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GROUND WATER RESOURCE ASSESSMENT OF HENDRY COUNTY, FLORIDA

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PART I - TEXT

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Hydrogeology Division
Resource Planning Department
South Florida Water Management District

EXECUTIVE SUMMARY

Three major fresh water aquifers provide the majority of ground water in Hendry County: the water table aquifer, the lower Tamiami aquifer and the sandstone aquifer. The water table and lower Tamiami aquifers occur within the Surficial Aquifer System. These aquifers are separated from each other by leaky confining layers called the Tamiami confining zone. In western Hendry County the confining zone is absent and the sediments that make up both aquifers are hydraulically connected. In these areas the Surficial Aquifer System acts as a single unconfined aquifer. A deeper aquifer, called the sandstone aquifer, occurs within the Intermediate Aquifer System and is separated from the overlying Surficial Aquifer System by the low permeable sediments of the upper Hawthorn confining zone. The sandstone aquifer consists of two lithologically distinct zones: a clastic zone and a deeper carbonate zone. These two zones exhibit good hydraulic connection. The sandstone aquifer occurs only in the western portion of the study area.

Ground water levels in the Surficial Aquifer System are highest near the Hendry County - Collier County border, north of Immokalee. The water flows away from this area under gentle gradients (less than one foot per mile) in all directions. Water levels within the water table and lower Tamiami aquifers are similar, but water levels in the lower Tamiami aquifer occur up to ten feet lower than those in the water table aquifer. Seasonal fluctuations in both aquifers average approximately five feet. Recharge to the water table aquifer occurs throughout the county as direct infiltration from rainfall, and through seepage from lakes, canals, and rivers. Recharge to the lower Tamiami Aquifer occurs mainly as downward leakage through the leaky confining beds of the Tamiami confining zone. Hydrographs of wells in the water table aquifer show a rapid response to precipitation events and changes in the water levels of surface water bodies. Water levels in the lower Tamiami Aquifer do not respond to these events as rapidly as the water table aquifer.

Ground water levels in the sandstone aquifer are highest in Collier County northeast of Immokalee. Water flows mainly to the north and west. Water levels in this aquifer are lower than those in the overlying Surficial Aquifer System. Seasonal fluctuations average less than five feet. Recharge to the sandstone aquifer occurs as downward leakage through the upper Hawthorn confining zone. A region of significant recharge occurs in the Immokalee area where the confining zone has a low clay content. The sandstone aquifer responds slowly to rainfall and water level changes in the Surficial Aquifer System.

Water quality in the water table aquifer is generally within potable standards. An exception to this is found in the LaBelle area where chloride concentrations exceed 1000 milligrams per liter (mg/l). This is a result of contamination from improperly constructed or abandoned Floridan Aquifer System wells. In addition, the water may be undesirable for potable use in localized areas due to high iron concentrations.

Water quality in the lower Tamiami aquifer is also generally within potable standards except for localized occurrences of high iron concentrations. In general, the water in this aquifer is slightly more mineralized than water in the water table aquifer.

Water quality in the sandstone aquifer is variable. Generally, water quality in this aquifer is poorest near the Caloosahatchee River and improves toward the south. Water in the sandstone aquifer is within potable standards in portions of southwest Hendry County and adjacent areas of Collier and Lee Counties. Water quality in this aquifer is acceptable for agricultural irrigation, although chloride concentrations approach 800 mg/l in an area southwest of LaBelle. Classification of water quality, based on trilinear analysis, suggests that there are subtle differences in water chemistry between the clastic and carbonate zones of the sandstone aquifer.

Ground water use in Hendry County is increasing rapidly due to large scale development of citrus and vegetable production combined with limited sources of surface water to meet the irrigation demands. Agricultural irrigation accounts for more than 99 percent of the permitted water use in Hendry County in 1986. Leach (1983) estimated ground water withdrawals for agricultural irrigation in 1980 to be 109.59 million gallons per day (MGD). Permitted ground water use for agricultural irrigation in 1986 was 222.77 MGD. Water use is highest during the months of January when vegetables are irrigated and May when citrus irrigation is at its peak.

Development potential for the Surficial Aquifer System is highest in central and southern Hendry County. This area is characterized by relatively thick sequences of the water table and lower Tamiami aquifers that yield large amounts of good quality water to wells. Although there are some areas of intense ground water use for irrigation, much of this area is pasture and rangeland which represents areas of low to moderate water use. Most of northern Hendry County has a moderate potential for ground water development from the Surficial Aquifer System. This is a result of thinner aquifers and lower aquifer transmissivity, which result in lower well yields. The northwest portion of Hendry County has the lowest ground water development potential from the Surficial Aquifer System due to thin or non-existent water producing units and poor water quality.

The sandstone aquifer has little potential for large scale development due to low yield and the amount of existing withdrawals. The northwest corner of Hendry County has the lowest potential for development due to high chloride concentrations and low yields. A localized area to the east of LaBelle has the highest development potential based on a relatively thick zone of water bearing materials and good quality water. The rest of the sandstone aquifer within the county has moderate development potential. However, existing citrus operations are already withdrawing large volumes of water from the sandstone aquifer in this area, and it may be approaching allocation limits.

The data collected for this report should be applied in developing a regional multi-layered ground water flow model for Hendry County. The purpose of this modelling will be to determine the impacts of all major ground water users and to determine ground water availability from each aquifer. The results could then be used to develop a regional ground water management plan for Hendry County.

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ABSTRACT

Increasing irrigation demands in Hendry County, Florida, require water managers to collect data and integrate information necessary for responsible development of the ground water resources. In response to this demand, this study was undertaken to define the areal extent and hydraulic characteristics of major fresh water aquifers in Hendry County.

Fresh ground water in Hendry County is obtained from three aquifers: the water table, the lower Tamiami, and the sandstone. The water table aquifer is composed mainly of unconsolidated sand and shell ranging in thickness from three to 150 feet. The thickest portions of the aquifer occur in western Hendry County where there is hydraulic connection between the sand and the permeable limestones of the Tamiami Formation.

In most of the county, up to 75 feet of silt and clay separate the water table aquifer from the lower Tamiami aquifer. The lower Tamiami aquifer, with measured transmissivities of 21,000 to 1,036,000 gallons per day per foot (gpd/ft), is a major source of groundwater. Wells completed into this sequence of moderately indurated, sandy limestones range in depth from 40 to 180 feet. Measured transmissivity values for the water table aquifer range between 14,000 and 1,070,000 gpd/ft. Wells completed into this aquifer are generally less than 40 feet deep.

The sandstone aquifer occurs only in western Hendry County and is the primary aquifer used there. It is divided into two zones, the clastic and the carbonate, which describe its lithologic nature. The sandstone aquifer is moderately productive with transmissivities ranging between 1,000 and 299,000 gpd/ft. Northwest of LaBelle, ground water is obtained from an unnamed white limestone aquifer, which has an average transmissivity of 15,000 gpd/ft. This aquifer may be part of the sandstone aquifer, but further study is needed to make that determination.

Water quality in all the aquifers is acceptable for most irrigation uses. Chloride levels are below 250 milligrams per liter (mg/l) in the water table and lower Tamiami aquifers. Southwest of LaBelle chloride levels exceed 800 mg/l due to contamination from improperly constructed Floridan Aquifer System wells.

Rainfall directly recharges the water table aquifer and also the lower Tamiami aquifer where the confining bed is absent. Elsewhere, the lower Tamiami aquifer and the sandstone aquifer receive recharge by downward leakage through overlying leaky confining beds. Discharge from the aquifers occurs through pumping for irrigation, evapotranspiration and discharge to the Caloosahatchee River.

Key words: (ground water, aquifer, hydraulic characteristics, water quality, water levels, ground water management)

INTRODUCTION

Ground water accounts for approximately half of the water used for municipal and agricultural supply in Hendry County. Lake Okeechobee and the Caloosahatchee River supply water to much of the county, and ground water is used in those areas not readily accessible to surface water. Until recently, most of the county was undeveloped pasture, sugarcane, and vegetable fields, and the availability of fresh water was not a concern. However, recent trends show a shift in land use to large scale production of citrus, resulting in increased water demands.

There is limited information on the water resources of Hendry County. Several localized investigations have been conducted and one regional study has been performed by the U. S. Geological Survey (USGS). The USGS maintains a monitor well network in the county. This network was evaluated and expanded by the South Florida Water Management District (SFWMD) in 1986.

This study combines existing and generated hydrogeologic information to determine the areal extent and characteristics of the ground water resources of the county. This information is designed to facilitate water management decision making.

Purpose and Scope

This study represents the second phase of a mult--county, multi-phase project to develop a comprehensive ground water management plan. This plan is based on quantifying the ground water resources through the development of numerical flow models. The models will then be used in determining the amount of "potentially permittable ground water" in Hendry County. The first phase of the study was completed in 1986 and involved the evaluation of the ground water monitor network and identification of areas of data deficiency.

This report presents the results of a compilation of the existing hydrogeologic data supplemented with data collected from extensive field investigations in Hendry County. The data were assessed to determine aquifer characteristics, ground water resource potential, and water use impacts in the region. The major tasks identified within this phase of the study were to:

1. Review existing literature and determine data gaps.
2. Complete exploratory drilling and hydraulic testing of wells to fill in data gaps.
3. Define the areal extent of regionally continuous ground water sources.
4. Determine regional flow patterns of major fresh water aquifers.
5. Determine regional water quality trends.
6. Determine "base line" values for future use in ground water flow modeling of Hendry County.
7. Present a preliminary assessment of the future development potential of ground water resources.

The final phase of this project will utilize the data collected to quantify the available ground water resources through the development of numerical flow models.

Location

Hendry County is located in the central portion of south Florida, south of Lake Okeechobee (Figure 1). The study area encompasses all of Hendry County and a one township border of the adjacent counties of Charlotte, Lee, Collier, Palm Beach, and Glades. It lies generally within Townships 42 through 49 and Ranges 27 through 35 and encompasses approximately 2,200 square miles (Figure 2). Two major bodies of fresh water, Lake Okeechobee and the Caloosahatchee River, fall within the boundaries of the study area. Land elevations vary from a maximum of 55 feet National Geodetic Vertical Datum (NGVD) to a minimum of 15 feet NGVD; however, most of Hendry County lies between 20 and 30 feet NGVD (Figure 3).

Several cities, towns, and small residential developments are located in the study area. The cities of LaBelle, Clewiston, Moore Haven, and the town of Immokalee are the primary urban centers in the area. Another growing urban development is Port LaBelle, located two miles east of LaBelle.

Physiography

Parker and Cooke (1944) defined three physiographic units within Hendry County: the sandy flatlands, the Everglades, and the Big Cypress Swamp (Figure 2). The sandy flatlands make up the majority of Hendry County and includes the Telegraph Swamp in Charlotte County and the Devil's Garden Wildlife Management Area in eastern Hendry County. The flatlands extend northward into Glades and Highlands counties, westward to the Gulf of Mexico and southward into Collier County. Land elevations vary from 10 to 50 feet above NGVD within the study area. The Everglades lie along the eastern edge of Hendry County and western Palm Beach County,

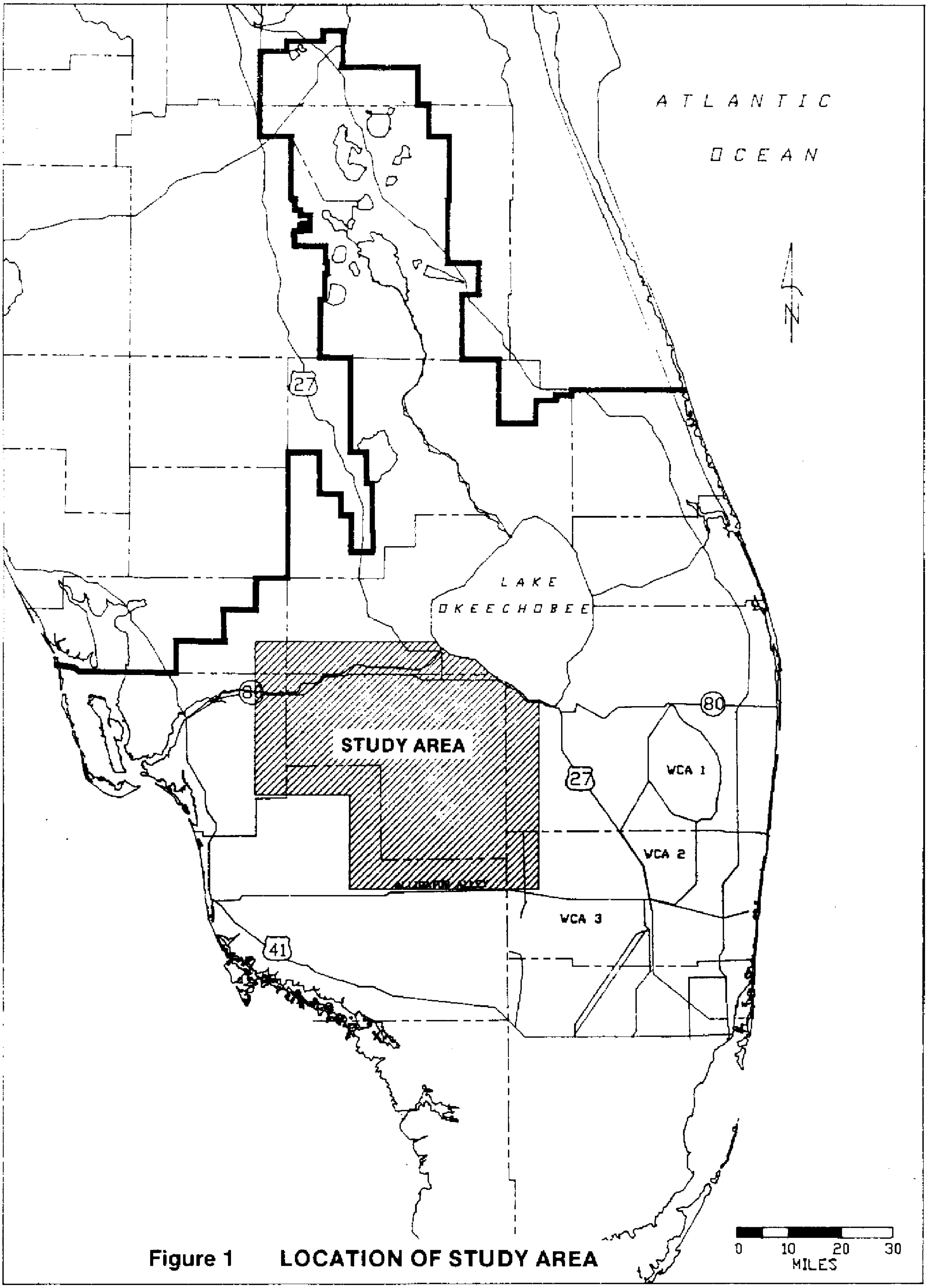


Figure 1 LOCATION OF STUDY AREA

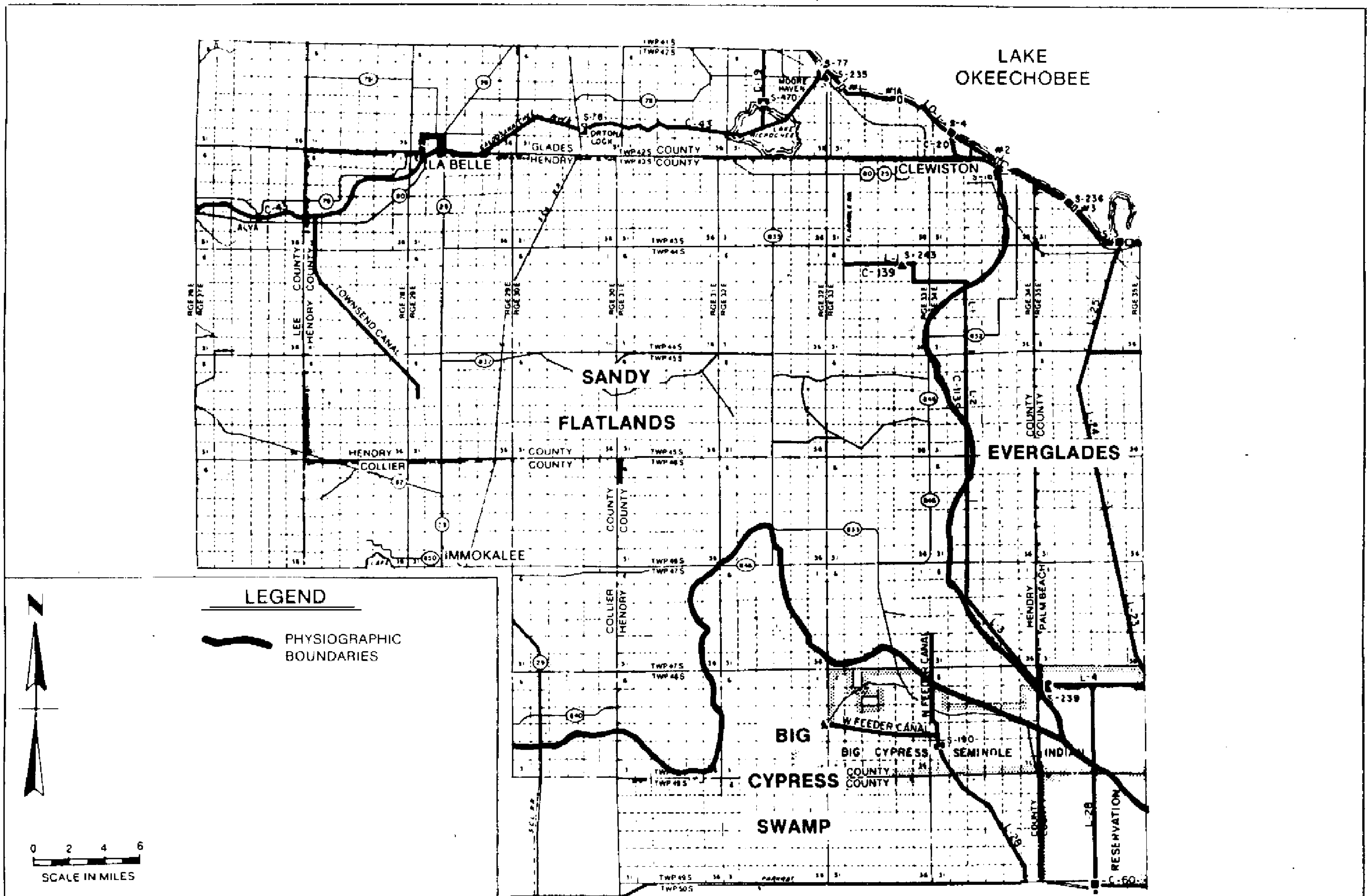


Figure 2 STUDY AREA AND PHYSIOGRAPHIC REGIONS

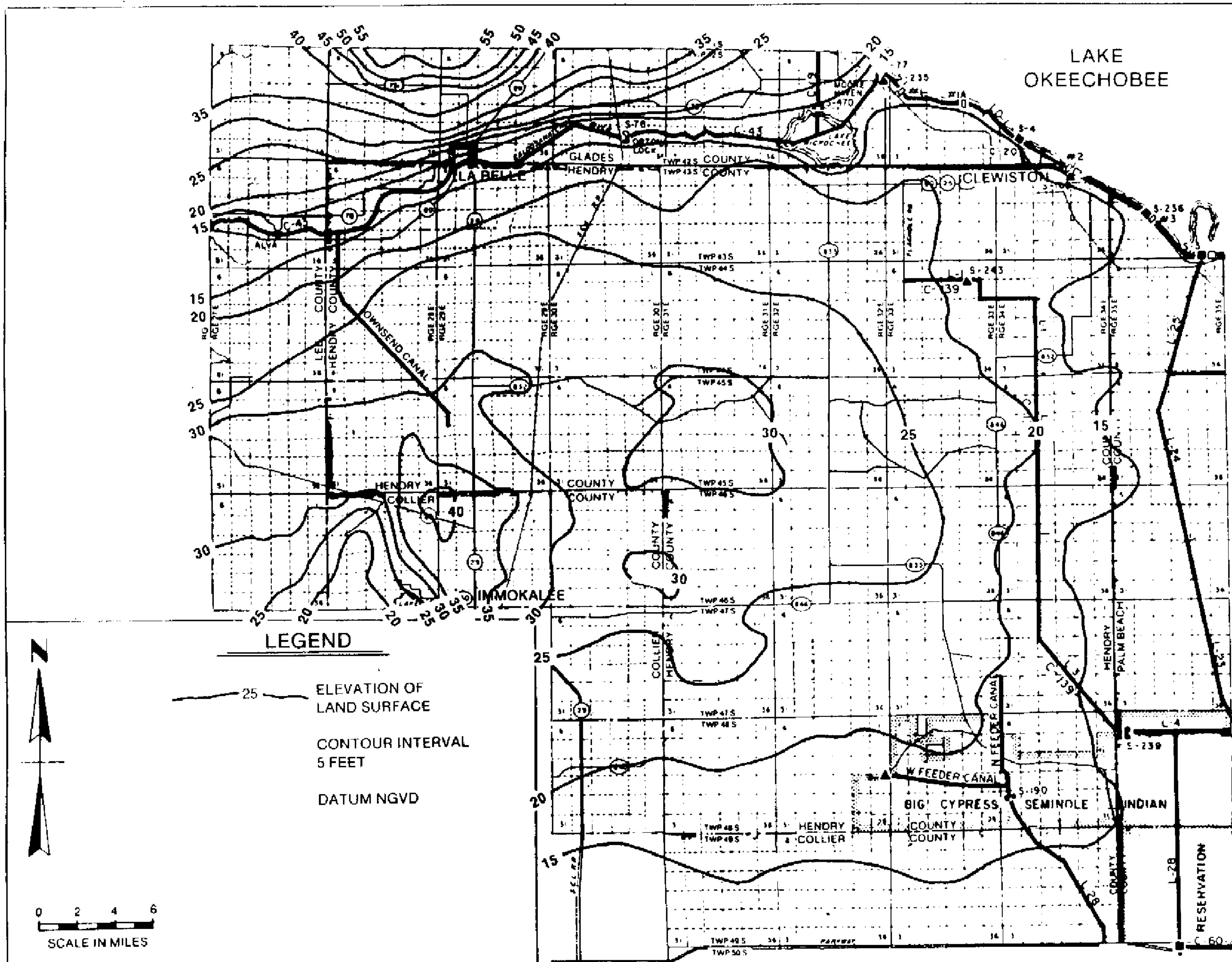


Figure 3 LAND SURFACE ELEVATION

extending from the southern portion of Lake Okeechobee to the south and southeast. The soil of the Everglades is predominantly organic and is composed almost entirely of peat to a maximum thickness of eight feet. The Big Cypress Swamp occupies a large section of southern Hendry County, including part of the Big Cypress Seminole Indian Reservation. The unit is characterized by flat swampy regions and small, pine hammock islands.

The hydrologic divide that separates the two drainage basins in Hendry County trends northeast-southwest through the center of the county. The northern and western portions of the county drain to the Caloosahatchee River. To the south, the Devil's Garden area drains slowly to the west into the Okaloacoochee Slough and ultimately to the Big Cypress Swamp (Klein, 1964). Surface runoff throughout the county is slow because of the flatness of the region.

Climate and Rainfall

The climate of Hendry County is subtropical with a mean annual temperature of 73°F. Summers are long, warm, and relatively humid; winters are mild and the temperature rarely falls below freezing. July and August have the highest average temperatures (81.3°F) while January and February have the lowest average temperatures (64.2°F).

Rainfall occurs in south Florida in two distinct periods; the wet season and the dry season. Usually more than fifty percent of the annual rainfal occurs during the four month period from June through September. Most of the rainfall in the summer occurs from local showers or thunderstorms, with occasional frontal systems and tropical depressions (hurricanes) contributing a significant amount. The average annual rainfall In Hendry County is about 50 inches.

Occasionally, the rainy season pattern emerges late or never materializes. In 1971, and again in 1981, the lack of rainfall caused Lake Okeechobee to drop to a level of approximately 10 feet above NGVD, while the optimum operating level is 15.5 to 17.5 above NGVD (Shaw and Trost, 1984). This lowered water level can have significant impact on water availability for Hendry County.

Methods

Data from seventy-four wells were analyzed and interpreted in order to construct the cross sections, structure, and isopach maps presented in this report. All wells have lithologic descriptions and many are supplemented with geophysical surveys. These wells are listed in Appendix A.

The lithologic descriptions available in the Appendix were generated on an IBM PC data base called the WELL LOG DATA SYSTEM. The PC data system was adapted by Geologic Information Systems in Gainesville from a program developed by the Florida Bureau of Geology and Florida State University to store geologic data on a mainframe computer in Tallahassee. STRATALOG, another program developed on the mainframe and adapted to the District's CDC Cyber computer system, generates stratigraphic columns from the stored data.

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

Geophysical surveys were run in all of the District's exploratory wells and were also available from many of the other wells used in this report. Geophysical logs for wells drilled by the SFWMD were obtained using one of the two Gearhart-Owens loggers owned and operated by the SFWMD. Each logger produces logs in analog and digital form. At the time of this study, the logger was unable to store the data in digital form. Therefore, the analog form of SFWMD logs, along with logs obtained from USGS files, were digitized with a summagraphics ID-RS232 digitizer. The information in digital form was stored on a floppy disk which was later read into the Cyber computer. Once on Cyber, the geophysical logs were plotted using in-house computer programs.

The geophysical logs were used to assist in evaluating and correlating well cuttings from each site. Available logs included Natural Gamma, Neutron Porosity, Caliper, 16 and 64 inch Normal Resistivity, 6 foot Lateral Resistivity, and

Spontaneous Potential. Some of these logs are shown in this report and the remainder are on file at the District.

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

Aquifer parameters were determined through specific capacity and duration aquifer pumping tests. A total of 15 aquifer tests were run in this study. Typical test sites consisted of a pumped well, two production zone observation wells, and two water table observation wells. Step drawdown tests were completed on each production well prior to the duration aquifer pumping test yielding specific capacity data. The specific capacity results were used to estimate transmissivity and for determining an acceptable discharge rate for the duration test.

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

Regional water level data were obtained from the USGS. These data were contoured for both the end of the 1986 wet season and 1987 dry season. Hydrographs were constructed from long term data available from several USGS wells. Rainfall and evapotranspiration data were accessed from the District's hydrologic data base, and bar graphs were plotted for each station. These are presented in Appendix B.

Water quality data are available from most of the USGS and District wells in the area. The USGS network is primarily sampled on a semi-annual basis. Complete inorganic major parameter analyses are available for some of the USGS wells, whereas chloride and conductivity values are measured on all sampled wells. The District wells, along with selected private wells, were sampled during October 1986 and April 1987 with complete inorganic major parameter water quality analyses performed by the District's water chemistry laboratory. Much of this data is presented in Appendix C, and average chloride and conductivity trends are discussed in the text.

Previous Investigations

Early investigations into the geology of south Florida were made by Matson and Clapp (1909), Matson and Sanford (1913), and Cooke and Mossom (1929). These studies were summarized by Parker et al. (1944, 1955). More recent work on the geology of south Florida was done by Missimer (1984).

The stratigraphy of the area was discussed in publications by Parker (1955), Puri and Vernon (1964), and Peck (1979). The stratigraphy and paleontology along the Caloosahatchee River was investigated by DuBar (1958). The stratigraphy and paleoecology of the Tamiami Formation was investigated by Slater (1978).

The most comprehensive study of the hydrogeology of Hendry County was done by Klein et al. (1964). Fish et al. (1983) expanded on the well inventory and described additional wells. More localized work was performed by Stringfield (1933) around Lake Okeechobee and McCoy (1967) in the Immokalee area. Investigations of adjacent counties with some information extending into Hendry County include two hydrogeologic reconnaissance studies by the SFWMD, Knapp et al. (1986) in Collier County and Wedderburn et al. (1982) in Lee County. Preliminary work by the SFWMD in Hendry County was summarized by Smith et al. (1988) as part of an assessment of the ground water monitoring network.

GEOLOGY

BACKGROUND INFORMATION

Hendry County lies at the extreme southern edge of the Ocala uplift (Vernon, 1951). The surficial deposits in this area generally conform to the regional uplift and dip gently to the south (Klein et al., 1964). Major subsurface structural features in the area are the South Florida Shelf and the Broward Syncline (Applin and Applin, 1944). The South Florida Shelf is described as a shallow flat area, trending northwest to southeast from Sarasota to Dade County. It includes all of Hendry County with the exception of the extreme northeast corner. The Broward Syncline runs parallel to and north of the South Florida Shelf. It extends from northeast Hendry County through Broward County.

The upper stratigraphic sequence in Hendry County consists primarily of carbonates with clastic materials present in formations of Miocene age (5.5 to 23.5 million years ago [Mintz, 1977]) or younger. The formations discussed in this report are limited to those of Miocene age or younger. They include the upper portion of the Hawthorn Group, the Tamiami Formation, and undifferentiated shallow deposits. The Hawthorn is recognized as a Group in this report based on work by Scott (1986) and others. The Tamiami Formation (Hunter and Wise, 1980) overlies the Hawthorn Group, and the undifferentiated deposits (Ft. Thompson Formation, Caloosahatchee Marl, Lake Flirt Marl, Pamlico and Talbot sands) lie on top of the Tamiami Formation.

Cuttings from 74 wells in Hendry, Glades, Collier and Lee counties were used to describe the geology and hydrogeology of Hendry County, and cutting descriptions from work done by private consultants were used to supplement the geologic data base. Figure 4 shows the locations of the geologic control wells. Cutting descriptions and available geophysics from the geologic control wells are presented in Appendix A. Contiguous rock units are grouped according to their lithologic and hydraulic properties. These groups are assigned to previously defined stratigraphic and hydrostratigraphic units. Figure 5 is a hydrostratigraphic column of well HY124 showing the relative vertical position of the units discussed in this report.

MIOCENE SERIES

Hawthorn Group

Puri and Vernon (1964) describe the Hawthorn Group as one of the most misunderstood units in the southeastern United States. It was first defined as the "Hawthorn Beds" by Dall and Harris (1892) as the phosphatic sediments being quarried near the town of Hawthorne in northern Florida. These sediments were described at the Devil's Mill Hopper by Johnson (1888), named by Dall and Harris (1892), and designated as a formation by Matson and Clapp (1909). The Devil's Mill Hopper and Brooks Sink were designated as type locations by Puri and Vernon (1964). Literature available on the Hawthorn is extensive, and the reader is referred to the publication list at the end of this report for additional information.

Recently, several authors, including Missimer (1984), and Scott and Knapp (1988) have recognized the Hawthorn as a group. Scott and Knapp (1988) divided it into two units: an upper zone that is composed primarily of clastic material, and a lower zone that is principally carbonate in nature. The contact between these two zones can often be recognized as a rubble bed of coarse quartz pebbles and phosphatic sand and gravel that gives a distinctive response on natural gamma logs (Knapp et al., 1986). However, the rubble zone is not found everywhere in Hendry County. In wells where the rubble zone is not found the distinction between the upper and lower zone must be made on the basis of their lithologies. In some areas of southwest Florida the upper clastic zone contains a unit of very coarse, well rounded quartz sand and gravel. This unit, referred to as the "Miocene coarse clastics" (Knapp et al., 1986), is found at or near the top of the clastic zone. This unit may be analagous to the Ortona sand informally referred to by Hunter (1978). This zone may also contain olive-gray dolosilts and phosphatic sand and gravel. Both zones of the Hawthorn Group are found in Hendry County.

The Hawthorn Group is composed primarily of a heterogenous mixture of silts, clays, calcareous clays, dolosilts, quartz sands, phosphates, limestones, and dolomites. In this report the top of the Hawthorn Group in Hendry County is recognized as the first appearance of olive-gray dolosilts, sands, sandstones, or silts below a biogenic, Tamiami type limestone. It is also identified as the first appearance of olive-gray or green clays, or the presence of phosphatic gravel, or phosphatic sand in quantities in excess of four percent (+ or - one percent). Klein (1964) estimated that the Hawthorn Group ranges in thickness from 300 to 500 feet in Hendry County. Only one of the geologic control wells in Hendry County (HY123) penetrates the entire thickness of the Hawthorn Group. The thickness reported in this well is 870 feet.

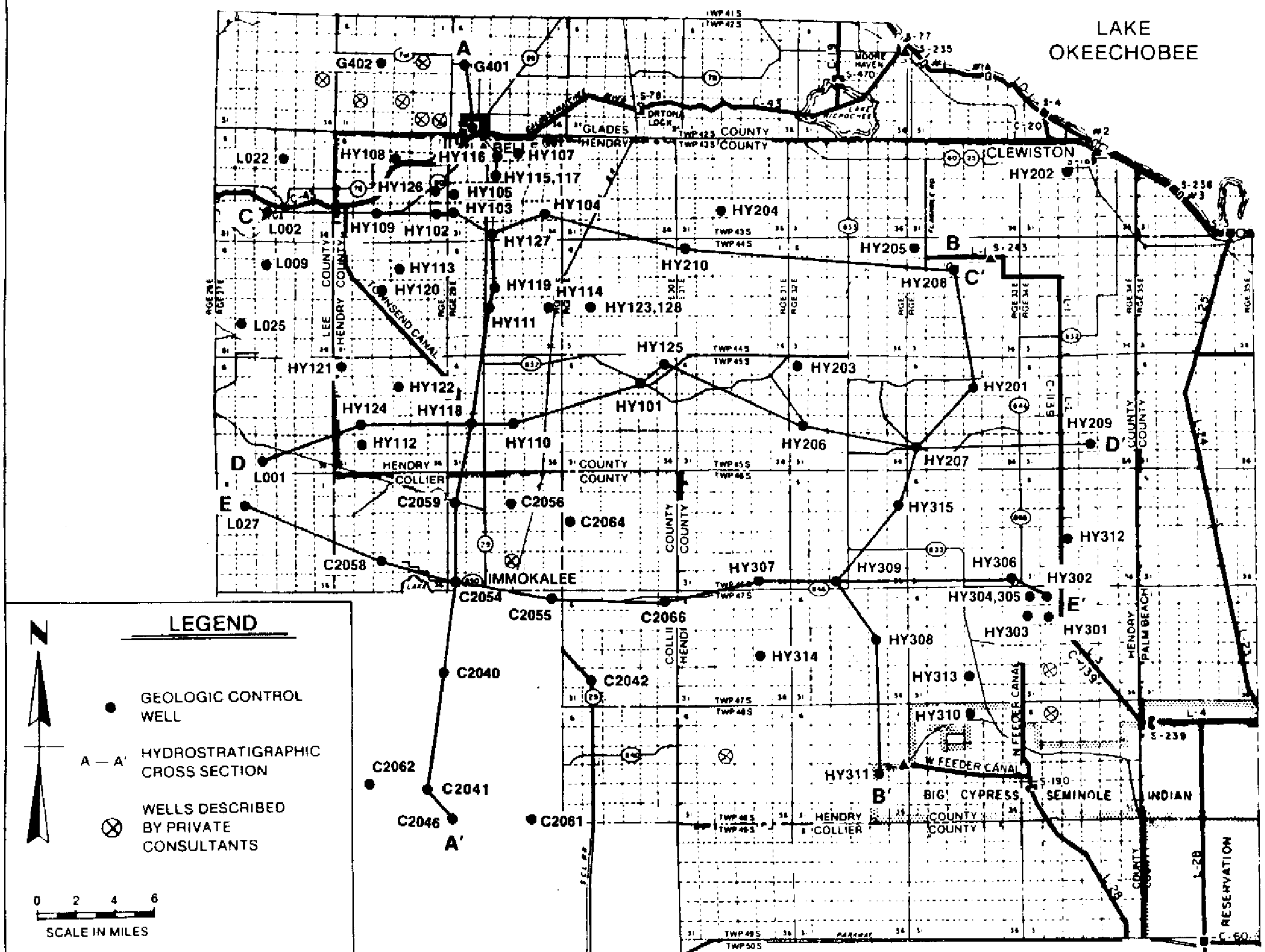
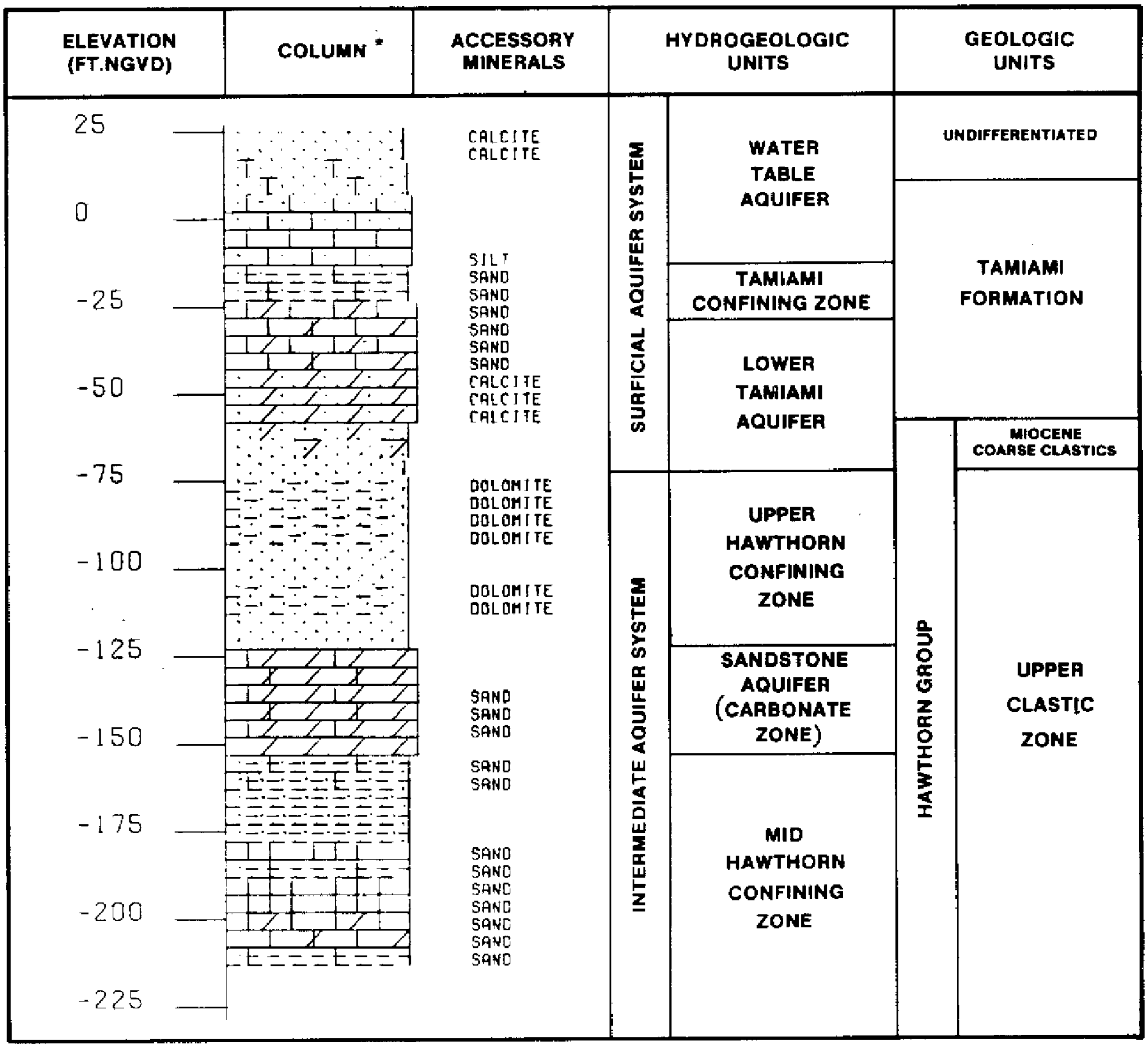


Figure 4 LOCATION OF GEOLOGIC CONTROL WELLS AND HYDROSTRATIGRAPHIC CROSS SECTIONS



* SEE APPENDIX A FOR EXPLANATION OF SYMBOLS

Figure 5 HYDROSTRATIGRAPHIC COLUMN OF WELL HY124

Figure 6 shows the top of the Hawthorn Group in the study area. Highest elevations form a ridge-like feature with elevations near zero feet NGVD. The ridge trends east-west from Clewiston towards Lehigh Acres in Lee County. The top of the Hawthorn dips to the north and south of this feature reaching depths in excess of -175 feet NGVD in eastern Hendry County. Two localized depressions in the top of the Hawthorn occur in the vicinity of LaBelle.

The upper clastic zone of the Hawthorn Group averages approximately 225 feet thick in Hendry County (Figure 7). It is thickest, up to 340 feet, near Immokalee. It also thickens in the northeastern portion of the study area near Lake Okeechobee. A localized area of thinning of the upper clastic zone occurs between LaBelle and the Townsend Canal, where it is less than 75 feet thick.

The Miocene coarse clastics were identified in 20 of the 73 geologic control wells. The entire thickness of the unit was penetrated in 14 wells. The coarse clastics form a trough on top of the fine sands and silt of the upper clastic zone. This feature trends northeast to southwest from Lake Okeechobee towards Immokalee (Figure 8). In Collier County the coarse clastics continue to the Gulf coast, gradually thinning from 150 feet near Immokalee to less than 50 feet at the coast (Knapp et. al., 1986). This occurrence suggests that the trough of coarse clastics may have been deposited as a deltaic lobe on top of the fine sands and silt of the upper clastic zone.

The top of the lower carbonate unit of the Hawthorn Group generally occurs at elevations of approximately -350 feet NGVD (Figure 9). The lower zone has its shallowest occurrence in a localized area to the southwest of LaBelle where it occurs at elevations above -150 feet NGVD. This area corresponds to a thin area of the upper clastic zone. Because only one of the geologic control wells penetrate the entire thickness of the Hawthorn Group, the thickness of the lower zone in Hendry County is unknown.

MIOCENE/PLIOCENE SERIES

Tamiami Formation

The "Tamiami Limestone" was first used by Mansfield (1939) to describe a sandy fossiliferous limestone exposed in ditches along the Tamiami Trail (U.S. 41) in Collier and Monroe Counties. Parker and Cooke (1944) expanded the Tamiami to include "white to cream-colored calcareous sandstone, sandy limestone, and beds and pockets of quartz sand". Parker et al. (1955) redefined the Tamiami Formation to include Mansfield's limestone and all of the upper Miocene materials in southern Florida. Hunter and Wise (1980, 1980a) showed that Parker's definition of the Tamiami Formation was inconsistent with the American Commission on Stratigraphic Nomenclature (1970). They suggested restricting the Tamiami Formation to the "original interfingering limestone members (Ochopee and Buckingham Limestones) and other equivilent facies such as the Pinecrest Sand." The subjacent Miocene clastic materials were returned to the Hawthorn.

The Tamaimi Formation has a varied lithology in Hendry County. In southern Hendry County it occurs as a relatively thick sequence of limestone. It typically occurs as a moderate to well indurated, biogenic, medium to coarse grained sandy limestone exhibiting good intergranular and moldic porosity. Sand content generally increases with depth. In most locations these limestones are interbedded with thin layers of moderately indurated calcareous sandstones or unconsolidated quartz sands. The limestones thin to the north and the sand and sandstone layers make up most of the thickness of the Tamiami Formation in central Hendry County. These sands, sandstones, and sandy limestones grade into the underlying thick sequence of the Miocene coarse clastics that occur in this area. The Tamiami Formation is thinner in central Hendry County due to the underlying Hawthorn Group occurring at higher elevations and the inclusion of the coarse sands in the Miocene coarse clastics. In areas of northern Hendry County (particularly in the LaBelle area) the Tamiami Formation is thin and its lithology makes it difficult to distinguish from the younger biogenic limestones of the Caloosahatchee Marl and the Fort Thompson Formation. These units can be distinguished from each other on the basis of biostratigraphy, but a detailed investigation of fossil assemblages is beyond the scope of this study. Therefore, in these areas, the Tamiami Formation was grouped with the undifferentiated deposits.

Figure 10 shows the top of the Tamiami Formation in Hendry County. Its surface is generally flat throughout most of the county with elevations between 0 and 20 feet NGVD. However, in southeastern Hendry County, it dips rapidly to the southeast with elevations decreasing to -68 feet NGVD. This generally corresponds to a similar feature in the top of the Hawthorn Group (Figure 6).

The thickness of the Tamiami Formation is shown in Figure 11. The thickness of this unit is variable throughout Hendry County. The Tamiami Formation is absent around the LaBelle, Immokalee, and Clewiston areas; it is thickest in east central

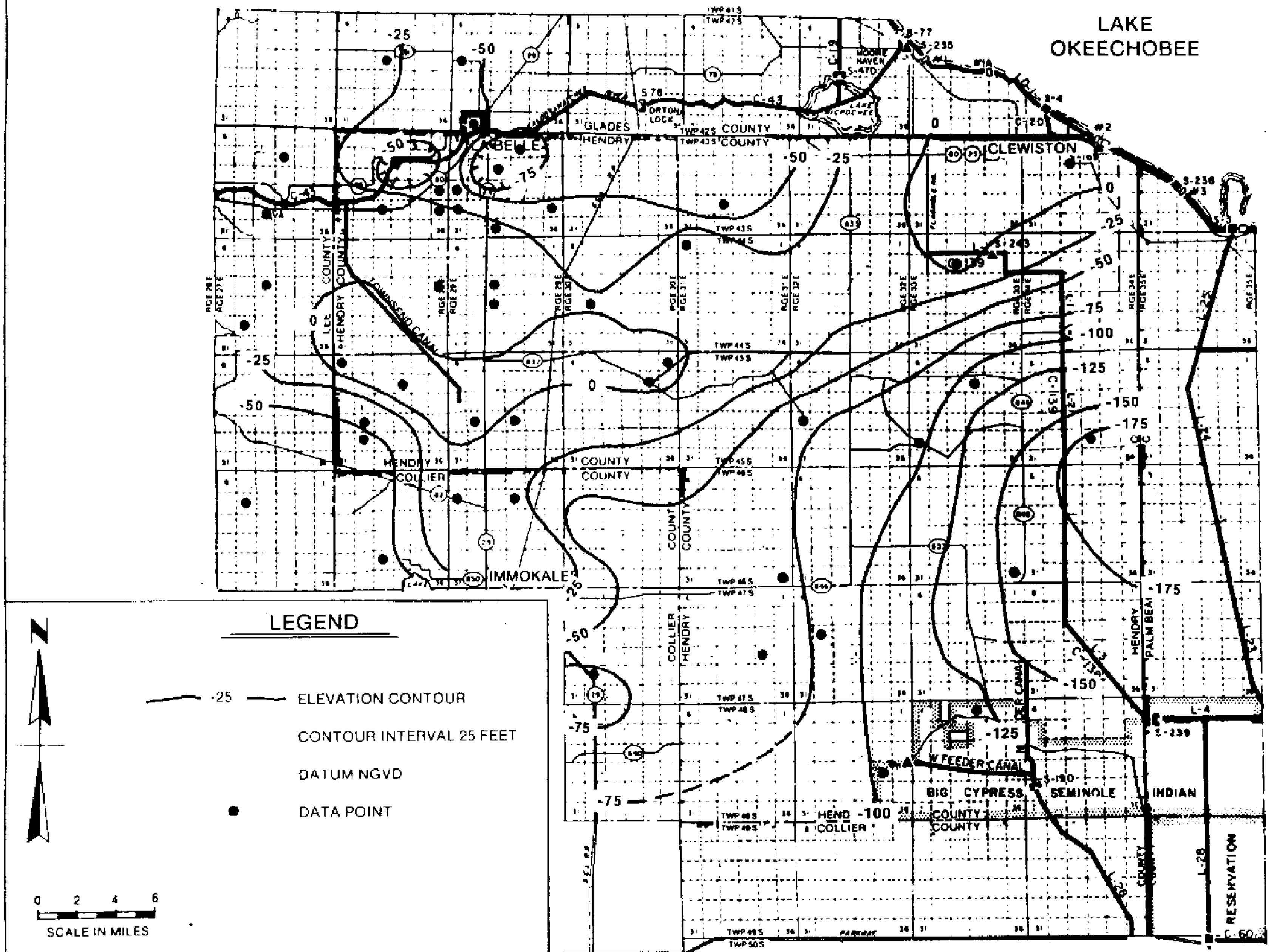


Figure 6 TOP OF THE HAWTHORN GROUP

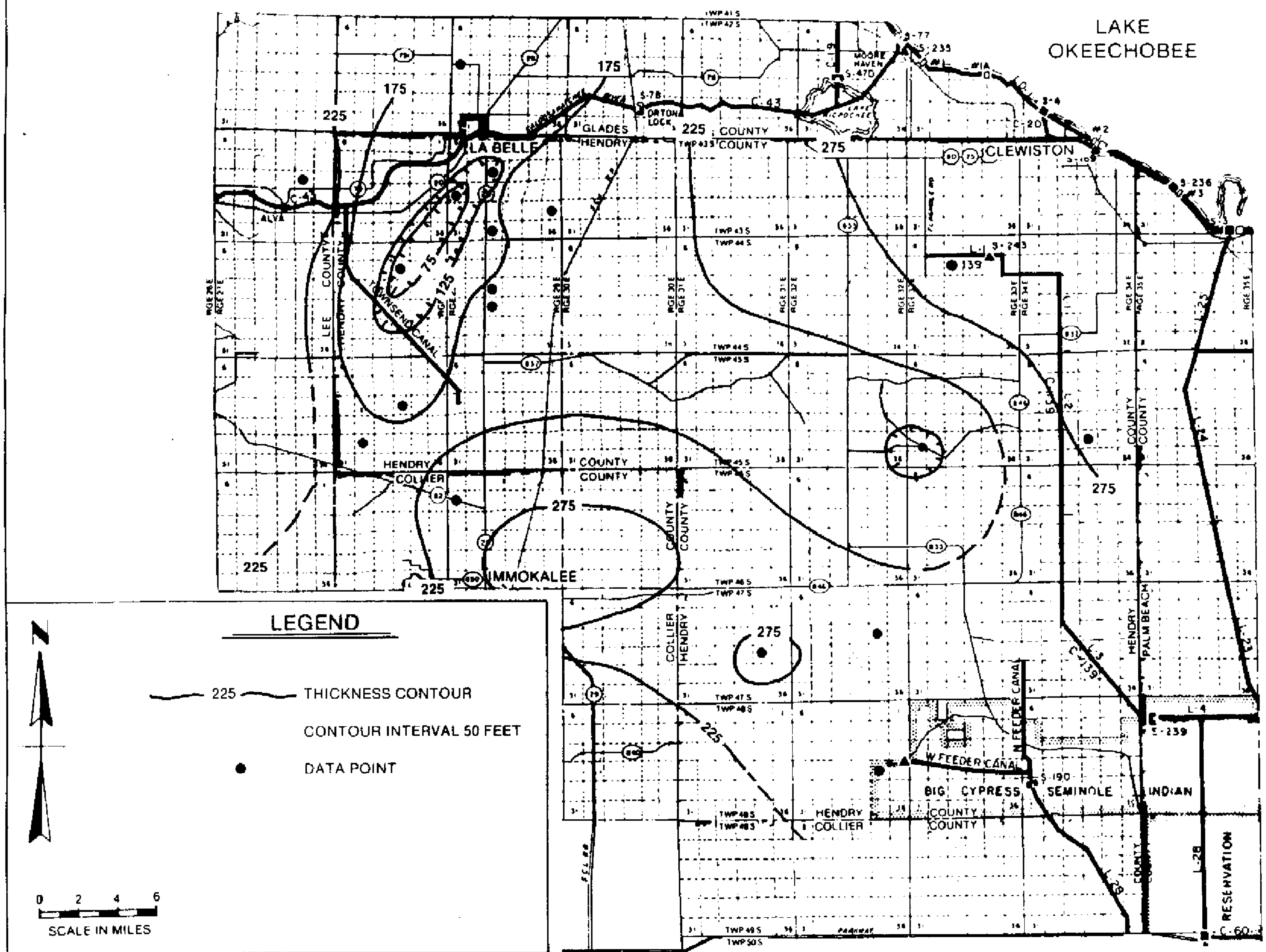


Figure 7 THICKNESS OF THE UPPER CLASTIC ZONE OF THE HAWTHORN GROUP

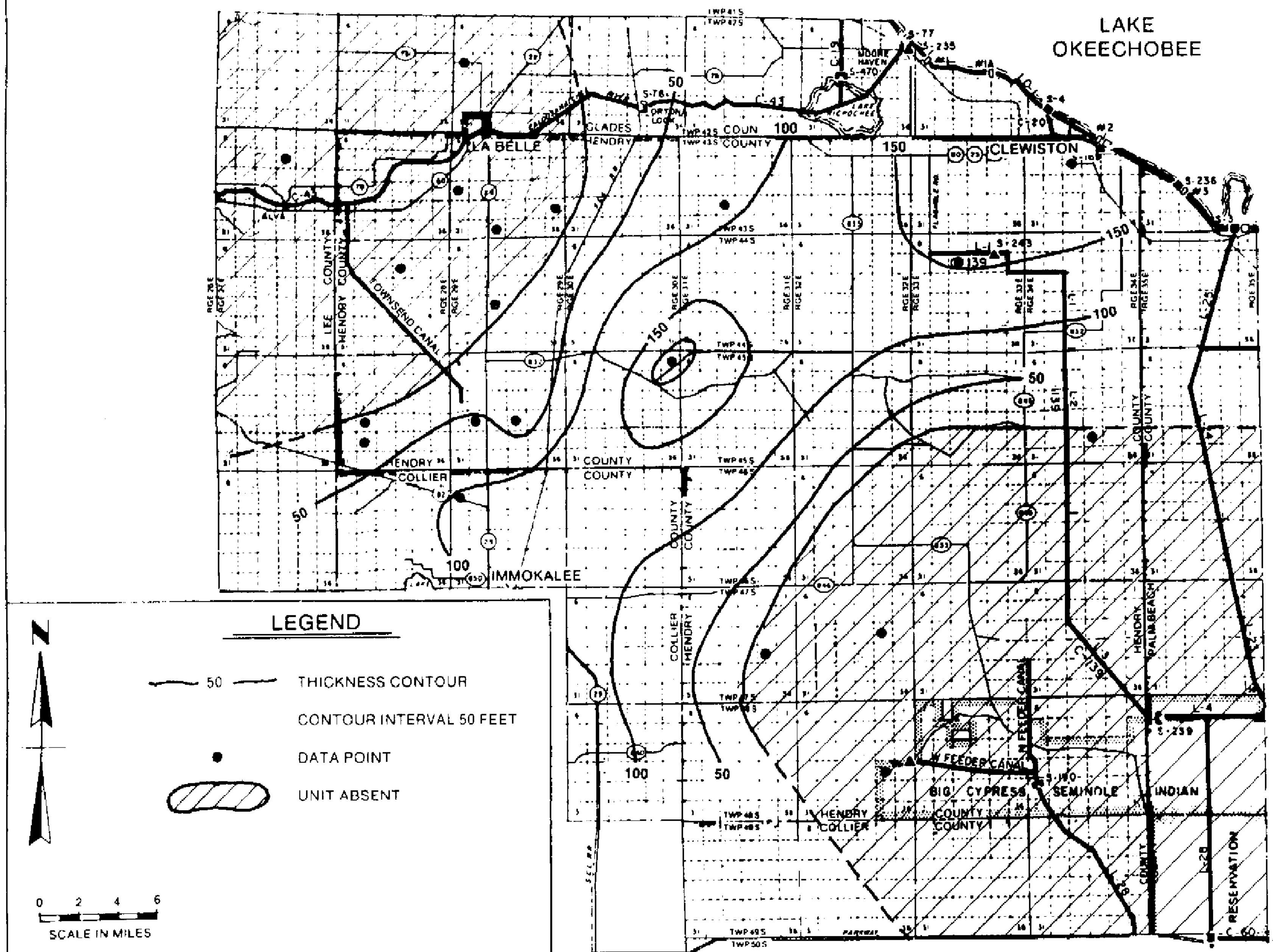


Figure 8 THICKNESS OF THE MIOCENE COARSE CLASTICS

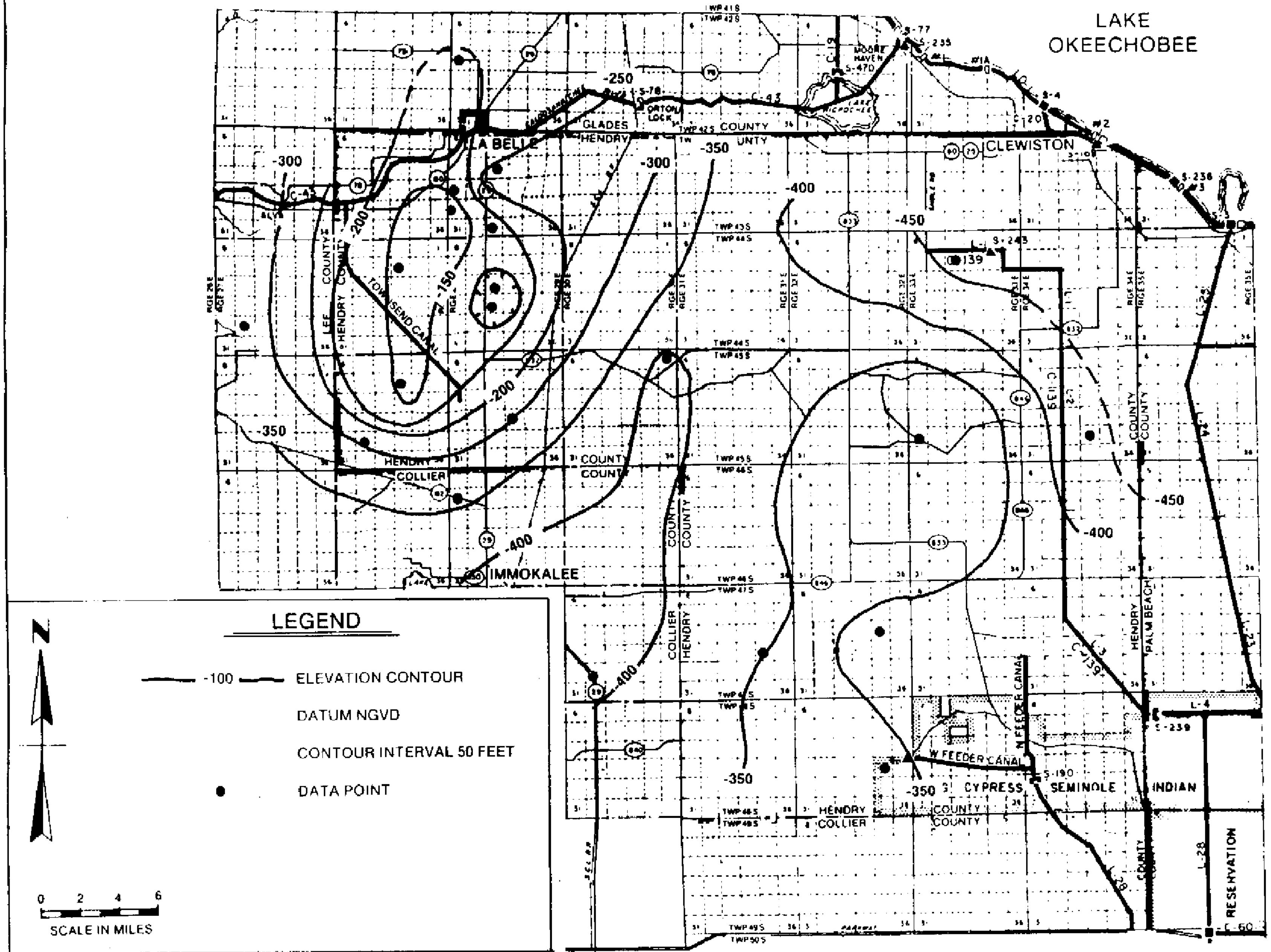


Figure 9 TOP OF THE LOWER CARBONATE ZONE OF THE HAWTHORN GROUP

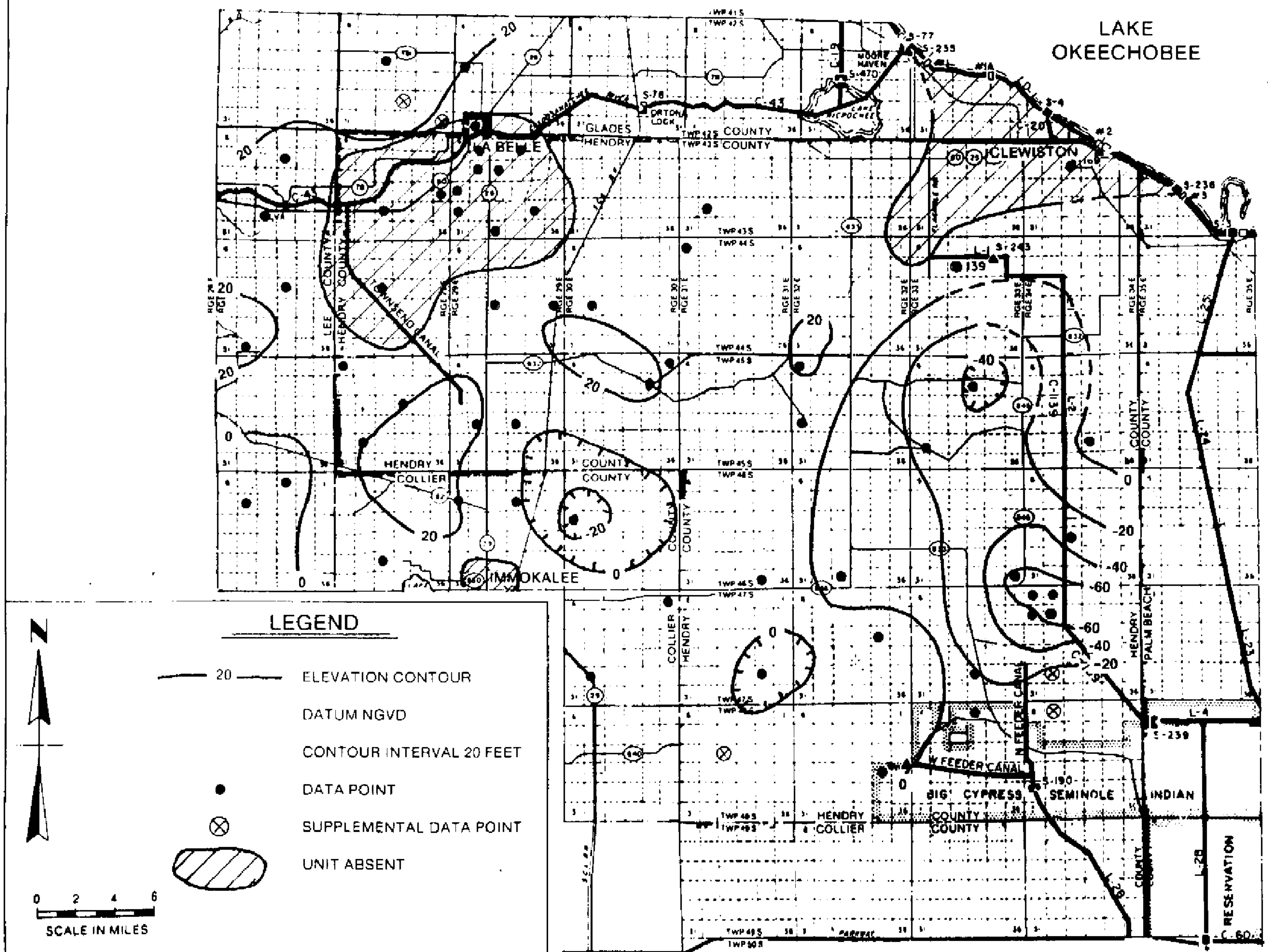


Figure 10 TOP OF THE TAMIAMI FORMATION

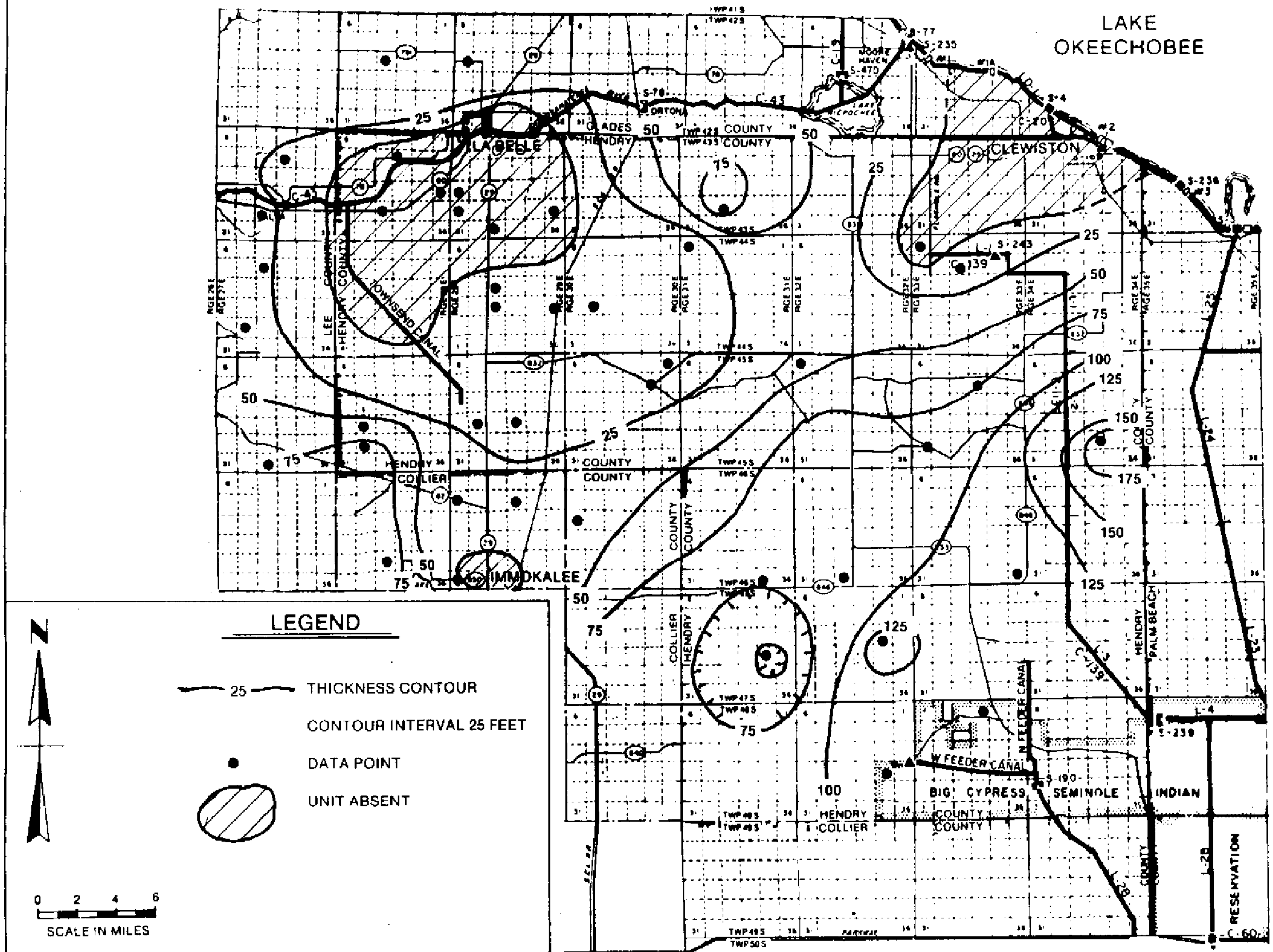


Figure 11 THICKNESS OF THE TAMIAMI FORMATION

Hendry County where a thickness of 176 feet is found in well HY209. Generally, the Tamiami Formation is thinnest in northern Hendry County and thickens towards the south.

PLEISTOCENE/HOLOCENE SERIES

Undifferentiated Deposits

Undifferentiated deposits of varying thicknesses and lithologies occur at land surface throughout Hendry County. These deposits consist mostly of quartz sands with varying amounts of silt, clay, shell, and organic material. In some areas high percentages of phosphatic sand occur in thin layers among the undifferentiated deposits. This may be the result of exposed Hawthorn material to the north of Hendry County being eroded, transported, and deposited here during Pleistocene and Holocene time.

Various authors have identified several units within the shallow sediments in Hendry County. The Fort Thompson Formation (Sellards, 1919; Cooke and Mossom, 1929), the Caloosahatchee Marl (Matson and Clapp, 1909), the Lake Flirt Marl (Sellards, 1919) and the Pamlico and Talbot sand terraces (Parker and Cooke, 1944) are names that appear in the literature. These units are all classified as undifferentiated in this report due to the limitations of the scope of this study. Also, deposits in the vicinity of LaBelle that may belong to the Tamiami Formation are included in the undifferentiated deposits because the Tamiami is very thin and difficult to distinguish from younger biogenic limestones in this area.

HYDROGEOLOGY

BACKGROUND INFORMATION

The geologic formations underlying Hendry County can be divided into aquifers and confining zones based on their hydraulic properties. An aquifer is defined as a formation, group of formations, or a part of a formation that contains sufficient saturated permeable material to yield economical amounts of water to wells and springs (Driscoll, 1986). Driscoll also defines a confining zone (aquiclude) as a saturated but poorly permeable bed, formation, or group of formations that does not freely yield water to wells or springs, but may transmit appreciable quantities of water to or from adjacent aquifers. For a formation to be included in an aquifer or confining zone it must exhibit the appropriate hydraulic properties and show significant horizontal and vertical continuity.

Kruseman and DeRidder (1970) define four basic types of aquifers that occur in nature: unconfined, semi-unconfined, semi-confined, and confined. Unconfined aquifers are composed of permeable materials that may be partially or completely saturated. Water levels are in equilibrium with atmospheric pressure. The upper boundary is called the water table or phreatic surface. The lower boundary is formed by a confining zone. A confined aquifer is completely saturated and bounded on both the top and bottom by impermeable beds. Hydrostatic pressure exceeds atmospheric pressure causing the potentiometric surface (the level which water rises in a tightly cased well open only to the confined aquifer) to occur above the top of the confined aquifer. Completely impervious beds rarely occur in nature and confined aquifers are less common than recognized. A semi-confined or leaky aquifer is completely saturated and is bounded on the top and bottom by low permeable or leaky confining zones. Water can move vertically through these confining zones at a rate dependent on the head differentials between the semi-confined aquifer and the source beds, and the permeabilities of the confining zones. Semi-unconfined aquifers are similar to semi-confined aquifers; however, the horizontal flow component within the adjacent confining zones is great enough that it cannot be ignored. Unconfined, semi-confined, and semi-unconfined aquifers occur in Hendry County.

Three major regional aquifer systems occur in Hendry County: The Surficial Aquifer System, the Intermediate Aquifer System, and the Floridan Aquifer System. The Surficial Aquifer System contains two aquifers, the water table aquifer and the lower Tamiami aquifer, separated by the Tamiami confining zone (Figure 5). The Intermediate Aquifer System underlies the Surficial Aquifer System and acts as a confining zone for the deeper Floridan Aquifer System. The sandstone and mid-Hawthorn aquifers are contained within the Intermediate Aquifer System. In addition, an unnamed white limestone aquifer is also found in this aquifer system northwest of LaBelle. Although similarity of water levels between the sandstone aquifer and the Surficial Aquifer System suggest that the sandstone aquifer may belong in the Surficial Aquifer System, it is included in the Intermediate Aquifer System because it occurs below the first regionally continuous confining zone (Southeastern Geological Society Committee on Florida Hydrostratigraphy 1986). The sandstone aquifer is separated from the Surficial Aquifer System by the upper Hawthorn confining zone and from the mid-Hawthorn aquifer by the mid-Hawthorn confining zone. The Floridan Aquifer System contains highly mineralized water in Hendry County (Klein et al., 1964) and is not discussed in this report.

Locations of five hydrogeologic cross sections are shown in Figure 4. Cross section A-A' (Figure 12) runs north-south from well G401 (north of LaBelle) parallel to State Road 29 to well C2046 (approximately 12 miles south of Immokalee). The Surficial Aquifer System is thickest in well HY115 near LaBelle and well C2040 near Immokalee. The lower Tamiami Aquifer is not present in wells HY106, HY116, HY115, HY119, HY127, and C2054. The absence of the Tamiami confining zone in these wells indicates that the entire thickness of the Surficial Aquifer System behaves as a single unconfined aquifer at these locations.

The thickness of the sandstone aquifer in cross section A-A' is variable, ranging from zero feet in wells HY106, HY115, G401, and C2046 to 150 feet in well C2054 where both the clastic and carbonate zones are present and separated by 40 feet of confining material. The top of the sandstone aquifer occurs from -56 to -153 NGVD in Hendry County. Towards the south into Collier County, the top of the sandstone aquifer dips to elevations of -270 NGVD in well C2040. The Surficial Aquifer System is also thickest at this location.

Cross section B-B' (Figure 13) extends north-south from well HY208 (southwest of Clewiston) to well HY311 on the Big Cypress Indian Reservation. In this cross section the Surficial Aquifer System

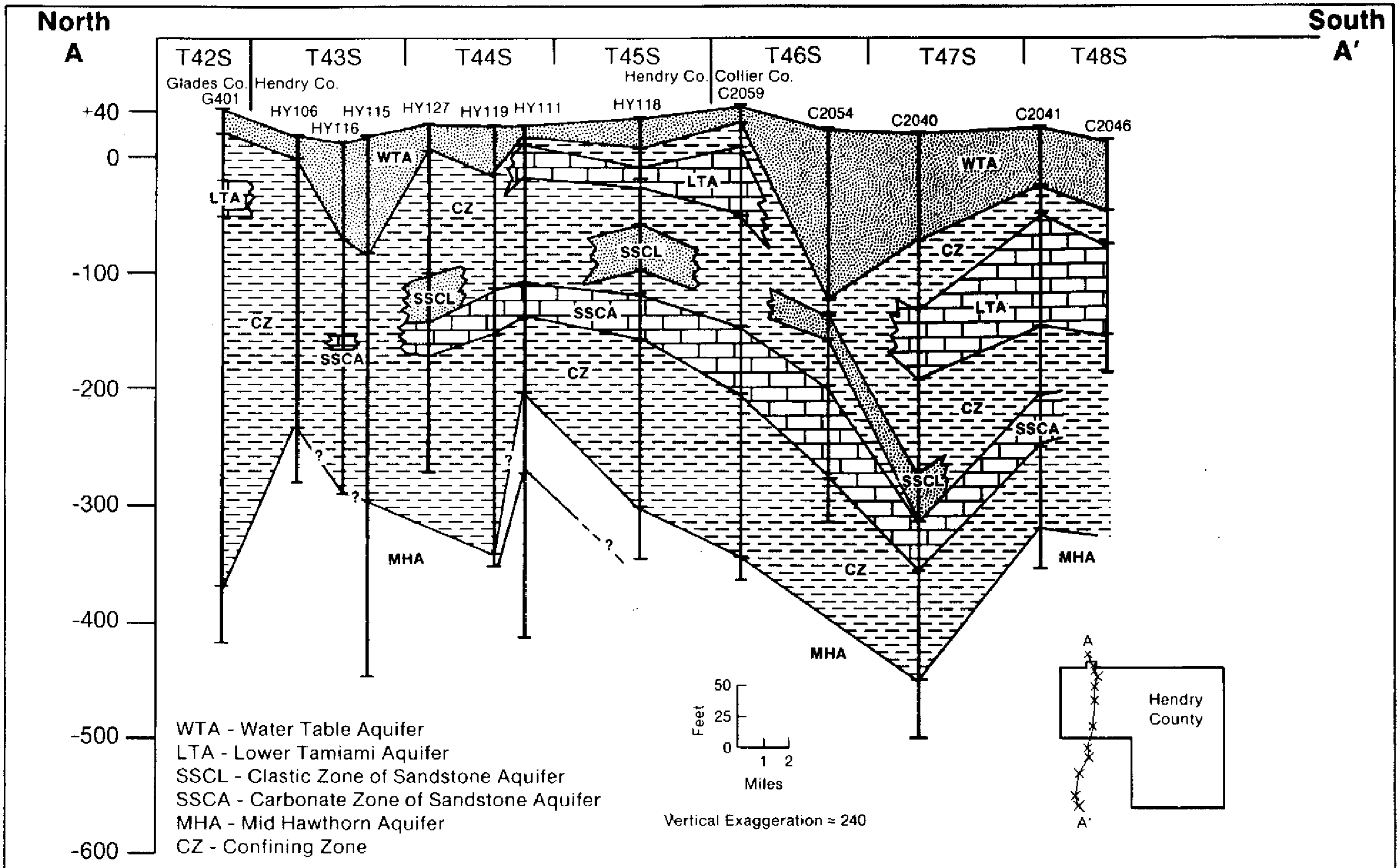


Figure 12 HYDROSTRATIGRAPHIC CROSS SECTION A-A′

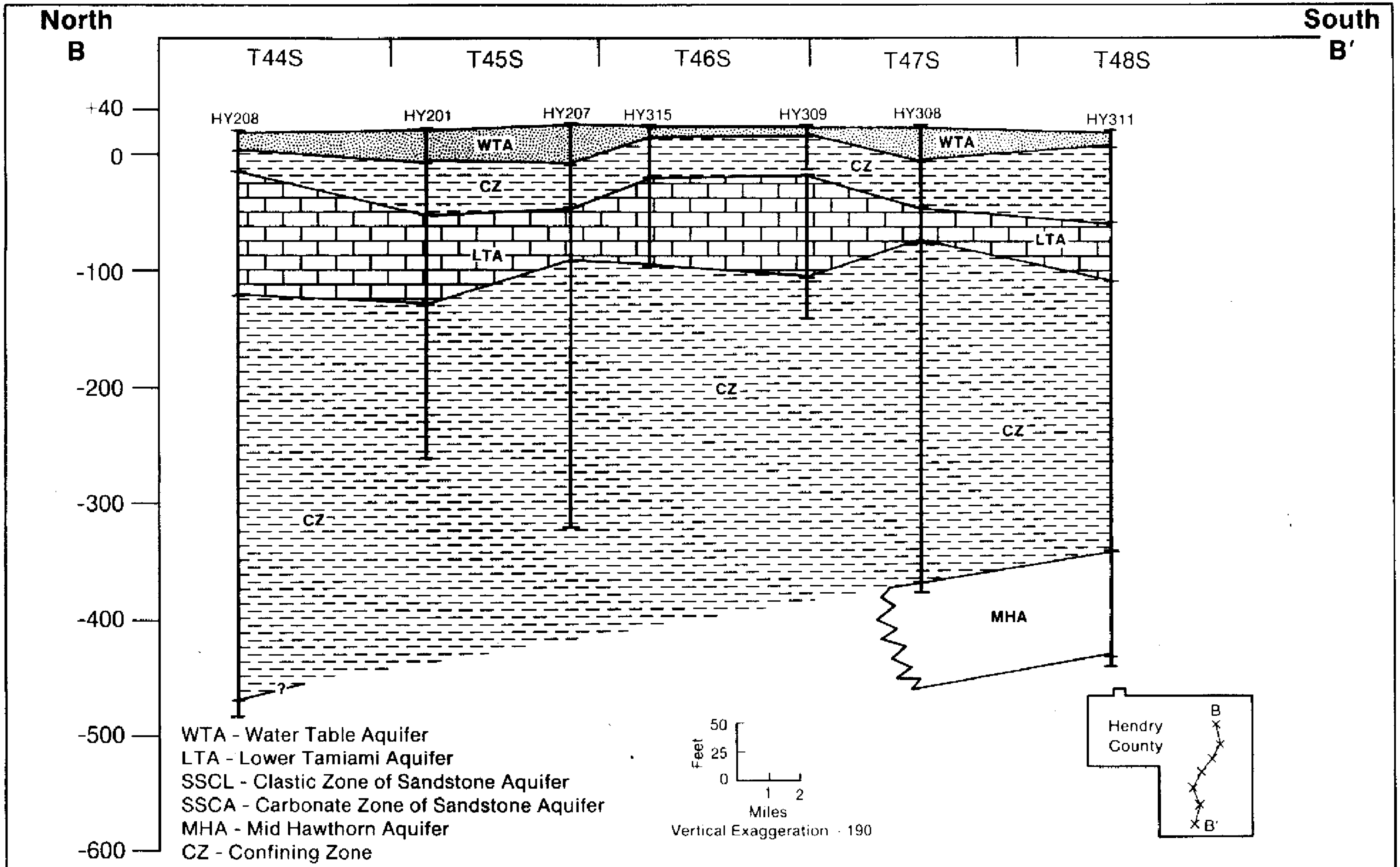


Figure 13 HYDROSTRATIGRAPHIC CROSS SECTION B-B′

ranges in thickness from 100 feet in well HY308 to 150 feet in well HY201. The lower Tamiami aquifer is between 30 and 105 feet thick, and is found at depths ranging from -16 to -52 feet NGVD. The sandstone aquifer does not occur in eastern Hendry County.

Cross section C-C' (Figure 14) extends west to east from well L002 near Alva to well HY208 (southwest of Clewiston). The Surficial Aquifer System is thickest in well HY208 where it consists mainly of a thick sequence of the lower Tamiami aquifer. The lower Tamiami aquifer thins toward the west and pinches out between wells HY210 and HY104. The Surficial Aquifer System continues to thin to the west, reaching its minimum thickness of four feet in well HY102 (approximately five miles southwest of LaBelle).

The sandstone aquifer occurs primarily as a carbonate facies in well L002. It is found at elevations between -46 feet and -158 feet NGVD. It thins and dips to the east, pinching out in the vicinity of well HY127 (just east of State Road 29). The clastic zone of the sandstone aquifer occurs in wells HY102, HY103, and HY127 at elevations between -77 and -103 feet NGVD. This zone also disappears to the east of well HY127. The clastic zone of the sandstone aquifer also pinches out to the west of well HY102.

Cross section D-D' (Figure 15) runs west to east from well L001 to well HY209. The Surficial Aquifer System is quite variable in thickness ranging from 40 feet in well HY110 (near State Road 29) to 185 feet in well HY125. The variable thickness of the Surficial Aquifer System is controlled by the occurrence and thickness of the lower Tamiami aquifer. The extent of the sandstone aquifer is similar to cross section C-C', where it occurs as a thick sequence of the carbonate zone in Lee County. The aquifer thins toward the east and pinches out east of State Road 29. However, it does not dip to the east in this cross section as it does in C-C'. The top of the carbonate zone is relatively flat. The thinning to the east is a result of changes in the elevation of the bottom of this zone from -300 feet NGVD in well L001 to -133 feet NGVD in well HY110. The clastic zone of the sandstone aquifer in this cross section is similar to that in C-C', although in D-D' it is thinner and shallower.

Cross section E-E' (Figure 16) extends west to east from well L027 (southeastern Lee County) to well HY302. The thickness of the Surficial Aquifer System ranges between 50 feet in well C2055 and 195 feet in well HY306. Again, the thickness of the Surficial Aquifer System is composed mostly of the lower Tamiami aquifer. However, in wells C2054 and C2055 the absence of the Tamiami confining zone causes the entire thickness of the Surficial Aquifer System to act as a single unconfined aquifer. The lower Tamiami aquifer is 205 feet thick in well HY306, thins to the west, and appears to pinch out west of well C2066. It appears again as a 10 foot section in well C2058 and thickens to the west. The clastic zone of the sandstone aquifer occurs at elevations between -70 feet NGVD in well C2058 and -135 feet NGVD in well C2055. This zone is thickest in the west and thins to the east, pinching out east of well C2055. The carbonate zone of the sandstone aquifer occurs at depths from -110 feet NGVD in well L027 to -195 NGVD in well C2055. The carbonate zone is in contact with the clastic zone in well C2055 and pinches out to the east. The hydrostratigraphic relationship between the sandstone aquifer and the lower Tamiami Aquifer between wells C2055 and C2066 is unclear. Since the lower Tamiami aquifer appears to dip to the west and the sandstone aquifer appears to be rising to the east, it is possible that the two aquifers come in contact with each other in this area. However, there are no data to support this at present. Future investigations in the area should include test drilling between wells C2055 and C2066 to determine the hydrostratigraphic relationship between the two aquifers.

SURFICIAL AQUIFER SYSTEM

The Surficial Aquifer System consists of the water table aquifer and hydraulically connected units above the top of the first occurrence of laterally extensive and vertically persistent beds of much lower permeability (SGCFH, 1986). The Surficial Aquifer System was called the shallow aquifer by Klein et al. (1964) and the surficial aquifer by Fish et al. (1983).

In Hendry County, the Surficial Aquifer System occurs mainly within the sediments of the Tamiami Formation and the undifferentiated deposits. However, in many areas throughout the county, the Miocene coarse clastics exhibit high permeability and are in direct contact with permeable zones of the Tamiami Formation or the undifferentiated deposits. In these areas, the Miocene coarse clastics are included in the Surficial Aquifer System.

The Surficial Aquifer System is divided into two aquifers: the water table aquifer and the lower Tamiami aquifer, separated by a leaky confining zone called the Tamiami confining zone. The Surficial Aquifer is bounded on the top by the water table and on the bottom by the low permeable beds of the upper Hawthorn confining zone. Figure 17 shows the thickness of the Surficial Aquifer System in the study area. It varies in thickness between four feet in well HY102 (southwest of LaBelle) to 208 feet in well C2040 (southwest of Immokalee). The Surficial

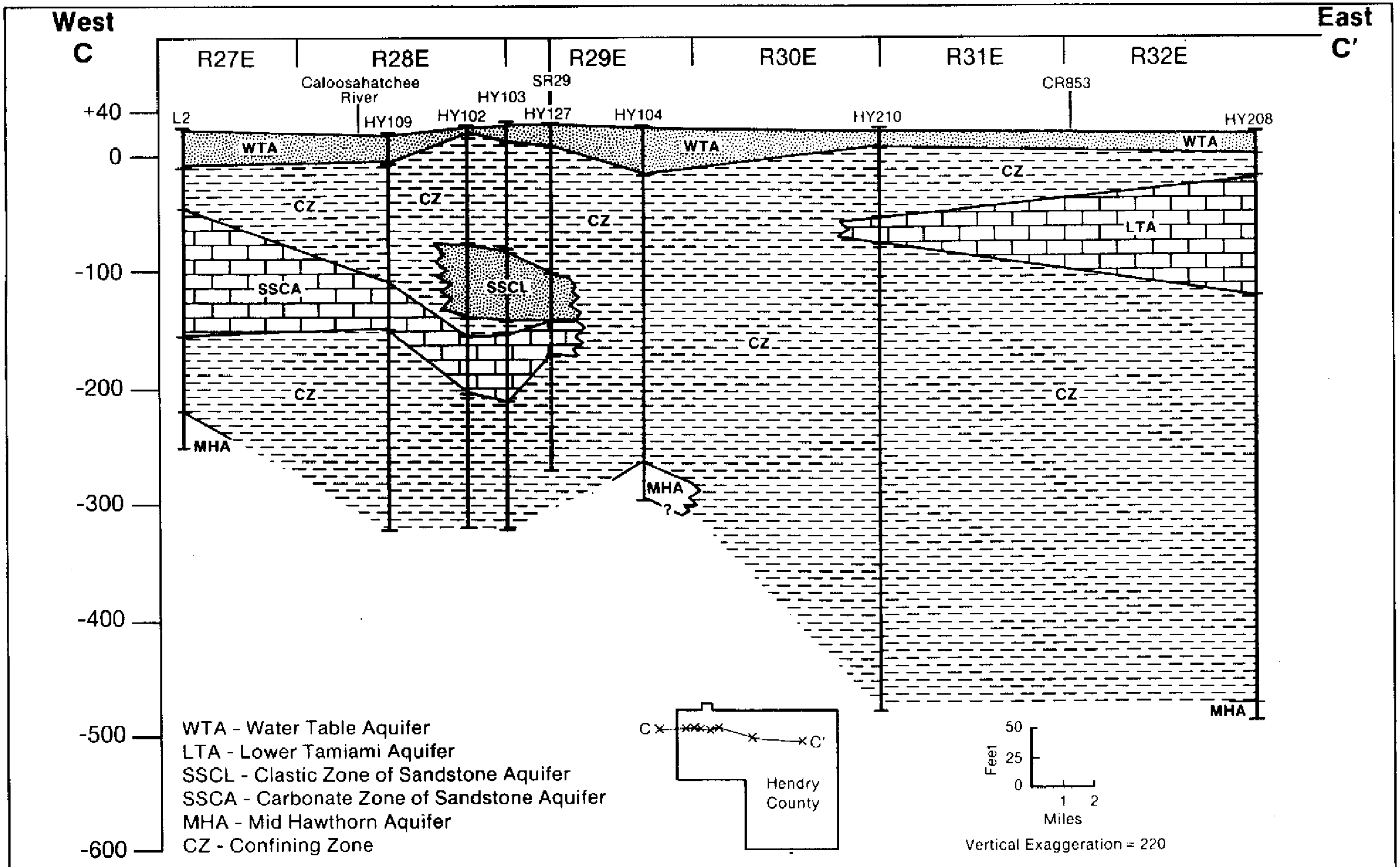


Figure 14 HYDROSTRATIGRAPHIC CROSS SECTION C-C′

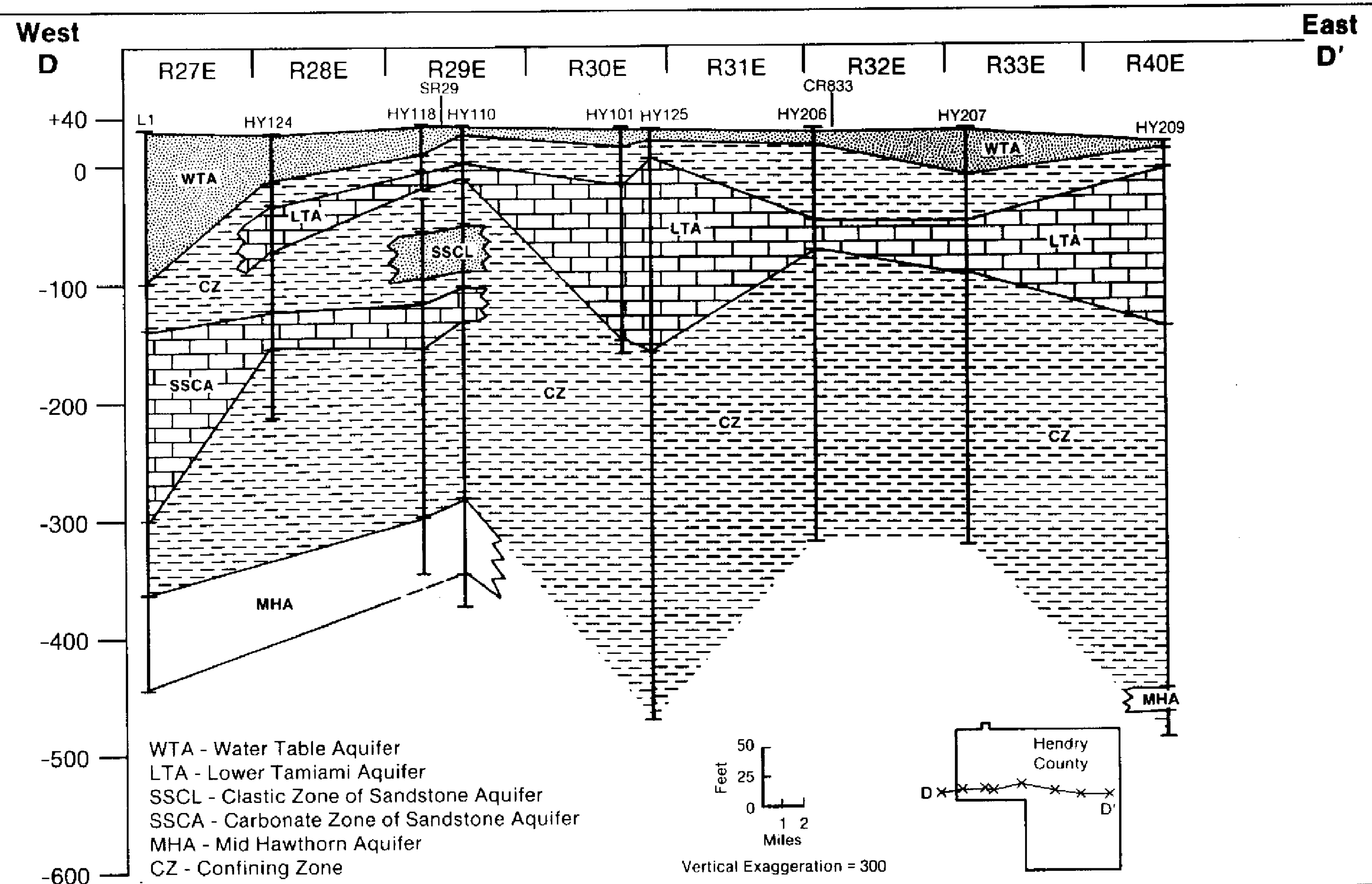


Figure 15 HYDROSTRATIGRAPHIC CROSS SECTION D-D′

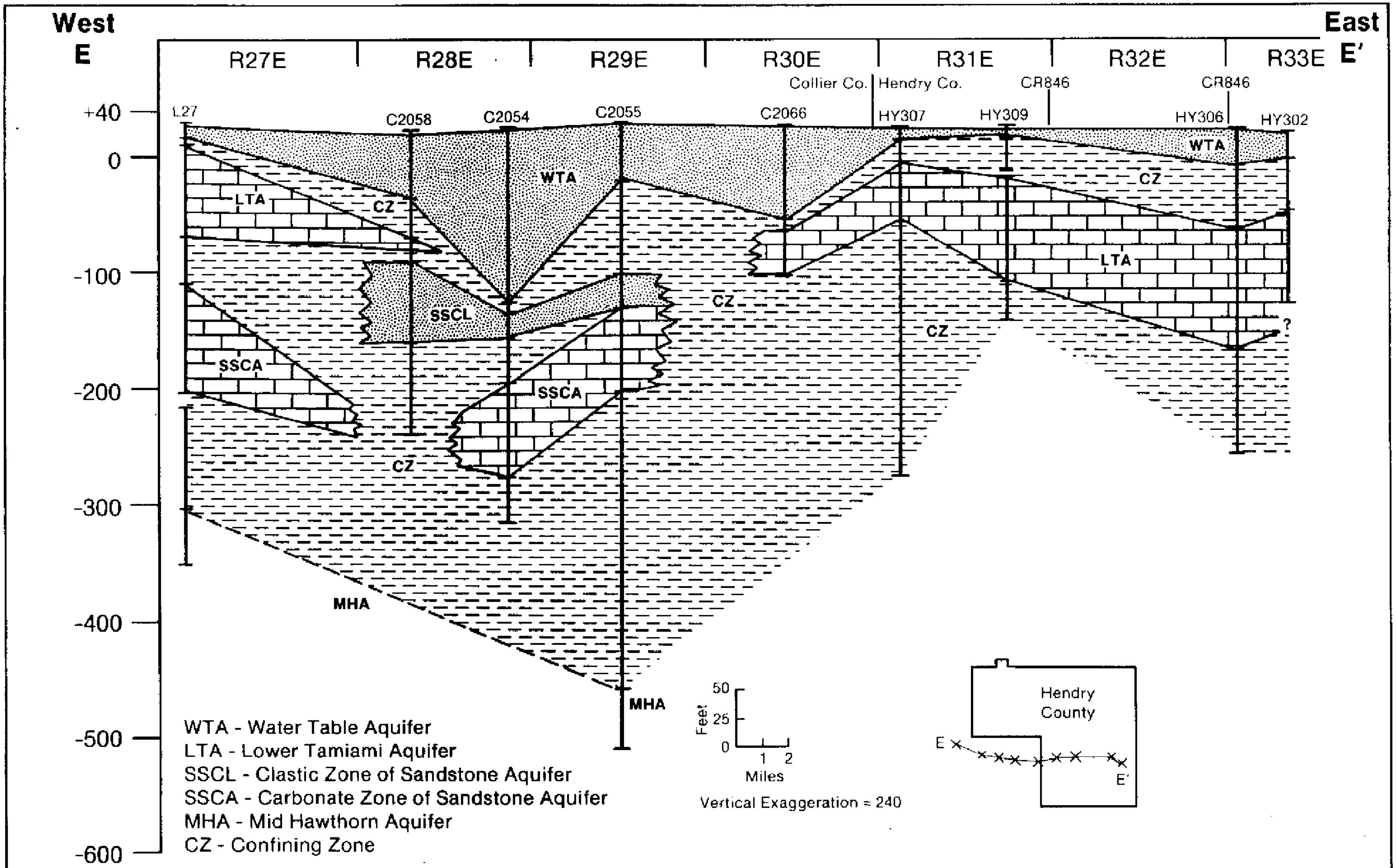


Figure 16 HYDROSTRATIGRAPHIC CROSS SECTION E-E'

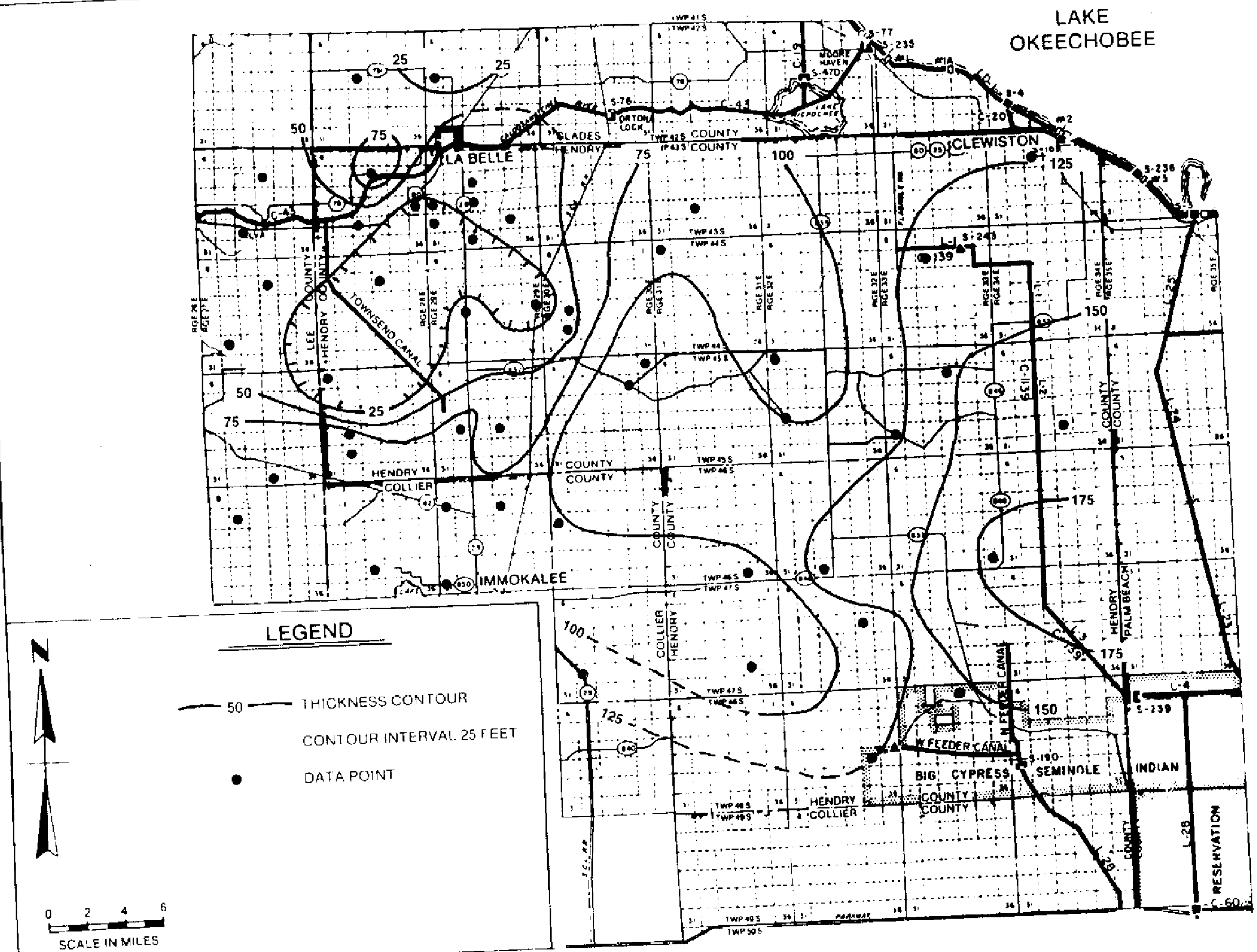


Figure 17 THICKNESS OF THE SURFICIAL AQUIFER SYSTEM

Aquifer System is thinnest in western Hendry County and thickens to the east and south.

The Surficial Aquifer System does not have a characteristic geophysical signature due to the wide variability in lithologies present. However, examination of the geophysical logs available in the study area reveals some trends. Natural gamma logs show relatively low levels of radioactivity in the aquifer system. Exceptions occur toward the base of the lower Tamiami aquifer where higher percentages of phosphatic sand (up to 4%) are sometimes present. This results in higher gamma activities in the lower portions of the aquifer system. Some wells, such as HY125, show high gamma activities near land surface due to the presence of thin layers of phosphatic sand. This may be reworked and redeposited Hawthorn material as discussed in the geology section. Electric logs (16 and 64 inch, 6 foot lateral) show relatively high resistivities throughout the surficial aquifer system. This is an indication of well indurated materials and/or low mineralized formation water (Driscoll, 1986). In some wells the resistivities gradually decrease with depth in the Surficial Aquifer System. This suggests that the sediments become less lithified with depth and/or that the water increases in salinity with depth.

Water Table Aquifer

In Hendry County the water table aquifer consists of fine to medium grained well sorted quartz sands with varying amounts of shell and minor amounts of organic material. In some areas a dense sandy limestone forms a cap rock at land surface. However, these rocks are highly fractured and solutioned and do not have a significant effect on recharge. In areas where the water table aquifer is over 40 feet thick the sandy, biogenic limestones of the Tamiami Formation form the deeper portions of the water table aquifer.

The thickness of the water table aquifer is shown in Figure 18. It is generally 20 to 40 feet thick with localized areas of thicker sections near LaBelle and south of Immokalee. The thickest section of water table aquifer was encountered near Immokalee in well C2054. This corresponds to an area where the Tamiami confining zone is absent and the water table aquifer accounts for the entire thickness of the Surficial Aquifer System.

Tamiami Confining Zone

The Tamiami confining zone is composed of low permeable silts, dolosilts, silty sands, sandy clays, and poorly indurated micritic limestones. This zone retards the vertical flow of water between the water table aquifer and the lower Tamiami aquifer. Leakage coefficient values (K'/b') for the unit have been estimated between 1×10^{-6} to 1 gallon per day per cubic foot (gpd/ft^3). The wide range of leakage values is a result of the variable thickness of the confining zone and the very high degree of lateral heterogeneity.

Figure 19 shows the thickness of the Tamiami confining zone in Hendry County. It is absent over a large portion of the western study area. In these areas, the water table aquifer is in direct hydraulic connection with the permeable zones of the Tamiami Formation; both units act as a single unconfined aquifer and both have been included in the water table aquifer. The Tamiami confining zone is thickest in central and southern Hendry County and thins in all directions. As the confining zone thins to the north and east it also undergoes a gradational change to a more sandy, less silty and clayey unit, thereby becoming more leaky to the north and east.

Lower Tamiami Aquifer

The lower Tamiami aquifer is the major source of ground water in most of Hendry County. It consists mainly of sandy biogenic limestones and calcareous sandstones found in the lower portions of the Tamiami Formation. In some areas the quartz sands found in the Tamiami Formation and the Miocene coarse clastics exhibit sufficient permeability to be included in this aquifer as well. Generally, the highest yields are associated with biogenic limestones exhibiting secondary porosity, and well sorted coarse grained sands. Well HY125 provides an example of this situation. The lower Tamiami aquifer penetrated by this well consists of five feet of sandy biogenic limestone underlain by 97 feet of well sorted, medium to coarse grained sands loosely cemented into a poorly indurated sandstone, which in turn is underlain by 63 feet of medium to very coarse unconsolidated quartz sand for a total thickness of 165 feet. The productivity of the aquifer in this situation is generally dependent on the amount of silt and fine sand present in the aquifer. In southern Hendry County, the lower Tamiami Aquifer consists entirely of the sandy biogenic limestone and calcareous sands and sandstones of the Tamiami Formation. In this area the productivity of the aquifer generally is dependent on the thickness of the aquifer and the amount of secondary permeability present. Well yields from the lower Tamiami aquifer are highest in the southern portion of the county.

The top of the lower Tamiami aquifer is shown in Figure 20. The surface of the aquifer is relatively flat with elevations averaging approximately -30 feet

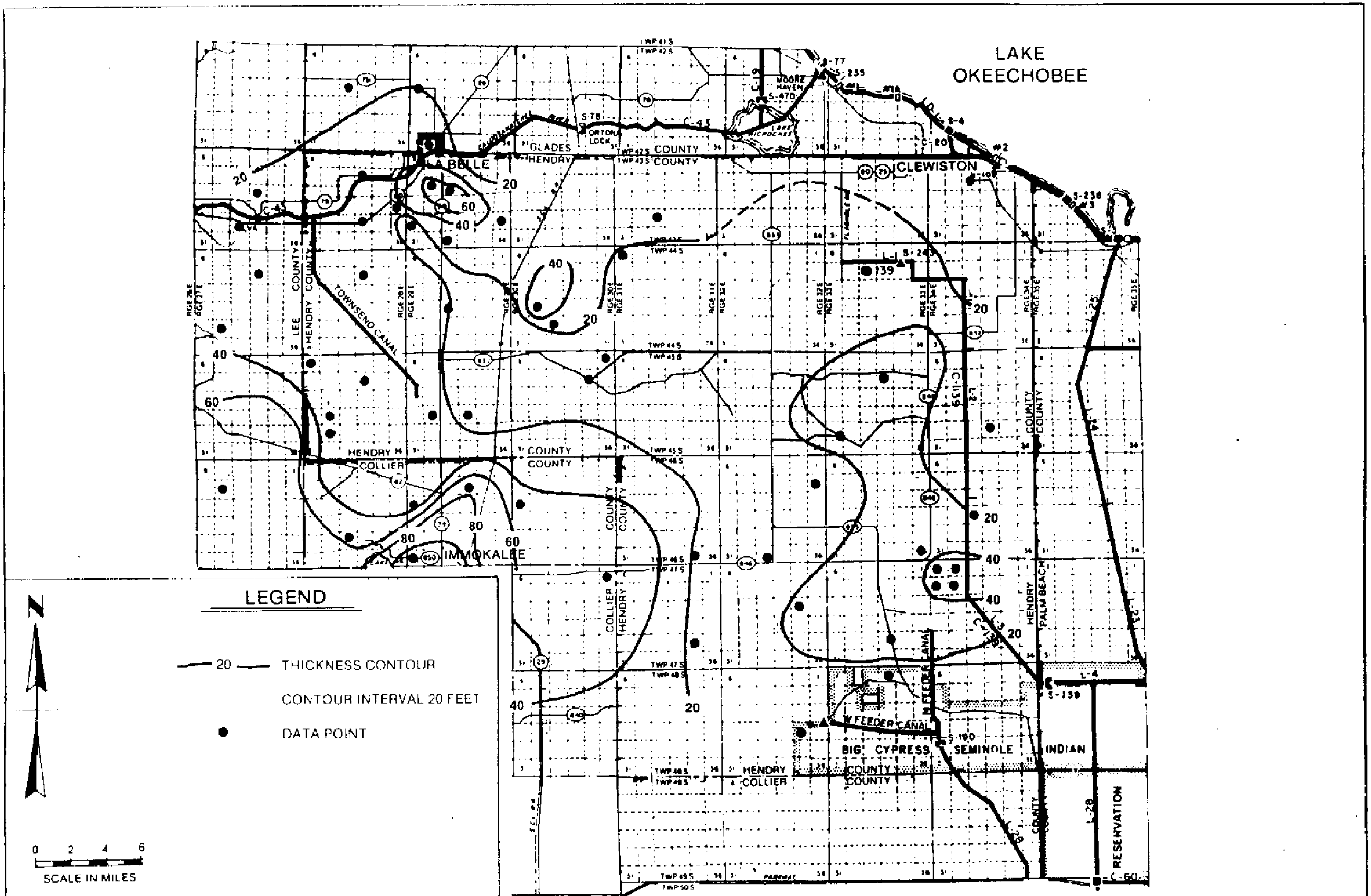


Figure 18 THICKNESS OF THE WATER TABLE AQUIFER

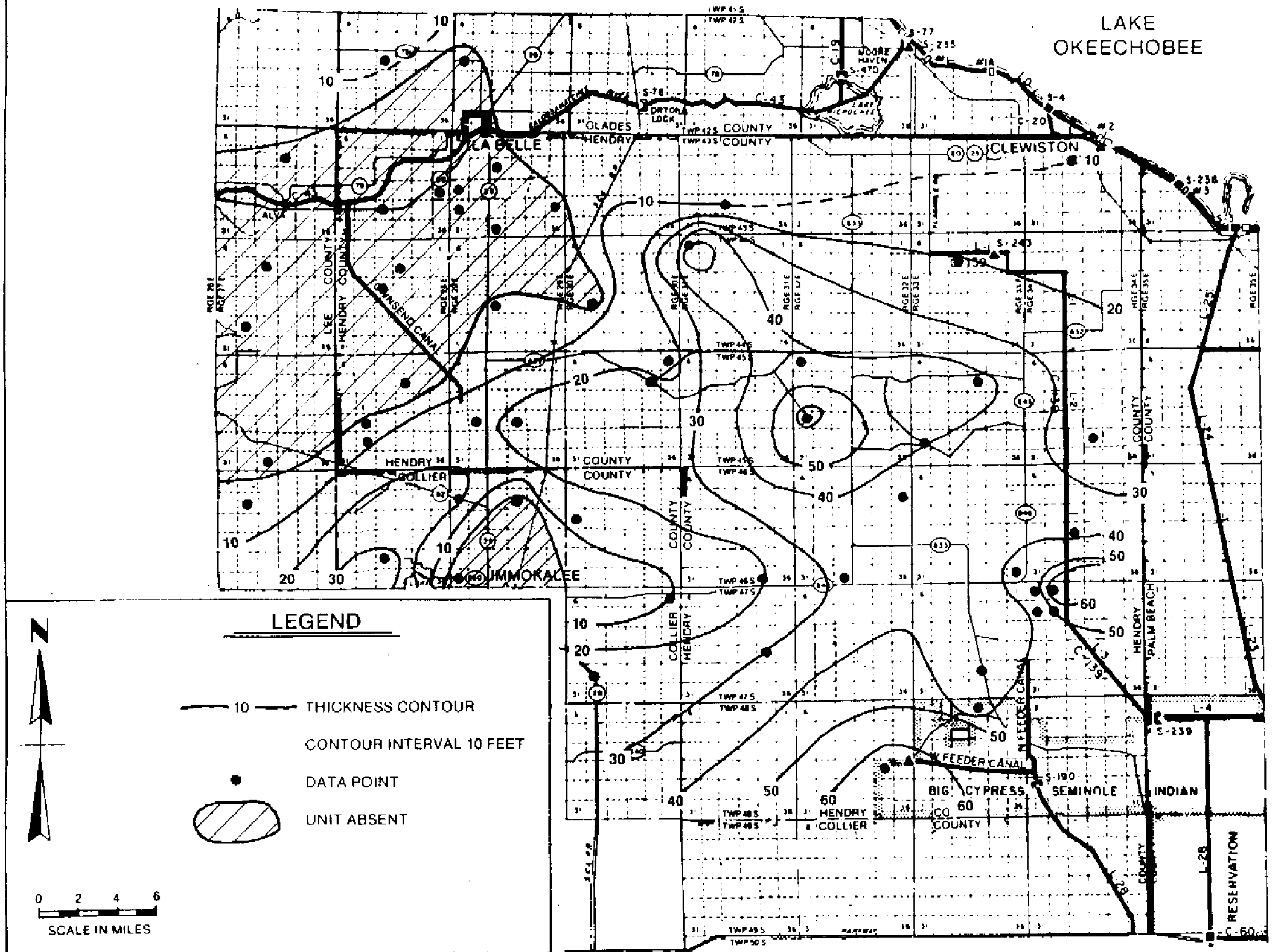


Figure 19 THICKNESS OF THE TAMIAMI CONFINING ZONE

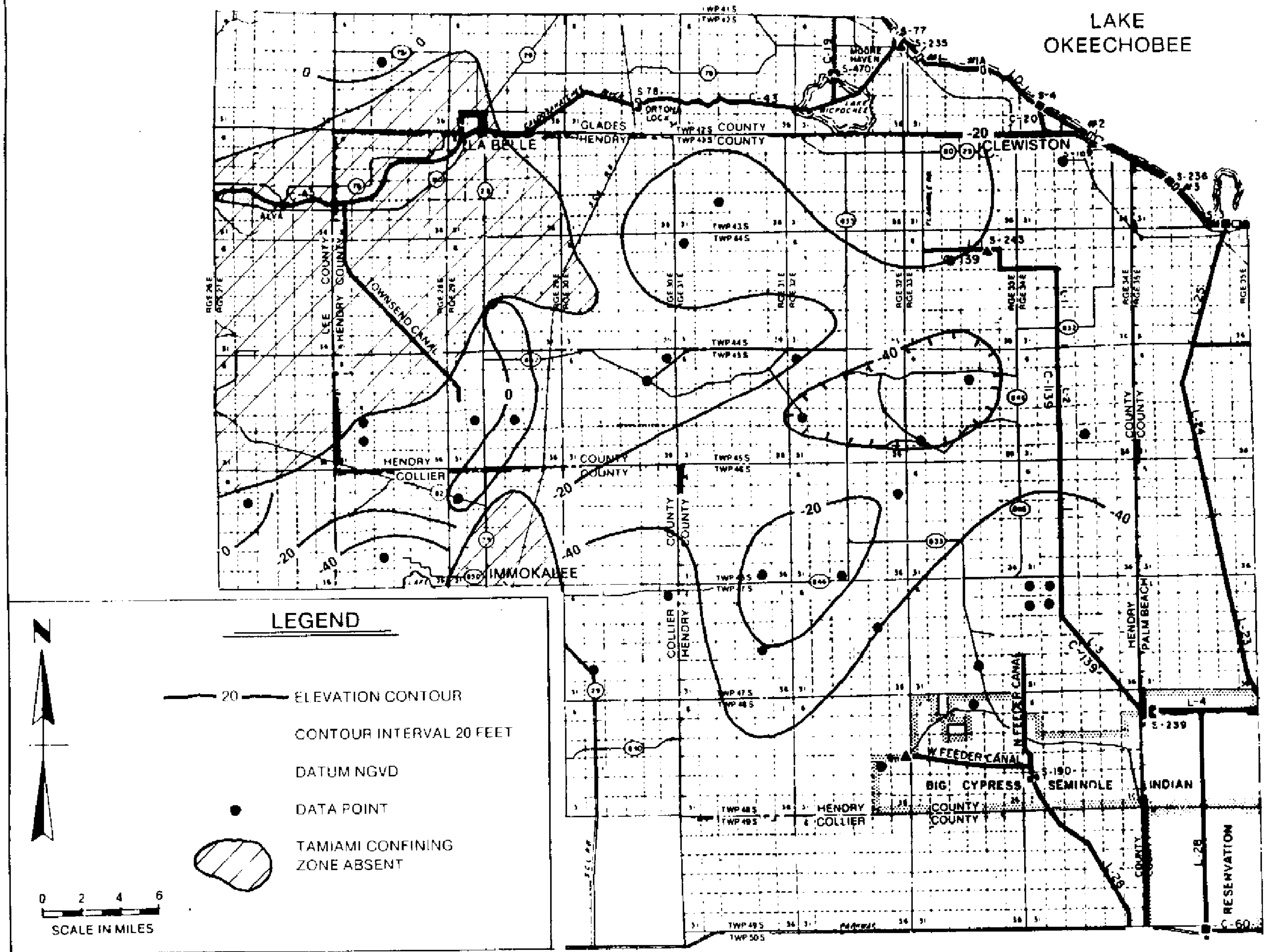


Figure 20 TOP OF THE LOWER TAMIAMI AQUIFER

NGVD. The aquifer displays its highest elevation along State Road 29 north of Immokalee. Figure 21 shows the thickness of the lower Tamiami aquifer. The aquifer is absent in large areas of western Hendry County and in the vicinity of Immokalee due to both the absence of the Tamiami confining zone and structural highs in the underlying upper Hawthorn confining zone. The aquifer generally thickens towards southeastern Hendry County where the thick sequences of Tamiami limestones occur.

INTERMEDIATE AQUIFER SYSTEM

The Intermediate Aquifer System acts as a confining unit to the deeper Floridan Aquifer System. This system is composed primarily of a heterogeneous mixture of low permeable clays, sandy clays, silts, and dolosilts. However, zones of relatively permeable limestones, dolostones, sands, and gravels occur in this aquifer system in portions of western Hendry County. These zones contain water under artesian pressure and act as semi-confined aquifers. The two primary aquifers that occur in the Intermediate Aquifer System in Hendry County are the sandstone aquifer and the mid-Hawthorn aquifer. An unnamed white limestone aquifer of unknown extent also occurs in this aquifer system northwest of LaBelle. The sandstone aquifer is separated from the Surficial Aquifer System by the upper Hawthorn confining zone and from the deeper mid-Hawthorn aquifer by the mid-Hawthorn confining zone. The mid-Hawthorn aquifer yields small amounts of poor quality water to wells in Hendry County and therefore is not discussed in depth.

The Intermediate Aquifer System is seen on natural gamma logs as a zone of generally higher gamma activity than the Surficial Aquifer System. This is due to the presence of phosphatic materials in the sediments of the Hawthorn Group that make up the Intermediate Aquifer System. Gamma activity is very strong adjacent to a rubble zone that marks the top of the mid-Hawthorn aquifer. Electric logs (16 and 64 inch, 6 foot lateral) show generally low resistivity associated with the clays and silts of the upper and mid-Hawthorn confining zones. Higher resistivities are seen to correspond to the limestones and dolostones of the sandstone aquifer. These higher resistivities are not apparent in areas where the aquifers contain brackish or saline water.

Upper Hawthorn Confining Zone

The upper Hawthorn confining zone is a term used by Wedderburn et. al. (1982) to designate a bed of low permeability in the uppermost part of the Hawthorn in Lee County. In this study the term upper Hawthorn confining zone is applied to the zone of low permeability that separates the Surficial Aquifer System from the aquifers of the Intermediate Aquifer System where they exist. The upper Hawthorn confining zone in Hendry County consists of low permeable sandy clays, silty sands and dolosilts. Phosphatic sand is usually present in amounts of five percent or more. The top of the upper Hawthorn confining zone is shown in Figure 22. It occurs at elevations between 20 feet NGVD about ten miles southeast of LaBelle to -275 feet NGVD near Immokalee. Generally, the top of the confining zone is highest in the area south of LaBelle and dips to the east and south. A localized depression in this surface occurs near LaBelle. This area corresponds to thick sequences of the Surficial Aquifer System in this area.

Sandstone Aquifer

Boggess and Missimer (1975) used the term "Sandstone aquifer" to describe the sand, sandstone, and limestone members of the Tamiami Formation that are hydraulically interconnected in the LeHigh Acres area of Lee County. Wedderburn et. al. (1982) mapped this unit in Lee County and included it in the Hawthorn. Knapp et. al. (1986) also mapped this unit in Collier County. In Hendry County, the sandstone aquifer occurs only in the western portion of the county. It is an important source of water in this area due to the absence of the lower Tamiami aquifer.

Lithologically, the sandstone aquifer is composed of two distinct zones: a clastic zone and a carbonate zone. The shallower clastic zone is composed of a mixture of sands, phosphatic sands, sandstones, and sandy limestones, with minor shell beds present at some locations. The productivity of this zone is related to the amount of silt, clay, dolosilt, and fine sand present. Examination of well cuttings suggest that these lower permeable materials exist as thin layers interbedded with the more permeable materials, separating the clastic zone into several producing zones. The top of the clastic zone of the sandstone aquifer is shown in Figure 23. The zone displays its highest elevation (above -50 feet NGVD) along the Townsend Canal and dips in all directions. The deepest occurrence of this zone (-288 feet NGVD) is southeast of Immokalee. Figure 24 shows the thickness of the clastic zone of the sandstone aquifer. It is generally between 20 and 40 feet thick, however, it appears to thin locally south of LaBelle.

The carbonate zone of the sandstone aquifer is composed of moderately to well indurated dolostones and limestones with minor occurrences of silty sands and dolosilts. This zone can be locally productive where secondary porosity exists. The carbonate zone

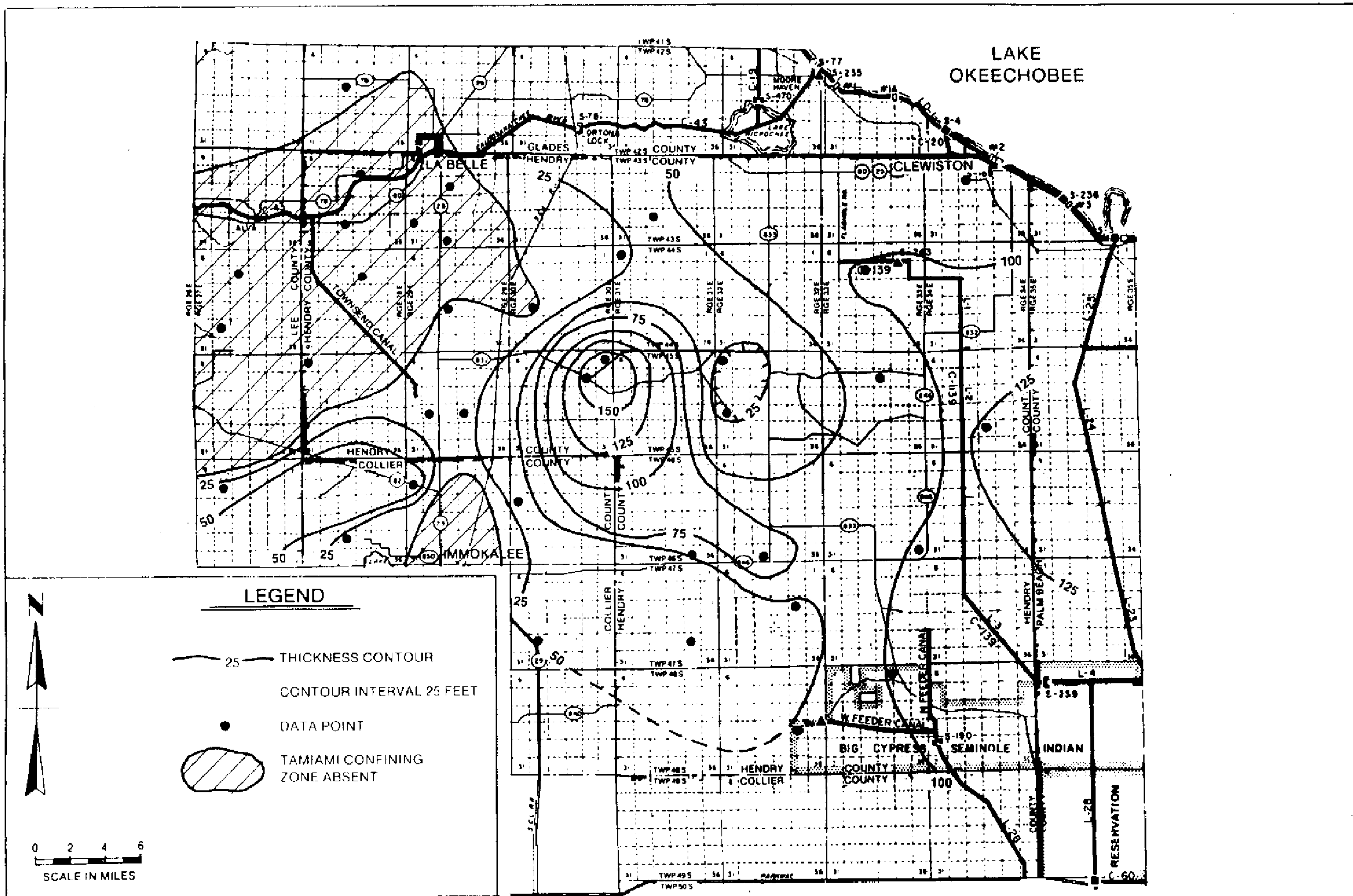


Figure 21 THICKNESS OF THE LOWER TAMIAMI AQUIFER

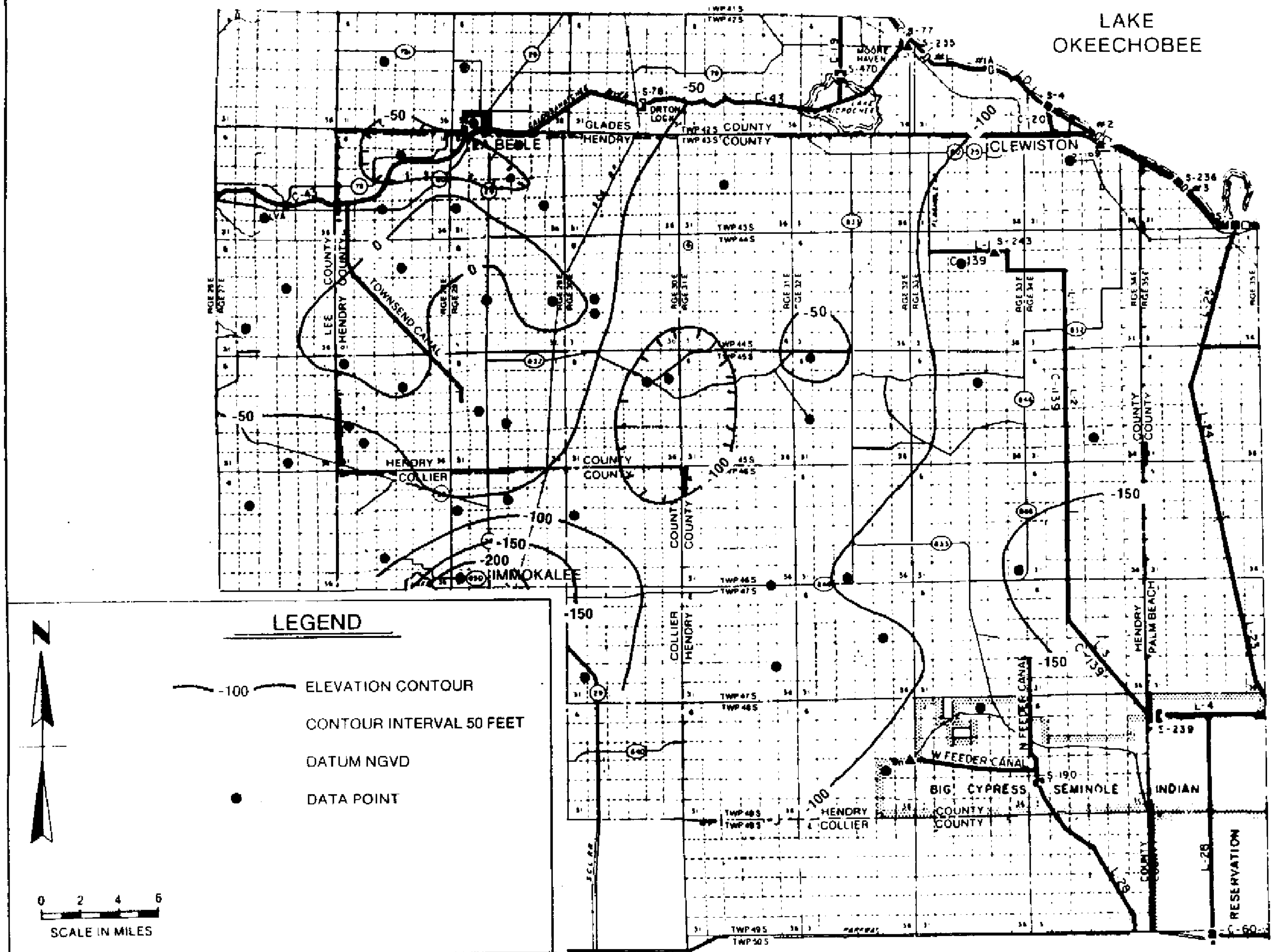


Figure 22 **TOP OF THE UPPER HAWTHORN CONFINING ZONE**

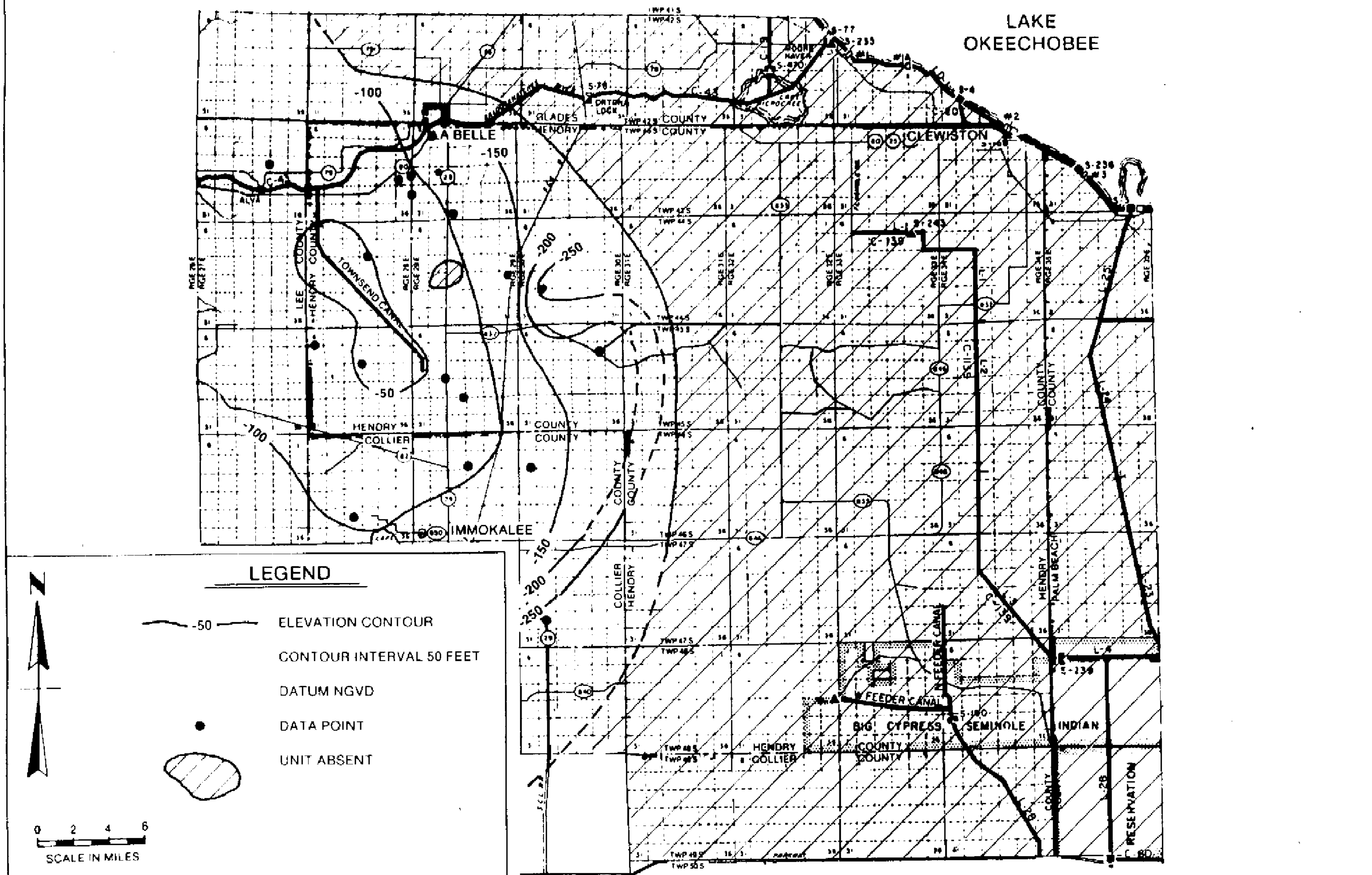


Figure 23 TOP OF THE CLASTIC ZONE OF THE SANDSTONE AQUIFER

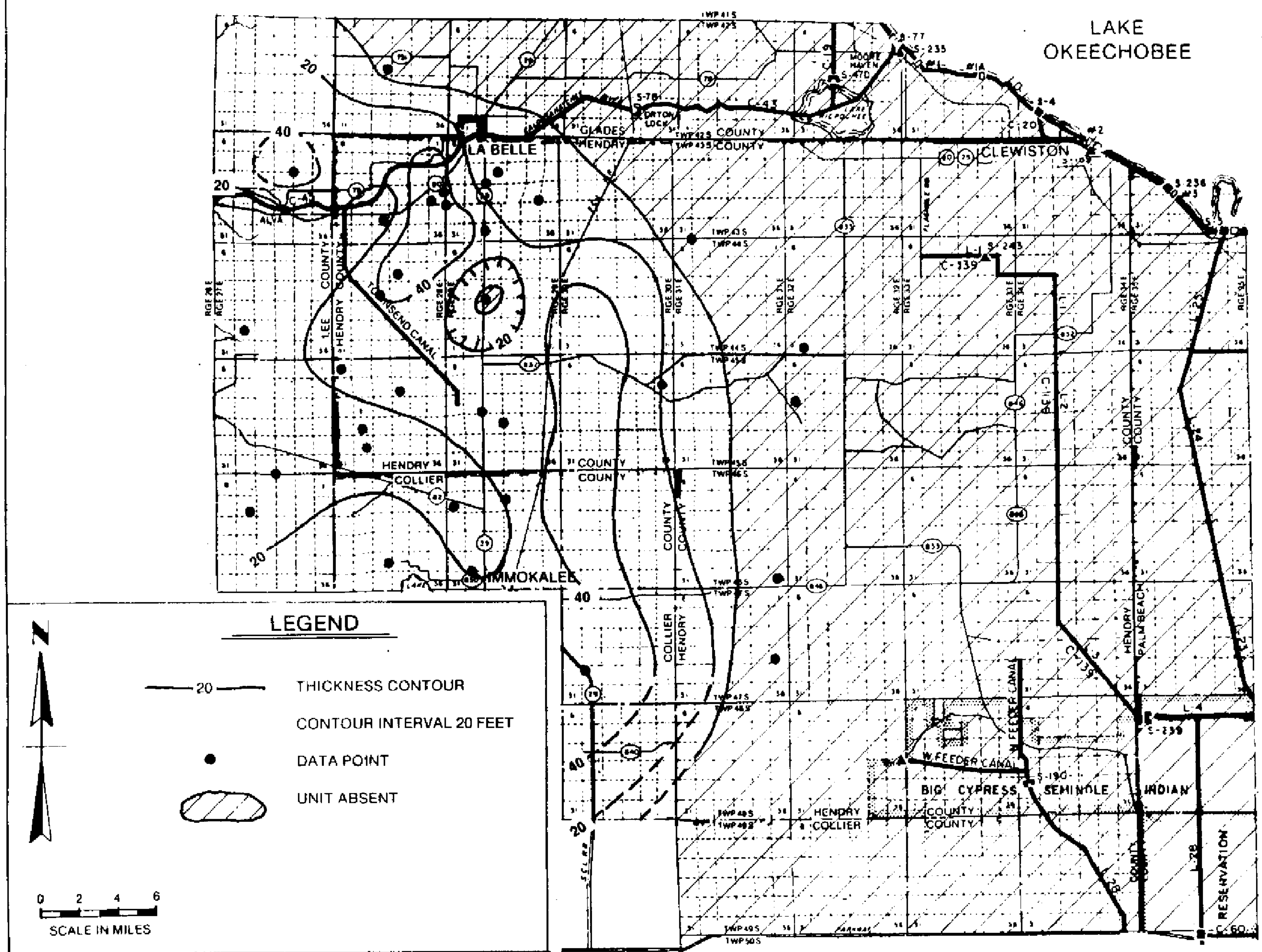


Figure 24 THICKNESS OF THE CLASTIC ZONE OF THE SANDSTONE AQUIFER

occurs at greater depths than the clastic zone (Figure 25). It is shallowest in an area south of Alva in Lee County and dips rapidly to the north, east, and south. This zone has its deepest occurrence (-335 feet NGVD) in well C2040, south of Immokalee. Figure 25 also shows that the carbonate zone does not occur as far to the east as the shallower clastic zone does. In areas where both zones occur, the relationship between the two zones varies. In some areas, the two zones are in contact with each other and act as a single, semi-confined aquifer, although the two zones possess different water bearing characteristics. In other areas the two zones are separated by as much as 70 feet of low permeable silty and clayey sands. This zone may act as a semi-confining layer and cause the clastic and carbonate zones to act as distinct aquifers where it is present. However, due to the extremely discontinuous nature of this zone of low permeability, it is not possible to predict its effect on the hydraulic properties of the sandstone aquifer. Figure 26 shows the thickness of the carbonate zone of the sandstone aquifer. It is over 125 feet thick in eastern Lee County and thins in an eastward direction until it pinches out several miles to the east of State Road 29.

Unnamed White Limestone Aquifer

An unnamed white limestone aquifer occurs principally in Glades County in an area northwest of LaBelle. Description of this unit is based on several unpublished consultant reports. It is included in the Intermediate Aquifer System because of its occurrence below the upper Hawthorn confining zone. It is composed of a sandy, white to pale orange limestone of unknown lateral extent. It occurs at elevations between -28 feet NGVD (section 14, township 42 south, range 28 east) to -130 feet NGVD (section 14, township 43 south, range 27 east). The top of this unit dips to the southwest. The aquifer varies in thickness between 17 and 40 feet. In northeastern Lee County the carbonate zone of the sandstone aquifer occurs at similar depths. It is not known at this time if the unnamed white limestone aquifer is a continuation of the sandstone aquifer or a separate unit. Further studies in Glades and Charlotte Counties are needed to resolve this issue.

Mid-Hawthorn Confining Zone

The mid-Hawthorn confining zone consists of thick sequences of sandy clays, clays, and dolosilts. It acts as a confining zone for the underlying mid-Hawthorn aquifer. A bed of very coarse sand, phosphatic sand, and phosphatic gravel is often found at the base of this unit. This rubble zone is evident on natural gamma logs as a zone of very high radioactivity. Because few wells in Hendry County penetrate the entire thickness of the mid-Hawthorn confining zone and the mid-Hawthorn aquifer is not used as a source of water in the county, neither of these units was investigated for this report.

Mid-Hawthorn Aquifer

The term "mid-Hawthorn aquifer" was used by Wedderburn et al. (1982) to refer to the phosphatic limestones and dolostones that occur below a regional disconformity (Missimer 1978) in Lee County. This unit is present through the lower west coast and produces significant quantities of water in some areas of Lee and Collier Counties. In Hendry County, the mid-Hawthorn aquifer consists of sandy and phosphatic limestones and dolostones interbedded with dolosilt and clay. It was found in 28 of the geologic control wells and appears to underlie the entire study area at elevations between -215 feet NGVD and -470 NGVD. The mid-Hawthorn aquifer is not used as a source of water in Hendry County because it yields small amounts of highly saline water.

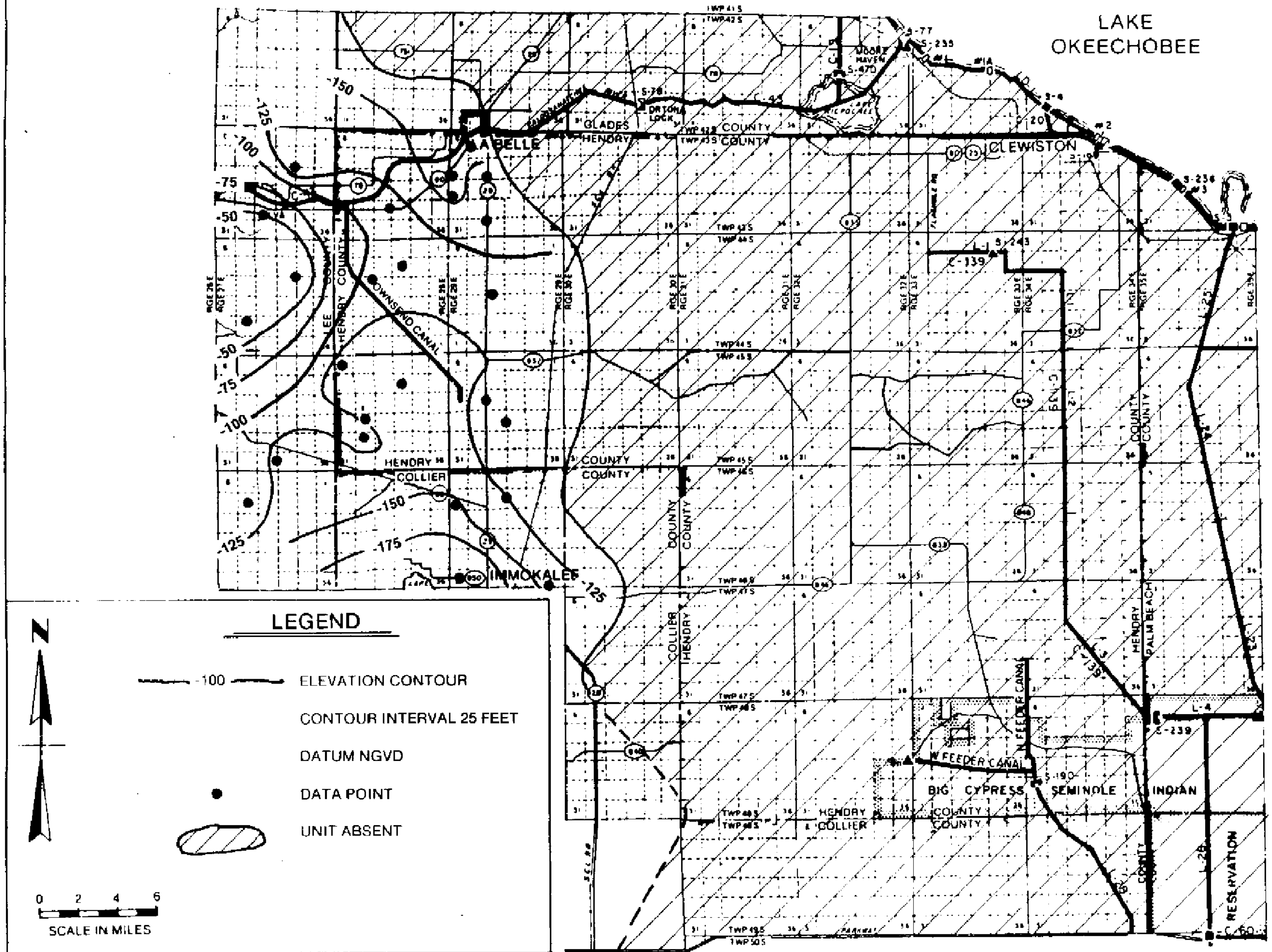


Figure 25 TOP OF THE CARBONATE ZONE OF THE SANDSTONE AQUIFER

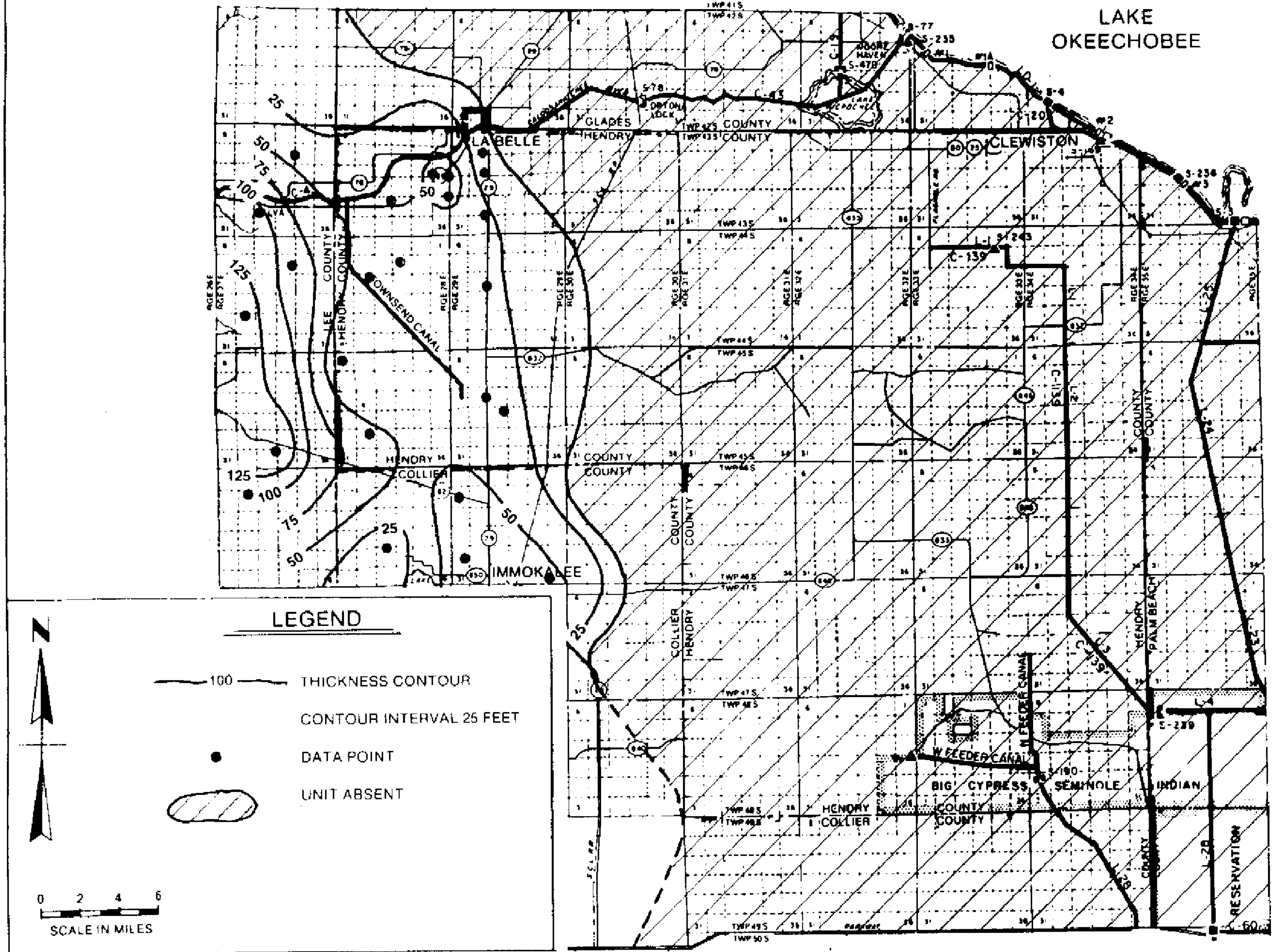


Figure 26 THICKNESS OF THE CARBONATE ZONE OF THE SANDSTONE AQUIFER

WATER LEVELS

BACKGROUND INFORMATION

Water level data are collected by the USGS from 46 wells throughout Hendry County. Data collection for 27 of the wells began in the mid-70's. Wells HE-3 and HE-5 have data beginning in 1950. In 1985, with an increased knowledge of regional aquifer systems in the area, the SFWMD undertook a quantitative evaluation of the groundwater monitoring network (Smith et al., 1988). In this study, the USGS wells were grouped by aquifer system and statistically evaluated to determine areas of monitor well deficiency and redundancy. Recommendations to add wells in areas of data deficiency resulted in a revised network which added 17 new wells and was implemented by October 1987. All water level data used in this report are presented in Appendix B and are on file at the Ft. Myers USGS office.

SURFICIAL AQUIFER SYSTEM

Water Table Aquifer

Data from 28 wells monitored by the USGS along with data from 12 SFWMD surface water stage recorders (Figure 27) were used to create contour maps. Figures 28 and 29 show the configuration of the water table aquifer in April and September of 1986.

The equipotential lines tend to follow the land surface contours (Figure 3). The highest water table elevations in the study area, approximately 36 feet in the wet season, occur slightly northwest of Immokalee where land elevations exceed forty feet NGVD. Ground water flows radially from this area; north to the Caloosahatchee River, east to the Everglades Agricultural Area and south into the Big Cypress Swamp.

The gradient of the water table aquifer varies from five feet per mile just north of Immokalee to 1/4 foot per mile in the center of Hendry County. Ground water gradients are primarily controlled by land surface elevation, aquifer lithology, permeability, and proximity to discharge and recharge areas.

Water Level Fluctuations

Hydrographs were made of all 28 wells used in the water level analysis (Appendix B). Highest water levels occur from August to October (end of the wet season) and the lowest levels in April and May (end of the dry season). The water table responds quickly to changes in rainfall. The decrease in rainfall during the drought of 1980-1981 and corresponding decline in water levels can be seen in all of the water table hydrographs.

The configuration of the water table shows a relatively small variation from wet to dry season of approximately two feet. The water level maps were constructed using data from a single day each month and therefore are strongly influenced by short term weather patterns.

All the wells were statistically analyzed for the period of record (Appendix B). Results of the statistical analysis are discussed in a technical memorandum by Smith et al. (1988). They found that water level fluctuations were consistently small, suggesting that surficial monitor wells in Hendry County reflect ambient water level conditions. Water levels fluctuated most during the later part of the dry season (March, April, May and June).

Recharge

Recharge to the water table aquifer comes from four principal sources: 1) direct infiltration from precipitation, 2) inflow from surface water bodies, 3) upward leakage from semi-confined aquifers, and 4) infiltration from free-flowing artesian wells at the surface.

Direct infiltration from rainfall is the main source of recharge to the water table aquifer. Figure 30 shows the location of rainfall recording stations and average annual rainfall for a ten year period, which ranges from 43 to 56 inches. Hydrographs comparing ground water levels with rainfall at a nearby recording station can be seen in Figure 31. Smith et al. (1988), through statistical analysis, found a two day lag time between rainfall events and corresponding water level changes in the Surficial Aquifer System.

Surface water bodies such as canals and lakes recharge the water table aquifer in some areas. Generally, recharge from these sources is minimal and occurs after rainfall events when surface runoff into canals and lakes causes a positive vertical head gradient downward toward the aquifer.

Upward leakage from the semi-confined lower Tamiami aquifer occurs locally in eastern Hendry County and western Palm Beach County, where water table elevations are maintained at low levels to

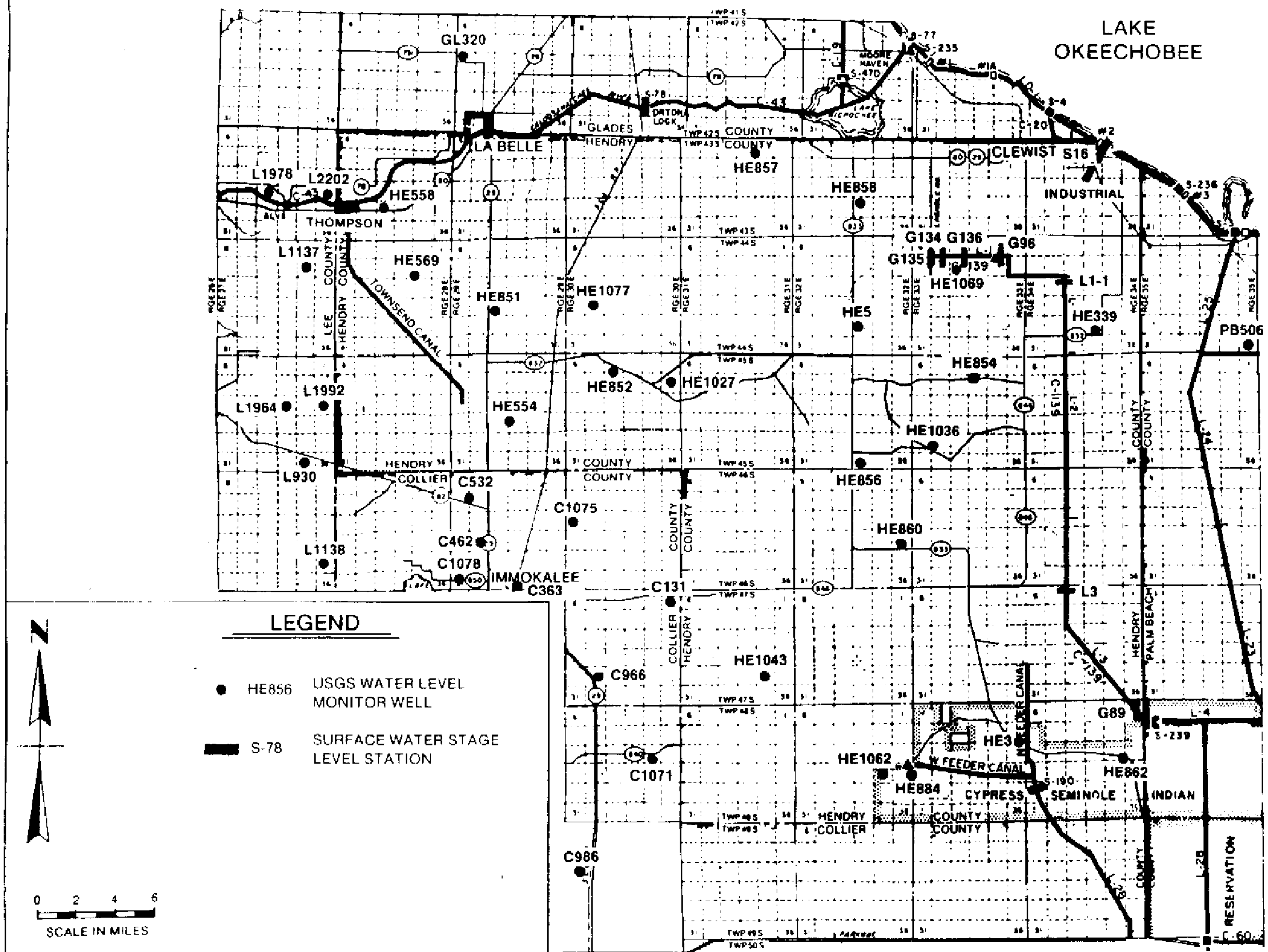


Figure 27 WATER TABLE AQUIFER MONITOR WELL AND SURFACE WATER STAGE LEVEL STATION LOCATIONS

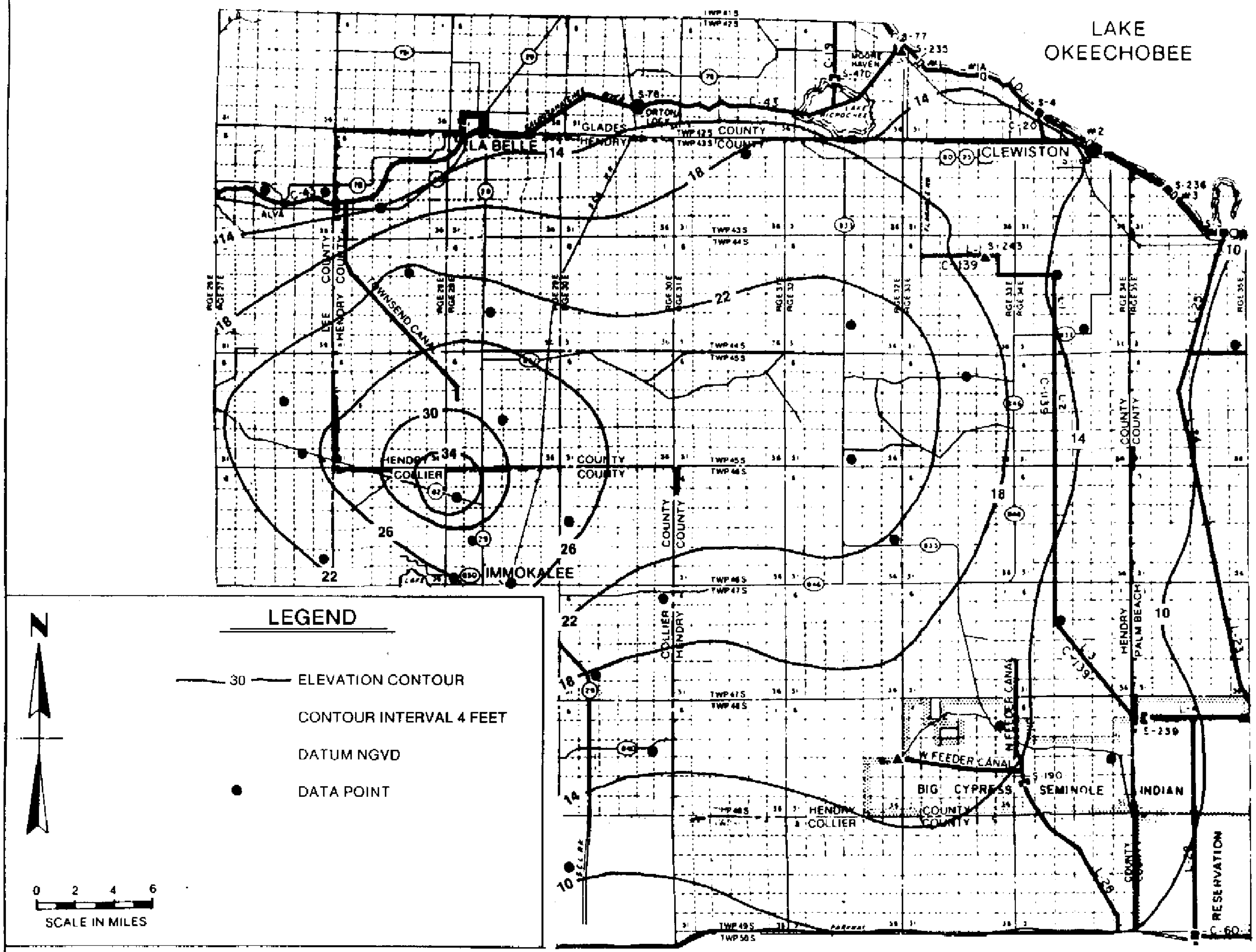


Figure 28 WATER LEVELS WITHIN THE WATER TABLE AQUIFER (APRIL 1986)

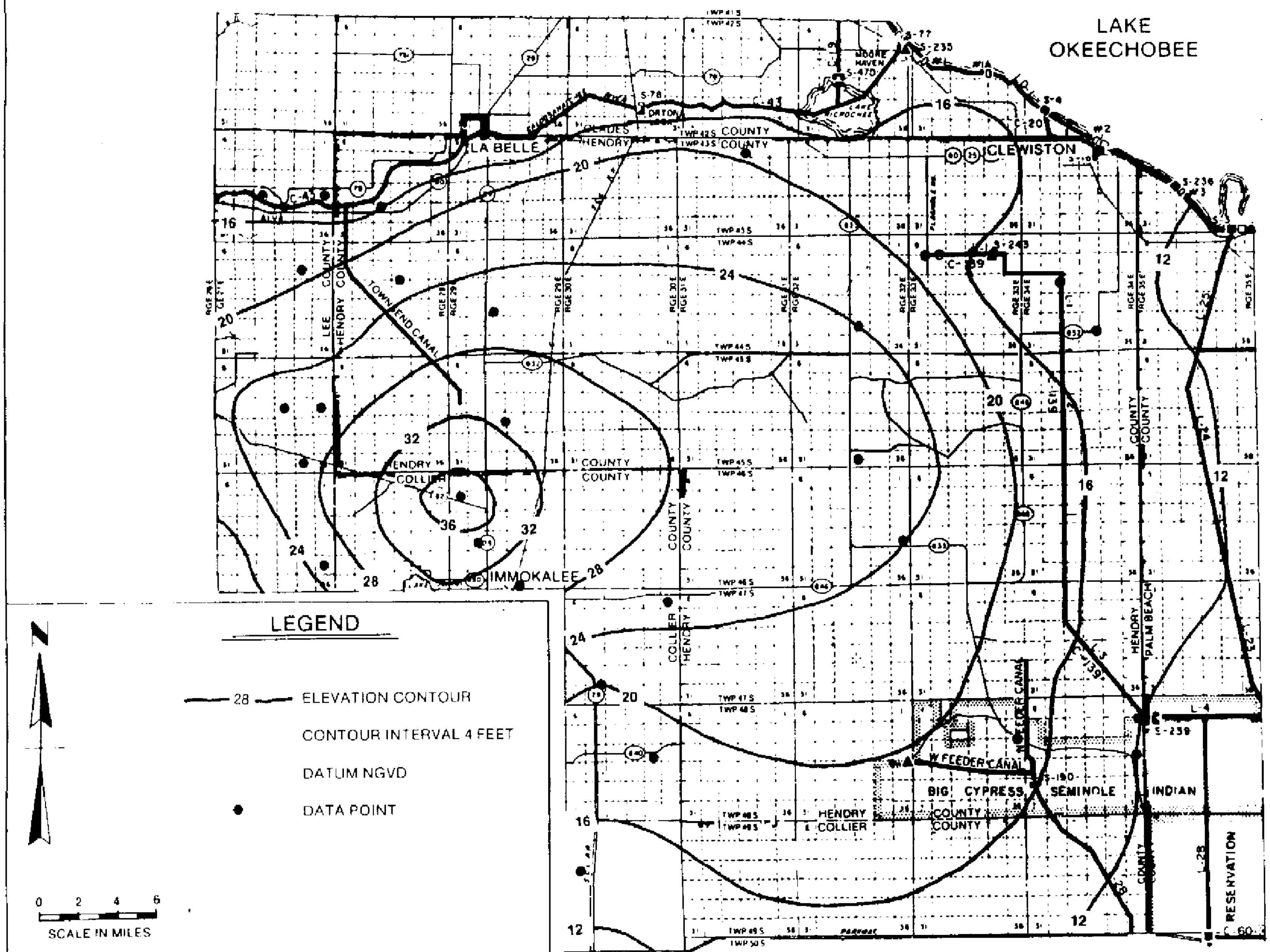


Figure 29 WATER LEVELS WITHIN THE WATER TABLE AQUIFER (SEPTEMBER 1986)

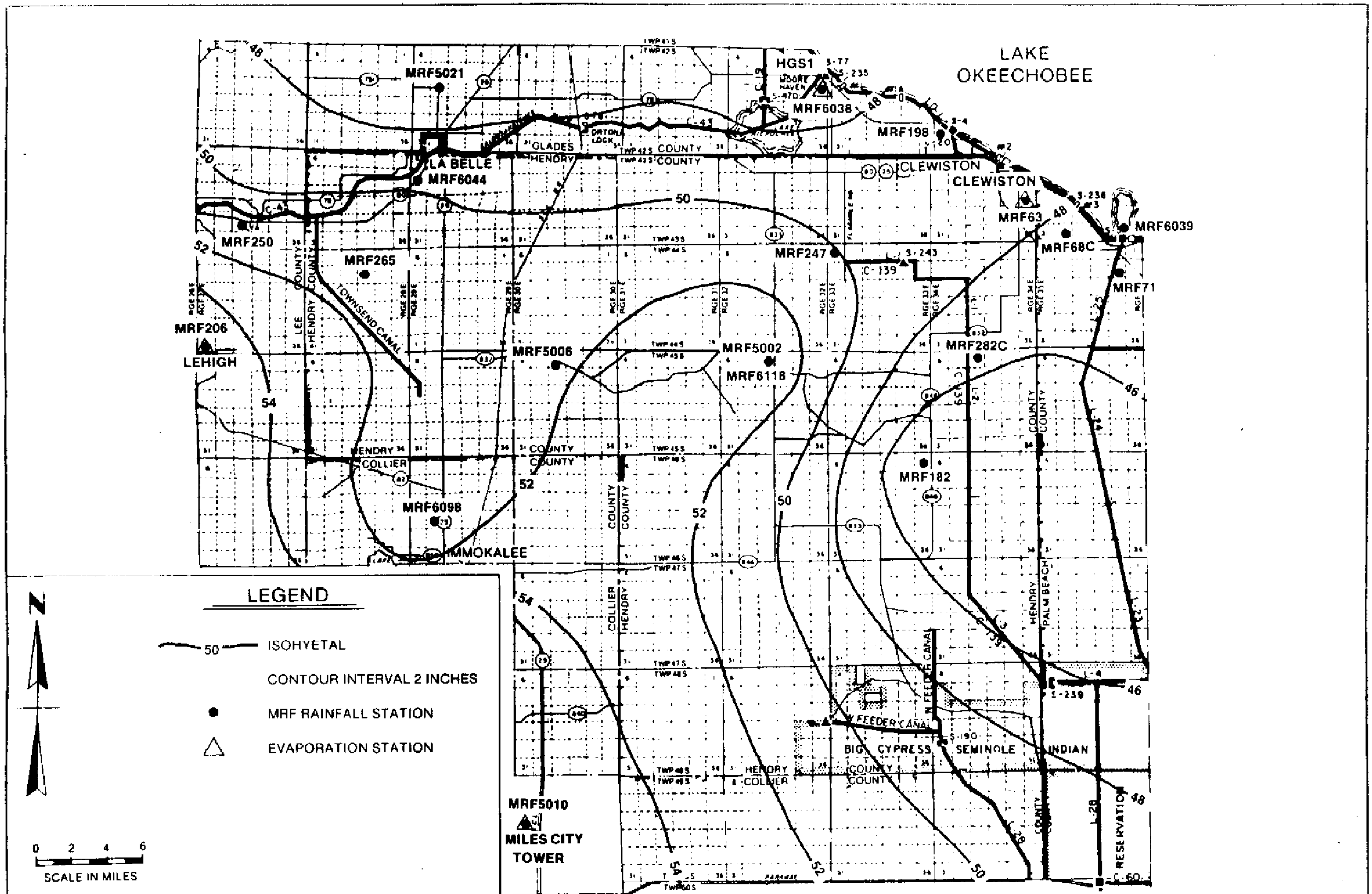


Figure 30 LOCATIONS OF SFWMD RAINFALL AND PAN EVAPORATION STATIONS AND AVERAGE ANNUAL RAINFALL (1977 - 1986)

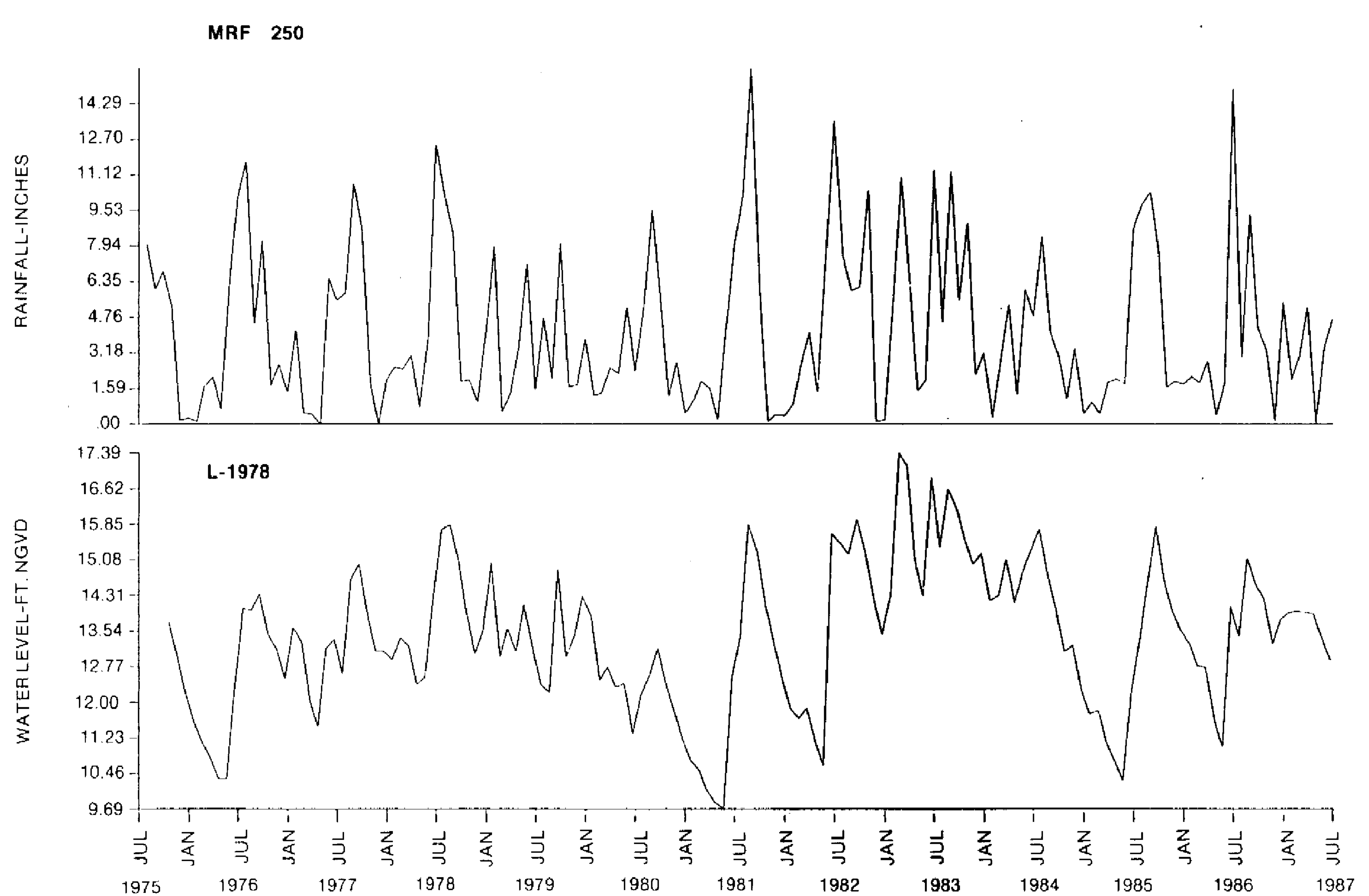


Figure 31 COMPARISON OF RAINFALL AT STATION MRF-250 AND WATER LEVELS IN WATER TABLE AQUIFER WELL L-1978

facilitate drainage. In some areas, water levels in the water table aquifer were up to four feet lower than the underlying lower Tamiami aquifer. However, under natural conditions, the water levels in both aquifers would be nearly equal. There is also potential for upward leakance from the lower Tamiami aquifer in areas where withdrawals from the water table aquifer result in a negative head difference between the two aquifers.

Discharge

Discharge from the water table aquifer occurs through: 1) evapotranspiration, 2) ground water flow to surface water bodies, 3) subsurface outflow to adjacent areas, 4) downward movement through leaky confining beds, and 5) withdrawal through pumped wells.

Evapotranspiration dominates the water balance and controls soil moisture content, ground water recharge, and stream flow. Evapotranspiration rates are controlled primarily by rainfall, wind and temperature, depth to the water table and type and density of vegetation (Dunne and Leopold, 1978).

Estimates of evapotranspiration are derived empirically from pan evaporation rates. Because evaporation pans receive large quantities of energy from radiation and conduction through its base and sides, evaporation from the pan is larger than for natural systems. Therefore, measurements of pan evaporation are multiplied by a pan coefficient (usually 0.7 for Florida conditions, but variable throughout the year) in order to estimate evapotranspiration (Jones et al., 1984). Using this value results in an average annual evapotranspiration rate of 44 inches at Clewiston, 56 inches at Moore Haven, 38 inches at the Miles City Forestry Tower in Collier county and 46 inches at Lehigh Acres in Lee County. Comparison of these rates to annual rainfall totals at the same locations indicates rainfall losses to evapotranspiration of 89% at Clewiston, 113% at Moore Haven, 67% at the Miles City Tower and 81% at Lehigh. Figure 32 shows the monthly pan evaporation at Clewiston from 1983 through 1988.

Ground water loss to surface water bodies is significant in the dry season when withdrawals from canals for irrigation are necessary. Normally, water table levels are higher than surface water levels in the dry season and surface water bodies gain from ground water base flow during this time. Where there are no structures controlling water elevation in the canals, the levels reflect water table elevations. This relationship can be seen in Figure 33 which compares stage data with ground water levels. The levels are similar and in some cases identical (see Figure 27 for the location of the stage data recorders).

The hydraulic gradient caused by the Immokalee Rise (an area of high elevations around Immokalee) results in continuous subsurface outflow of ground water to the east, west, and south. Subsurface flow to the north is restricted by the Caloosahatchee River. Quantification of subsurface outflow can be estimated through the use of flow net analysis. It is calculated that 47% of basin inflow to the Caloosahatchee River is comprised of ground water seepage (Fan and Burgess, 1983).

Discharge by downward leakage to the lower Tamiami and sandstone aquifers occurs through semi-confining beds. The rate of leakage is a function of the hydraulic gradient between aquifers, the vertical hydraulic conductivity of the confining bed, and the thickness of the confining bed. In general, water levels in the lower Tamiami aquifer are similar to those in the water table aquifer. However, in areas where wellfields withdraw from the lower Tamiami aquifer, its water levels drop below those of the water table aquifer, resulting in downward flow of water from the water table aquifer into the lower Tamiami aquifer. Under ambient conditions, water levels in the sandstone aquifer are generally 2 feet lower than those in the water table aquifer. However, in the Immokalee area they are up to 10 feet lower due to pumpage from the sandstone aquifer.

Withdrawals from wells constitute a large portion of discharge from the water table aquifer. The majority of the withdrawals are for agricultural purposes. A portion of the pumped water returns to the aquifer through seepage.

Lower Tamiami Aquifer

Data from 11 monitor wells (Figure 34) were used to generate potentiometric surface maps of the lower Tamiami aquifer. Figures 35 and 36 depict the potentiometric surface of the aquifer in the 1986 dry and wet seasons, respectively. Because of the small number of data points in the northern portion of the county, contours could not be drawn here with any certainty. In the western and southern portions of the county, contours were drawn using data from adjoining counties.

In the western portion of the study area where the lower Tamiami aquifer is unconfined, water levels correspond to those in the water table aquifer. The two aquifers are indistinguishable in these areas. In eastern Hendry County, water levels are slightly lower than the water table and generally conform with

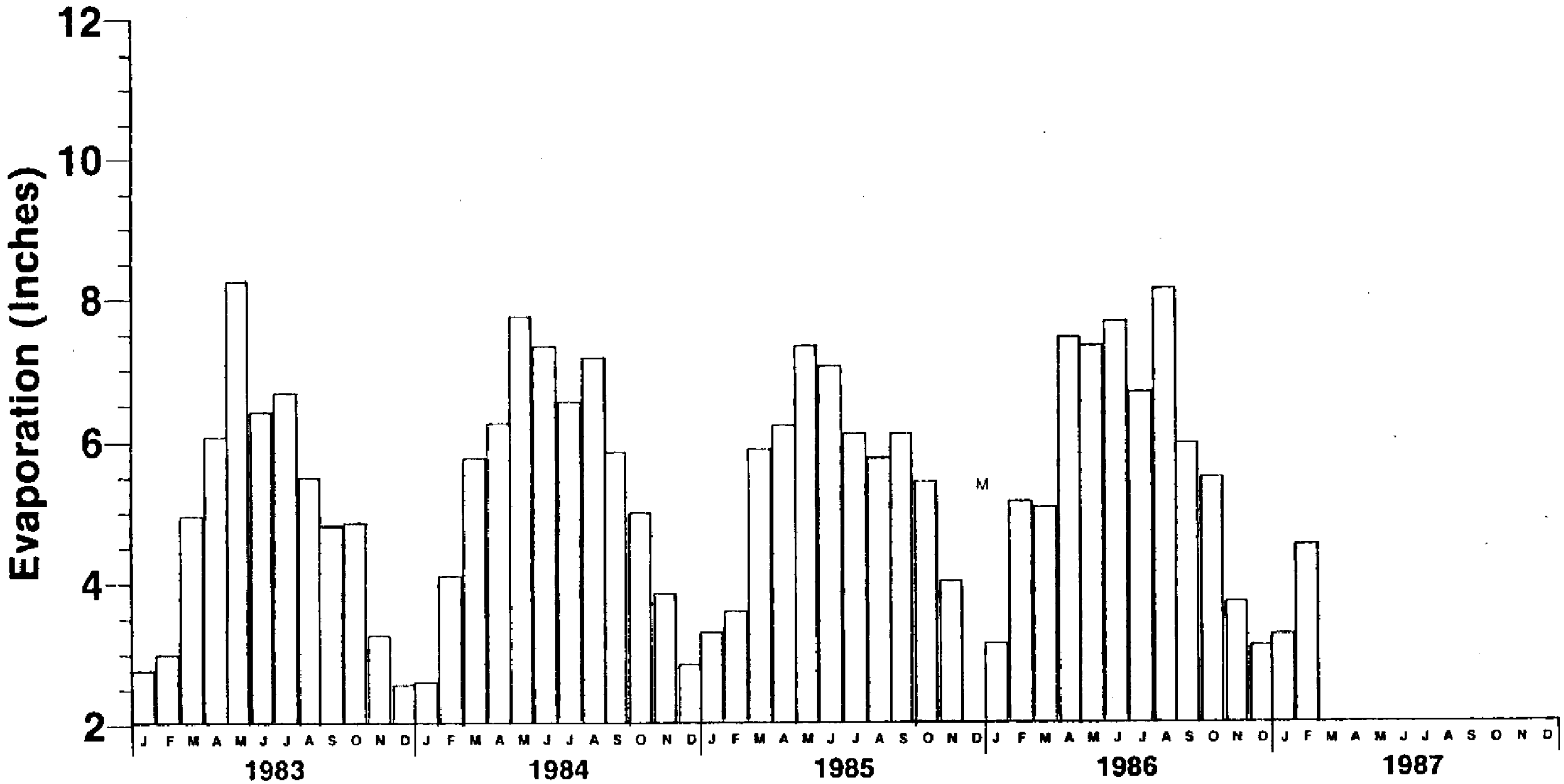


Figure 32 PAN EVAPORATION AT CLEWISTON (1983-1987)

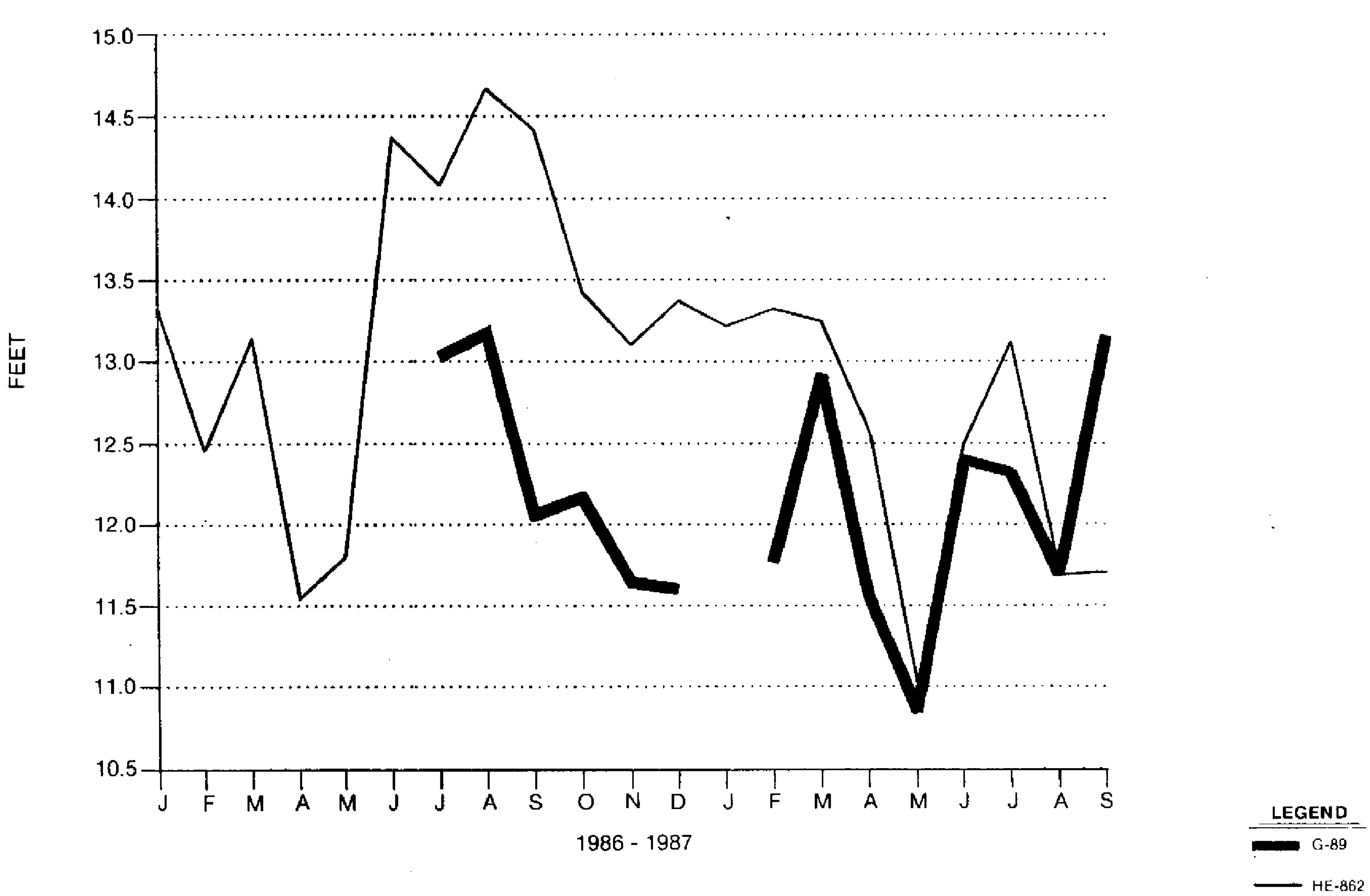


Figure 33 **COMPARISON OF WATER LEVELS AT WATER TABLE AQUIFER WELL HE-862 AND SURFACE WATER STATION G-89**

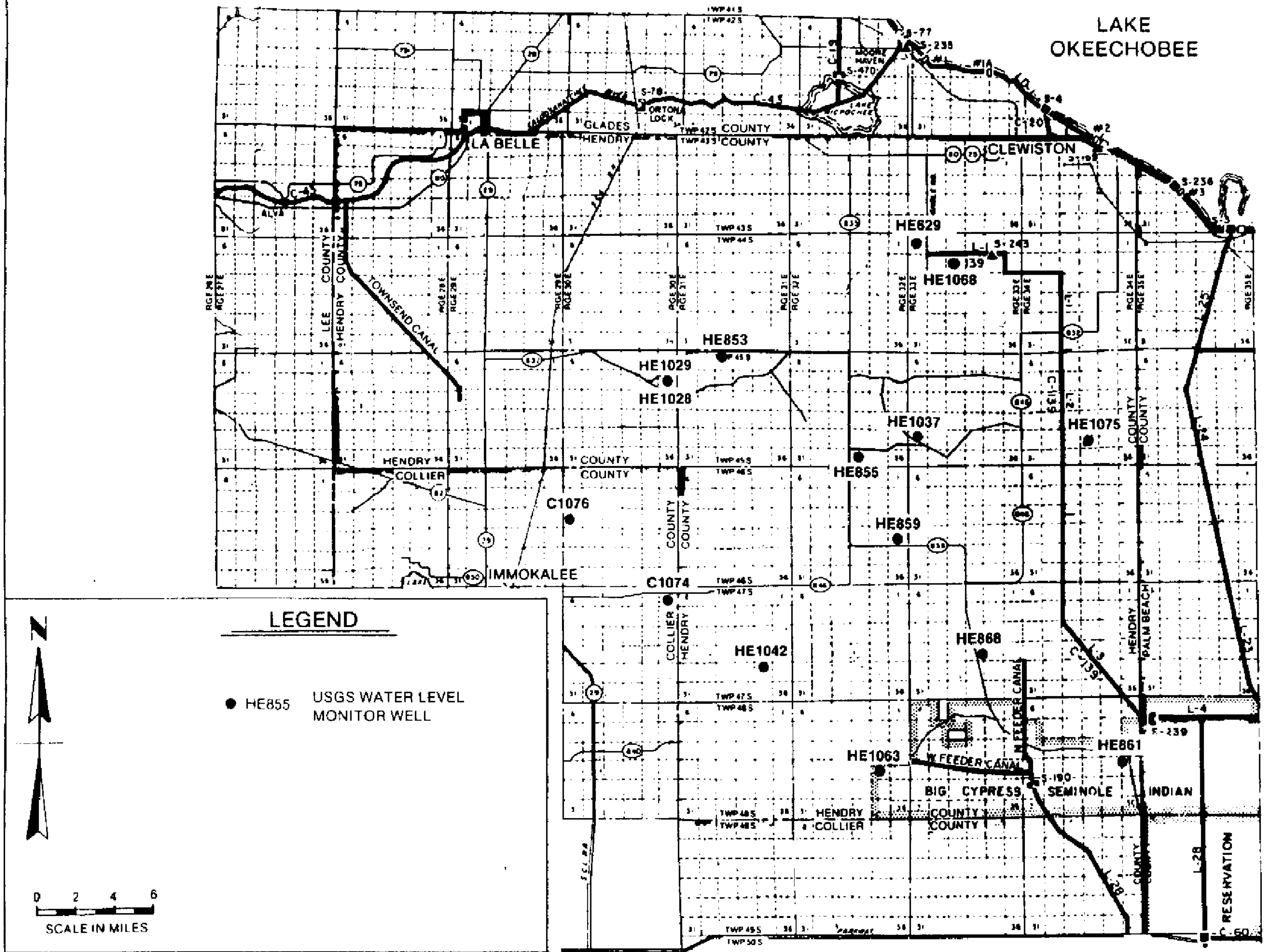


Figure 34 LOWER TAMIAMI AQUIFER MONITOR WELL LOCATIONS

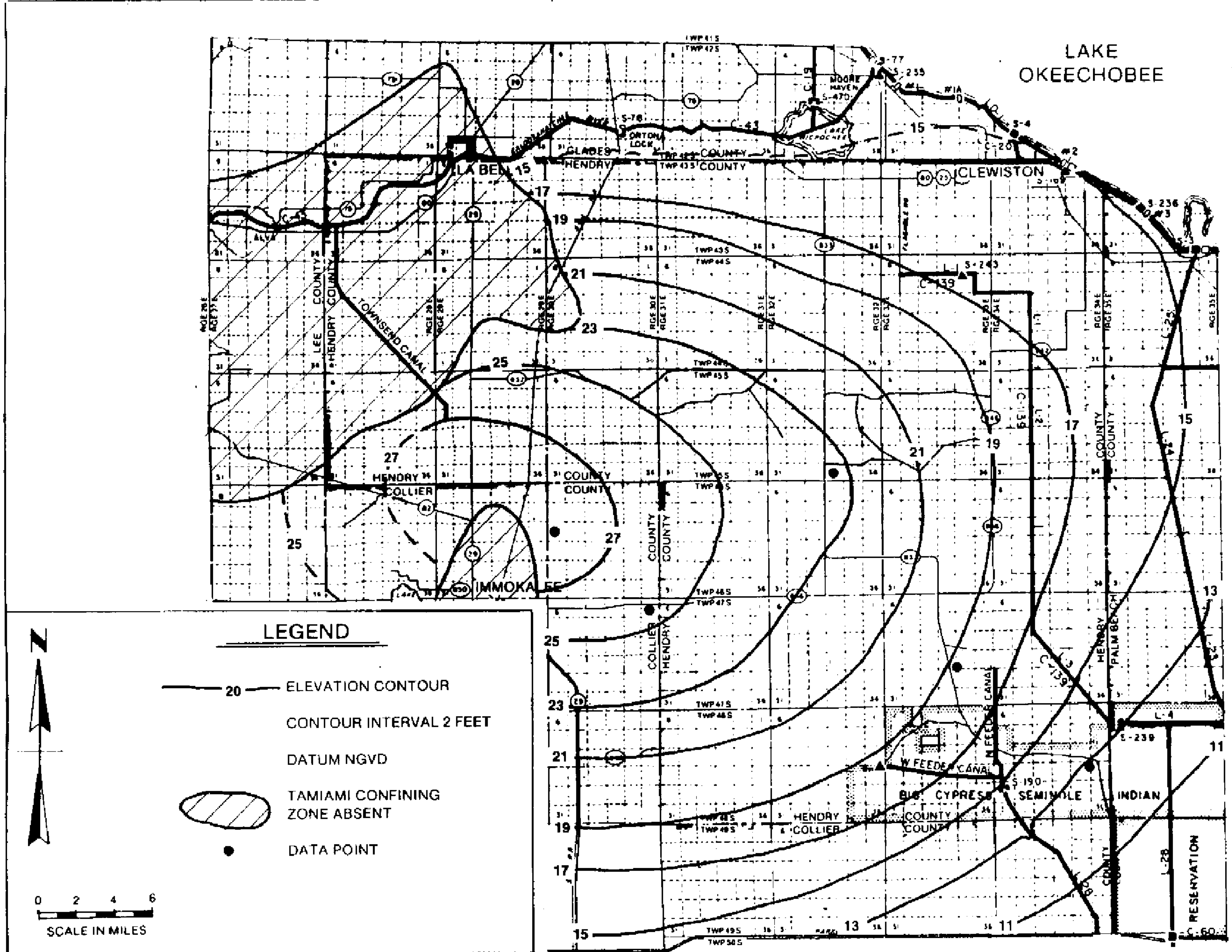


Figure 35 POTENTIOMETRIC SURFACE OF THE LOWER TAMIAMI AQUIFER (APRIL 1986)

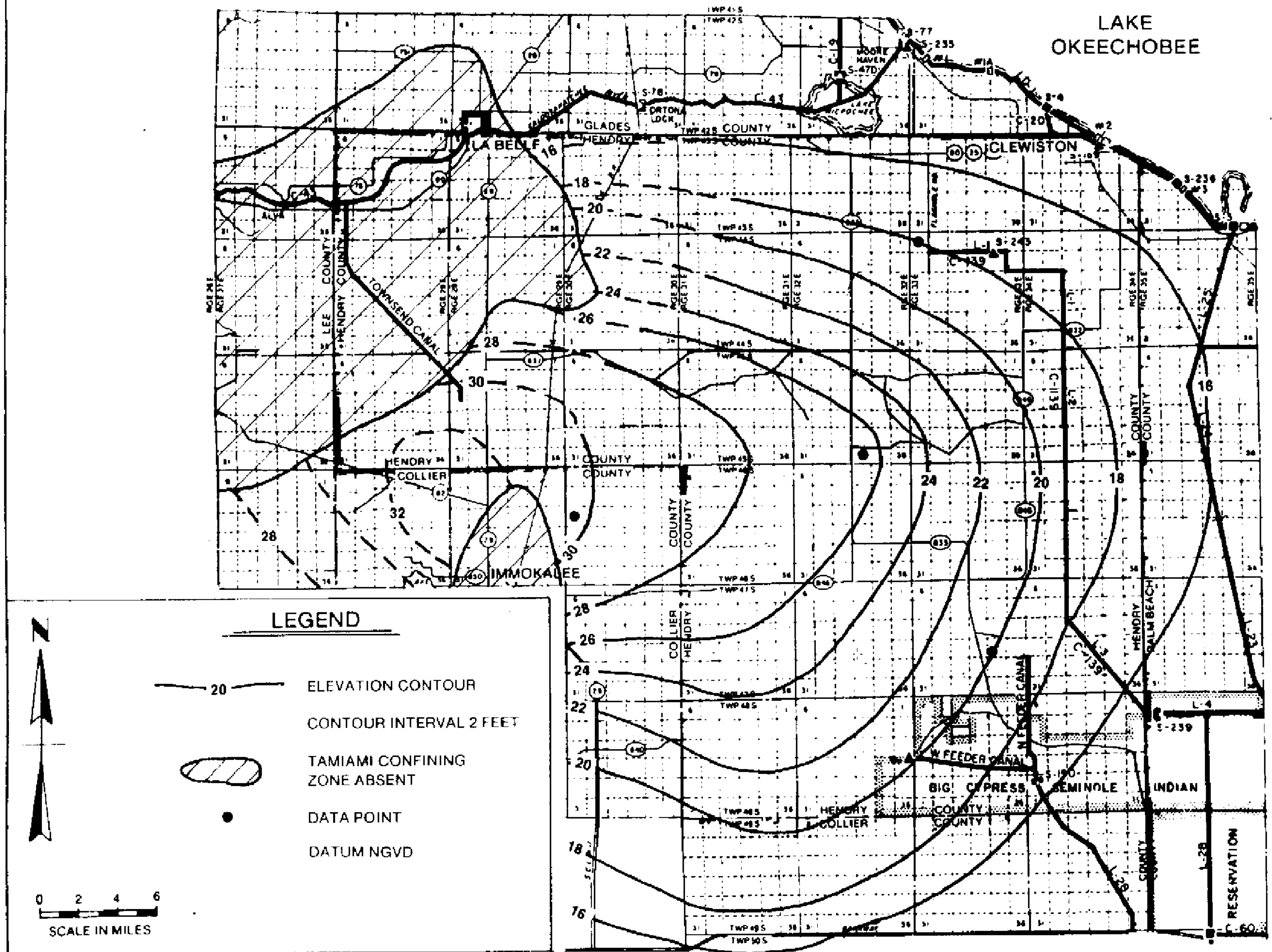


Figure 36 POTENTIOMETRIC SURFACE OF THE LOWER TAMIAMI AQUIFER (SEPTEMBER 1986)

the water table, which is the prime source of recharge to the lower Tamiami aquifer. In localized areas, where the water table is depressed due to drainage, water levels in the lower Tamiami aquifer may be several feet higher than those of the water table aquifer. The regional flow pattern radiates outward from the Immokalee Rise. The hydraulic gradient of the lower Tamiami aquifer varies from two feet per mile near Immokalee to one-half foot per mile in the eastern portion of Hendry County. These gradients are affected locally by pumpage from the aquifer.

Water Level Fluctuations

Hydrographs of all the lower Tamiami aquifer wells are presented in Appendix B along with a statistical analysis of the data. Both the hydrographs and accompanying statistics are provided using end of the month water level measurements.

The hydrographs and contour maps show a seasonal water level fluctuation of one to four feet. The greatest fluctuations are in areas where water levels are affected not only by climactic conditions but also by pumpage. This can be seen in wells in the Immokalee area.

Recharge

The lower Tamiami aquifer receives recharge from three possible sources: 1) leakance from overlying or underlying aquifers, 2) direct recharge by rainfall in areas where the aquifer is unconfined, and 3) inflow from interconnecting surface water bodies.

The primary source of recharge to the aquifer is leakage from the water table aquifer. Water level configurations of these two units are essentially the same. However, after rainfall events, levels in the water table exceed those of the lower Tamiami aquifer and downward leakage occurs. Water levels within this aquifer and rainfall are compared and presented in Appendix B.

In the LaBelle and Immokalee areas, the overlying confining bed is discontinuous and there is direct recharge to the aquifer. This recharge comes from rainfall and inflow from interconnecting surface water bodies.

Because of the thick and clayey nature of the confining bed between the lower Tamiami aquifer and the Intermediate Aquifer System throughout most of the study area, there is no evidence of recharge from this underlying aquifer system. In the western portion of the study area where the sandstone aquifer exists, the potentiometric surface in the sandstone aquifer is considerably lower which also prevents upward recharge into the lower Tamiami aquifer.

Discharge

Discharge from the lower Tamiami aquifer occurs through three principal modes: 1) leakage to adjacent aquifers, 2) withdrawal from wells, and 3) subsurface outflow to adjacent areas.

In general, leakage to other aquifers occurs downward in the western portion of the study area and upward in the eastern portion and in localized areas. Because the potentiometric head of the lower Tamiami aquifer is higher than the water table in the Everglades Agricultural Area, upward leakage occurs to recharge the water table aquifer. This situation also occurs locally in areas where the water table aquifer is pumped. Comparison of data from C-131 (water table aquifer) and C-1074 (lower Tamiami aquifer) shows the water levels in C-1074 are generally higher than those in C-131. The area around this paired monitor well site is agricultural and the daily data from C-131 clearly indicates the influence of pumpage on the water table aquifer (Figure 37).

In the southwestern portion of the study area, the lower Tamiami aquifer overlies the sandstone aquifer. Cuttings descriptions of wells in the area indicate minimal confining between the aquifers and that water levels are higher in the lower Tamiami aquifer. Therefore, it is probable that there is leakage to the sandstone aquifer.

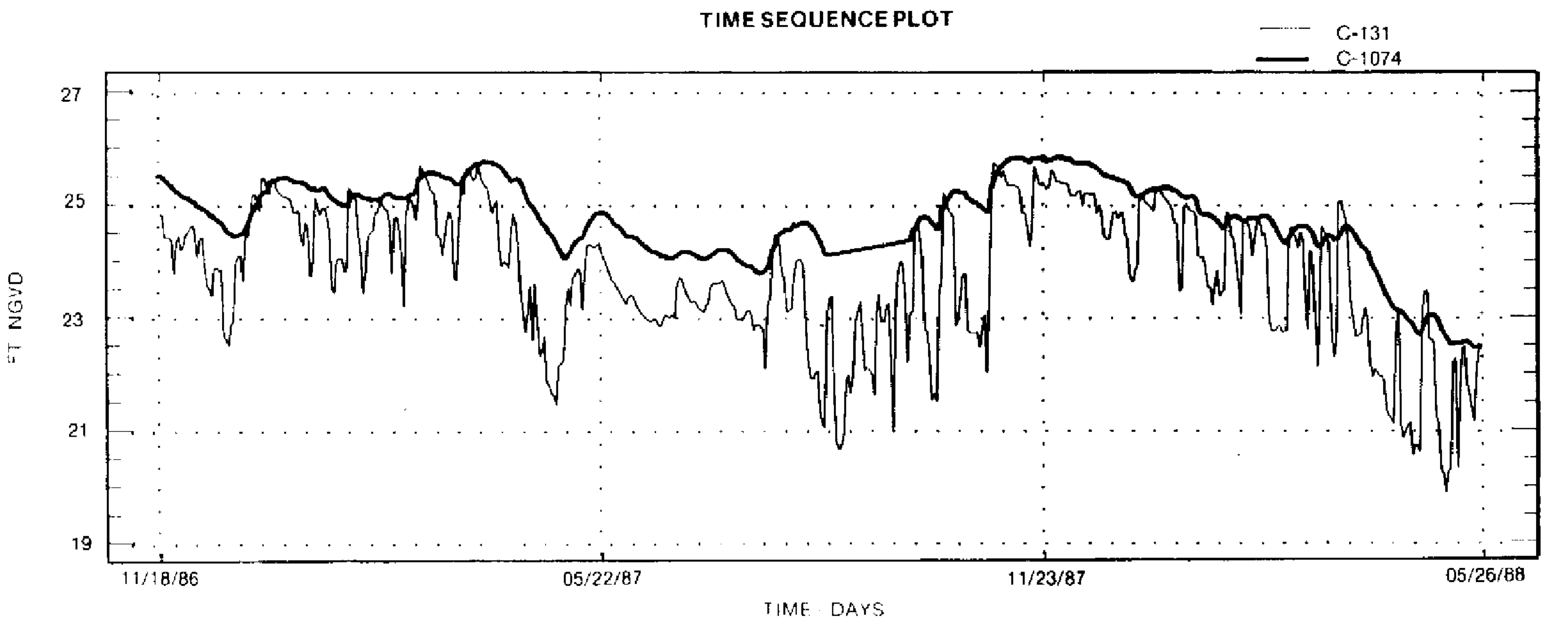
The lower Tamiami aquifer is the major ground water source in Hendry County. Extensive withdrawals from this aquifer occur throughout the county. Withdrawals from wells affect flow patterns in areas of intensive use.

Subsurface flow occurs radially from the potentiometric high that corresponds to the Immokalee Rise. From there, it flows east into Palm Beach County, west into Lee County and south into Collier County. Flow is restricted to the north by the Caloosahatchee River.

INTERMEDIATE AQUIFER SYSTEM

Sandstone Aquifer

The sandstone aquifer is a semi-confined aquifer with a potentiometric head that is 60 to 200 feet above the top of the aquifer. Throughout Hendry County, the water levels in the sandstone aquifer are lower than ground elevation so wells in this aquifer do not



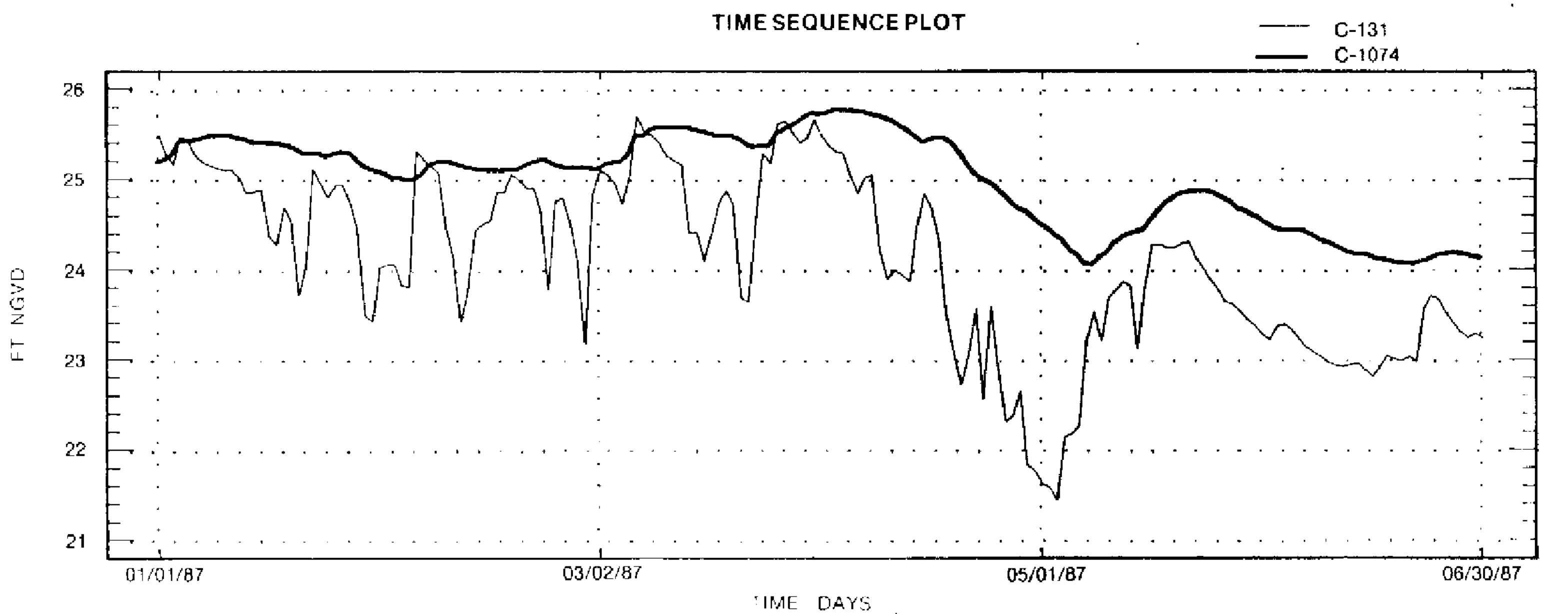


Figure 37 COMPARISON OF WATER LEVELS BETWEEN THE WATER TABLE AND LOWER TAMIAMI AQUIFERS

flow at land surface. However, some sandstone aquifer wells flow at land surface along the Caloosahatchee River in Lee County. For the water level analysis, the sandstone aquifer wells were designated as completed in either the clastic or carbonate zones and mapped separately (see Figure 38 for location and designation). From analysis of the data, it appears that water levels are very similar in both zones with differences of one foot or less in most areas. Some of the monitor wells are open to both zones and therefore the water levels from these wells were not included on the potentiometric maps. However, these wells are located on the monitor network map and hydrographs and statistical analyses are presented in Appendix B.

Potentiometric surface maps of the sandstone aquifer were generated using water level data from eleven clastic zone and nine carbonate zone wells for the wet and dry seasons (Figures 39, 40, 41, and 42). The configuration of both the clastic and carbonate units resembles that of the water table aquifer. The hydraulic gradient in both zones of the sandstone aquifer ranges from one-half foot per mile to four feet per mile throughout the study area. The highest water levels in the carbonate zone of the sandstone aquifer, approximately 28 feet NGVD in the wet season, occur just north of the Hendry-Collier border and west of SR29. Although there are no monitor wells in the clastic zone in this area, it is probable that water levels in the clastic zone are also highest here. There is minimal confinement between the sandstone aquifer and overlying sands of the Surficial Aquifer System in this area. Analysis of daily water level readings between a well in the water table aquifer (HE-554) and one in the carbonate zone of the sandstone aquifer (HE-529) reveals that the two aquifers exhibit significant hydraulic connection. In fact, as pumping causes water levels in the sandstone aquifer to decline, the water table aquifer responds with a corresponding decline. The one foot difference in head between the aquifers can probably be attributed to variations in hydraulic conductivity between the clastic material of the water table aquifer and the limestone of the carbonate zone of the sandstone aquifer.

<u>Water Level Fluctuations</u>

Hydrographs of all the sandstone aquifer wells can be found in Appendix B along with statistical data on each well. An analysis of the statistics was presented by Smith et al. (1988). Results showed that seasonal variations in water levels were higher in the sandstone aquifer than in the Surficial Aquifer System. They concluded that this was due to greater development of the sandstone aquifer accompanied by low transmissivity and storage.

The potentiometric surface maps for the clastic zone (Figures 39 and 40) show that in areas where the aquifer is not pumped, water levels vary by two feet or less from wet to dry season. However, in the developed southwestern portion of the study area, water levels fluctuate as much as ten feet seasonally.

Water levels in the carbonate zone of the sandstone aquifer (Figures 41 and 42) show similar trends. In the vicinity of the Townsend Canal, where surface water is used instead of the sandstone aquifer, water levels vary two feet between the wet and dry seasons. This probably reflects ambient conditions. From LaBelle to the Hendry-Collier border and in the Lee County portion of the study area, water levels vary four to six feet seasonally. In the Collier County portion of the study area, where sandstone aquifer usage is greatest, water levels fluctuate from eight to twelve feet seasonally.

<u>Recharge</u>

Recharge to the sandstone aquifer occurs principally through vertical leakage from adjacent aquifers and rainfall. Hydrographs comparing rainfall with water levels in each zone of the sandstone aquifer can be found in Appendix B. As previously discussed, northeast of Immokalee, the sandstone and the Surficial Aquifer System are in direct contact. Water level changes from rainfall occur almost simultaneously in paired monitor wells HE-554 (water table aquifer) and HE-529 (sandstone aquifer-carbonate zone). The monitor well pair, HE-554 AND HE-529, were also cross-correlated and results attributed 94% of water level changes in the carbonate zone of the sandstone aquifer to changes in the overlying water table aquifer (Figure 43). Examining lag times between water level changes in the water table aquifer and corresponding changes in the sandstone aquifer showed the largest correlation at zero days. This supports the belief that there is significant hydraulic connection between the two aquifers in this area.

In most areas the source of recharge is vertical leakage from overlying aquifers through semi-confining beds rather than direct rainfall. Throughout Hendry County, water levels in the Surficial Aquifer System are higher than those in the sandstone aquifer. This, along with the similarities in water level configuration between the sandstone, water table, and lower Tamiami aquifers, indicate that the primary recharge source is the Surficial Aquifer System. Results of cross-correlating water levels in the the Surficial Aquifer System (HE-851) and the carbonate zone of the sandstone aquifer (HE-556), attributed 73% of water level changes in the

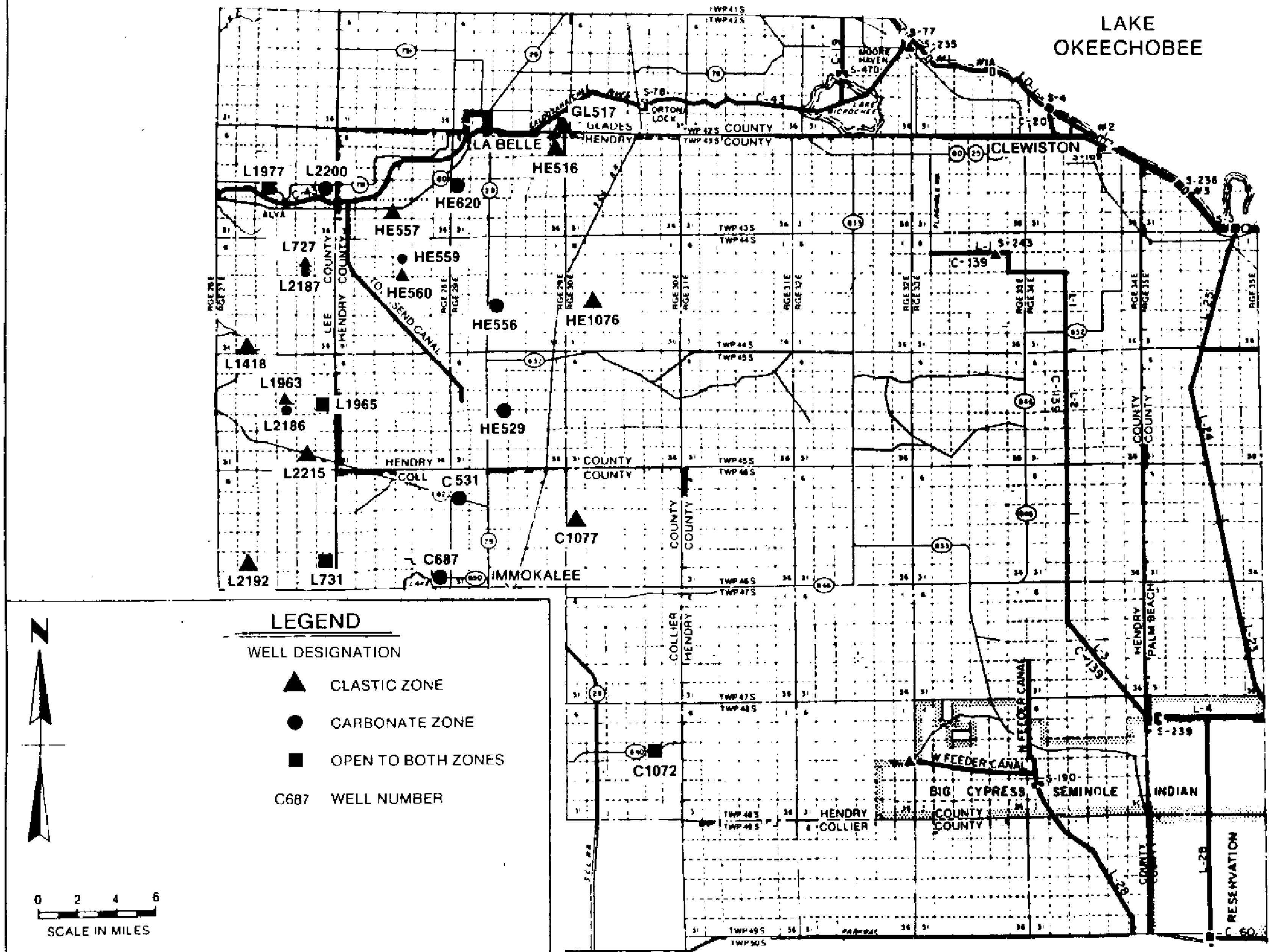


Figure 38 SANDSTONE AQUIFER MONITOR WELL LOCATIONS

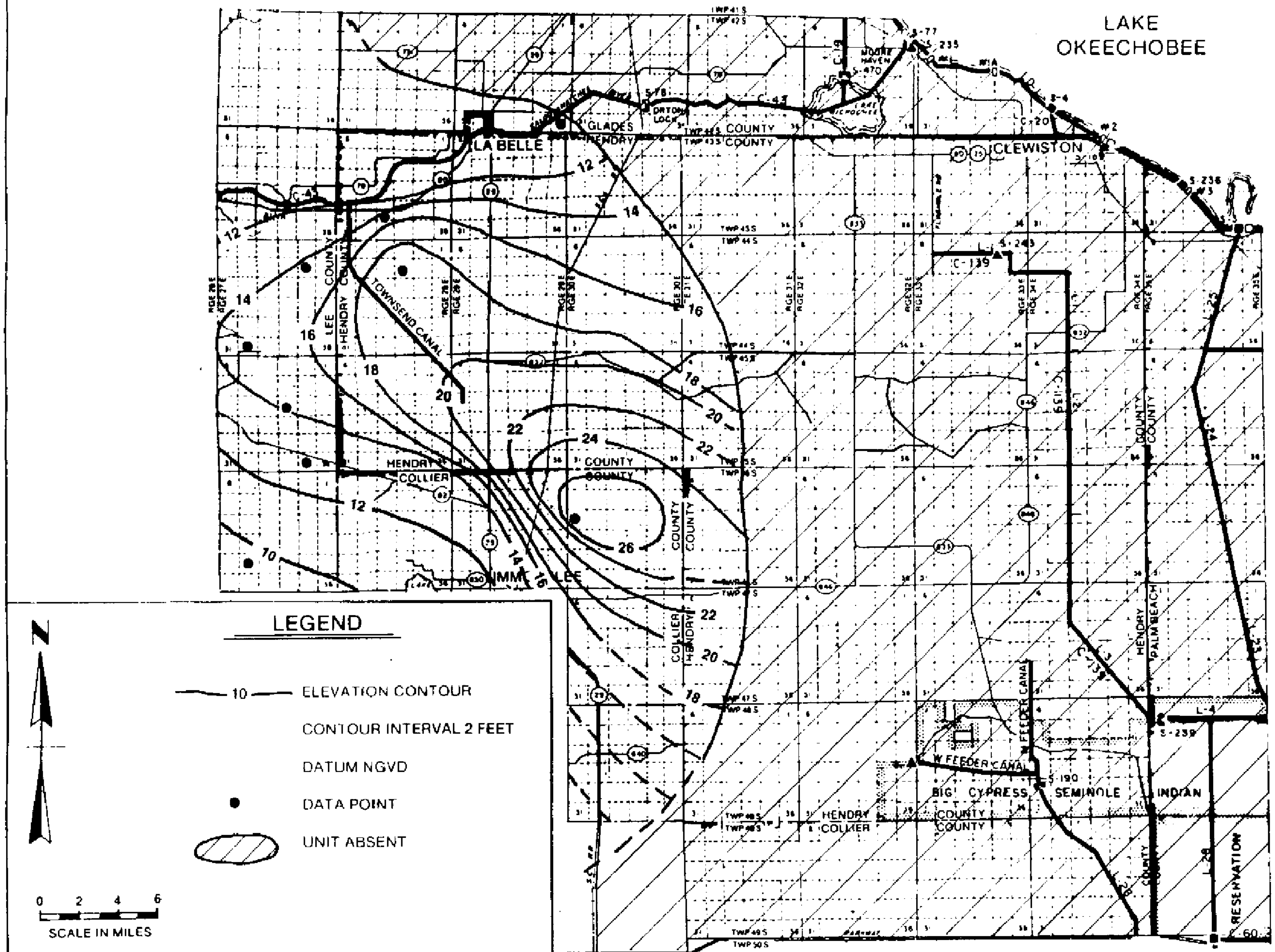


Figure 39 POTENTIOMETRIC SURFACE OF THE CLASTIC ZONE-SANDSTONE AQUIFER (APRIL 1986)

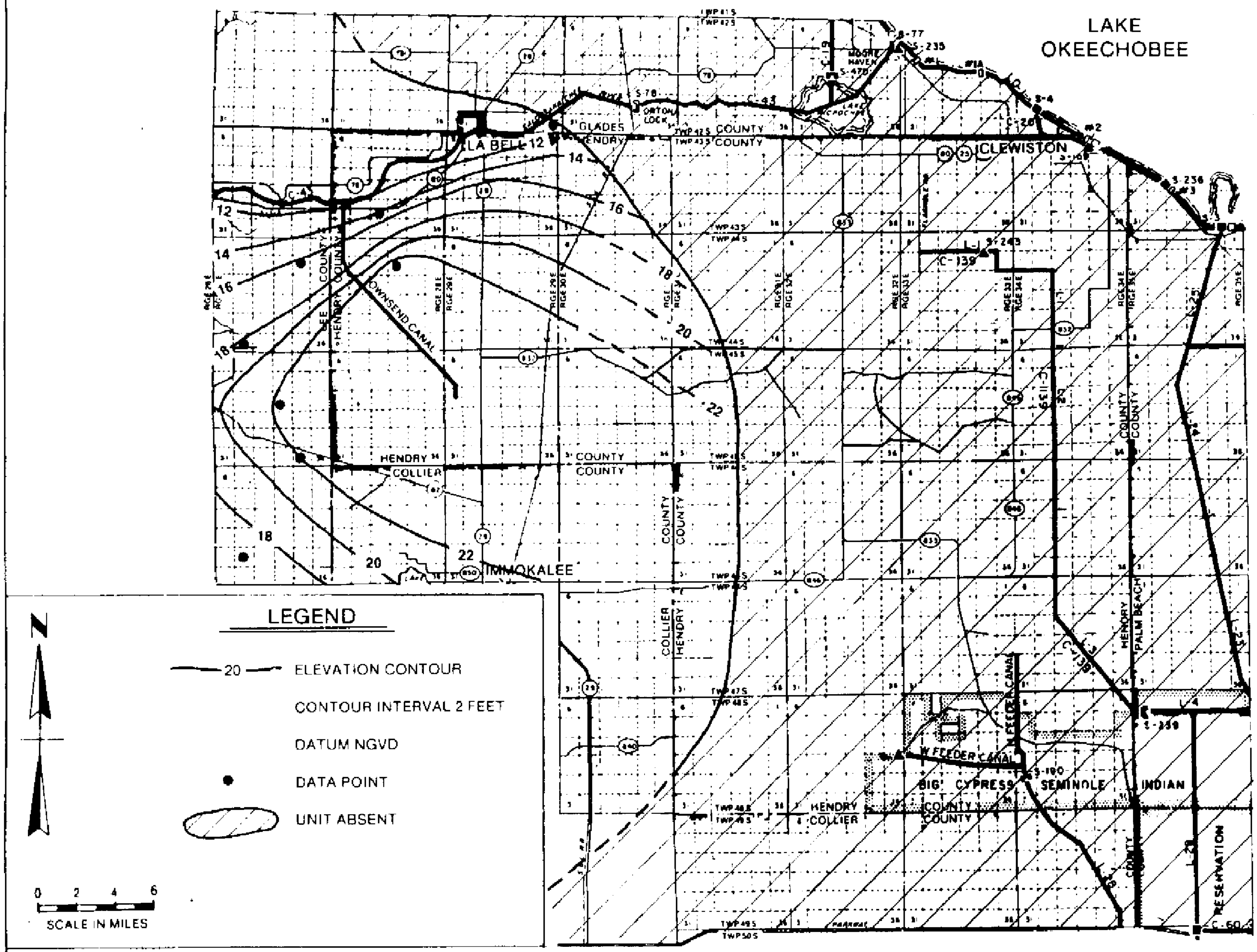


Figure 40 POTENTIOMETRIC SURFACE OF THE CLASTIC ZONE -SANDSTONE AQUIFER (SEPTEMBER 1986)

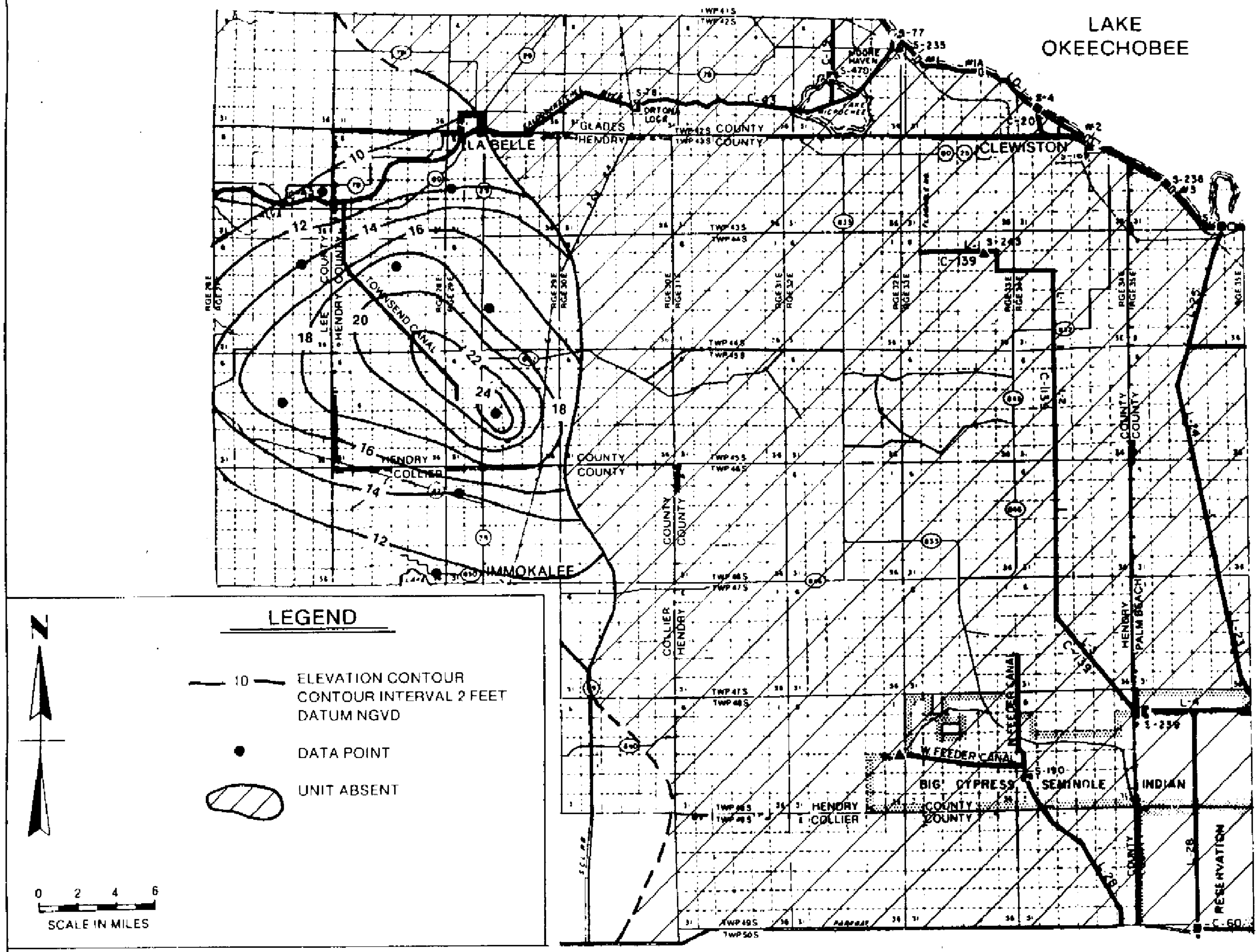


Figure 41 POTENTIOMETRIC SURFACE OF THE CARBONATE ZONE-SANDSTONE AQUIFER (APRIL 1986)

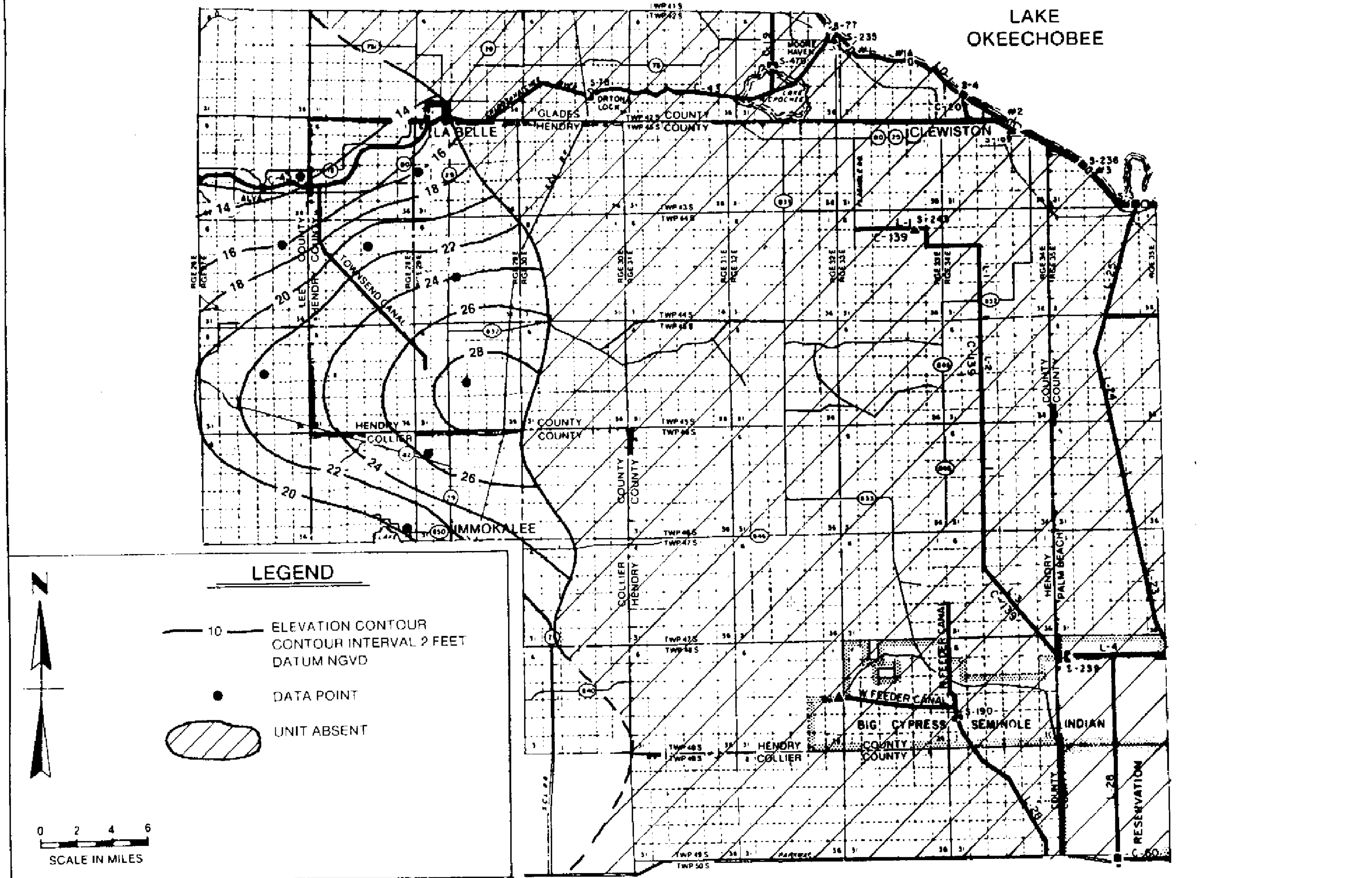


Figure 42 POTENTIOMETRIC SURFACE OF THE CARBONATE ZONE-SANDSTONE AQUIFER (SEPTEMBER 1986)

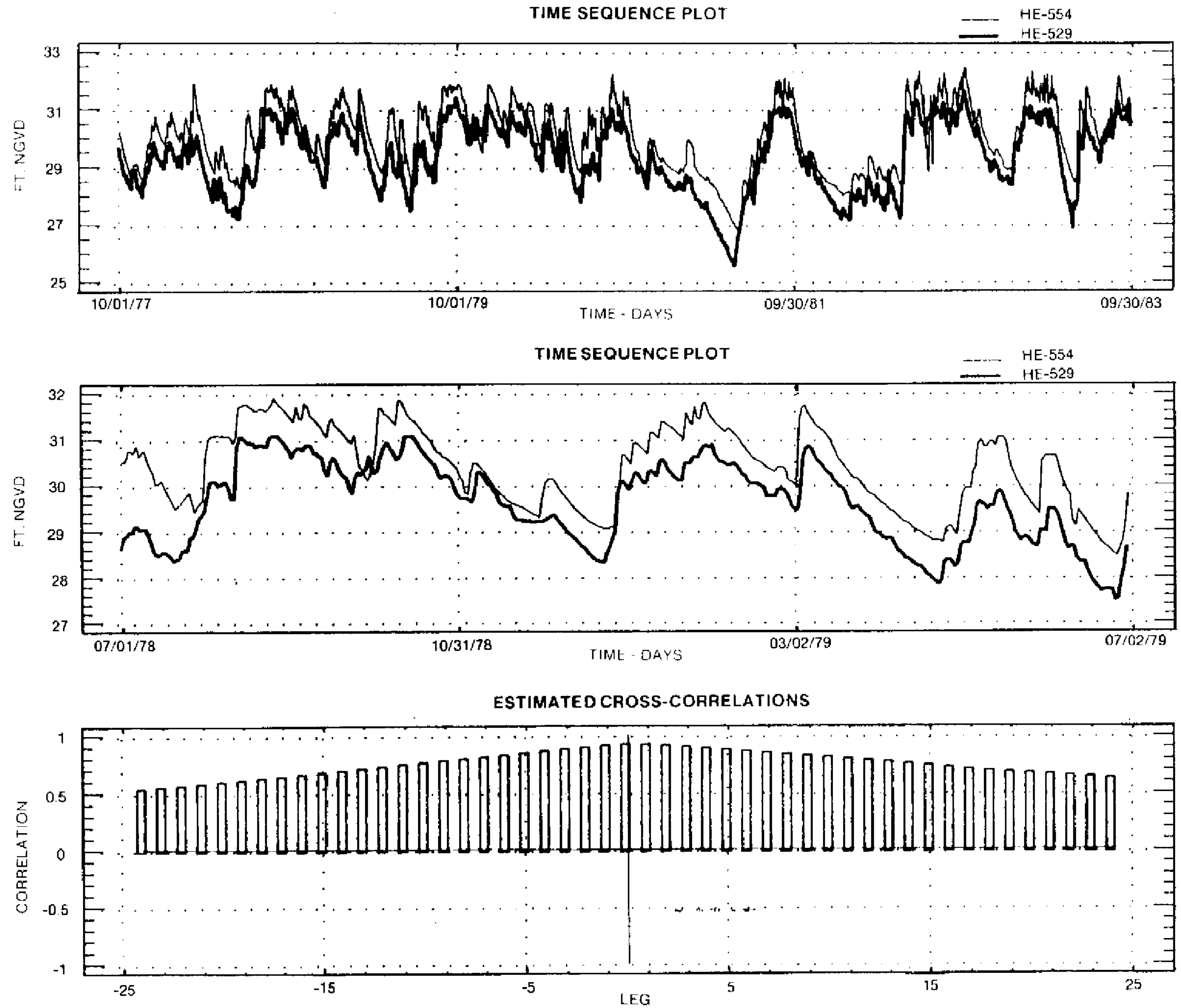


Figure 43 COMPARISON OF WATER LEVELS IN THE WATER TABLE AQUIFER AND POTENTIOMETRIC LEVELS IN THE SANDSTONE AQUIFER-CARBONATE ZONE

sandstone aquifer in central western Hendry County to changes in the overlying Surficial Aquifer System. Examining lag times between water level changes in the Surficial Aquifer System and corresponding changes in the sandstone aquifer showed the largest correlation occurred after 2 days. There is 75 feet of sandy (up to 50%) clay separating the two aquifers at this location. Only one monitor well pair, L-1137 (water table aquifer) and L-727 (sandstone aquifer-clastic zone), has the daily water level data needed to cross-correlate the water table aquifer with the clastic zone of the sandstone aquifer (Figure 44). Results of cross-correlation attribute 90% of water level changes in the clastic zone of the sandstone aquifer to changes in the water table aquifer with a lag time of three days. There is a corresponding increase in lag time with the increase in clay content of the upper Hawthorn confining zone. Review of lithologic descriptions shows that in this confining zone sand content decreases and clay content increases from the area around well HE-529 northwest to the Caloosahatchee River. There is no daily water level data currently available to determine the interrelationship of the two zones of the sandstone aquifer. However, sandstone monitor well pairs are currently in the USGS network and data could easily be gathered by installing recorders at these sites. The underlying mid-Hawthorn aquifer also displays higher potentiometric levels than the sandstone aquifer, but there is insufficient paired, daily data to determine correlation at this time.

In summary, the lithologic characteristics of the confining zone in the area northeast of Immokalee indicate that it is an area where significant downward recharge to the sandstone aquifer takes place. In addition, the highest potentiometric levels in the sandstone aquifer occur in this area, and water levels in the sandstone aquifer respond very rapidly to changes in the overlying water table aquifer which further indicates that this is a principal recharge area for the sandstone aquifer. The areal extent of this recharge area is not fully defined at this time.

Discharge

Discharge from the sandstone aquifer occurs principally by: 1) subsurface outflow to adjacent areas and 2) withdrawals from wells.

Outflow occurs radially from the area northeast of Immokalee where potentiometric levels are highest. Water flows northward toward LaBelle, westward into Lee County, and southward into Collier County. Because of large withdrawals in Collier County, the flow gradient is steepest toward this area.

Withdrawal from wells is the major source of discharge from the sandstone aquifer. Permitted annual withdrawals in Hendry County in 1986, for example, were approximately 5.5 billion gallons. The effects of the withdrawals are more noticeable in the dry season when citrus irrigation is most intense. However, in most portions of the study area wellfield withdrawals have only a localized effect.

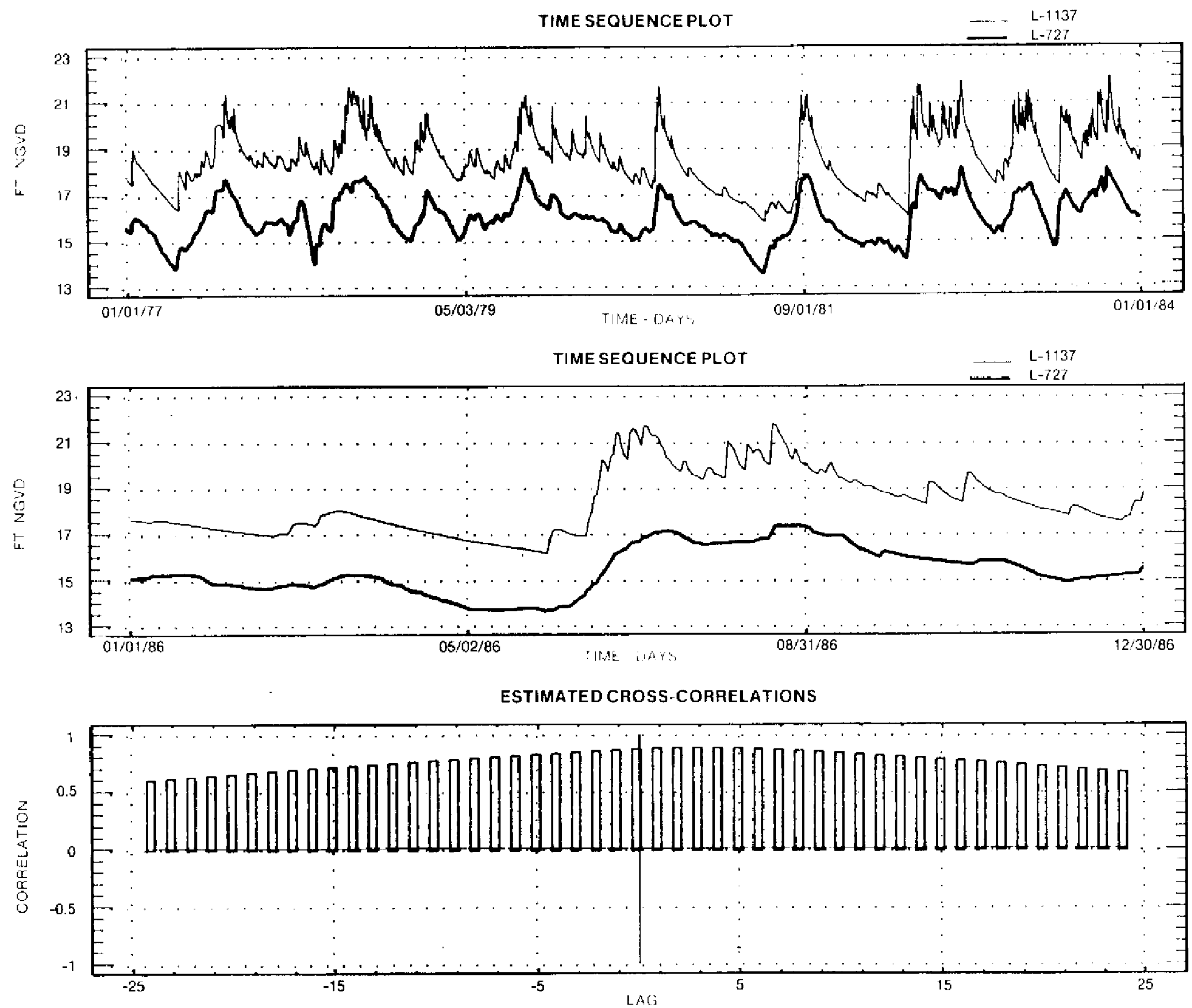


Figure 44 COMPARISON OF WATER LEVELS IN THE WATER TABLE AQUIFER AND POTENTIOMETRIC LEVELS IN THE SANDSTONE AQUIFER-CLASTIC ZONE

WATER QUALITY

BACKGROUND INFORMATION

All naturally occurring water contains varying amounts of dissolved material. The amounts and distribution of the dissolved constituents in ground water are primarily dependent on the source of the water, the lithology of the aquifer in which it resides, and the amount of time the water has been in the aquifer. Another factor that can have an effect on the quality of ground water is the mixing of waters with differing chemical properties. Inter-aquifer mixing can occur as a result of improper well construction, or the encroachment of salt water. Ground water quality can also be impacted by surface activities. Agricultural activities such as the use of fertilizers, herbicides and pesticides can result in the contamination of ground water. Disposal of solid wastes in landfills, industrial discharges, sewage disposal and animal wastes can also result in the contamination of ground water.

The types and concentrations of the chemical constituents present in ground water determine whether it is suitable for particular purposes. Water of acceptable quality for some uses may not be suitable for other uses. The Department of Environmental Regulation has adopted standards for a variety of chemical constituents for many different types of uses. A current list of primary and secondary drinking water quality standards is shown in Table 1.

Piper trilinear diagrams (Piper, 1944) are particularly useful for studying water quality changes with respect to space and time. Frazee (1982) used trilinear diagrams to group similar waters into patterns which represent characteristic water types that indicate the origin and the degree of mineralization. Frazee developed these patterns for environments common to northeastern Florida. Originally, it was not clear if these patterns would need to be modified for environments found in Hendry County and the lower west coast. A detailed analysis aimed at developing geochemical patterns for the study area is beyond the scope of this report. However, general lithologies and their corresponding depositional environments are similar throughout peninsular Florida. Therefore, it was determined Frazee's patterns may be used throughout this area to approximate water types. Figure 45 illustrates Frazee's classification diagram for waters in the southeastern limestone regional aquifer system. Five general classes of water are shown on this diagram: fresh water, fresh recharge water, transitional water, connate water and laterally intruded water. Fresh recharge water is characterized by low percentages of chloride, sulfate, sodium, and potassium, and higher percentages of calcium, magnesium, and bicarbonate (Frazee, 1982). Connate water is water that was not present in the aquifer materials when they were deposited, but has been out of contact with the atmosphere for an appreciable amount of a geologic period (Fetter, 1980). Contrary to some definitions, connate water is not restricted to water which has been virtually static since the burial of the rocks. Some connate water undoubtedly has migrated many miles since burial (Davis and DeWiest, 1966). Because of the large amount of time this water has

TABLE 1. DER WATER QUALITY CLASSIFICATIONS AND STANDARDS FOR GROUND WATER

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

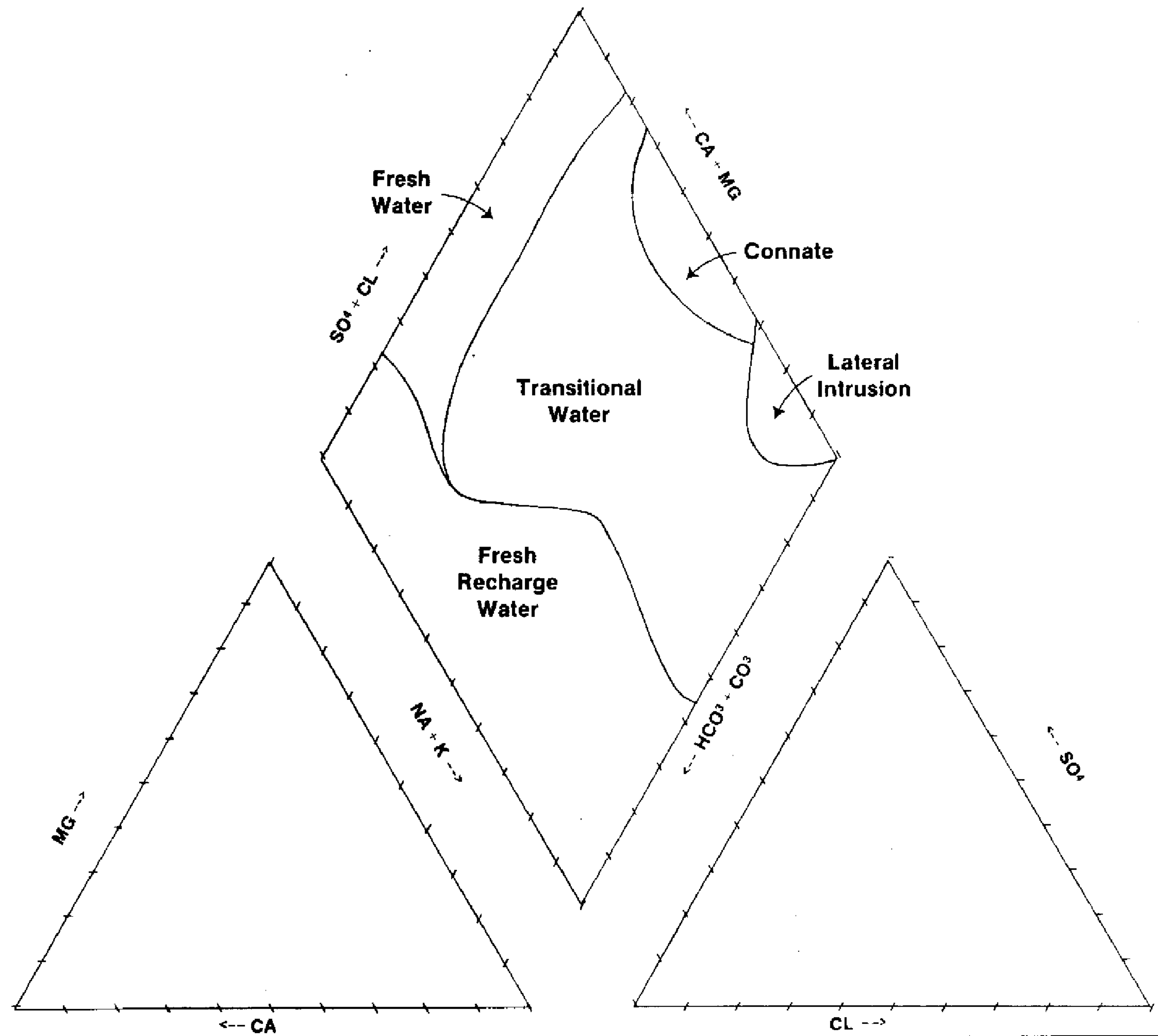


Figure 45 CLASSIFICATION OF WATERS WITHIN THE SOUTHEASTERN REGIONAL AQUIFER SYSTEM (AFTER FRAZEE, 1982)

resided in the aquifer, it has had sufficient time to reach geochemical equilibrium with the aquifer materials. Therefore, the chemical characteristics of connate water are a good indicator of the lithology of the parent aquifer. Laterally intruded water is similar in composition to sea water. It has high concentrations of sodium and chloride. Transitional water has the characteristics of both fresh recharge water and either laterally intruded water or connate water, depending on the source of water being mixed.

For this study, a computer program modified from a code developed by Morris and others (1983) was used for the trilinear analysis. The program requires input for concentrations of the required parameters and converts them to milliequivalents per liter, calculates the cation and anion percentages, calculates the ion-balance error, and plots the points on the trilinear diagram. The program also has an output option that shows the total ionic concentration of each sample as a circle centered on the plotted point. Readers desiring more information on the construction and use of trilinear diagrams are directed to the references cited in this section.

Water samples were collected from 51 USGS wells, 34 private wells, and 20 wells constructed by SFWMD. These samples were analyzed in the SFWMD chemistry laboratory. Measured parameters include sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), chlorides (Cl), sulfates (SO_4), bicarbonate alkalinity (HCO_3), fluoride(F), silicon dioxide ($Si0_2$), total dissolved strontium (Sr), total iron (Fe), total dissolved iron, total dissolved solids (TDS), color, conductivity, and pH. Historical data from the USGS was also reviewed. All of the data used in the analyses discussed in this section are included in Appendix C.

Areal distribution of water quality trends are discussed using chloride and conductivity data. These parameters were chosen because they are easily measured and commonly used to identify areas of potential sea water intrusion or intrusion (upconing) of mineralized relict waters. Maps of chloride concentrations and conductivity values for each aquifer in May 1987 are presented in this section.

Chloride in Florida ground water is usually a result of incomplete flushing of sea water present in the aquifer materials as they were deposited or recent intrusion of saline water. High concentrations of chlorides in water become apparent as a salty taste. The DER drinking water standard for chlorides is 250 milligrams per liter (mg/l). While different crops have varying tolerances with respect to chlorides, 800 mg/l is the approximate limit for most citrus crops in Florida (USDA, 1982).

Conductivity is the ability of water to conduct electricity. Generally, as more solids are dissolved in water, its ability to conduct electricity increases. Therefore, conductivity is a good indicator of the degree of mineralization of water. However, the type of ions present in solution and the temperature at which the measurement is made affect the conductivity value.

RESULTS

Water Table Aquifer

Water samples were collected from 31 water table aquifer wells throughout Hendry County in October 1986 and May 1987. Conductivity values and chloride concentrations from these wells were used to construct the water table quality maps presented in this section. In addition, historical chloride and conductivity data on selected USGS wells is available. All the chloride and conductivity data, as well as maps showing well locations, are presented in Appendix C.

Chloride concentrations in the water table aquifer range from 4 mg/l to 1118 mg/l. Figure 46 depicts the distribution of chloride concentrations in the water table aquifer in May 1987. This map shows a localized area of high chlorides near LaBelle. This may be due to upward leakage of saline water through some of the many Floridan Aquifer System or oil test wells in the area. Chloride concentrations in the water table aquifer throughout the rest of Hendry County are within potable water standards. The data displays little seasonal fluctuation in the chloride concentrations within the water table aquifer.

Conductivity values in the water table aquifer range from 251 umhos/cm to 4750 umhos/cm. Figure 47 shows the conductivity values in the water table aquifer in May 1987. This map shows the same localized area of poor quality water near LaBelle. Conductivity values in the water table aquifer in the remainder of Hendry County are generally below 1000 umhos/cm. There is little seasonal fluctuation displayed by the conductivity values within the water table aquifer.

A detailed study of water quality in the LaBelle area was conducted in the 1960's by the USGS. Klein et al. (1964) noted that chloride concentrations in the water table aquifer in LaBelle were as high as 488 mg/l as far back as 1952. Figure 48 is a map of chloride concentrations around LaBelle in 1952-1953.

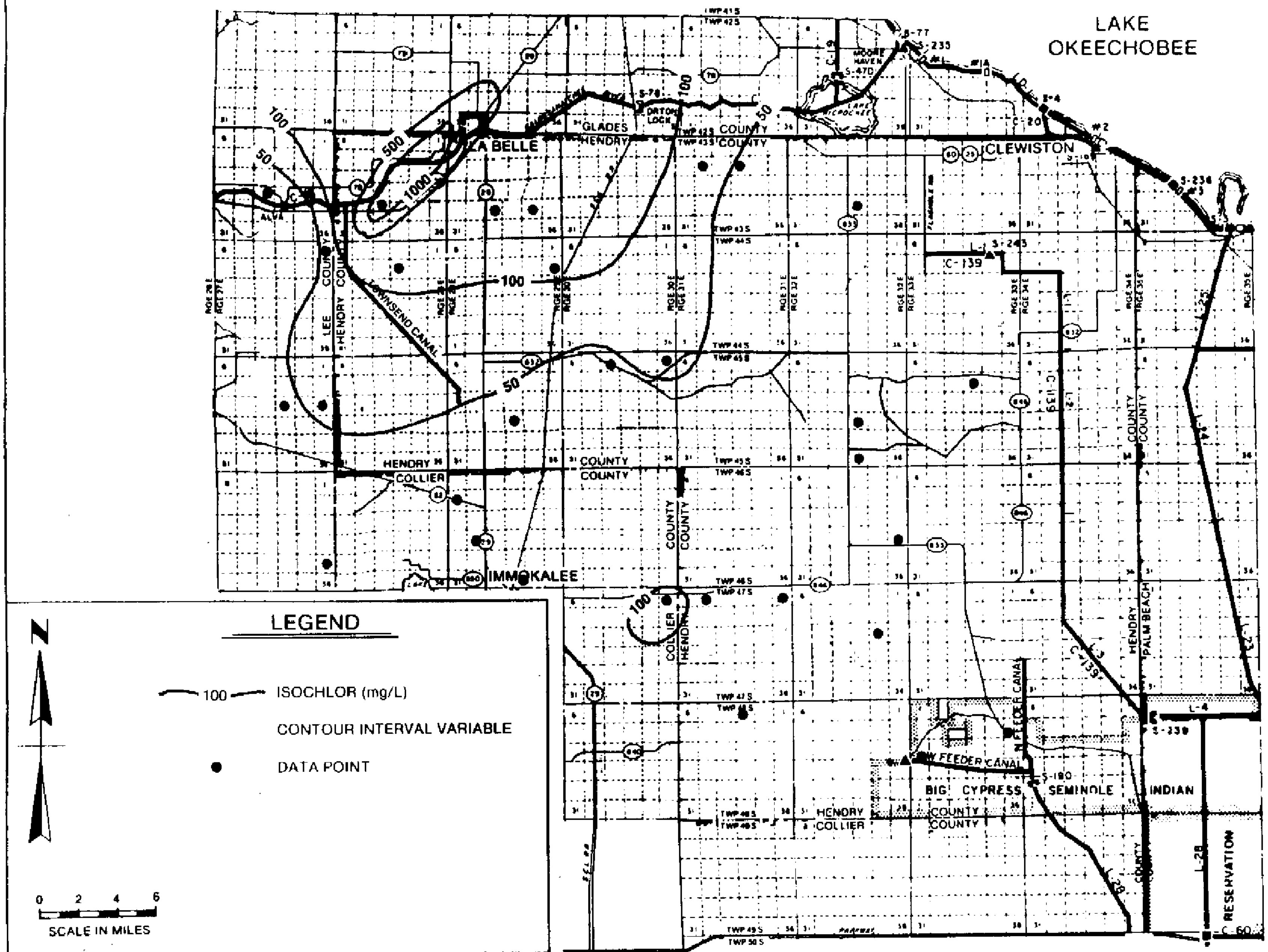


Figure 46 CHLORIDE CONCENTRATIONS WITHIN THE WATER TABLE AQUIFER (MAY 1987)

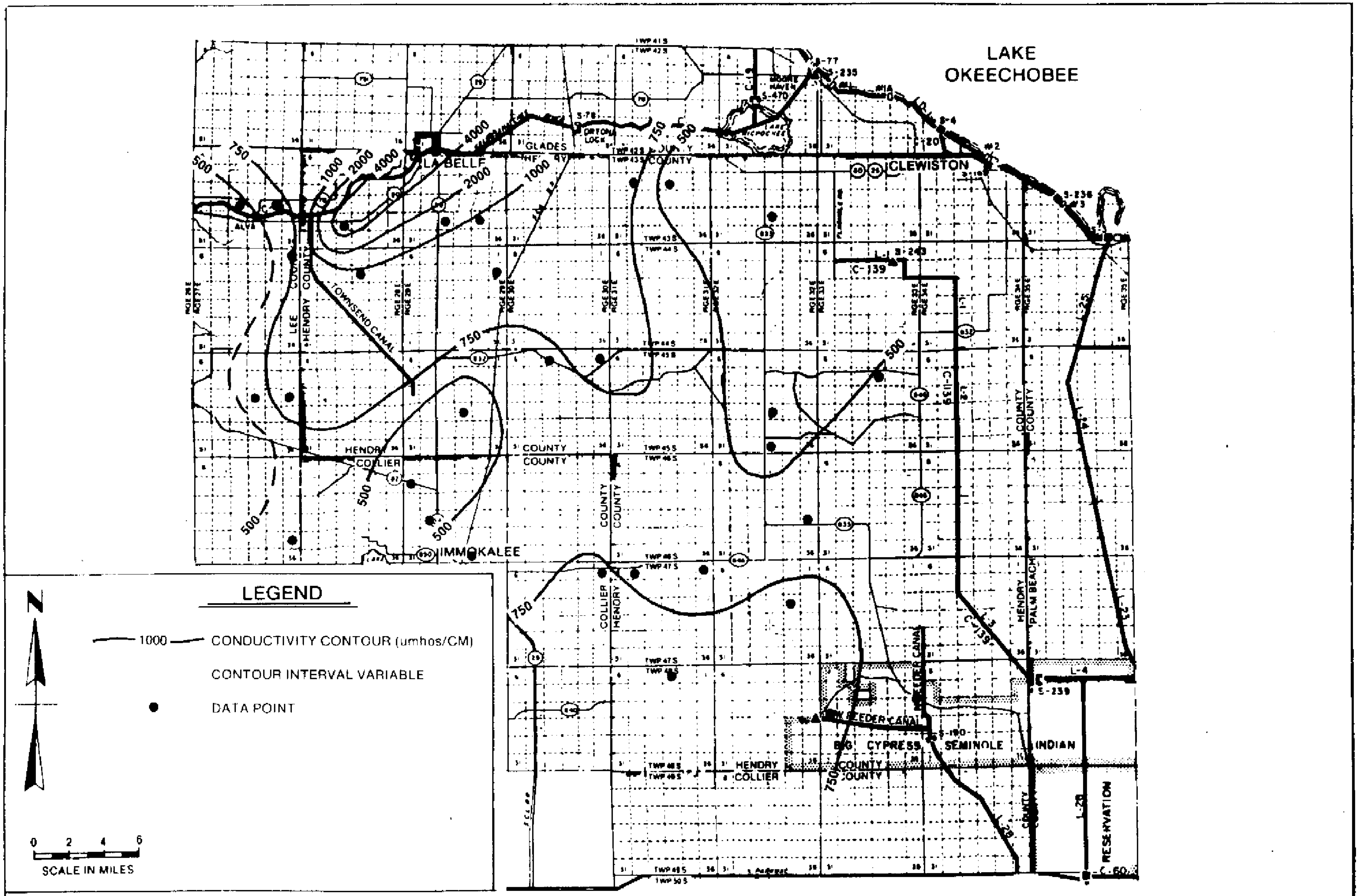


Figure 47 CONDUCTIVITY VALUES WITHIN THE WATER TABLE AQUIFER (MAY 1987)

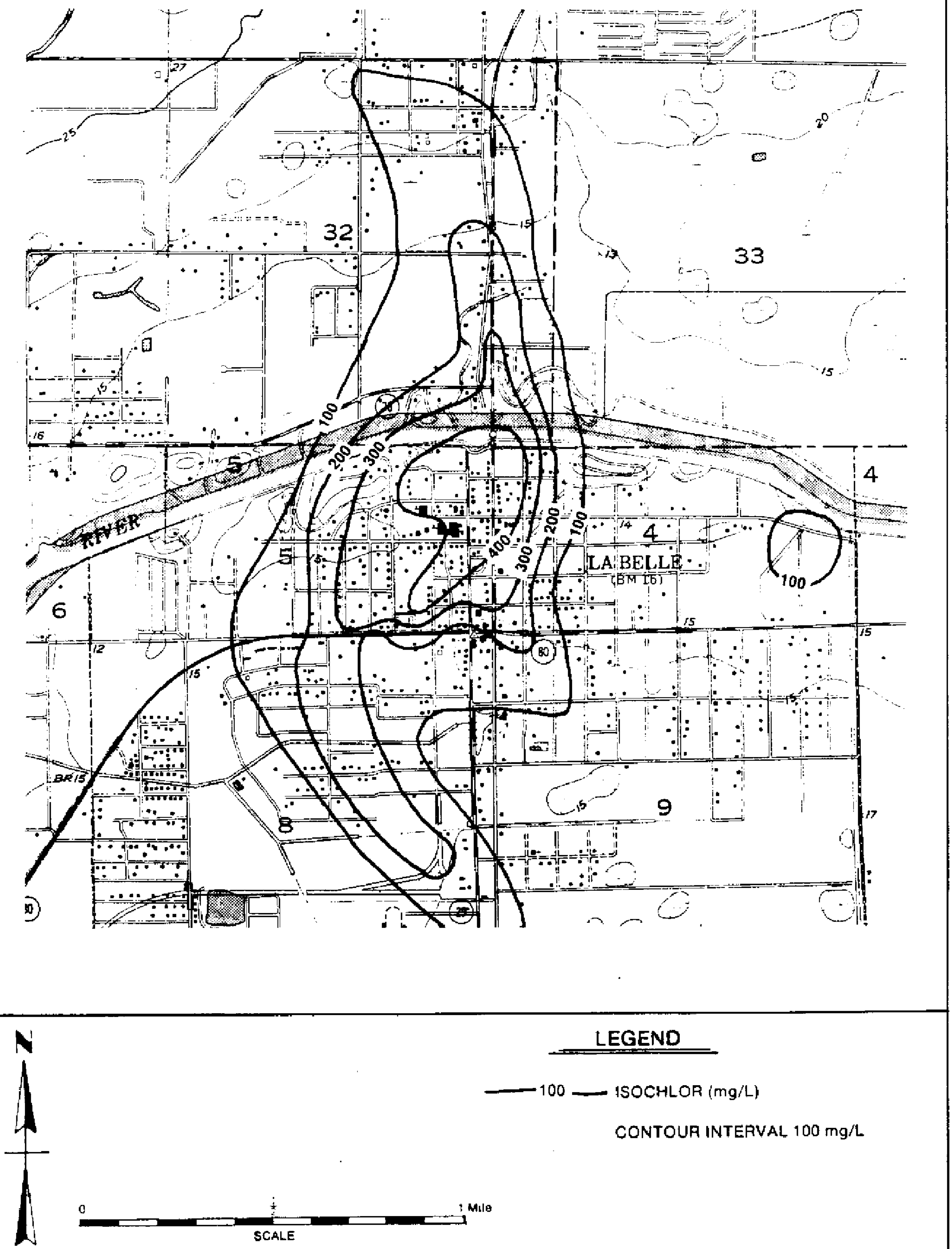


Figure 48 CHLORIDE CONCENTRATIONS WITHIN THE WATER TABLE AQUIFER NEAR LA BELLE (1952-1953) (AFTER KLEIN, 1964)

Klein attributed the high chlorides to seven improperly constructed Floridan Aquifer System wells. These wells, which were drilled before 1930, range in depth from 600 to 800 feet with only 80 feet of casing (Klein et al., 1964). The potentiometric surface of the Floridan Aquifer System in this area is more than 25 feet above water levels within the water table, so upward leakage of Floridan water into the water table aquifer through these well bores has been occurring continuously since before 1930. Analysis of water samples from adjacent water table and Floridan wells shows the water chemistry to be nearly identical.

Fish et al. (1983) also found areas of high chlorides near LaBelle. Figure 49 is a map of chloride concentrations around LaBelle using data collected between 1975 and 1977. It can be seen that the chloride levels in the water table aquifer at this time were much the same as they were in 1952-1953.

Figure 50 is a trilinear diagram of selected water table wells sampled in May 1987. Most of the samples plotted in this figure can be classified as fresh recharge water. Wells HE569 (Plot No. 9) and L1992 (Plot No. 10) fall into the classification of transitional water. The chemical characteristics of samples obtained from these wells indicate that they are a mixture of fresh recharge water and Floridan Aquifer System water. Well HE558 (Plot No. 11) is located near a flowing Floridan well, and its location on the trilinear diagram demonstrates that the water present in the water table aquifer at this location is almost pure Floridan Aquifer System water. HE569 and L1992 are located in the western part of Hendry County where there is a large number of old Floridan Aquifer System wells. Upward leakage of water through these wells as a result of improper construction (short casing), rusted or corroded casing, or allowing the well to free flow for long periods, is a probable source of the connate water found at these locations.

Water from the water table aquifer is generally suitable for all uses. Exceptions occur in the area of poor quality water near LaBelle and localized areas throughout the county where high levels of iron may require treatment prior to use.

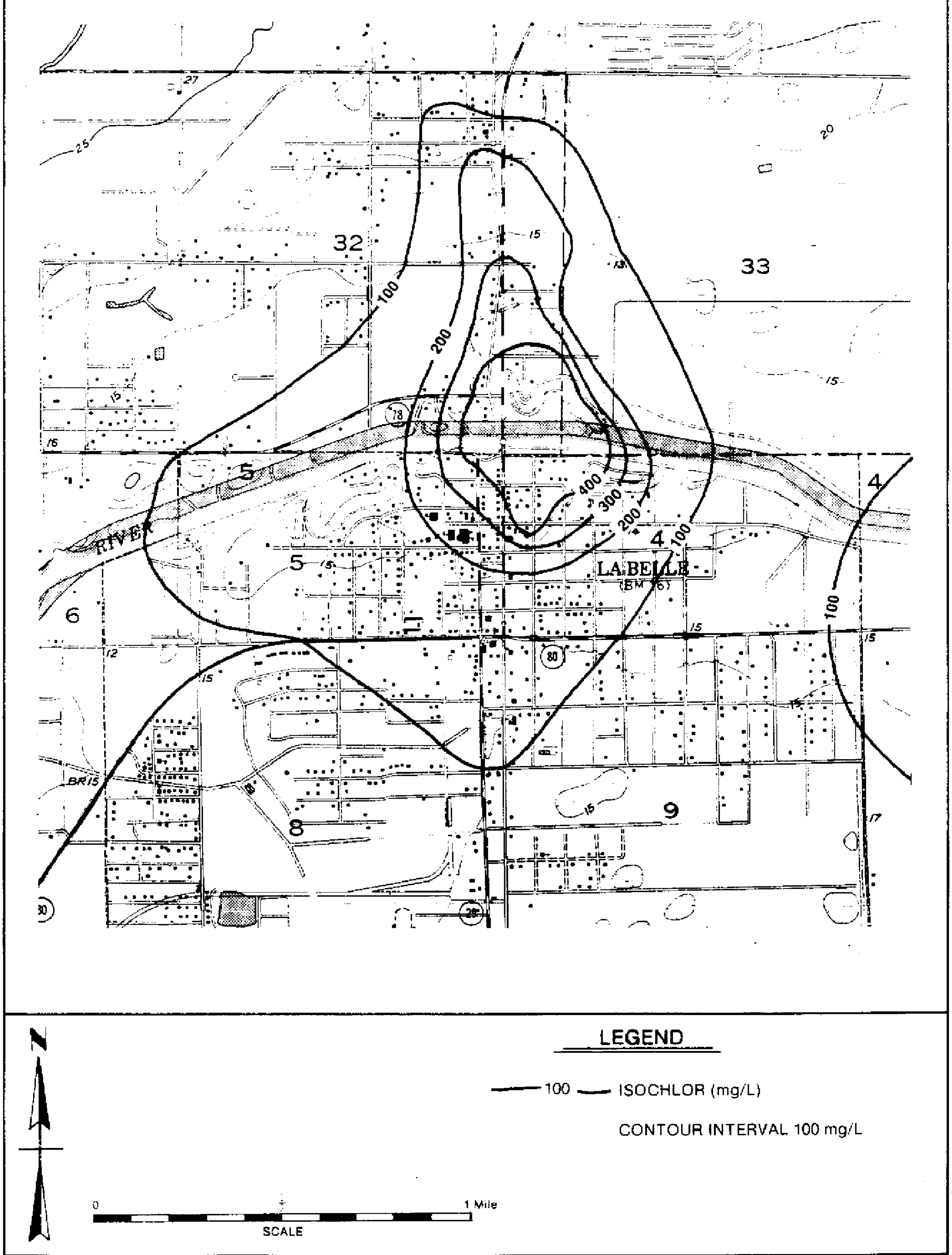
Lower Tamiami Aquifer

Water samples were collected from 33 wells in the lower Tamiami aquifer in October 1986 and May 1987. This data and historical chloride and conductivity data from selected USGS wells monitoring the lower Tamiami aquifer is presented in Appendix C. Since the lower Tamiami aquifer is hydraulically connected to and receives most of its recharge from the overlying water table aquifer, the chemical characteristics of the water contained in these two aquifers are similar.

Figure 51 is a map of the chloride concentrations within the lower Tamiami aquifer in May 1987. Chloride concentrations in this aquifer are generally higher than in the water table aquifer, but still within the DER safe drinking water standards. Chloride concentrations in the lower Tamiami aquifer range from 6 mg/l to 194 mg/l. Two anomolous values (606 and 593 mg/l) were measured in well HY311 located on the Big Cypress Seminole Indian Reservation. These values proved to be the result of improper well development. After further development of the well, a chloride concentration of 194 mg/l was measured which is considered to be more representative of the chloride concentrations of this area.

Conductivity values in the lower Tamiami aquifer range from 130 umhos/cm to 2160 umhos/cm. Figure 52 shows the conductivity values within the lower Tamiami aquifer in May 1987. Conductivity values in the western portion of Hendry County range between 500 and 1000 umhos/cm. The values tend to gradually increase toward the east and south, until values in excess of 2000 umhos/cm are encountered on the Big Cypress Seminole Indian Reservation. This high value may not be representative of conductivity values in the area. The range of conductivity in this well (HY311) varied between 1450 umhos/cm in March 1987 and 2760 umhos/cm in October 1986. This fluctuation may be related to a similar well development problem as discussed earlier.

Figure 53 is a trilinear diagram of selected lower Tamiami wells sampled in May 1987. The samples fall into two categories: fresh recharge water and transitional water. The samples that are classified as fresh recharge water are similar in chemical composition to samples obtained from the water table aquifer (see Figure 50) except they have slightly higher relative concentrations of sodium-potassium and chlorides. The total ionic concentrations of the samples from the lower Tamiami aquifer are also generally slightly higher than the water table aquifer as seen by the larger concentration circles. This indicates that the water in the lower Tamiami aquifer is more mineralized than the water in the water table aquifer. The samples that are classified as transitional water are also slightly higher in sodium-potassium and chlorides than the samples that were classified as transitional from the water table aquifer. This suggests that the transitional water in the lower Tamiami aquifer may be a result of incomplete flushing of the sea water present at the time of



LEGEND

100 ISOCHLOR (mg/L)

CONTOUR INTERVAL 100 mg/L

0 1 Mile
SCALE

Figure 49 CHLORIDE CONCENTRATIONS WITHIN THE WATER TABLE AQUIFER NEAR LA BELLE (1975-1977)

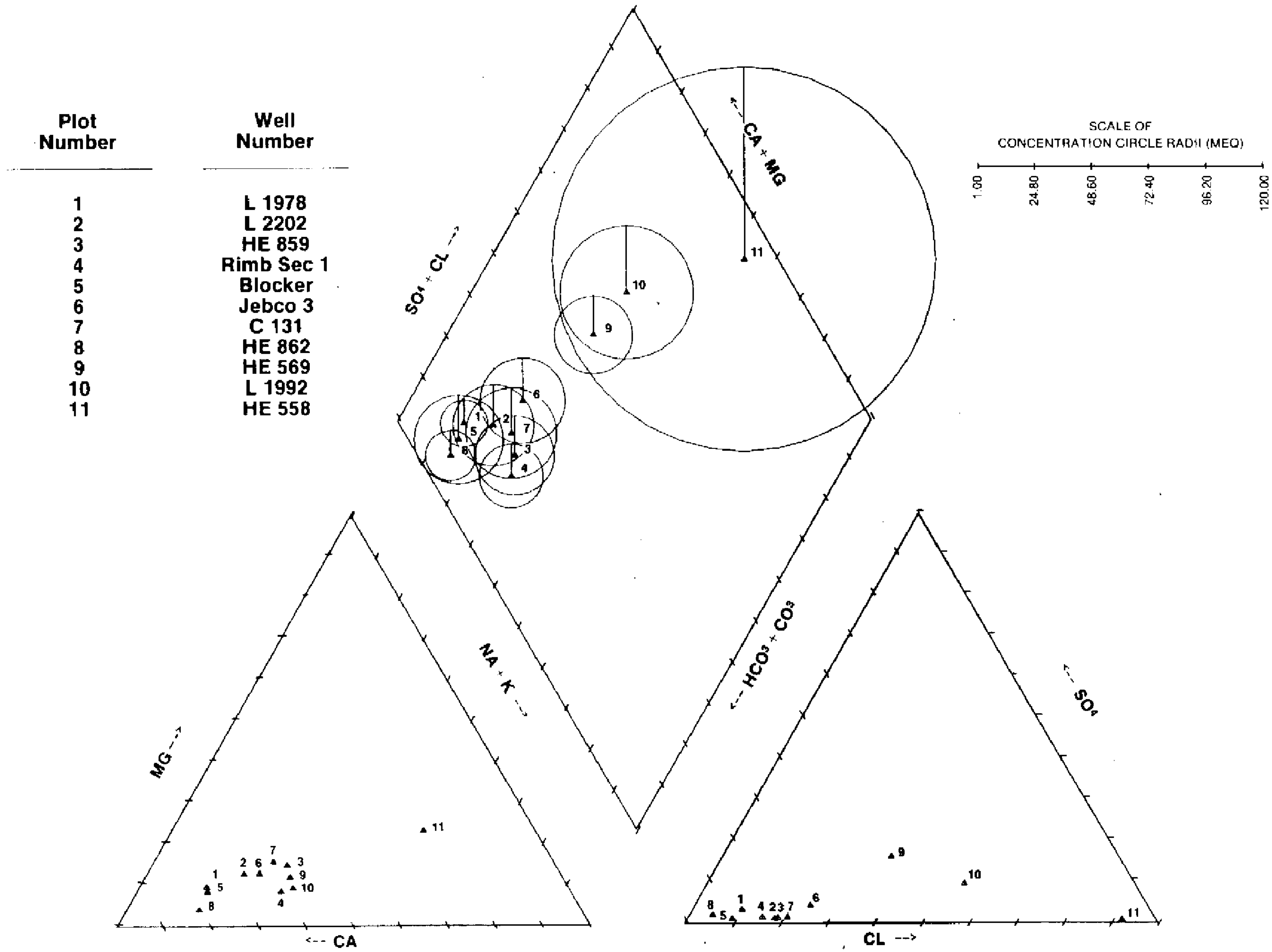


Figure 50 TRILINEAR DIAGRAM OF SELECTED SAMPLES FROM THE WATER TABLE AQUIFER (MAY 1987)

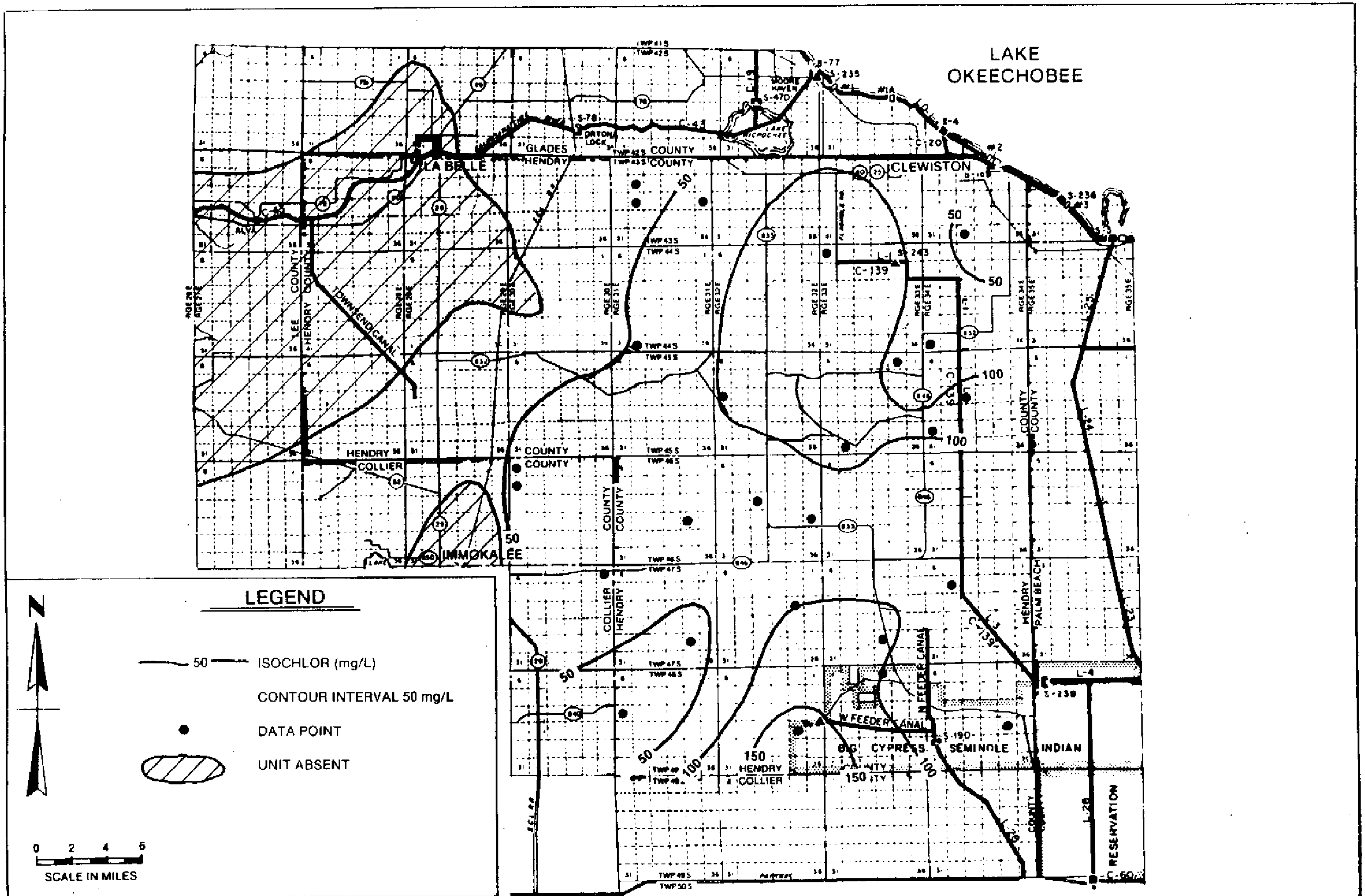


Figure 51 CHLORIDE CONCENTRATIONS WITHIN THE LOWER TAMIAMI AQUIFER (MAY 1987)

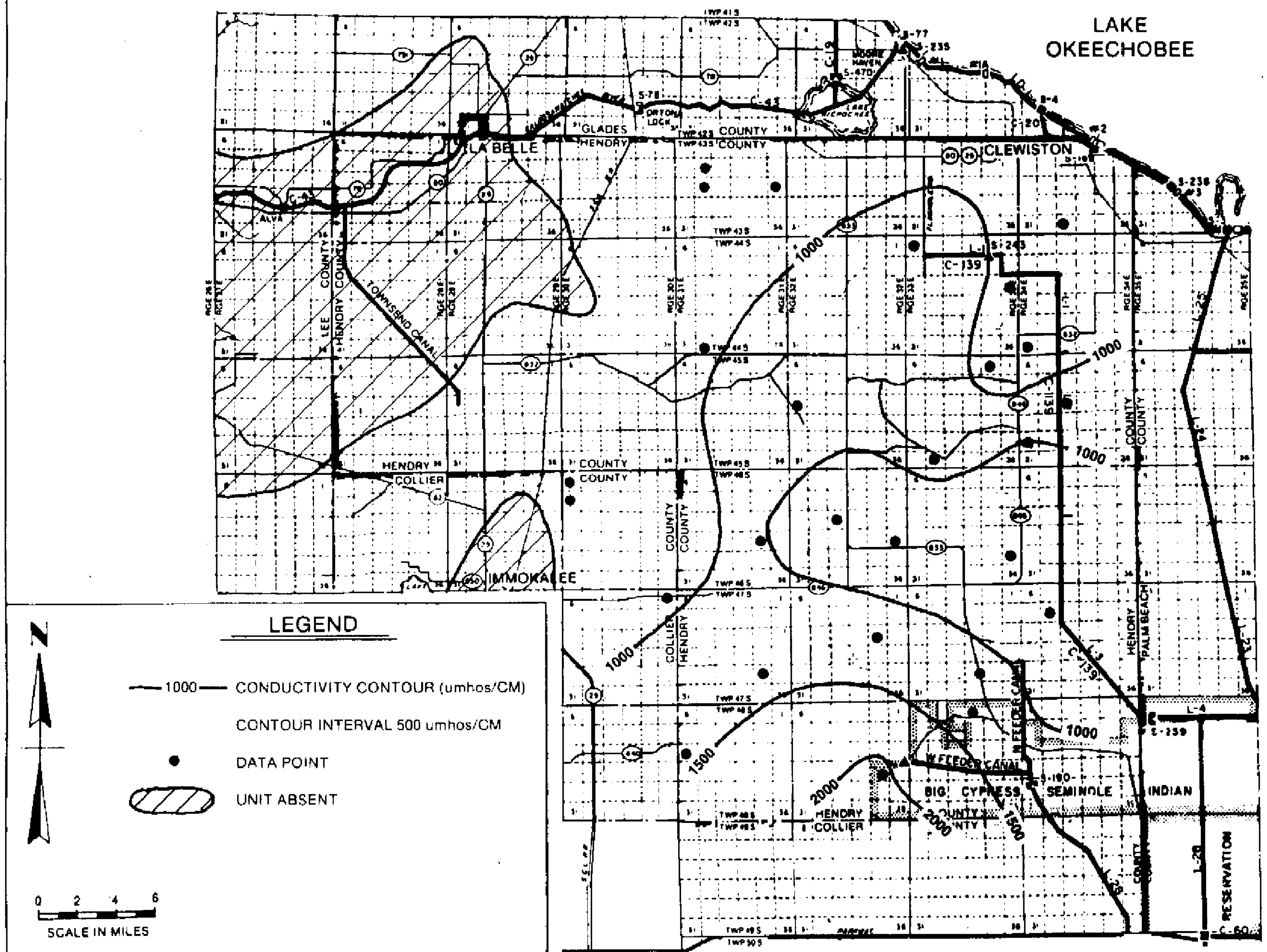


Figure 52 CONDUCTIVITY VALUES WITHIN THE LOWER TAMIAMI AQUIFER (MAY 1987)

Plot Number	Well Number
1	HE 859
2	C 1074
3	Alico 18
4	Witt
5	Alico 32
6	HY 311
7	HY 314
8	HY 206
9	HY 207
10	HY 208

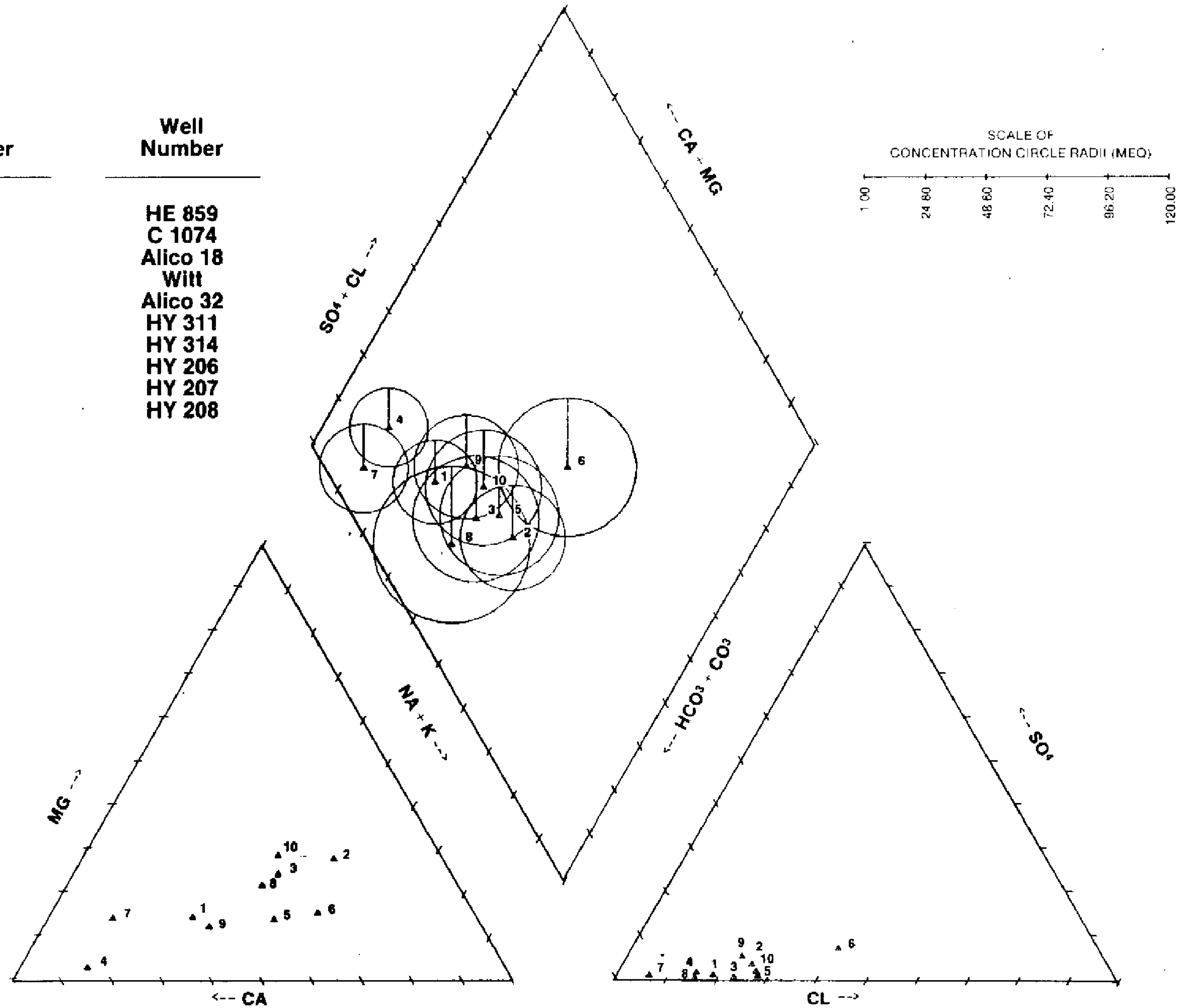


Figure 53 TRILINEAR DIAGRAM OF SELECTED SAMPLES FROM THE LOWER TAMIAMI AQUIFER(MAY 1987)

deposition and not connate water which is found in the water table aquifer.

Water from the lower Tamiami aquifer is generally suitable for all uses. Exceptions occur in localized areas throughout the county where high iron levels may require treatment prior to use.

Sandstone Aquifer

Water samples were collected from 23 wells in the sandstone aquifer in October 1986 and May 1987. Conductivity values and chloride concentrations from these wells were used to construct the sandstone aquifer water quality maps presented here. This data and historical chloride and conductivity data from selected USGS wells monitoring the sandstone aquifer are presented in Appendix C.

As mentioned previously, the sandstone aquifer is divided into two zones in the study area: a clastic zone and a carbonate zone. Twelve wells monitor the clastic zone and seven wells monitor the carbonate zone. Data existing from four wells that are open to both zones are not included in the water quality maps.

Chloride concentrations in the clastic zone of the sandstone aquifer range from 21 mg/l to 1131 mg/l. Figure 54 shows the areal distribution of chloride concentrations in this unit in May 1987. Conductivity values in the clastic zone range from 567 umhos/cm to 4870 umhos/cm (Figure 55). An area of poor quality water near LaBelle can be seen on both maps. There is little seasonal fluctuation seen in the water quality data from this unit. An exception to this is well HE557 which is in an area contaminated with Floridan Aquifer System water. Water in the clastic zone of the sandstone aquifer is suitable for most irrigation purposes.

Chloride concentrations in the carbonate zone of the sandstone aquifer range from 22 mg/l to 885 mg/l. Figure 56 is a map of the areal distribution of chloride concentrations in this unit during May 1987. Conductivity values in the carbonate zone range from 624 umhos/cm to 4600 umhos/cm (Figure 57). The area of poor quality water near LaBelle appears in both maps. As with the clastic zone, there is little seasonal fluctuation in water quality in this zone except for the wells located in the area contaminated with water from the Floridan Aquifer System (HE559 and HE620). Water from the carbonate zone of the sandstone aquifer is also suitable for most irrigation purposes.

Chlorides and conductivities are generally slightly higher in the upper clastic portion than the lower carbonate portion of the sandstone aquifer. Trilinear analysis suggests subtle differences in water chemistry between the two zones (Figures 58 and 59). Wells CPI20 and HE559 (Plot Nos. 3 and 6, Figure 59) and HE 557 (Plot No. 8, Figure 58) all show substantial contamination by Floridan aquifer water. All of these wells are located near old Floridan aquifer wells or in areas that were once irrigated with water from the Floridan aquifer. When these samples are discounted some general trends become apparent. Water in the clastic zone tends to have higher percentages of calcium and sodium-potassium, while water in the carbonate zone tends to have higher percentages of magnesium and alkalinity. This is probably due to solutioning of the dolomitic materials found in the carbonate zone. Water in the clastic zone also tends to be slightly more mineralized the water in the carbonate zone. Although there are subtle differences in water chemistry between the two zones of the sandstone aquifer, the overall water quality of both zones are similar which suggests that the water originated from the same source. Water samples obtained from wells completed in both zones of the sandstone aquifer do not show significant differences in chemistry from water samples obtained from either the carbonate or clastic zones. This is an indication that wells completed in both zones will not adversely impact the water quality of either zone.

Unnamed White Limestone Aquifer

Water samples were collected from two wells in the unnamed white limestone aquifer. While the sample size is too small to discuss trends, the samples indicate that the water in these two wells is acceptable for most irrigation uses.

Mid-Hawthorn Aquifer

Samples were collected from four wells in the mid-Hawthorn aquifer. Figure 60 is a trilinear diagram of these samples. There is not enough data available to discuss water quality trends in this aquifer in Hendry County. Water from this aquifer is not used for any purpose in Hendry County.

Analysis of Multiple Aquifer Sites

There are ten sites in Hendry County where wells are completed in two or more aquifers (Figure 61). This allows for comparison of water quality between aquifers without seeing variation caused by differing well locations. Comparison of the water quality of different aquifers at the same site may indicate if exchange of water between aquifers (recharge) is occurring. Table 2 describes each multiple aquifer site used in this analysis.

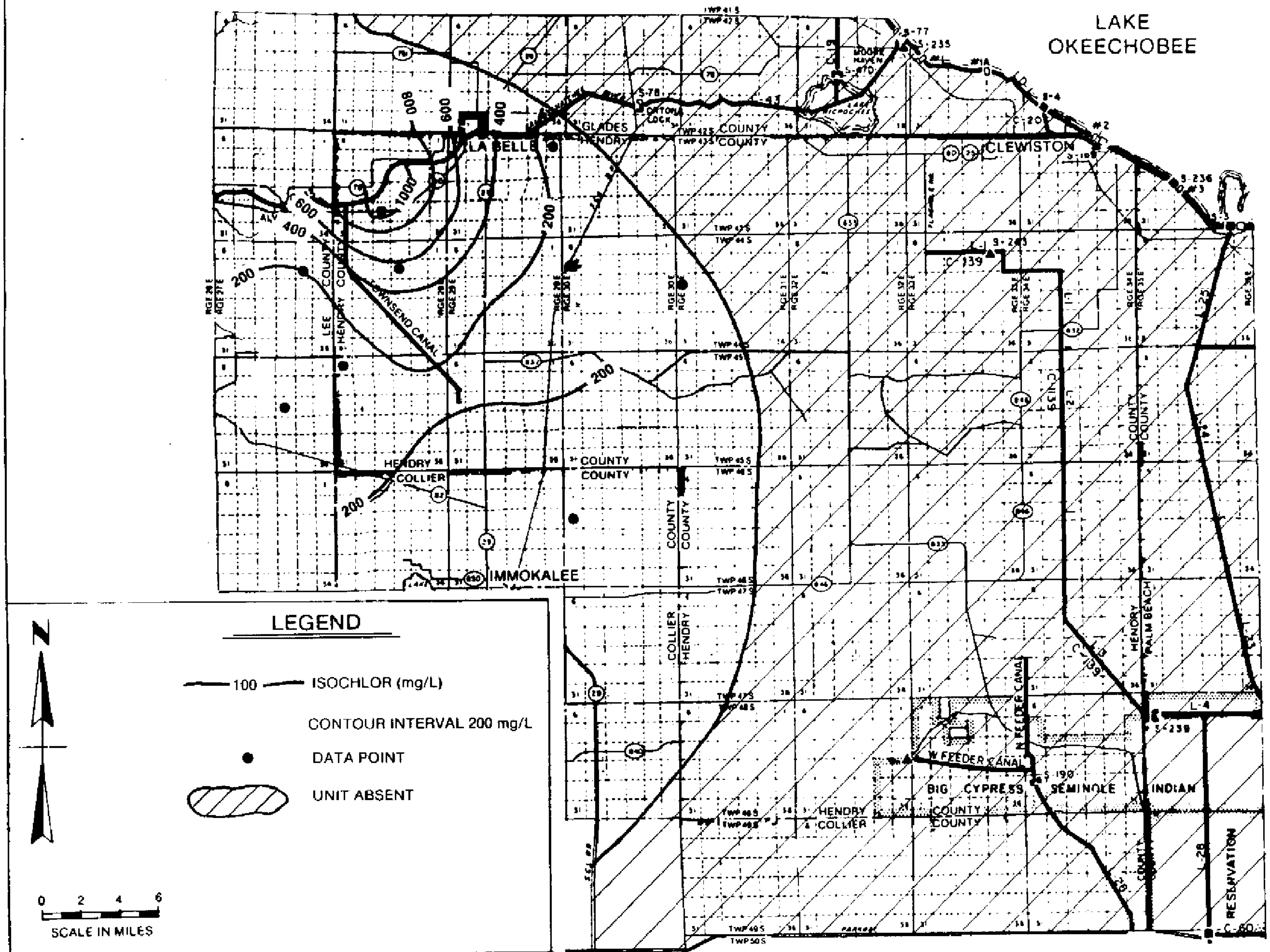


Figure 54 CHLORIDE CONCENTRATIONS WITHIN THE CLASTIC ZONE OF THE SANDSTONE AQUIFER (MAY 1987)

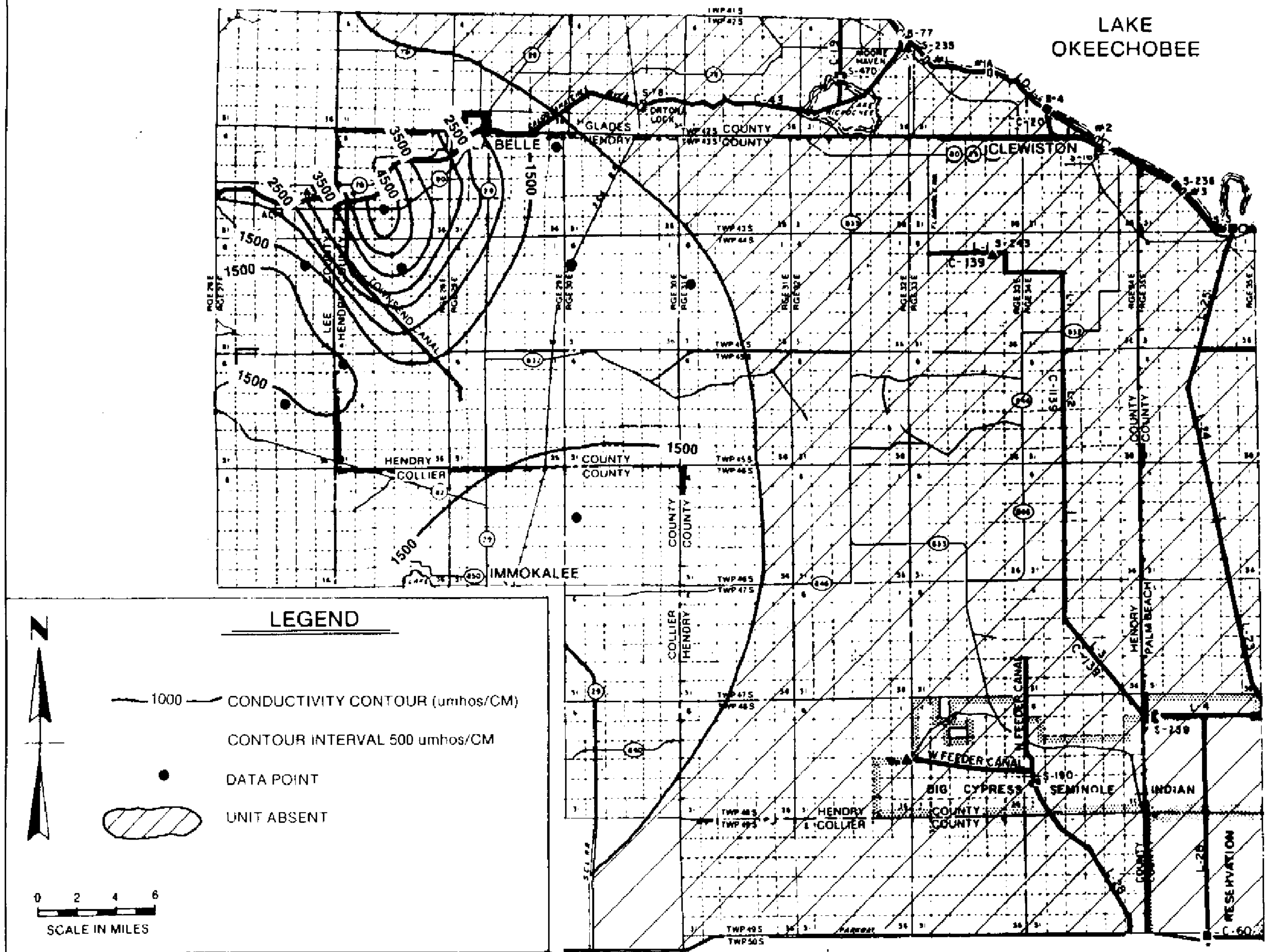


Figure 55 CONDUCTIVITY VALUES WITHIN THE CLASTIC ZONE OF THE SANDSTONE AQUIFER (MAY 1987)

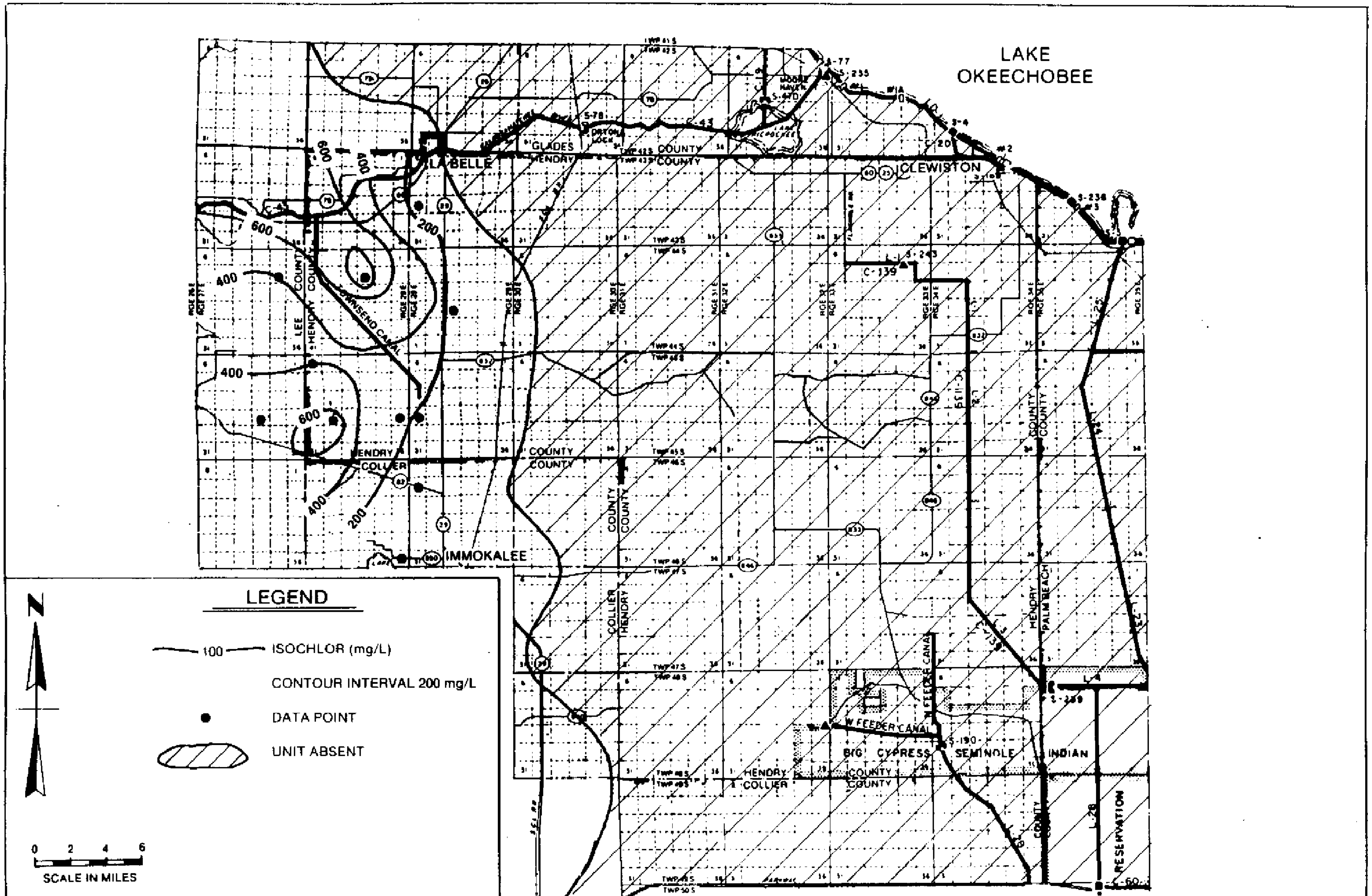


Figure 56 CHLORIDE CONCENTRATIONS WITHIN THE CARBONATE ZONE OF THE SANDSTONE AQUIFER (MAY 1987)

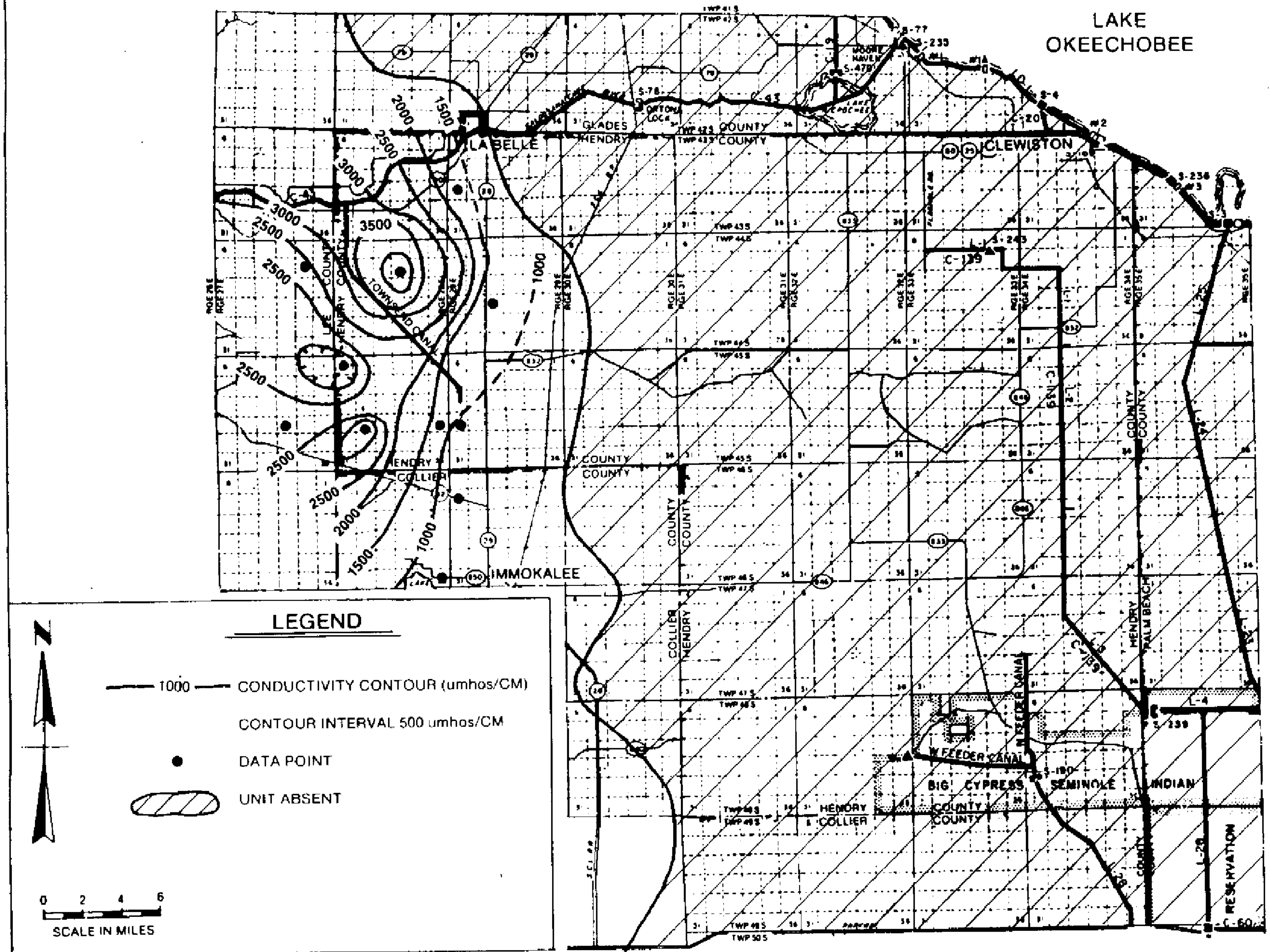


Figure 57 CONDUCTIVITY VALUES WITHIN THE CARBONATE ZONE OF THE SANDSTONE AQUIFER (MAY 1987)

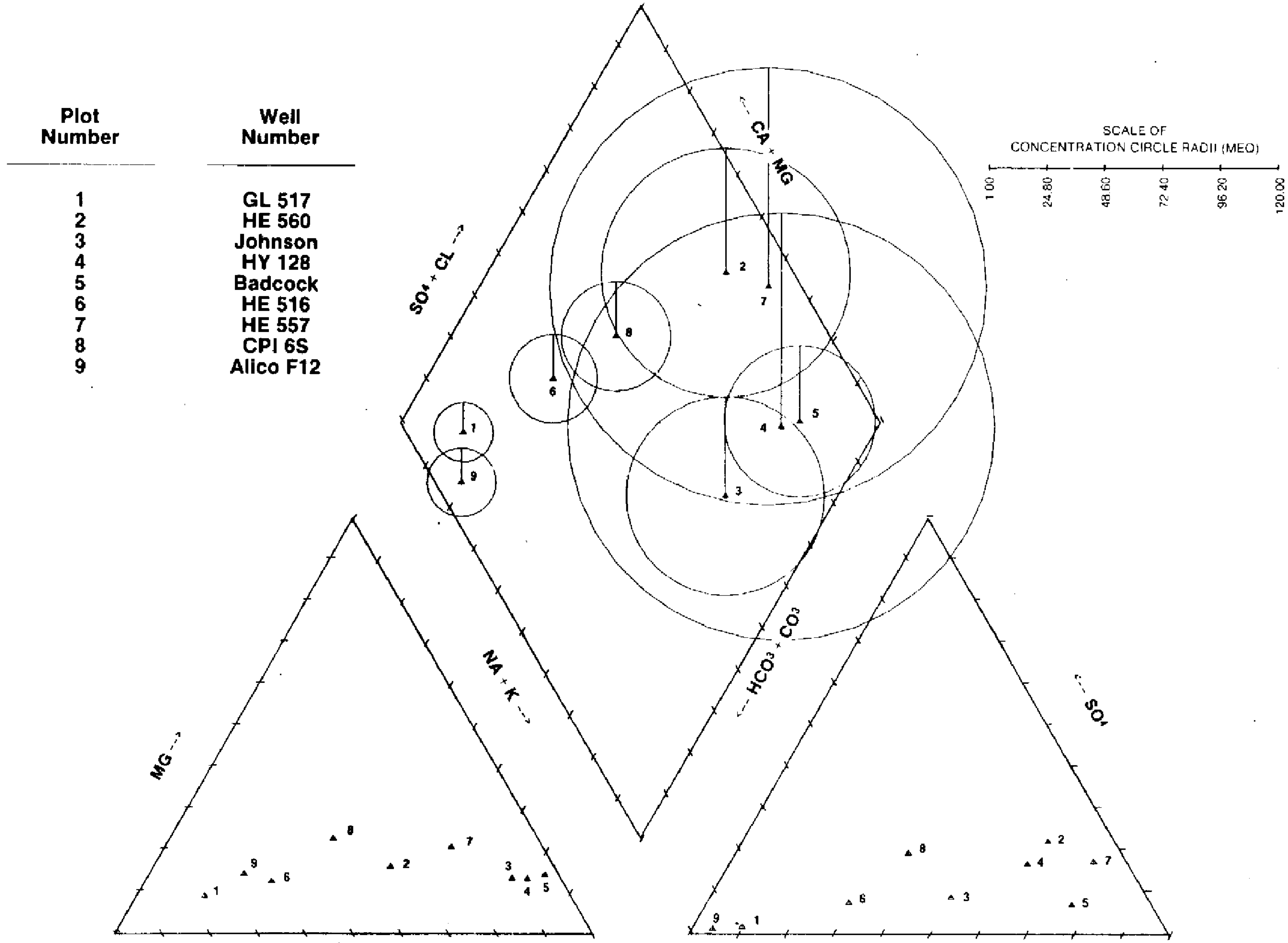


Figure 58 TRILINEAR DIAGRAM OF SELECTED SAMPLES FROM THE CLASTIC ZONE OF THE SANDSTONE AQUIFER (MAY 1987)

Plot Number	Well Number
1	HE 529
2	L 2187
3	CPI 20
4	CPI 6D
5	RTA 5
6	HE 559
7	HE 620
8	HE 556

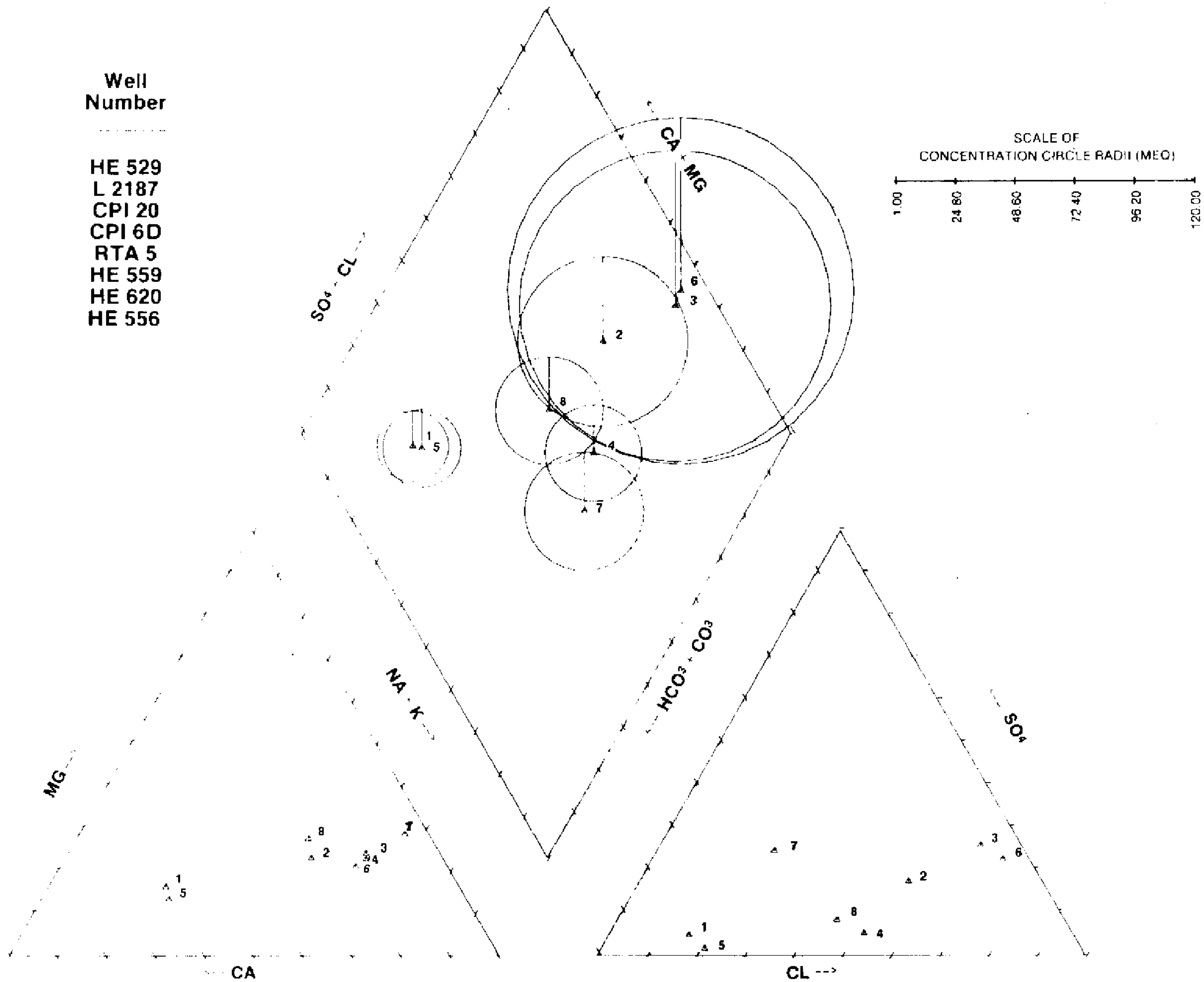


Figure 59 TRILINEAR DIAGRAM OF SELECTED SAMPLES FROM THE CARBONATE ZONE OF THE SANDSTONE AQUIFER (MAY 1987)

Plot Number	Well Number
1	GL 319
2	GL 321
3	BCMHAW
4	HE 555

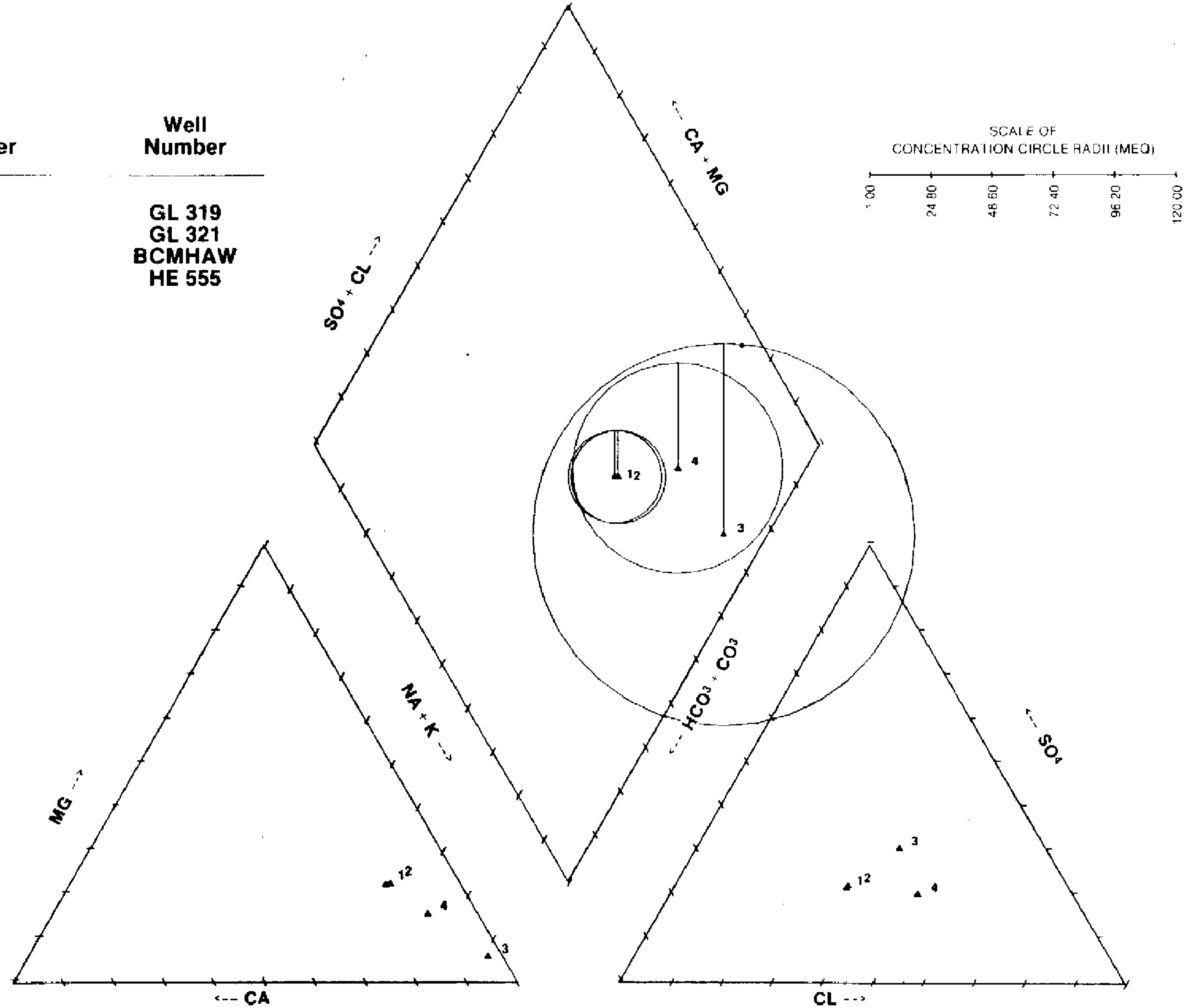


Figure 60 TRILINEAR DIAGRAM OF SELECTED SAMPLES FROM THE MID-HAWTHORN AQUIFER (MAY 1987)

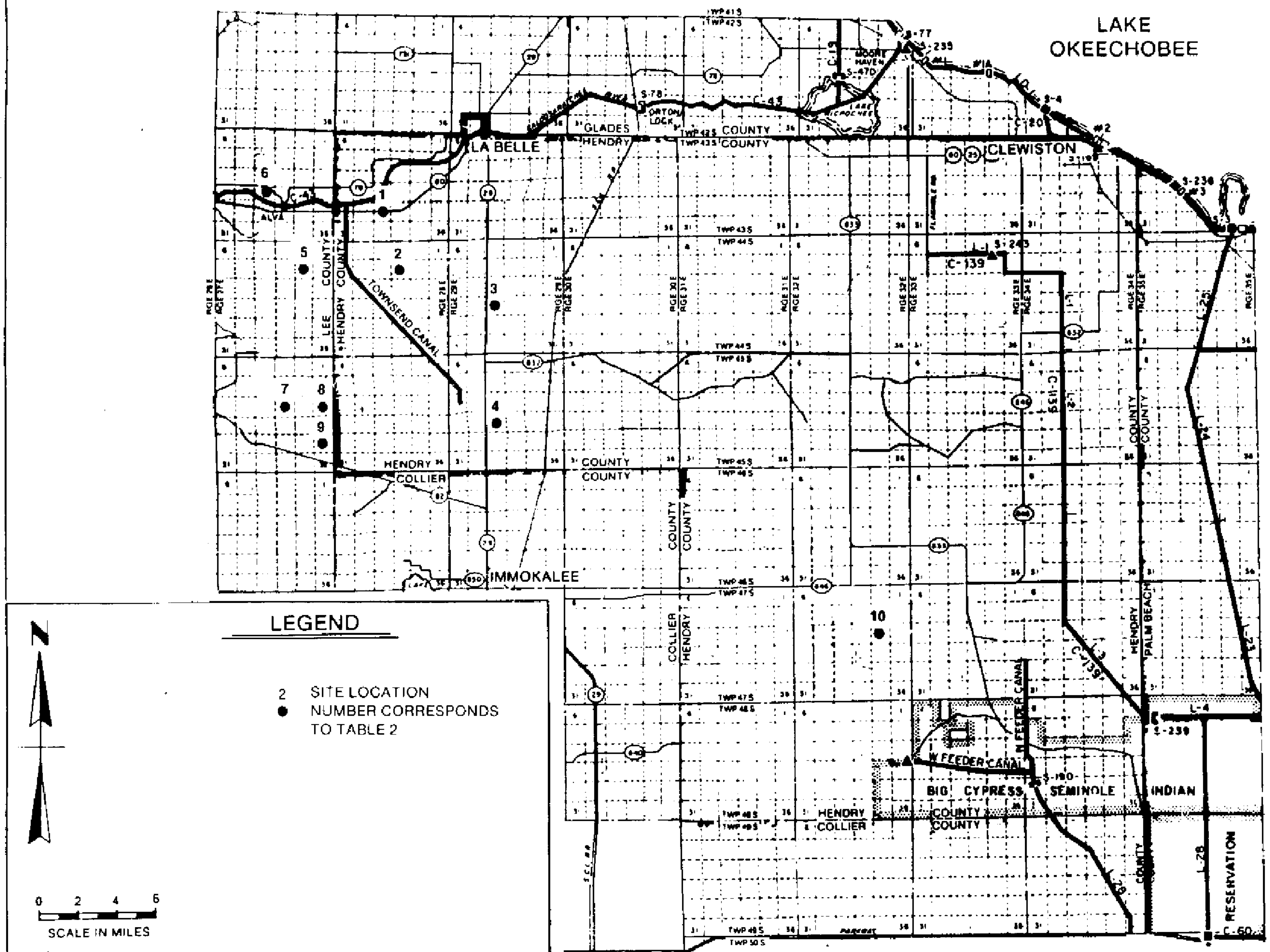


Figure 61 MULTIPLE AQUIFER WELL SITE LOCATIONS

Figure 62 is a trilinear diagram of water samples obtained in October 1986 from each of the multiple well sites. The arrows between plotted points are drawn from the shallowest well to the deepest well at each site. Therefore these lines are an indication of the water quality trends with increasing depth at each location. Most of the trends plot generally in a horizontal orientation with the data point representing the deeper wells located to the right and slightly higher than the shallower wells. This may be an indication that the shallower aquifers are recharging the deeper aquifers at these locations. As the water moves slowly down through the aquifers and confining beds, it dissolves more of the material through which it passes and becomes more mineralized with depth. If the water remains in the cycle long enough, it completes the transition from fresh recharge water in the shallower aquifers to transitional water to connate water in the deeper aquifers where the water has been out of contact with the atmosphere for the longest time.

There are several multiple well sites that do not follow the generalized trends discussed above. Wells L1977, L1965, and L731 (Plots No. 14, 18 and 20) are open to both zones of the sandstone aquifer. Therefore, the water samples obtained from these wells are a mix of water which may affect the analysis at sites 6, 8 and 9 (Figure 61). The trend between wells HE851, HE556, and HE555 (Plots No. 6, 7, and 8) is toward a sodium chloride water with increasing depth. Normally, this trend would indicate intrusion of sea water. However, since this site (No. 3, Figure 61) is located more than thirty miles from the sea, it is more likely that this trend is a result of incomplete flushing of sea water present in the sediments at the time of deposition. The variation between wells HE558 and HE557 (Plots No. 1 and 2) is very small as a result of both wells being contaminated by the same flowing Floridan Aquifer System well. The trend between wells HE554 and HE529 (Plots No. 9 and 10) is to water with increased alkalinity and decreasing relative concentrations of chlorides and sulfates with depth, indicating a tendency towards fresher water with depth. This could be a result of contamination of the water table aquifer through infiltration of poor quality water obtained from deeper aquifers for irrigation. The presence of many old Floridan aquifer irrigation wells throughout western Hendry County supports this hypothesis.

TABLE 2. DATA ON MULTIPLE AQUIFER SITES WATER QUALITY ANALYSIS

Site Number	Well Numbers	Aquifers	Classification of Water*
1	HE-558	Water Table	Connate
1	HE-557	Sandstone (Clastic)	Connate
2	HE-569	Water Table	Fresh Recharge
2	HE-560	Sandstone (Clastic)	Transitional Connate
2	HE-559	Sandstone (Carbonate)	Connate
3	HE-851	Water Table	Fresh Recharge
3	HE-556	Sandstone (Carbonate)	Transitional
3	HE-555	Mid-Hawthorn	Transitional/Lateral
4	HE-554	Water Table	Fresh Recharge
4	HE-529	Sandstone (Carbonate)	Fresh Recharge
5	L-1137	Water Table	Fresh Recharge
5	L-2187	Sandstone (Carbonate)	Transitional Connate
6	L-1978	Water Table	Fresh/Transitional
6	L-1977	Sandstone (Both)	Connate
7	L-1964	Water Table	Fresh Recharge
7	L-1963	Sandstone (Clastic)	Transitional Connate
8	L-1992	Water Table	Transitional
8	L-1965	Sandstone (Both Zones)	Fresh Recharge
9	L-1138	Water Table	Transitional/Fresh
9	L-731	Sandstone (Both Zones)	Transitional/Fresh
10	HY-308S	Water Table	Fresh Recharge
10	HY-308D	Lower Tamiami	Fresh Recharge

*After Frazee, 1982

Plot Number	Well Number
1	HE 558
2	HE 557
3	HE 569
4	HE 560
5	HE 559
6	HE 851
7	HE 556
8	HE 555
9	HE 554
10	HE 529
11	L 1137
12	L 2187
13	L 1978
14	L 1977
15	L 1964
16	L 1963
17	L 1992
18	L 1965
19	L 1138
20	L 731
21	HY 308S
22	HY 308D

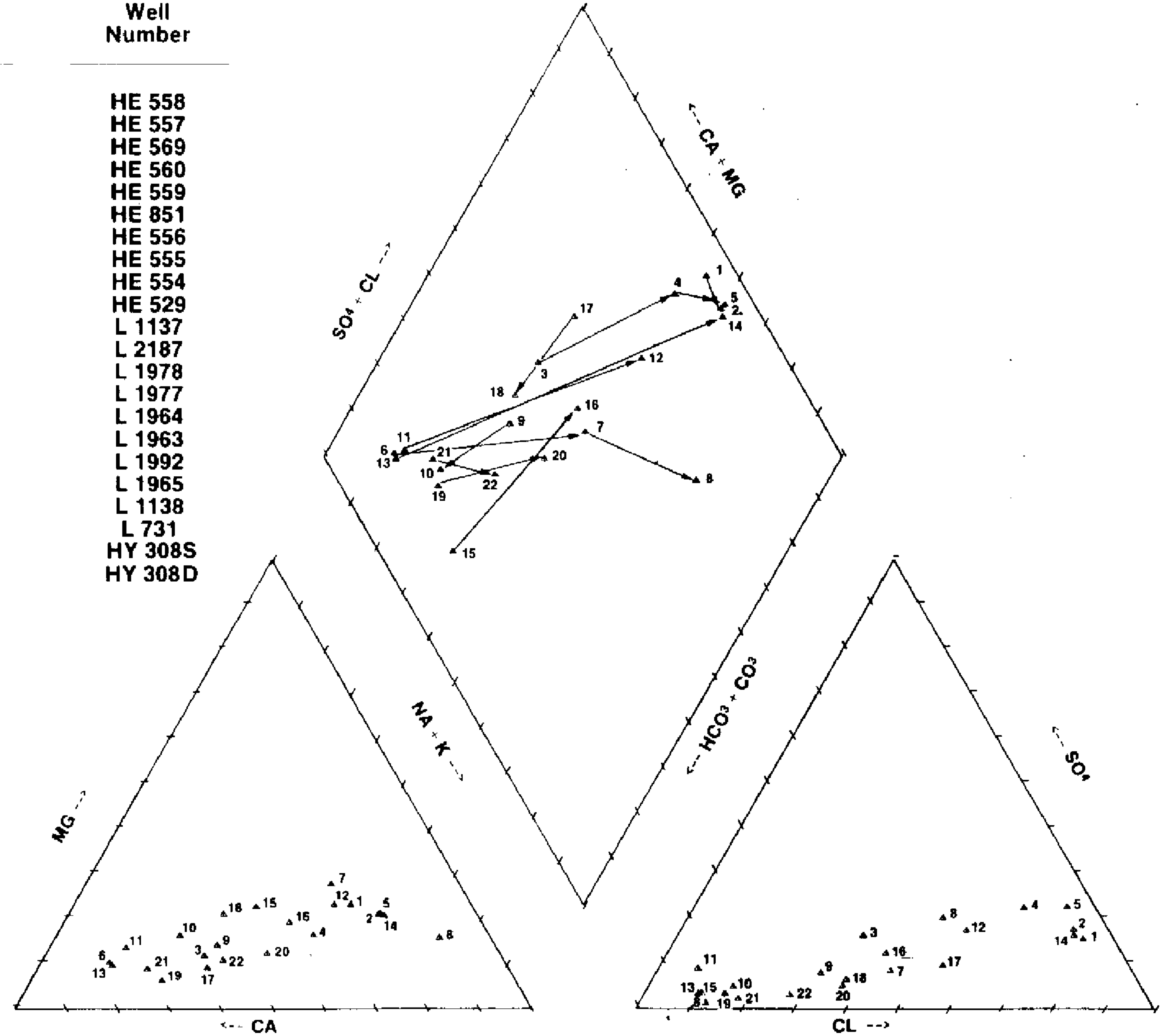


Figure 62 TRILINEAR DIAGRAM OF SAMPLES FROM MULTIPLE AQUIFER SITES

WATER USE

BACKGROUND INFORMATION

All water uses, with the exception of use by single family homes and duplexes, and water used strictly for fire-fighting purposes, require a water use permit from the SFWMD. There are two types of water use permits: individual and general. Individual permits are required if the average daily water use equals or exceeds 100,000 gallons. In addition, individual water use permits are required in Reduced Threshold Areas (RTA) if the average daily water use exceeds 10,000 gallons, or if the maximum daily water use exceeds 20,000 gallons. Figure 63 illustrates designated RTA's, which include an area of approximately 140 square miles in the northwest corner of Hendry County and the southwest corner of Glades County. All of Lee County is also designated as an RTA. General water use permits are required for all non-exempt uses with average daily uses less than 10,000 gallons per day in an RTA, or less than 100,000 gallons per day in the remainder of the District.

The duration of water use permits for agricultural irrigation, livestock use, and landscape irrigation are based on the expiration date of the hydrologic basin where the permit is located. Hendry County is located within two basins, and therefore permits have two expiration dates (see Figure 63). Permits in most of northern, western, and extreme eastern areas of the county expired on July 15, 1987. Permits reissued in this area have been given short term renewals (to October 15, 1991) in anticipation of the revision of the District's Basis of Review and development of Water Use Management Plans. Agricultural water use permits in the remainder of the county will expire on October 15, 1989. Public supply water use permits have durations of up to ten years. Permits for golf course irrigation can have durations of up to three years, not to exceed a basin expiration date.

Permitted water uses in Hendry County are grouped under six types. They are, in order of magnitude of total permitted allocation: agricultural irrigation, public supply, mining/dewatering, livestock, industrial, and landscape. Table 3 is a summary of the permitted water use in Hendry County in July 1986.

Land Use

Land use in Hendry County was investigated to determine present and future trends in water use. Currently, agriculture is the dominant land use in the county. Since most of the agricultural land is not located near surface water sources, growth in agriculture is expected to have a substantial effect on the ground water resources of the county. General assumptions regarding potential for agricultural development were applied to 1984 areal survey data to approximate future land use changes. This was undertaken to provide an estimate of future water use needs with respect to areal distribution. This information will be quantitatively evaluated in a later study to determine if growth of this magnitude would adversely impact the water resources of the county. The proposed land use changes are conceptual and do not represent any plans or commitments of the county or private landowners.

TABLE 3. SUMMARY OF PERMITTED WATER USE IN HENDRY COUNTY* (July 1986)

	Ground Water Use		Surface Water Use		Total Use	
Type of Use	MGM	(%)	MGM	(%)	MGM	(%)
Agricultural Irrigation	31,018.25	(99.2)	32,992.70	(99.9)	64,010.95	(99.5)
Public Supply	95.09	(0.3)	48.60	(0.1)	143.69	(0.2)
Mining/Dewatering	125.26	(0.4)	0	(0)	125.26	(0.2)
Livestock	12.81	(>0.1)	0	(0)	12.81	(>0.1)
Industrial	8.6	(>0.1)	0	(0)	8.6	(>0.1)
Landscape	0	(0)	7.3	(>0.1)	7.3	(>0.1)
Totals	31,260.01	(100)	33,048.60	(100)	64,308.61	(100)

MGM = Million Gallons Per Month
*Data assembled from SFWMD permit files.

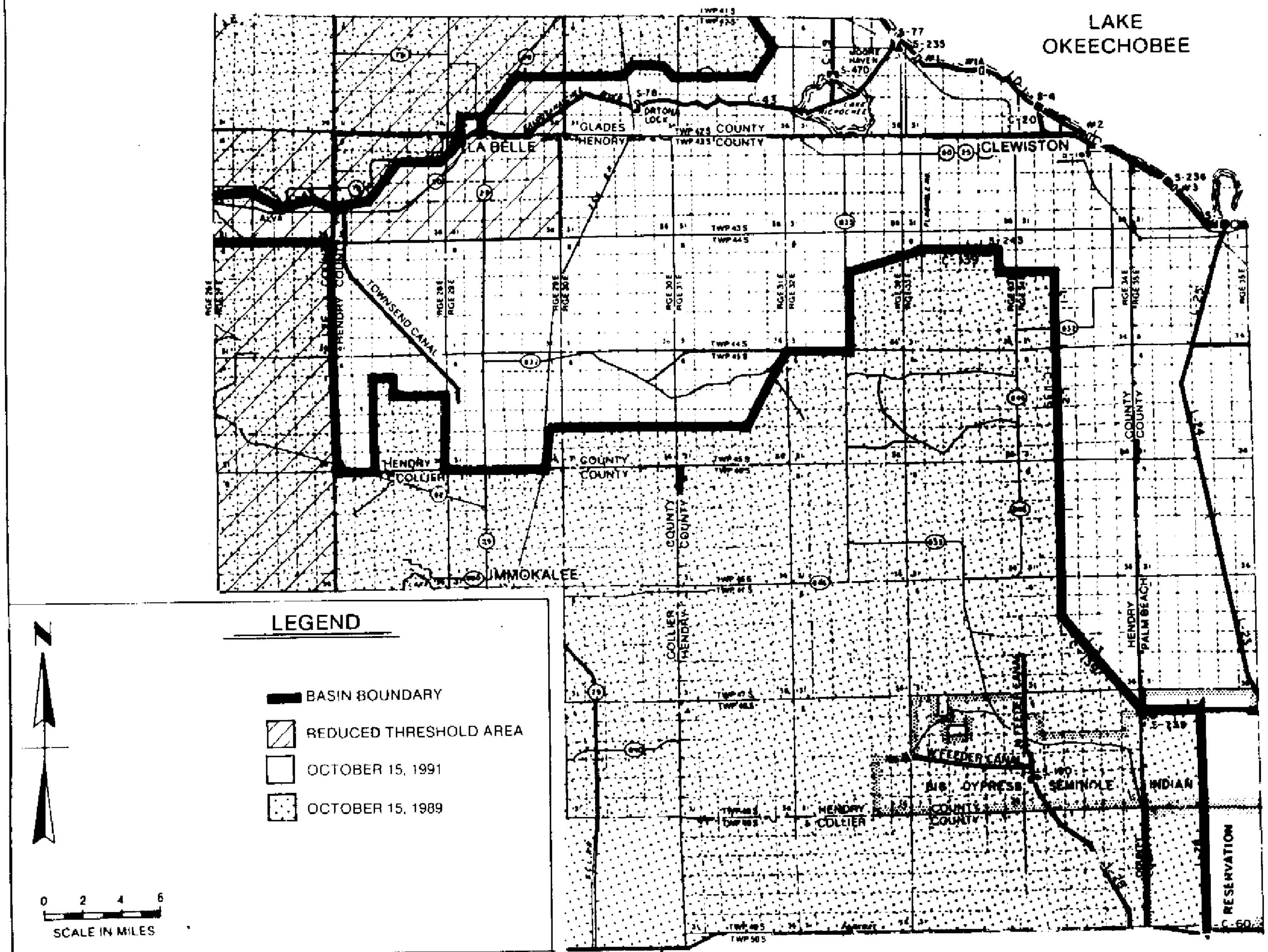


Figure 63 BASIN EXPIRATION DATES AND LOCATION OF REDUCED THRESHOLD AREAS

Land use classifications for this study were determined by examination of aerial photographs taken in 1984 at a scale of 1:24000. Each aerial photograph was divided into parcels, each corresponding to a section of land (approximately one square mile each). Each section was assigned one of the following land use types according to the dominant land use in the section: agriculture, wetlands, forest and range, and urban.

The examination of aerial photographs show that in 1984 50.8% of the land in the study area was used for agriculture. Approximately 47% of this agricultural land is in citrus production or currently being converted to citrus. Undeveloped wetlands make up 30.2% of the study area, while isolated areas of forest and range account for 14.1% of the study area. Urban lands comprise only 4.9% of the study area. The majority of the urban areas are concentrated near Lake Okeechobee and along the Caloosahatchee River.

The large amounts of forest and rangeland, combined with the temperate climate, make Hendry County very attractive for citrus development. It is estimated that since 1977 approximately 25% of the pasture, range, and forested uplands in the study area have been or are in the process of being converted into citrus groves (Ray Burgess, personal communication).

Figure 64 shows the potential for conversion of existing land uses to citrus production. This map was constructed using the same aerial photographs that were used to determine the land use in the study area. Every section of land in the study area was examined and assigned a conversion potential of high, low, or existing, based on the dominant land use in that section. Sections that consist mostly of rangeland, forested uplands, or pasture were assigned a high potential for conversion to citrus production. The sections designated as having a low potential for conversion to citrus consist mostly of wetlands, urban land, and developed agriculture such as sugar cane and vegetables. The areas designated as existing are citrus groves that appear on the aerial photographs, and those areas with a water use permit or permit application for citrus irrigation as of July 1986. Figure 64 shows that approximately 24% of the study area (47% of the developed agricultural land) is already in citrus production or planned for conversion in the near future. Thirty-seven percent of the study area has been assigned a high potential for conversion to citrus production, and 39% has been assigned a low potential for conversion. This does not mean that an area with a high potential for conversion will become citrus groves. If future economic, environmental and political conditions are such that Hendry County becomes (more) attractive to citrus production, the areas of high potential are more likely to be converted to citrus production than the areas of low potential.

Most of the land that would be converted to citrus production is currently rangeland, forested uplands, and pasture. Since none of this land is irrigated, conversion to citrus production would cause a substantial increase in water use. Much of the improved pasture in Hendry County has been allocated water in Consumptive Use Permits, although pasture irrigation seldom occurs. Therefore, permitted water use may not increase as much as actual water use, as a result of conversion to citrus production. If the growth of the citrus industry in Hendry County continues to increase at the current rate, by 1990 25 to 30% (approximately 71,000 acres) of the pasture, range, and forested uplands may be converted to citrus production. Using the modified Blaney-Criddle formula (USDA, 1970) to calculate the supplemental irrigation requirement for citrus, an increase of 46.8 billion gallons in the county's annual water use would result. This represents a 42.1% increase over the 1986 permitted water use. Since much of the land that has a high potential for citrus development is not located near surface water, the calculated increase in water use may put the ground water system under stress in localized areas. As previously discussed, some of the ground water in southeastern Hendry County flows into Lee and Collier Counties. Therefore, stress in the recharge areas in Hendry County may affect water levels in Lee and Collier Counties.

Agricultural Irrigation

Agricultural water use accounts for 99.5% of the total permitted water use in Hendry County in 1986. The water use is divided almost evenly between surface water withdrawals (51.5%) and ground water withdrawals (48.5%). The ground water withdrawals are dispersed throughout the county. Surface water withdrawals are concentrated in three areas: the Everglades Agricultural Area, which includes the extreme eastern portion of Hendry County; the area adjacent to the Caloosahatchee River in northern Hendry County, and the area adjacent to the Townsend and Roberts canals in western Hendry County. Ground water use is addressed in this section.

In July 1986 there were 92 agricultural ground water use permits. These permits represented 81,799 acres of pasture, 42,388 acres of citrus, and 33,027 acres of vegetables and other crops, for a total of 157,214 acres under cultivation or planned for cultivation during the duration of the permits. This translates to permitted agricultural ground water use of 81.311 billion gallons per year. Table 4 shows all

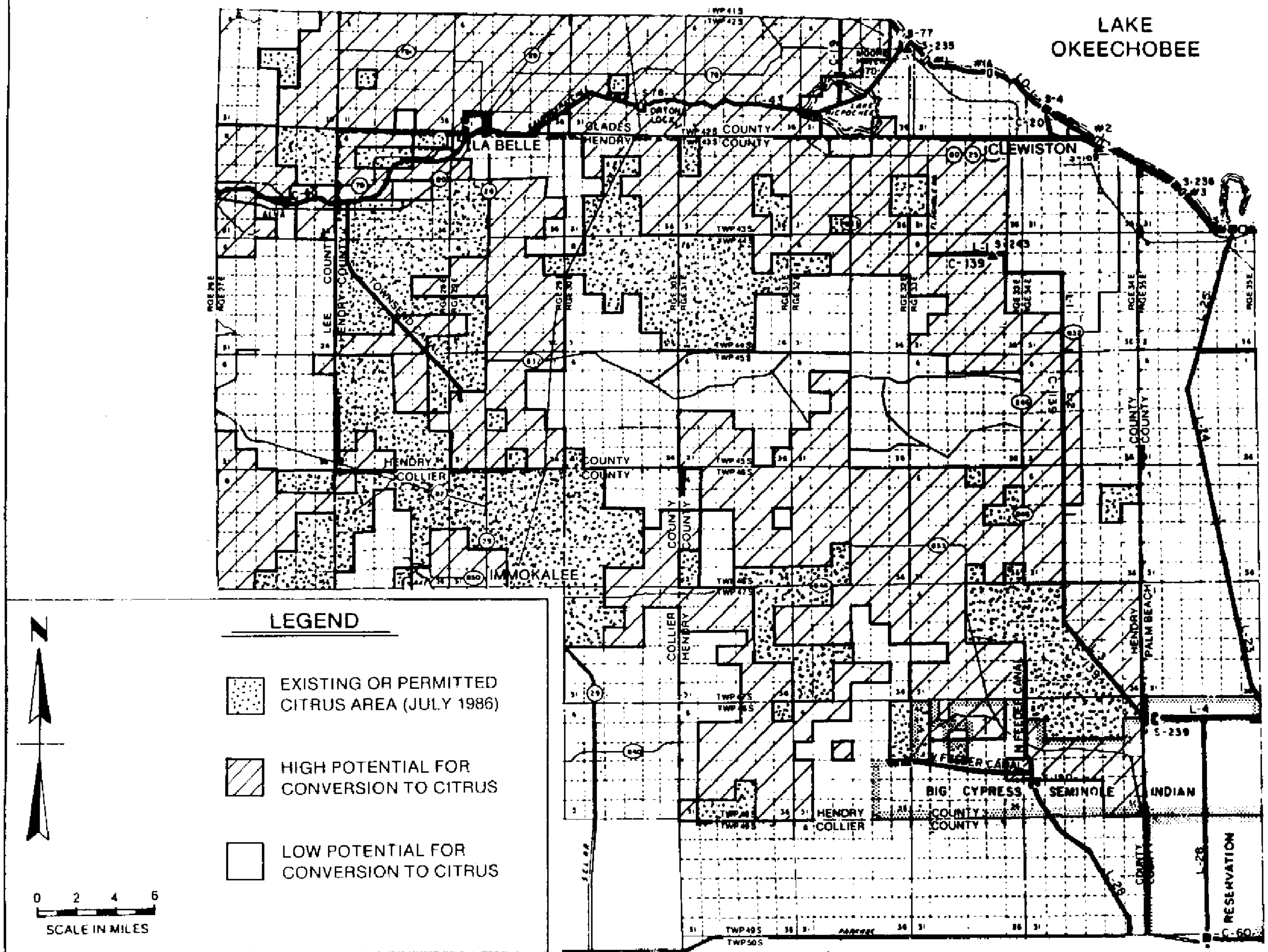


Figure 64 POTENTIAL FOR CONVERSION TO CITRUS PRODUCTION

TABLE 4. AGRICULTURAL GROUND WATER PERMITS OVER ONE BILLION GALLONS PER YEAR (July 1986)*

Annual Allocation (mg)	Source	Permittee	Permit Number
7042	Tamiami	Zipperer Farms, Inc.	26-000143
6888	Tamiami	R. McDaniels, Sr.	26-00087
6118	Tamiami	U. S. Sugar, Corp.	26-00094
5051	Tamiami/Water Table	Alico, Inc.	26-00108
3780	Tamiami/Water Table	RIMB	26-00107
3780	Tamiami/Water Table	Barron Collier III Trust	26-00112
2773	Tamiami	Joe M. Hilliard	26-00020
2499	Tamiami	Evelyn Jackson & Sons	26-00115
2412	Sandstone	CPI, Inc.	26-00159
1114	Tamiami	Joe M. Hilliard	26-00072
1000	Tamiami	Reynolds & Thomas, Inc.	26-00023

mg = million gallons
*Data assembled from SFWMD permit files.

agricultural users of ground water with allocations in excess of one billion gallons per year. The eleven permits included in Table 4 account for 57.6% of the total agricultural ground water use in the county. Several of these permits have undergone revisions since July 1986, so current permitted water use may differ from the values presented in the table.

Estimates of monthly water use in 1986 were made using the modified Blaney-Criddle formula. Peak monthly withdrawals occur in January (3.1 billion gallons) when vegetables are irrigated and May (5.25 billion gallons) when citrus irrigation is at its peak. These figures are less than the permitted monthly amounts because irrigation of pasture was not included. Pasture in Hendry County is generally not irrigated, although it is included in many water use permit allocations.

Leach (1983) estimated water use throughout Florida by selectively metering different water uses. Estimated average ground water withdrawals for irrigation in Hendry County was 109.59 million gallons per day (MGD). Monthly withdrawals for agricultural use of ground water and surface water are shown in Table 5. This data shows that 66% of the agricultural water use occurs during the months of March, April, and May. Most of the ground water use occurs in south central Hendry County and is obtained from the lower Tamiami Aquifer, or in the western areas of the county from the Sandstone aquifer.

It is important to note that permitted water use differs from actual water use. The major reason for the difference is that in most cases the allocation of water is based on the maximum monthly irrigation requirement based on the driest month of a drought that occurs statistically twice in a given ten year period. Because of the seasonal nature of rainfall in Florida, actual use approaches the amount allocated only during the driest months of the year. In addition, many crops are not planted in a given year, which also causes the actual water use to be lower. Many water use permits are issued for projects which are proposed or under construction, so the actual water use may not begin until several years after the permit was issued. Finally, different methods of calculating water use have been employed over the years resulting in different allocations.

Public Water Supply

While public water supply is the second largest use category in Hendry County, it represents only 0.2% of the total water use and 0.3% of the ground water use (see Table 3). There are five permitted public water supply users in the county, and their uses are summarized in Table 6. In addition, Lee County South, the city of Immokalee, Florida Cities, Green Meadows, Lehigh Acres, and the city of Moore Haven operate public supply wellfields within the study area. Figure 65 shows the locations of all the public water supply wellfields within the study area.

TABLE 5. ESTIMATED IRRIGATION WATER USE IN HENDRY COUNTY, 1980 (LEACH 1983)

	Ground Water (MGD)	Surface Water (MGD)
January	40.143	49.579
February	89.838	109.801
March	286.246	349.856
April	296.956	362.946
May	286.352	349.986
June	55.860	68.274
July	30.004	36.671
August	19.530	23.870
September	17.497	21.265
October	98.850	120.817
November	46.727	57.111
December	46.751	57.140
Total (MGD)	**1314.78**	**1607.32**

MGD = Million Gallons Per Day

Permitted allocations for public water supply in Hendry County totaled 4.7 MGD in July 1986. Of this total, 1.62 MGD was allocated from ground water sources, and 3.08 MGD was allocated from surface water. Leach estimated the 1980 public water usage in Hendry County to be 2.0 MGD or 152 gallons per capita per day. Ground water use accounted for 0.38 MGD, the rest is withdrawn from Lake Okeechobee by Clewiston and U. S. Sugar Corporation. The discrepancy between permitted allocations and actual use is due to the fact that the public water supply allocation is based on projections of future populations, so the allocation may exceed the actual use in the early years of the permit.

In addition to public water supply, many homes in rural areas obtain their potable water from individual wells completed in the water table or lower Tamiami aquifers. Leach estimated water withdrawn for this rural self-supplied use to be 0.84 MGD in 1980. This figure includes water used for watering livestock as well.

Leach (1984) projected public water use and rural self-supplied water use for Florida through the year 2020. Projections for Hendry County are summarized in Table 7. Projected public water supply and rural self-supplied water use in 2020 represent a 115% increase from 1980.

Other Water Uses

There are several other types of water uses scattered throughout the county that taken together account for approximately 0.3% of the total water use in Hendry County. For example, there are several small sand and gravel operations that dewater their pits to facilitate removal of material. In addition, U. S. Sugar Corporation has a back-up wellfield in

TABLE 6. PUBLIC WATER SUPPLY PERMITS IN HENDRY COUNTY* (JULY 1986)

Annual Allocation (mg)	Source	Permittee	Permit Number
1180.00	Lake Okeechobee/ Water Table	U. S. Sugar Corp./ Clewiston	26-00024
280.00	Water Table	La Belle	26-000105
158.00	Sandstone	Port La Belle	26-00096
123.81	Tamiami	Hendry Co. Dept. of Corrections	26-000164
6.32	Water Table	M. J. Borgess, Jr.	26-00167

mg = million gallons
*Data assembled from SFWMD permit files.

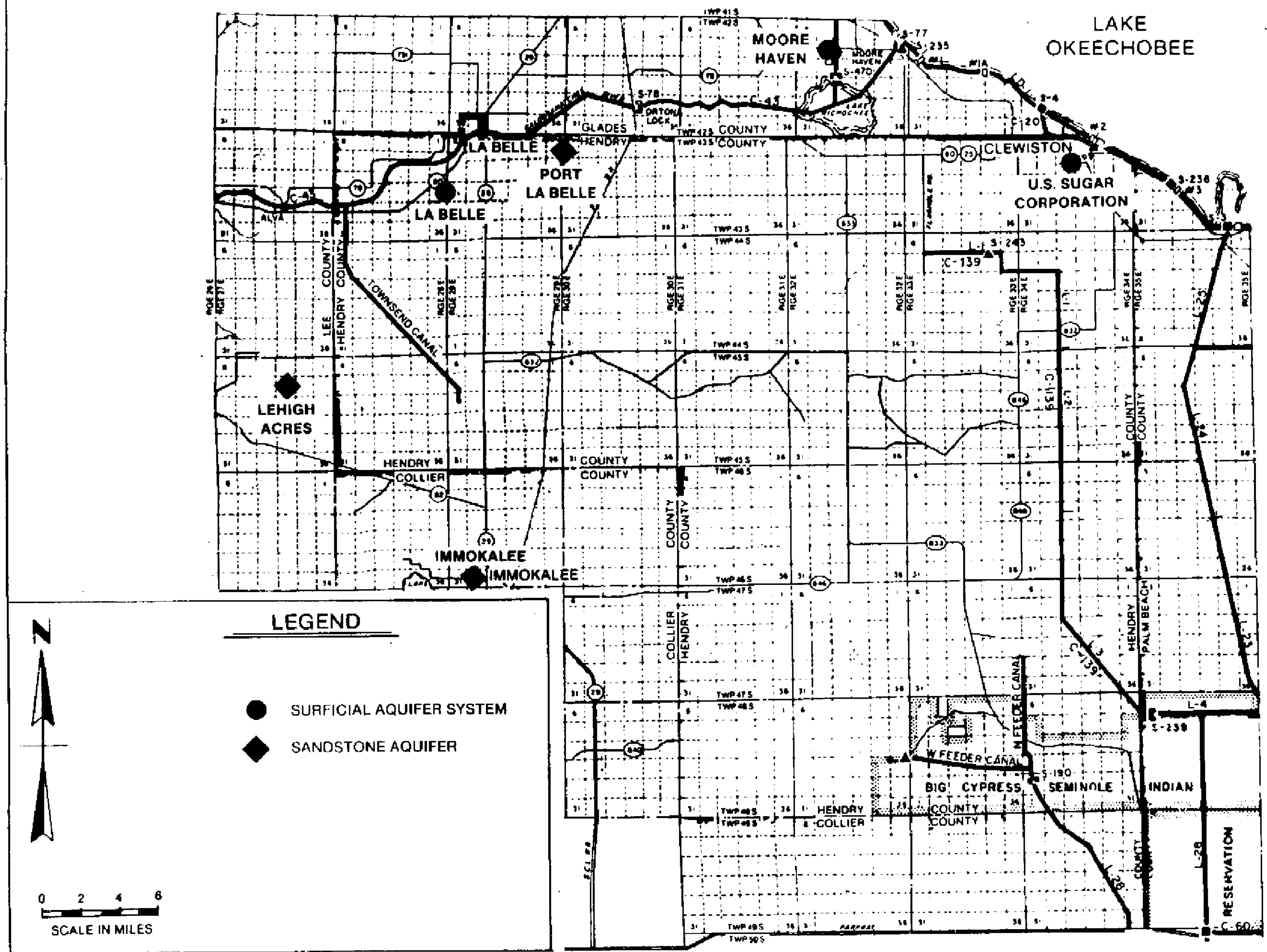


Figure 65 LOCATION OF PUBLIC SUPPLY WELLFIELDS WITHIN THE STUDY AREA

TABLE 7. PROJECTED PUBLIC WATER SUPPLY AND RURAL SELF-SUPPLIED WATER USE IN HENDRY COUNTY (from Leach 1984)

	1980	2000	2020
Population	18,600	31,500	40,000
Public Water Supply (MGD)	2.00	3.39	4.30
Rural Self-Supplied (MGD)*	2.50	4.23	5.38
Total (MGD)	4.50	7.62	9.68

MGD = Million Gallons Per Day
*Includes livestock use

Clewiston to supply water for emergency use. Finally, there are several small plant nurseries that withdraw surface water for irrigation.

Seminole Indian Compact

An agreement between the SFWMD, the State of Florida, and the Seminole Indians was approved by the District's Governing Board on May 15, 1987. The purpose of this agreement is to settle issues that have been disputed for the last 100 years and to bring the Big Cypress, Brighton, and Hollywood reservations into the State's water management system. It also addresses the tribe's water needs in order to sustain development on the three reservations. Since the Big Cypress Reservation is located in an area of rapid agricultural development in southern Hendry County, this agreement is critical to the management of the water resources of the area.

FUTURE GROUND WATER POTENTIAL

BACKGROUND INFORMATION

The results obtained from exploratory drilling and aquifer testing were analyzed to determine future ground water potential under specified criteria. Water quality, aquifer characteristics, and aquifer thickness (in areas where no pump test data were available) were used to determine future ground water development potential in Hendry County. Permitted water use was then added to indicate areas where the resource is partially or highly developed. With the development of a three-dimensional flow model planned for the next phase of this study, water managers can more accurately assess the amount of available ground water resources in Hendry County. This discussion is presented as a preliminary assessment of the ground water development potential.

There are very few localized areas where water quality is a limiting factor to ground water potential. Recommended water quality standards for irrigation water were used to determine potential use, since irrigation accounts for 99% of the permitted ground water use in Hendry County. Development potential based on chloride concentrations was classified as follows: less than 250 mg/l (good), between 250 mg/l to 800 mg/l (moderate), and greater than 800 mg/l (poor). The recommended maximum chloride concentration in waters applied for citrus irrigation is 800 mg/l (USDA, 1982). High chloride water in Hendry County is the result of upward migration of highly saline water from the Floridan Aquifer System through improperly constructed wells or from localized areas of relict seawater. High iron concentrations inhibit the use of drip irrigation systems because iron bacteria clogs the emitters. Calcium hardness also clogs emitters when fertilizer added to the water causes the calcium to precipitate. There are many water quality parameters to check when determining the ground water potential for a public water supply site and some are listed in Table 1 in the water quality section.

Transmissivity, aquifer storage, and leakance were evaluated to determine relative aquifer yield. The SFWMD conducted 15 aquifer performance tests in the study area. Data was also collected from previous reports by the United States Geological Survey and private consultants. Regionalization of aquifer parameters is beyond the scope of this study. However, this process will be incorporated during the development of a three-dimensional flow model which is planned as the next phase of the study.

Transmissivity values were categorized as follows: ranges of values over 100,000 gpd/ft were considered as good yield potential; 20,000 to 100,000 gpd/ft were considered moderate; and less than 20,000 gpd/ft were considered poor development potential. In areas lacking data on aquifer characteristics, potential was evaluated as follows: if the aquifer was less than 20 feet thick or contained more than 10 percent silt or clay, it was considered to have poor yield potential.

The Surficial Aquifer System in the northwest portion of the study area has not been tested because of the prevailing use of the sandstone aquifer throughout this region. Therefore, in this area, ground water development potential for the Surficial Aquifer System is only predicted by variations in aquifer lithology and thickness.

AVAILABILITY OF WATER FROM THE SURFICIAL AQUIFER SYSTEM

Aquifer Characteristics

Hydraulic characteristics of the Surficial Aquifer System are presented in Table 8. Locations of the aquifer test sites are shown in Figure 66. Tests of the lower Tamiami aquifer comprise the majority of available information. Transmissivity values range from 50,000 gallons per day/ft (gpd/ft) southwest of Clewiston to 1,000,000 gpd/ft near the Hendry-Collier county line, east of Immokalee. Transmissivity decreases to the north as the aquifer becomes more clastic with increasing clay content. Site #2 on County Highway 832 is in a thick sequence of clean, coarse sand which yielded a transmissivity of 850,000 gpd/ft. This cannot be considered indicative of regional values because the areal extent of this clean sand unit is not known.

While transmissivity values indicate the rate at which water can be transmitted through an aquifer, storage values are an indication of the amount of water stored in an aquifer (Fetter, 1980). Storage values in the Surficial Aquifer System in Hendry County range from 10^{-5} to 10^{-3}, while the majority of the values are 10^{-4}.

Leakance indicates how much water moves into the pumped aquifer from adjoining beds. Values of leakance for the Surficial Aquifer System in Hendry County range from 10^{-6} to 10^{-1} gallons per day per foot (gpd/ft^3). In southern Hendry County, leakance is high (10^{-3} to 10^{-2} gpd/ft^3), indicating a lesser degree of

MAP #	LAND OWNER	SOURCE	AQUIFER	S/T/R	DATE OF TEST	PUMPED WELL #	OBSERV. WELL #	PROD. WELL CASED/TOTAL	OBS. WELL CASED/TOTAL	DISTANCE r (FT)	PUMP RATE (GPM)	HOURS PUMPED	MAXIMUM DRAWDOWN	TRANSMISSIVITY (GPD/FT)	STORAGE	LEAKANCE (GPD/FT3)	ANALYSIS METHOD
1	J. J. Wiggins	U.S.G.S.	unknown	1/42/31	8-14-58	GL-260	GL-258	-/80	-/73	3200	340	11.5	0.51	115,000	2.95E-04	1.65E-07 *	Cooper
1							GL-259		-/82	855			1.57	105,000	2.06E-04	1.31E-07 *	Cooper
2	Alico (Site A)	S.F.W.M.D.	lower Tamiami	12/45/30	1-25-88	HE-1023	HE-1025 (1I)	97/187	20/60	200.8	1171	71.5	1.80	849,283	1.24E-03		Cooper
2							HE-1026 (1D)		92/182	202.6			1.96	919,087	3.60E-04		Cooper
2							HE-1028 (2I)		20/60	101.7			1.85	849,283	5.49E-03		Cooper
2							HE-1029 (2D)		92/182	99.75			2.27	938,368	1.31E-04		Cooper
3	Alico	U.S.G.S.	water table	19/45/31	7-30-58	HE-320	HE 322	-/34	-/34	165	700	23	3.67	100,000	1.39E-03	4.89E-06 *	Cooper
3							HE-323		-/23	2400			0.66	140,000	9.26E-04	1.44E-06 *	Cooper
4	Alico (Site B)	S.F.W.M.D.	lower Tamiami	19/45/32	8-31-87	HY-206	1-D	80/100	80/100	74.5	227	66	2.00	104,888	6.60E-04	7.55E-03	Cooper
4							2-D		80/100	151			2.48	72,256	1.06E-04	5.07E-03	Cooper
5	Alico	U.S.G.S.	lower Tamiami	14/45/32	6-26-58	HE-300	HE-299	-/97	-/72	615	840	24	3.05	110,000	2.73E-04	1.08E-06 *	Cooper
5							HE-301		-/98	2300			1.12	120,000	2.30E-04	1.03E-06 *	Cooper
6	Alico (Site C)	S.F.W.M.D.	lower Tamiami	30/45/33	8-17-87	HE-1035	HE-1037 (1D)	70/120	70/120	104.5	343	70	1.64	238,211	9.00E-05	2.21E-05	Cooper
6							HE-1039 (2D)		70/120	195			1.52	245,655	1.90E-05	6.43E-06	Cooper
6							HE-1040 (3D)		40/80	47.25			1.94	280,749	6.52E-05	1.26E-04	Cooper
7	E. C. Mills	S.F.W.M.D.	lower Tamiami	10/44/33	10-19-87	HE-1068	HE-1071 (1D)	60/160	60/160	76.25	234	72	2.61	43,249	7.17E-05	1.19E+00	Cooper
7							HE-1073 (2D)		60/160	150			2.05	68,755	7.04E-04	3.05E-02	Cooper
8	Collier Corp.	U.S.G.S.	water table	6/47/31	6-17-58	HE-286	HE-285	-/40	-/40	1380	1300	25	0.63	935,000	2.98E-04	2.33E-07 *	Cooper
8							HE-287		-/51	3220			0.40	1,070,000	1.98E-04	5.47E-07 *	Cooper
8							HE-288		-/40	3580			0.32	995,000	2.73E-04	1.08E-06 *	Cooper
8							HE-306		-/41	140			1.28	935,000	4.16E-04	2.05E-06 *	Cooper
8							C-131		-/54	2750			0.41	995,000	2.76E-04	1.10E-06 *	Cooper
8							C-165		-/51	5550			0.21	830,000	3.85E-04	1.60E-06 *	Cooper
9	Barron Collier	S.F.W.M.D.	lower Tamiami	26/47/31	5-18-87	HE-1041	HE-1042 (1D)	40/80	40/80	76.6	760	72	1.99	455,966	2.10E-04	9.72E-03	Cooper
9							HE-1045 (2D)		40/80	200.8			1.64	458,366	1.20E-04	1.05E-02	Cooper
10	Collier Corp.	U.S.G.S.	lower Tamiami	31/46/32	6-18-58	HE-289	HE-290	-/70	-/80	1800	1570	14	1.41	500,000	1.63E-04	2.80E-07 *	Cooper
10							HE-291		-/92	2300			1.21	515,000	1.49E-04	3.60E-07 *	Cooper
11	US Sugar Corp.	Missimer	lower Tamiami	34/46/32	2-10-87	H-M-310	H-M-311	65/105	65/110	200	882	72	1.58	610,000	6.00E-05	1.40E-02	Hantush-Jacob
11	(Rogers Ranch)						H-M-312		65/110	600			0.99	580,000	1.50E-04	4.10E-02	Hantush-Jacob
11							H-M-319		50/79	830			0.79	485,000	1.60E-04	6.00E-02	Hantush-Jacob
11							H-M-320		41/66	2200			0.38	780,000	2.50E-04	3.20E-02	Hantush-Jacob
12	Carl Gallagher	S.F.W.M.D.	lower Tamiami	14/47/32	2-27-87	HE-1054	HE-1057 (1D)	70/100	70/100	100.5	869	72.5	0.88	748,718	3.29E-04	1.19E-01	Cooper
12							HE-1058 (2D)		70/100	54.5			1.09	663,867	7.13E-04	3.57E-01	Cooper
12							HE-1056 (3D)		70/100	250.9			0.83	659,470	2.12E-04	1.05E-01	Cooper
13	Robert McDaniels	HydroDesigns	lower Tamiami	21/47/33	4-17-86	PW	Obs.	60/118	52/62	206.1	765	68	1.25	461,000	2.10E-04	1.70E-02	Hantush
14	S & M Farms	U.S.G.S.		18/47/34	6-3-58	HE-303	HE-302	-/120	-/121	600	1400	43	3.30	230,000	6.00E-04	5.90E-07 *	Cooper
14							HE-304		-/122	1415			2.68	265,000	2.97E-04	1.23E-07 *	Cooper
15	US Sugar Corp.	Missimer	lower Tamiami	5/47/34	2-27-86	H-M-235	H-M-231	65/125	67/129	197	754	72	5.89	105,000	3.70E-04	1.10E-03	Hantush-Jacob
15	(So. Div. Ranch)						H-M-236		65/130	497			4.46	96,000	3.90E-04	2.50E-03	Hantush-Jacob
15							H-M-237		65/126	997			2.98	105,000	5.00E-04	1.10E-03	Hantush-Jacob
15							H-M-241		-/112	1278			2.39	123,000	6.00E-04	1.10E-03	Hantush-Jacob

* USGS leakage coefficient values listed as gpd/ft2 (K'), confining zone thickness (b') not available

Table 8 AQUIFER PARAMETERS FOR THE SURFICIAL AQUIFER SYSTEM

MAP #	LAND OWNER	SOURCE	AQUIFER	S/T/R	DATE OF TEST	PUMPED WELL #	OBSERV. WELL #	PROD. WELL CASED/TOTAL	OBS. WELL CASED/TOTAL	DISTANCE r (FT)	PUMP RATE (GPM)	HOURS PUMPED	MAXIMUM DRAWDOWN	TRANSMISSIVITY (GPD/FT)	STORAGE	LEAKANCE (GPD/FT3)	ANALYSIS METHOD
16	US Sugar Corp.	Missimer	lower Tamiami	29/47/31	11-6-86	H-M-301	H-M-302	76/124	77/140	127	831	72	2.82	320,000	3.40E-04	1.30E-04	Hantush-Jacob
16	(So. Div. Ranch)						H-M-303		77/140	397			2.17	330,000	2.60E-04	1.00E-04	Hantush-Jacob
16							H-M-309		77/120	1540			1.43	330,000	8.00E-04	1.40E-03	Hantush-Jacob
17	US Sugar Corp.	Missimer	lower Tamiami	9/48/31	4-17-87	H-M-328	H-M-329	75/133	75/95	420	508	71	0.94	490,000	2.60E-04	2.50E-03	Hantush-Jacob
17	(So. Div. Ranch)						H-M-330		-/126	865			0.67	520,000	2.40E-04	3.40E-03	Hantush-Jacob
17							H-M-331		75/95	1200			0.65	430,000	3.30E-04	4.30E-03	Hantush-Jacob
18	Seminole Tribe	Murray-Milleson	lower Tamiami	14/48/34	5-24-87	PW	OB 1	63/120	63/120	50	197	12	0.49	501,700	3.60E-04	3.20E-03	Glover
18							OB 2		70/120	100			0.42	537,529	4.20E-04	1.90E-03	Glover
18							OB 3		75/126	240			0.33	520,080	4.60E-04		Jacob
19	Seminole Tribe	S.F.W.M.D.	lower Tamiami	3/48/33	2-9-87	HY-310	1-D	50/135	50/135	194.5	641	44	1.1	419,733	2.20E-04	1.79E-02	Cooper
19							2-D		50/135	49			1.59	412,658	2.42E-04	1.72E-02	Cooper
19							3-D		50/135	99.2			1.37	453,415	2.86E-04	1.85E-02	Cooper
20	Seminole Tribe	S.F.W.M.D.	lower Tamiami	23/48/32	3-16-87	HE-1061	HE-1063 (1D)	78/123	78/123	51.65	298	70.6	1.03	330,024	4.08E-04	1.98E-03	Cooper
20							HE-1065 (2D)		78/123	200.25			0.86	373,668	1.30E-04	9.35E-04	Cooper
20							HE-1067 (3D)		78/123	77.1			0.97	390,653	1.96E-04	1.05E-03	Cooper
21	Hendry Corr. Inst.	Leggette, Brashears	lower Tamiami	18/48/31	10-14-83	12	11	97/125	107/140	400	100	48	0.89	155,300	2.00E-06		Jacob
21							13		97/125	400			0.59	178,400	5.58E-05		Jacob
21							14		97/125	800			0.45	147,500	2.26E-04		Jacob
22	Collier Enterprises	Murray-Milleson	lower Tamiami	34/46/29	7-12-86	PWs	MW1	0-40,80-100c	42/84	75	400	23	4.73	21,828			Hantush-Jacob
22	(Gopher Ridge)						MW2	40-80,100-150s	100/150	275			2.59	104,182	3.50E-04	4.00E-03	Hantush-Jacob
23	Collier Enterprises	Murray-Milleson	lower Tamiami	5/47/32	3-14-88	TPW	OBS 1	65/105	65/105	108	2350	70.5	3.45	769,457	1.20E-04	2.60E-02	Cooper
23	(Crow's Nest South)						OBS 2		65/90	620			2.27	673,275	2.00E-04	7.00E-02	Cooper
23							OBS 3		65/105	1215			1.98	1,035,808	1.70E-04	7.00E-03	Cooper
24	Williams Farm	Murray-Milleson	water table	6/47/29	10-29-86	TPW	OB#1	28/28	26/26	250	510	32	1.87	171,900			Walton
24							OB#2		27/27	700			1.05	177,109			Walton
24							OB#3		25/25	250			1.46	162,350			Walton
25	Alban-Gould	Murray-Milleson	water table	28/42/28	1-20-87	TPW	OB #1	13/32	11/27	100	180	64	5.32	14,734	1.59E-01		Walton
25							OB #2		12/27	300			2.99	14,734	5.35E-02		Walton
25							OB #3		13/45	100			4.29	18,752	5.57E-02		Walton

Table 8 (Continued) **AQUIFER PARAMETERS FOR THE SURFICIAL AQUIFER SYSTEM**

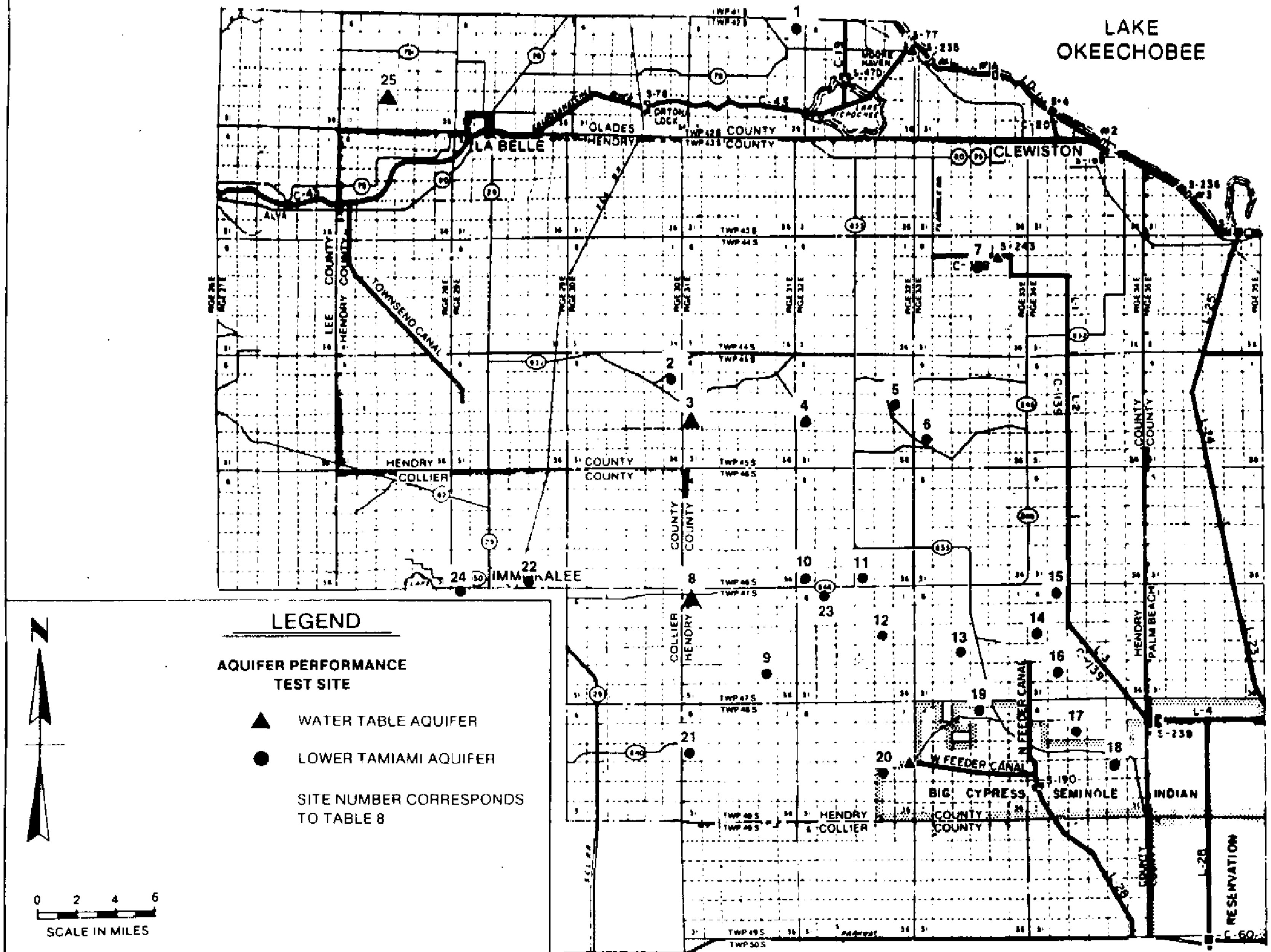


Figure 66 AQUIFER PERFORMANCE TEST LOCATIONS FOR THE SURFICIAL AQUIFER SYSTEM

confinement between the lower Tamiami aquifer and the overlying water table aquifer. Leakance values are lower in central Hendry County where the confining unit contains more clay.

Potential for Water Supply

Because of the limited data on the water table aquifer alone, the ground water potential was determined for the entire Surficial Aquifer System. Figure 67 displays the assessment of the development potential for the Surficial Aquifer System.

Water quality is generally good throughout the Surficial Aquifer System. Chloride concentrations are less than the drinking water standard of 250 mg/l, except for an isolated area west of LaBelle. Chloride concentrations in that area approach 1000 mg/l, due to saltwater contamination from upward migration of poor quality water through improperly constructed wells drilled into the Floridan Aquifer System. The concentrations of most other dissolved ions also meet drinking water standards, except for a few isolated spots with high iron concentrations. Color exceeds standards in almost all of Hendry County, which is a consideration for locating future potable supplies. The possibility of pesticides and fertilizers entering the aquifer exists in the vicinity of agricultural properties and landfills.

Southern Hendry County (designated as Region I, Figure 67) has the best potential for development. Transmissivity values are high and water quality is good. Large portions of this area are currently being developed for citrus. There are several areas where current allocations exceed one billion gallons per year per nine square mile area. These are indicated by dark shading. No quantitative attempt was made in this phase of the study to determine the potential of further development in these agricultural areas.

Region II is considered a zone of moderate development potential (Figure 67). This region includes transmissivity values in the 20,000 to 100,000 gpd/ft range. This range is considered adequate for small to moderate agricultural development and small public water supplies.

The northeast portion of Hendry County currently uses surface water supplied by the Caloosahatchee River for irrigation needs. However, Fan and Burgess (1983), in their study of surface water availability in the Caloosahatchee Basin, concluded that "with the present structural configuration, the surface water resource... has been developed to it's maxi-mum capacity." This area was given low priority when deciding the location of pump tests to be performed by the SFWMD due to current surface water usage. This resulted in a lack of aquifer characteristics in the area. Consequently, inclusion of this area into Region II is subjective and is based on the fact that there are limited ground water withdrawals in this area for agriculture. Recognizing limitations of the Caloosahatchee River for future supply, additional development may place greater demands on ground water as an alternative source. Prior to allocating large volumes of ground water in this area, it would be advisable to require pumping tests to determine aquifer characteristics.

Region III denotes an area of poor development potential (see Figure 67). This is mainly due to poor water quality and thin or non-existent water producing units which occur within the Surficial Aquifer System. The ground water in the area around the Caloosahatchee River contains chloride concentrations of 1000 mg/l. The lower Tamiami aquifer pinches out in this area and the water table aquifer consists of silty and clayey sand and shell beds yielding low volumes of water. Water for large scale uses is supplied mainly by the Caloosahatchee River and associated tributaries. While Region III is denoted as an area of poor potential, small scale withdrawals (less than 100 gallons per minute) in most areas should yield acceptable water quality and quantity to meet demands. However, each withdrawal in Region III should be evaluated on a case by case basis to determine impacts on adjacent users.

AVAILABILITY OF WATER FROM THE INTERMEDIATE AQUIFER SYSTEM

Aquifer Characteristics

Hydraulic characteristics of the Intermediate Aquifer System are presented in Table 9 and the aquifer test locations are shown in Figure 68. Within the study area there are three aquifers in the Intermediate Aquifer System. They are the sandstone aquifer, containing both clastic and carbonate facies, an unnamed white limestone aquifer in the northwest corner of the study area and the mid-Hawthorn aquifer.

As previously discussed, it is unknown at this time if the unnamed aquifer is a continuation of the sandstone aquifer or a separate localized unit within the Intermediate Aquifer System. Further studies in Glades and Charlotte counties are needed to resolve this issue.

Transmissivities determined from seven aquifer tests within the clastic zone of the sandstone aquifer range from less than 10,000 to 30,000 gpd/ft,

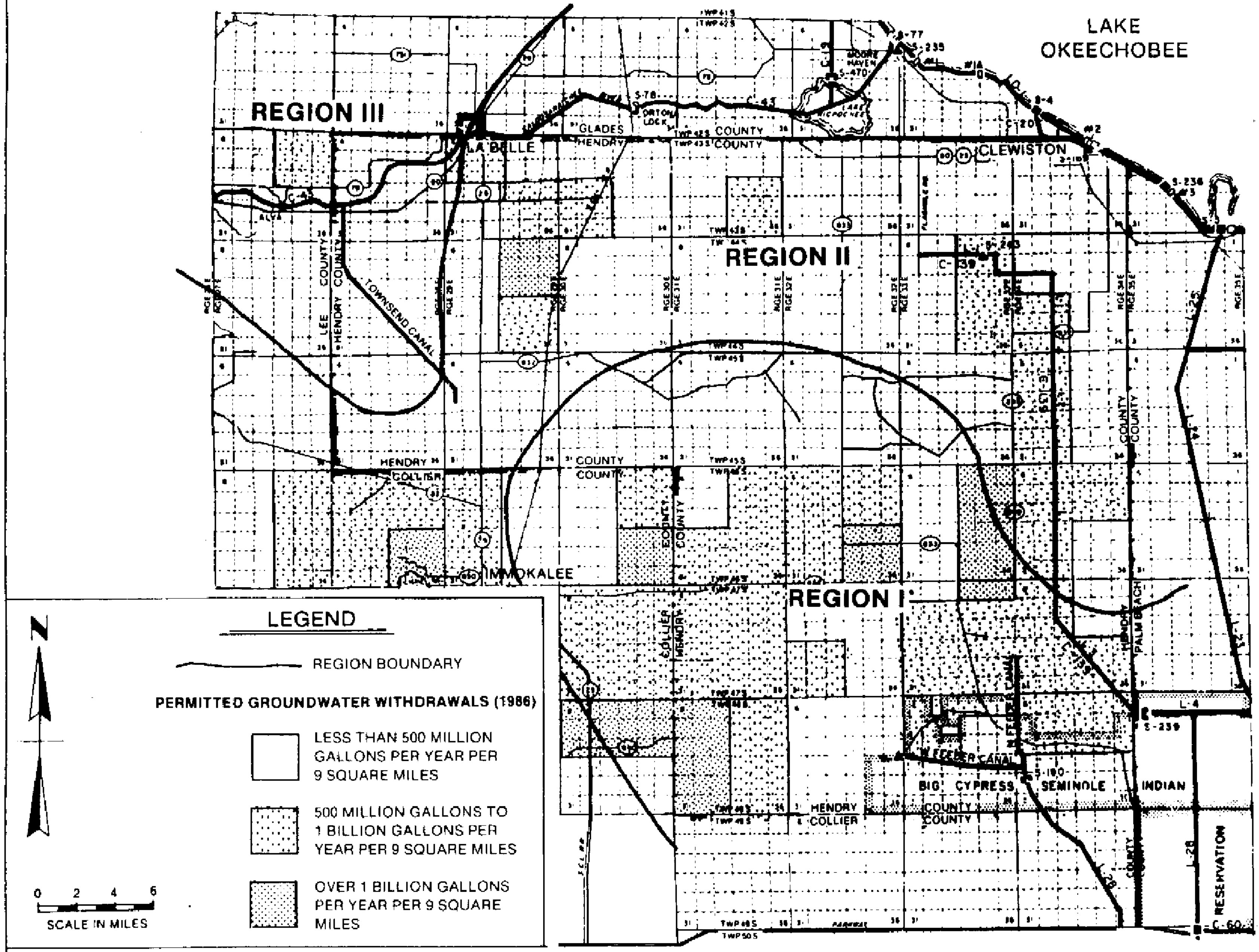


Figure 67 DEVELOPMENT POTENTIAL FOR THE SURFICIAL AQUIFER SYSTEM

MAP #	LAND OWNER	SOURCE	AQUIFER	S/T/R	DATE OF TEST	PUMPED WELL #	OBSERV. WELL #	PROD. WELL CASED/TOTAL	OBS. WELL CASED/TOTAL	DISTANCE (FT)	PUMP RATE (GPM)	HOURS PUMPED	MAXIMUM DRAWDOWN	TRANSMISSIVITY (GPD/FT)	STORAGE	LEAKANCE (GPD/FT3)	ANALYSIS METHOD
1	A. Querasa	U.S.G.S.	sandstone - both zones?	28/43/28	5-20-58	HE 313	HE-312	-/125	-/125	1850	310	8.5	0.31	70,000	6.05E-04	2.77E-06 *	Cooper
2	Walter Ferguson	Murray Milleson	unnamed aquifer	27/42/28	3-15-87	TPW	2	90/100	54/100	250	740	48	12.75	113,072	2.50E-04	6.65E-04	Glover
2							3		54/100	400			11.15	84,804	4.30E-04	1.13E-04	Glover
3	I. J. Nobles	Murray Milleson	unnamed aquifer	36/42/28	4-5-87	TPW1	1	97/170	100/164	100	700	70	32.92	16,044	1.10E-04	2.54E-03	Glover
3							2		100/164	300			27.99	13,370	6.70E-05	1.50E-03	Glover
4	Rainbow Ranch	Murray-Milleson	unnamed aquifer	14/42/28	11/6/86	PW	OB1	68/105	72/87	150	87	47	4.42	9,550	5.40E-04	4.20E-03	Cooper
4							OB2		68/85	300			4.95	9,550	1.79E-04	1.10E-03	Cooper
5	David Lee	Murray-Milleson	unnamed aquifer	29/42/28	4-30-87	TPW	MW1	100/185	150/195	150	200	68.5	14.55	15,529	2.10E-05		Hantush-Jacob
5							MW2		100/195	500			12.12	16,762	2.00E-05		Hantush-Jacob
5							MW3		100/185	700			8.85	18,857	2.00E-05		Hantush-Jacob
6	Six L's	Gail Murray	unnamed aquifer	18/42/28	11-1-83	8	9	-/165	-/200	1509	524	25	12.25	13,647	3.16E-05	5.46E-04	Walton
7	Rowland Walker	Brian McMahon	unnamed aquifer	16/42/28	8-9-82	22	21	74/180	80/165	2000	478	72	4.63	43,012	1.71E-04	7.22E-04	Walton
7							23		80/163	1700			10.[illegible]	15,729	6.11E-05	4.44E-04	Walton
7							OBS 1		70/[illegible]	50			14.96	24,081	4.89E-03	2.60E-02	Walton
7							OBS 3		70/120	200			13.76	22,931	4.98E-04	2.20E-03	Walton
7							OBS 4		79/123	650			12.65	21,137	1.05E-04	4.67E-03	Walton
8	Port LaBelle	Geraghty & Miller	sandstone - clastic zone	1/43/29	1-6-82	PW 2	81-1	218/278	115/135	34	1569	21		262,200			Jacob Mod.-Early
8							81-1							119,100			Jacob Mod.-Late
8							71-1		[illegible]	1250				245,200	3.60E-04		Walton
8							71-1							128,800	4.70E-04		Jacob Mod.-Late
8							72-7		[illegible]/276	14				129,600			Jacob Mod. of Theis
8							80-2		[illegible]	186				298,900	3.00E-04		Walton-Early
8							80-2							128,100	3.60E-04		Jacob Mod.-Late
8							80-3		[illegible]	165				239,100	4.30E-04		Walton-Early
8							80-3							128,800	4.30E-04		Jacob Mod.-Late
9	Kinser Property	Missimer	sandstone - clastic zone	8/43/28	1-20-82	H-M-73	H-M-70	[illegible]	[illegible]	184	[illegible]	16	11.29	21,700	2.00E-04	7.80E-03	Hantush-Jacob
9							H-M-71		[illegible]	[illegible]			19.12	9,[illegible]60	2.60E-03	8.00E-03	Hantush Jacob
9							H-M-72		[illegible]	[illegible]			9.45	9,300	5.00E-04		Hantush-Jacob
10	CPI	Missimer	sandstone - clastic zone	6/45/28	3-20-85	H-M-177	H-M-176	65/[illegible]	[illegible]	465	[illegible]	24	[illegible]	24,000	7.00E-03	1.00E-01	Hantush Jacob
10							H-M-179		[illegible]/128	[illegible]			[illegible]	35,000	5.00E-04	1.80E-04	Hantush-Jacob
10	Turner Corporation	Missimer	sandstone - carbonate zone	6/45/28	4-12-83	H-M-120	H-M-121	162/250	[illegible]/150	51			15.71	17,600	1.50E-04	1.10E-02	Hantush-Jacob
10	North Site						H-M-122		[illegible]	[illegible]			13.08	19,500	1.00E-04	3.10E-03	Hantush-Jacob
10							H-M-123		[illegible]	[illegible]			7.59	26,800	6.50E-05	1.80E-03	Hantush-Jacob
11	Turner Corporation	Missimer	sandstone - both zones	30/45/28	2-15-83	H-M-82	H-M-83	-/155,175/189-	same as HM82	100	475	72	8.71	72,000	1.40E-04	7.70E-06	Hantush-Jacob
11	South Site						H-M-84	155/175,189/24-	155/24-	316			3.67	140,000	1.50E-04	8.10E-05	Hantush-Jacob
12	Jo Mar Fl	Missimer	sandstone - clastic zone	29/45/29	1-20-87	H-M-318	H-M-315	80/150	130/150	167	480	48	10.17	25,000	2.00E-04	8.90E-03	Hantush Jacob
12							H-M-316		130/151	485			5.63	31,000	3.00E-04	5.30E-03	Hantush-Jacob
13	Silver Strand Grove	Missimer	sandstone - both zones	10/46/29	7-7-83	CO-755	CO-753	130/185	120/183	70	520	48	35.97	12,955	7.70E-04	2.30E-03	Hantush-Jacob
13							CO-754		120/183	225			22.74	14,188	3.70E-03	1.00E-03	Hantush-Jacob
13							CO-756		150/195	[illegible]			13.02	14,898	1.30E-04	4.70E-04	Hantush-Jacob
14	Site RIA 5	S.F.W.M.D.	sandstone - carbonate zone	20/45/29	4-17-84	HY118	Ob 1	165/250	165/201	98	65	20	7.73	6,771	9.77E-05	6.34E-04	Cooper
15	Site RIA 6	S.F.W.M.D.	sandstone - carbonate zone	16/44/29	4-24-84	HY-119	HE-556	140/165	135/155	202	70	24	2.34	27,660	4.95E-05		Cooper
16	Site RIA-7	S.F.W.M.D.	unnamed aquifer	18/42/29	6-4-84	PW	Ob 1	60/80	60/80	100	53	22	8.28	6,261	7.44E-05		Cooper
17	Site RIA-9I	S.F.W.M.D.	sandstone - clastic zone	16/44/28	5-9-84	HY-120I	Ob 1	50/80	50/80	70.5	96	13	5.47	14,128	1.82E-04		Cooper
17	Site RIA-9S	S.F.W.M.D.	sandstone - carbonate zone	16/44/28	5-7-84	HY-120S	Ob 1	155/180	155/180	74	90	22	11.97	54,280	4.06E-05		Cooper
18	Alico (Site D)	S.F.W.M.D.	sandstone - clastic zone	20/44/30	1-11-88	HE-1076	HE-1078	300/340	300/340	73	113	72	2.11	59,900	8.80E-05	1.05E-02	Cooper
18							HE-1079		300/340	197			1.51	67,580	1.74E-04	6.96E-04	Cooper
19	Frank Green	S.F.W.M.D.	sandstone - clastic zone	10/43/27	7-15-81	PW	OB 1	140/19-	140/190	105	90	25	4.32	1,213	1.61E-04	2.92E-01	Cooper

* USGS leakage coefficient values are listed as gpd/ft2 (K'), confining zone thickness (b') not available

Table 9 AQUIFER PARAMETERS FOR THE INTERMEDIATE AQUIFER SYSTEM

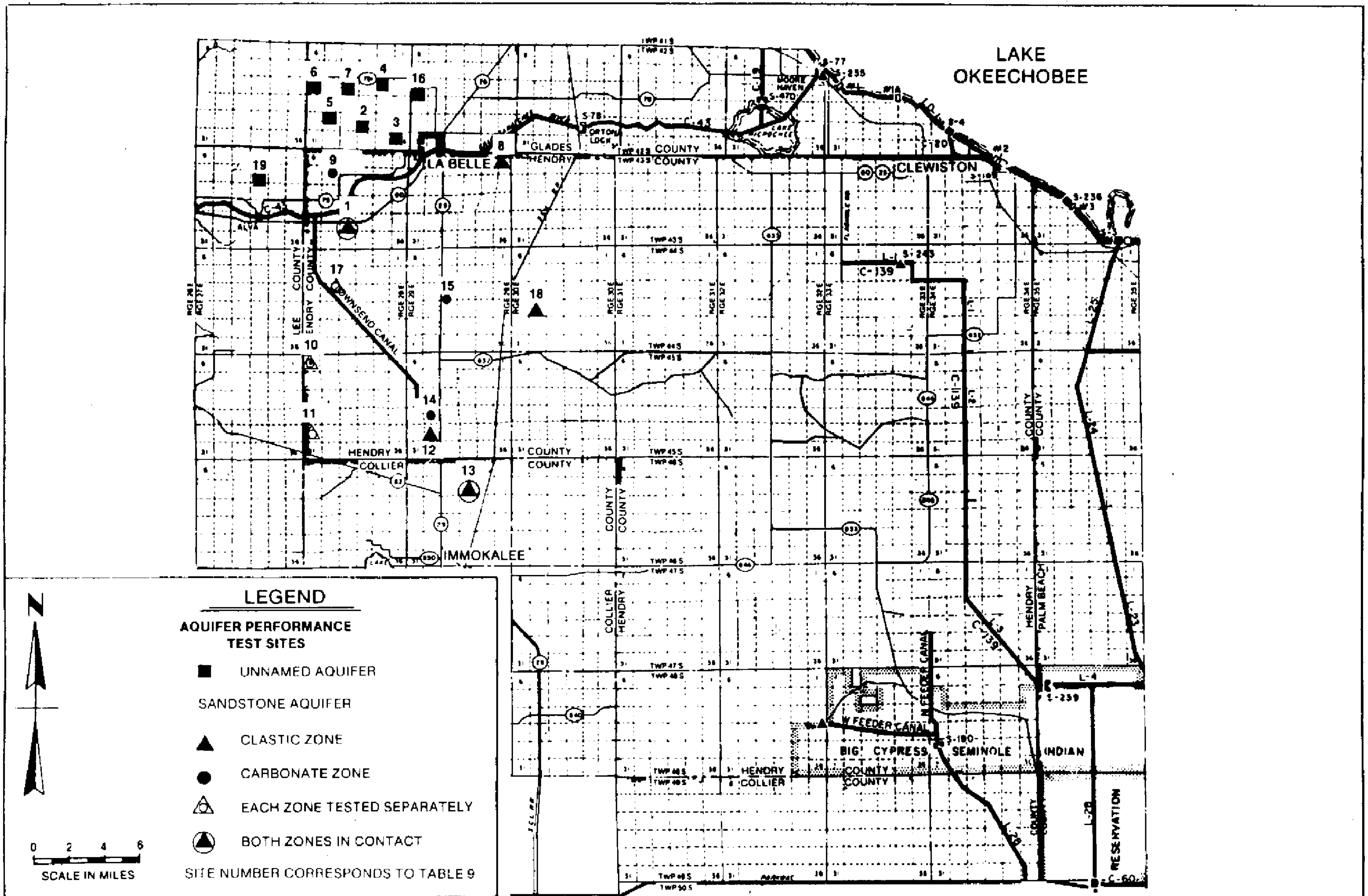


Figure 68 AQUIFER PERFORMANCE TEST LOCATIONS FOR THE INTERMEDIATE SYSTEM

depending on the amount of silt and/or clay present in the sequence. The highest transmissivities were found in a 60 foot thick sequence of carbonates in the Port LaBelle area west of LaBelle. Calculated transmissivity values ranged from 118,000 to 298,000 gpd/ft. However, the areal extent of this thick sequence is thought to be limited. Large scale withdrawals from an aquifer with low transmissivities produces deep cones of influence of small areal extent. The carbonate zone is composed of moderately to well indurated dolomites and limestones. Transmissivities determined from four aquifer tests range from 14,000 gpd/ft to 70,000 gpd/ft. As this zone thins to the south near Immokalee, transmissivity decreases.

In Figure 68, the aquifer tests conducted at locations 1 and 13 are in areas where the clastic and carbonate zones are in direct contact with each other. Aquifer tests conducted at locations 10 and 11 occur in areas where the two zones are separated by a confining layer of silty and sandy clays. In these areas individual tests of each zone were performed. At location 11, the transmissivity value from the clastic zone was calculated to be approximately half of the value from the carbonate zone. At all sandstone aquifer test locations, results indicate that transmissivity values obtained from the clastic zone are lower than those obtained from the carbonate zone.

The unnamed white limestone aquifer north of LaBelle consists of a 20 to 40 foot thick sequence of white sandy limestone overlain by coarse sands and clays. Transmissivity values obtained from data collected in seven tests (Figure 68) range from 1,200 gpd/ft to 90,000 gpd/ft, with the majority of values near 15,000 gpd/ft.

The majority of the storage values for the Intermediate Aquifer System are 10^{-4} while five sites (two carbonate zone sites, three unnamed aquifer sites) were determined to have storage values in the 10^{-5} range. Leakance values range from 10^{-5} to 10^{-1} gpd/ft^3. Northwest of LaBelle, tests of the unnamed white limestone aquifer have calculated leakance values of 10^{-4} gpd/ft^3. Leakance values in both the clastic and carbonate zones of the sandstone aquifer range from 10^{-5} to 10^{-3} gpd/ft^3.

The mid-Hawthorn aquifer occurs at depths ranging from -250 feet NGVD to -450 feet NGVD throughout Hendry County. However, because the mid-Hawthorn aquifer yields small amounts of poor quality water throughout the study area, it was not considered when assessing ground water potential of the Intermediate Aquifer System.

Potential for Water Supply

Future ground water potential in the Intermediate Aquifer System is shown in Figure 69. Due to low yield, both the sandstone and unnamed aquifers have little potential for widespread large scale development. However, the carbonate zone of the sandstone aquifer, in areas where the water quality is sufficient, can yield sufficient water for moderate development. Development in the sandstone aquifer requires the use of turbine or submersible pumps due to the large drawdowns associated with low well yields. The thick sequence of the clastic zone east of LaBelle has the greatest potential for ground water development. However, because surface water from the Caloosahatchee River is readily available, there has been no drilling or aquifer testing in the area other than at Port LaBelle. Consequently, the overall extent of Region I indicating high ground water development potential is not known at this time (see Figure 69). Water quality is generally moderate in the Intermediate Aquifer System. In general, chloride concentrations in the sandstone aquifer range between 250 mg/l to 800 mg/l with values exceeding 800 mg/l in localized areas of northwestern Hendry County. Chloride concentrations decrease to the southeast. In isolated areas, sulfate and iron concentrations exceed USDA recommended levels for agricultural use.

Most of the western portion of Hendry County (sandstone aquifer) is considered to have moderate development potential and is designated as Region II in Figure 69. Transmissivities in the 20-to 100,000 gpd/ft range are considered adequate for small to medium sized developments. Extensive citrus development in the area uses the sandstone aquifer as its principal water source, and it may be approaching its allocation limits. Figure 69 contains shaded areas indicating 1986 allocations assigned to the Intermediate Aquifer System. As with the Surficial Aquifer System, a determination of safe allocation limits is not within the scope of this study but will be determined in the next phase of development.

Region III is considered to have the least potential for ground water development (see Figure 69). Within this region, transmissivities are typically below 20,000 gpd/ft, adequate only for small scale development and individual use. The ground water chloride concentrations exceed 800 mg/l south of the Caloosahatchee River, which also limits its potential. Because the sandstone aquifer disappears to the east and the mid-Hawthorn aquifer displays poor water quality and low transmissivities, there is little potential for ground water development from the Intermediate Aquifer System in eastern Hendry County.

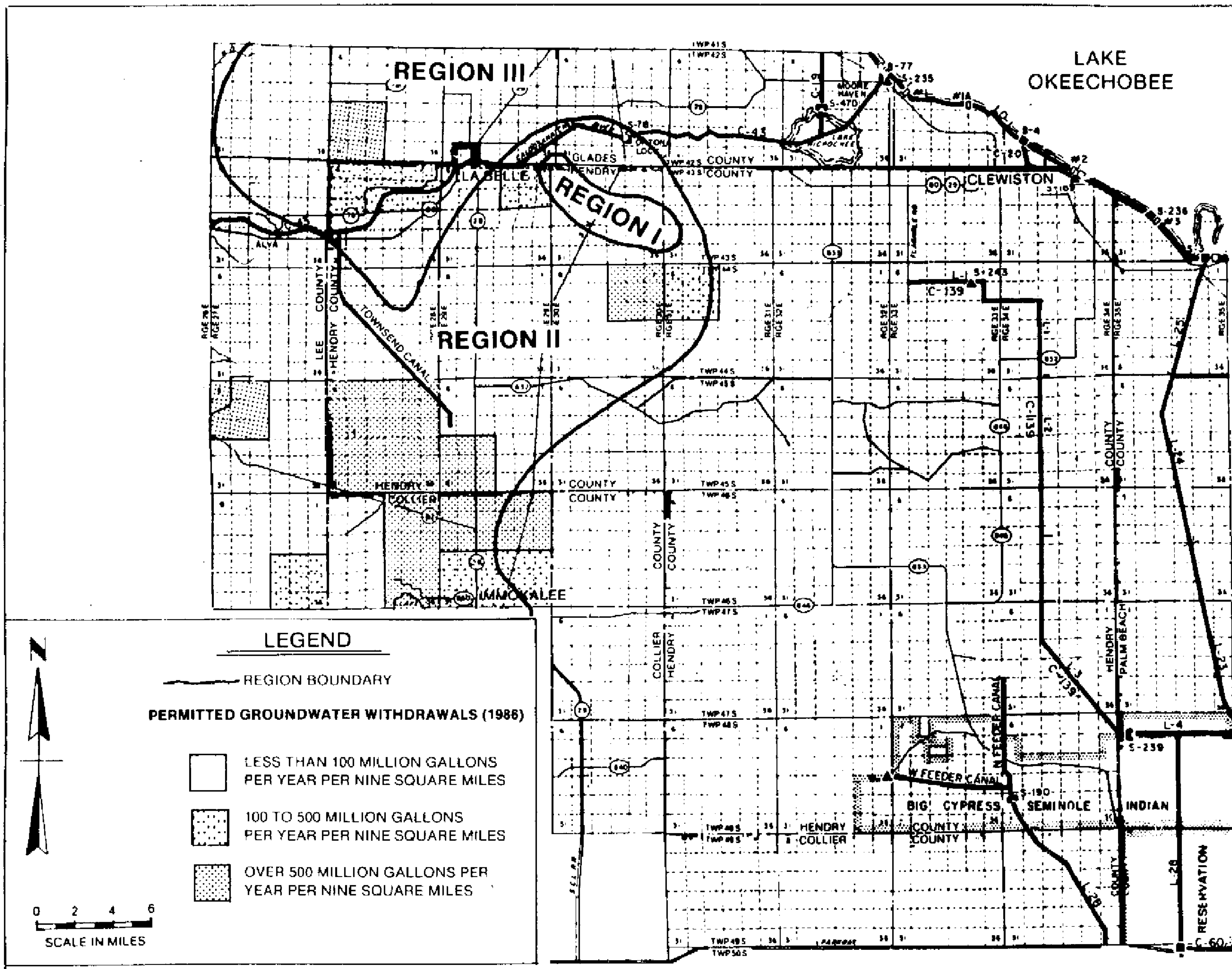


Figure 69 DEVELOPMENT POTENTIAL FOR THE INTERMEDIATE AQUIFER SYSTEM

CONCLUSIONS

1. The Surficial Aquifer System occurs throughout Hendry County. It is composed of two aquifers: the water table and the lower Tamiami. The two aquifers are separated by beds of low perme-ability called the Tamiami confining zone. This system can produce large quantities of good quality water throughout most of Hendry County.

   The water table aquifer is the only aquifer that occurs everywhere in Hendry County. It varies in thickness from 3 to 150 feet. In areas where the aquifer consists of thick sequences of permeable limestones or well sorted sands, it can display transmissivities in excess of 1,000,000 gpd/ft. However, transmissivity values between 50,000 and 100,000 gpd/ft are more representative of this aquifer on a regional basis. Storage values range between 1.3×10^{-4} and 1.6×10^{-1} in the water table aquifer.

   The lower Tamiami aquifer is the major source of ground water in Hendry County. In the western portions of the county it is in direct contact with the water table aquifer, and both units behave as a single unconfined aquifer. In the rest of the county, the lower Tamiami aquifer is separated from the overlying water table aquifer by low permeable sediments, and varies in thickness between 10 and 165 feet. In some areas of central Hendry County the lower Tamiami aquifer is hydraulically connected to the highly permeable sands of the Miocene coarse clastics. Transmissivities displayed by this aquifer range between 21,000 gpd/ft and 1,036,000 gpd/ft. Leakance values obtained from this aquifer vary between 1×10^{-2} gpd/ft^3 and 1×10^{-7} gpd/ft^3. Storage values obtained from the lower Tamiami aquifer range between 2×10^{-6} and 5.5×10^{-3}.

2. The Intermediate Aquifer System consists of the sandstone, the mid-Hawthorn, and an unnamed white limestone aquifer northwest of LaBelle. The mid-Hawthorn aquifer yields small amounts of poor quality water and is not used as a source of water in Hendry County. Little is known about the areal extent and the water bearing characteristics of the unnamed white limestone aquifer. However, existing data suggests that it might be a zone of the sandstone aquifer.

   The sandstone aquifer is the primary aquifer composing the Intermediate Aquifer System in Hendry County. It consists of a clastic zone and a deeper carbonate zone, and varies in thickness up to 160 feet. Occurrence of the sandstone aquifer is limited to western Hendry County. Both zones are capable of producing moderate amounts of water with transmissivities ranging between 11,000 gpd/ft and 299,000 gpd/ft. Storage values found in this aquifer range from 4×10^{-5} to 7×10^{-3}. Leakance values obtained range from 2×10^{-6} to 1×10^{-1} gpd/ft^3. Aquifer parameters, water quality, and water level data generated in this project indicate that the two zones of the Sandstone aquifer exhibit sufficient similarity to be considered a single aquifer in Hendry County.

3. The water table aquifer receives recharge by direct infiltration of rainfall. Annual precipitation throughout the county averages 50 inches. Evapotranspiration accounts for a majority of the discharge from this aquifer. Highest water levels in the water table aquifer occur north of Immokalee. Ground water flows away from this area in all directions under gentle gradients (less than one foot per mile). Flow patterns in the lower Tamiami aquifer are similar to those in the water table aquifer. The lower Tamiami aquifer receives direct recharge in the areas of western Hendry County where the Tamiami confining zone is absent. In the remainder of the county, the lower Tamiami aquifer receives recharge by downward leakage from the water table aquifer through the Tamiami confining zone.

   The sandstone aquifer receives recharge by downward leakage through the upper Hawthorn confining zone. Calculated lag times between the Surficial Aquifer and the sandstone aquifer ranged from zero to three days, indicating minimal confinement. The lowest lag times occurred near Immokalee, and the highest lag times occured near the Caloosahatchee River. This reflects the variability of the clay content in the confining zone, which is highest near LaBelle and decreases to the south. The highest recharge potential to the sandstone aquifer is in the Immokalee area. The potentiometric surface of the sandstone aquifer is highest north of Immokalee. In Hendry County the water in this aquifer flows in an asymmetrical radial pattern outward from this high area, much of it toward the Caloosahatchee River. Most of the discharge from the lower Tamiami aquifer and the Sandstone aquifer occurs through well pumpage.

4. Water quality in the water table, lower Tamiami, and sandstone aquifers is generally acceptable for most irrigation uses. Exceptions occur southwest of Labelle where the aquifers have been contaminated with Floridan Aquifer System water through improperly constructed wells. Water in the lower Tamiami and water table aquifers generally meets the Florida DER drinking water standards for potable supply. However, localized areas of high iron concentrations may require treatment prior to use.

5. Agricultural irrigation accounts for more than 99 percent of the permitted ground water use in Hendry County. Extensive withdrawals occur throughout the county, except for those areas near the Caloosahatchee River and major canals. Peak monthly withdrawals occur in January (3.4 billion gallons) when small vegetables are irrigated and in May (5.25 billion gallons) when citrus irrigation is at its peak. Withdrawal of ground water for irrigation is expected to increase as more of the county becomes developed and surface water sources reach their allocation limits.

6. The potential for ground water development from the Surficial Aquifer System is greatest in central and southern Hendry County. Areas of intensive water use from the aquifer system exist in the southern area of the county, however, and may limit additional development in this area. Lowest development potential for this aquifer system occurs in northwest Hendry County in an area of poor quality water combined with thin sequences of the water table and lower Tamiami aquifers.

7. A localized area of good development potential in the sandstone aquifer exists east of LaBelle. In this area, Port LaBelle obtains its water supply from the clastic zone of the sandstone aquifer. The extent of this area is not known, but available information suggests it is very limited. The lowest development potential in the sandstone aquifer occurs in an area southwest of LaBelle which has poor quality water and low yields.

RECOMMENDATIONS

1. Using information presented in this report a regional, multi-layered ground water flow model should be developed for Hendry County. The results of this modelling effort could form the basis for a future water management plan for the area.

2. The areal extent and water bearing characteristics of the unnamed white limestone aquifer should be investigated. Specifically, it should be determined if this unit is part of the sandstone aquifer or a separate aquifer.

3. A test well should be constructed in southwestern Hendry County between wells C2055 and C2066 to determine the relationship between the lower Tamiami and the sandstone aquifers in the area. This area already has significant ground water withdrawals and has a high potential for conversion to citrus production.

4. The ground water development potential in north central Hendry County should be investigated further. While the water use demands in this area are currently met by withdrawals from the Caloosahatchee River, increasing demands could cause the allocation limit of the river to be reached. If this happens, the increased demands would have to be met by ground water supply. This area also has a high potential for conversion to citrus production.

5. Floridan Aquifer System wells in the LaBelle area should be located and logged to determine if they are improperly constructed, thereby allowing Floridan Aquifer System water to leak into the aquifers of the Surficial and Intermediate Aquifer Systems. If such wells are found, they should be plugged and abandoned.

6. Agricultural water use in the county should be quantified. Current data, based on the maximum monthly or maximum annual irrigation requirements, do not accurately reflect actual water use. Quantification of the water use is necessary in the development of ground water flow models and water management plans.

7. Wells completed into both zones of the Sandstone aquifer in Hendry County should be allowed as long as they meet the construction standards set forth in Chapter 4OE-3, F.A.C. Data indicates that the carbonate zone and the clastic zone, while different on a lithologic basis, act as a single semi-confined aquifer.

8. Water levels in the water table, lower Tamiami, sandstone, and mid-Hawthorn aquifers need to be cross-correlated to determine their hydraulic interrelationships. To provide the data required for this analysis, water level recorders should be placed on the following wells: HE-529, HE-554, HE-851, HE-556, HE-560, HE-569, and HE-559. Since these wells are paired with wells in different aquifers at the same locations, correlation can be investigated without variations due to spatial differences.

BIBLIOGRAPHY

American Commission on Stratigraphic Nomenclature 1970. Code of Stratigraphic Nomenclature. American Association of Petroleum Geologists.

Applin, P.L., and E.R Applin. 1944. Regional Subsurface Stratigraphy and Structure of Florida and Southern Georgia. Bulletin of American Association of Petroleum Geologists, Vol. 28, No. 12.

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.

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

Cooper, H.H.,Jr. 1963. Type Curves for Non-Steady Radial Flow in an Infinite Leaky Artesian Aquier. U.S. Geological Survey Water-Supply Paper 1545-C, pp. C48-C55.

Dall, W.H., and G.D. Harris. 1892. Correlation Papers, Neogene. U.S. Geological Survey, Bulletin 84.

Davis, Stanley N., and Roger J. M. DeWiest. 1966. Hydrogeology, John Wiley and Sons, Inc.

Driscoll, F.G. 1986. Groundwater and Wells, Second Edition. Johnson Division.

DuBar, J.R. 1958. Neogene Statigraphy of Southwestern Florida. Gulf Coast Association of Geological Societies Transactions, Vol VIII.

Dunne, T., L. and Leopold. 1978. Water in Environmental Planning. W. H. Freeman and Co.

Fan, A., and R. Burgess. 1983. Surface Water Availability of the Caloosahatchee Basin. Technical Memorandum, South Florida Water Management District, Water Resources Division, Resource Planning Department.

Fetter, C. W., Jr. 1980. Applied Hydrogeology, Charles E. Merrill Company.

Fish, J.E., C.R. Causaras, and T.H. O'Donnell. 1983. Records of Selected Wells and Lithologic Logs of Test Holes, Hendry County and Adjacent Areas, Florida. U.S. Geological Survey Open-File Report 83-134.

Frazee, J.M., Jr., 1982. Geochemical Pattern Analysis: A Method of Describing the Southeastern Regional Limestone Aquifer System. Georgia Southwestern College, Special Publication No. 1, pp. 46-58.

Geraghty and Miller, Inc. 1983. Ground Water Resources at Port LaBelle, Glades and Hendry Counties, Florida. Report to Villages of Port LaBelle, General Development Corporation.

Hunter, M.E. 1978. What is the Caloosahatchee Marl? Hydrogeology of South Central Florida, Southeastern Geological Society, Publication No. 20, pp. 61-88.

Hunter, M.E., and S.W. Wise. 1980a. Possible Restriction and Redefinition of the Tamiami Formation of South Florida. Points of Discussion, Florida Scientist, Vol 43, Supplement No. 1, p.42.

Hunter, M.E., and S.W. Wise. 1980b. Possible Restriction and Redefinition of the Tamiami Formation of South Florida. Points for Further Discussion, Miami Geological Society Field Trip Exp., Edited by P.J. Gleason.

Hydrodesigns 1986. Robert McDaniels Ranch. Report to SFWMD for Consumptive Use Permit #26-00087-W.

Johnson, L.C. 1888. The Stucture of Florida. American Journal of Science (Series 3), Vol 36, pp. 230-236.

Jones, J.W., L.H. Allen, S.F. Shih, J.S. Rogers, L.C. Hammond, A.G. Smajstrala, and J.D. Martsolf. 1984. Estimated and Measured Evapotranspiration for Florida Climate, Crops, and Soils. University of Florida Institute of Food and Agricultural Sciences Technical Bulletin 840.

Klein, H., M.C. Schroeder, and W.F. Lichtle. 1964. Geology and Ground-Water Resources of Glades and Hendry Counties, Florida. Florida Geological Survey, Report of Investigations No. 37.

Knapp, M.S., W.S. Burns, and T.S. Sharp. 1986. Preliminary Assessment of the Ground Water Resources of Western Collier County, Florida. Technical Publication 86-1, South Florida Water Management District, Hydrogeology Division, Resource Planning Department.

Kruseman, G.P., and M.A. DeRidder. 1970. Analysis and Evaluation of Pumping Test Data. International

Institute for Land Reclamation and Improvement, Bulletin II, Wageningen, The Netherlands.

Leach, S.D. 1980. Source, Use and Disposition of Water in Florida, 1980. U.S. Geological Survey Water-Resources Investigations 82-4090.

Leach, S.D. 1984. Projected Public Supply and Rural (Self-Supplied) Water Use in Florida Through Year 2020. U.S. Geological Survey Map Series 108.

Leggette, Brashears and Graham. 1983. Hydrologic Investigation at Hendry Correctional Institution, Hendry County, Florida. Report to Greeley and Hansen.

Mansfield, W.C. 1939. Notes on the Upper Tertiary and Pleistocene Mollusks of Peninsular Florida. Florida Geological Survey, Bulletin 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 Second Annual Report.

Matson, G.G., and s. Sanford. 1913. Geology and Ground Waters of Florida. U.S. Geological Survey Water-Supply Paper 319.

McCoy, J. 1967. Groundwater in the Immokalee Area. Florida Geological Survey, Information Circular No. 51.

McMahon, Brian. 1982. Groundwater Resources of the 6 L's Site, Glades County, Florida. Report to Rowland Walker.

Mintz, L. W. 1977. Historical Geology, Second Edition. Charles E. Merrill Company.

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

Missimer, T.M. 1984. The Geology of South Florida: Environments of South Florida Present and Past. Miami Geological Society.

Missimer and Associates, Inc. 1981. Assessment of Ground Water Resources, Kinser Property. Report to Bob Paul, Inc.

Missimer and Associates, Inc. 1983a. Hydrogeology of the Silver Strand North Grove. Report to the Barron Collier Company/Silver Strand Division.

Missimer and Associates, Inc. 1983b. Turner Corporation Application #08272-A, Submittal of Geohydrologic Data. Report to Water Use Division, Resource Control Department, SFWMD.

Missimer and Associates, Inc. 1985. Groundwater Resources in Section 6, C.P.I., Hendry County, Florida. Unpublished consultant report.

Missimer and Associates, Inc. 1987a. Jo-Mar-El Citrus Development. Status Report of Geohydrologic Conditions. Report to SFWMD for Consumptive Use Application 07016-F.

Missimer and Associates, Inc. 1987b. Ground Water Resources of the Southern Division Ranch Site, Hendry County, Florida, Phase I and II. Report to U. S. Sugar Corporation.

Missimer and Associates, Inc. 1987c. Ground Water Resources of the Southern Division Ranch Site, Hendry County, Florida, Phase III. Report to U. S. Sugar Corporation.

Missimer and Associates, Inc. 1987d. Ground Water Resources of the Rogers Ranch Citrus Project, Hendry County, Florida. Report to U. S. Sugar Corporation.

Morris, M.D., J.A. Beck, and Y.A. Krulik. 1983. A Computer Program for a Trilinear Plot and Analysis of Water Mixing Systems. Groundwater 21(1):67-78.

Murray-Milleson, Inc. 1986a. Hydrogeologic Study, First Phase of Grove Development for Collier Enterprises. Unpublished Consultant Report.

Murray-Milleson, Inc. 1986b. Hydrogeologic Study for Rainbow Ranch. Unpublished Consultant Report.

Murray-Milleson, Inc. 1986c. Hydrogeologic Study for Williams Farm. Unpublished Consultant Report.

Murray-Milleson, Inc. 1987a. Hydrogeologic Study for Walter Ferguson. Unpublished Consultant Report.

Murray-Milleson, Inc. 1987b. Hydrogeologic Study for David Lee. Unpublished Consultant Report.

Murray-Milleson, Inc. 1987c. Hydrogeologic Study for L. J. Nobles. Unpublished Consultant Report.

Murray-Milleson, Inc. 1987d. Hydrogeologic Study for the Seminole Tribe of Florida. Unpublished Consultant Report.

Murray-Milleson, Inc. 1987e. Hydrogeologic Study for Alban-Gould. Unpublished Consultant Report.

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

Parker, G.G.,G.E. Ferguson, S.K. Love, et al. 1955. Water Resources of Southeastern Florida. U.S. Geological Survey, Water Supply Paper 1255.

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 Association of Geological Societies Transactions, Vol 29.

Puri, H.S., R.O. and Vernon. 1964. Summary of the Geology of Florida and a Guidebook to the Classic Exposures. Florida Geological Survey, Special Publication No. 5 (revised).

Scott, T.M. 1986. A Revision of the Miocene Lithostratigraphic Nomenclature, Southwestern Florida. Gulf Coast Association of Geological Societies Transactions, Vol. XXXVI.

Scott, T.M., and M.S. Knapp. 1988. The Hawthorn Group of Peninsular Florida. Miami Geological Society, Memoir No. 3.

Sellards, E.H. 1919. Geologic Section Across the Everglades, Florida. Florida Geological Survey 12th Annual Report, pp. 67-76.

Shaw, J.E., and S.M. Trost. 1984. Hydrogeology of the Kissimmee Planning Area, South Florida Water Manage District. Technical Publication 84-1, South Florida Water Management District, Groundwater Division, Resource Planning Department.

Slater, D.H. 1978. The Stratigraphy and Paleoecology of the Tamiami Formation in Hendry County, Florida. Master's Thesis, Florida State University, Department of Geology.

Smith, K.R., T.S. Sharp, and G. Shih. 1988. Investigation of Water Use, Land Use, and the Ground Water Monitor Network in Hendry County, Florida. Technical Memorandum, South Florida Water Management District, Hydrogeology Division, Resource Planning Department.

Southeastern Geological Society Committee on Florida Hydrostratigraphic Unit Definition 1986. Hydrogeological Units of Florida. Florida Geological Survey, Special Publication No. 28.

Stringfield, V.T. 1933. Ground Water in the Lake Okeechobee Area, Florida. Florida Geological Survey, Report of Investigations No. 2.

United States Department of Agriculture, Soil Conservation Service, 1970. Irrigation Water Requirements, Technical Release No. 21.

United States Department of Agriculture, Soil Conservation Service, 1982. Florida Irrigation Guide.

Vernon, R.O. 1951. Geology of Citrus and Levy Counties, Florida. Florida Geological Survey, Bulletin No. 33.

Wedderburn, L.A., M.S. Knapp, D.P. Waltz, and W.S. Burn. 1982. Hydrogeologic Reconnaissance of Lee County, Florida. Technical Publication 82-1, South Florida Water Management District, Groundwater Division, Resource Planning Department.