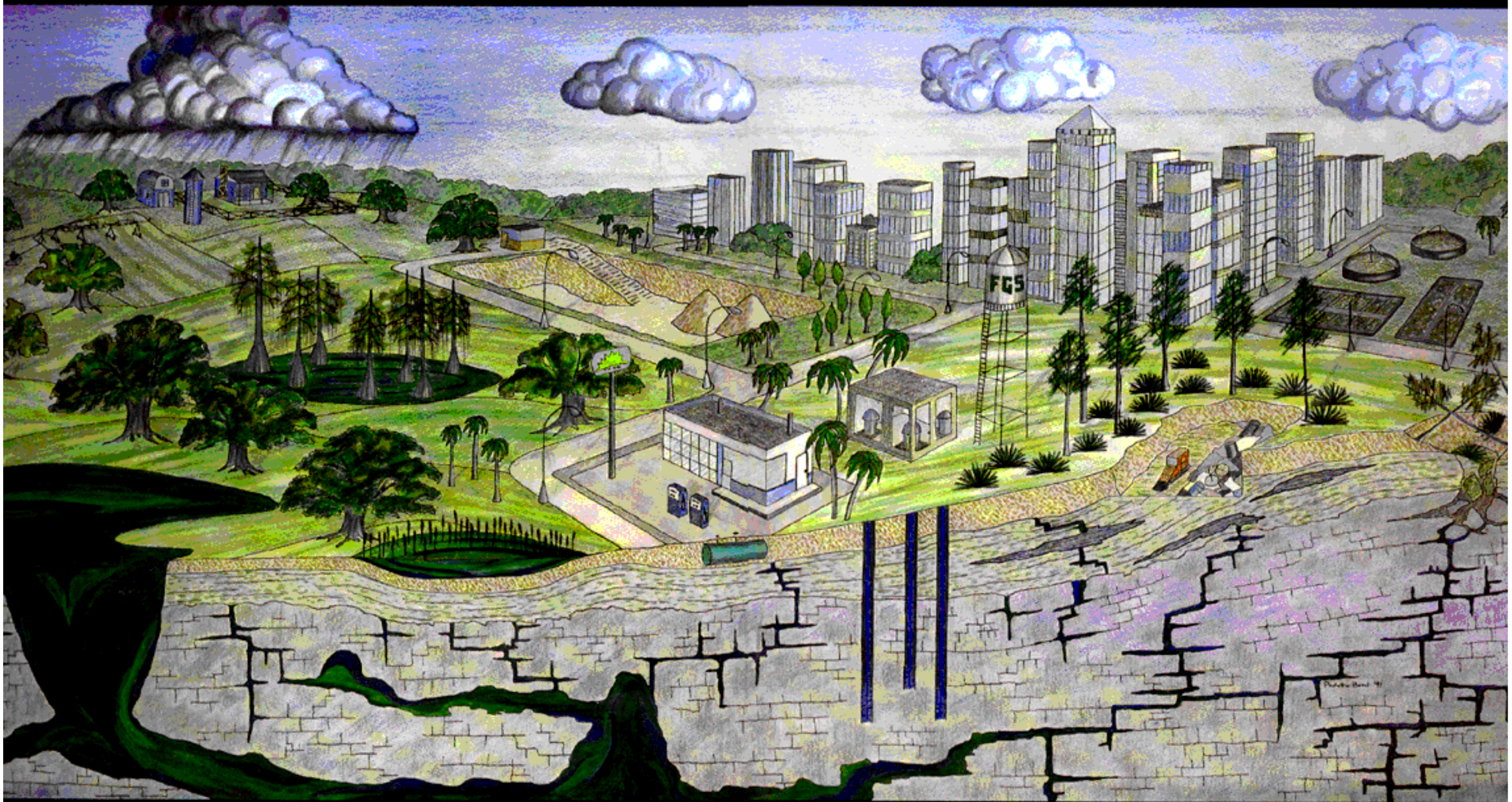
FLORIDA'S GROUND WATER QUALITY MONITORING PROGRAM



HYDROGEOLOGIC FRAMEWORK

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FLORIDA GEOLOGICAL SURVEY SPECIAL PUBLICATION

FLORIDA'S GROUND WATER QUALITY MONITORING PROGRAM
BACKGROUND HYDROGEOCHEMISTRY

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LETTER OF TRANSMITTAL

Florida Geological Survey
Tallahassee
October, 1992

Governor Lawton Chiles, Chairman
Florida Department of Natural Resources
Tallahassee, Florida 32301

Dear Governor Chiles:

The Florida Geological Survey, Division of Resource Management, Department of Natural Resources, is publishing, as its Special Publication 34, Florida's Ground Water Quality Monitoring Program - Background Hydrogeochemistry. This publication is the second in a series which will present the results of the ground water quality network program established by the 1983 Water Quality Assurance Act (Florida Statutes, Chapter 403.063). It is primarily a series of maps which provide the background hydrogeochemical parameters present within the principal aquifer systems of Florida. These results can be used by state and local governments, planners, and developers for land-use planning, conservation, and protection of Florida's valuable water resources.

Respectfully yours,

Walter Schmidt, Ph.D., P.G.
State Geologist and Chief
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Cover Illustration
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Florida's population growth creates ever-increasing pressures on fragile water resources. This drawing illustrates many of the complex relationships that exist between a Florida community and the environment which sustains it. Water for various uses is withdrawn from subsurface limestones which are extremely porous and permeable. Ground water which resides in these limestones is naturally protected from various types of contaminants by a widespread clayey confining layer. The situation is complicated by the presence of discontinuous carbonate lenses and fractures within the confining layer. Limestone is vulnerable to extensive dissolution leading to the development of sinkholes which may breach the confining unit in the process of their formation. This same dissolutional process results in the formation of the large springs, highly prized features of Florida's environment, from which large amounts of ground water discharge constantly. The spring pictured here includes as part of its recharge mechanism, the newly formed sinkhole, ostensibly distant from it. The surficial sands and clayey sands which blanket the confining layer are subject to major impacts resulting from the activities of man. Subsurface storage tanks will be buried within them, municipal solid waste will be disposed into them and locally, small domestic wells may be drilled into them where their permeability and porosity make them a viable surficial aquifer. At the same time, precipitation moving down into these shallow materials may locally enter sinkholes or fractures within the confining layer, contributing to recharge of the underlying limestone aquifer system.

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INTRODUCTION

By

Gary Maddox and
Jacqueline M. Lloyd, P.G. #74

Usable fresh water is Florida's most important natural resource. Pressure on this resource comes from rapid land use changes associated with urban and agricultural development. In order to insure sufficient fresh water for the state's current and future needs, this resource must be defined,protected and conserved.

As of 1980, 87% of Florida's public water supply came from subsurface aquifers. The remaining 13% was extracted from surface water sources, such as rivers and lakes. Most surface water requires considerably more treatment than ground water before use as a potable water source (Fernald and Patton, 1984). Florida's ground-water and surface-water systems are intimately connected. Lake and river waters recharge underlying aquifers at times when surface-water levels are higher than water-table elevations. Conversely, ground water flows into rivers and lakes through seepage and spring flow when water-table levels exceed surface-water levels. Where karst features, such as sinkholes, are well developed, there may be a direct connection between surface water and ground water. Shallow aquifers often have little or no protective, overlying aquitard or aquiclude. These common hydrogeologic conditions increase the risk of contamination of Florida's water supply.

Land-use planning must take hydrogeologic conditions into account. Whether through percolation or direct connection, polluted surface water can eventually contaminate ground water. Pesticides, herbicides and fertilizers from agricultural areas, metals and organics from urban stormwater runoff, and hydrocarbons from leaking storage tanks are all threats to Florida's aquifer systems.

In addition to these water quality considerations, land-use planning must also take into account water quantity. Excessive withdrawal of fresh water from an aquifer may lead to replacement of lighter, fresh water by denser, connate seawater. This is a problem in high volume ground-water withdrawal areas, such as in the vicinity of urban well fields. Excessive fresh water use in coastal areas may lead to the lateral intrusion of salt water from the sea.

Recharge areas where significant amounts of meteoric and surface water enter the aquifer are particularly sensitive to land uses. Some land uses may contribute contaminants to soil or surface waters or restrict the downward percolation of meteoric and surface waters. Protecting these areas from heavy development aids in the preservation of the quality and quantity of the ground-water supply.

Ground Water Quality Monitoring Program

The Florida legislature, acknowledging the need to protect our ground-water resources, passed the Water Quality Assurance Act in 1983. The legislature recognized that we must understand the impact of man's activities on our ground-water systems before we can determine appropriate protective measures. Thus, a portion of the Act required the Department of Environmental Regulation (DER) to "establish a ground-water quality monitoring network designed to detect or predict contamination of the state's ground-water resources" (Florida Statutes, Chapter 403.063). The Act required DER to work cooperatively with other federal and state agencies, including Florida's five water management districts (WMD's) (Figure 1), in the establishment of the network. The Florida Geological Survey (FGS) and the Water Resources Division of the U.S. Geological Survey provided technical support. In addition, several studies were funded through the State University System. Appendix 1 contains contact information for these agencies. Appendix 2 contains a list of reports and publications resulting from these efforts.

The major goals of the Ground Water Quality Monitoring Program are:

1. To establish the baseline ground-water quality of major aquifer systems in the state;
2. To detect and predict changes in ground-water quality resulting from the effects of various land uses and potential sources of contamination;
3. To disseminate water quality data generated by the program to local governments and the public.

Hydrogeologic Map Production and Publication

To meet the goals set forth above, a hydrogeologic framework must first be defined. This publication is primarily a series of maps which portray the basic hydrogeologic conditions present within the principal aquifer systems of Florida. These maps were prepared by the water management districts, the FGS and the DER.

Most maps were compiled on water management district base maps. Specific map coverage varied between districts. Single-topic maps may not be comparable between districts because they were not initially produced as a cooperative effort. For example, contour intervals may differ, making edge-matching impractical. The maps for each district generally include:

1. Isopach and structure contour maps of the surficial, intermediate and Floridan aquifer systems;
2. Isopach and structure contour maps of beds acting as aquitards and aquicludes;
3. Areas where the Floridan aquifer system is at or near the surface, and areas where it is under water-table conditions;
4. Areas of recharge to the Floridan aquifer system;
5. Potentiometric surface of the Floridan aquifer system;
6. Areas of saltwater intrusion;
7. Areas of karst development;
8. Ground-water and surface-water basins.

Ground Water Quality Monitoring Network And Future Publications

The hydrogeologic framework defined by the maps in this publication provide the background necessary to establish the monitoring network, set priorities, and determine strategies for meeting the goals of the program.

The Ground Water Quality Monitoring Network is made up of three principal elements: two major subnetworks and one survey, each of which has unique monitoring priorities and goals. These elements are:

1. Background Network, designed to help define background ground-water quality through a network of approximately 1800 wells that tap all major potable aquifers within the state (Figure 2);
2. VISA (Very Intense Study Area) Network, designed to monitor the effects of various land usage on ground-water quality within specific aquifer systems in selected areas (Figure 3);
3. Private Well Survey, designed to analyze ground-water quality from 50 private drinking water wells in each of Florida's 67 counties. This survey is a joint effort between the Florida Department of Health and Rehabilitative Services (HRS) and the DER.

The water-quality data collected, analyzed, and evaluated through these elements will be published in separate volumes.

Background Network

A well in the Background Network is designed to monitor an area of the aquifer system which is representative of the general ground-water quality of a region. For this publication, a region is defined as constituting an area greater than or equal to the size of an average Florida county. It is further defined by aquifer system extent and, if possible, by ground-water basin. Background Network wells are actually used to define baseline rather than original background ground-water quality. Baseline differs from background in that it refers to current, representative regional water

quality. Widespread changes in water quality associated with regional land uses may be present. Thus, Background Network water quality may differ from the original water quality that existed before there was measurable human impact on the aquifer system. Wells which indicate specific contamination sources are not included in the Background Network. The statewide distribution of Background Network wells is shown in Figure 2.

Before drilling of Background Network monitoring wells began, existing wells suitable for inclusion in the network were sought. An inventory of potentially useful existing monitoring sites was compiled by the U.S. Geological Survey and the water management districts. The following criteria were used to determine eligibility:

1. Depth of well and cased internal known;
2. Open hole internal taps only one aquifer or water-bearing zone;
3. Precise site location known;
4. Well owner cooperative;
5. Future accessibility for sampling granted;
6. History of the site (prior land use, previous sampling results) known.

Other non-mandatory, but desirable criteria include:

7 Site ownership by local, state or federal agency;
8. Prior water-quality data available;
9. Well diameter known;
10. Lithological and geophysical logs available;
11. Hydrogeologic information available.

To further aid in well selection and placement, the locations of potential and confirmed sources of ground-water contamination were determined. These included point sources such as locations of free-flowing wells, major landfills, injection and recharge wells, surface impoundments, industrial and hazardous waste generators, sewage treatment plants, and mining areas. Nonpoint sources included sewered versus septic areas, pesticide application (agricultural) areas, wastewater application areas, stormwater facilities and fresh water outfalls.

Over 1200 existing wells were initially selected for inclusion in the Background Network. Although optimal quality assurance and control could be more fully realized by drilling all monitoring wells expressly for use in the network, the associated costs prohibited such an approach.

Approximately 600 new wells were drilled for inclusion in the network. Depending on the hydrostratigraphy at each new site, a single well or cluster of wells was installed, allowing each major water-bearing zone to be separately monitored. Geological information was obtained at each site during drilling. A core from the uppermost significant confining bed was obtained from many sites for laboratory determination of permeability and lithologic description of the constituent sediments.

The initial sampling of each well in the network involved the measurement of a comprehensive set of field, chemical, and micro-biological parameters, as well as naturally-occurring radioactivity (Table 1). These analyses, combined with historical data, are used to estimate baseline ground-water quality. This data is then used to help delineate areas where ground-water quality degradation has occurred.

As funds allow, the entire Background Network will be re-sampled and all the parameters listed in Table 1 will be re-measured. This continued monitoring of the network will reveal water-quality changes over time, as well as targeting the onset of degradation or contamination.

A subset of the Background Network is the Temporal Variability Subnetwork (the "TV Net"). These wells are sampled more frequently (on a monthly or quarterly basis) for a smaller set of field parameters (Table 1). These field or "indicator parameters" will be used to quantify temporal water-quality variations. The feasibility of installing dedicated sampling equipment allowing continuous monitoring of a few selected wells is currently under consideration.

Refinement of the Background Network is an ongoing task. Wells which provide redundant information or do not represent baseline water quality are removed from the network. New wells are installed where needed.

VISA Network

The Very Intense Study Area (VISA) Network (Figure 3) monitors specific areas believed to be highly susceptible to ground-water contamination from surface sources. VISA Network wells are monitored for an extensive suite of chemical and field parameters, as well as organics, pesticides, herbicides and naturally-occurring radioactivity (Table 1). VISA's are selected based on an assessment of predominant land use and hydrogeologic susceptibility. The purpose of the VISA Network is to quantify the effects on ground-water chemistry of different land uses within a specific hydrogeologic environment. A VISA well is designed to monitor the effects of multiple sources of contamination on ground-water quality within a segment of the aquifer. Most VISA wells monitor the uppermost aquifer system present within the study area, since that is where surface-introduced contaminants should first be detected. This information might ultimately serve as a predictive tool, allowing ground-water professionals to ascertain the potential effects of changing land use on ground-water quality in areas with similar hydrogeological conditions.

Predominant land-use areas were located using the Florida Summary Mapping System, a microcomputer-mapping package developed at the University of Florida. The system contains land-use data derived from ad valorem tax information obtained from each of Florida's 67 counties. These data have been summarized for each square-mile section of the state based on the Public Land Survey System (Section, Township and Range). This system allowed rapid access to a large volume of annually updated land-use data. One hundred Florida Department of Revenue land-use codes exist in the database; a subset of these were grouped into sixteen more general categories for the purpose of VISA selection.

Hydrogeologic conditions which determine aquifer-system vulnerability were determined using DRASTIC, a mapping system developed jointly by the U.S. Environmental Protection Agency and the National Water Well Association (Aller et al, 1985). DRASTIC is an acronym representing the seven hydrogeological parameters considered most indicative of relative pollution potential. These are:

D - Depth to water;

R - Net recharge;

A - Aquifer media;

5 - Soil media;

T - Topography;

I - Impact of the vadose zone;

C - Hydraulic conductivity.

Each of these parameters is mapped separately for each aquifer, using existing data. Numerical scores are assigned to each map polygon. The score for each polygon is then multiplied by a weighting factor. The seven parameter maps are next overlain and the resulting polygons and weighted scores are summed to create a composite DRASTIC aquifer vulnerability map. Higher scores indicate higher relative pollution potential. These maps indicate overall relative aquifer-system vulnerability. Combined with the knowledge gained through analysis of the VISA Network results, these maps will be an invaluable land-use planning tool. DRASTIC maps are currently being produced for each county in Florida. These maps, covering the surficial and Floridan aquifer systems, will be published in a separate volume.

Twenty-one initial VISAs were selected, based on the above criteria (Table 2). Initial sampling of these VISAs occurred in late 1990. Results from these analyses will be published in a separate volume.

Private Well Survey

The Florida Department of Health and Rehabilitative Services (HRS) is conducting a survey of private drinking-water systems to determine their general water quality. DER and HRS entered into a cooperative agreement to select up to 70 wells per county (50 primary, 20 backup) for the survey, using the same criteria developed to select existing Background wells. HRS is sampling these wells for approximately 180 parameters (Table 1). The data generated from these wells is supplementing the Background and VISA data, while also indicating the general quality of water consumed by private well owners. The sampling process will not be completed for several years.

SAMPLING PROTOCOL

Sampling of the statewide network began in mid-1985 and was carried out by the water management districts. A portion of the existing wells were sampled using permanently installed pumps. The remaining existing wells and all new wells were sampled using teflon bailers, bladder pumps or submersible pumps specifically designed and manufactured with non-contaminating materials. Sampling protocol followed procedures established by the U.S. Environmental Protection Agency. All sampling agencies and analytical laboratories were required to submit quality assurance plans to maximize uniformity of results. The initial sampling episode included a more comprehensive set of physical and chemical parameters than were monitored during subsequent routine sampling (Table 1).

The frequency of sampling and the chemical parameters monitored at each site were based on several factors, including network designation, land-use activity, available resources, and geologic sensitivity of the site. After initial sampling, several wells were dropped from one network and added to another, based on analysis of sampling results. For instance, some wells believed not to represent background-water quality were dropped from the Background Network and included in the VISA Network. This refinement process is ongoing. When significant concentrations of potentially harmful parameters were detected, the well was resampled to confirm or deny contamination. When contamination was confirmed in a private well, HRS was notified so that potential health threats could be assessed.

DATA BASE SYSTEMS

A variety of data base and software systems have been used and developed to store, manipulate and display information related to the Ground Water Quality Monitoring program. These include the Florida Summary Mapping System (FSMS), the Generalized Well Information System (GWIS), the Well Log Data System and DERMAP.

The FSMS is a microcomputer land-use database and retrieval system developed at the University of Florida (Miller, et al., 1986) and currently marketed by ARMASI, Inc. This system uses state ad valorem tax information annually compiled by each county tax assessor. Land-use information is compiled and displayed in raster format using the Public Land Survey System grid as a map base. The resulting one square mile resolution allows general delineation of areas of predominant land use.

GWIS is a microcomputer database and retrieval system which contains all well and analytical water-quality information generated by the network. It consists of two separate data sets: 1) physical well characteristics, and 2) sampling results. The two data sets are linked by a common well identifier. DER developed the system to quickly and efficiently manage the large volume of data generated by the network. Data can be retrieved by predefined groups or dates, for values exceeding specified limits (e.g. EPA standards), or by any combination of physical well attributes. Data entry programs allow the user to add new well and analytical information to the system. Output can be tabular or graphic (when combined with a PC CAD package). Network data is also available in dBASE III Plus format. GWIS programs and data are available to the public for a nominal disk charge or free via a computer bulletin board system, accessible by telephone.

For further information, contact:

Florida Department of Environmental Regulation
Bureau of Drinking Water and Ground Water Resources Ground Water Quality Monitoring Section 2600 Blair Stone Road Tallahassee, Florida 32399-2400

Staff: (850) 921-9425
Bulletin Board Service: (850) 487-0461

The FGS maintains an extensive database of geologic well data (lithologic descriptions and formational contacts of well core and cutting samples). The Well Log Data System includes a series of BASIC programs written by Dr. Robert Lindquist (GeoLogic Information Systems, Gainesville, FL) to manage and use this database. The system was written for IBM-PC compatibility, providing the FGS and other users access to the statewide geologic database. It also provides a standard format for additions to the database. The programs can be used for data entry and editing, as well as for generating both graphic and text output of geologic data.

DERMAP integrates data from the FSMS, GWIS and the Well Log Data System. DERMAP was developed by ARMASI, Inc. in cooperation with GeoLogic Information Systems. DERMAP allows data from all three databases to be displayed simultaneously on a common map, allowing the user to visually relate water quality to land use and geology.

DERMAP and GWIS programs and data are available from DER. The FGS can be contacted for current well log data. FSMS can be obtained from ARMASI, Inc. and the Well Log Data System can be obtained from GeoLogic Information Systems. Appendix 1 contains contact information for these agencies and companies.

All network chemical and physical well information is also stored in DER's mainframe computer system. This central repository allows access to the data by other state agencies.

Data Analysis and Application of Program Results

The Ground Water Quality Monitoring Program was designed to improve understanding of man's impact on Florida's ground-water resources. Data collected and analyzed by this program will ultimately yield tools for describing and predicting the complex interactions between land use, hydrogeologic conditions, water quality and quantity. Specifically, data generated by the network will be analyzed to:

1. Determine the extent and thickness of the major aquifer systems containing potable water;
2. Define regional hydrogeological conditions;
3. Map recharge and discharge areas;
4. Map physical and chemical aquifer characteristics;
5. Statistically define geochemically homogeneous segments within each aquifer system;
6. Determine the boundaries of ground-water basins and their relationship to the geochemically-defined aquifer segments;
7. Determine current general ground-water quality for each major aquifer system statewide;
8. Establish average baseline and background-water quality by parameter and aquifer segment;
9. Determine effects of potential contamination sources;
10. Evaluate water-quality changes over time;
11. Define relationships between land use and ground-water quality;
12. Quantify and predict changes in ground-water quality due to land-use changes;
13. Delineate physical ground-water divides;
14. Correlation of ground-water quality changes with water-level fluctuations to aid in defining quality-quantity relationships;
15. Determine ground-water basins for each monitored aquifer;
16. Establish the baseline-water quality of similar aquifer sediments within each basin;
17. Produce water-quality maps by parameter.

TABLE 1
GROUND WATER QUALITY NETWORK MONITORING PARAMETERS

PARAMETERS	NETWORK					STANDARD METHOD 1,2
	Background	VISA	HRS	Quarterly	Monthly	
MAJOR IONS						
Bicarbonate	B	V		Q		406
Carbonate	B	V				406
Chloride	B	V	H	Q		407A, 407B, or 407D
Cyanide	B	V				412B, 412C, or 412D
Fluoride	B	V	H	Q		413A, 413B, 413C, or 413E
Nitrate	B	V	H	Q		418C or 418F
Phosphate	B	V	H	Q		424F or 424G
Sulfate				Q		426Aor 426C
METALS						
Arsenic	B	V	H			303E
Barium	B	V	H			303C
Cadmium	B	V	H			303Aor 303B
Calcium	B	V	H	Q		303A or 311C
Chromium	B	V	H			303A or 303B
Copper	B	V	H			303A
Iron	B	V	H	Q		303Aor 315B
Lead	B	V	H			303Aor 303B
Magnesium	B	V	H	Q		303A or 319B
Manganese	B	V	H	Q		303Aor 319B
Mercury	B	V	H			303F
Nickel	B	V				303Aor 322B
Potassium	B	V		Q		303Aor 322B
Selenium	B	V	H			303E
Strontium		V				
Silver	B	V	H			303Aor 303B
Sodium	B	V	H	Q		303Aor 325B
Zinc	B	V	H	Q		303Aor 303B
FIELD PARAMETERS						
Conductivity	B	V		Q	M	205
pH	B	V		Q	M	423
eH					M	
Dissolved Oxygen (DO)					M	
Temperature	B	V		Q	M	212
Water levels	B	V		Q	M	
Odor			H			
MICROBIOLOGICAL						
Fecal Coliform	B	V				908C or 909C
Total Coliform	B	V				908Aor 909A
ORGANICS AND PESTICIDES						
Total Organic Carbon (TOC)	B	V		Q		505
Volatile Organic Carbon (VOC)	B					EPA 601 & 602, or EPA 624
Aldicarb & related compounds		V				EPA 531
Purgeable Halocarbons		V				EPA 601
Purgeable Aromatics		V	H			EPA 602
Pesticides		V				EPA Alt. 614
PCBIs, Chlorinated Pesticides		V	H			EPA Alt. 617
Pesticides		V				EPA Alt. 619
Organophosphate Pesticides			H			EPA 622
Mixed Purgeables			H			EPA 624
Base / Neutral / Acid Extractables		V	H			EPA 625
Carbamate Pesticides		V	H			EPA 632
Pesticides		V				EPA 644
Herbicides			H			
Fumigant Pesticides		V	H			
RADIOMETRICS						
Gross Alpha	B	V				703
Gross Beta	B	V				703
Radon	B					
Radium	B					
OTHERS						
Total Dissolved Solids (TDS)	B	V		Q		209B
Ammonia		V				
Silica		V				

TABLE 2
LIST OF SELECTED VISAS BY WATER MANAGEMENT DISTRICT

LOCATION	AQUIFER	LAND USE	AREA (mi2)
ALACHUA COUNTY:			
1) Gainesville	Surficial	Mixed Urb./Suburb.	20
NORTHWEST FLORIDA WMD:			
1) Pensacola	Sand & Gravel	Heavy Industrial	10
2) Gulf Breeze	Sand & Gravel	Mixed Urb./Suburb.	- 10
3) SW Tallahassee	Surficial & Floridan	Light Industrial	- 15
4) NE Jackson Co.	Unconfined Floridan	Cropland Agricul.	-120
5) Panama City	Surficial	Mixed Urban/Ind.	25
ST. JOHNS RIVER WMD:			
1) Palm Bay	Surficial	Single Family	8
2) N. Lake Apopka	surficial	Cropland Agricul.	39
3) Jax. Talleyrand	Surficial	Heavy Industrial	3
4) Ocala	Unconfined Floridan	Urban/Suburban	3
SOUTH FLORIDA WMD:			
1) NE Dade Co.	Biscayne	Heavy Industrial	6
2) NE Broward Co.	Biscayne	Mixed Urban/Ind.	16
3) 5. Orange Co.	Surficial	Mixed Urban/Ind.	28
4) Martin Co.	Surficial	Orchards, Citrus	30
5) S. Lee Co.	Surficial	Single-Family	6
SOUTHWEST FLORIDA WMD:			
1) E. Polk Co.	Surficial	Orchards, Citrus	20
2) E. Polk Co.	Floridan	Orchards, Citrus	20
3) NE Hillsborough	Surficial & Floridan	Single-Family	20
4) Pinellas Co.	Surficial	Light Industrial	7
SUWANNEE RIVER WMO:			
1) Live Oak	Unconfined Floridan	Mixed Urban/Ind.	- 10
2) Lafayette Co.	Unconfined Floridan	Crop. Ag./Dairies	- 30

NOTES, TABLE 1:

1 Methods are from Standard Methods for the Examination of Water and Wastewater, 15th edition (American Public Health Association, 1980), or from the Florida Department of Environmental Regulation's Supplement "A" to Standard Operating Procedures and Quality Assurance Manual (1981).

2 Other approved methods with the same or better minimum detection limits, accuracy and precision are also acceptable.

* A subset of approximately 100 Background Network wells is being sampled for radon and/or radium.

Data generated by the Ground Water Quality Monitoring Program can be used to determine protective measures for water quality and quantity for a variety of practical applications. Example applications include:

1. Land use planning and zoning decisions;
2. Development of Local Government Comprehensive Plans;
3. Protection of the quality and quantity of public water supplies;
4. Prediction of saltwater intrusion due to excessive fresh-water withdrawal in fields and coastal areas;
5. Surface-water/ground-water co-management;
6. Mapping of potential aquifer system vulnerability;
7. Development of aquifer resource management strategies and protection.

A GEOLOGICAL OVERVIEW OF FLORIDA

By
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Introduction

The State of Florida lies principally on the Florida Platform. The western panhandle of Florida occurs in the Gulf Coastal Plain to the northwest of the Florida Platform. This subdivision is recognized on the basis of sediment type and depositional history. The Florida Platform extends into the northeastern Gulf of Mexico from the southern edge of the North American continent. The platform extends nearly four hundred miles north to south and nearly four hundred miles in its broadest width west to east as measured between the three hundred foot isobaths. More than one- half of the Florida Platform lies under water leaving a narrow peninsula of land extending to the south from the North American mainland.

A thick sequence of primarily carbonate rocks capped by a thin, siliciclastic sediment-rich sequence forms the Florida Platform. These sediments range in age from mid-Mesozoic (200 million years ago [mya]) to Recent. Florida's aquifer systems developed in the Cenozoic sediments ranging from latest Paleocene (55 mya) to Late Pleistocene (<100,000 years ago) in age (Figure 4). The deposition of these sediments was strongly influenced by fluctuations of sea level and subsequent subaerial exposure. Carbonate sediment deposition dominated the Florida Platform until the end of the Oligocene Epoch (24 mya). The resulting Cenozoic carbonate sediment accumulation ranges from nearly two thousand feet thick in northern Florida to more than five thousand feet in the southern part of the state. These carbonate sediments form the Floridan aquifer system, one of the world's most prolific aquifer systems, regional intra-aquifer confining units and the sub-Floridan confining unit. The sediments supradjacent to the Floridan aquifer system include quartz sands, silts, and clays (siliciclastics) with varying admixtures of carbonates as discrete beds and sediment matrix. Deposition of these sediments occurred from the Miocene (24 mya) to the Recent. The Neogene (24 mya to 1.6 mya) and Quaternary (1.6 mya to the present) sediments form the intermediate aquifer system and/or confining unit and the surficial aquifer system (Figure 4).

Geologic History

Florida's basement rocks, those rocks older than Early Jurassic (>200 mya), are a fragment of the African Plate which remained attached to the North American Plate when the continents separated in the mid-Mesozoic. This fragment of the African Plate provided the base for the development of a carbonate platform which included the Bahama Platform and the Florida Platform (Smith, 1982). The Florida Straits separated the Bahama Platform from the Florida Platform by the beginning of the Late Cretaceous (approximately 100 mya) (Sheridan et al., 1981).

Carbonate sediments dominated the depositional environments from the mid-Mesozoic (approximately 145 mya) in southern and central Florida and from the earliest Cenozoic (approximately 62 mya) in northern and the eastern panhandle Florida. Carbonate sedimentation predominated in the Paleogene (67 to 24 mya) throughout most of Florida. Evaporite sediments, gypsum, anhydrite and some halite (salt), developed periodically due to the restriction of circulation in the carbonate depositional environments. The evaporites are most common in the Mesozoic and the Paleogene carbonates at and below the base of the Floridan aquifer system, where they help form the impermeable sub-Floridan confining unit.

During the early part of the Cenozoic, the Paleogene, the siliciclastic sediment supply from the north, the Appalachian Mountains, was limited. The mountains had eroded to a low level through millions of years of erosion. The minor amount of sediment reaching the marine environment was washed away from the Florida Platform by currents in the Gulf Trough (Suwannee Straits) (Figures 5a and b). This effectively protected the carbonate depositional environments of the platform from the influx of the siliciclastic sediments. As a result, the carbonates of the Paleogene section are very pure, with extremely limited quantities of siliciclastic sediments. In the central and western panhandle areas, which are part of the Gulf Coastal Plain, siliciclastic deposition continued well into the Paleogene. Significant carbonate deposition did not begin in this area until the Late Eocene (40 mya). During the later Eocene, as the influx of siliciclastics declined dramatically, carbonate depositional environments developed to the north and west of the limits of the Florida Platform. Carbonate deposition was continuous in the central panhandle and intermittent in the western panhandle through the Late Oligocene (approximately 28 mya).

During the Late Oligocene to Early Miocene, an episode of renewed uplift occurred in the Appalachians (Stuckey, 1965). With a renewed supply of sediments being eroded and entering the fluvial transport systems, siliciclastic sediments flooded the marine environment near the southeastern North American coastline. The influx of massive quantities of these sediments filled the Gulf Trough and encroached onto the carbonate platform through longshore transport, currents and other means. At first, the sands and clays were mixed with the carbonate sediments. Later, as more and more siliciclastics were transported south, the carbonate sediment deposition declined to only limited occurrences. Siliciclastic sediments, with varying amounts of carbonate in the matrix, dominated the depositional environments. The carbonate depositional environments were pushed further to the south until virtually the entire platform was covered with sands and clays. The influx of siliciclastics has diminished somewhat during the later Pleistocene and the Recent resulting in carbonate deposition occurring in limited areas around the southern portion of the Florida Platform.

The Miocene-aged siliciclastics appear to have completely covered the Florida Platform providing a relatively impermeable barrier to the vertical migration of ground water (Stringfield, 1966; Scott, 1981). This aquiclude protected the underlying carbonate sediments from dissolution. Erosion breached the confining unit by the early Pleistocene (?) allowing aggressive waters to dissolve the underlying carbonates. The progressive dissolution of the limestones enhanced the secondary porosity of the near-surface sediments of the Floridan aquifer system and allowed the development of numerous karst features.

Karst features formed in the Florida peninsula at least as early as the latest Oligocene as determined from the occurrence of terrestrial vertebrate faunas (MacFadden and Webb, 1982). Based on subsurface data from the interpretation of FGS cores, it appears that the development of karst in Florida occurred during the Paleogene. Unpublished work by Hammes and Budd (progress report to the FGS, U. Hammes and D. Budd, University of Colorado, 1990) indicates the occurrence of numerous "intraformational disconformities" which resulted in the development of "karst, caliche and other subaerial exposure features...". These disconformities were the result of sea level fluctuations on a very shallow water, carbonate bank depositional environment. At this time there is no documentation of large scale karst features forming during these episodes of exposure.

Structure

The oldest structures recognized as affecting the deposition of sediments of the Florida Platform are expressed on the pre-Middle Jurassic erosional surface (Arthur, 1988). These include the Peninsular Arch, South Florida Basin, Southeast Georgia Embayment, Suwannee Straits and the Southwest Georgia Embayment or Apalachicola Embayment (Figure 5a). These structures affected the deposition of the Mesozoic sediments and the Early Cenozoic (Paleogene) sediments. The structures recognized on the top of the Paleogene section are somewhat different than the older features. The younger features, which variously affected the deposition of the Neogene and Quaternary sediments, include the Ocala Platform, Sanford High, Chattahoochee Anticline, Apalachicola Embayment, Gulf Trough, Jacksonville Basin (part of the Southeast Georgia Embayment), Osceola Low and the Okeechobee Basin (Figure 5b). For more specific information on these structures and their origins refer to Chen (1965), Miller (1986) and Scott (1988a).

The occurrence and condition of the aquifer systems are directly related to their position with respect to the structural features. The Floridan aquifer system lies at or near the surface under poorly confined to unconfined conditions on the positive features such as the Ocala Platform, Sanford High and the Chattahoochee Anticline. Within the negative areas, (the Apalachicola Embayment, Jacksonville Basin, Osceola Basin and the Okeechobee Basin) the Floridan aquifer system is generally well confined. The intermediate aquifer system is generally absent from the positive structures and best developed in the negative areas. The surficial aquifer system may occur anywhere in relation to these structures where the proper conditions exist.

The occurrence and development of the beds confining the Floridan aquifer system also relate to the subsurface structures. On some of the positive areas (Ocala Platform and Chattahoochee Anticline) the confining beds of the intermediate confining unit are absent due to erosion and possibly nondeposition. In those areas where the confining units are breached, dissolution of the carbonate sediments developed a karstic terrain. Dissolution of the limestones enhanced the porosity and permeability of the Floridan aquifer system including the development of some cavernous flow systems.

Geomorphology

Florida's land surface is relatively flat and has very low relief. The surface features of Florida are the result of the complex interaction of depositional and erosional processes. As sea level fluctuated during the later Cenozoic, the Florida Platform has repeatedly been inundated by marine waters resulting in marine depositional processes dominating the development of Florida's geomorphology. The relict shoreline features found throughout most of the state are most easily identified at lower elevations, nearer the present coastline. Inland and at higher elevations, these features have been subjected to more extensive erosion and subsequent modification by wind and water. In those areas of the state where carbonate rocks and shell-bearing sediments are subjected to dissolution, the geomorphic features may be modified by development of karst features. The extent of the modification ranges from minor sagging due to the slow dissolution of carbonate or shell to the development of large collapse sink-holes. The changes that result may make identification of the original features difficult.

White (1970) subdivided the State into three major geomorphic divisions, the northern or proximal zone, the central or mid-peninsular zone and the southern or distal zone (Figure 6). The northern zone encompasses the Northwest Florida Water Management District and the northern portions of the Suwannee River and St. Johns River Water Management Districts. The central zone includes the southern portions of the Suwannee River and St. Johns River Water Management Districts, the Southwest Florida Water Management District and the northern part of the South Florida Water Management District. The southern zone comprises the remainder of the South Florida Water Management District.

In a broad general sense, the geomorphology of Florida consists of the Northern Highlands, the Central Highlands and the Coastal Lowlands (White, Vernon and Puri in Puri and Vernon, 1964). White (1970) further subdivided these features as shown in Figures 7 thru 11. In general, the highlands are well drained while the lowlands often are swampy, poorly drained areas. The highland areas as delimited by White, Vernon and Puri in Puri and Vernon (1964) often coincide with the areas of "high recharge" as recognized by Stewart (1980). Only a few, limited areas of "high recharge" occur in the Coastal Lowlands.

Many of the highland areas in the peninsula to the central panhandle exhibit variably developed karst features. These range from shallow, broad sinkholes that develop slowly to those that are large and deep and develop rapidly (Sinclair and Stewart, 1985). The development of the karst features and basins has a direct impact on the recharge in the region. The karst features allow the rapid infiltration of surface water into the aquifer systems and offer direct access to the aquifers by pollutants.

Lithostratigraphy and Hydrostratigraphy

The aquifer systems in Florida are composed of sedimentary rock units of varying composition and induration which are subdivided into geologic formations based on the lithologic characteristics (rock composition and physical characteristics). Lithostratigraphy is the formal recognition of the defined geologic formations based on the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983). Many units are related by the similarities of the sediments while others may be defined on the sediment heterogeneity. An aquifer is a body of sediment or rock that is sufficiently permeable to conduct ground-water and to yield economically significant quantities of water to wells and springs (Bates and Jackson, 1987). Florida's primary aquifers are referred to as aquifer systems due to the complex nature of the water-producing zones they contain. The aquifer systems are identified independently from lithostratigraphic units and may include more than one formation or be limited to only a portion of a formation. The succession of hydrostratigraphic units forms the framework used to discuss the ground-water system in Florida (Figure 4) (Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986).

The lithostratigraphic and hydrostratigraphic framework of Florida shows significant variability from north to south and west to east in the peninsula and the panhandle. The formational units discussed are only those Cenozoic sediments that relate to the Floridan aquifer system, the intermediate aquifer system/confining unit and the surficial aquifer system.

LITHOSTRATIGRAPHY

The lithostratigraphic units that comprise the aquifer systems in Florida occur primarily as subsurface units with very limited surface exposures. As a result of the generally low relief of the state, virtually all the lithostratigraphic descriptions are from well cuttings and cores used to study the sediments. Geophysical logs have proven useful in studying the sediments and attempting regional correlations (Chen, 1965; Miller, 1986; Scott, 1988a; Johnson, 1984).

The following description of the lithologic parameters of the various units associated with the aquifer systems is brief and generalized. More complete information concerning these groups and formations can be obtained by referring to Florida Geological Survey and U. S. Geological Survey publications relating to specific areas and/or specific aquifers. Statewide data concerning the thickness and tops of sediments of Paleocene (67-55 mya) and Eocene (55-38 mya) age (chronostratigraphic units) can be found in Chen (1965) and Miller (1986). Miller (1986) provides this data for Oligocene (38-25 mya) and Miocene (25-5.3 mya) sediments. Scott (1988a) provides detailed information on the Miocene strata in the eastern panhandle and peninsular areas. The Plio-Pleistocene (5.3-.01 mya) and the Holocene (.01 mya-Present) sediments which make up the surficial aquifer system, are discussed in a number of references which are cited in the appropriate section of this paper. Figure 4

shows the lithostratigraphic nomenclature utilized in this text.

Cenozoic Erathem
Tertiary System
Paleocene Series

In general, most of the Paleocene sediments in the Florida peninsula form the sub-Floridan confining unit and only a limited portion of these rocks are part of the Floridan aquifer system. Siliciclastic sediments predominate in the Paleocene section in much of the panhandle (Chen, 1965; Miller, 1986). The siliciclastic sediments are composed of low permeability marine clays, fine sands and impure limestone (Miller,1986) which lie below the base of the Floridan aquifer system. Following Miller (1986), the siliciclastic sediments are referred to as "Undifferentiated Paleocene Rocks (Sediments)" and are not discussed further.

The siliciclastic sediments grade laterally into carbonate sediments across the Gulf Trough in the eastern panhandle (Chen, 1965). Carbonate sediments, mostly dolostone, occur interbedded with evaporite minerals throughout the Paleocene section in the peninsula (Chen, 1965). These sediments are included in the Cedar Keys Formation and occur throughout the peninsular area and into the eastern panhandle.

Cedar Keys Formation

The Cedar Keys Formation consists primarily of dolostone and evaporites (gypsum and anhydrite) with a minor percentage of limestone (Chen, 1965). The upper portion of the Cedar Keys consists of coarsely crystalline, porous dolostone. The lower portion of the Cedar Keys Formation contains more finely crystalline dolostone which is interbedded with anhydrite. The Cedar Keys Formation grades into the Undifferentiated Paleocene Sediments in the eastern panhandle (Miller, 1986) which equate with the Wilcox Group (Braunstein et al., 1988).

The configuration of the Paleocene sediments in peninsular Florida reflect depositional controls inherited from the pre-existing Mesozoic structures, including the Peninsular Arch, Southeast Georgia Embayment, and the South Florida Basin (Miller, 1986). The Cedar Keys Formation forms the base of the Floridan aquifer system throughout the peninsula except in the northwestern-most peninsular area where the Oldsmar Formation forms the base (Miller, 1986). The upper, porous dolostone comprises the lowest beds of the Floridan aquifer system. The lower Cedar Keys Formation is significantly less porous, contains evaporites and forms the sub-Floridan confining unit.

Eocene Series

The sediments of the Eocene Series that form portions of the Floridan aquifer system are carbonates. During the Early Eocene, deposition followed a distribution pattern similar to the Paleocene carbonate sediments. However, through the Eocene, carbonate-forming environments slowly encroached further north and west over what had been siliciclastic depositional environments during the Paleocene. The Eocene carbonate sediments are placed in the Oldsmar Formation, Avon Park Formation and the Ocala Group. The Eocene carbonate sediments comprise a large part of the Floridan aquifer system.

Claiborne Group

The Lower to Middle Eocene Claiborne Group unconformably (?) overlies the undifferentiated Lower Eocene and Paleocene sediments. The Claiborne Group consists of the Tallahatta and Lisbon Formations which are lithologically nearly identical and are not separated. The group is composed of glauconitic, often clayey sand grading into fine-grained limestone to the south (Allen, 1987). The Claiborne Group ranges from 250 to 400 feet below NGVD and is up to 350 feet thick (Allen, 1987). It is unconformably overlain by the Ocala Limestone.

Oldsmar Formation

The Oldsmar Formation consists predominantly of limestone interbedded with vuggy dolostone. Dolomitization is usually more extensive in the lower portion of the section. Pore-filling gypsum and thin beds of anhydrite occur in some places, often forming the base of the Floridan aquifer system (Miller, 1986).

The Oldsmar Formation is recognized throughout the Florida peninsula. It grades laterally in the eastern panhandle into Undifferentiated Lower to Middle Eocene sediments equivalent to the Claiborne Group. The undifferentiated sediments are marine shales, siltstones, fine sandstones and impure limestones (Miller, 1986).

Avon Park Formation

The Middle Eocene sediments of peninsular Florida as originally described by Applin and Applin (1944) were subdivided, in ascending order, into the Lake City Limestone and the Avon Park Limestone. Miller (1986) recommended the inclusion of the Lake City in the Avon Park based on the very similar nature of the sediments. Miller also changed the term limestone to formation due to the presence of significant quantities of dolostone within the expanded Avon Park Formation.

The Avon Park Formation is primarily composed of fossiliferous limestone interbedded with vuggy dolostone. In a few, limited areas of west-central Florida, evaporites are present as vug fillings in dolostone.

The Avon Park Formation occurs throughout the Florida peninsula and the eastern panhandle in a pattern very similar to the underlying Oldsmar Formation. The oldest rocks cropping out in Florida belong to the Avon Park Formation. These sediments are locally exposed on the crest of the Ocala Platform in west-central peninsular Florida.

The carbonate sediments of the Avon Park Formation form part of the Floridan aquifer system and serve to subdivide it into an upper and lower Floridan in many areas. Miller (1986) recognized that portions of the Avon Park Formation are fine-grained and have low permeability, often acting as a confining bed in the middle of the Floridan aquifer system. In Brevard County, for example, these low permeability beds are relied upon to keep less desirable water injected into the lower Floridan from migrating into the potable water of the upper Floridan.

Ocala Limestone

Dall and Harris (1892) referred to the limestones exposed in central peninsular Florida near the city of Ocala in Marion County as the Ocala Limestone. Puri (1957) raised the Ocala to group and recognized formations based on the incorporated foraminiferal faunas. As a result of the biostratigraphic nature of these subdivisions, formational recognition is often difficult. In keeping with the intent of the Code of Stratigraphic Nomenclature, in this text, the Florida Geological Survey is returning to the use of the Ocala Limestone terminology.

The lower and upper subdivisions of the Ocala Limestone are based on distinct lithologic differences. The lower subdivision consists of a more granular limestone (grainstone to packstone). The lower facies is not present everywhere and may be partially to completely dolomitized in some regions (Miller, 1986). The upper unit is composed of variably muddy (carbonate), granular limestone (packstone to wackestone with very limited grainstone). Often this unit is very soft and friable with numerous large foraminifera. In southern Florida, virtually the entire Ocala Limestone consists of a muddy (carbonate) to finely pelletal limestone (Miller,1986). Chert is a common component of the upper portion of the Ocala Limestone. The Bumpnose "Formation", a very early Oligocene fossiliferous limestone, is lithologically very similar to the Ocala Limestone. It is included in the Ocala Limestone in this report.

The sediments of the Ocala Limestone form one of the most permeable zones within the Floridan aquifer system. The Ocala Limestone comprises

much of the Floridan aquifer system in the central and western panhandle. The extensive development of secondary porosity by dissolution has greatly enhanced the permeability, especially in those areas where the confining beds are breached or absent. The Ocala Limestone forms the lower portion of the Floridan in the western panhandle (Wagner, 1982). In much of the peninsular area, it comprises all or part of the upper Floridan.

By Late Eocene, carbonate sediments were deposited significantly further to the north and west than had previously occurred during the Cenozoic. The Ocala Limestone is present throughout much of the State except where the unit has been erosionally removed. This occurs in outcrop on the crest of the Ocala Platform and in the subsurface on the Sanford High, a limited area in central Florida and a relatively large area in southernmost Florida (Miller, 1986). Chen (1965) suggests that the Ocala Limestone is also absent in a portion of Palm Beach County in eastern southern Florida. The surface and thickness of the Ocala Limestone are highly irregular due to dissolution of the limestones as karst topography developed.

Oligocene Series

The carbonate sediments of the Oligocene Series form much of the upper portion of the Floridan aquifer system in Florida. The depositional pattern of the Oligocene sediments shows that carbonate sediments were deposited well updip to the north of the Florida Platform (Miller, 1986). In the central panhandle and to the west, siliciclastic sediments began to be mixed with the carbonates.

The Oligocene sediments in peninsular Florida and part of the panhandle are characteristically assigned to the Suwannee Limestone. The Oligocene sediments in the central and western panhandle are placed in the Marianna, Bucatunna and Chickasawhay Formations (Miller, 1986). In the westernmost panhandle, the lower carbonates of the Suwannee Limestone grade into the siliciclastic Byram Formation (Braunstein et al., 1988).

Suwannee Limestone

The Suwannee Limestone consists primarily of variably vuggy and muddy (carbonate) limestone (grainstone to packstone). The occurrence of a vuggy, porous dolostone is recognized in the type area, the eastern to central panhandle and in southwest Florida. The dolostone often occurs interbedded between limestone beds.

The Suwannee Limestone is absent throughout a large area of the northern and central peninsula probably due to erosion. Scattered outliers of Suwannee Limestone are present within this area. Where it is present, the Suwannee Limestone forms much of the upper portion of the Floridan aquifer system. The reader is referred to Miller (1986) for a map of the occurrence of the Suwannee Limestone in the peninsula.

Marianna Limestone

The Marianna Limestone is a fossiliferous, variably argillaceous limestone (packstone to wackestone) that occurs in the central panhandle. It is laterally equivalent to the lower portion of the Suwannee Limestone. The Marianna Limestone forms a portion of the uppermost Floridan aquifer system in the central panhandle region.

Bucatunna Clay Member of the Byram Formation

The Bucatunna Clay Member is silty to finely sandy clay. Fossils are generally scarce in the Bucatunna (Marsh, 1966). The sand content of the Bucatunna ranges from very minor percentages to as much as 40 percent (Marsh, 1966).

The Bucatunna Clay Member has a limited distribution in the western panhandle. It occurs from the western end of the state eastward to approximately the Okaloosa-Walton County line where it pinches out (Marsh, 1966). The Bucatunna Clay Member provides an effective intra-aquifer confining unit in the middle of the Floridan aquifer system in the western panhandle.

Chickasawhay Formation

Marsh (1966) describes the Chickasawhay Formation as being composed of highly porous limestone and dolomitic limestone. This is often interbedded with porous to compact dolomitic limestone to dolostone. The Chickasawhay Formation grades into the upper Suwannee Limestone eastward. Due to difficulty in separating the Chickasawhay from the Lower Miocene limestones in the western panhandle, both Marsh (1966) and Miller (1986) included thin beds of possible Lower Miocene carbonate in the upper portion of the Chickasawhay Formation. The permeable sediments of the Chickasawhay Formation form part of the upper Floridan in the western panhandle (Wagner, 1982).

Miocene Series

The Miocene Epoch was a time of significant change in the depositional sequence on the Florida Platform and the adjacent Gulf and Atlantic Coastal Plains. During the early part of the Miocene, carbonate sediments continued to be deposited over most of the State. Intermixed with the carbonates were increasing percentages of siliciclastic sediments. By the end of the Early Miocene, the deposition of carbonate sediments was occurring only in southern peninsular Florida. Siliciclastic deposition dominated the Middle Miocene statewide with this trend continuing into the Late Miocene.

The basal Miocene carbonate sediments often form the uppermost portion of the Floridan aquifer system. The remainder of the Miocene sediments form much of the intermediate aquifer system and intermediate confining system. In some instances, these sediments may also be included in the surficial aquifer system.

Unusual depositional conditions existed during the Miocene as is evident from the occurrence of abundant phosphate, palygorskite, opaline cherts and other uncommon minerals plus an abundance of dolomite within the Hawthorn Group (Scott, 1988a). The presence of these minerals may influence ground-water quality in areas where the Miocene sediments are being weathered. Ground-water quality may also be affected where these sediments form the upper portion of the Floridan aquifer system or portions of the intermediate aquifer system.

Current geologic thought holds that in the peninsula the Miocene section is composed of the Hawthorn Group. The Tampa Formation is included as a member in the basal Hawthorn Group. In the panhandle, the Lower Miocene remains the Chattahoochee and St. Marks Formations, the Middle Miocene Alum Bluff Group and the Upper Miocene Choctawhatchee Formation and equivalents. Formations previously mentioned in the literature as being Miocene in age include the Tamiami, which is Pliocene in age, and the Miccosukee Formation which is now recognized as being Late Pliocene to possibly early Pleistocene in age.

The Miocene sediments are absent from the Ocala Platform and the Sanford High (Scott, 1988a). These sediments are as much as 800 feet thick in southwest Florida (Miller, 1986; Scott, 1988a), 500 feet thick in the northeastern peninsula (Scott, 1988a) and 900 to 1000 feet thick in the westernmost panhandle (Miller, 1 986) .

Chattahoochee Formation

The Chattahoochee Formation is predominantly a fine-grained, often fossiliferous, silty to sandy dolostone which is variable to a limestone (Huddlestun, 1988). Fine-grained sand and silt may also form beds with various admixtures of dolomite and clay minerals. Clay beds may also be common in some areas (Puri and Vernon, 1964).

The Chattahoochee Formation occurs in a limited area of the central panhandle from the axis of the Gulf Trough westward. It appears that the Chattahoochee grades to the west into a carbonate unit alternately referred to as Tampa Limestone (Marsh, 1966; Miller, 1986) or St. Marks (Puri and Vernon, 1964; NWFWMD Staff, 1975). Northward into Georgia, this unit grades

into the basal Hawthorn Group (Huddlestun, 1988). To the east of the axis of the Gulf Trough, the Chattahoochee Formation grades into the St. Marks Formation (Puri and Vernon, 1964; Scott, 1986). The gradational change between the Chattahoochee and St. Marks Formations occurs over a broad area of Leon and Gadsden Counties (Scott, 1986). The sediments of the Chattahoochee Formation comprise the upper zone of the Floridan aquifer system in the central panhandle.

St. Marks Formation

The St. Marks Formation is a fossiliferous limestone (packstone to wackestone). Sand grains occur scattered in an often very moldic limestone. The lithology of the St. Marks and the associated units in the Apalachicola Embayment and to the west are often difficult to separate (Schmidt, 1984). The St. Marks Formation lithology can be traced in cores grading into the Chattahoochee Formation (Scott, 1986). This formation forms the upper part of the Floridan aquifer system in portions of the eastern and central panhandle.

Hawthorn Group

The Hawthorn Group is a complex series of the phosphate-bearing Miocene sediments in peninsular and eastern panhandle Florida. The carbonate sediments of the Hawthorn Group are primarily fine-grained and contain varying admixtures of clay, silt, sand and phosphate. Dolostone is the dominant carbonate sediment type in the northern two-thirds of the peninsula while limestone predominates in the southern peninsula and in the eastern panhandle area.

The siliciclastic sediment component consists of fine- to coarse-grained quartz sand, quartz silt and clay minerals in widely varying proportions. The clay minerals present include palygorskite, smectite and illite with kaolinite occurring in the weathered sediments.

The top of the Hawthorn Group is a highly irregular erosional and karstic surface. This unconformable surface can exhibit dramatic local relief especially in outcrop along the flanks of the Ocala Platform. Figures 12 through 19 show the top and thickness of the Hawthorn Group sediments which comprise the intermediate aquifer system/confining unit.

In the peninsula, the Hawthorn Group can be broken into a northern section and a southern section. The northern section consists of interbedded phosphatic carbonates and siliciclastics with a trend of increasing siliciclastics in the younger sediments. In ascending order, the formations in northern Florida are the Penney Farms, Marks Head and Coosawhatchee and its lateral equivalent Statenville (Scott, 1988a). The sediments comprising these formations characteristically have low permeabilities and form an effective aquiclude, the intermediate confining unit. In a few areas, permeabilities within the Hawthorn sediments are locally high enough to allow the limited development of an intermediate aquifer system.

The southern section consists of a lower dominantly phosphatic carbonate section and an upper phosphatic siliciclastic section. In the southern area, in addition to increasing siliciclastics upsection, there is also a trend of increasing siliciclastics from west to east in the lower carbonate section. The Hawthorn Group in southern Florida has been subdivided into, in ascending order: the Arcadia Formation with the former Tampa Formation as a basal member; and the Peace River Formation (Scott, 1988a). Throughout much of south Florida these sediments have limited or low permeabilities and form an effective intermediate confining unit. However, where the Tampa Member is present and permeable enough, it may form the upper portion of the Floridan aquifer system. In portions of southwestern Florida the Hawthorn sediments are permeable enough to form several important producing zones in the intermediate aquifer system (Knapp et al.l 1986; Smith and Adams 1988) .

The Hawthorn Group, Torreya Formation sediments in the eastern panhandle are predominantly siliciclastics with limited amounts of carbonates (Scott) 1988a). In this area, carbonates become increasingly important in the Gulf Trough where the basal Hawthorn sediments are fine-grained carbonates. The siliciclastic sediments are very clayey and form an effective intermediate confining unit. The carbonate sediments may locally be permeable enough to form the upper portion of the Floridan aquifer system.

Bruce Creek Limestone

Huddlestun (1976) applied the name Bruce Creek Limestone to late Middle Miocene limestones occurring in the Apalachicola Embayment and coastal areas of the central and western panhandle. The Bruce Creek Limestone is a fossiliferous variably sandy limestone (Schmidt, 1984). This lithology becomes indistinguishable, to the east, from lithologies found in the St. Marks Formation (Schmidt, 1984). The Bruce Creek Limestone is laterally equivalent to and grades into the lower portion of the Alum Bluff Group (Schmidt, 1984). The Bruce Creek Limestone forms part of the upper Floridan aquifer system in the central and western panhandle.

Alum Bluff Group

West of the Apalachicola River in the Florida panhandle, the Hawthorn Group is replaced by the Alum Bluff Group. The Alum Bluff Group includes the Chipola Formation, Oak Grove Sand, Shoal River Formation and the Choctawhatchee Formation (Braunstein et al.l 1988). The formations included in this group are generally defined on the basis of their molluskan faunas and are of variable area, extents. These sediments can be distinguished as a lithologic entity at the group level and will be referred to as such in this text.

The Alum Bluff Group consists of clays, sands and shell beds which may vary from a fossiliferous, sandy clay to a pure sand or clay and occasional carbonate beds or lenses. The Jackson Bluff Formation is currently thought to be Late Pliocene in age; and, even though Huddlestun (1976) included it in the Alum Bluff Group, it was not included in the Alum Bluff Group on the latest correlation charts (Braunstein et al.l 1988). Sediments comprising the Jackson Bluff Formation are very similar to those making up the Alum Bluff Group.

The sediments comprising the Alum Bluff Group are generally impermeable due to the abundance of clay-sized particles. These sediments form an important part of the intermediate confining unit in the central panhandle.

Pensacola Clay

The Pensacola Clay consists of three members: lower and upper clay members and a middle sand member; the Escambia Sand (Marsh, 1966). Lithologically, the clay members consist of silty, sandy clays with carbonized plant remains (Marsh, 1966). The sand member is fine to coarse, quartz sand. Marine fossils are rarely present in the Pensacola Clay with the exception of a fossiliferous layer near the base (Clark and Schmidt, 1982). The Pensacola Clay grades laterally into the lower portion of the (Miocene Coarse Clastics) to the north and the Alum Bluff Group and the lower Intracoastal Formation to the east (Clark and Schmidt, 1982).

The Pensacola Clay forms the intermediate confining unit for the Floridan in the western panhandle. It lies immediately supradjacent to the limestones of the upper Floridan aquifer system.

Intracoastal Formation

Schmidt (1984) describes the Intracoastal Formation as a very sandy, highly microfossiliferous, poorly consolidated, argillaceous, calcarenitic limestone." Phosphate is generally present in amounts greater than one percent. This unit is laterally gradational with the Pensacola Clay and Mio-Pliocene "Coarse Clastics" (Schmidt, 1984). The lower Intracoastal Formation is Middle Miocene while the upper portion is Late Pliocene. Wagner (1982) indicates that the Intracoastal Formation forms part of the intermediate confining unit in the central to western panhandle.

Pliocene-Pleistocene Series

The sediments of the Pliocene-Pleistocene Series occur over most of the State. These sediments range from nonfossiliferous, clean sands to very fossiliferous, sandy clays and carbonates.

Lithologic units comprising this series include the 'Coarse Clastics, Tamiami Formation Citronelle Formation, Miccosukee Formation Cypresshead Formation, Nashua Formation, Caloosahatchee formation, Fort Thompson Formation, Key Largo Limestone, Miami Limestone, Anastasia Formation and Undifferentiated Pleistocene-Holocene sediments. The upper portion of the Intracoastal Formation is Pliocene and is discussed with the lower Intracoastal Formation under the Miocene Series.

"Coarse Clastics"

The name "Coarse Clastics" has been applied to sequences of quartz sands and gravels in a number of areas around Florida. These sediments are often referred to in the literature as "Miocene Coarse Clastics" (for example) Puri and Vernon 1 964)

In northern Florida, these sediments are referred to as the Cypresshead Formation of Late Pliocene to Early Pleistocene age (Scott, 1988b). In southern Florida Knapp et al. (1986) referred to these sediments as the (Miocene Coarse Clastics) and placed them in the Hawthorn Group. In the panhandle, Marsh (1966) mentions the"Miocene Coarse Clastics" as sands and gravel with some clay which underlie the Citronelle Formation.

In the panhandle, the "Coarse Clastics" are variably clayey sands with gravel and some shell material (Clark and Schmidt, 1982). These siliciclastics occur in Escambia, Santa Rosa and western Okaloosa Counties in the western panhandle. They equate in part to the upper part of the Pensacola Clay, part of the Intracoastal Formation and part of the Alum Bluff Group.

In southern peninsular Florida the coarse siliciclastics are fine to very coarse quartz sands with quartz gravel and variable amounts of clay, carbonate and phosphate. These sediments may equate with the Cypresshead Formation sediments in central and northern Florida.

These siliciclastic sediments form important aquifer systems in portions of southern and panhandle Florida. In the western panhandle, the "Coarse Clastics" form a portion of the Sand-and-Gravel aquifer, part of the surficial aquifer system. These sediments also comprise a portion of the surficial aquifer system in the peninsular area, especially in southern Florida.

Tamiami Formation

The Tamiami Formation consists of the Pinecrest Sand Member; the Ochopee Limestone Member; and the Buckingham Limestone Member (Hunter, 1968). The various facies of the Tamiami occur over a wide area of southern Florida. The relationships of the facies are not well known due to: 1- the complex set of depositional environments that were involved in the formation of the sediments and 2- the Tamiami Formation most often occurs as a shallow subsurface unit throughout much of its extent. Many of the facies are important from a hydrogeologic perspective in an area of ground-water problems.

The limestone in the Tamiami Formation occurs as two types: 1- a moderately to well- indurated, slightly phosphatic, variably sandy, fossiliferous limestone (Ochopee) and 2- a poorly indurated to unindurated, slightly phosphatic, variably sandy, fossiliferous limestone (Buckingham). The sand facies is often composed of a variably phosphatic and sandy, fossiliferous, calcareous, quartz sand often containing abundant, well-preserved mollusk shells (Pinecrest). The sand varies from a well-sorted, clean sand with abundant well-preserved shells and traces of silt- sized phosphate in the type Pinecrest Sand Member (Hunter, 1968) to a clayey sand with sand-sized phosphate, clay-sized carbonate in the matrix and abundant, well preserved mollusk shells. Siliciclastic sediments (undifferentiated) of this age appear to occur along the eastern side of the peninsula but have not been assigned to the Tamiami Formation.

Sediments of the Tamiami Formation exhibit variable permeabilities and form the lower Tamiami aquifer and Tamiami confining beds of the surficial aquifer system (Knapp et al., 1986). Smith and Adams (1988) indicate that the upper Tamiami sediments form the basal portion of the water table aquifer overlying the Tamiami confining beds.

Citronelle Formation

The Citronelle Formation is composed of fine to very coarse siliciclastics. The name was extended to include the siliciclastics comprising the central ridge system in the Florida peninsula by Cooke (1945). As it is currently recognized, the Citronelle Formation occurs only in the panhandle. The unit is recognized from central Gadsden County on the east to the western boundary of the State. The Citronelle Formation is composed of very fine to very coarse, poorly sorted, angular to subangular quartz sand. The unit contains significant amounts of clay, silt and gravel which may occur as beds, lenses or stringers and may vary rapidly over short distances. Limonite nodules and limonitic cemented zones are common .

The Citronelle Formation extends over much of the central and western panhandle. Previous investigators encountered problems in the separation of the Citronelle and the overlying terrace deposits and generally considered the thickness of the Citronelle including these younger sediments (Marsh, 1966; Coe, 1979). The Citronelle Formation grades laterally into the Miccosukee Formation through a broad transition zone in Gadsden County. The Citronelle Formation forms an important part of the Sand-and-Gravel aquifer in the western panhandle and produces up to 2,000 gallons of water per minute (Wagner, 1982).

Miccosukee Formation

Hendry and Yon (1967) describe the Miccosukee Formation as consisting of interbedded and cross-bedded clay, silt, sand and gravel of varying coarseness and admixtures. Limonite pebbles are common in the unit. The Miccosukee Formation occurs in the eastern panhandle from central Gadsden County on the west to eastern Madison County on the east. Due to its clayey naturel the Miccosukee Formation does not produce significant amounts of water. It is generally considered to be part of the surficial aquifer system (Southeastern Geological Society 1 986) .

Cypresshead Formation

The name Cypresshead Formation was first used by Huddlestun (1988). It was extended into Florida by Scott (1988b). The Cypresshead Formation is composed entirely of siliciclastics; predominantly quartz and clay minerals. The unit is characteristically a mottled, fine- to coarse-grained, often gravelly, variably clayey quartz sand. As a result of weathering, the clay component of these sediments has characteristically been altered to kaolinite. Clay serves as a binding matrix for the sands and gravels. Clay content may vary from absent to more than fifty percent in sandy clay lithologies although the average clay content is 10 to 20 percent. These sediments are often thinly bedded with zones of cross bedding. The Cypresshead Formation appears to occur in the Central Highlands of the peninsula south to northern Highlands County, although the extent of the Cypresshead Formation has not been accurately mapped in this area. This unit may locally comprise the surficial aquifer system where clay content is low.

Nashua Formation

The Nashua is a fossiliferous, variably calcareous, sometimes clayey, quartz sand. The fossil content is variable from a shelly sand to a shell hash. The dominant fossils are mollusks.

The extent of the Nashua in northern Florida is not currently known. It extends some distance into Georgia and appears to grade laterally into the Cypresshead Formation (Huddlestun, 1988). The Nashua Formation may produce limited amounts of water in localized areas where it forms part of the surficial aquifer system.

Caloosahatchee Formation

The Caloosahatchee Formation consists of fossiliferous quartz sand with variable amounts of carbonate matrix interbedded with variably sandy, shelly limestones. The sediments vary from non-indurated to well indurated. The fauna associated with these sediments are varied and often well preserved. Fresh water limestones are commonly present within this unit.

Sediments identified as part of the Caloosahatchee Formation by various investigators occur from north of Tampa on the west coast south to Lee County, eastward to the East Coast then northward into northern Florida (DuBar, 1974). The Caloosahatchee Formation as used here includes those sediments informally referred to as the Bermont Formation (DuBar 1974).

In most hydrogeologic investigations of southern Florida the Caloosahatchee Formation is not differentiated from the Fort Thompson Formation and other faunal units. The undifferentiated sediments form much of the surficial aquifer system.

Fort Thompson Formation

The Fort Thompson Formation consists of interbedded shell beds and limestones. The shell beds are characteristically variably sandy and slightly indurated to unindurated. The sandy limestones present in the Fort Thompson Formation were deposited under both freshwater and marine conditions. The sand present in these sediments is fine- to medium-grained. The sediments of Fort Thompson age in central Florida along the east coast, consist of fine to medium quartz sand with abundant mollusk shells and a minor but variable clay content.

The Fort Thompson Formation, as the Caloosahatchee Formation, is part of the undifferentiated sediments in southern Florida. It forms a portion of the surficial aquifer system.

Key Largo Limestone

The Key Largo Limestone is a coralline limestone composed of coral heads encased in a matrix of calcarenite (Stanley, 1966). Hoffmeister and Multer (1968) indicate that the Key Largo Limestone occurs in the subsurface from as far north as Miami Beach to as far south as the Lower Keys. The fossil reef tract represented by the Key Largo sediments may be as much as 8 miles wide (DuBar, 1974). Near the northern and southern limits of the Key Largo Limestone, it is overlain conformably by the Miami Limestone with which the Key Largo is, in part, laterally equivalent.

The Key Largo Limestone forms a part of the Biscayne aquifer of the surficial aquifer system. The Biscayne aquifer provides water for areas of Dade, Broward and Monroe Counties.

Miami Limestone

The Miami Limestone includes an oolitic facies and a bryozoan facies. The bryozoan facies underlies and extends west of the western boundary of the oolitic facies. The bryozoan facies consists of calcareous bryozoan colonies imbedded in a matrix of ooids, pellets and skeletal sand. It generally occurs as a variably sandy, recrystallized, fossiliferous limestone (Hoffmeister et al.l 1967). The oolitic facies consists of variably sandy limestone composed primarily of oolites with scattered concentrations of fossils.

Hoffmeister et al. (1967) indicate that the Miami Limestone covers Dade County, much of Monroe County and the southern part of Broward County. It grades laterally to the south into the Key Largo Limestone and to the north into the Anastasia Formation. The oolitic facies underlies the Atlantic Coastal Ridge southward from southern Palm Beach County to southern Dade County.

The Miami Limestone forms a portion of the Biscayne aquifer of the surficial aquifer system. It is very porous and permeable due to the dissolution of carbonate by ground water as it recharges the aquifer system.

Anastasia Formation

The Anastasia Formation consists of interbedded quartz sands and coquinoid limestones. The sand beds consist of fine to medium- grained, variably fossiliferous, calcareous, quartz sand. The contained fossils are primarily broken and abraided mollusk shells. The limestone beds, commonly called coquina, are composed of shell fragments, scattered whole shells and quartz sand enclosed in a calcareous matrix, usually sparry calcite cement.

The Anastasia Formation forms the Atlantic Coastal Ridge through most of its length (White, 1970). Natural exposures of this unit occur scattered along the east coast from St. Augustine south to southern Palm Beach County near Boca Raton. South of this area the Anastasia Formation grades into the Miami Limestone. Cooke (1945) felt that the Anastasia Formation extended no more than three miles inland from the Intracoastal Waterway. Field work by this author (Scott) suggests that the Anastasia may extend as much as 10 miles Inland; although, Schroeder (1954) suggests that this unit may occur more than 20 miles Inland.

The Anastasla Formation forms a portion of the surficial aquifer system along the eastern coast of the state. Ground water Is withdrawn from the Anastasia Formation In many areas along the Atlantic Coastal Ridge where, locally, it may be the major source of ground water. Near the southern extent of the Anastasia Formation, it forms a portion of the Biscayne aquifer (Hoffmeister, 1974).

Undifferentiated Pleistocene-Holocene Sediments

The sediments referred to as the undifferentiated Pleistocene-Holocene sediments" cover much of Florida effectively hiding most older sediments. Included in this category are marine "terrace" sediments, eolian sand dunes, fluvial deposits, fresh water carbonates, peats and a wide variety of sediment mixtures. These sediments often occur as thin layers overlying older formations and are not definable as formations. As such, these sediments have been referred to by many different names including Pliocene to Recent sands, Pleistocene sands, Pleistocene Terrace Deposits.

The sediments incorporated In this category are most often quartz sands. The sands range from fine- to coarse-grained, nonindurated to poorly Indurated and nonclayey to slightly clayey. Gravel may be present In these sediments in the panhandle area. Other sediments included in this group include peat deposits, some clay beds, and freshwater carbonates. The freshwater carbonates occur in many freshwater springs and In large areas of the Everglades.

Locally, these sediments may form a portion of the surficial aquifer system. The greatest thicknesses of these sediments occurs infilling paleokarst features where more than 300 feet of undifferentiated Pleistocene-Holocene sediments have been recorded (Florida Geological Survey, unpublished well data).

HYDROSTRATIGRAPHY

The hydrostratigraphy of the Florida Platform has been the focus of numerous investigations by the various water management districts, the USGS and the FGS. The hydrostratigraphic framework recognized in Florida consists of a thick sequence of Cenozoic sediments which comprise the Floridan aquifer system, the intermediate aquifer system/confining unit and the surficial aquifer system (Figure 4) (Southeastern Geological Society Ad Hoc Committee, 1986). The Floridan aquifer system underlies much of the State, providing abundant potable water for a rapidly expanding population (Figure 20). In limited areas throughout the State, the intermediate aquifer system is utilized. Water is also withdrawn from the surficial aquifer system in many areas particularly in the western panhandle and southern Florida. As an example, Figure 21 illustrates the extent and occurrence of ground-water systems in the NWFWMD area of the panhandle.

The hydrologic parameters of each aquifer system vary widely from one area of the state to another as do the lithologies of the sediments. Hydrologic subdivisions do not have to conform to the lithostratigraphic framework.

Each water management district has identified surface-water basins and ground- water areas. The surface-water basins (Figures 22 through 26) delineate the areas influenced by the tributaries of the major drainage features. The ground-water areas (Figures 27 through 31) were delineated as convenient study areas. Maps representing the potentiometric surface of the Floridan aquifer system were constructed for each district (Figures 32 through 36).

Surficial aquifer system

The surficial aquifer system is defined by the Southeastern Geological Society (SEGS) Ad Hoc Committee on Florida Hydro-stratigraphic Unit Definition (1986) as "the permeable hydrologic unit contiguous with the land surface that is comprised principally of unconsolidated to poorly indurated, siliciclastic deposits. It also includes well-indurated carbonate rocks, other than those of the Floridan aquifer system where the Floridan is at or near land surface. Rocks making up the surficial aquifer system belong to all or part of the Upper Miocene to Holocene Series. It contains the water table, and the water within it is under mainly unconfined conditions; but beds of low permeability may cause semi- confined or locally confined conditions to prevail in its deeper parts. The lower limit of the surficial aquifer system coincides with the top of the laterally extensive and vertically persistent beds of much lower permeability".

Some areas of the state rely heavily upon the surficial aquifer system for potable water in areas where the water quality of the Floridan aquifer system is poor. The two main aquifers of the surficial aquifer system to which names have been applied are the Sand and Gravel Aquifer of northwestern panhandle Florida and the Biscayne Aquifer in southeastern Florida. The distribution of these aquifers is limited (Figure 20). Maps delineating the thickness of the surficial aquifer system were provided by the Northwest Florida Water Management District (NWFWMD) (Figure 37) and the Southwest Florida Water Management District (SWFWMD) (Figure 38). The South Florida Water Management District provided a map of the base of the surficial aquifer system (Figure 39). Figure 40 depicts those areas of the SJRWMD where the surficial aquifer system is a primary groundwater supplier.

The surficial aquifer system is composed of Pliocene to Holocene quartz sands, shell beds and carbonates (Figure 4). In the Florida panhandle, these units include the Citronelle and Miccosukee Formations and undifferentiated sediments. In the northern portion of the peninsula, sediments belonging to the Anastasia Formation, Cypresshead Formation and Undifferentiated Sediments, which include shell beds and limestones that are time equivalent to the Caloosahatchee and Fort Thompson Formations, comprise the surficial aquifer system. In southern Florida, the surficial aquifer system consists of the Tamiami, Caloosahatchee, Fort Thompson, and Anastasia Formations, the Key Largo and Miami Limestones and the undifferentiated sediments. Following the definition of the Tamiami as proposed by Hunter and Wise (1980), the portion of the Tamiami previously considered to be the lower Tamiami confining unit now forms the upper part of the Hawthorn Group of the intermediate confining unit. Where a clay bed separates the upper and lower limestones of the Tamiami, as in Hendry County (Smith and Adams, 1988), the clay bed is recognized as a thin confining unit within the surficial aquifer system.

Intermediate aquifer system/confining unit

The SEGS (1986) defines the intermediate aquifer system/confining unit as "all rocks that lie between and collectively retard the exchange of water between the overlying surficial aquifer system and the underlying Floridan aquifer system. These rocks in general consist of fine-grained siliciclastic deposits interlayered with carbonate strata belonging to all or parts of the Miocene and younger series. In places, poorly-yielding to non-water-yielding strata mainly occur and there the term "intermediate confining unit" applies. In other places, one or more low- to moderate-yielding aquifers may be interlayered with relatively impermeable confining beds; there the term "intermediate aquifer system" applies. The aquifers within this system contain water under confined conditions.

The top of the intermediate aquifer system/confining unit "coincides with the base of the surficial aquifer system. The base of the intermediate aquifer or confining unit, is at the top of the vertically persistent, permeable, carbonate section that comprises the Floridan aquifer system, or, in other words, that place in the section where siliciclastic layers of significant thickness are absent and permeable carbonate rocks are dominant. Where the upper layers of the persistent carbonate section are of low permeability, they are part of either the intermediate aquifer system or intermediate confining unit, as applicable to the area."

The sediments comprising the intermediate aquifer system/confining unit exhibit wide variability over the state. In the central and western panhandle, this section acts principally as an intermediate confining unit for the Floridan aquifer system. The formations belonging to the intermediate confining unit include the Alum Bluff Group, Pensacola Clay, Intracoastal Formation, and the Chipola Formation (SEGS, 1986). In the eastern panhandle, the confining unit includes primarily the Hawthorn Group sediments. Figures 41 and 42 show the top and thickness of the intermediate confining unit in the NWFWMD area while Figures 12 and 13 show the top and thickness of the Hawthorn Group sediments in the eastern part of the District. In the northern peninsula, the Hawthorn Group sediments form the intermediate confining unit with minor occurrences of aquifer zones (Figures 14 through 17). In the southern peninsula, the Hawthorn Group sediments form both an intermediate confining unit and an intermediate aquifer system. The top and thickness of the intermediate aquifer system/confining unit in the SWFWMD area is shown in Figures 43 and 44. The top and isopach of the Hawthorn Group sediments in southern Florida (SWFWMD and SFWMD) are shown on Figures 18 and 19. In many areas of the state, impermeable carbonates of Eocene and Oligocene age may form the base of the intermediate confining unit. Conversely, permeable carbonates occurring at the base of the Hawthorn Group may be hydraulically connected to the Floridan aquifer system and locally form the top of the Floridan.

The intermediate aquifer system plays a very important role in the ground-water resources of southwestern peninsular Florida. In the Lee County and surrounding areas, the intermediate aquifer system provides relatively large quantities of potable water. The Hawthorn Group may contain two producing zones (Wedderburn et al., 1982) referred to as the mid-Hawthorn aquifer and the sandstone aquifer. Figure 45 illustrates the top of the mid-Hawthorn confining zone in Lee County. Figure 46 delineates the base of the sandstone aquifer while Figure 47 shows the top of the mid-Hawthorn aquifer.

The intermediate confining unit occurs widespread in the state providing an effective aquiclude for the Floridan aquifer system. On the crests of the Ocala Platform, Sanford High, St. Johns Platform, Brevard Platform and the Chattahoochee Anticline (Figure 4) these beds are absent due to erosion. In these areas, surface water has a direct avenue to recharge the Floridan aquifer system. Immediately surrounding these areas, the intermediate confining unit is present but is breached by karst features which also allow surface water and water from the surficial and intermediate aquifer systems direct access to the Floridan. In the west-central portion of the peninsula and along the west coast from Hillsborough County into the eastern panhandle, the intermediate confining unit is generally absent and the Floridan aquifer system occurs unconfined. In the east-central peninsula, the intermediate confining unit is thin and provides only limited confinement for the underlying Floridan aquifer system. Miller (1986) mapped a maximum thickness of the intermediate confining unit as being greater than 1000 feet thick in the western-most panhandle and in southwestern Florida.

Floridan aquifer system

The Floridan aquifer system is one of the world's most productive aquifers. The sediments that comprise the aquifer system underlie the entire state although potable water is not present everywhere (Figure 20).

The Floridan aquifer system may occur as a continuous series of vertically connected carbonate sediments or may be separated by sub-regional to regional confining beds (Miller, 1986). Often the confining beds consist of low permeability carbonates. In the western panhandle, the intra-aquifer confining unit is the Bucatunna Clay. Elsewhere, the confining beds are carbonate sediments belonging to the Ocala Limestone, Avon Park Formation or the Oldsmar Formation. When intra~aquifer confining beds are present, the Floridan aquifer system can be subdivided into an upper and lower Floridan. Figures 48 through 51

indicate the configuration of the top and the thickness of the upper and lower limestones of the Floridan aquifer system. Figures 52 and 53 reveal the top and thickness of the Bucatunna Clay, the intra-aquifer confining unit in the western panhandle. Figure 54 shows the top of the lower Floridan aquifer system in the SJRWMD area.

The Floridan aquifer system in peninsular Florida and the eastern panhandle is composed of all or parts of the Cedar Keys Formation, Oldsmar Formation, Avon Park Formation, Ocala Limestone, Suwannee Limestone, St. Marks Formation and, possibly, the basal carbonates of the Hawthorn Group in limited areas of the state (Figure 4). The Floridan aquifer system encompasses the Ocala Limestone, Marianna Limestone, Suwannee Limestone, Chickasawhay Limestone, Chattahoochee Formation, St. Marks Formation and ~bruce Creek Limestone (Figure 4) in the central and western panhandle.

The elevation of the upper surface of the Floridan aquifer system is directly related to the positioning on the major structural features (Figure 5). The top of the Floridan aquifer system ranges in elevation from greater than +100 feet NGVD on the Ocala Platform and Chattahoochee Arch to more than -1400 feet NGVD in the western-most panhandle and more than -1100 feet NGVD in the Okeechobee Basin of southern Florida (Figures 55 through 59). The thickness of the Floridan aquifer system (including those areas where water from the Floridan aquifer system may not be potable) varies from less than 100 feet along the state line in north-central panhandle to more than 3000 feet in the Apalachicola Embayment and 3400 feet in southern peninsular Florida (Figures 60 through 64). The base of the Floridan aquifer system in the NWFWMD area is shown in Figure 65.

The degree of confinement of the Floridan aquifer system also varies in relation to the position of the major structural features. The Floridan may be unconfined or semiconfined on the major features including the Ocala Platform and the Chattahoochee Anticline (Figures 66 through 68). In the negative areas such as the Jacksonville Basin, Okeechobee Basin and the Gulf Coast Basin, the Floridan aquifer system is well confined. Many areas of central peninsular Florida and in the eastern panhandle exhibit the development of karst features that breach the confining unit allowing localized recharge to occur. Figure 69 illustrates the NWFWMD area karst development. Throughout most of southern Florida, particularly the SFWMD area, the Floridan aquifer system occurs under confined conditions. The thickness of the beds confining the Floridan aquifer system in the SWFWMD area is shown in Figure 70.

Recharge to the Floridan aquifer system is directly related to the confinement of the system. The highest recharge rates occur where the Floridan is unconfined or poorly confined as in those areas where the Floridan aquifer system is at or near land surface (Figure 71). Recharge may also be high in areas where the confining layers are breached by karst features as shown for the NWFWMD area (Figure 69). Figures 72 through 76 indicate the relative recharge rates around the state.

The potentiometric surface of the Floridan aquifer system varies widely throughout the state. In localized areas, the potentiometric surface may be affected by intensive pumpage of ground water. Figures 32 through 36 Indicate the elevation of this surface relative to NGVD. In those areas where the potentiometric surface is higher than the ground elevation, artesian conditions occur. Figures 77 through 82 delineate the areas where artesian flow is expected based on current data.

The intrusion of saline waters into fresh water producing zones is a major concern for Florida's coastal, and some inland, communities. Excessive pumpage of fresh water may draw the saline waters laterally or may cause an upconing of underlying nonpotable water. The salt water that can affect the potable water supply may be connate water trapped during the deposition of the sediments forming the aquifer system. It may represent saline waters that entered the aquifer system during previous high sea level stands which have not been flushed from the aquifer.

The limits of salt water intrusion are shown on Figures 83 through 86.

The Claiborne aquifer occurs in a limited area of the central-northern panhandle. It is a permeable portion of the sub-Floridan Confining Unit in that area. It is poorly defined and rarely used at this time (Allen, 1987).

CONCLUSION

This volume presents a review of the current knowledge of the Cenozoic lithostratigraphy and hydrostratigraphy as it relates to ground water in Florida. This publication represents the efforts of the five water management districts, the Department of Environmental Regulation and the Florida Geological Survey, Department of Natural Resources to provide a geologic framework of the state's ground-water resources. Recognition of the geologic framework of the aquifer systems and confining units is imperative for determining and understanding the ambient ground-water quality in Florida. Through recognizing the geologic frame-work, areas that are particularly sensitive to pollution may be defined and proper ground-water management techniques can be applied to protect these resources.

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APPENDIX 1
Additional Sources of Information

ALACHUA COUNTY DEPARTMENT OF ENVIRONMENTAL SERVICES
#1 Southwest 2nd Place
Gainesville, Florida 32606
(904) 336-2442

DADE COUNTY DEPARTMENT OF ENVIRONMENTAL RESOURCE MANAGEMENT
111 Northwest 1st Street
Suite 1310
Miami, Florida 33128
(305) 375-3318

FLORIDA DEPARTMENT OF ENVIRONMENTAL REGULATION
Bureau of Drinking Water and Ground Water Resources
Ground Water Quality Monitoring Section
2600 Blair Stone Road
Tallahassee, Florida 32399
(904) 488-3601

NORTHWEST FLORIDA WATER MANAGEMENT DISTRICT
Route 1, Box 3100
Havana, Florida 32333
(904) 539-5999

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT
P.O. Box 1429
Palatka, Florida 32078
(904) 328-8321

SOUTH FLORIDA WATER MANAGEMENT DISTRICT
P.O. Box 24680
3301 Gun Club Road
West Palm Beach, Florida 33416
(407) 694-0546

SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT
Tampa Service Office
7601 U.S. 301 North
Tampa, Florida 33637
(813) 985-7481

SUWANNEE RIVER WATER MANAGEMENT DISTRICT
Route 3, Box 64
Live Oak, Florida 32060
(904) 362-1001

Database and Software Distributors

FLORIDA SUMMARY MAPPING SYSTEM (FSMS) -
Land Use Database:

Automated Resource Mapping & Analysis Systems Integration
(ARMASI, Inc.)
P.O. Box 13027
Gainesville, Florida 32607
(904) 462-2955

WELL LOG DATA SYSTEM (WLDS)
Well Log Analysis Software:
GeoLogic Information Systems
P.O. Box 15224
Gainesville, Florida 32604
(904) 338-1128

Well Log Data can be obtained from:

FLORIDA GEOLOGICAL SURVEY
903 West Tennessee Street
Tallahassee, Florida 32304-7700
(904) 488-9380

GENERALIZED WELL INFORMATION SYSTEM
(GWIS), DERMAP (Integral Mapping Package for GWIS, WLDS, FSMS), Ground Water Quality Data (GWIS or dBASE 111 + format):

Florida Department of Environmental Regulation
Bureau of Drinking Water and Ground Water Resources
Ground Water Quality Monitoring Section
2600 Blair Stone Road
Tallahassee, Florida 32399-2400
(904) 488-3601

Computer Bulletin Board System (904) 487-3592

* The BBS (Computer Bulletin Board) allows access to GWIS and the most recent water quality data from any PC with a modem, telephone line and communications software. The BBS runs 24 hours a day, seven days a week. Users can either run GWIS remotely, performing retrievals and then downloading the results, or can download the full program and data sets for use on another PC.

DERMAP and GWIS are also available on disk by mail, for a small media fee. Contact the DER staff for further information.

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List of Related Reports and

ALACHUA COUNTY:

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SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT:

Moore, D.L., D.W. Martin, S.T. Walker and J.T. Rauch
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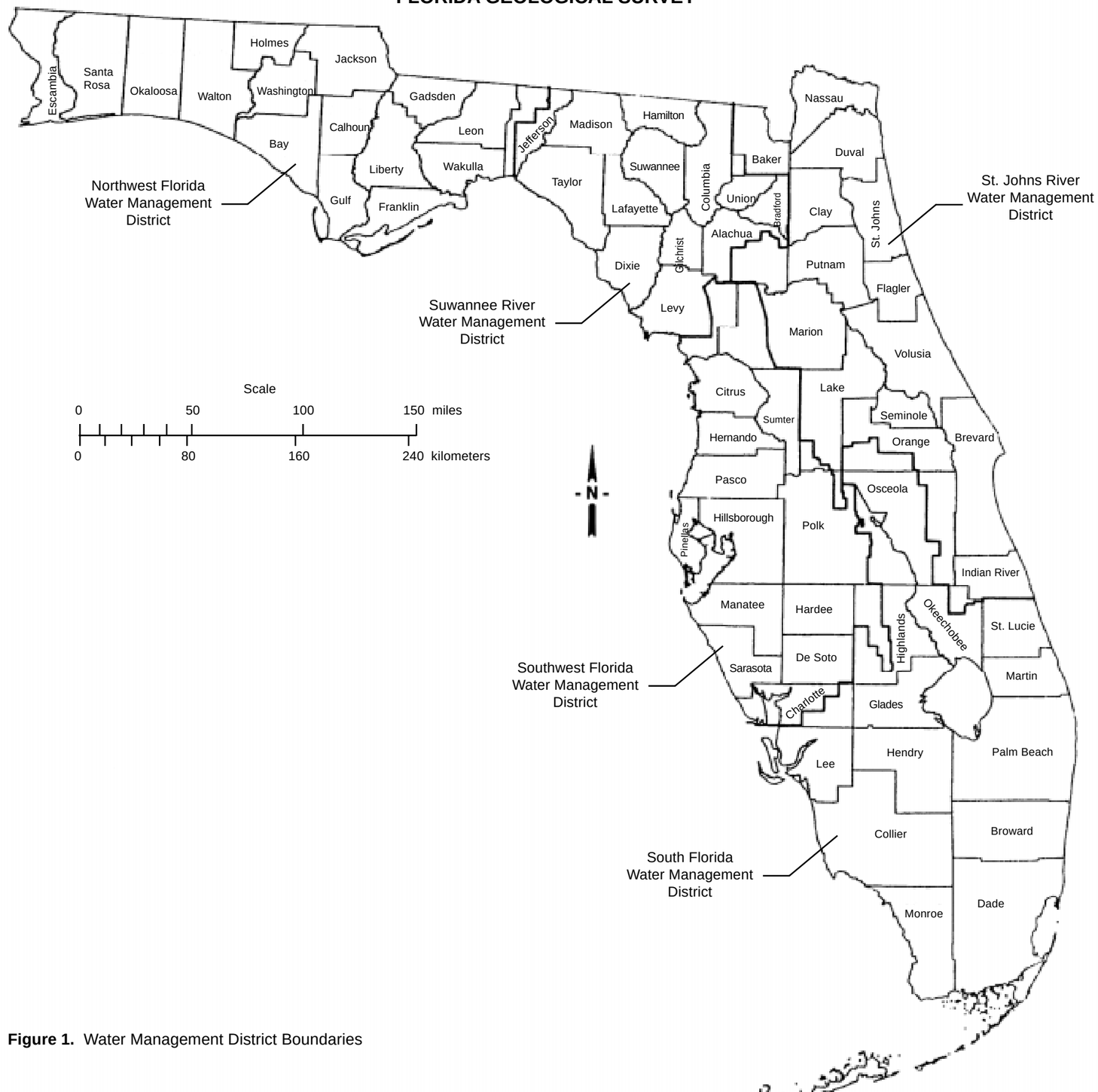


Figure 1. Water Management District Boundaries

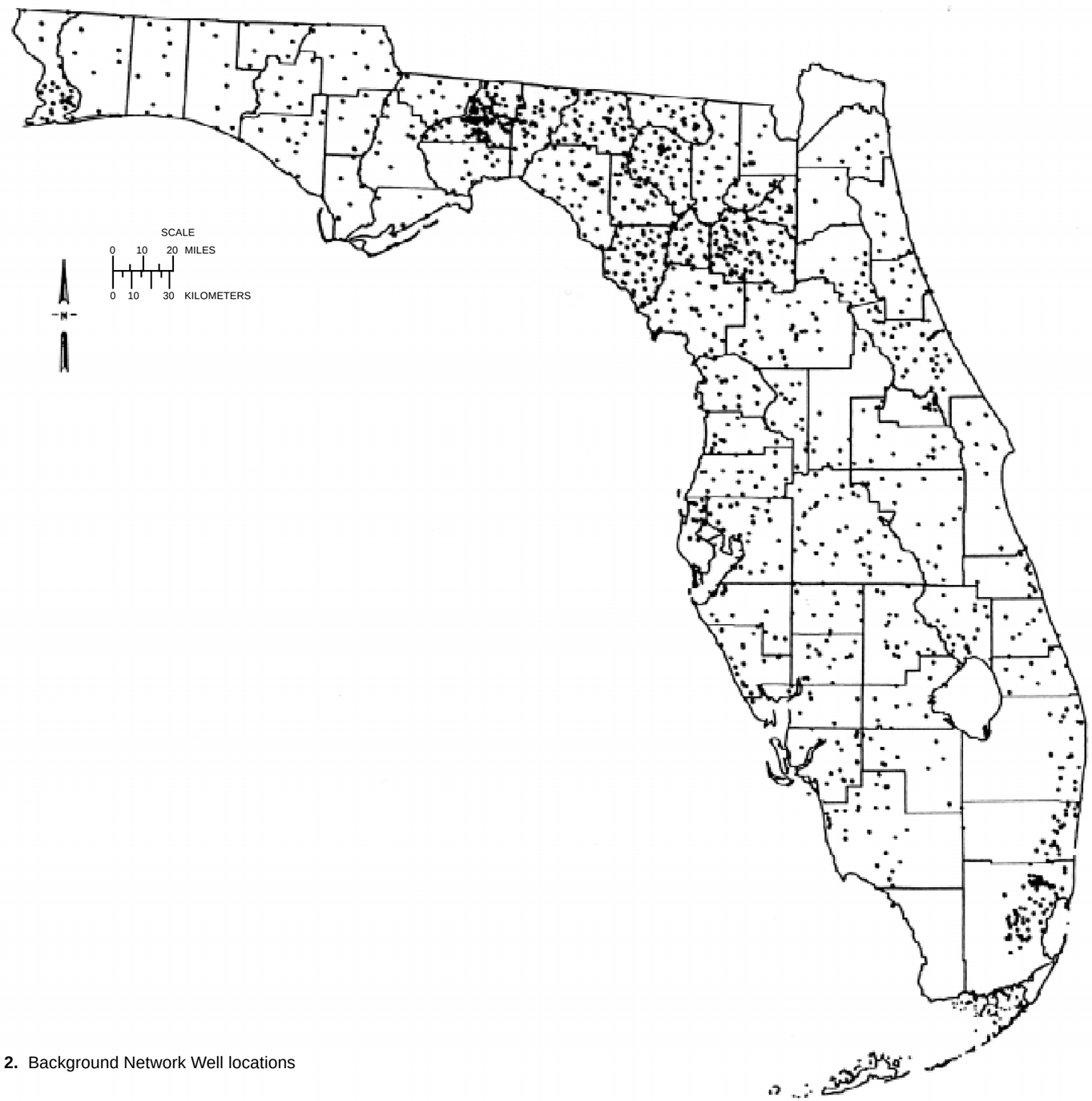


Figure 2. Background Network Well locations

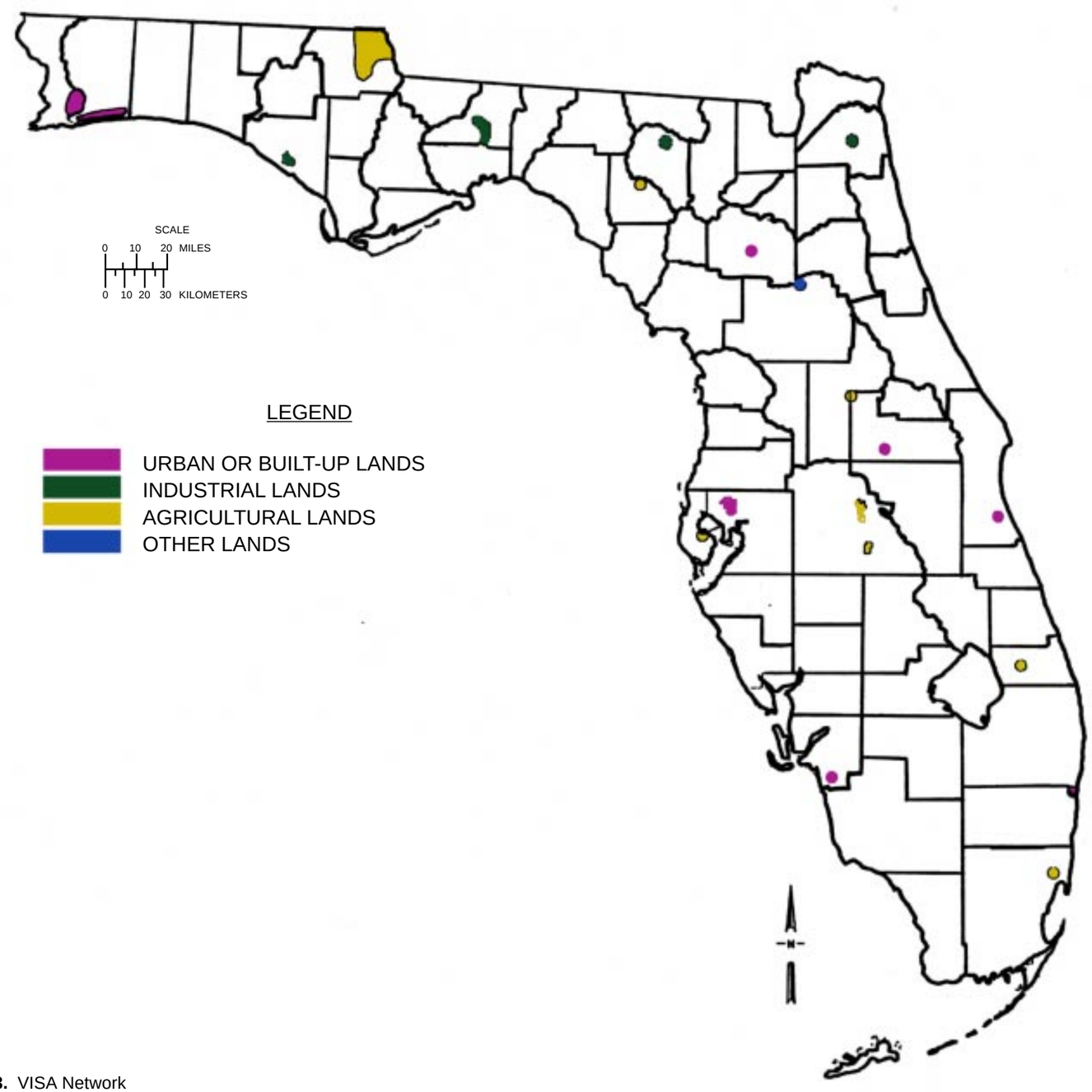


Figure 3. VISA Network

		PANHANDLE FLORIDA		NORTH FLORIDA		SOUTH FLORIDA	
SYSTEM	SERIES	LITHOSTATIGRAPHIC UNIT	HYDROSTRATI-GRAPHIC UNIT	LITHOSTATIGRAPHIC UNIT	HYDROSTRATI-GRAPHIC UNIT	LITHOSTATIGRAPHIC UNIT	HYDROSTRATI-GRAPHIC UNIT
QUATERNARY	HOLOCENE	UNDIFFERENTIATED PLEISTOCENE-HOLOCENE SEDIMENTS	SURFICIAL AQUIFER SYSTEM	UNDIFFERENTIATED PLEISTOCENE-HOLOCENE SEDIMENTS	SURFICIAL AQUIFER SYSTEM	UNDIFFERENTIATED PLEISTOCENE-HOLOCENE SEDIMENTS	SURFICIAL AQUIFER SYSTEM
	PLEISTOCENE					MIAMI LIMESTONE KEY LARGO LIMESTONE ANASTASIA FORMATION FORT THOMPSON FORMATION	
TERTIARY	PLIOCENE	CITRONELLE FORMATION MICCOSUKEE FORMATION COARSE CLASTICS		MICCOSUKEE FORMATION CYPRESSHEAD FORMATION NASHUA FORMATION		TAMIAMI FORMATION	
	MIOCENE	ALUM BLUFF GROUP PENSACOLA CLAY INTRACOASTAL FORMATION HAWTHORN GROUP BRUCE CREEK LIMESTONE ST. MARKS FORMATION CHATTAHOOCHEE FORMATION	INTERMEDIATE CONFINING UNIT	HAWTHORN GROUP STATENVILLE FORMATION COOSAWHATCHIE FM. MARKSHEAD FORMATION PENNEY FARMS FORMATION ST. MARKS FORMATION	INTERMEDIATE AQUIFER SYSTEM OR CONFINING UNIT	HAWTHORN GROUP PEACE RIVER FORMATION BONE VALLEY MEMBER ARCADIA FORMATION	INTERMEDIATE AQUIFER SYSTEM OR CONFINING UNIT
	OLIGOCENE	CHICKASAWHAY LIMESTONE SUWANNEE LIMESTONE MARIANNA LIMESTONE BUCATUNNA CLAY	FLORIDAN AQUIFER SYSTEM	SUWANNEE LIMESTONE	FLORIDAN AQUIFER SYSTEM	TAMPA-NOCATEE MEMBERS SUWANNEE LIMESTONE	FLORIDAN AQUIFER SYSTEM
	EOCENE	OCALA LIMESTONE CLAIBORNE GROUP UNDIFFERENTIATED SEDIMENTS	SUB-FLORIDAN CONFINING UNIT	OCALA LIMESTONE AVON PARK FORMATION OLDSMAR FORMATION		OCALA LIMESTONE AVON PARK FORMATION OLDSMAR FORMATION	
	PALEOCENE	UNDIFFERENTIATED PALEOCENE ROCKS		CEDAR KEYS FORMATION	SUB-FLORIDAN CONFINING UNIT	CEDAR KEYS FORMATION	SUB-FLORIDAN CONFINING UNIT
CRETACEOUS AND OLDER		UNDIFFERENTIATED		UNDIFFERENTIATED		UNDIFFERENTIATED	

Figure 4. Hydrostratigraphic Nomenclature (modified from Southeastern Geological Society Ad Hoc Committee on Florida Hydorstratigraphic Unit Definition, 1986)

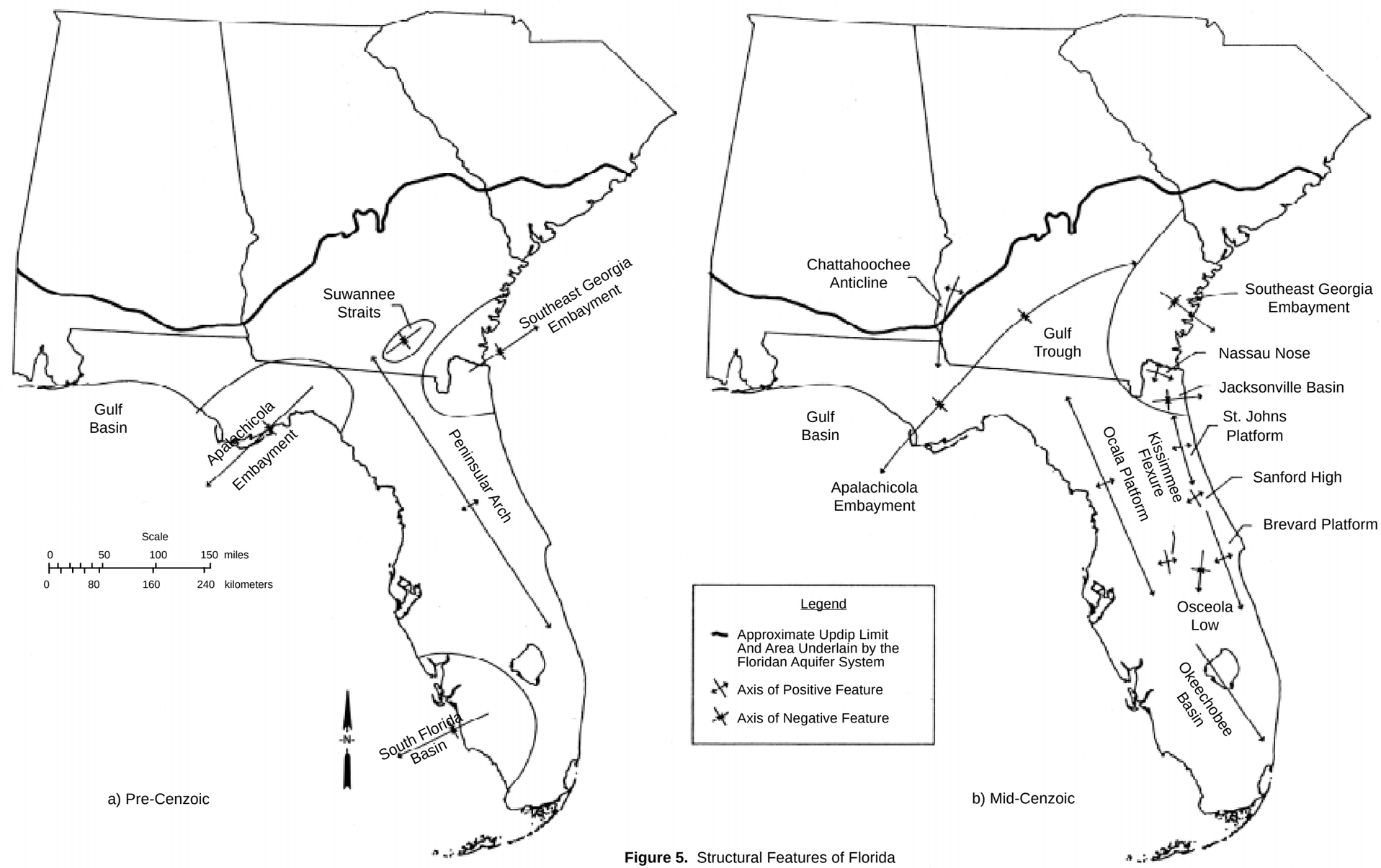


Figure 5. Structural Features of Florida
a) Pre-Cenzoic
b)Mid-Cenzoic

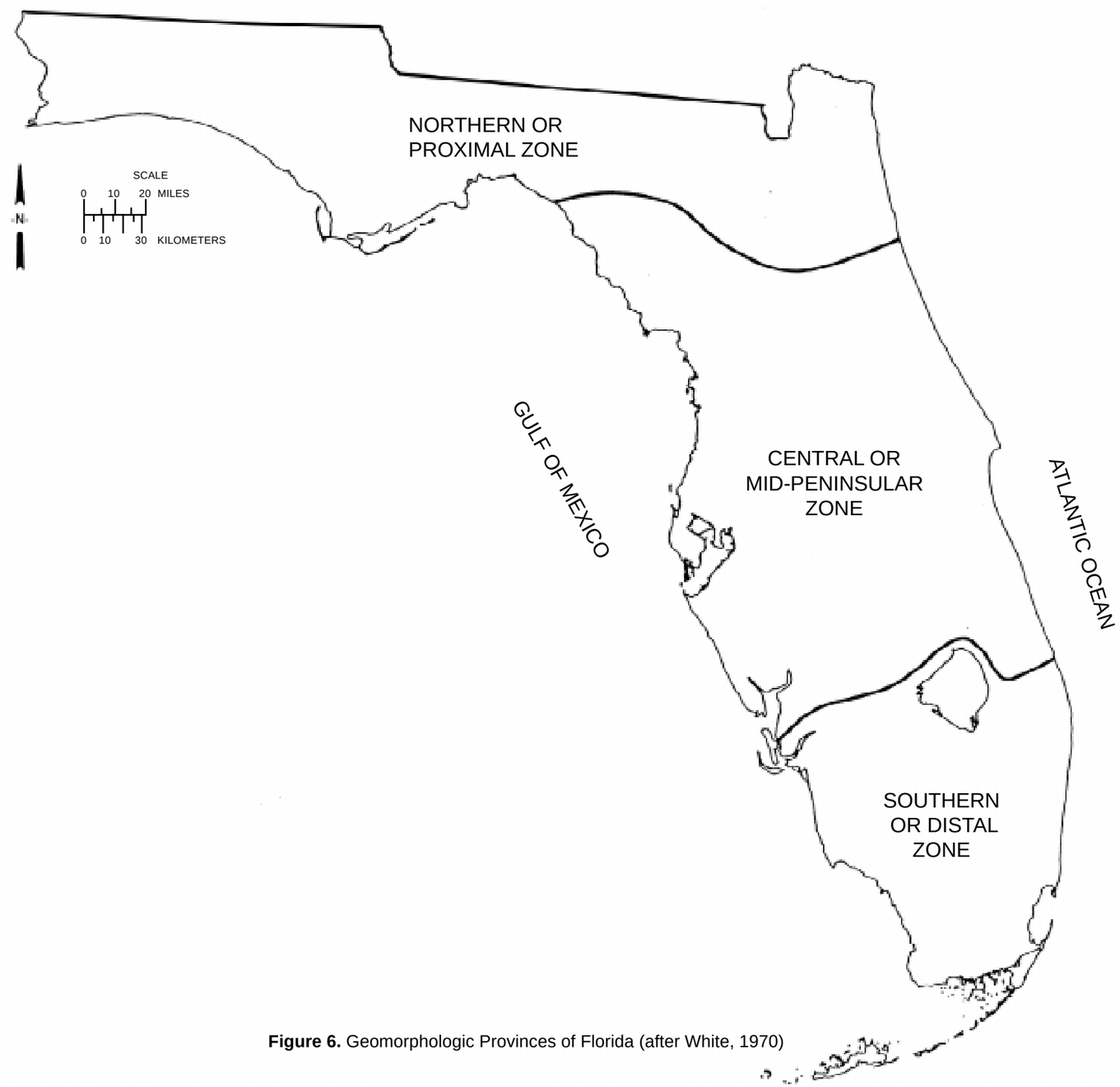


Figure 6. Geomorphologic Provinces of Florida (after White, 1970)

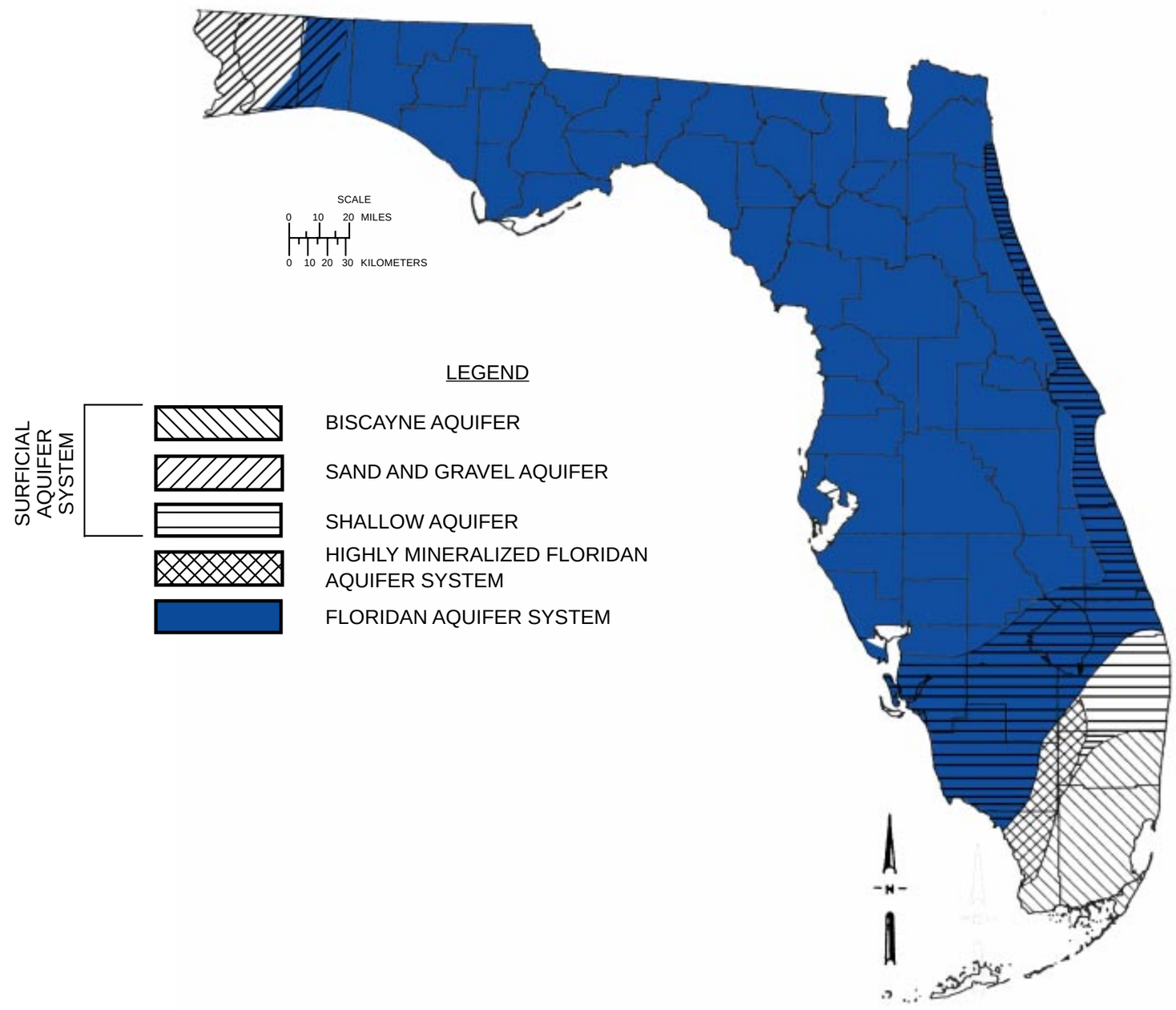


Figure 20. Statewide aquifer map

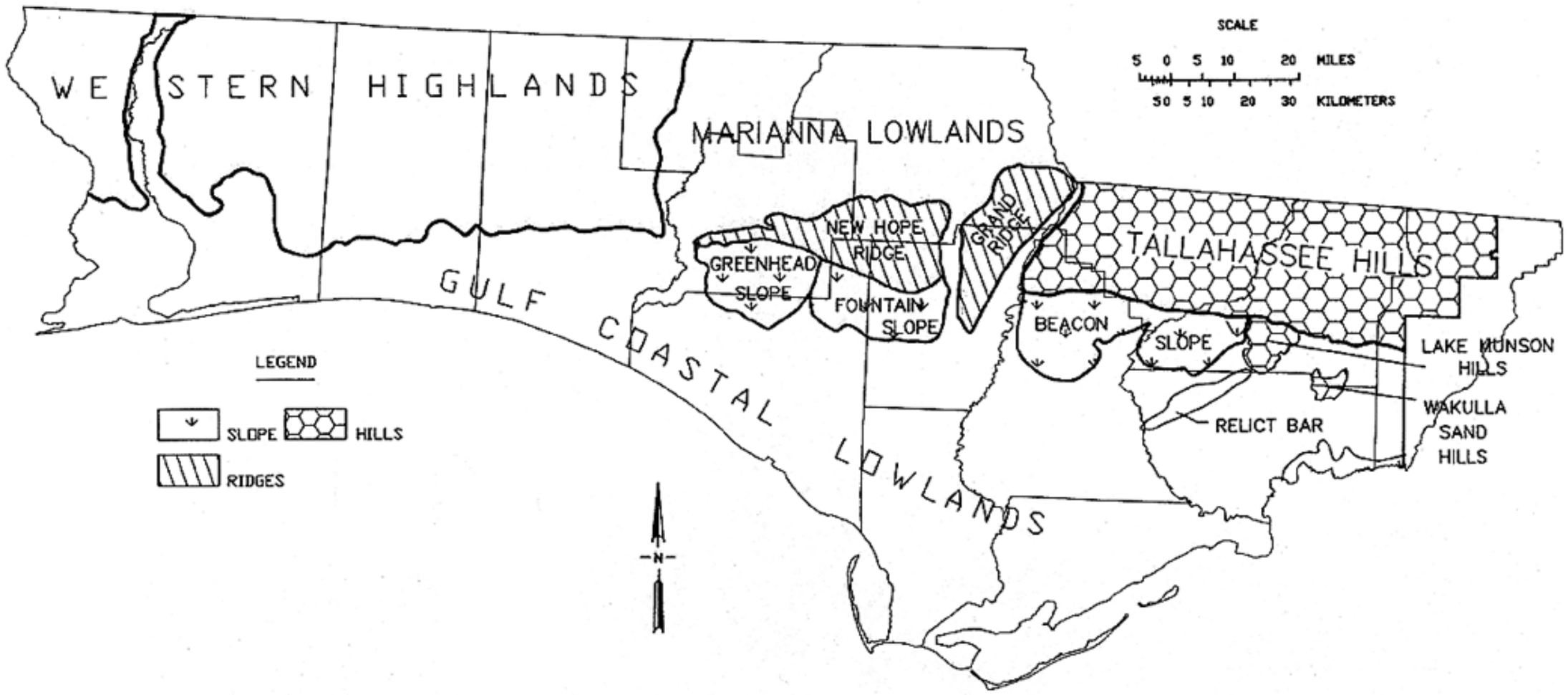


Figure 7. Geomorphologic Features of Northwest Florida Water Management District (NWFWMD) (after White, Puri and Vernon in Puri and Vernon, 1964)

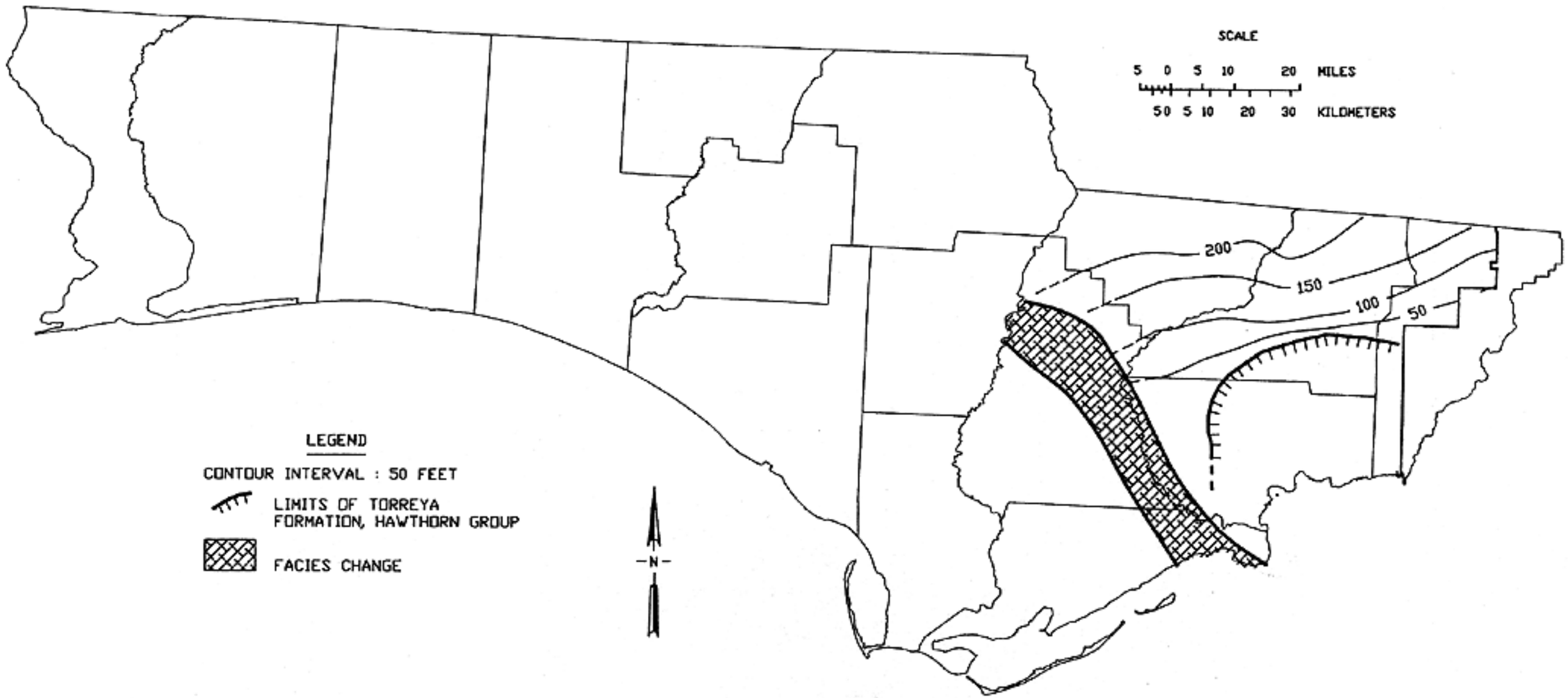


Figure 12. Top of Hawthorn Group, NWFWMD (after Scott, 1988a)

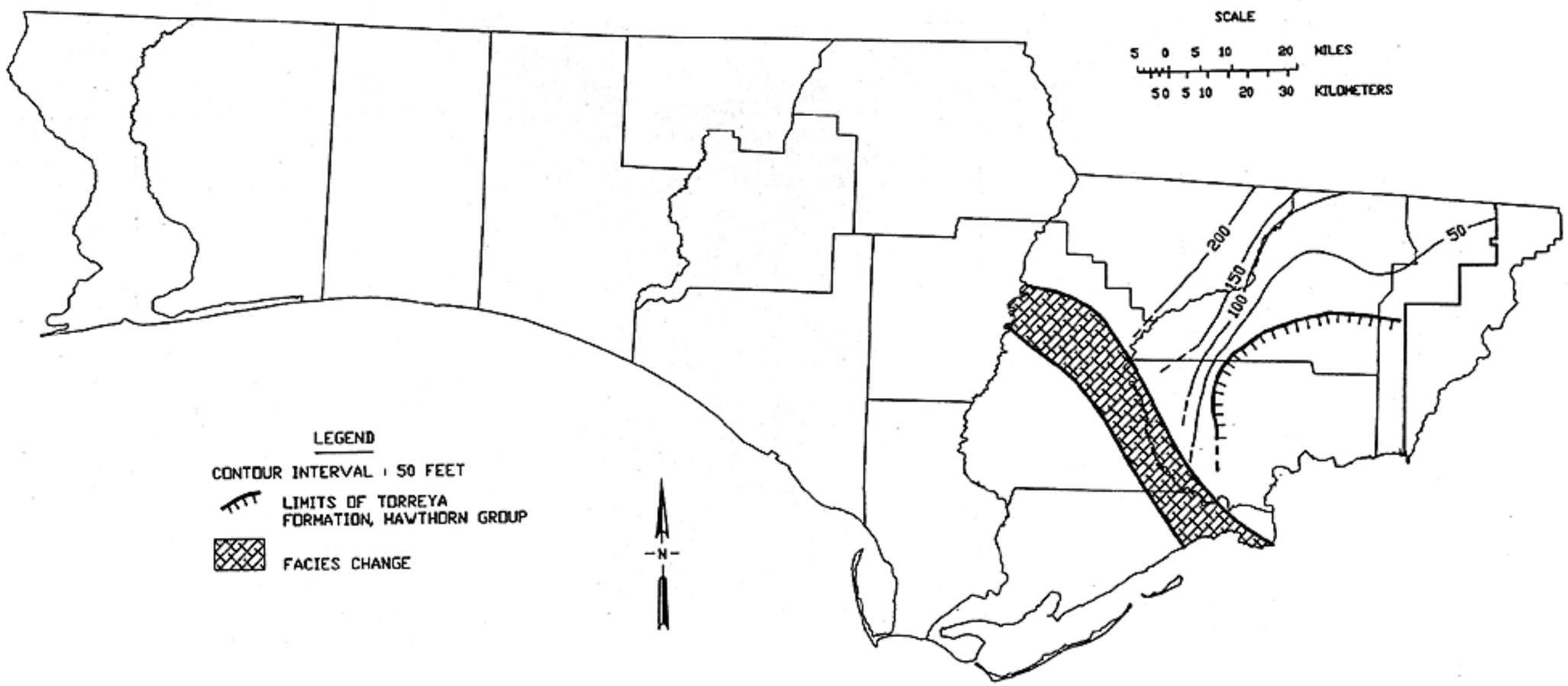
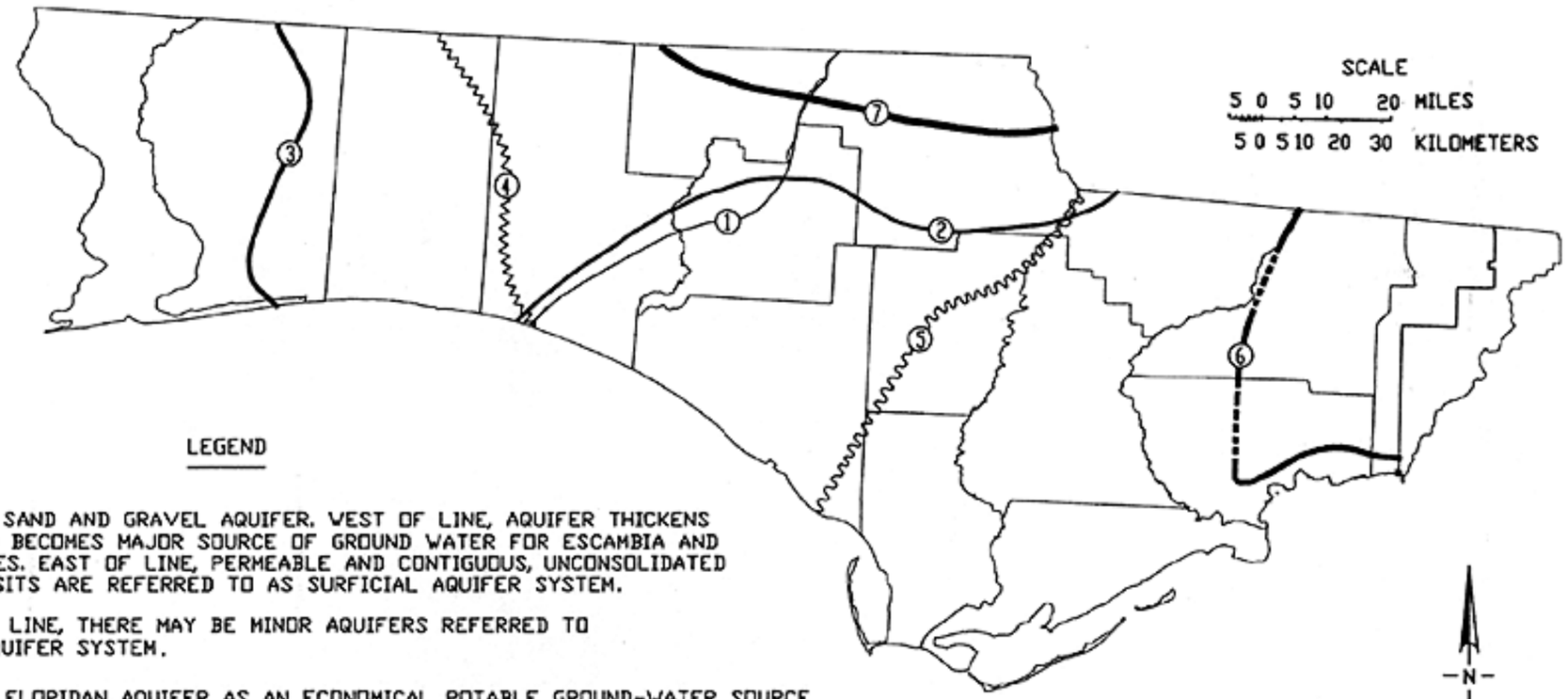


Figure 13. Isopach of Hawthorn Group, NWFWMD (after Scott, 1988a)



LEGEND

(1) EASTERN LIMITS OF SAND AND GRAVEL AQUIFER. WEST OF LINE, AQUIFER THICKENS PROGRESSIVELY AND BECOMES MAJOR SOURCE OF GROUND WATER FOR ESCAMBIA AND SANTA ROSA COUNTIES. EAST OF LINE, PERMEABLE AND CONTIGUOUS, UNCONSOLIDATED SILICICLASTIC DEPOSITS ARE REFERRED TO AS SURFICIAL AQUIFER SYSTEM.

(2) SOUTH AND EAST OF LINE, THERE MAY BE MINOR AQUIFERS REFERRED TO AS INTERMEDIATE AQUIFER SYSTEM.

(3) WESTERN LIMITS OF FLORIDAN AQUIFER AS AN ECONOMICAL POTABLE GROUND-WATER SOURCE.

(4) EASTERN EXTENT OF BUCATUNNA CLAY CONFINING UNIT. WEST OF LINE, FLORIDAN AQUIFER SYSTEM IS SUB-DIVIDED INTO UPPER LIMESTONE AND LOWER LIMESTONE OF FLORIDAN AQUIFER SYSTEM. EAST OF LINE, FLORIDAN AQUIFER SYSTEM IS UNDIFFERENTIATED.

(5) WEST OF LINE, IT IS GENERALLY ACCEPTED THAT LOW PERMEABILITY BEDS IN THE UPPER LISBON FORMATION FORM THE SUB-FLORIDAN CONFINING UNIT. EAST OF LINE, LITHOLOGIC CHANGES CAUSE CLAIBORNE GROUP TO BE PART OF FLORIDAN AQUIFER SYSTEM. EAST OF LINE, SUB-FLORIDAN CONFINING UNIT HAS NOT BEEN DEFINED.

(6) WEST AND SOUTH OF LINE, UNDIFFERENTIATED CLAIBORNE GROUP PORTION OF FLORIDAN AQUIFER SYSTEM CONTAINS HIGHLY MINERALIZED WATER. EAST AND NORTH OF LINE, FLORIDAN AQUIFER CONTAINS FRESH WATER.

(7) SOUTH OF LINE, IT IS ASSUMED THAT CLAIBORNE/LISBON AND WILCOX/CLAYTON AQUIFER SYSTEMS ARE NOT PRESENT.

Figure 21. Occurrence and extent of ground water in NWFWMD

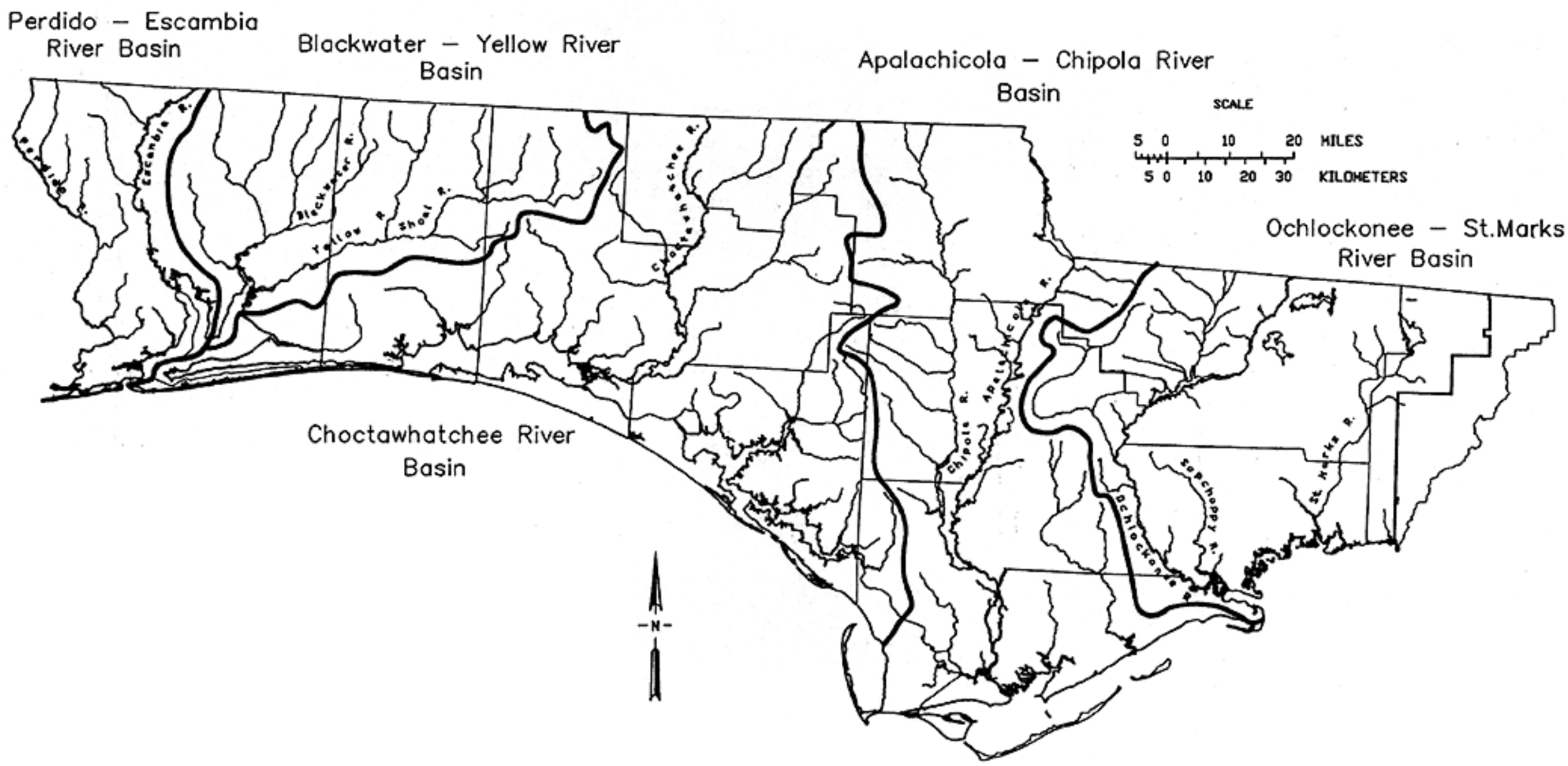


Figure 22. Surface-water basins, NWFWMD

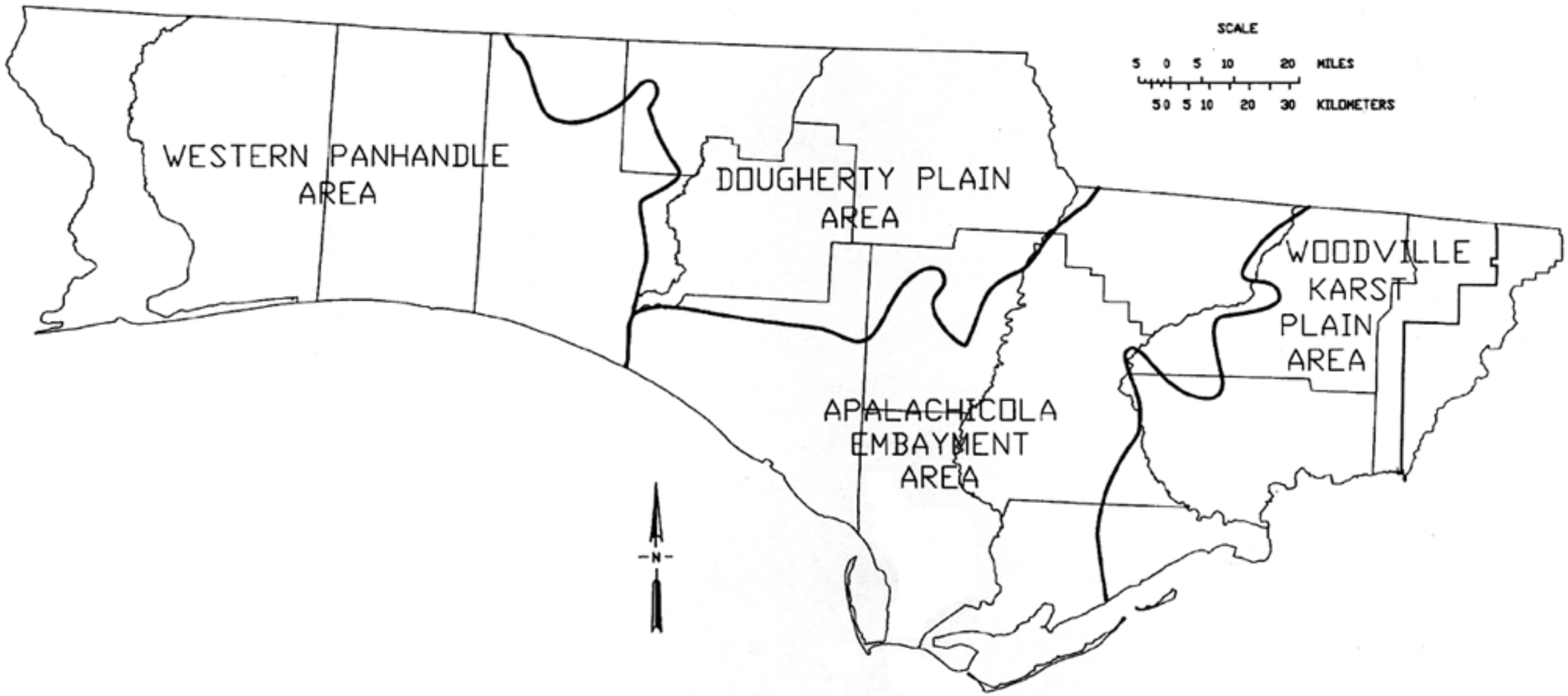


Figure 27. Ground-water areas, NWFWMD

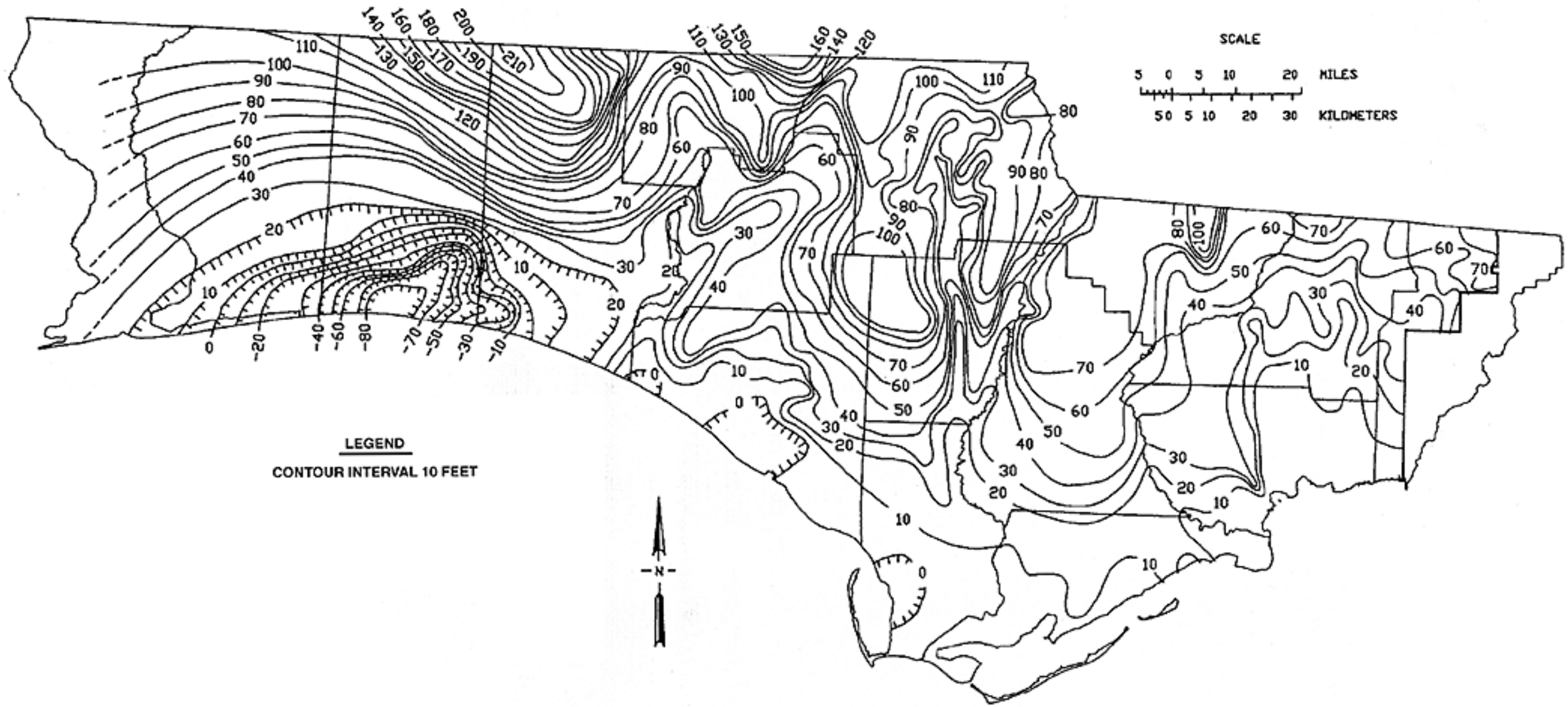


Figure 32. Floridan aquifer system potentiometric surface, NWFWMD (modified from Wagner, 1989)

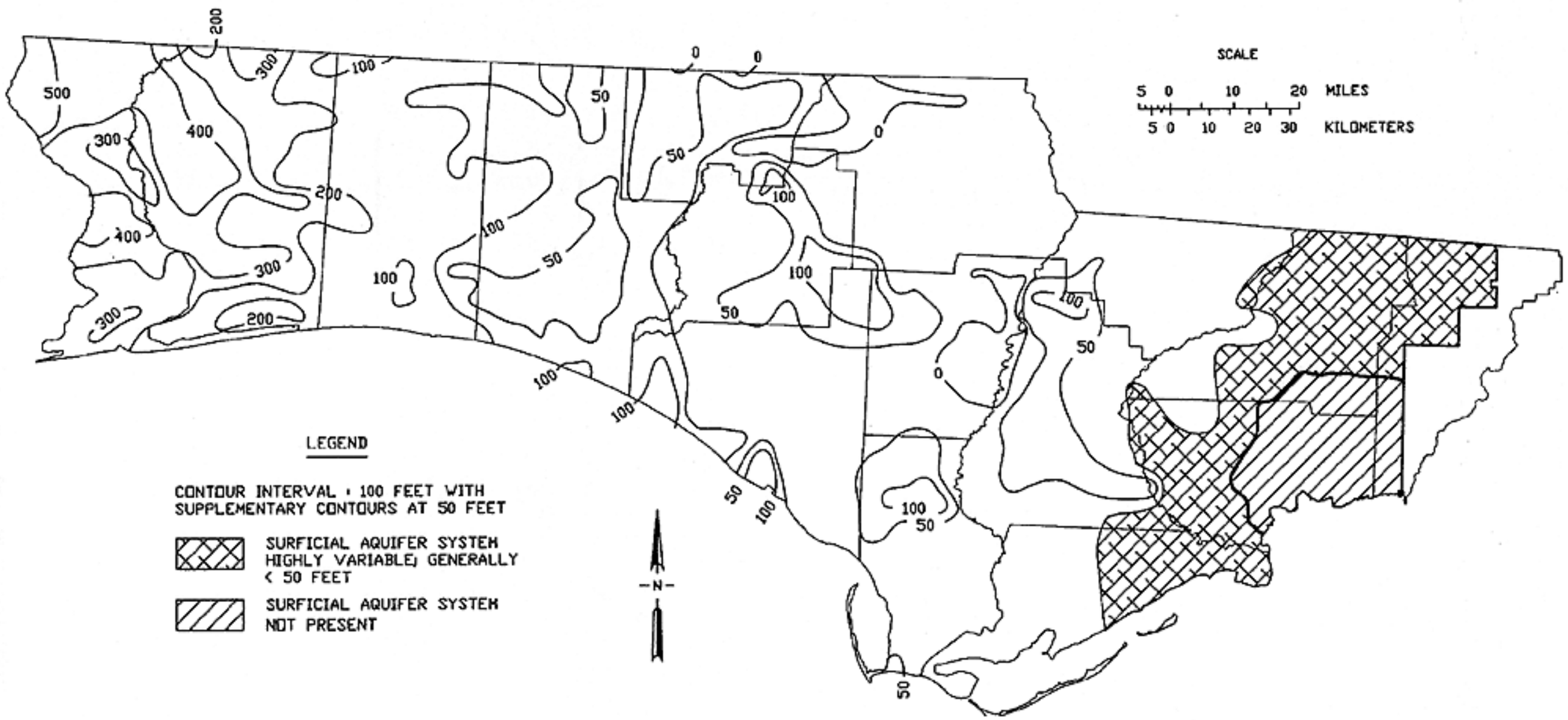


Figure 37. Surficial aquifer system thickness, NWFWMD. This does not represent one continuous aquifer over the extent of the district.

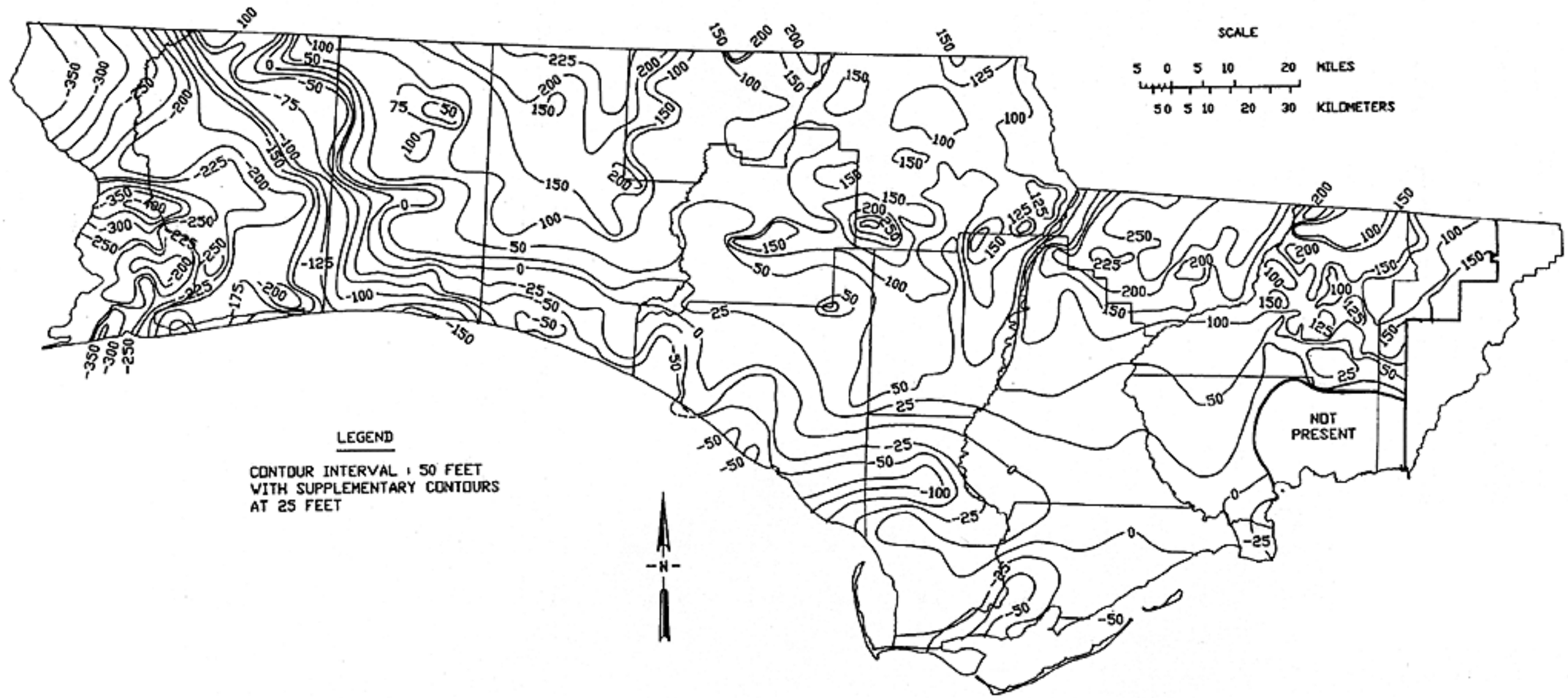


Figure 41. Top of intermediate aquifer system/confining unit, NWFWMD

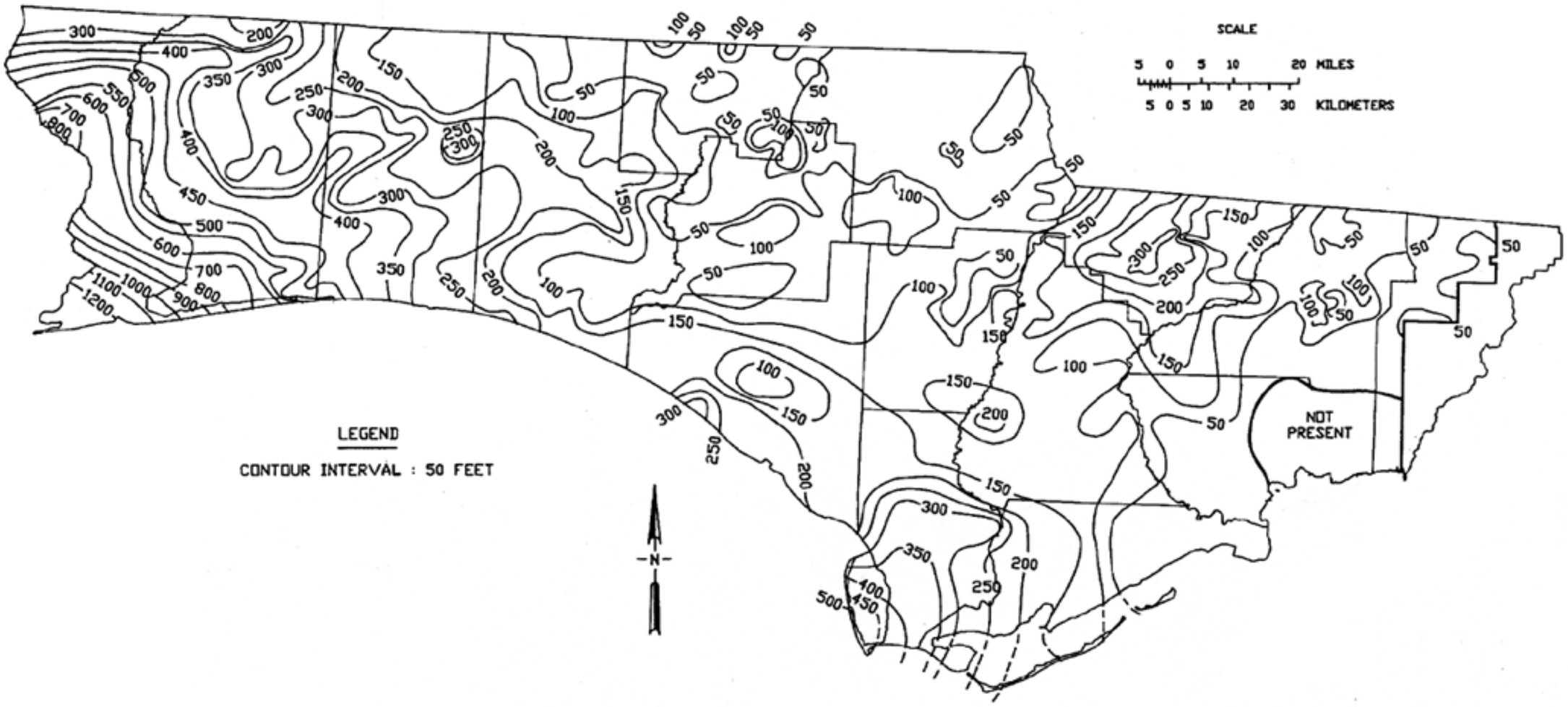
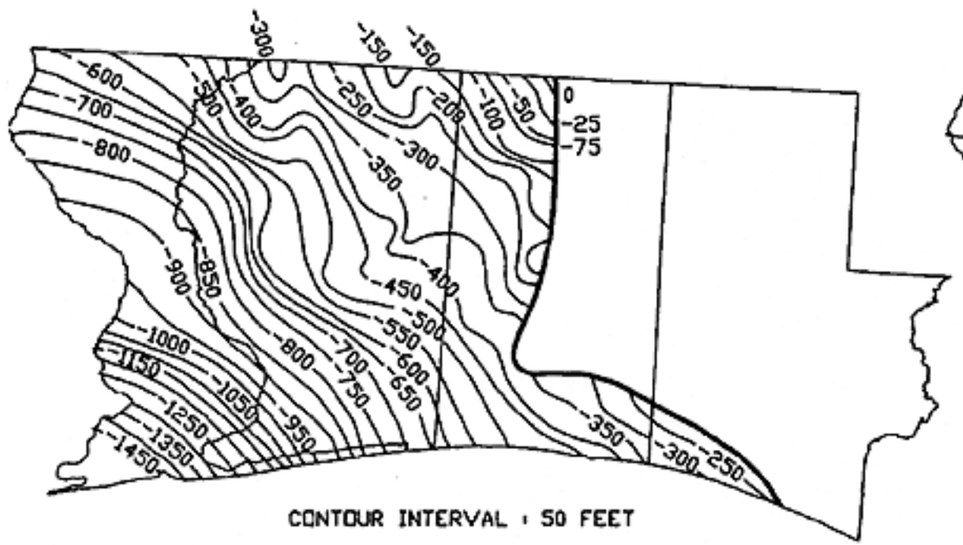
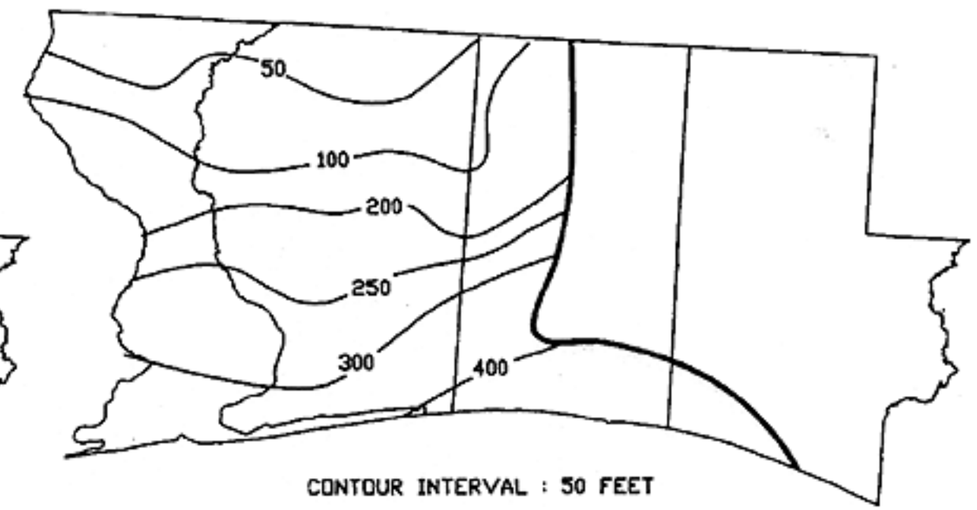


Figure 42. Isopach of the intermediate aquifer system/confining unit, NWFWMD





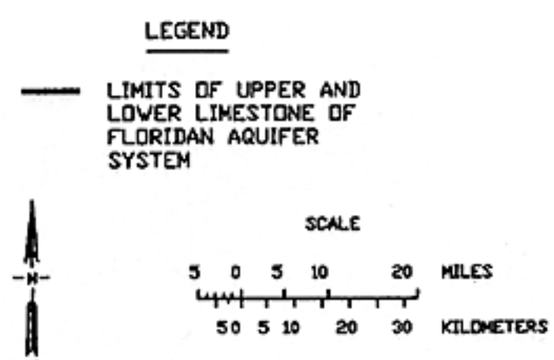
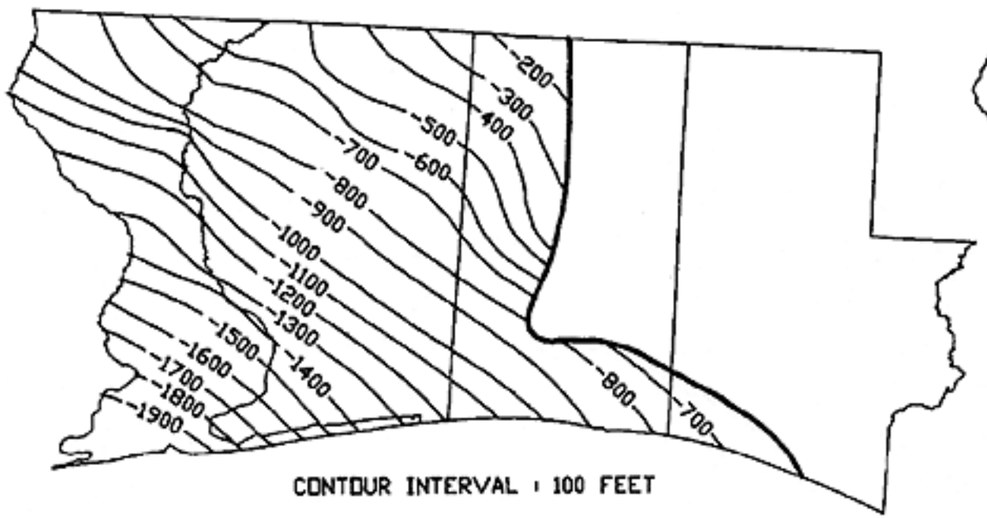
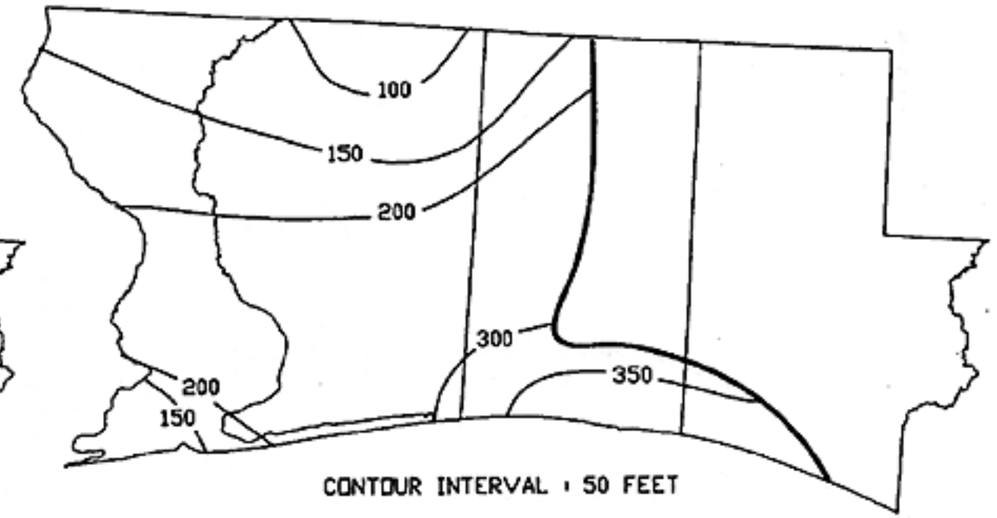


Figure 48. Top of the upper Floridan aquifer system, NWFWMD

Figure 49. Thickness of the upper Floridan aquifer system, NWFWMD





LEGEND

LIMITS OF UPPER AND LOWER LIMESTONE OF FLORIDAN AQUIFER SYSTEM

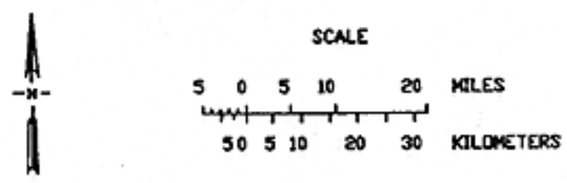


Figure 50. Top of the lower Floridan aquifer system, NWFWMD

Figure 51. Thickness of the lower Floridan aquifer system, NWFWMD

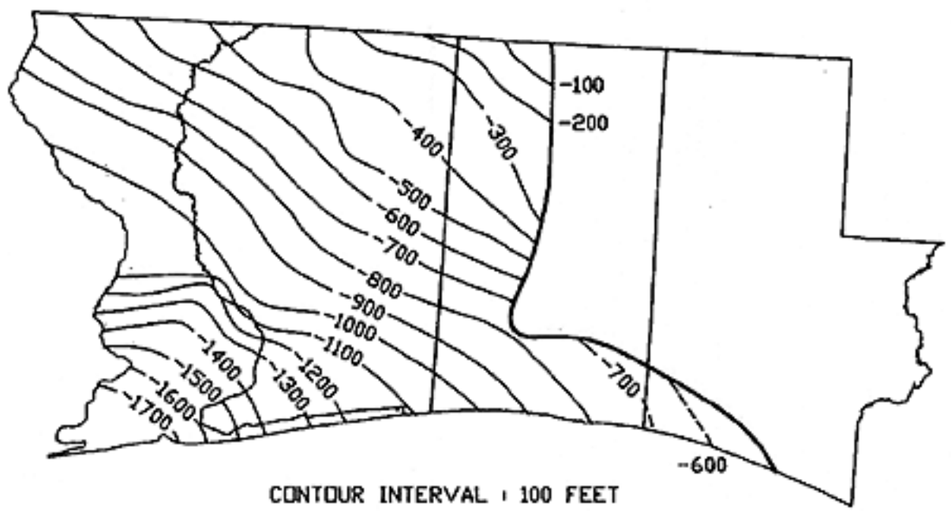


Figure 52. Top of the Bucatunna Clay, NWFWMD

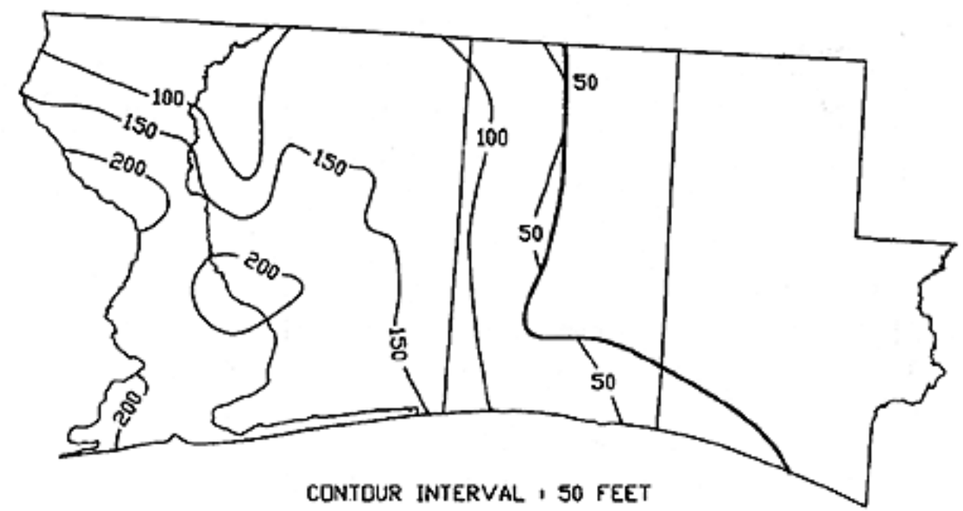
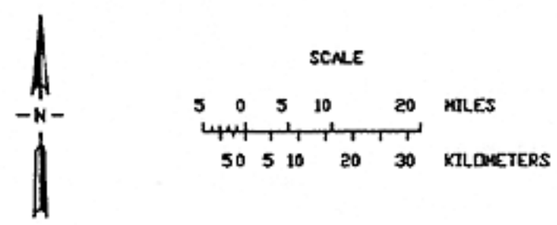


Figure 53. Thickness of the Bucatunna Clay, NWFWMD

LEGEND

EASTERN EXTENT OF THE BUCATUNNA CLAY CONFINING UNIT



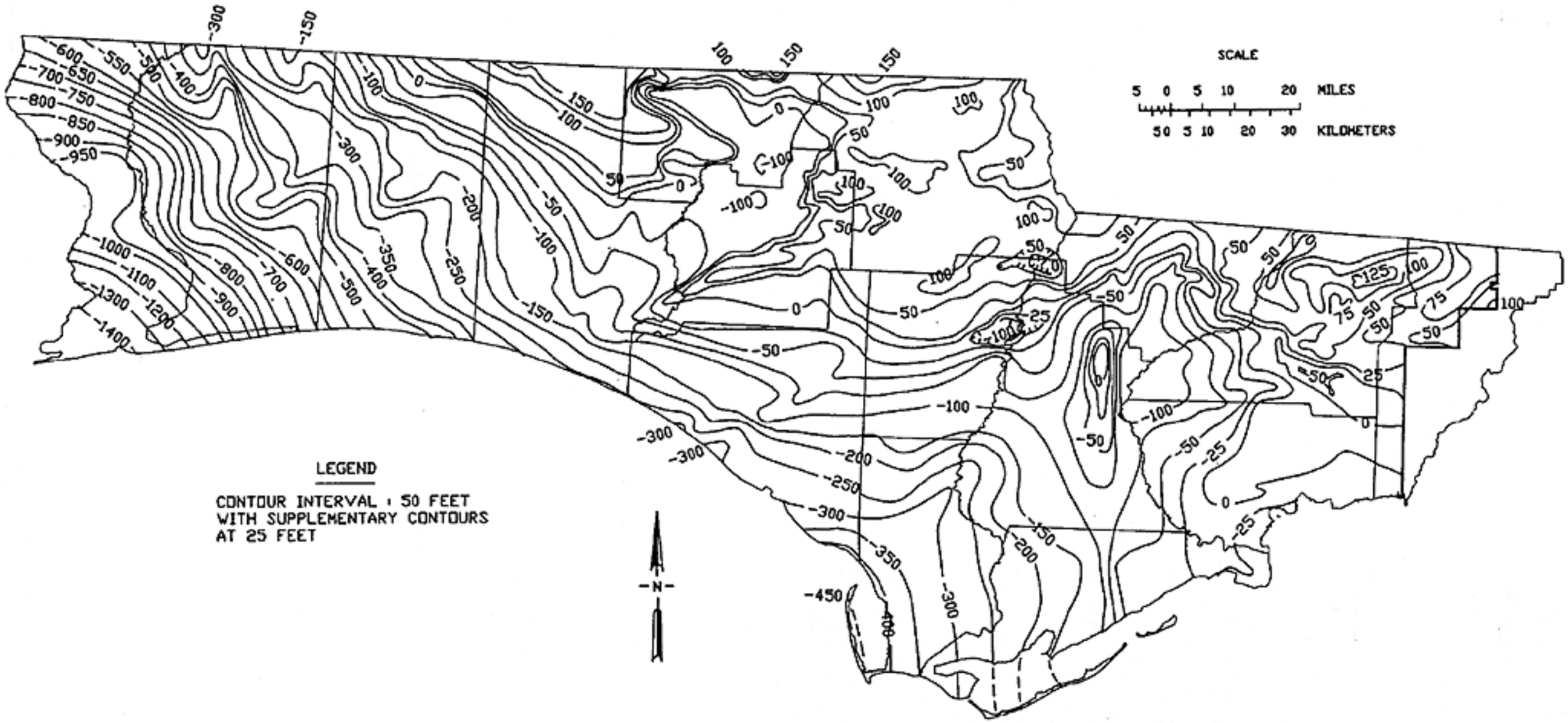


Figure 55. Top of the Floridan aquifer system, NWFWMD

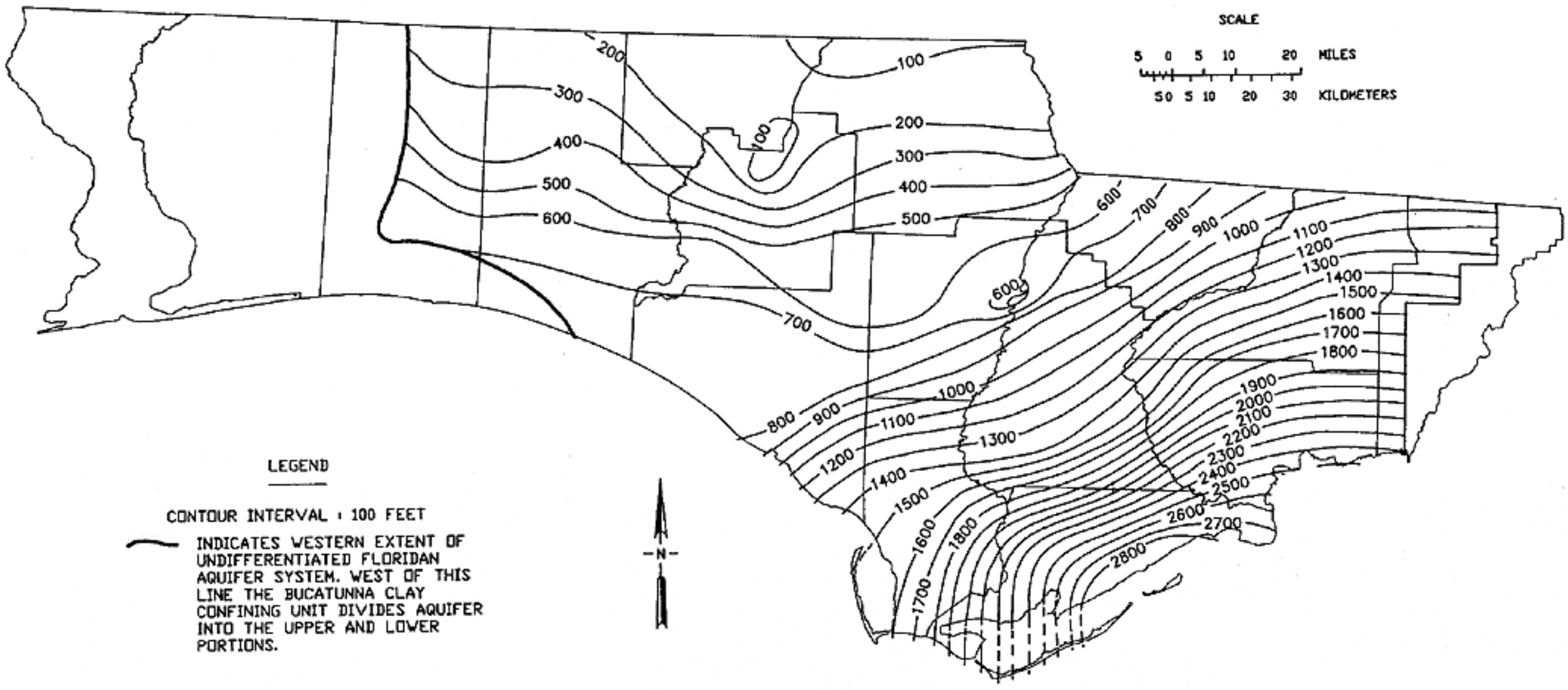


Figure 60. Thickness of the Floridan aquifer system, NWFWMD

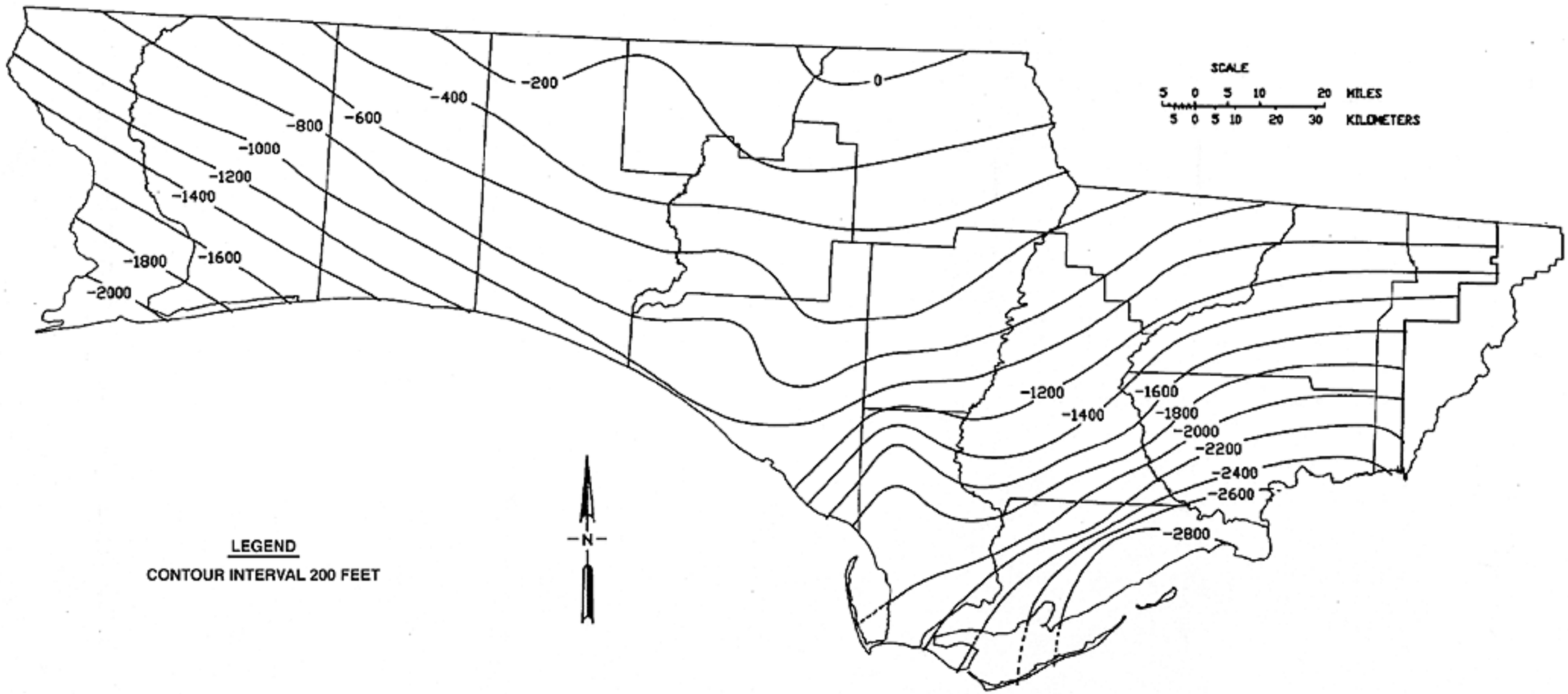


Figure 65. Base of the Floridan aquifer system, NWFWMD

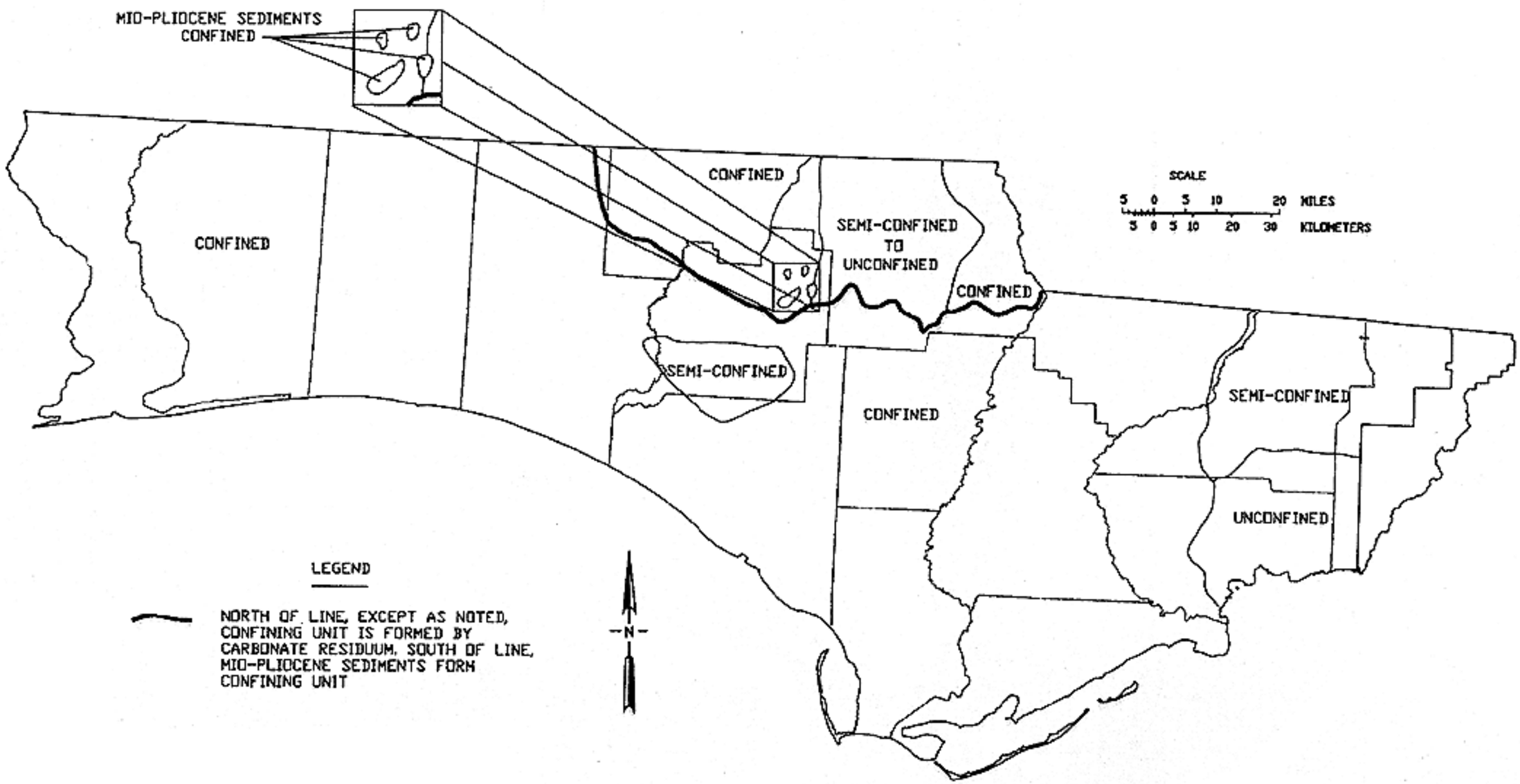


Figure 66. Confinement of the Floridan aquifer system, NWFWMD

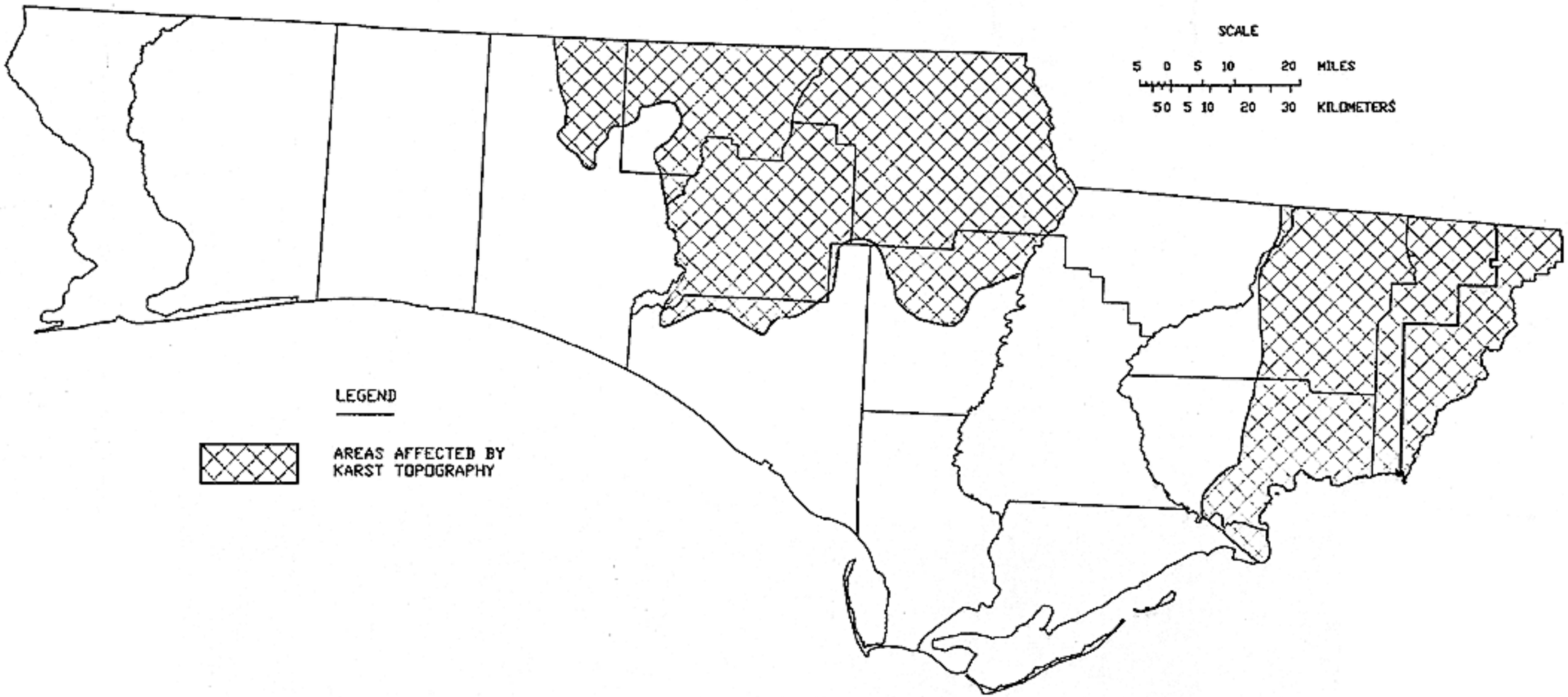


Figure 69. Areas of karst development in NWFWMD

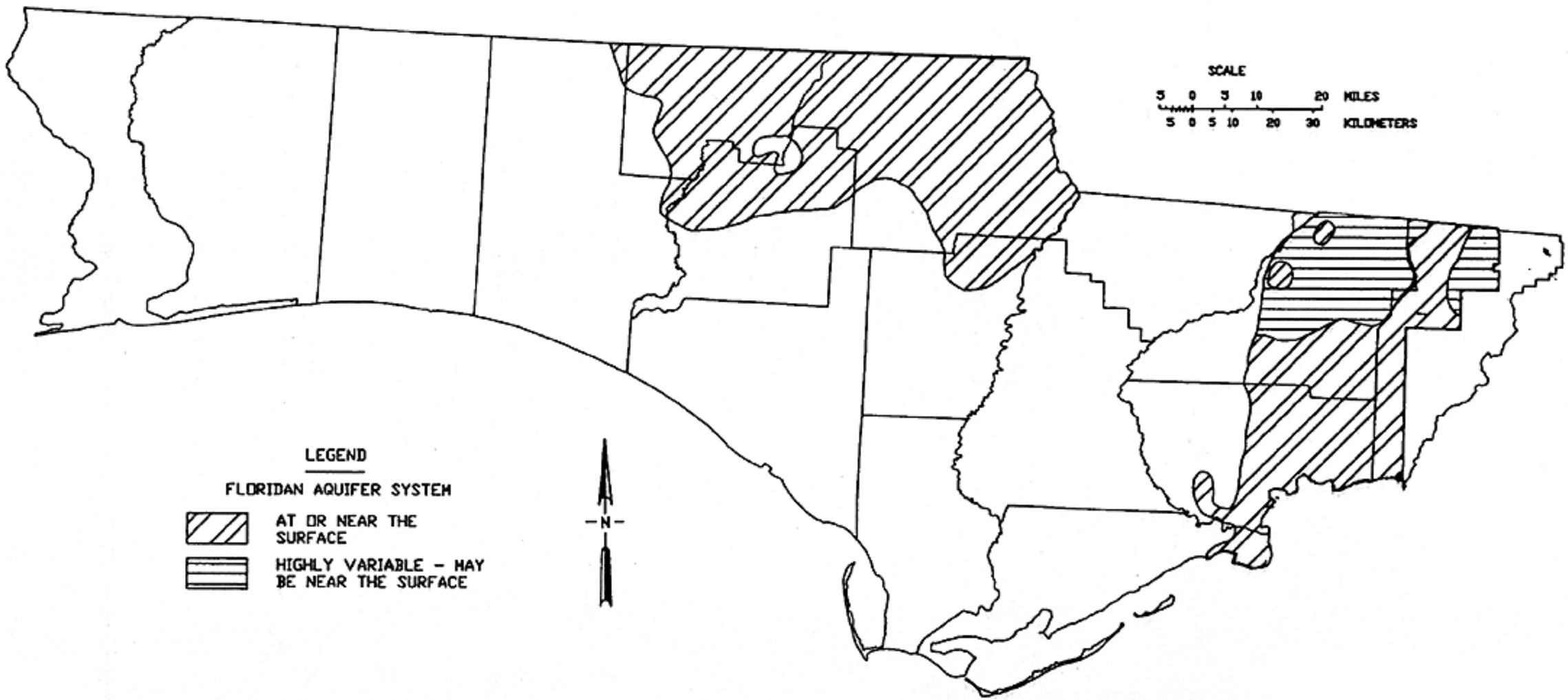


Figure 71. Areas where the Floridan aquifer system is at or near the surface, NWFWMD

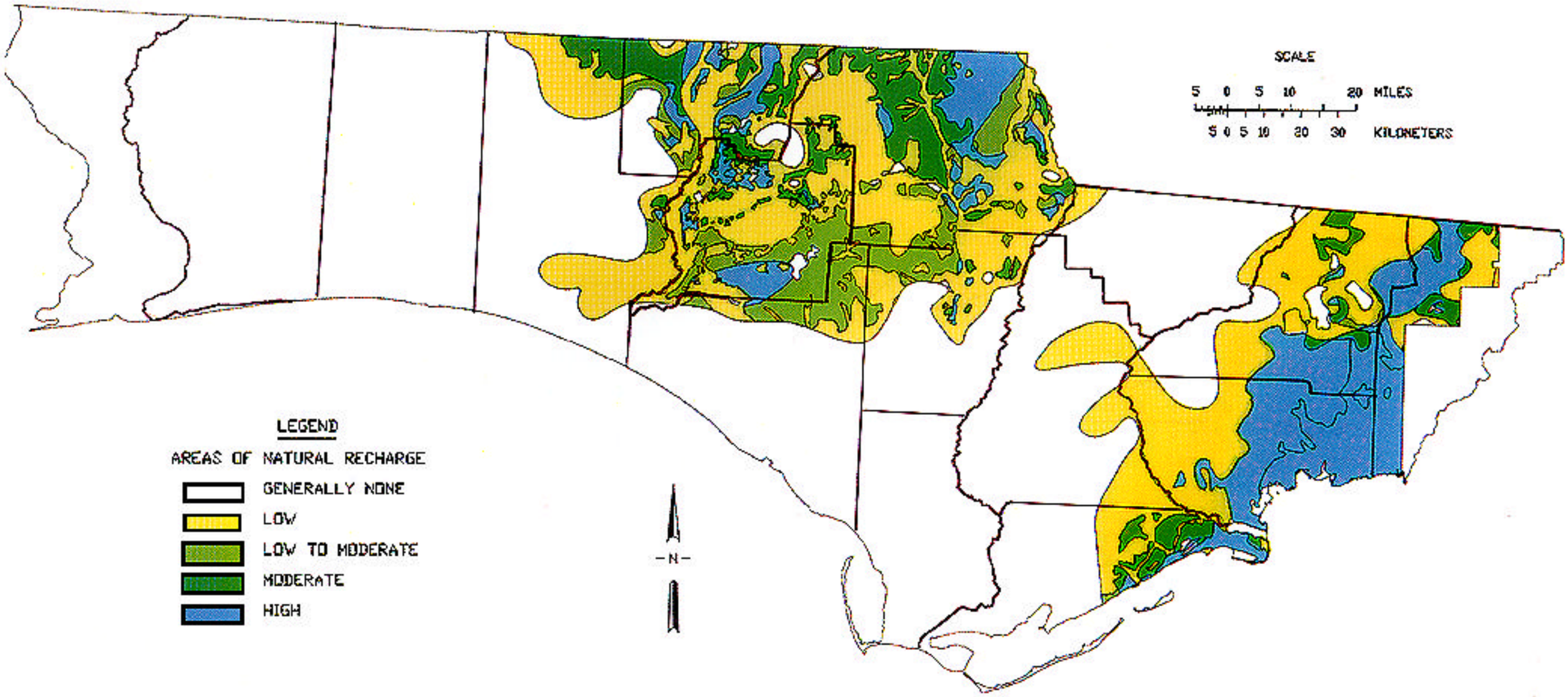


Figure 72. Floridan aquifer system recharge potential, NWFWMD

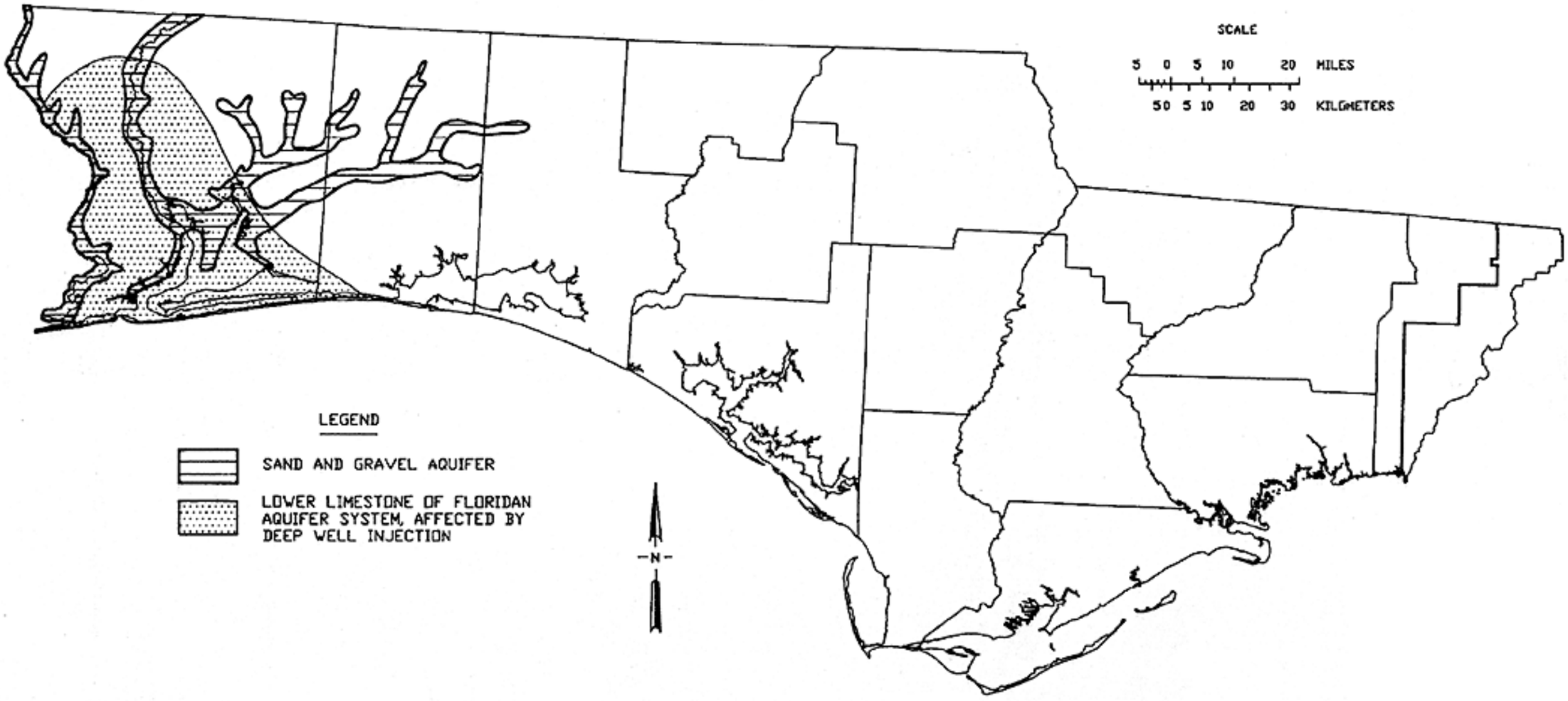


Figure 77. Areas of artesian flow from the sand and gravel aquifer and lower Floridan aquifer system, NWFWMD

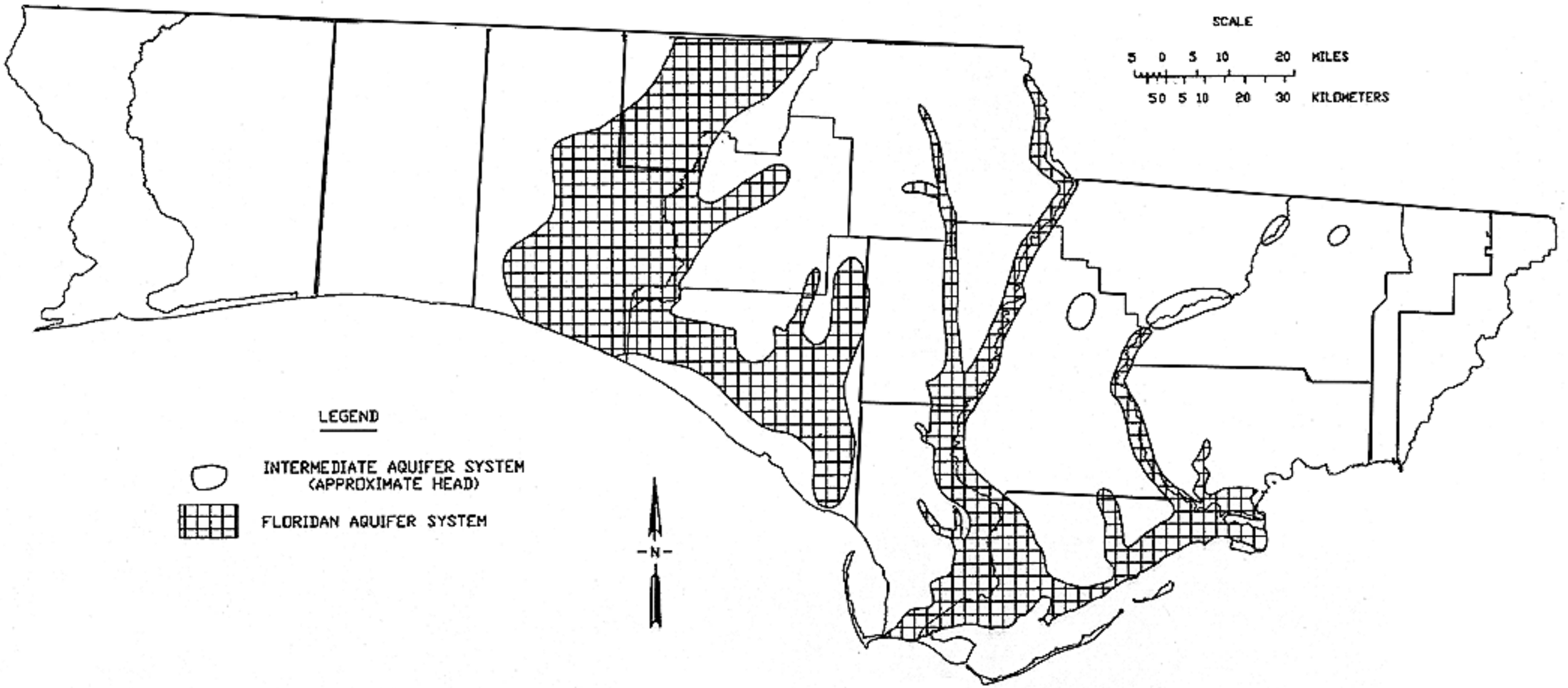


Figure 78. Areas of artesian flow from the intermediate aquifer system and Floridan aquifer system, NWFWMD

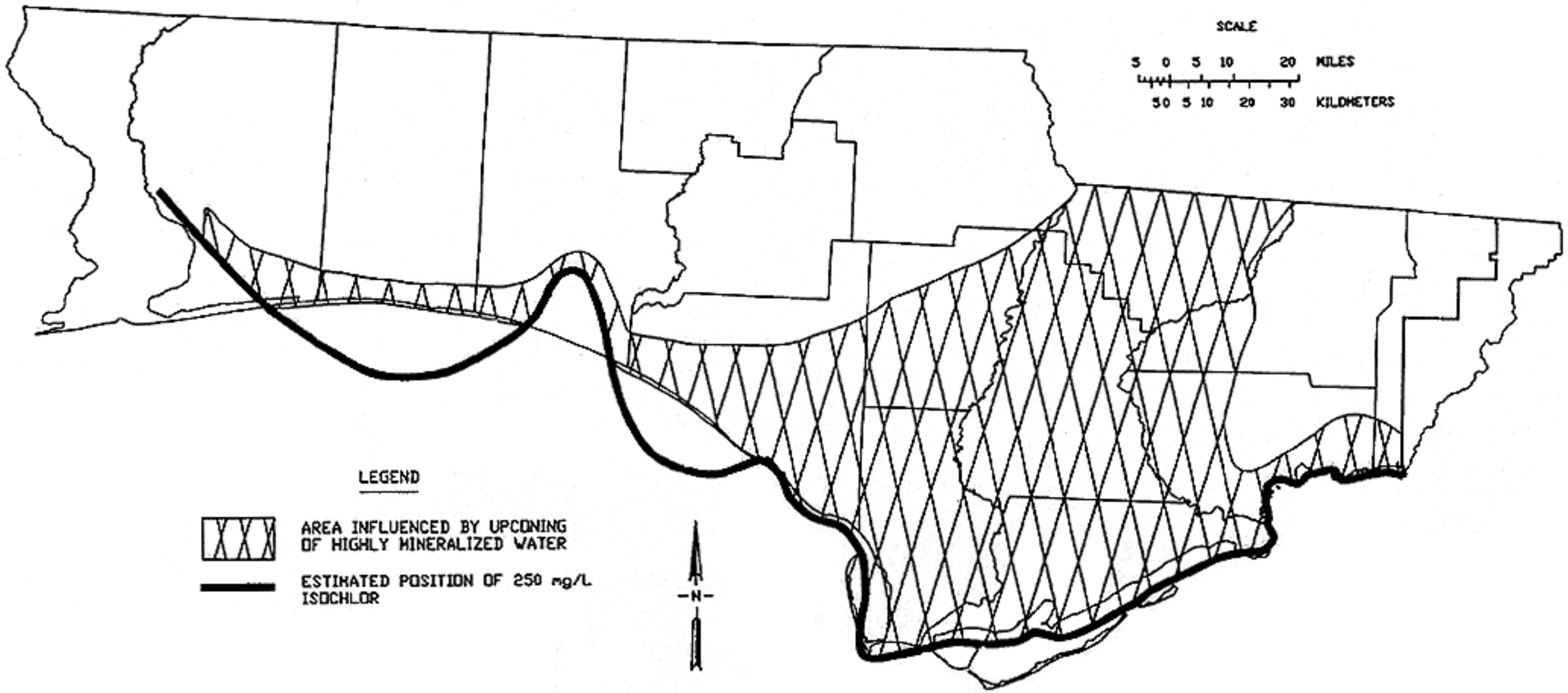


Figure 83. Areas of mineralized water in the Floridan aquifer system, NWFWMD