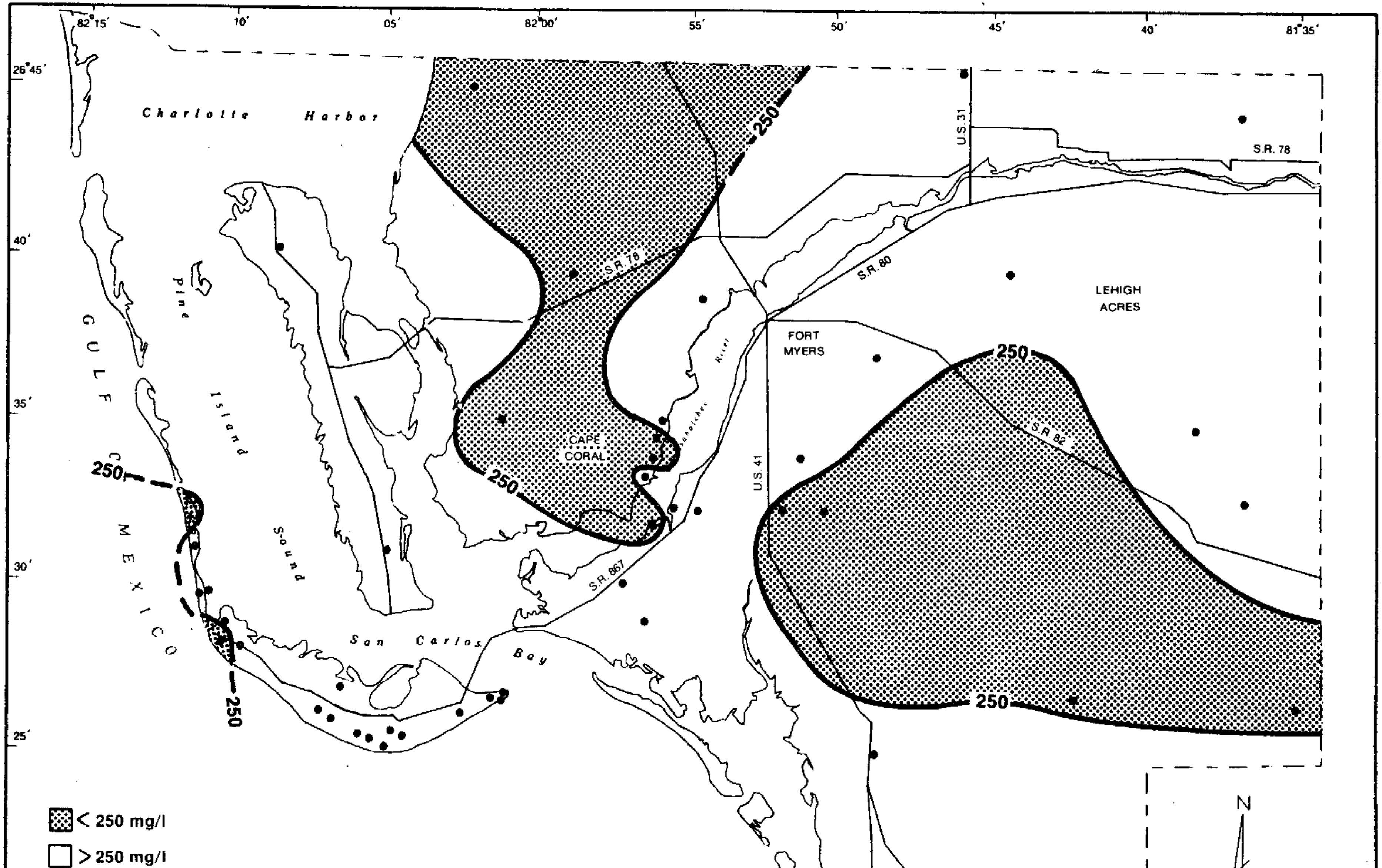


Figure 45

SULFATE CONCENTRATIONS IN THE LOWER HAWTHORN AQUIFER (MOST RECENT DATA)

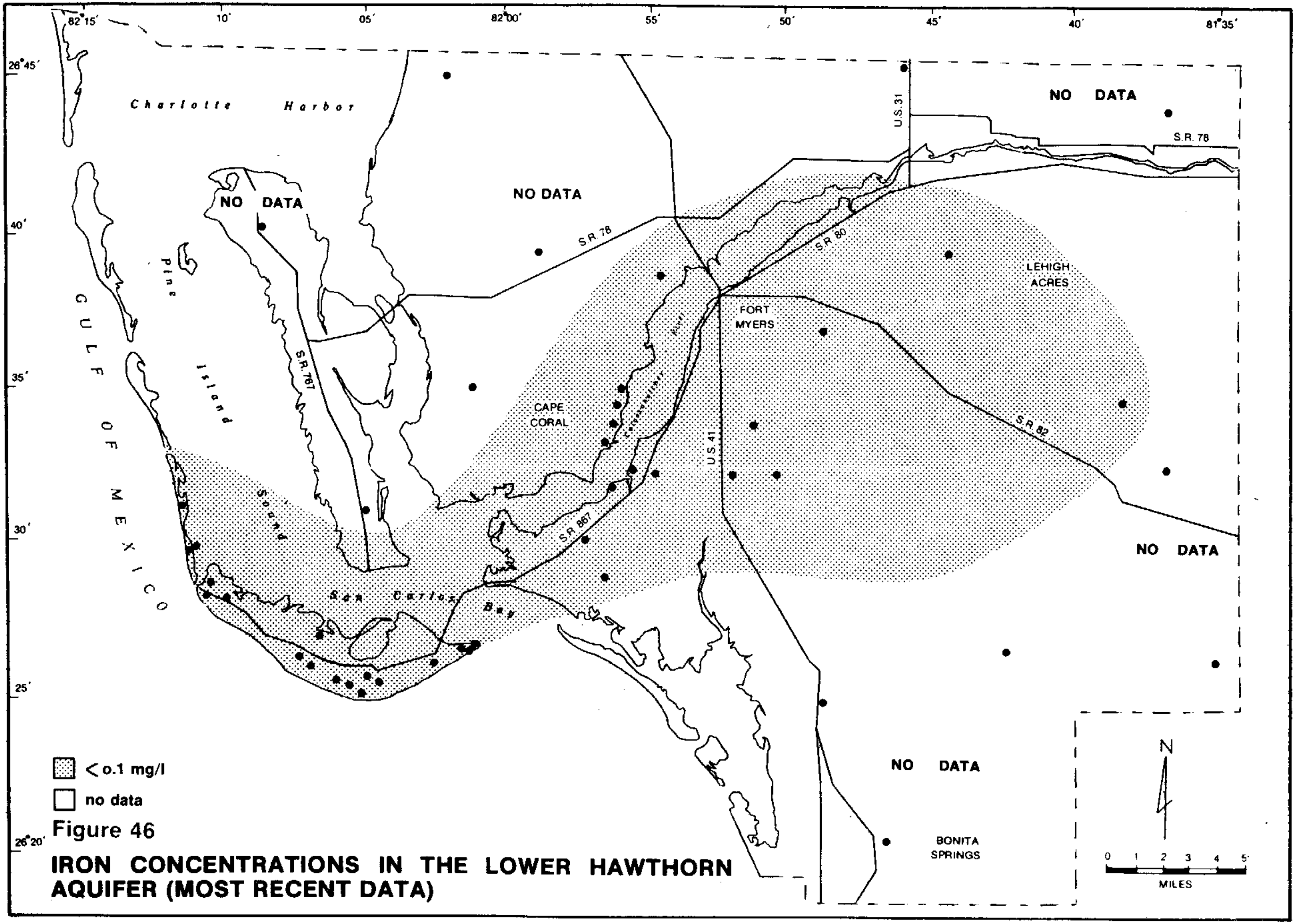


Figure 46

IRON CONCENTRATIONS IN THE LOWER HAWTHORN AQUIFER (MOST RECENT DATA)

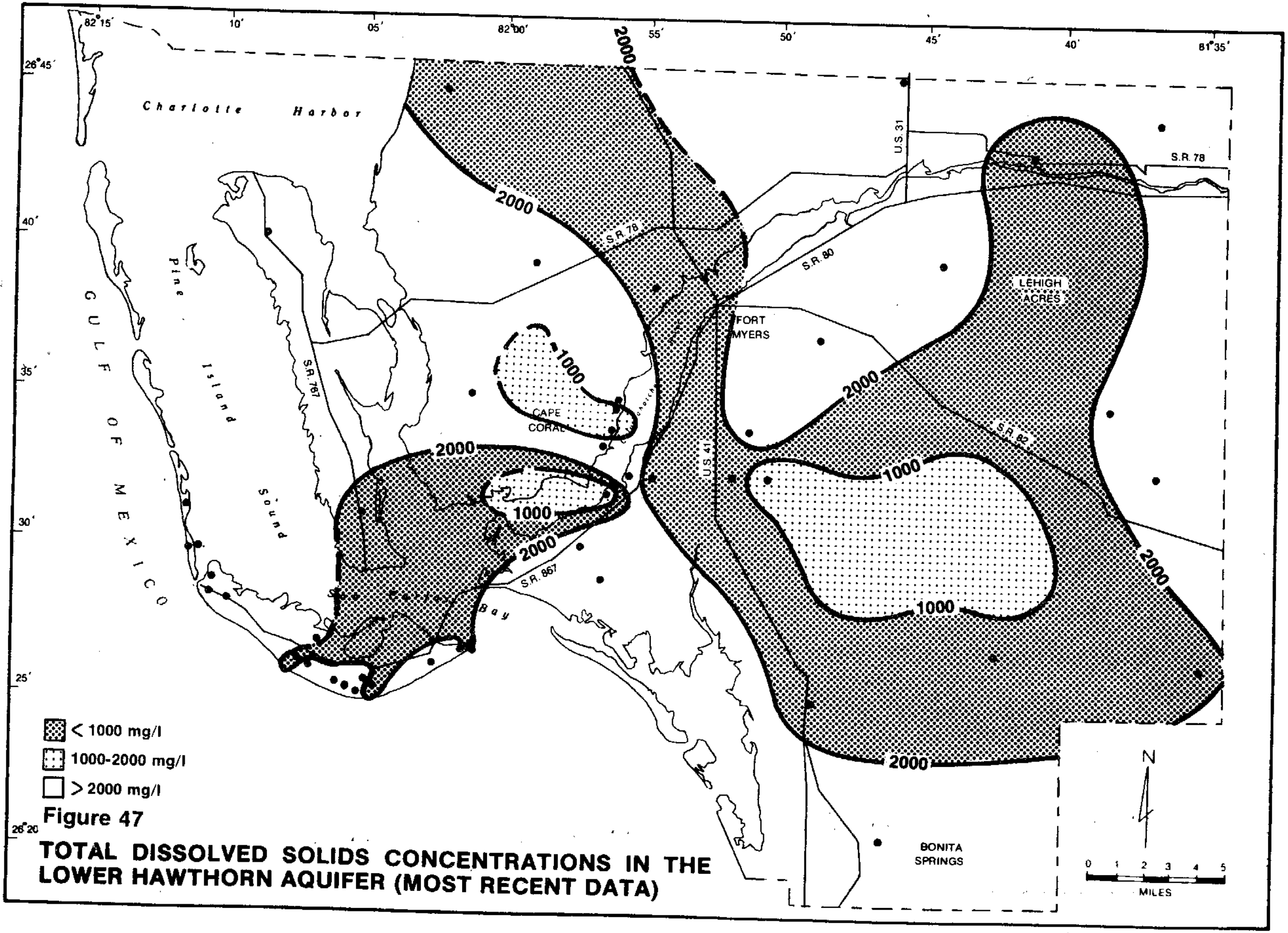


Figure 47

TOTAL DISSOLVED SOLIDS CONCENTRATIONS IN THE LOWER HAWTHORN AQUIFER (MOST RECENT DATA)

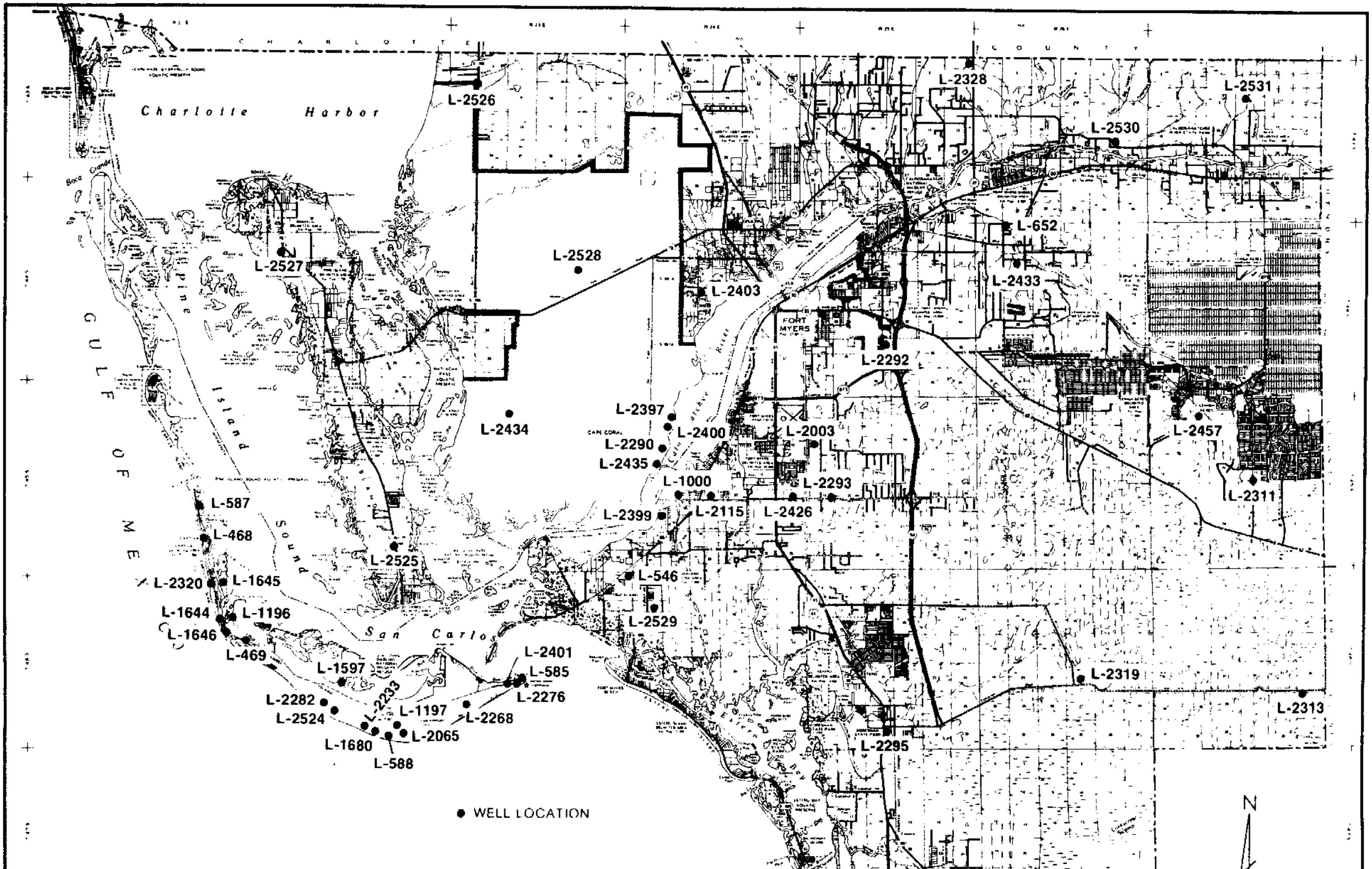


Figure 18 WATER QUALITY WELL LOCATIONS, LOWER HAWTHORN AQUIFER

Over most of the area, chloride concentrations are between 500 mg/l and 1000 mg/l. Five areas are shown on Figure 44 where chlorides exceed 1000 mg/l. Three of these areas have been delineated on the basis of a single well - each with concentrations in excess of 1000 mg/l. The well near Bonita Springs (Well L-2310) showed concentrations of 2900 mg/l while concentrations in the other two wells were 1200 mg/l (Well L-2311) and 1100 mg/l (Well L-2328). In the other two areas, chloride concentrations above 1000 mg/l are found in a number of wells. These areas include parts of Fort Myers, Pine Island, and Sanibel Island. The highest chloride concentration (4300 mg/l) was found in Well L-2397 located in Cape Coral.

Very little data on chloride concentrations specific to the lower Hawthorn/Tampa producing zone exists. The information available, however, indicates that areally, water quality in this zone varies from potable quality to more than 5000 mg/l, but that there is little vertical variation. For example, water samples taken during reverse air drilling of an exploratory well in north-central Lee County (Well 12, Plate 1, Atlas) shows a maximum of 1000 mg/l and a minimum of 900 mg/l chloride within this zone. However, at Alden Pines on Pine Island (Well 20, Plate 1, Atlas) and on Sanibel Island (Well 56, Plate 1, Atlas) some variation in water quality in thin producing beds within this zone have been reported (Missimer and Associates, Inc., 1978 and 1981).

Variations in chloride concentrations with time appear to be influenced by factors such as withdrawals from the aquifer and leakance across semi-confining beds. A well located east of Fort Myers (shown as WA-45 on Figure 50) which is used only during the dry season, was tested in April 1946 and at that time showed a chloride concentration of 890 mg/l. When retested during January 1980, the chloride concentration was 970 mg/l. It can be concluded from these two analyses that very little variation in chloride concentrations occurred during this 34 year period. In contrast, a well near Iona (shown on Figure 50 as WA-144) was continuously used to supply water to an irrigation system. In September 1950, the chloride concentration was 1180 mg/l, and 30 years later, in May 1981, had increased to 5635 mg/l, probably reflecting the effects of continued use of the well.

The high ranges in chloride concentrations are generally found in localized pockets which are scattered throughout the county; examples of these are a well in north Cape Coral (WA-147, Figure 50) which showed a concentration of 4300 mg/l, and the previously mentioned well WA-144 at the end of Bass Road in central Lee County,which had a concentration of 5635 mg/l. However, in the southern part of the county, near Bonita Springs, the high chloride concentrations in the aquifer are more consistent. Well L-2310 in Bonita Springs is considered to tap this producing zone, and this well showed chloride concentrations of 2900 mg/l. Boggess (1974) found that waters in the lower Hawthorn aquifer near Bonita Springs showed higher chloride concentrations than were found in the same horizon in other parts of the county, except for those areas where intrusion from deep artesian sources had occurred. This may not be representative of the lower Hawthorn/Tampa producing zone as defined in this report, however, since the data on which this conclusion was based were derived from wells which, for the most part, did not penetrate the lower Hawthorn/Tampa producing zone.

Other areas, where high chloride concentrations have been found in this zone, are the Gulf coast and Sanibel, Captiva, and Pine Islands, although some wells located in these areas show relatively low concentrations (eg., Well L-1645 on Sanibel Island, 340 mg/l; Figure 48). Missimer reported test well data from wells on Sanibel Island which showed increasing salinity with depth (Missimer and Associates, Inc., 1978, 1981), and suggested that the localized zones with relatively fresh water are limited in yield and subject to contamination from below.

Areas of low chloride concentrations occur on a more regional and consistent basis in the west central part of Lee County. The lowest reported chloride concentration in this area was at Well WA-26 in northwestern Lehigh Acres (239 mg/l). However, concentrations of 226 mg/l and 190 mg/l have been reported for Well WA-110 (Figure 50) on Bunch Beach and Well L-587 on Captiva Island. These wells, however, probably do not penetrate the full thickness of this zone.

Very little data on chloride concentrations is available for the underlying Suwannee aquifer. Missimer reported a chloride concentration of 20,000 mg/l from samples taken near the base of the Suwannee aquifer in a well at Bokeelia (Well No. 20, Plate 1, Atlas). However, water samples taken from the aquifer during reverse air drilling of a well at the Landings Development (Well 44, Plate 1, Atlas) and a well in north-central Lee County (Well 12, Plate 1, Atlas) both showed substantially lower chloride concentrations (1350 mg/l and 700 mg/l, respectively).

The deeper aquifers which underlie the Suwannee aquifer are generally believed to contain water which is too highly mineralized for direct use for most purposes. This conclusion is supported by the fact that in Well 20 (see Atlas) water quality at the base of the Suwannee aquifer already showed chloride concentrations of 20,000 mg/l. However, substantial areal variations in chloride concentrations appear to occur in the aquifer, although data to support this conclusion is sparse. A recently drilled well in Lee County (Well 12, Plate 1, Atlas) showed concentrations below 800 mg/l 300 feet below the base of the Suwannee aquifer. The quality of this water was better than that of waters from the lower Hawthorn/Tampa producing zone or the upper portion of the Suwannee aquifer. Other wells penetrating the deeper aquifers in southern and eastern Lee County have been reported by drillers to contain better quality water than the overlying Suwannee aquifer, but these reports are unconfirmed.

Sulfate

The sulfate concentrations shown on Figure 45 are considered representative of concentrations in the upper part of the Floridan Aquifer System. No data are available for the Suwannee and deeper aquifers. Concentrations range from 20 mg/l to 890 mg/l. Over most of the area concentrations exceed 250 mg/l. Four areas are shown on Figure 45 where sulfate concentrations are less than 250 mg/l. The two major areas are located in the northeast and central parts of the county. Two isolated wells located on the barrier islands also show low concentrations.

Iron

Iron concentrations shown on Figure 46 are representative of concentrations in the upper part of the Floridan Aquifer System. Although no data are available for the deeper parts of the System, it is believed that concentrations are similar throughout. The shaded portion of Figure 46 represents the area within which data are available. All wells showed iron concentrations less than 0.1 mg/l. There is little variation in concentrations, and no areal trends are apparent.

Total Dissolved Solids

Total dissolved solids concentrations shown on Figure 47 are considered representative of concentrations in the upper portion of the Floridan Aquifer System. No direct data on this parameter are available for the deeper aquifers of the Floridan System. Concentrations range from 437 mg/l to 8600 mg/l. However, only one well had concentrations less than 500 mg/l (Well L-2400, 437 mg/l). Four wells had concentrations less than 1000 mg/l. Over most of the area concentrations exceed 1000 mg/l, and in a large portion of the aquifer they exceed 2000 mg/l.

Specific Conductance

Specific conductance data for the lower Hawthorn/Tampa producing zone and the Suwannee aquifer were obtained during investigations carried out by the South Florida Water Management District in connection with the plugging of abandoned wells. These data are considered to be more specific to these zones than the U. S. Geological Survey Data, since they were obtained by point sample methods and from interpretation of geophysical logs.

Figures 49 to 52 present these data and show the locations of the wells. Additional data on the wells used to prepare these maps is given in Appendix 5. The highest specific conductance values for the lower Hawthorn/Tampa producing zone were found in the southern part of the county near Bonita Springs and in an area southeast of Cape Coral (see Figure 49). In these areas values exceed 5000 umhos/cm. Specific conductance values between 2500 umhos/cm and 5000 umhos/cm were found in three areas located north of Cape Coral, in the vicinity of Lehigh Areas and near Fort Myers. Most of the remainder of the area showed values less than 2500 umhos/cm. No data were available for the islands.

In the Suwannee aquifer areas of high specific conductance (7500 mg/l) occur in three main locations in the county; along the Caloosahatchee River south of the I-75 bridge to a point south of the Cape Coral bridge; in the southwestern part of the county, including Sanibel Island, Fort Myers Beach, Estero and Bonita Springs; and northwestern Lee County, including north Pine Island and Burnt Store Marina. As was the case for the lower Hawthorn/Tampa producing zone, the areas of low specific conductance are found particularly in the northeast, southern, and central parts of the county, including Buckingham, Lehigh Acres, Fort Myers and the coastal area adjacent to Bonita Springs.

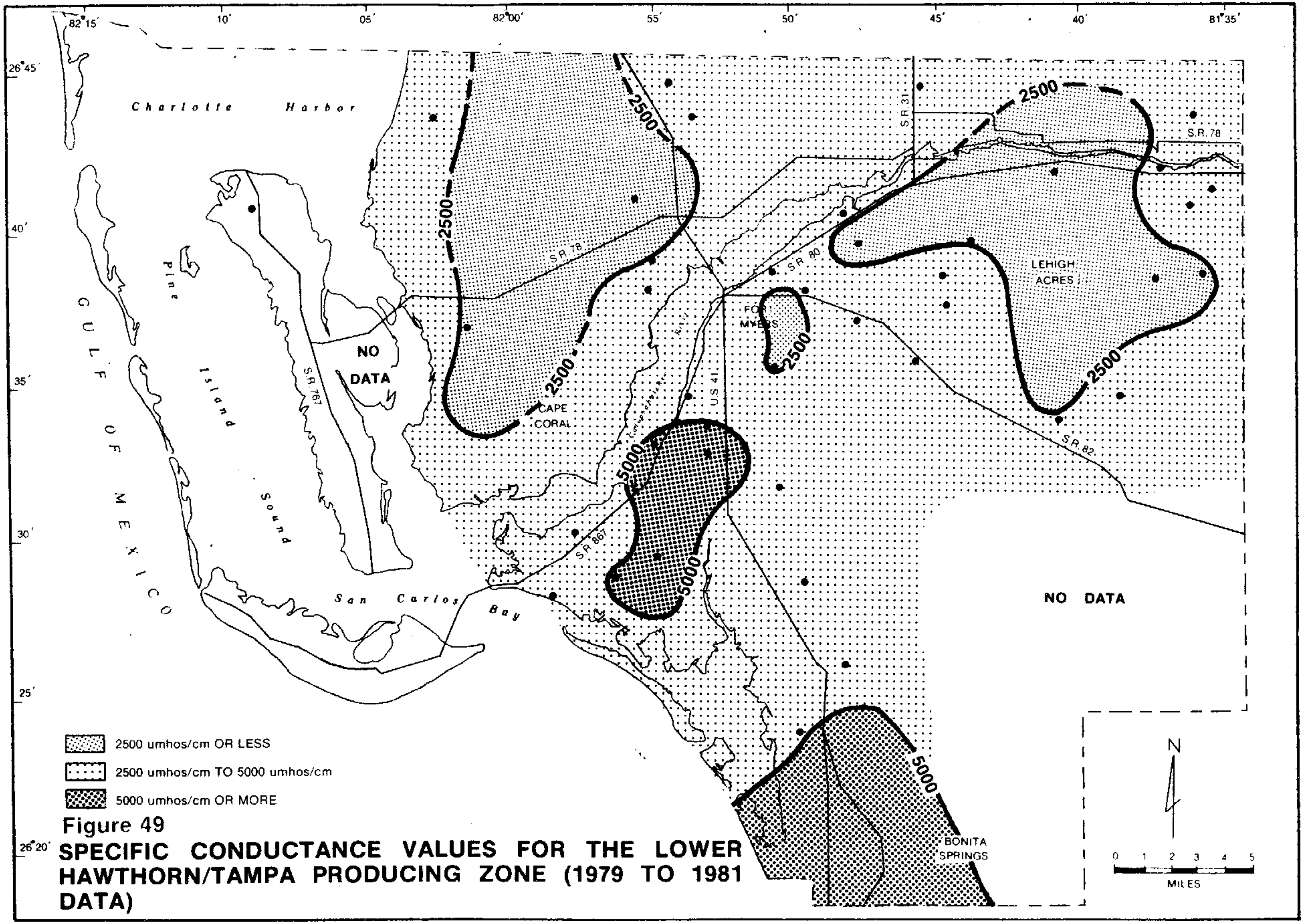
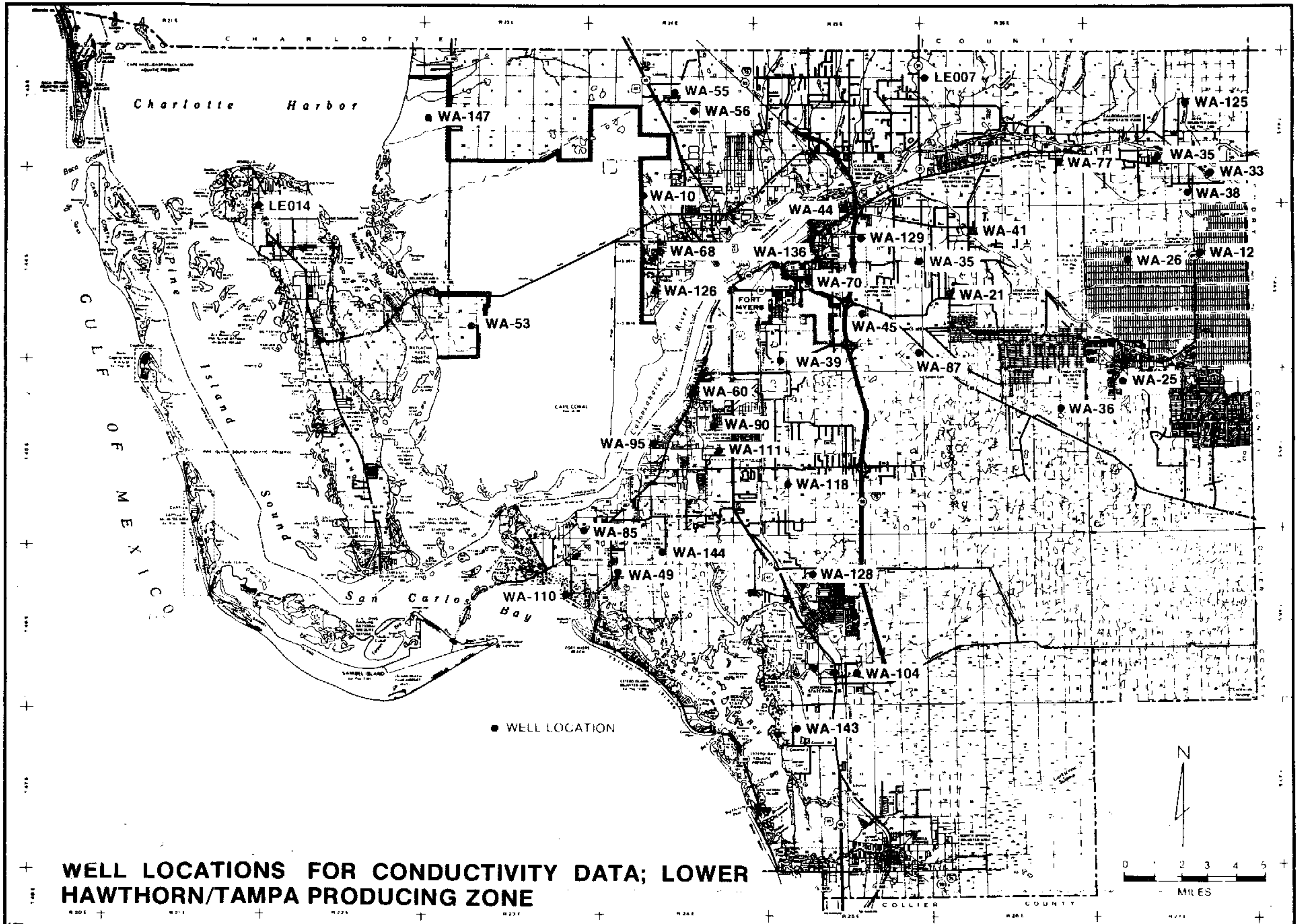
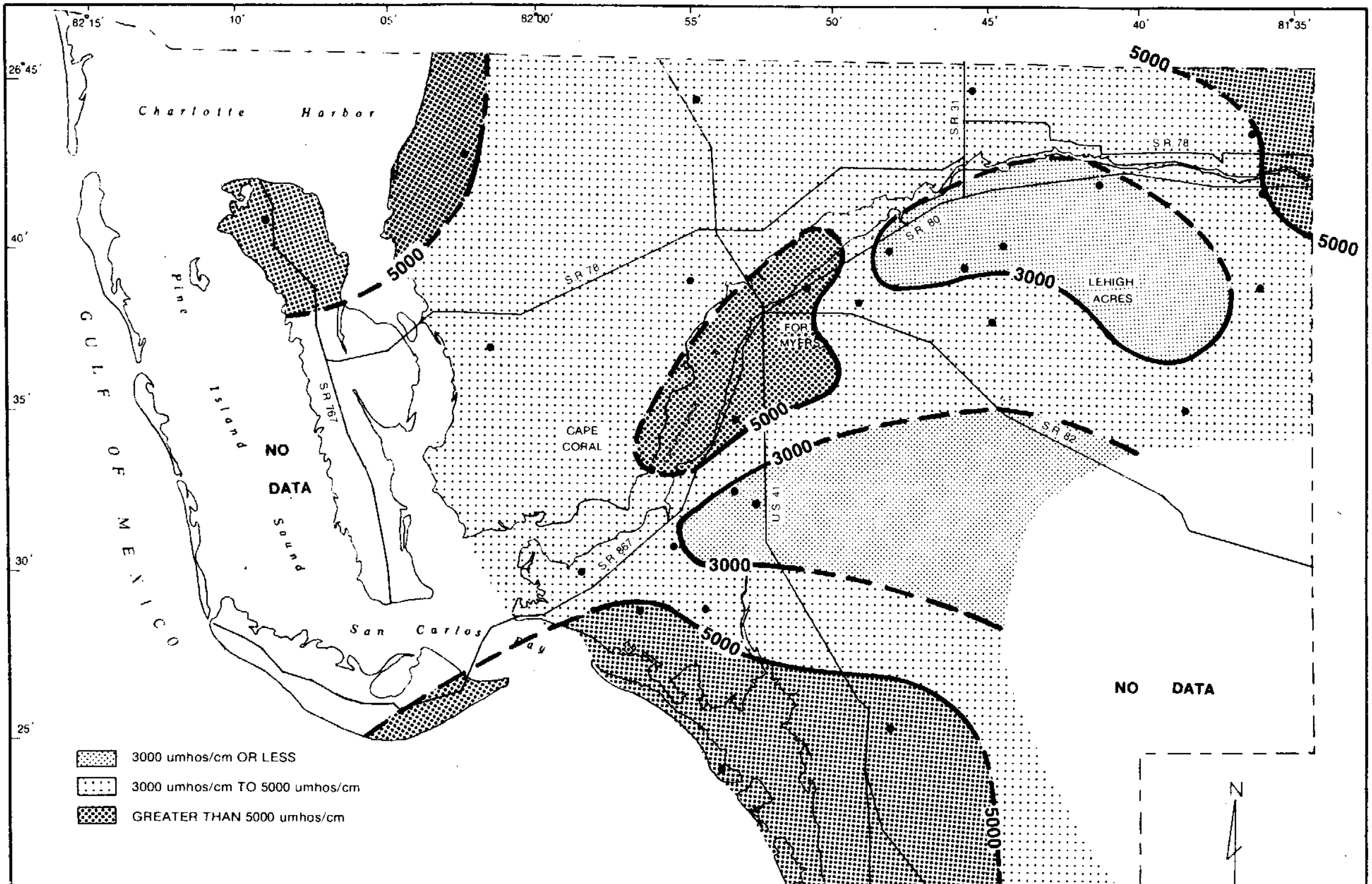


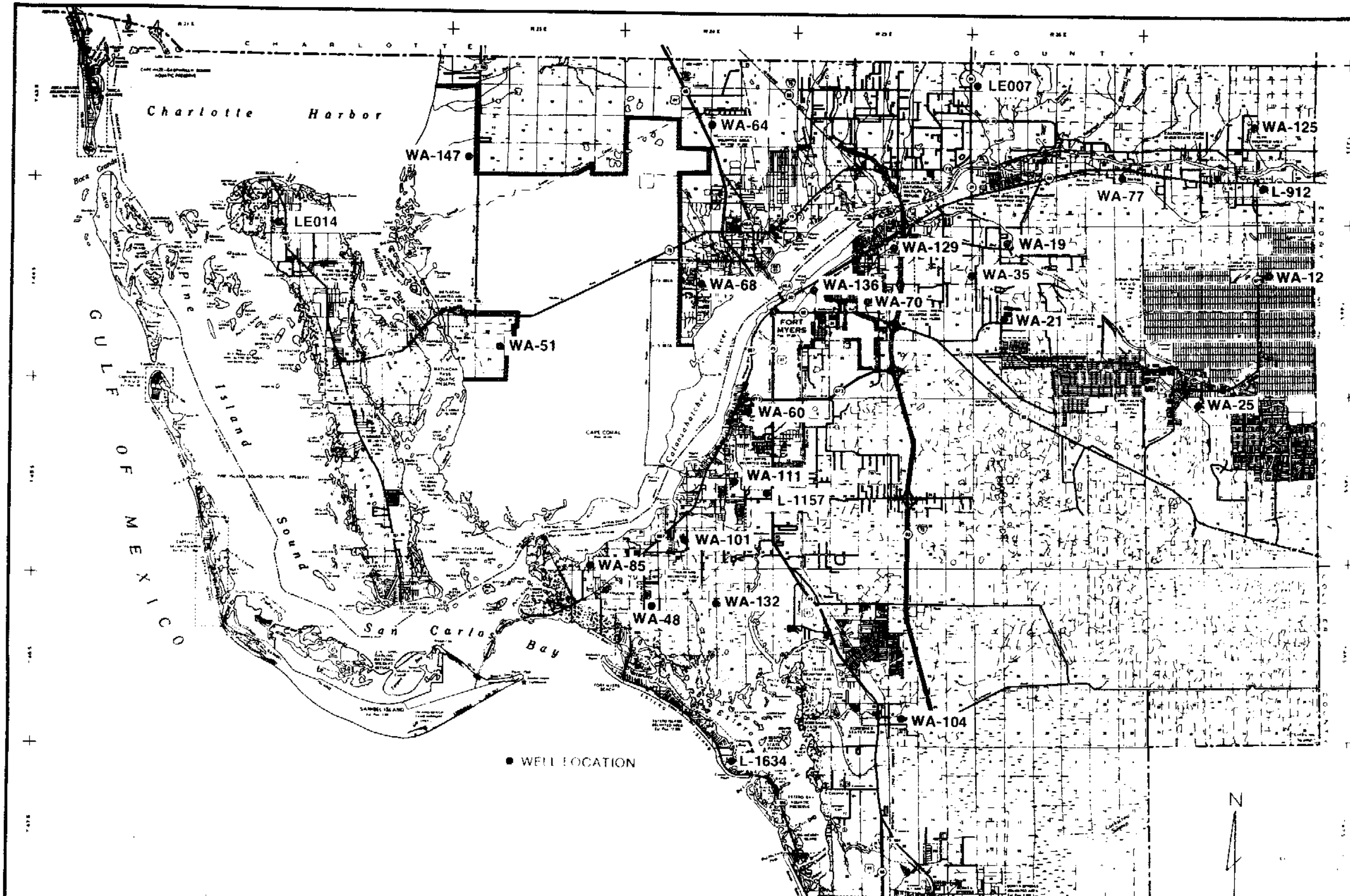
Figure 49
SPECIFIC CONDUCTANCE VALUES FOR THE LOWER HAWTHORN/TAMPA PRODUCING ZONE (1979 TO 1981 DATA)



WELL LOCATIONS FOR CONDUCTIVITY DATA; LOWER HAWTHORN/TAMPA PRODUCING ZONE



SPECIFIC CONDUCTANCE VALUES FOR THE SUWANNEE AQUIFER (1979 TO 1981 DATA)



WELL LOCATIONS FOR CONDUCTIVITY DATA; SUWANNEE AQUIFER

Summary

The Floridan Aquifer System contains mainly non-potable water, except in isolated areas. Generally water quality deteriorates with depth, but there are some indications that in localized areas better quality water may underlie poorer quality water (see Figure 53). The lower Hawthorn/Tampa producing zone is separated from the Suwannee aquifer by a zone of low permeability rocks, and water quality in the two units is generally different. The lower Hawthorn/Tampa producing zone shows little vertical variation in water quality over most of the county. However, vertical variations in water quality in the Suwannee aquifer appear to be substantial.

Due to the semi-confining nature of the basal bed of the lower Hawthorn/Tampa producing zone that separates it from the Suwannee aquifer, the possibility of upward leakage of water exists, if the lower Hawthorn/Tampa producing zone is stressed. This could result in deterioration of water quality in this zone in areas where the Suwannee aquifer is more saline.

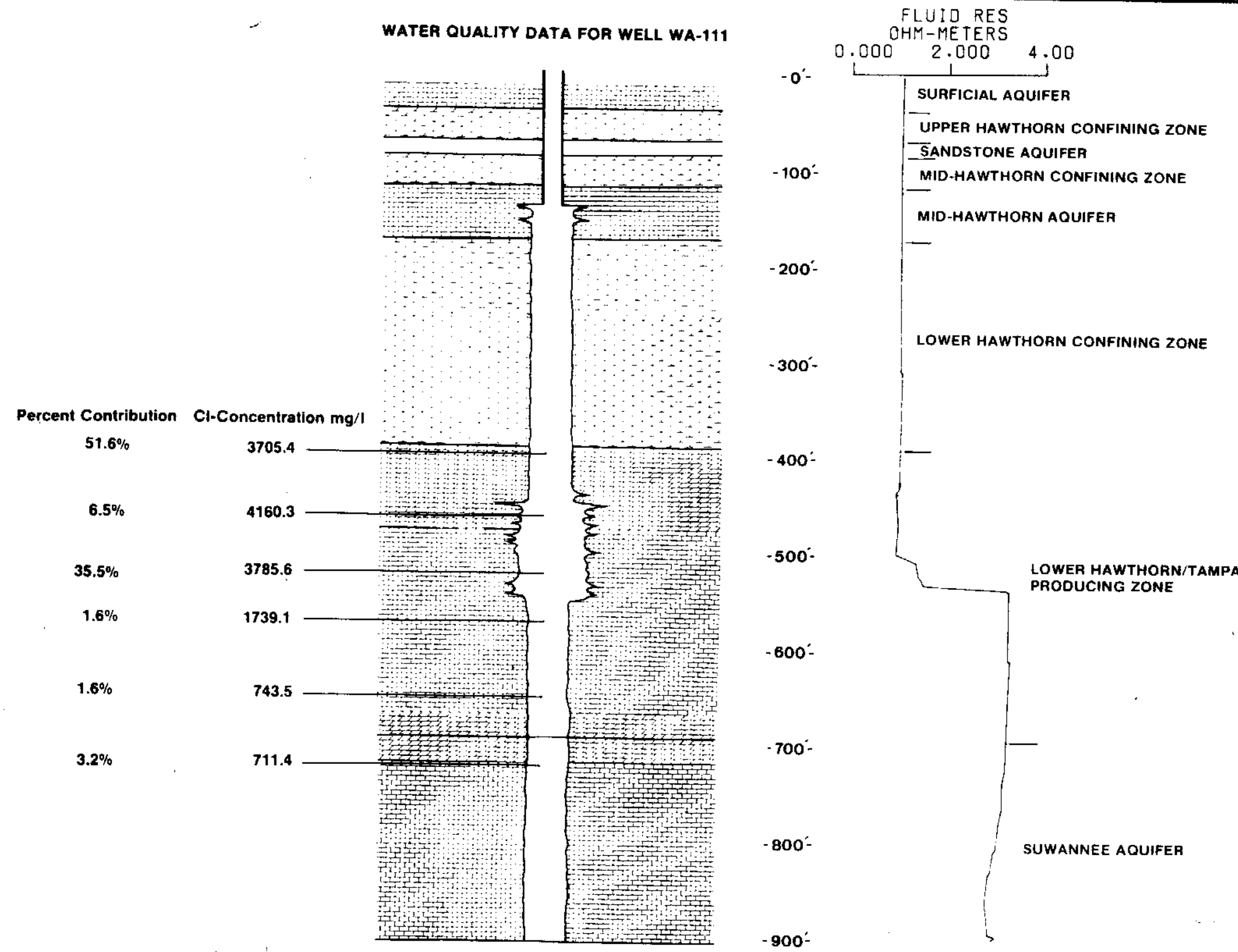


Figure 53 SIMPLIFIED CROSS SECTION OF WA-111 (L-1715) SHOWING POINT SAMPLE DATA AND CORRECTED FLOW CONTRIBUTION.

AVAILABILITY OF GROUNDWATER IN LEE COUNTY

Lee County is characterized by a complex hydrogeologic system which exhibits a high degree of vertical and horizontal variability in lithology, permeability and water quality. A number of aquifers and producing zones have been identified in this area. Data on water quality and water levels for these have been presented previously. In this section the availability of water from the Surficial aquifer, the Sandstone aquifer, the Mid-Hawthorn aquifer, and the lower Hawthorn/Tampa producing zone will be discussed.

The major constraints on the availability of groundwater for most purposes are well yield and water quality. The yield of a properly constructed well is dependent principally on the hydraulic characteristics of the aquifer and the available inflows to the aquifer.

In Lee County, the potential of the aquifer for water supply is significantly affected by the degree to which the aquifer is contaminated by salt water. In this area saline water in an aquifer may originate from one of the following sources:

a) Direct saline intrusion from the sea or tidal bodies due to lowering of the water levels or potentiometric surface adjacent to these bodies.

b) Relict sea water emplaced during or after deposition of the rocks. This water may become concentrated by evaporation in tidal lagoons or other enclosed bodies.

c) Movement of saline water between aquifers due to poor well construction or leakage across semi-confining beds.

The hydraulic characteristics of an aquifer which determine well yield are transmissivity and storage. Available data on the hydraulic characteristics of the aquifers are given in Table 4. Figure 59 shows the locations

TABLE 4. AQUIFER CHARACTERISTICS, LEE COUNTY

LOCATION NUMBER	DEPTH (FT.)	AQUIFER	TRANSMISSIVITY (GPD/FT.)	STORAGE COEFFICIENT	SOURCE OF DATA
1	28	Surficial	8,400	-	Missimer & Assoc., Inc., 1980b
2	164	Surficial	200,000	0.00003	Post, Buckley, Schuh & Jernigan, Inc., 1978
3	33	Surficial	65,000	0.05	Missimer & Assoc., Inc., 1981b
4	120	Surficial	60,000	0.0001	Missimer & Assoc., Inc., 1981b
5	105	Sandstone	2,100	0.0002	Missimer & Assoc., Inc., 1980
6	85	Sandstone	24,700	0.0004	SFWMD (1980)
7	84	Sandstone	38,000	-	SFWMD (1980)
8	200	Sandstone	9,700	-	SFWMD (unpublished)
9	159	Mid-Hawthorn	5,000	0.0004	Missimer & Assoc., Inc., 1978
10	198	Mid-Hawthorn	3,600	0.00004	Missimer & Assoc., Inc., 1980
11	195	Mid-Hawthorn	35,000	0.0016	
12	235	Mid-Hawthorn	42,000 to 47,000	-	Layne-Western, 1981
13	305	Mid-Hawthorn	20,000	0.00003	Post, Buckley, Schuh & Jernigan, INc., 1978
14	200	Mid-Hawthorn	6,700	0.0004	Layne-Western, 1977
15	185	Mid-Hawthorn	12,000	-	Layne-Western, 1977
16	227	Mid-Hawthorn	5,100	0.0001	Layne-Western, 1977
17	225	Mid-Hawthorn	70,000	0.00005	Missimer & Assoc., Inc., 1981b
18	570	Mid-Hawthorn	60,000	0.0001	Missimer & Assoc., Inc., 1981a

TABLE 4. AQUIFER CHARACTERISTICS, LEE COUNTY (Continued)

LOCATION NUMBER	DEPTH (FT.)	AQUIFER	TRANSMISSIVITY (GPD/FT.)	STORAGE COEFFICIENT	SOURCE OF DATA
19	765	L. Hawthorn/ Tampa & Suwannee	80,000 to 350,000	0.003	Black, Crow & Eidsness, 1976
20	700	L. Hawthorn/ Tampa & Suwannee	31,000	0.001	Black, Crow & Eidsness, 1976
21	610	L. Hawthorn/ Tampa & Suwannee	15,600	0.00009	Missimer & Assoc., Inc., 1978a
22	650	L. Hawthorn/ Tampa & Suwannee	6,000	0.00003	Geraghty & Miller, 1978
23	774	L. Hawthorn/ Tampa & Suwannee	74,000	0.0002	Missimer & Assoc., Inc., 1979
24	715	L. Hawthorn/ Tampa & Suwannee	80,000	0.0001	Missimer & Assoc., Inc., 1980a
25	625	L. Hawthorn/ Tampa & Suwannee	13,750	0.00003	Geraghty & Miller, 1978

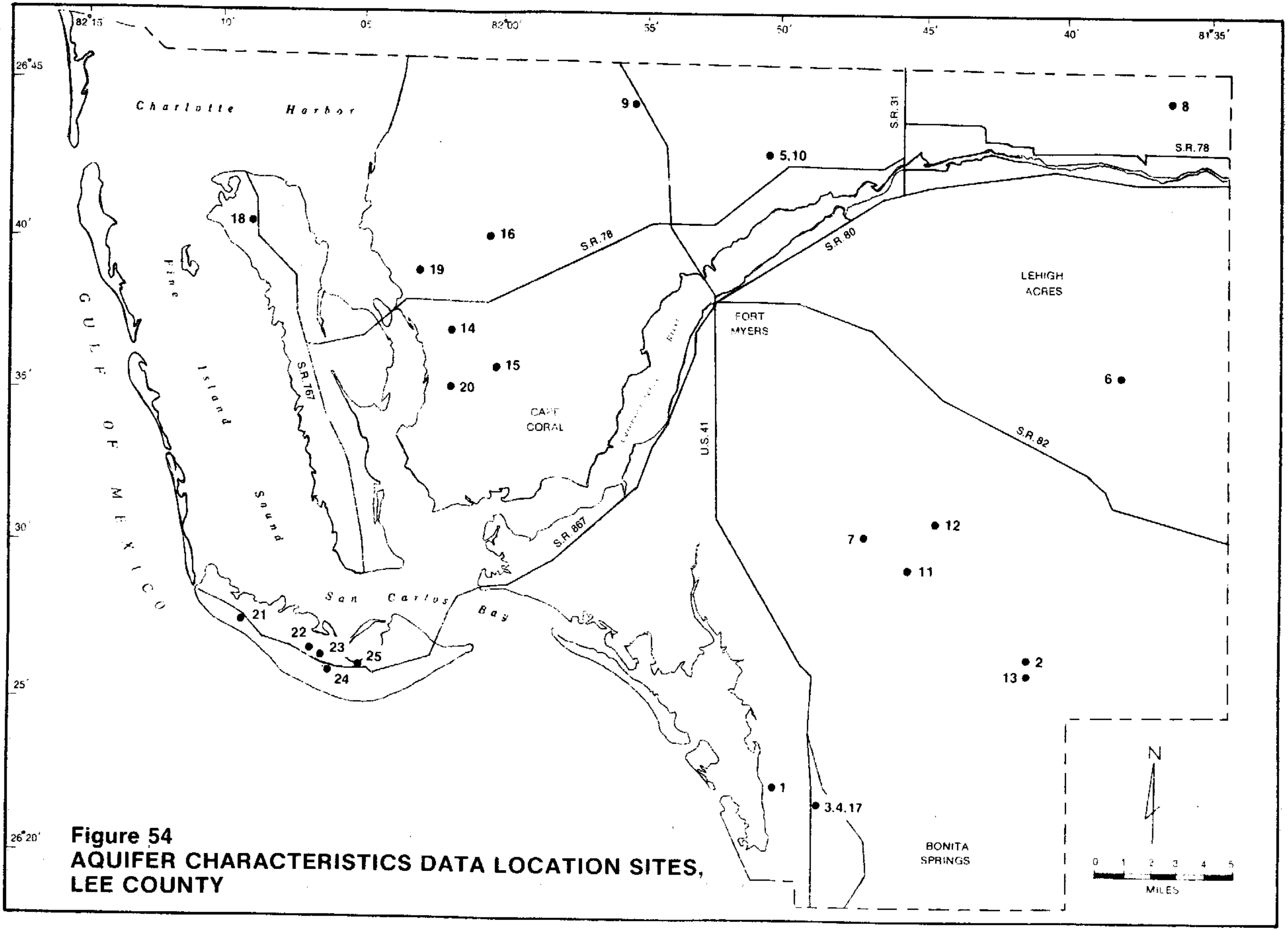


Figure 54
AQUIFER CHARACTERISTICS DATA LOCATION SITES, LEE COUNTY

of sites for which data is available. Transmissivity is a measure of the ability of an aquifer to transmit water. In customary U. S. Geological Survey units it is the quantity of water, in gallons per day, that will move through a vertical section of the aquifer one foot wide and extending the full saturated height of the aquifer, under a unit hydraulic gradient (Theis, 1935). The coefficient of storage is a measure of the ability of the aquifer to store water. It is defined as the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in head normal to that surface.

Inflows to the aquifers include a number of possible components, and may be either beneficial or non-beneficial depending on the quality of the water recharged. Direct infiltration of precipitation is a major source of inflows to near surface aquifers. More than 75 percent of the rainfall is lost to evapotranspiration. The remainder contributes to direct surface runoff, detention and moisture storage, and percolation to the water table. Since the water table in Lee County is close to the surface and the overlying rocks allow easy infiltration and percolation, most of the rainfall which is not lost to evapotranspiration probably contributes to inflow to the aquifer. This quantity therefore gives a gross estimate of the net direct inflow from precipitation.

The major inflow to the semi-confined aquifers in Lee County is from subsurface movement of groundwater from adjacent areas. A second important source of inflows results from interaquifer transfer of water. Transfer of water across a semi-confining bed is defined by the "leakage coefficient" which is the quantity of water that crosses a unit area of the interface between the aquifer and its semi-confining bed, if the difference between the head in the principal aquifer and in the bed supplying the leakage is unity. Uncontrolled interaquifer flow of water through improperly cased wells may also be a contributary source of recharge.

Gross inflows to an aquifer have been used as a rough estimate of long term sustained yield. However, it should be realized that both subsurface inflow and net infiltration are affected by changes in water levels in the area. For example, large withdrawals of groundwater close to an inflow boundary will result in increased inflows from adjacent areas. Lowering of the water table will also result in lower evapotranspiration rates and thus tend to increase net infiltration. Inflow to the aquifer may also include infiltration of irrigation water withdrawn from other aquifers and percolation from surface water bodies.

Discharge of water from the aquifer may also affect water availability. This is particularly true in near-coastal areas where it is necessary to maintain water levels above sea level (or the levels of other saline bodies with which the aquifer is in contact) to prevent saline intrusion. This results in unavoidable loss of fresh water to these saline bodies. Uncontrolled flow of abandoned wells may also reduce the quantity of water in storage in the aquifer and thus affect its availability. For environmental and other purposes, groundwater outflow to estuaries, bays, or coastal wetlands may also be necessary. In some areas groundwater levels are intentionally lowered by means of a network of canals to provide drainage. This may also be a significant factor in groundwater availability in these areas.

It should be pointed out that a number of other factors such as wellfield location, wellfield design, pumping rates, minimum water quality requirement and available technology for treatment of the water may affect groundwater availability for particular purposes.

AVAILABILITY OF WATER FROM THE SURFICIAL AQUIFER

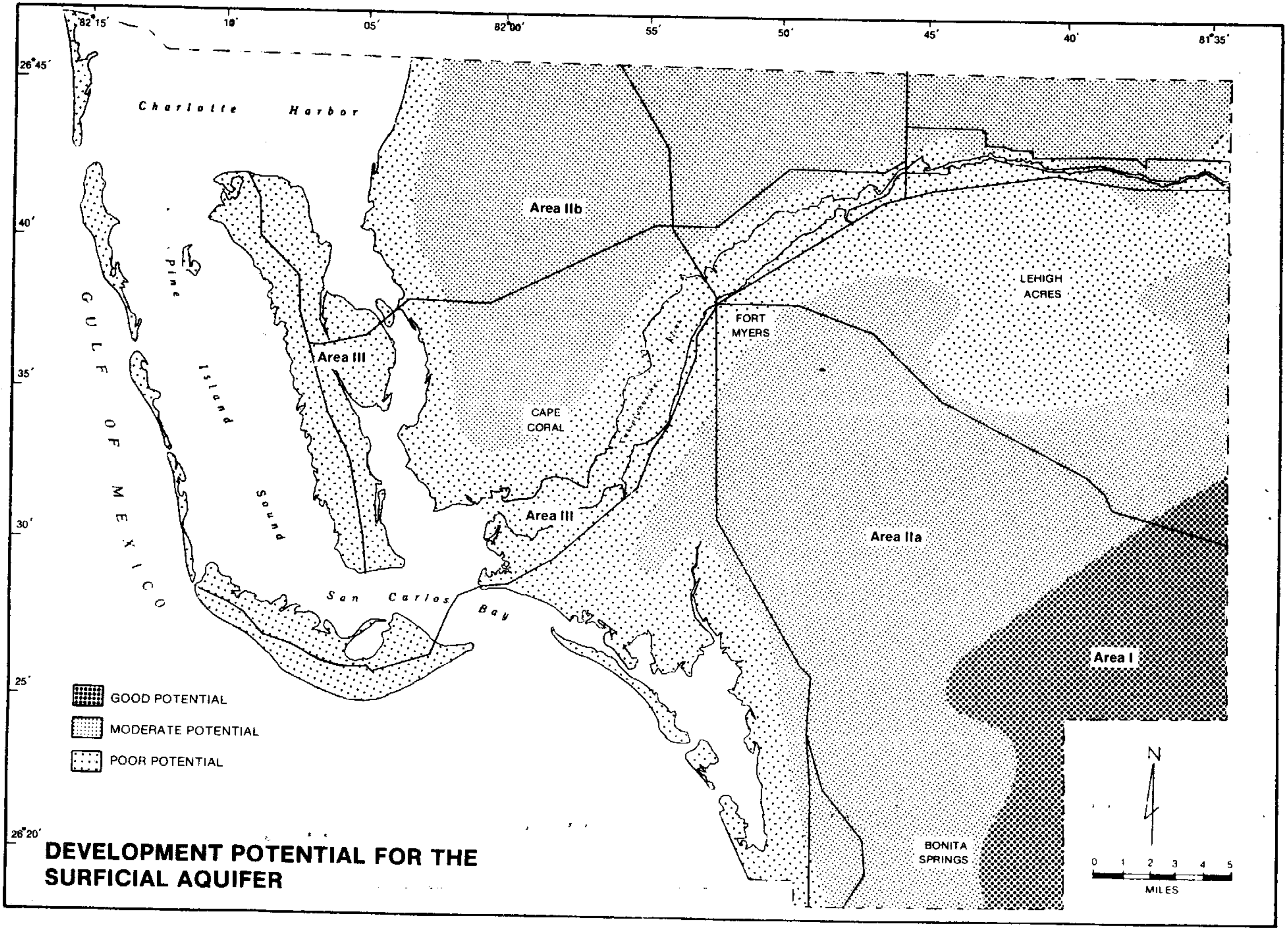
Aquifer Characteristics

The hydraulic characteristics of the Surficial aquifer vary depending on lithology and thickness of the rock units which comprise the aquifer. Highest transmissivities are found in the southeastern part of the area where the aquifer is thickest and where a highly solution-riddled, porous reef deposit (the Coral Reef aquifer of Missimer and Associates, Inc., 1981) has been identified. A transmissivity of 200,000 gallons per day per foot (gpd/ft.) has been reported in this area (see Figure 54 and Table 4). In the central and eastern parts of the county transmissivities of from 24,000 gpd/ft. to 38,000 gpd/ft. have been reported (see Figure 54 and Table 4). Lowest transmissivities are recorded near Estero Bay (8,400 gpd/ft.)(Missimer and Associates, Inc., 1981). In other areas where the aquifer is thin (see Plate 2, Atlas) transmissivities are expected to be correspondingly low.

Storage coefficient values reported from pumping tests in the Surficial aquifer range from 0.05 to 0.0003 (see Figure 54 and Table 4). The lower values are probably representative of wells finished in the semi-confined lower part of the aquifer, while the higher values represent unconfined portions of the aquifer.

Potential for Water Supply

Figure 55 is a qualitative assessment of the potential of the Surficial aquifer for water supply. These assessments are based on the water quality and yield characteristics of the aquifer which were previously discussed. Although this assessment is subjective, it should serve as a general guide in a regional choice of areas most suitable for groundwater development.



DEVELOPMENT POTENTIAL FOR THE SURFICIAL AQUIFER

An area in southeast Lee County is shown as having good potential for groundwater development. As previously mentioned transmissivities as high as 200,000 gpd/ft. have been recorded in this area. The higher transmissivities are due both to higher permeabilities, particularly in the coral reef facies, and to a thicker section of permeable material. Aquifer thickness in this area is generally between 50 feet and 150 feet. Groundwater is generally of potable quality in this area. The area is more than 10 miles from saline bodies and is therefore not easily susceptible to saline contamination. Water levels are also more than 20 feet above sea level.

Areas IIa and IIb are considered to have moderate potential for development of groundwater. This assessment is based on lower transmissivity values (20,000 to 40,000 gpd/ft.) which are probably related to the fact that the aquifer is thinner in this area (25 feet to 40 feet). However, these areas also lack thick, highly permeable beds such as those found in Area I. However, water quality is generally acceptable in this area and moderate supplies could be developed with proper well construction and wellfield design. Wells finished in the Surficial aquifer in Areas IIa and IIb would probably yield less water than wells in Area I.

The area of the Surficial aquifer bordering the Caloosahatchee River and the coastline and including the islands (Area III) is considered as having poor potential for development. This assessment is based on the low transmissivity of the aquifer due to thinning of the permeable strata in this area, and also on the relatively poor water quality (chlorides and total dissolved solids greater than potable standards). In this area the aquifer is also susceptible to saline intrusion which restricts the allowable drawdown. Most wells in this area would probably yield less than 100 gpm and would probably be suitable only for limited domestic, irrigation or industrial use.

In general, the Surficial aquifer in Lee County is considered to be of less importance than other aquifers as a source of groundwater for large municipal and other users, in most parts of Lee County. This is due to the generally modest yield of water which can be withdrawn from individual wells in this aquifer in some areas. It may also be due to the fact that historically, the areas of greatest municipal water demands have not coincided with areas of high groundwater potential in this aquifer. However, the Surficial aquifer is the source of water for thousands of domestic and irrigation wells (Sproul, et al., 1972), in spite of the relatively high iron content and objectionable color of water that is withdrawn. Groundwater level data indicate that in spite of these withdrawals there is still significant outflow of groundwater to the Caloosahatchee River and the sea. This indicates that additional potential exists for development of the aquifer.

The major constraint on full development of the Surficial aquifer is its susceptibility to intrusion by saline water from surface water bodies or leakage from deeper aquifers. It should also be recognized that this aquifer is a major source of recharge to the Sandstone aquifer and development of one will inevitably affect the other. Since it receives direct recharge from surface infiltration, and water levels are close to the surface, the aquifer is susceptible to contamination from waste discharges and other activities of man. Intentional or unintentional disposal of saline waters on the land surface also pose a potential threat to this aquifer.

AVAILABILITY OF WATER FROM THE SANDSTONE AQUIFER

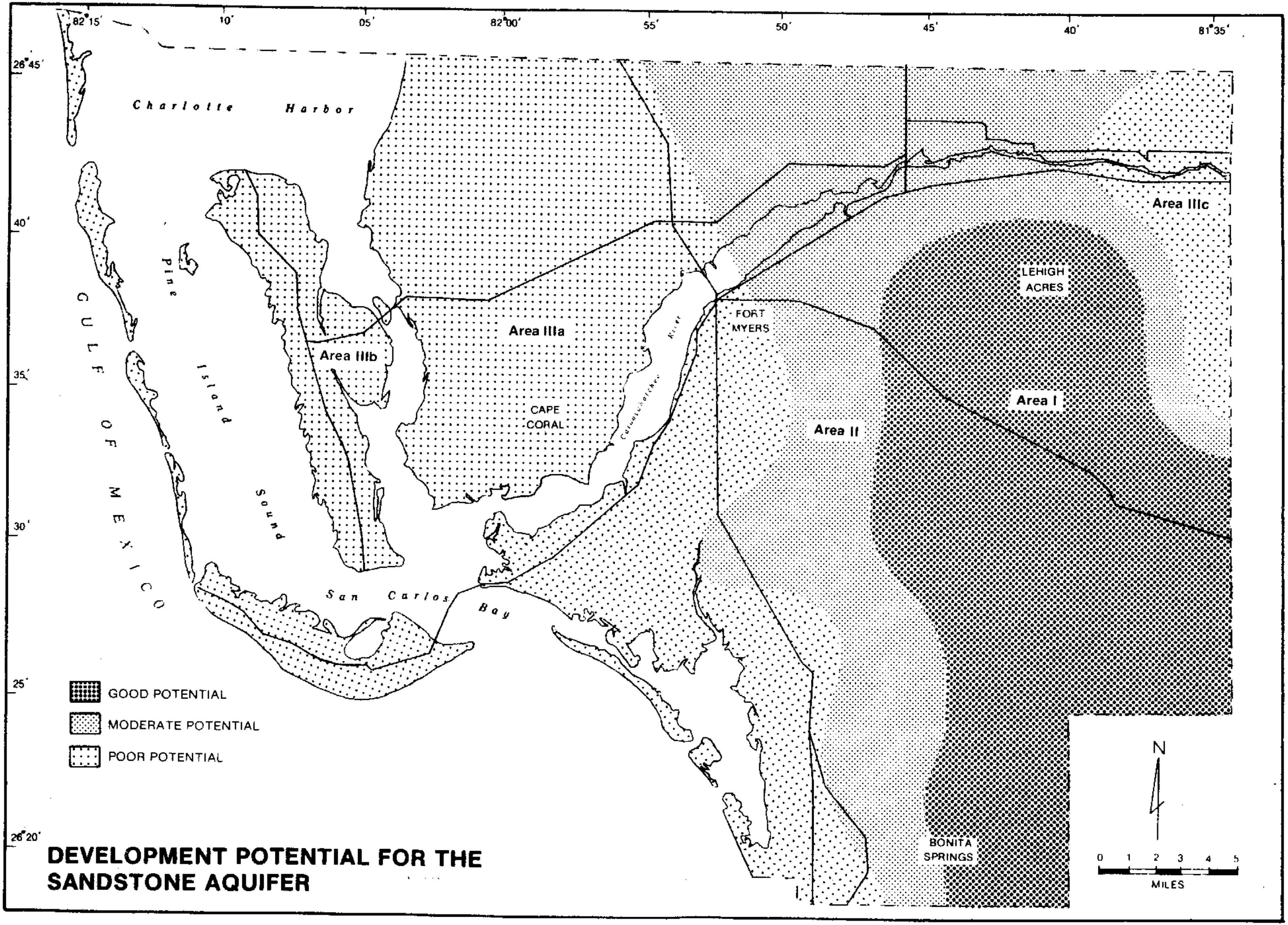
Aquifer Characteristics

Calculated transmissivity values for the Sandstone aquifer within Lee County are generally low. Missimer and Associates (1980) reported a value of 2100 gpd/ft. at the North Lee County Wellfield. A pumping test carried out as part of this study yielded a value of 9,700 gpd/ft. at the exploratory site in Alva. Transmissivities of 24,700 gpd/ft. and 38,000 gpd/ft. have been reported in the Lehigh Acres area. Reported storage coefficients range from 0.0002 to 0.0004, reflecting the semi-confined nature of the aquifer. Data on the hydraulic characteristics of this aquifer are shown in Table 4 and Figure 54.

Potential for Water Supply

The Sandstone aquifer is thin in the western part of Lee County and is absent in the Cape Coral Area (see Plate 6, Atlas). It is, however, a major source of water in eastern Lee County. This aquifer supplies water to municipal wellfields in Fort Myers, Bonita Springs, and Lehigh Acres and is also the source for many domestic irrigation wells.

The area of the Sandstone aquifer which appears to have the highest potential as a water supply source lies in the eastern and southeastern corner of the county (Area I, see Figure 56) and includes the Lehigh Acres area. This assessment is based on the fact that the aquifer is thickest in this area (75 to 125 feet thick), and lithologic data indicate that the interbedded sands, sandstone and limestones which form the aquifer are relatively permeable. Water quality in this area is within drinking water standards. Indications are that most of the inflow to the Sandstone aquifer through leakage from the Surficial aquifer takes place in or close



DEVELOPMENT POTENTIAL FOR THE SANDSTONE AQUIFER

to this area. The upper Hawthorn confining zone which separates the Surficial aquifer from the Sandstone aquifer is thin in this area (25 feet) and the water table elevation is as much as 5 feet higher than the potentiometric level in the Sandstone aquifer.

Due to the high water levels, relatively long distance from saline water bodies, and nearness to a source of inflow of good quality water, this section of the aquifer is relatively well protected from saline contamination.

Area II (Figure 56) which surrounds the areas of high potential is designated as one of moderate potential. Aquifer thickness decreases in this area (25 feet to 100 feet thick) and water quality in some parts of this area fall below potable standards.

The western part of the county, including the Islands, and the north-eastern edge of the County have been designated as areas of poor potential (Areas IIIa, IIIb, and IIIc, Figure 56). This assessment is based on the fact that the aquifer is less permeable, thin, or absent in the western part of the county and water quality in the northeastern part of the county is relatively poor. In western Lee County the thickness of the aquifer varies from zero in the Cape Coral area to nearly 70 feet in Useppa Island. In the areas where the aquifer is relatively thick, however, the unit consists predominantly of low permeability sandy clays and well cemented sandstones, with only a few feet of permeable sand and shell beds. A transmissivity value of 2,100 gpd/ft. has been reported in this area (location 5, Figure 54) by Missimer and Associates, Inc., 1980. Yields from wells tapping this aquifer in this area are expected to be low (less than 50 gpm). Water quality would probably deteriorate with heavy withdrawals from this area, due to accompanying large drawdowns and increased leakage through confining beds or from leaking abandoned wells.

At present the Sandstone aquifer is an important source of potable water, mainly in central and eastern Lee County (see Appendix 5). In these areas additional water of good quality is available. In the western part of the area there appears to be little potential for development of wellfields for major supplies. However, throughout most of Lee County in areas where the aquifer exists, groundwater of good quality is available to individual domestic wells for potable and lawn irrigation use.

AVAILABILITY OF WATER FROM THE MID-HAWTHORN AQUIFER

Aquifer Characteristics

Hydraulic characteristics of the mid-Hawthorn aquifer are given in Table 4. Site locations for these values are shown on Figure 54.

Reported transmissivities in the mid-Hawthorn aquifer vary from 3600 gpd/ft. to 70,000 gpd/ft. Lower transmissivity values are found in the north-central part of the county. The highest recorded transmissivity for this aquifer is in the southern part of the county east of Bonita Springs. Reported storage coefficient values range from 0.0016 to 0.00005.

Potential for Water Supply

Designations of variations in water supply potential for the mid-Hawthorn aquifer are tentative, due to lack of data in some parts of the county. The designations shown on Figure 57 are based on differences in lithologic character and thickness of the aquifer, transmissivity and water quality data, and water levels.

The sections designated as having good potential (Areas Ia and Ib) are located in the central and eastern parts of the county (Figure 57). In these areas the aquifer is relatively thick (> 75 feet) and consists lithologically of permeable sandy, phosphatic dolomites interbedded with low permeability clayey dolo-silts. Transmissivity values as high as 47,000 gpd/ft. have been recorded in the central part of the county. Water quality trends indicate that potable water may exist in the aquifer in these areas. Water levels are close to or above land surface and flowing artesian conditions exist.

The major part of the county is designated as having moderate potential (Area II, Figure 57). Aquifer thickness in this area is variable, and

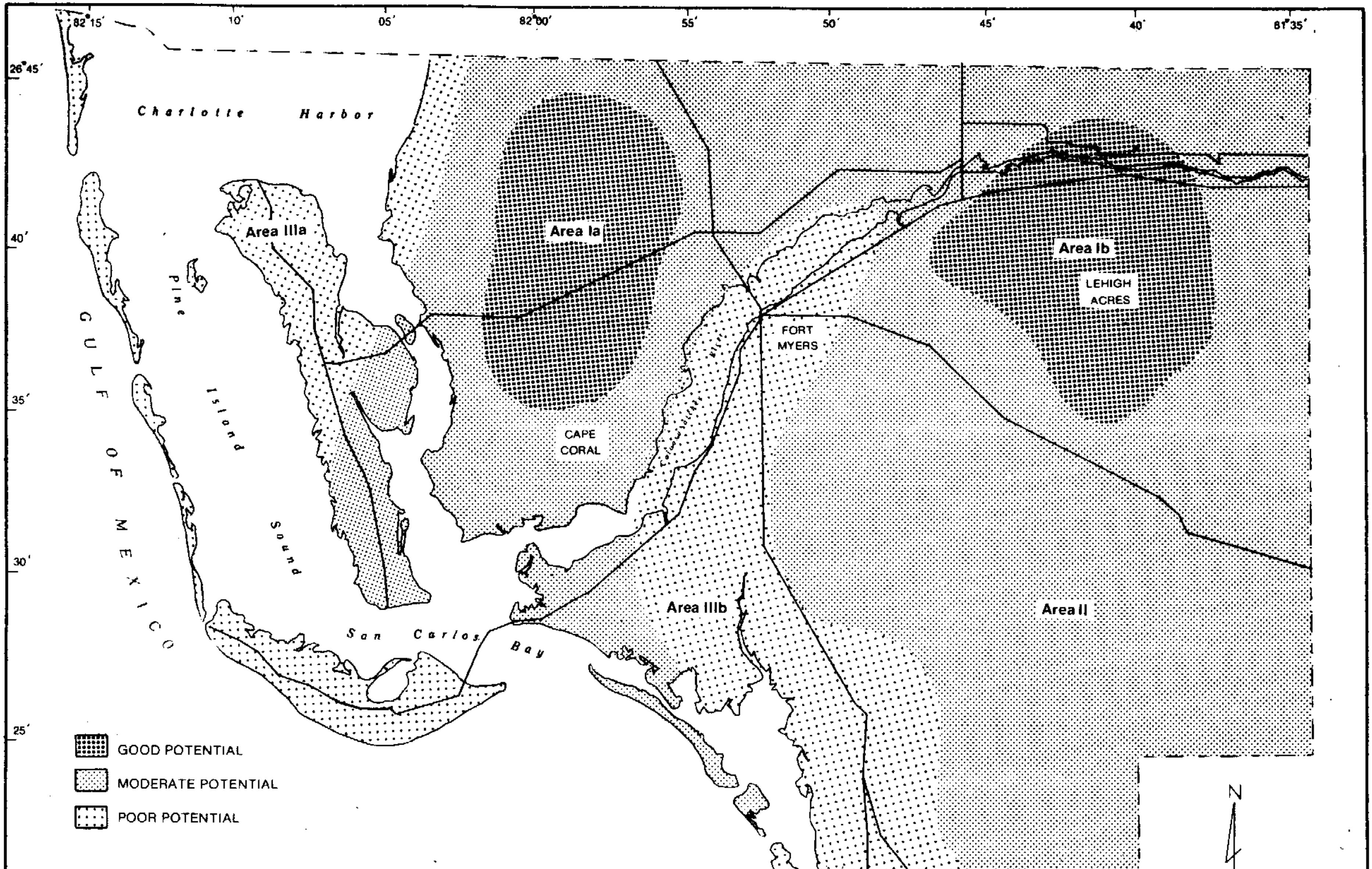


Figure 58
DEVELOPMENT POTENTIAL FOR THE FLORIDAN AQUIFER SYSTEM

generally does not exceed 75 feet. Transmissivities are generally low to moderate (1,600 to 20,000 gpd/ft.) although a relatively high value (70,000 gpd/ft.) has been reported in one area (location 17, see Figure 54 and Table 4). Water quality is variable, but is within or close to potable standards.

Water levels are close to or above land surface except in the Cape Coral area where withdrawals of groundwater from the aquifer has dramatically lowered the potentiometric surface (see Plates 25 and 26, Atlas). In this area there is evidence of deteriorating water quality which appears to be directly related to overstressing of the aquifer.

The coastal areas of the county and the islands have been designated as having low potential for groundwater development. This assessment is based on the fact that the aquifer is relatively thin in this area and water quality is below potable drinking water standards. In this part of Lee County the aquifer contains relatively more low permeability clayey dolo-silts. Transmissivity values range from 5,100 gpd/ft. to 12,000 gpd/ft.

In general, the mid-Hawthorn aquifer is presently an extensively used source of water in Lee County. It provides water to the City of Cape Coral, North Fort Myers, and Cypress Lake wellfields (see Appendix 5). Water quality throughout most of the aquifer is good, with the exception of those parts of the aquifer which underlie the coastal area of the county and the islands. The aquifer has, however, been overstressed in the Cape Coral area, and it is unlikely that further major groundwater development can be carried out without the risk of water quality deterioration. Leakage of saline water from deeper, inadequately cased wells is also a factor in water quality deterioration in this aquifer.

AVAILABILITY OF WATER FROM THE FLORIDAN AQUIFER SYSTEM

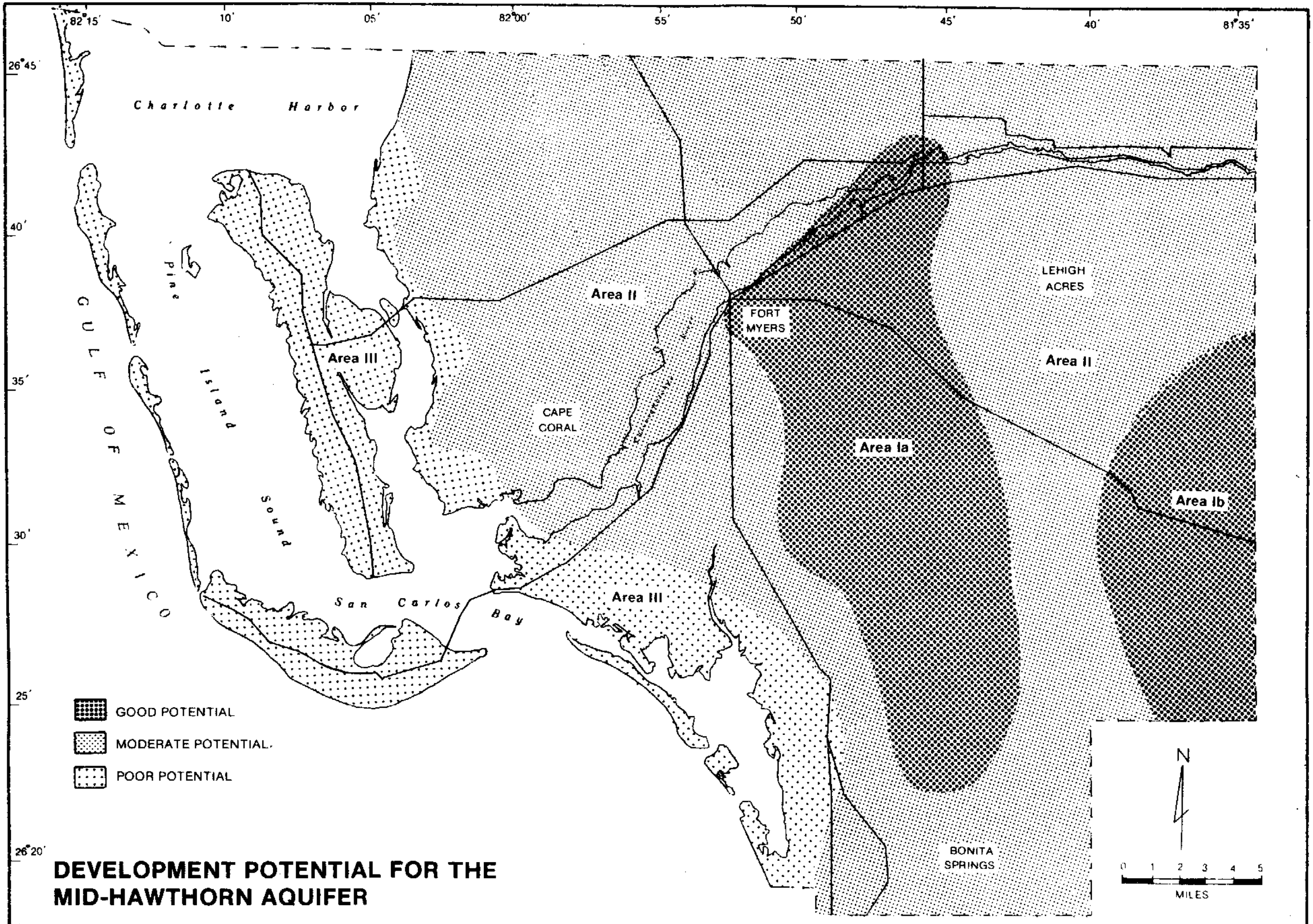
The Floridan Aquifer System in Lee County, comprising the lower Hawthorn/Tampa producing zone, the Suwannee aquifer and Deeper aquifers contains mainly brackish or saline water. Its potential will therefore be discussed in terms of the availability of this quality water, for direct use where possible or for appropriate treatment prior to use. The deeper aquifers will be excluded from this discussion as they are considered to contain water which is too saline for direct use or for economical treatment.

Aquifer Characteristics

Reported transmissivity values for wells which penetrate one or more producing intervals in the Floridan Aquifer System are shown on Table 4. Values range from 6000 gpd/ft. to 350,000 gpd/ft. Some of the variability shown in Table 4 may, however, be due to the number of producing intervals which have been penetrated by the tested well. Storage coefficients range from 0.003 to 0.0003.

Potential for Water Supply

The lower Hawthorn/Tampa producing zone and the Suwannee aquifer both contain, in some areas, water of potable quality. In other areas, however, one or both of these units may contain brackish or saline water. The areas of good groundwater potential shown on Figure 58 are those areas in which both aquifers have relatively good quality water (less than 3000 mg/l chlorides) and in which the aquifer is thick or transmissivity is high. The two areas which meet these criteria are Area Ia (north of Cape Coral) and Area Ib (adjacent to and including Lehigh Acres). In these areas the combined thickness of the lower Hawthorn/Tampa producing zone and the Suwannee aquifer



DEVELOPMENT POTENTIAL FOR THE MID-HAWTHORN AQUIFER

exceeds 500 feet. Total dissolved solids concentrations in the lower Hawthorn/Tampa producing zone is generally below 2000 mg/l. Although water quality information for the underlying Suwannee aquifer is sparse, indications are that concentrations are below 2500 mg/l in this area. For example, water quality data obtained during drilling of wells in the City of Cape Coral wellfield showed total dissolved solids concentrations of 1382 mg/l and 2650 mg/l. Transmissivity values in this wellfield ranged from 80,000 gpd/ft. to 350,000 gpd/ft. (Black, Crow and Eidsness, 1976). In the Lehigh Acres area, total dissolved solids concentrations of 2,500 mg/l have been reported. Potentiometric levels in both areas are above land surface elevation. Most of the area is designated as having moderate potential. This assessment is based on the fact that the combined thickness of the lower Hawthorn/Tampa producing zone and the Suwannee aquifer is less than 500 feet, and total dissolved solids in the Suwannee aquifer exceed 3,000 mg/l. In these areas, the possibility of upward leakage of poorer quality water exists.

Areas designated as having poor potential are those areas where both aquifers contain water with total dissolved solids concentrations above 3,000 mg/l, or where the Suwannee aquifer contains water with total dissolved solids concentrations above 10,000 mg/l. These areas (IIIa and IIIb) are located adjacent to the Caloosahatchee River and underlie most of the islands.

In general, the Floridan Aquifer System is a potential source of large supplies of brackish or saline water. In some areas, the water quality is adequate for agricultural use. However, all the water from this aquifer would need treatment before use as a domestic supply. Treatment could include desalination and/or mixing.

GROUNDWATER WITHDRAWALS

Groundwater is widely used in Lee County for domestic, irrigation, industrial, and other purposes. Leach (1978) estimated that of the 64.06 mgd of water used in Lee County in 1975 for irrigation, 48.53 mgd was obtained from groundwater sources. Of the 19.15 mgd used for municipal and rural supply it is estimated that less than 15 percent is obtained from sources other than groundwater. Total groundwater withdrawals for beneficial use in Lee County is therefore approximately 60 to 70 mgd.

Data on municipal wellfields permitted by the South Florida Water Management District in Lee County is given in Appendix 5 (see Figure 5 for locations of these wellfields). Currently, 14 municipal water use permits have been issued in Lee County. Daily and annual allocations from the wellfields which are shown in the Appendix were based on water demand and assessment of the availability of water from the aquifers. The total maximum permitted withdrawal for all permitted municipal wellfields is 35 mgd, which represents approximately 15 mgd in excess of current demand. In addition to these permitted withdrawals, a large number of wells with withdrawals below the permit minimum (100,000 gpd) exist. These wells are used for lawn irrigation or for individual (rural) domestic supply.

Agricultural uses represent the largest withdrawal of water from the aquifer. Currently there are 88 water use permits for agricultural uses; however, these permitted wells are believed to represent only a small number of wells in use in the county for irrigation purposes. Leach (1978) estimates irrigation groundwater withdrawal at 48.53 mgd. In addition, there are an estimated 3000 flowing abandoned wells in Lee County which mainly tap the Floridan aquifer. Estimates made by the South Florida Water Management District of the uncontrolled discharge from these wells are as high as 120 million gallons per day. This quantity is significantly more than total fresh water withdrawals in the county (given by Leach, 1978 as 91.72 mgd for 1975).

Industrial use of groundwater includes use for mining and power generation. Leach (1978) estimates that for 1975, this amounted to 8.5 mgd. Mining use includes water removed from the aquifer for dewatering purposes.

Not all of the water withdrawn from the aquifers is consumptively used. For example, water used for irrigation or removed for dewatering purposes or water withdrawn by free-flowing abandoned wells is largely spread on the ground surface and some portion of this will percolate to shallow aquifers. However, due to the high evapotranspiration losses in Lee County (estimated 75 percent of rainfall by the South Florida Water Management District) much of this water will be lost.

Reliable data on water use from individual aquifers or producing zones are not available. However, it appears that many of the larger groundwater withdrawals from the area are from the lower aquifers (mid-Hawthorn and lower aquifers). The use and disposal of this more salty water, coupled with leakage from free flowing wells, could be a factor in water quality deterioration in the Surficial aquifer and the Sandstone aquifer.

SALINE WATER INTRUSION IN LEE COUNTY

Contamination of fresh water through movement of saline water from salt water bodies, more saline aquifers, or more saline parts of the same aquifer is a serious problem affecting many areas in Lee County. All of the aquifers discussed crop out beneath or underlie the Gulf of Mexico, and the possibility for sea water intrusion exists. The shallower aquifers are more likely to be affected as their outcrops are closer to the shoreline, and consequently, closer to areas of potential groundwater withdrawals. The penetration of saline water into coastal aquifers is determined by the fresh water head in the aquifer close to the coast and the rate of groundwater outflow (Cooper, et al., 1964). Consequently, withdrawal of groundwater from the aquifers in Lee County must be regulated to minimize inland migration of sea water. The lower tidal reaches of canals, drainage ditches, streams, and major rivers may also contain saline water which could contaminate fresh water portions of the aquifer with which it is in contact, especially if withdrawals close to these bodies cause a reversal of groundwater gradients. In the case of the islands which are surrounded by saline water, only a thin lens of fresh water exists on top of saline water. Attempts to withdraw this fresh water can result in further contamination of the aquifer if withdrawals are not properly controlled. Since salt water is more dense than fresh water, removal of salt water from portions of the aquifer which have become contaminated is difficult.

Upward leakage of saline water from saline aquifers into aquifers with fresh water is also a significant problem in Lee County. This leakage may take place across semi-confining beds or by way of improperly constructed wells. In Lee County, groundwater in deeper saline aquifers has a higher potentiometric head than water in overlying aquifers, and transfer of water across semi-confining beds takes place. Saline water under pressure can leak through corroded casings or move into other aquifers through uncased portions of the borehole. It is estimated that in the Lee County area as many as 3000 abandoned flowing wells exist, many in a derelict condition. Many older irrigation wells which are no longer used flow directly on to the land surface, allowing saline water to contaminate surface water and shallow groundwater bodies.

Contamination of fresh groundwater by saline groundwater can be minimized or avoided by proper well construction and control of groundwater withdrawals. Proper well construction would include casing the well so as to completely isolate individual aquifers or producing zones, proper grouting, and an operating discharge valve. Regulation of groundwater withdrawal would include restrictions on maximum drawdowns in sensitive areas. Construction of control structures on canals, ditches, streams, or rivers, where possible, would also retard upstream migration of salt water.

Overdrainage of the Surficial aquifer through the construction of canals should also be avoided as these canals might serve not only as a source of saline water, but may also lower groundwater heads and thus increase saline water intrusion from other sources.

SUMMARY AND CONCLUSIONS

This report presents a comprehensive hydrogeologic reconnaissance of Lee County, Florida. Data on the stratigraphy, lithology, hydrostratigraphy, and hydrogeology of the area have been collected, compiled, analyzed and presented in a user-oriented format. The descriptive text (Part 1) describes and, where appropriate, quantifies all the major elements of the study in detail. This includes discussions on the geology, hydrostratigraphy, water levels, water quality trends and potentials for water supply of the major aquifers, producing zones, and aquifer systems in the area. The hydrologic implications of variations in hydraulic properties, water levels, and water quality are outlined.

A folio of 28 maps has been prepared (Part 2) showing the elevations to the top of stratigraphic and hydrogeologic units in the area, the thicknesses of these units, and water levels in the aquifers. These maps and accompanying cross sections define the areal and vertical extent of the various units, allow for easy identification and correlation of the units, and show their relationship to identifiable borehole geophysical signatures. Other maps show dry and wet season water levels in major aquifers and producing zones. The final part of the report (Part 3) is a series of appendices which display the relevant basic data used in this study.

The following is a summary of the major elements of the study and conclusions derived from the study.

1. The stratigraphic sequence described ranges in age from Eocene to Recent. Eocene rock units include the Lake City Limestone, Avon Park Limestone, and Ocala Group. Other rock units present include

The Suwannee Limestone of Oligocene age, the Hawthorn Formation of Miocene age, the Tamiami Formation of Pliocene age, and the Undifferentiated deposits of Pleistocene and Holocene age.

2. The formations and characteristic lithologies within them can be identified on the basis of geophysical signatures. Specific marker beds have been identified and correlated with the geophysical data. These marker beds can be traced throughout Lee County.

3. Within the upper part of this stratigraphic sequence, five major aquifer or producing zones have been identified and mapped. These are: (a) the Surficial aquifer; (b) the Sandstone aquifer; (c) the mid-Hawthorn aquifer; (d) the lower Hawthorn/Tampa producing zone of the Floridan Aquifer System; and (e) the Suwannee aquifer of the Floridan Aquifer System.

4. The aquifers and producing zones are separated by semi-confining beds consisting of dolo-silts, clays, or clayey limestones. The semi-confining beds allow leakage of groundwater between aquifers. The confining properties of these beds vary, depending on lithology and thickness.

5. The aquifers consist of sand, sandstone, shell beds, limestones, and dolomite, interbedded with clays and dolo-silts. In these aquifers intergranular, moldic, fracture, and solution porosity have been developed. The thicknesses, lithology, and water bearing properties of these aquifers is highly variable.

6. The Surficial aquifer is recharged locally by precipitation. A major area of recharge to this aquifer has been located in the east central part of the county. All the aquifers in Lee County receive recharge through subsurface inflow from adjacent areas.

7. Groundwater quality is highly variable. Generally, water quality deteriorates with depth, although in some parts of the deeper aquifers better quality water has been found to underlie poorer quality water. The Surficial and Sandstone aquifers contain mainly potable water. The mid-Hawthorn aquifer contains both potable and non-potable water. Aquifers of the Floridan System contain for the most part brackish or saline non-potable water. Water quality in all of the aquifers is affected by saline intrusion from salt water bodies, upward leakage of saline water through semi-confining beds, movement of water between aquifers through improperly constructed wells,and percolation of saline water withdrawn from deeper aquifers.

8. Groundwater levels normally range from less than 20 feet below ground surface to more than 25 feet above land surface. Generally, groundwater flow is towards the west (the Gulf of Mexico), although in the Surficial aquifer there is some flow towards the Caloosahatchee River. Locally, water levels have declined in some of these aquifers as a result of withdrawals. This decline is most noticeable in the mid-Hawthorn aquifer as shown by a large and deep depression in the potentiometric surface in the Cape Coral area.

9. Areas of relatively good, moderate, and poor potential for groundwater supply have been identified for the Surficial aquifer, Sandstone aquifer, mid-Hawthorn aquifer, and lower Hawthorn/Tampa producing zone, and Suwannee aquifer. These areas have been identified based on the water bearing properties of the aquifers, aquifer thicknesses, and water quality.

10. Groundwater levels indicate that additional water is available in some parts of all the aquifers studied. Well hydrographs show no substantial changes in water levels in many areas as a result of withdrawals from the aquifers. On the other hand, significant changes in water levels are noted in some areas, notably in the mid-Hawthorn aquifer in the Cape Coral area.

RECOMMENDATIONS

1. Further detailed investigations should be undertaken to quantify the availability of water from each of the aquifers and producing zones in Lee County. These investigations should include drilling of additional exploratory wells in areas of sparse data. Core drilling is suggested to provide better lithologic samples, and/or reverse air drilling to provide information on water quality with depth. Where possible packers should be used to isolate individual water producing units so that reliable water level and water quality data can be obtained.

2. A program for the collection of water use data for each aquifer should be implemented to assist in the assessment of long-term sustained yields from the aquifers and evaluate impacts on adjacent aquifers.

3. The existing water level and water quality data collection network should be reevaluated and, where necessary, modified so that specific aquifers and producing zones are isolated and monitored. The network should be expanded in areas where data is absent or scarce. The network density should be increased in areas which show potential or incipient water quality problems. Consistent long-term water quality data should be collected to document trends in water quality variations.

4. Additional and more specific data on aquifer hydraulic characteristics should be developed by pumping tests. Wells used for these tests should be screened so that an individual aquifer or producing zone is isolated and tested.

5. Consideration should be given to design and use of a predictive flow model to be used as a tool in the development and management of the water resources.

However, due to the complexity of the hydrologic system in this area, this task may prove difficult.

6. Specific planning to protect water quality and availability in the sensitive areas of the aquifers in Lee County should be undertaken. Some concepts that can be evaluated include:

   a. Restrictions on groundwater development and drawdown levels in excessively stressed portions of the aquifers.

   b. Restrictions on excessive drainage of the Surficial aquifer through canal systems.

   c. Prevention or mitigation of upstream migration of saline surface water in tidal sections of canals and rivers, where this may affect water quality in the Surficial aquifer.

   d. Proper construction of wells to ensure that aquifers or producing zones with different quality waters are not connected through the well bore. Minimum well construction standards should be developed and implemented to achieve this objective.

   e. Restrictions on the use of wells that withdraw saline water which is deposited on the land surface, and which water may percolate to the near surface aquifers and degrade groundwater quality.

   f. Decentralization of groundwater withdrawals for municipal use, as far as is possible, to prevent localized overstressing and the development of large cones of depression.

   g. Protection of major regional recharge areas of the Surficial aquifer through land use planning and other methods.

   h. The program for identification, testing and plugging of abandoned, derelict wells should be continued. These wells have been shown to be a source of contamination for groundwater in Lee County. The program of monitoring to document the effects of plugging these wells should also be continued.

REFERENCES

Akers, W. H., 1974. Age of Pinecrest Beds, South Florida: Tulane Studies Geology and Paleontology, Vol. 11.

Applin, P. L. and E. R. Applin, 1944. Regional Subsurface Stratigraphy and Structure of Florida and Southern Georgia: Bull. of Am. Assoc. of Petroleum Geologist, Vol. 28, No. 12, Washington, D.C.

Applin, P. L. and E. R. Applin, 1965. The Comanche Series and Associated Rocks in the Subsurface in Central and South Florida: U. S. Geological Survey Prof. Paper No. 447.

Bennett, Bishop and Passalequa, Inc., 1965. Final Supply Report for the Greater Pine Island Water Association: Engineering Report.

Black, Crow and Eidsness, Inc., April, 1976. Results of Drilling and Testing Floridan Aquifer Water Supply Wells for the City of Cape Coral, Florida: Engineering Report.

Blow, W. H., 1969. Late Middle Eocene to Recent - Planktonic Foraminiferal Biostratigraphy, in P. Bronniman and H. H. Renz, eds., Proc. 1st Internat. Conf. on Planktonic Microfossils, Geneva, 1967.

Boggess, D. H., 1973. The Effects of Plugging a Deep Artesian Well on the Concentration of Chloride in Water in the Water Table Aquifer at Highland Estates, Lee County, Florida: U. S. Geological Survey Open File Report 73003, 20 p.

Boggess, D. H., 1974. Saline Groundwater Resources in Lee County, Florida: U. S. Geological Survey Open File Report 74-247, 62 p.

Boggess, D. H., 1974a. The Shallow Fresh-Water System of Sanibel Island, Lee County, Florida, with Emphasis on the Sources and Effects of Saline Water: Florida Bureau of Geology, Report of Investigations No. 69, 62 p.

Boggess, D. H., and T. M. Missimer, 1974b. A Reconnaissance of Hydrogeologic Conditions in Lehigh Acres and Adjacent Areas of Lee County, Florida: U. S. Geological Survey Open File Report 75-55, 106 p. (preliminary draft).

Boggess, D. H., and T. M. Missimer, 1975. A Reconnaissance of Hydrogeologic Conditions in Lehigh Acres and Adjacent Areas of Lee County, Florida: U. S. Geological Survey Open File Report 75-55, 88 p.

Boggess, D. H., T. M. Missimer and T. H. O'Donnell, 1977. Saline-Water Intrusion Related to Well Construction in Lee County, Florida: U. S. Geological Survey Water Resources Investigation 77-33, 29 p.

Brown, M. P. and D. E. Reece, 1979. Hydrogeologic Reconnaissance of the Floridan Aquifer System, Upper East Coast Planning Area: South Florida Water Management District, Tech. Map Series 79-1.

Buono, A. and A. T. Rutledge, 1979. Configuration of the Top of the Floridan Aquifer, Southwest Florida Water Management District and Adjacent Areas: U. S. Geological Survey Water Resources Investigations 78-34.

Ceryak, R., M. S. Knapp, and T. Burnson, 1981. The Geology and Water Resources of the Upper Suwannee River Basin, Florida: Florida Bureau of Geology, Report of Investigations 89, in press.

Chen, C. S., 1965. The Regional Lithostratigraphic Analysis of Paleocene and Eocene Rocks of Florida: Florida Geological Survey, Bull. No. 45.

Cooke, C. W., 1915. The age of the Ocala Limestone: U. S. Geological Survey Prof. Paper 95.

Cooke, C. W. and S. Mossom, 1929. Geology of Florida, Florida Geological Survey, 20th Annual Report.

Cooke, C. W. and W. C. Mansfield, 1936. Suwannee Limestone of Florida (Abstract): Geological Society of America Proc.

Cooke, C. W., 1945. Geology of Florida: Florida Geological Survey, Bull. 29.

Colton, R. C., 1978. The Subsurface Geology of Hamilton County, Florida, with emphasis on the Oligocene Age Suwannee Limestone: Unpublished Master's Thesis, Florida State University, Tallahassee, Florida.

Cooper, H. H., F. A. Kohout, H. R. Henry, and R. E. Glover, 1964. Sea Water in Coastal Aquifers: U. S. Geological Survey Water-Supply Paper 1613-C, 84 pp.

Dall, W. H. and G. D. Harris, 1892. Correlation papers, Neocene: U. S. Geological Survey, Bull. 84.

DuBar, J. R., 1958. Stratigraphy and Paleontology of the Late Neogene Strata of the Caloosahatchee River Area of Southern Florida: Florida Geological Survey, Bull. No. 40.

DuBar, J. R., 1962. Neogene Biostratigraphy of the Charlotte Harbor Area in Southwestern Florida: Florida Geological Survey, Bull. 43.

Environmental Protection Agency, 1975. National Interim Primary Drinking Water Regulations, EPA Office of Water Supply, EPA-570/9-76-003, 159 p.

Folk, R. L., 1968. Petrology of Sedimentary Rocks: University of Texas, Austin, Texas.

Geraghty and Miller, Inc., January, 1978. Effects of Groundwater Withdrawals from the Lower Hawthorn Aquifer on Sanibel Island, Florida: Prepared for the Island Water Association, Inc.

Hendry, C. W. and C. R. Sproul, 1966. Geology and Ground-Water Resources of Leon County, Florida: Florida Bureau of Geology, Bull. 47.

Hunter, M. E., 1968. Molluscan Guide Fossils in Late Miocene Sediments of Southern Florida: Gulf Coast Assoc. of Geol. Socs. Trans., Vol. 18.

Hunter, M. E. and S. W. Wise, 1980. Possible Restriction and Redefinition of the Tamiami Formation of South Florida: Points of Discussion: Florida Scientist, Vol. 43, Suppl. No. 1.

Hunter, M. E. and S. W. Wise, 1980a. Possible Restriction and Redefinition of the Tamiami Formation of South Florida: Points for Further Discussion: Miami Geological Soc. Field Trip Exp., P. J. Gleason Editor.

Johnson, L. C., 1888. The Structure of Florida: Am. Jour. Sci. (Ser. 3), Vol. 36.

King, K. C. and R. Wright, 1979. Revision of the Tampa Formation, West-Central Florida: Gulf Coast Assoc. of Geol. Socs. Trans., Vol. 29.

Knapp, M. S., 1979. Top of the Floridan Aquifer of North Central Florida: Florida Bureau of Geology, Map Series 92.

Knapp, M. S. 1980. Environmental Geology Series - Tampa Sheet: Florida Bureau of Geology, Map Series 97.

Kreiger, R. A. and J. L. Hatchett and J. L. Poole, 1957. Preliminary Survey of the Saline-Water Resources of the United States: U. S. Geological Survey Water-Supply Paper 1374, 172 p.

Kruseman, G. P., and M. A. DeRidder, 1970. Analysis and Evaluation of Pumping Test Data, International Institute for Land Reclamation and Improvement, Bull. II, Wageningen, The Netherlands.

Kwader, T. and W. Schmidt, 1978. Top of the Floridan Aquifer in Northwest Florida: Florida Bureau of Geology, Map Series 86.

Lane, E., 1981. Environmental Geology Series - West Palm Beach Sheet: Florida Bureau of Geology, Map Series 100.

LaRose, R., 1977. Fluctuations of Ground-Water Levels in Lee County, Florida, in 1976 Water Year: U. S. Geological Survey Open File Report 77-771, 98 pp.

Layne-Western, 1977. Water Supply Study, Cape Coral, Florida.

Layne-Western, Hydrology Division, May, 1981. Green Meadows, Wells No. 6 and No. 8: Prepared for the Florida Cities Water Co.

Leach, S. D., 1978. Source Use and Disposition of Water in Florida, 1975. U. S. Geological Survey Water Resources Investigations No. 78-17.

Lichtler, W. F., 1960. Geology and Ground-Water Resources of Martin County, Florida. Florida Geological Survey Report of Investigations No. 23, 149 pp.

Lohman, S. W., 1972. Ground-Water Hydraulics, U. S. Geological Survey Prof. Paper 708, 70 pp.

Mansfield, W. C., 1937. Mollusks of the Tampa and Suwannee Limestones of Florida: Florida Geological Survey, Bull. 15.

Mansfield, W. C., 1939. Notes on the upper Tertiary and Pleistocene Mollusks of Peninsular Florida: Florida Geological Survey, Bull. 18.

Matson, G. G., and F. G. Clapp, 1909. A Preliminary Report on the Geology of Florida with Special Reference to the Stratigraphy: Florida Geological Survey 2nd Annual Report.

Meeder, J. F., 1979. The Pliocene Fossil Reef of Southwest Florida: Miami Geological Society 1979 Field Trip Guidebook, 18 p.

Missimer, T. M. and D. H. Boggess, 1974. Fluctuations of the Water Table in Lee County, Florida, 1969-73: U. S. Geological Survey Open File Report 74019.

Missimer, T. M. and T. H. O'Donnell, 1975. Fluctuations of Groundwater Levels in Lee County Florida in 1974: U. S. Geological Survey Open File Report FL-75008, 75 p.

Missimer, T. M. and R. A. Gardner, 1976. High Resolution Seismic Reflection Profiling for Mapping Shallow Aquifers in Lee County, Florida: U. S. Geological Survey Water Resources Investigations 76-45.

Missimer, T. M., 1978. The Tamiami Formation - Hawthorn Formation Contact in Southwest Florida: Florida Scientist, V. 41, No. 1, 33-39 p.

Missimer and Associates, Inc., September, 1978. Hydrologic Investigation of the Upper Part of the Hawthorn Aquifer System at Indian Pines Development, Lee County, Florida: Prepared for Lan Ron Enterprises, Inc.

Missimer and Associates, Inc., August, 1978a. Hydrologic Investigation of the Hawthorn Aquifer System in the Northwest Area, Sanibel, Florida: Prepared for the Island Water Association.

Missimer and Associates, Inc., February, 1979. Hydrologic Investigation of the Hawthorn and Suwannee Aquifer System in the Central Area, Sanibel, Florida: Prepared for the Island Water Association, Inc.

Missimer and Associates, Inc., February, 1980. Hydrology and Geology of a New Wellfield Site in North Fort Myers, Lee County, Florida: Prepared for Lee County Division of Environmental Protection.

Missimer and Associates, Inc., April, 1980a. Hydrologic Investigation of the Hawthorn and Suwannee Aquifer Systems at the New Island Water Association Wellfield Well Site No. 2: Prepared for the Island Water Association, Inc.

Missimer and Associates, Inc., September, 1980b. Groundwater Resources of the Spring Creek Village Development, Lee County, Florida: Prepared for Flordeco, Inc.

Missimer and Associates, Inc., 1981. Groundwater Resources of the Cocohatchee Watershed, Collier County, Florida: Prepared for the Big Cypress Basin, South Florida Water Management District.

Missimer and Associates, Inc., February, 1981a. Groundwater Resources of the Alden Pines Country Club Development, Lee County, Florida: Prepared for Alden Pines Country Club.

Missimer and Associates, Inc., October, 1981b. Groundwater Resources of the Bonita Bay Development, Lee County, Florida: Prepared for David B. Shakarian and Associates, Inc.

Missimer, T. M. and R. S. Banks, 1981. Miocene Cyclic Sedimentation in Western Lee County, Florida: Miocene Symposium of the Southeastern United States proceedings, in press.

National Academy of Sciences, National Academy of Engineering, 1973. Water Quality Criteria, 1972: U. S. Environmental Protection Agency, EPA-R3-73-033, 594 p.

Nuzman, C. E. and D. P. Waltz, 1977. Water Supply Study - Cape Coral, Florida: Water Supply Study for the City of Cape Coral.

O'Donnell, T. H., 1977. Municipal Water Supplies in Lee County, Florida: 1974: U. S. Geological Survey Open File Report 77-277.

Parker, G. G. and C. W. Cooke, 1944. Late Cenozoic Geology of Southern Florida, with a Discussion of the Groundwater: Florida Geological Survey, Bull. 27, 119 pp.

Parker, G. G. and V. T. Stringfield, 1950. Effects of Earthquakes, Trains, Tides, Winds and Atmospheric Pressure Changes on Water in the Geologic Formations of Southern Florida: Econ. Geology, V. 45, No. 5, pp. 441-460.

Parker, G. G., G. E. Ferguson, S. K. Love, et al., 1955. Water Resources of Southeastern Florida, with Special Reference to the Geology and Groundwater of the Miami Area: U. S. Geological Survey Water-Supply Paper 1255, 965 pp.

Peck, D. M., D. H. Slater, T. M. Missimer, S. W. Wise, and T. H. O'Donnell, 1977. Stratigraphy and Paleontology of the Tamiami Formation in Lee and Hendry Counties, Florida: Florida Academy of Sciences, Abstract.

Peck, D. M., D. H. Slater, T. M. Missimer, S. W. Wise, and T. H. O'Donnell, 1979. Stratigraphy and Paleoecology of the Tamiami Formation in Lee and Hendry Counties, Florida: Gulf Coast Assoc. of Geol. Socs. Trans., Vol. 29.

Pirkle, E. C., 1956. The Hawthorne and Alachua formations of Alachua County, Florida: Quart. Jour. Florida Acad. Sci., Vol. 19.

Pirkle, E. C., 1958. Lithologic features of Miocene sediments exposed in the Devil's Mill Hopper, Florida: Quart. Jour. Florida Acad. Sci., V. 21.

Pirkle, E. C., W. H. Yoho, and A. T. Allen, 1965. Hawthorne, Bone Valley and Citronelle Sediments of Florida: Quart. Jour. Florida Acad. Sci., Vol. 28, No. 1.

Post, Buckley, Schuh & Jernigan, and Missimer and Associates, March, 1978. Hydrology and Geology of a Proposed New Wellfield Site in South Lee County, Florida: Prepared for Lee County.

Pressler, E. D., 1947. Geology and Occurrence of Oil in Florida: Am. Assoc. Petroleum Geologists Bull., Vol. 31, No. 10.

Puri, H. S., 1953. Zonation of the Ocala Group in Peninsular Florida (Abstract): Jour. of Sed. Petrology, Vol. 23.

Puri, H. S., 1954. Contribution to the Study of the Miocene of the Florida Panhandle: Florida Geological Survey, Bull. 36.

Puri, H. S. and R. O. Vernon, 1964. Summary of the Geology of Florida and a Guidebook to the Classic Exposures: Florida Geological Survey, Special Publication #5 (revised).

Puri, H. S. and G. O. Winston, 1974. Geologic Framework of the High Transmissivity Zones in South Florida: Florida Bureau of Geology, Special Publication No. 20.

Scott, T. M. and M. Hajishafie, 1980. Top of the Floridan Aquifer in the St. Johns River Water Management District: Florida Bureau of Geology, Map Series No. 95.

Scott, T. M., 1981. A Comparison of the "Cotype" Localities and Cores of the Miocene Hawthorn Formation in Florida: Miocene Symposium of the Southeastern United States Proceedings, in press.

South Florida Water Management District, April, 1980. Water Use and Supply Development Plan, Lower West Coast: Volume - IIIC.

South Florida Water Management District, January, 1981. Permit Application No. 10191, Staff Report: Application by David B. Shakarian and Associates, Bonita Bay.

Sproul, C. R., D. H. Boggess, and H. J. Woodard, 1972. Saline Water Intrusion from Deep Artesian Sources in the McGregor Isles Area of Lee County, Florida: Florida Bureau of Geology, Information Circular 75, 30 p.

Stringfield, V. T., 1966. Artesian Water in Tertiary Limestone in the Southeastern States: U. S. Geological Survey Professional Paper 517, 226 pp.

Sutcliffe, H. Jr., 1975. Appraisal of the Water Resources of Charlotte County, Florida: Florida Bureau of Geology, Report of Investigations No. 78.

Tanner, W. F., 1965. The Origin of the Gulf of Mexico: Gulf Coast Assoc. of Geol. Socs. Trans., Vol. 25.

Theis, C. V., 1935. The Relation Between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Ground-water Storage: Trans. Am. Geophys. Un., 16th Annual Meeting, Pt. 2.

U. S. Congress, 1974. Public Law 93-523, Safe Drinking Water Act: Washington, D.C.

REFERENCES (Continued)

U. S. Geological Survey, 1976. Water-Data Report FL-75-2, Water Resources Data for Florida, Water Year 1976: Vol. 2, p. 771 to 1451.

U. S. Geological Survey, 1977. Water-Data Report FL-76-2, Water Resources Data for Florida, Water Year 1976: Vol. 2, p. 635 to 1140.

U. S. Geological Survey, 1978. Water-Data Report FL-77-2B, Water Resources Data for Florida, Water Year 1977, Volume 2B.

U. S. Geological Survey, 1979. Water-Data Report FL-78-2B, Water Resources Data for Florida, Water Year 1978, Vol. 2B.

U. S. Geological Survey, 1980. Water-Data Report FL-79-2B, Water Resources for Florida, Water Year 1979, Vol. 2B.

U. S. Public Health Service, 1962. Drinking Water Standards; U. S. Dept. of Health, Education and Welfare: Public Health Service Publication No. 956, 61 p.

Vaughan, T. W. and C. W. Cooke, 1914. Correlation of the Hawthorn Formation: Washington Acad. Sci. Jour., V. 4, p. 250-253.

Vernon, R. O., 1951. Geology of Citrus and Levy Counties, Florida: Florida Geological Survey, Bull. 33.

White, W. A., 1958. Some Geomorphic Features of Central and Peninsular Florida, Florida Geological Survey, Bull. 41.

White, W. A., 1970. The Geomorphology of the Florida Peninsula: Florida Bureau of Geology, Bull. No. 51.

Yon, J. W., 1966. Geology of Jefferson County, Florida: Florida Bureau of Geology, Bull. 48.