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PART 1-TEXT

HYDROGEOLOGY OF THE KISSIMMEE PLANNING AREA, SOUTH FLORIDA WATER MANAGEMENT DISTRICT

by

Jonathan E. Shaw & Sharon M. Trost

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SUMMARY

The Kissimmee Planning Area (KPA) of the South Florida Water Management District (SFWMD) encompasses an area of approximately 3,500 square miles, including parts of Orange, Osceola, Okeechobee, Polk, Highlands, and Glades Counties. In the late 1970's, reconnaissance work began on the Floridan Aquifer System in the KPA. This lead to the establishment of a groundwater monitoring network over the six-county area. This report is the culmination of the reconnaissance study. The data are presented and interpreted to facilitate water management decision making, and to be applicable to computer simulation of groundwater conditions in the Floridan Aquifer System.

Three hydrostratigraphic units were identified based upon lithologic and geophysical information: the Floridan Aquifer System, the confining beds of the Hawthorn Formation, and the Surficial Aquifer System. The Floridan Aquifer System is composed of Eocene and Late Miocene age sediments of the Avon Park Limestone, the Ocala Group, and the basal units of the Hawthorn Formations. The base of the aquifer is unknown, but is believed to be encountered at depths greater than 2000 feet below National Geodetic Vertical Datum of 1929 (NGVD). The confining beds are composed of Miocene age sediments of the Hawthorn Formation and range in thickness from less than 50 feet to greater than 400 feet. The Surficial Aquifer System is composed of undifferentiated Plio-Pleistocene age deposits of sand, shell, and clay that range in thickness from 38 feet to 225 feet.

The potentiometric surface of the Floridan Aquifer System is highest in western Polk County where it is more than 120 feet above NGVD. The region of potentiometric highs is elongated in the north-south direction and trends along the Lake Wales Ridge. Potentiometric levels decline gradually but non-uniformly throughout the southeastern portion of the planning area to less than 40 feet above NGVD. Since the groundwater flows from areas of

potentiometric highs towards areas of potentiometric lows, and water levels outside the western District boundary are higher than those inside the District, inflow to the study area occurs from the west. This inflow originates from recharge to the aquifer within the Southwest Florida Water Management District (SWFWMD). The average magnitudes of seasonal and annual fluctuations in hydraulic head for all monitor wells ranged from about 1 to 5 feet from 1980 through 1982, with maximum fluctuations at certain individual wells of 10-13 feet. Record low levels of hydraulic head were observed in May 1981. Many wells penetrating the Floridan Aquifer System exhibit relatively constant long-term water levels. Some wells which were pumped extensively, such as those used for public water supply, showed noticeable downward trends in water levels over the period of record. Therefore, it is important to have long term continual water level measurements to monitor the effects of groundwater withdrawals. The maintenance of flowing artesian conditions is especially crucial. Reduction in hydraulic head to a level below land surface will cause flow to cease in wells within the area of head reduction. Cessation of flowing artesian conditions would necessitate the installation of pumps for the withdrawal of water, which would have a major economic impact on the water user.

Water quality trends were determined from the concentration and distribution of physical and chemical water quality parameters in the Floridan Aquifer System. Four different techniques were used to interpret the water quality data as follows: 1) contour mapping, 2) Stiff patterns, 3) Piper trilinear diagrams, and 4) factor analysis. The Piper trilinear diagram proved to be the most useful in this regional study. The diagrams showed that water quality is best in the northwestern portion of the District. Groundwater in Polk and Osceola Counties is predominantly a calcium-bicarbonate type. Groundwater in southern Osceola and Polk Counties and in northern Highlands County is of moderate quality and is transitional between calcium-bicarbonate and sodium-chloride type waters. Groundwater in southern Highlands and in Okeechobee and Glades Counties is of the poorest quality and is a sodium-chloride type water. Poor water quality may limit the potential of the aquifer in this area to supply potable water. Wells which penetrate the Floridan Aquifer System should be constructed to avoid interaquifer exchange of this poor quality water with fresher shallower groundwater supplies.

The major sources of groundwater in the Kissimmee Planning Area are the Surficial Aquifer System and the Floridan Aquifer System. Throughout the Kissimmee Planning Area, the Surficial Aquifer System (non-artesian aquifer) will yield sufficient water for small domestic and irrigation requirements; however, previous work by Bishop (1956) and Lichtler and others (1968) indicates that the quality of the water obtained may be undesirable for certain uses due to pollution from fertilizers, surface runoff, organic contaminants, and suspended solids present depending upon the local lithology. The transmissivity of the Surficial Aquifer System is highly variable.

The Floridan aquifer is the principal source of groundwater throughout the planning area. The usage of groundwater from this system varies in different regions of the planning area due to differences in water quality and variations in depth to water-bearing zones. The transmissivity of the Floridan Aquifer System varies both locally and regionally. The northern portion of the study area has the highest transmissivity values ranging from 100,000 to greater than 1,000,000 gallons per day per foot (gpd/ft). The central portion of the planning area exhibits a transmissivity range of 50,000 to 100,000 gpd/ft. To the south the transmissivity is the lowest and ranges from 1,000 to 50,000 gpd/ft. Since the transmissivity represents the rate at which water is transmitted through the aquifer, the northern area has the greatest potential for groundwater yield. Since the Floridan Aquifer System in this part of the study area also has the best water quality, this area is considered best suited for water supply development. The area lies generally north of latitude 27°50'30".

ACKNOWLEDGEMENTS

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This study would not have been possible without the cooperation of property owners who allowed us to use their wells for monitoring purposes. These owners are to be thanked for their continued cooperation. This report was completed under the supervision of Nagendra Khanal, Director, Groundwater Division, whose critical review in the important final stages was greatly appreciated. The authors would like to extend a special acknowledgement to Leslie A. Wedderburn for his helpful guidance throughout the study and critical review of the manuscript.

INTRODUCTION

Purpose and Scope

The South Florida Water Management District (SFWMD) has been charged by the Florida legislature to "Attain maximum reasonable-beneficial use of water" and to "attain maximum economic development of the water resources consistent with other uses." The District has thus established as one of its goals to "assure availability of an adequate and affordable supply of water for all reasonable-beneficial uses." To reach this goal, the District embarked on a program of regional hydrogeologic investigations, data collection, and storage. Toward this end, the Resource Planning Department divided the District area into planning areas which could be studied individually.

The Kissimmee Planning Area (KPA) is one subdivision of the 17,930 square miles encompassed by the District. In the late 1970's reconnaissance work began on the Floridan Aquifer System in the KPA. This included the establishment of a groundwater monitoring network over the six-county area and the collection and compilation of all pertinent hydrogeologic data.

This report is the culmination of the reconnaissance study. The data are presented and interpreted to facilitate water management decision making, and to be applicable to computer simulation of groundwater conditions in the Floridan Aquifer System.

Location and Extent of Study Area

The KPA of the SFWMD encompasses an area of approximately 3500 square miles, including parts of Orange, Osceola, Okeechobee, Polk, Highlands and Glades Counties (Figure 1). It lies approximately within latitudes 28°33' and 27°00' and longitudes 81°40' and 80°45'. The initial extent of the KPA study did not include the Indian Prairie-Lake Istokpoga basin which was considered a separate planning area. Therefore, the report, "Hydrogeologic Data Collected

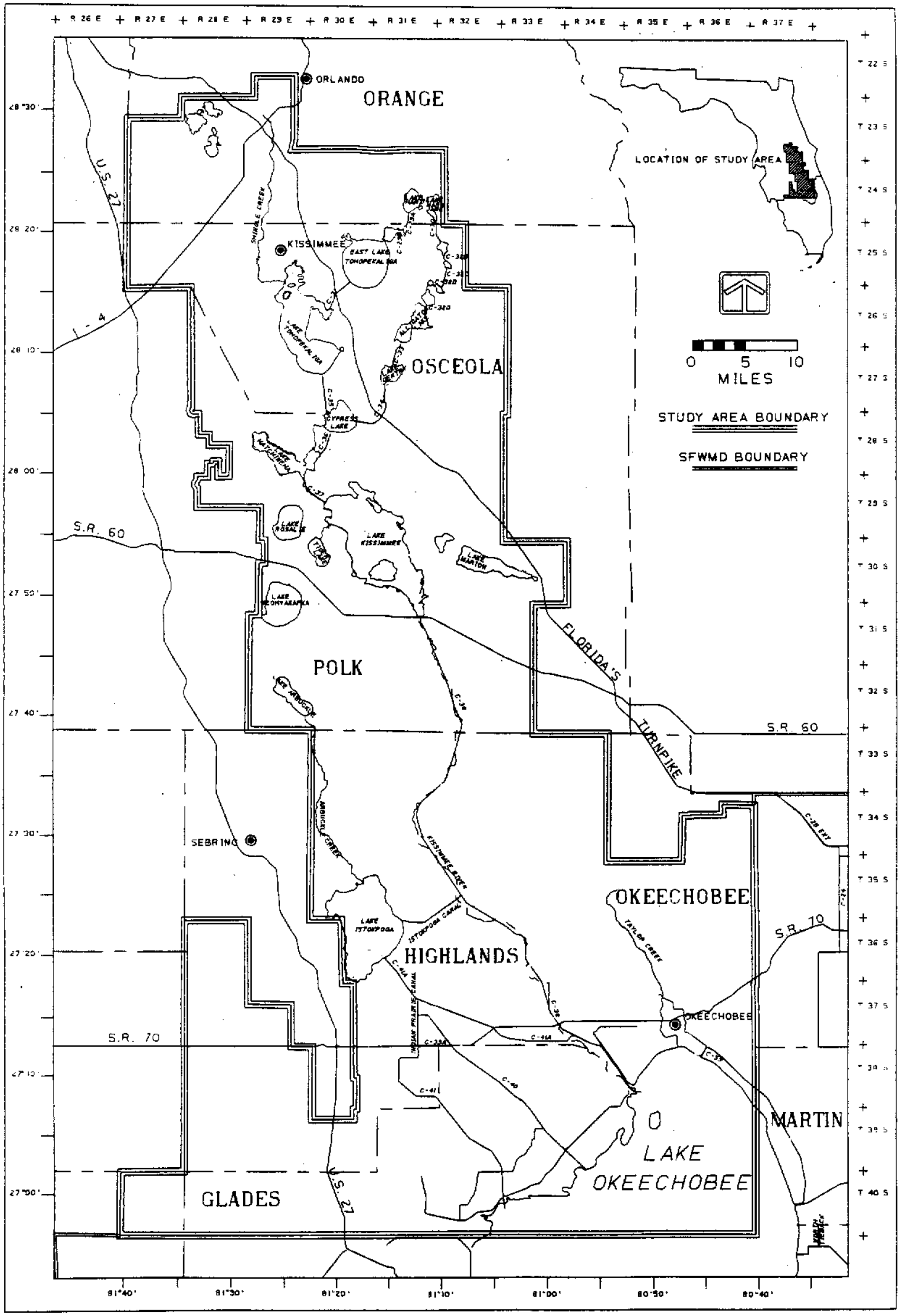


Figure 1 LOCATION OF STUDY AREA

from Kissimmee Planning Area, South Florida Water Management District" (Reece, and others, 1984), does not include data from the Indian Prairie-Lake Istokpoga basin. However, the area has since been included in the KPA and additional data collected from the area are presented in the Appendices. The planning area is elongated in a north-south direction extending from Orlando to Okeechobee. The eastern boundary is east of Okeechobee and the western boundary roughly approximates the Highlands/DeSoto county line.

Previous Investigations

Early investigators who made significant contributions to the understanding of the geology of south Florida include Matson and Clapp (1909), Cooke and Mossom (1929), and Cooke (1945). Stringfield (1936) discussed the principal artesian aquifer, or Floridan aquifer, while Parker and Cooke (1944) and Parker, Ferguson, Love and others (1955) addressed the geology and water resources of south Florida and presented a definition of the Floridan aquifer.

Many investigators have studied the hydrogeologic regimes of various counties within the KPA. Bishop (1956) discussed the geology and groundwater resources of Highlands County; Klein and others (1964) performed a similar study in Glades and Hendry Counties; Stewart (1966) described the groundwater resources of Polk County; Lichtler and others (1968) examined the water resources of Orange County.

Other studies of the hydrogeology of specific areas or geomorphic features within the KPA include a description of hydrologic features of the Lake Istokpoga and Lake Placid areas by Kohout and Meyer (1959), as well as an assessment of hydrologic conditions in the Lakeland Ridge area performed by Robertson (1973). Portions of the KPA were included in a publication by Lichtler (1972) which discussed water resources in east-central Florida. The consulting firm of Geraghty and Miller (1980) examined the hydrogeology of the

Highlands Ridge. Chemical aspects of the Floridan Aquifer System were examined by Hanshaw and others (1965), Shampine (1965), Back and Hanshaw (1970), and Plummer (1977). The top of the Floridan Aquifer System has been mapped in various regions of the state by Vernon (1973), Kwader and Schmidt (1978), Knapp (1979), and Scott and Hajishafie (1980). The potential of the Floridan Aquifer System for recharge purposes was first examined by Unklesbay and Cooper (1946) and then evaluated by Watkins (1977). Knochenmus (1975) prepared a study on the feasibility of artificially recharging the Floridan Aquifer System in eastern Orange County. Kimrey and Fayard (1982) prepared a report on drainage wells in Florida. Areas of natural recharge were mapped by Stewart (1980).

Physiography

White (1970) divides the State of Florida into three major divisions (Figure 2a). The northern, or proximal zone, is characterized by continuous high ground which forms a broad upland. The central, or mid-peninsular zone, is marked by discontinuous highlands in the form of sub-parallel ridges and valleys. The southern, or distal zone, is characterized by a broad, flat, gently sloping and poorly drained plain.

The majority of the KPA lies within the central, or mid-peninsular zone. The southernmost portion of the planning area is located in the southern, or distal zone.

The major geomorphic features found in the KPA are: the Osceola Plain and the Bombing Range Ridge, the Okeechobee Plain, small portions of the Caloosahatchee Incline, the Lake Wales Ridge, the Orlando Ridge, and a portion of the Mount Dora Ridge (Figure 2b).

The Osceola Plain is a generally broad terrace bounded by the Lake Wales Ridge to the west and the Eastern Valley to the east, both of which are marine

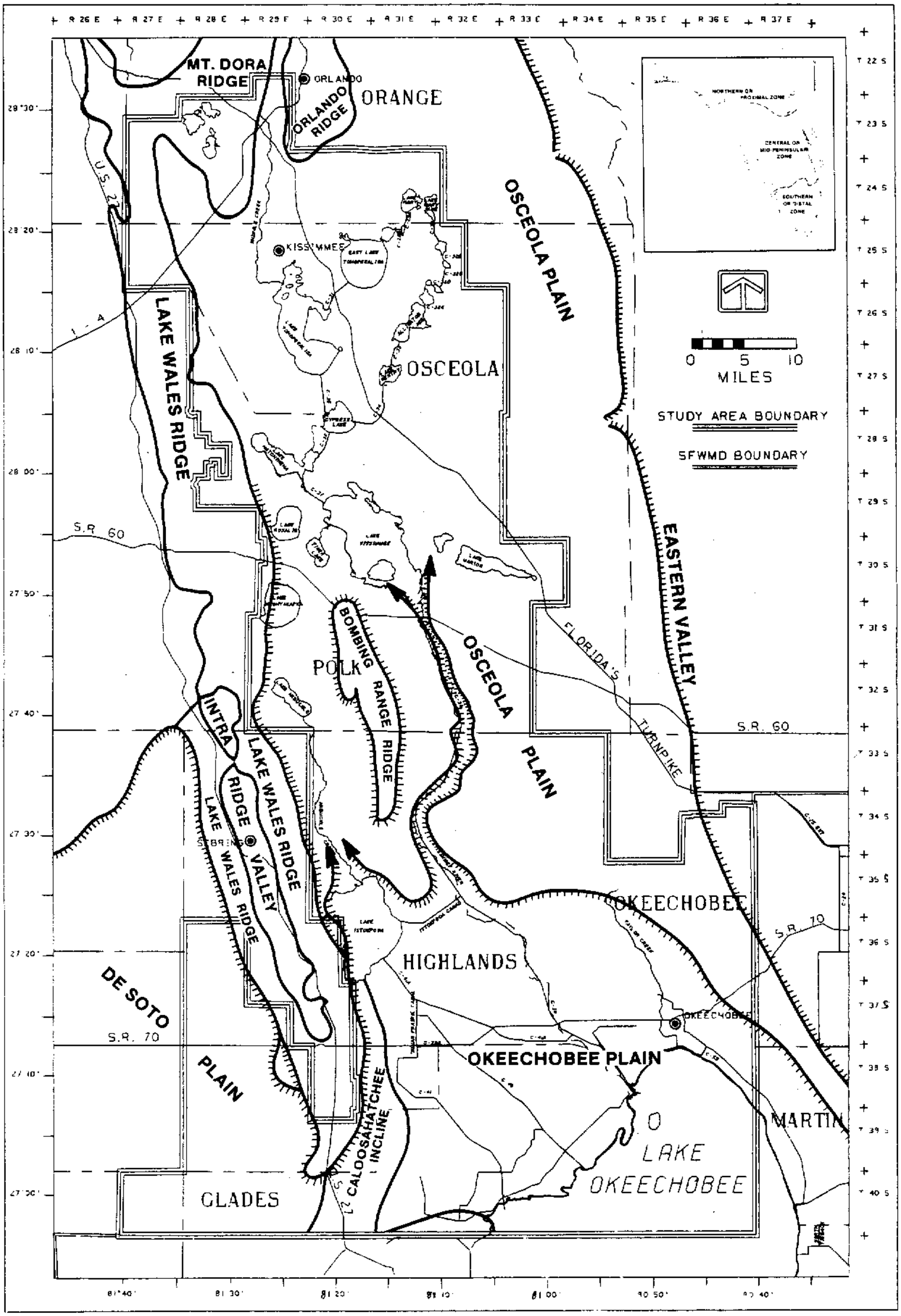


Figure 2 A) MAJOR PHYSIOGRAPHIC DIVISIONS OF FLORIDA, (SEE INSET) AND B) MAJOR GEOMORPHIC FEATURES OF THE KPA (FROM WHITE, 1970)

scarps. The Osceola Plain has locally little relief and generally has an elevation of 60 to 70 feet above the National Geodetic Vertical Datum of 1929 (NGVD). A prominent feature of the Osceola Plain is known as the Bombing Range Ridge (White, 1970). The ridge resembles a large marine bar. To the west of the Bombing Range Ridge is the valley that drains Lake Arbuckle into Lake Istokpoga via Arbuckle Creek. To the east of the Bombing Range is the Kissimmee River. According to White (1970):

> "The Kissimmee River passes through the length of the Osceola Plain slightly west of the center line roughly parallel with the axis of the peninsula. For the southernmost 25 miles of this route it occupies a valley about a mile and a half wide which is cut rather sharply into the surface of the plain. But from Lake Kissimmee northward (upstream) the valley opens out into a large group of big lakes which take up a large percentage of the area of the northern half and western three quarters of the main part of the Osceola Plain. This group of lakes includes some of the largest in Florida such as Lakes Kissimmee, Weohyakapka, Tohopekaliga, East Tohopekaliga, Hatchineha, Marion, Alligator, Hart, etc. Through much of the sprawling chain of lakes the Kissimmee drainage system maintains a recognizable valley with a flood plain discrete from the upland surface of the Osceola Plain. But in most places the distinction between the drainage ways and the upland surface is obscure."

The Okeechobee Plain, which dips very gradually to the south, is one of the flattest parts of the United States (White, 1970). At its northern boundary at the toe of the Osceola Plain, the elevation is 30-40 feet above NGVD and slopes gently southward to an elevation of 20 feet above NGVD at the north shore of Lake Okeechobee. The narrow northern portion of this plain consists of the Kissimmee River Valley. The Lake Wales Ridge, which forms the most prominent topographic feature of the Florida Peninsula, rises abruptly above the Okeechobee Plain to an elevation of over 150 feet NGVD (White, 1970). The Lake Wales Ridge dominates the topography along the western boundary of the KPA. The ridge area is probably the remains of a larger upland which has been reduced by erosion. The southern portion of the Lake Wales Ridge is divided into two secondary ridges separated by the Intraridge

Valley which contains a chain of small solution lakes. The Intraridge Valley lies outside of the District boundary where it comprises the portion of Highlands County which is located in the Southwest Florida Water Management District (SWFWMD).

The Caloosahatchee Incline forms a long, narrow, sloping surface which inclines gently eastward between the Lake Wales Ridge and the Okeechobee Plain. The elevation of the Caloosahatchee Incline ranges from about 50 to 60 feet NGVD, which is comparable to the Osceola Plain. White (1970) theorized that these two geomorphic features may have had a similar origin.

The Orlando Ridge and the southern portion of the Mount Dora Ridge lie to the north of the Osceola Plain. Both are elevated sandy ridges and may be relict capes similar to Cape Canaveral to the east, resulting from a higher sea level stand (White, 1970).

Climate and Rainfall

The climate of the KPA is subtropical with a mean annual temperature of approximately 72 degrees Farenheit (^{o}F). Summers are long, warm, and relatively humid; winters are mild due to the warm ocean waters and southern latitude. July and August have the highest average temperatures while December and January have the lowest average temperatures. The average annual rainfall in the KPA is about 50 inches (MacVicar, 1983). This is a large amount of precipitation compared to the National average of 28.82 inches (personal communication, National Climatic Center) and plays a major role in supplying fresh water to the groundwater system.

Rainfall occurs in south Florida in two distinct periods; the rainy season and the dry season. Usually, more than fifty percent of the annual rainfall occurs during the four month period between June and September. Most of the rainfall in the summer is derived from local showers or thundershowers.

Showers are often heavy, last approximately 1-2 hours, and occur during the hottest portion of the day. Significant rainfall is also due to frontal systems and tropical depressions (hurricanes).

However, Florida is not free from drought. Periodically the heavy summer rains do not fall. In 1971, and again in 1981, record low rainfalls caused Lake Okeechobee to drop to a level of approximately 10 feet above NGVD while the optimum operating level is 15.5 to 17.5 feet above NGVD.

Drainage and Surface Water Flow

Drainage and surface water flow in the KPA is dominated by the Kissimmee River Basin. The basin can be divided at the southern outlet of Lake Kissimmee into upper and lower sections.

The upper portion of the KPA contains numerous surface water lakes and streams that drain large amounts of water from agricultural and urban areas. The lakes in the upper portion of the basin occupy a surface area of more than 200 square miles (Huber, et al, 1976).

The lower portion of the river system is channelized and includes three square miles of surface water which flows south to Lake Okeechobee through a narrow flood plain draining agricultural land. An annual average of 10 inches of runoff is conveyed to Lake Okeechobee. Since the average annual evaporation is approximately equal to the average annual rainfall, most of the net water available from the lake comes from Kissimmee River flow. The Kissimmee River is the major river in the KPA and flows from north to south down the center of the planning area. The average flow of the Kissimmee River measured near Lake Okeechobee is approximately 2,000 cubic feet per second (cfs) at a velocity of 1.58 feet/second (USGS, 1974). Lake Okeechobee is the largest lake in the planning area. Table 1 shows the surface area of selected lakes in the KPA.

TABLE 1. SURFACE AREA OF SELECTED LAKES IN THE KPA

Lake	Surface Area (Square Miles)
Okeechobee	717 at elevation 17.5'
Kissimmee, Hatchineha, Cypress	130 at elevation 54.0'
Istokpoga	51 at elevation 42.0'
Tohopekaliga	36 at elevation 56.0'
East Tohopekaliga	22 at elevation 60.0'
Weohyakapka	17 at elevation 65.0'

DATA COLLECTION NETWORK AND METHODS

Well Numbering System

The SFWMD assigned a number to each well as it was added to the study. This number is preceded by the first two letters of the county in which the well is located, followed by the letter "F" which indicates that the well penetrates the Floridan Aquifer System to some extent. For example, well HIF-6 would represent the 6th such well added to the network in Highlands County and so on. Since a well may subsequently be deleted by failing to meet certain necessary criteria, the numbers are not always consecutive. The U. S. Geological Survey (USGS) has assigned a station identification number to most of the wells included in the study.

A number of Florida Bureau of Geology (BOG) wells were included in the program. Geologic cutting descriptions compiled by the Bureau of Geology for these wells were utilized in the study. These wells have the BOG designation of "W", followed by a number.

A number of USGS wells were also included in the program but not assigned SFWMD numbers. They consist of Floridan Aquifer System wells used to compile water level readings. These wells, for the purpose of this report, have been designated by an "X", followed by a number.

Monitoring Network

The initial thrust of the program was to establish a Floridan Aquifer System monitoring network. This involved locating all of the accessible Floridan Aquifer System wells in the planning area and then selecting wells for inclusion in the monitoring network based on the following criteria:

1) Cooperation of owner,
2) Likelihood of obtaining accurate water-level measurements and representative water samples,

3) Availability of well construction and geologic information,

4) Deep penetration of aquifer,

5) Access for borehole geophysical logging,

6) Suitability for specific-capacity testing,

7) Geographic distribution of wells, and

8) Suitability of installation of water-level recorder.

A given well did not have to meet all 8 requirements to be added to the network. The W and X wells are not considered part of the monitoring network. An additional four wells were drilled by SFWMD to improve the areal coverage and collect additional hydrogeologic data.

Data collected from the monitoring network, as well as the W and X wells include: (1) hydraulic head or water level measurements; (2) water quality; (3) geophysical logs; (4) geologic descriptions of drill cuttings; and (5) aquifer characteristics, i.e. specific capacity and transmissivity. Table 2 lists the availability of these data for each well.

The description of each monitor well, including SFWMD station number, USGS station number, latitude and longitude, section, township, range, depth of well, source of depth, depth of casing, casing diameter, type of pump, and the name of owner is summarized in Table 3.

The description of each W well, including Bureau of Geology number, latitude and longitude, section, township, range, depth and owner are summarized in Table 4.

The description of each X well, including designated number, USGS station number, latitude and longitude, depth, source of depth information, casing depth, and diameter are summarized in Table 5.

The locations of the wells are shown on Figure 3.

TABLE 2. DATA AVAILABILITY IN KPA MONITORING NETWORK, W AND X WELLS

WELL NUMBER	WATER LEVELS	WATER QUALITY	GEOPHYSICAL LOGS	GEOLOGIC LOGS	AQUIFER CHARACTERISTICS
GLF- 1	X	X	X		
GLF- 2	X	X	X		
GLF- 3	X	X			
GLF- 5	X	X	X		
HIF- 1	X	X			X
HIF- 2	X	X			
HIF- 3	X	X			
HIF- 4	X	X			
HIF- 5	X		X		
HIF- 6	X	X	X		X
HIF- 7	X	X			
HIF- 8	X	X			
HIF- 9	X	X			
HIF-10		X			
HIF-11		X	X		
HIF-13	X	X			
HIF-14	X	X			
HIF-15	X				
HIF-16	X	X			
HIF-17	X				
HIF-18	X				
HIF-19		X			
HIF-20	X				
HIF-21	X	X			
HIF-22	X	X			
HIF-23	X	X			
HIF-24	X				
HIF-25	X		X		
HIF-26	X				
HIF-27	X	X			
HIF-28	X	X			

TABLE 2. DATA AVAILABILITY IN KPA MONITORING NETWORK, W AND X WELLS (Continued)

WELL NUMBER	WATER LEVELS	WATER QUALITY	GEOPHYSICAL LOGS	GEOLOGIC LOGS	AQUIFER CHARACTERISTICS
HIF-29	X	X			
HIF-30	X	X			
HIF-31	X	X			
HIF-32	X	X			
HIF-33	X				
HIF-34	X				
HIF-35		X	X	X	
HIF-37	X	X			
HIF-38	X	X	X		
HIF-39			X		X
HIF-41				X	X
MF-20		X	X	X	
OKF- 1		X			
OKF- 2	X	X	X		
OKF- 3	X	X	X		
OKF- 4	X	X			
OKF- 5	X	X	X		X
OKF- 6	X	X	X		
OKF- 7	X	X	X		X
OKF- 9	X				
OKF-10	X				
OKF-13	X	X			X
OKF-15	X	X			X
OKF-16	X	X	X		
OKF-17	X	X	X		X
OKF-18	X	X	X		X
OKF-19	X	X	X		
OKF-22	X	X			
OKF-23	X	X		X	
OKF-24		X		X	

TABLE 2. DATA AVAILABILITY IN KPA MONITORING NETWORK, W AND X WELLS (Continued)

WELL NUMBER	WATER LEVELS	WATER QUALITY	GEOPHYSICAL LOGS	GEOLOGIC LOGS	AQUIFER CHARACTERISTICS
OKF-25	X	X			
OKF-26		X		X	X
OKF-27		X		X	X
OKF-29		X	X	X	
OKF-30	X	X			
OKF-31	X	X			
OKF-34	X		X		X
OKF-35	X	X			
OKF-36	X	X	X		
OKF-37	X	X	X		
OKF-40		X			
OKF-42	X	X	X	X	X
OKF-50	X	X			
OKF-51	X	X			
OKF-52	X				
OKF-53	X	X			
OKF-54	X	X	X		X
OKF-56	X	X			
OKF-75	X	X			
OKF-76	X	X			
OKF-77	X	X			
ORF- 1	X				
ORF- 2	X				
ORF- 6	X				
ORF- 7	X		X		
ORF-11					
ORF-15	X		X		
ORF-16	X				
ORF-17	X				
ORF-18	X				
ORF-19	X				

TABLE 2. DATA AVAILABILITY IN KPA MONITORING NETWORK, W AND X WELLS (Continued)

WELL NUMBER	WATER LEVELS	WATER QUALITY	GEOPHYSICAL LOGS	GEOLOGIC LOGS	AQUIFER CHARACTERISTICS
ORF-21	X		X		
ORF-22	X				
ORF-25	X		X		
ORF-26	X				
ORF-29	X	X			
ORF-30	X	X			
ORF-31	X	X	X		
ORF-32	X	X			
ORF-33	X				
ORF-34	X		X		
ORF-35	X				
ORF-36	X				
ORF-37	X				
ORF-40	X				
ORF-41	X				
ORF-42					
ORF-43				X	X
OSF- 1	X	X			
OSF- 2	X	X	X		X
OSF- 3		X	X	X	
OSF- 4	X	X		X	
OSF- 5	X	X	X		
OSF- 6	X	X			
OSF- 7		X			
OSF- 8	X	X			
OSF- 9	X	X	X	X	X
OSF-10	X	X		X	X
OSF-11	X	X	X		X
OSF-12	X	X			
OSF-13	X	X			

TABLE 2. DATA AVAILABILITY IN KPA MONITORING NETWORK, W AND X WELLS (Continued)

WELL NUMBER	WATER LEVELS	WATER QUALITY	GEOPHYSICAL LOGS	GEOLOGIC LOGS	AQUIFER CHARACTERISTICS
OSF-14	X	X			
OSF-15	X	X		X	
OSF-16	X	X			
OSF-17	X	X			
OSF-18	X	X			
OSF-19		X	X		
OSF-20	X				
OSF-21	X				
OSF-22	X	X	X	X	
OSF-23	X			X	
OSF-24	X	X	X		
OSF-25		X	X	X	X
OSF-26		X	X	X	X
OSF-27	X	X	X	X	X
OSF-28	X	X			
OSF-29	X				
OSF-30		X			
OSF-31	X			X	X
OSF-32	X	X			
OSF-33	X	X	X		
OSF-34	X	X			
OSF-35	X	X			
OSF-37	X	X			
OSF-38	X	X			
OSF-39	X		X		
OSF-41			X		
OSF-42	X	X	X		X
OSF-44	X	X	X		X
OSF-45				X	
OSF-50				X	
OSF-52	X	X	X	X	X

TABLE 2. DATA AVAILABILITY IN KPA MONITORING NETWORK, W AND X WELLS (Continued)

WELL NUMBER	WATER LEVELS	WATER QUALITY	GEOPHYSICAL LOGS	GEOLOGIC LOGS	AQUIFER CHARACTERISTICS
OSF-53	X	X	X	X	X
OSF-54				X	X
OSF-55				X	X
POF- 1	X	X	X		
POF- 2	X	X	X		X
POF- 3	X	X	X		
POF- 4	X	X	X		X
POF- 5	X	X	X		
POF- 6	X	X			X
POF- 7		X			X
POF- 8	X	X			
POF- 9	X	X			
POF-10	X	X			
POF-11	X	X			
POF-12	X	X	X		
POF-13	X	X		X	
POF-14	X	X	X		
POF-15	X	X			
POF-17	X	X			
POF-18	X	X			
POF-19	X	X		X	
POF-20	X	X	X	X	X
W-519				X	
W-623				X	
W-696				X	
W-697				X	
W-894				X	
W-965				X	
W-1411				X	
W-1464				X	

TABLE 2. DATA AVAILABILITY IN KPA MONITORING NETWORK, W AND X WELLS (Continued)

WELL NUMBER	WATER LEVELS	WATER QUALITY	GEOPHYSICAL LOGS	GEOLOGIC LOGS	AQUIFER CHARACTERISTICS
W-1754				X	
W-1770				X	
W-1882				X	
W-1949				X	
W-2163				X	
W-2397				X	
W-2398				X	
W-2399				X	
W-2859				X	X
W-4750				X	
W-4896				X	
W-6282				X	
W-9127				X	
W-9129				X	
W-9130				X	
W-9145				X	
W-9151				X	
W-9156				X	
W-11366				X	
W-11369				X	
W-11954				X	
W-13942				X	
X- 1	X				
X- 2	X				
X- 3	X				
X- 4	X				
X- 5	X				
X- 6	X				
X- 7	X				

TABLE 2. DATA AVAILABILITY IN KPA MONITORING NETWORK, W AND X WELLS (Continued)

WELL NUMBER	WATER LEVELS	WATER QUALITY	GEOPHYSICAL LOGS	GEOLOGIC LOGS	AQUIFER CHARACTERISTICS
X- 8	X				
X- 9	X				
X-10	X				
X-11	X				
X-12	X				
X-13	X				
X-14	X				
X-15	X				
X-16	X				
X-17	X				
X-18	X				
X-19	X				
X-20	X				
X-21	X				
X-22	X				
X-23	X				
X-24	X				
X-25	X				
X-26	X				
X-27	X				
X-28	X				
X-29	X				
X-30	X				
X-31	X				
X-32	X				
X-33	X				
X-34	X				
X-35	X				
X-36	X				
X-37	X				
X-38	X				

TABLE 2. DATA AVAILABILITY IN KPA MONITORING NETWORK, W AND X WELLS (Continued)

WELL NUMBER	WATER LEVELS	WATER QUALITY	GEOPHYSICAL LOGS	GEOLOGIC LOGS	AQUIFER CHARACTERISTICS
X-39	X				
X-40	X				
X-41	X				
X-42	X				
X-43	X				
X-44	X				
X-45	X				
X-46	X				
X-47	X				
X-48	X				
X-49	X				
X-50	X				
X-51	X				
X-52	X				
X-53	X				
X-54	X				
X-55	X				
X-56	X				
X-57	X				
X-58	X				
X-59	X				

TABLE 3 .--WELL LOCATIONS AND DESCRIPTIONS FOR SFWMD MONITOR WELLS

SFWMD STATION NUMBER	USGS STATION NUMBER	LAT-ITUDE	LONG-ITUDE	SECTION-TOWNSHIP-RANGE	DEPTH OF WELL (FT)	SOURCE OF DEPTH	DEPTH OF CASING (FT)	CASING DIAM-ETER (IN)	TYPE OF PUMP	NAME OF OWNER
COUNTY=GLADES										
GLF- 1	270848080552401	270848	805524	28-38S-34E	824	LOGS	464	6	NONE	JOHN PEARCE
GLF- 2	270216081010401	270218	810104	34-39S-33E	824	LOGS	390	6	NONE	BILL WIERSMA
GLF- 3	270115081212901	270102	812129	06-40S-30E	1500	OWNER	200	10	TURBINE	R.B. OXER
GLF- 5	265454081151001	265454	811510	08-41S-31E	1620	LOGS	290	12	NONE	LYKES BROS. INC.
COUNTY=HIGHLANDS										
HIF- 1	271335081052001	271335	810520	26-37S-32E	640	OWNER	.	6	NONE	LYKES BROS. INC.
HIF- 2	272237081070701	272237	810707	03-36S-32E	900	OWNER	.	6		LYKES BROS. INC.
HIF- 3	273138081154201	273138	811542	18-34S-31E	1260	OWNER	.	12	TURBINE	CLAUDE HOWERTON
HIF- 4	272906081142001	272906	811420	28-34S-31E	1300	OWNER	.	.	TURBINE	CARLOS FALLA JR.
HIF- 5	271134081234301	271137	812338	11-38S-29E	1510	LOGS	602	12	NONE	CHARLES STIDHAM
HIF- 6	271456081074701	271454	810741	21-37S-32E	520	LOGS	310	4	NONE	LYKES BROS. INC.
HIF- 7	271306081271701	271306	812717	31-37S-29E	1450	OWNER	.	10	TURBINE	DORYLE CARLTON
HIF- 8	271306081284801	271306	812848	26-37S-28E	1450	OWNER	.	16	TURBINE	DORYLE CARLTON
HIF- 9	271521081285401	271519	812853	14-37S-28E	1450	OWNER	.	16	TURBINE	DORYLE CARLTON
HIF-10		272728	811934	04-35S-30E	1420	OWNER	.	16	TURBINE	DAVIS CATTLE CO.
HIF-11		271612	811132	11-37S-31E	693	LOGS	290	3.5	NONE	EDNA P. LOCKETT
HIF-13	272512081122901	272512	811229	22-35S-31E	.		.	.	TURBINE	PHILLIP METZGER
HIF-14	271726081163901	271726	811639	01-37S-30E	1500	OWNER	.	8	TURBINE	PAUL G. PHYPERS
HIF-15	272224081323301	272224	813233	05-36S-28E	.		.	10	TURBINE	HAROLD YOUNG
HIF-16	272048081322101	272048	813221	17-36S-28E	1225	OWNER	.	16	TURBINE	C.M. PAYNE
HIF-17	271842081322701	271842	813227	29-36S-28E	1750	DRILLER	.	16	TURBINE	MITCHELL MILLER
HIF-18	271517081250801	271517	812508	16-37S-29E	1100+	OWNER	.	16	TURBINE	WESTBY CORP.
HIF-19		271259	812557	32-37S-29E	1000	OWNER	110	12	TURBINE	WESTBY CORP.
HIF-20	271028081264901	271028	812649	17-38S-29E	1350	OWNER	.	.	NONE	KAYO WELLS
HIF-21	270235081272001	270235	812720	31-39S-28E	1594	DRILLER	695	16	TURBINE	FISHEATING CREEK DAIRY
HIF-22	270700081291001	270700	812910	02-39S-28E	1560	OWNER	.	16	TURBINE	THE GRAHAM CO.
HIF-23	270627081313101	270627	813131	04-39S-28E	1560	OWNER	.	16	TURBINE	THE GRAHAM CO.
HIF-24	271334081330901	271334	813309	30-37S-28E	.		.	.	NONE	EDNA CARLTON
HIF-25	271045081283001	271045	812830	12-38S-28E	780	LOGS	622	8	NONE	EDNA CARLTON
HIF-26	270556081204701	270556	812047	08-39S-30E	1645	LOGS	.	.	NONE	J.H. HENDRIE
HIF-27	270653081210401	270653	812104	06-39S-30E	.		.	.	TURBINE	J.H. HENDRIE
HIF-28	270751081245301	270751	812453	33-38S-29E	1400	OWNER	350	12	TURBINE	RANDY DRESSEL
HIF-29	270751081242401	270751	812424	34-38S-29E	1610	OWNER	700	12	TURBINE	H.S. DARROH
HIF-30	270953081242901	270953	812429	22-38S-29E	1500	OWNER	700	12	TURBINE	H.S. DARROH
HIF-31	271216081235101	271216	812351	02-38S-29E	1585	OWNER	700	12	TURBINE	H.S. DARROH
HIF-32	272915081190201	272915	811902	27-34S-30E	1360	OWNER	250	12	TURBINE	GILFORD TOMLINSON
HIF-33	273105081135101	273105	811351	16-34S-31E	1100	OWNER	.	16	TURBINE	EVERETT BONEY
HIF-34		271253	812455	33-37S-29E	1130	OWNER	160	12	TURBINE	WESTBY CORP.
HIF-35		272114	810954	18-36S-32E	1240	LOGS	346	10	TURBINE	LYKES BROS. INC.
HIF-37	271330081113401	271330	811134	33-37S-31E	1450	DRILLER	619	12	NONE	GRIGSBY BROS.
HIF-38	270245081283301	270245	812833	36-39S-28E	1430	LOGS	750	12	NONE	GARDNIER
HIF-39		272158	810827	08-36S-32E	1332	LOGS	370	10	TURBINE	LYKES BROS. INC.
HIF-41		272655	812132	07-35S-30E	1205	DRILLER	420	16	TURBINE	SEBRING UTILITIES COMM.

TABLE 3 .--WELL LOCATIONS AND DESCRIPTIONS FOR SFWMD MONITOR WELLS

SFWMD STATION NUMBER	USGS STATION NUMBER	LAT-ITUDE	LONG-ITUDE	SECTION-TOWNSHIP-RANGE	DEPTH OF WELL (FT)	SOURCE OF DEPTH	DEPTH OF CASING (FT)	CASING DIAM-ETER (IN)	TYPE OF PUMP	NAME OF OWNER
COUNTY=MARTIN										
MF-20	270919080365001	270919	803650	22-36S-37E	1200	LOGS	434	8	NONE	BOB'S GROVES
COUNTY=OKEECHOBEE										
OKF- 1	272815080425401	272815	804254	03-35S-36E	.		.	4	NONE	CHARLES SCOTT RANCH
OKF- 2	273238080424201	273238	804242	02-34S-36E	686	LOGS	218	6	NONE	EVANS
OKF- 3	271110080414501	271114	804145	02-38S-36E	433	LOGS	430	8	NONE	JIM ENRICO
OKF- 4	272427080555301	272427	805553	21-35S-34E	.		.	6	NONE	CLARENCE LOFTON
OKF- 5	271855080482501	271855	804825	26-36S-35E	1181	LOGS	440	8	NONE	FRANK WILLIAMSON JR.
OKF- 6	272318080561901	272318	805619	33-35S-34E	872	LOGS	417	6	NONE	CLARENCE LOFTON
OKF- 7	272158080470901	272156	804709	01-36S-35E	962.6	LOGS	412	8	NONE	ROGER JONES
OKF- 9	272833080560301	272833	805603	33-34S-34E	850	OWNER	.	10	NONE	GRIFFITH RANCH
OKF-10	272817080560301	272817	805732	31-34S-34E	.		.	8	NONE	GRIFFITH RANCH
OKF-13	273043080440001	273043	804400	21-34S-36E	1200	OWNER	.	12	NONE	FRANK WILLIAMSON JR.
OKF-15	271934080591301	271934	805913	24-36S-33E	1600	OWNER	.	8	NONE	CURTIS WALDRON
OKF-16	272003080551301	272003	805513	15-36S-34E	.		.	4	NONE	LARSON DAIRY
OKF-17	272010080550801	272010	805508	15-36S-34E	986	LOGS	538	6	NONE	LARSON DAIRY
OKF-18	272726081003901	272726	810039	03-35S-33E	1015	LOGS	255	8	NONE	OSCAR BASS
OKF-19	272701080575501	272701	805755	06-35S-34E	948	LOGS	235	8	NONE	ELWYN BASS
OKF-22	271439080565301	271439	805619	16-37S-34E	700	OWNER	.	6	NONE	C.E. NEWCOMER
OKF-23	271514080511601	271514	805116	17-37S-35E	925	DRILLER	496	6	NONE	BOB FLOYD
OKF-24	271340080444001	271340	804440	29-37S-36E	1448	DRILLER	611	6	NONE	MONRAD CHANDLER
OKF-25	271438080571901	271438	805719	17-37S-34E	.		.	6	NONE	C.E. NEWCOMER
OKF-26	271830080493502	271830	804935	27-36S-35E	825	DRILLER	.	12	TURBINE	FLORIDA SCHOOL FOR BOYS
OKF-27	271830080493501	271830	804935	27-36S-35E	725	DRILLER	477	.	TURBINE	FLORIDA SCHOOL FOR BOYS
OKF-29	272630080503001	272630	805030	09-35S-35E	1039	LOGS	336	6	NONE	MCARTHUR DAIRY
OKF-30	271411080461201	271425	804610	19-37S-36E	.		.	8	NONE	MURPHY WHITE DAIRY
OKF-31	271340080504001	271340	805040	28-37S-35E	1079	OWNER	.	6	NONE	ROBERT L. LAMARTIN
OKF-34	273217081012601	273217	810126	09-34S-33E	1143	LOGS	276	10	NONE	COMMUNITIES FINANCIAL
OKF-35	271456080500701	271456	805007	16-37S-35E	1327	OWNER	.	6	NONE	B.P. ABNEY
OKF-36	273124081012401	273122	810140	16-34S-33E	896	LOGS	190	10	NONE	COMMUNITIES FINANCIAL
OKF-37	272852080595801	272852	805958	26-34S-33E	1039	LOGS	300	6	NONE	COMMUNITIES FINANCIAL
OKF-40	272430081035501	272430	810355	19-35S-33E	.		300	6	TURBINE	LARSON DAIRY
OKF-42	272403081065801	272403	810658	07-35S-28E	1152	LOGS	370	6	NONE	S.F.W.M.D.
OKF-50	273740080535101	273740	805356	02-33S-34E	.		.	.	TURBINE	DORYLE CARLTON
OKF-51	273632080535601	273625	805325	14-33S-34E	.		.	.	TURBINE	DORYLE CARLTON
OKF-52	273604080533501	273614	805336	14-33S-34E	.		.	.	TURBINE	DORYLE CARLTON
OKF-53	273502080535501	273509	805347	23-33S-34E	.		.	.	TURBINE	DORYLE CARLTON
OKF-54	273740080551201	273740	805512	03-33S-34E	973	LOGS	260	12	NONE	DORYLE CARLTON
OKF-56	272704081053501	272704	810533	02-35S-32E	.		.	10	TURBINE	PETE CLEMONS
OKF-75	271640080571501	271640	805715	05-37S-34E	1100	OWNER	.	6	CENTRIFUGAL	PELAEZ AND SONS
OKF-76	271552080564201	271552	805642	08-37S-34E	1100	OWNER	.	8	CENTRIFUGAL	PELAEZ AND SONS
OKF-77	272512081014001	272512	810140	21-35S-33E	1100	OWNER	.	8	TURBINE	CHRISTINA P. HOOKER

TABLE 3 .--WELL LOCATIONS AND DESCRIPTIONS FOR SFWMD MONITOR WELLS (Continued)

SFWMD STATION NUMBER	USGS STATION NUMBER	LAT- ITUDE	LONG- ITUDE	SECTION- TOWNSHIP- RANGE	DEPTH OF WELL (FT)	SOURCE OF DEPTH	DEPTH OF CASING (FT)	CASING DIAM- ETER (IN)	TYPE OF PUMP	NAME OF OWNER
COUNTY=ORANGE										
ORF- 1	282508081185802	282508	811858	09-24S-30E	400	OTHER	.	5	NONE	CITY OF ORLANDO
ORF- 2	282704081214301	282704	812143	25-23S-29E	455	OWNER	.	8	NONE	ORANGE COUNTY
ORF- 6	282257081383201	282257	813832	19-24S-27E	.		.	2	NONE	UNKNOWN
ORF- 7	282545081240901	282545	812409	03-24S-29E	450	LOGS	212	8	NONE	FLORIDA D.O.T.
ORF-11	282539081315001	282539	813150	05-24S-28E	432	OWNER	107	6	NONE	I. S. PRESCOTT
ORF-15	282051081183401	282051	811834	34-24S-30E	400	LOGS	199	4	NONE	U.S. GEOLOGICAL SURVEY
ORF-16	282250081302101	282250	813021	22-24S-28E	252	DRILLER	171	4	NONE	R.C.I.D.
ORF-17	282354081313001	282354	813130	17-24S-28E	281	DRILLER	145	4	NONE	R.C.I.D.
ORF-18	282528081340901	282528	813409	01-24S-27E	223	DRILLER	104	8	NONE	R.C.I.D.
ORF-19	282202081384601	282202	813846	30-24S-27E	318	DRILLER	103	6	NONE	U.S. GEOLOGICAL SURVEY
ORF-21	282141081241701	282141	812417	34-24S-29E	435	LOGS	317	4	NONE	U.S. GEOLOGICAL SURVEY
ORF-22	282521081214201	282521	812142	01-24S-29E	467	DRILLER	232	8	NONE	FLA. RANCH LANDS, INC.
ORF-25	282241081112801	282241	811128	23-24S-31E	302	LOGS	240	4	NONE	U.S. GEOLOGICAL SURVEY
ORF-26	282556081302401	282556	813024	34-24S-29E	230	DRILLER	130	4	NONE	U.S. GEOLOGICAL SURVEY
ORF-29	282331081370801	282331	813708	22-23S-28E	166	DRILLER	68	4	NONE	U.S. GEOLOGICAL SURVEY
ORF-30	282647081354801	282647	813648	33-23S-27E	135	OWNER	90	4	NONE	U.S. GEOLOGICAL SURVEY
ORF-31	282738081341401	282738	813414	25-23S-27E	132	LOGS	103	4	NONE	U.S. GEOLOGICAL SURVEY
ORF-32	282835081305201	282839	813026	22-23S-28E	235	LOGS	161	4	NONE	U.S. GEOLOGICAL SURVEY
ORF-33	282434081283101	282434	812831	11-24S-28E	235	LOGS	158	4	NONE	U.S. GEOLOGICAL SURVEY
ORF-34	282611081320501	282611	813205	32-23S-28E	180	LOGS	95	4	NONE	U.S. GEOLOGICAL SURVEY
ORF-35	282709081283001	282709	812830	25-23S-28E	205	DRILLER	68	4	NONE	U.S. GEOLOGICAL SURVEY
ORF-36	282623081153801	282623	811538	31-23S-31E	439	LOGS	245	4	NONE	U.S. GEOLOGICAL SURVEY
ORF-37	283253081283401	283253	812834	26-22S-28E	350	DRILLER	328	6	NONE	ORANGE CO.
ORF-40	282218081335001	282218	813350	25-24S-28E	141	OWNER	128	3	NONE	R.C.I.D.
ORF-41	282434081260301	282434	812603	08-24S-29E	203	LOGS	131	4	NONE	U.S. GEOLOGICAL SURVEY
ORF-42	283018081321801	283018	813218	08-23S-28E	409	DRILLER	124	5		ORLANDO UTILITIES
ORF-43		282622	811828	34-23S-30E	500	DRILLER	211	12	TURBINE	ORLANDO AVIATION AUTH.
COUNTY=OSCEOLA										
OSF- 1	281931081280301	281931	812803	12-24S-28E	378	OWNER	.	4	NONE	KISSIMMEE K.O.A.
OSF- 2	281802081351601	281802	813516	23-25S-27E	450	LOGS	.	10	NONE	HELLER BROS. INC
OSF- 3	275222081030701	275222	810307	18-30S-33E	310	LOGS	243	4	NONE	U. S. GEOLOGICAL SURVEY
OSF- 4	275609081132001	275609	811320	28-29S-31E	400	DRILLER	287	4	SUBMERSIBLE	JOE OVERSTREET
OSF- 5	281536081324801	281536	813248	31-25S-28E	261	LOGS	63	6	CENTRIFUGAL	FLORIDA POWER CORP.
OSF- 6	280820081213901	280820	812139	13-27S-29E	318	DRILLER	176	4	SUBMERSIBLE	S.F.W.M.D.
OSF- 7	280709081052201	280709	810522	22-27S-32E	.		.	.	TURBINE	BILLY MALONE
OSF- 8	281559081260701	281559	812607	32-25S-29E	200	OTHER	.	4	NONE	CHARLES E. MOORE JR.
OSF- 9	281937081245901	281937	812459	09-25S-29E	1195	LOGS	283	16	TURBINE	CITY OF KISSIMMEE
OSF-10	281937081250101	281937	812501	09-25S-29E	458	DRILLER	278	16	TURBINE	CITY OF KISSIMMEE
OSF-11	280905081270101	280905	812701	06-27S-29E	398	LOGS	134	6	NONE	POINCIANA DEVELOPMENT
OSF-12	281443081140501	281443	811405	08-26S-31E	400	OTHER	.	4	SUBMERSIBLE	FLA. DEPT. OF FORESTRY
OSF-13	281356081290901	281356	812909	11-26S-28E	360	OWNER	.	6	NONE	HAM BROWN
OSF-14	281429081290501	281429	812905	11-26S-28E	.		.	6	NONE	HAM BROWN
OSF-15	280632081050101	280632	810501	26-27S-32E	718	DRILLER	344	8	SUBMERSIBLE	[illegible]

TABLE 3 .--WELL LOCATIONS AND DESCRIPTIONS FOR SFWMD MONITOR WELLS (Continued)

SFWMD STATION NUMBER	USGS STATION NUMBER	LAT-ITUDE	LONG-ITUDE	SECTION-TOWNSHIP-RANGE	DEPTH OF WELL (FT)	SOURCE OF DEPTH	DEPTH OF CASING (FT)	CASING DIAM-ETER (IN)	TYPE OF PUMP	NAME OF OWNER
OSF-16	281653081221101	281653	812211	25-25S-29E	700	OTHER	.	12		COCA COLA FOOD DIV.
OSF-17	281440081150901	281440	811509	07-26S-31E	538	OTHER	320	12	TURBINE	COCA COLA FOOD DIV.
OSF-18	281006081162601	281006	811626	01-27S-30E	500	OWNER	.	4	SUBMERSIBLE	THOMAS SCHEID
OSF-19	275429081071901	275429	810719	04-30S-32E	318	LOGS	234	4	SUBMERSIBLE	PRAIRIE LAKE STATE PARK
OSF-20	274500081040001	274500	810400	30-31S-33E	.		.	.	TURBINE	ALTO ADAMS
OSF-21	274856080594401	274856	805944	02-31S-33E	800	OWNER	.	10	TURBINE	PAUL HAYMAN
OSF-22	281714081093001	281714	810930	30-25S-32E	750	LOGS	394	8	NONE	G.A.C.
OSF-23	281144081213001	281144	812130	30-26S-30E	550	DRILLER	280	10	TURBINE	IVEY GROVES INC.
OSF-24	281037081075101	281037	810751	32-26S-32E	457	LOGS	282	8	NONE	HAY SALES COMPANY
OSF-25	281955081370701	281955	813707	11-25S-27E	300	LOGS	99	6	SUBMERSIBLE	HOLIDAY INNS INC.
OSF-26	281159081142801	281159	811428	29-26S-31E	622	LOGS	322	10	TURBINE	CLARENCE W. JOHNS
OSF-27	282051081133201	282051	811332	04-25S-31E	463	LOGS	373	6	SUBMERSIBLE	LAKE AJAY ESTATES
OSF-28	281341081281301	281341	812813	13-26S-28E	.		.	6	SUBMERSIBLE	HAM BROWN
OSF-29	280054081103901	280054	811039	25-28S-31E	500	OWNER	.	6	TURBINE	GLENN PADGETT
OSF-30	280033081015801	280033	810158	33-28S-33E	800	OWNER	.	10	TURBINE	O'DELL BRONSON
OSF-31	281719081134001	281719	811340	28-25S-31E	474	LOGS	239	8	SUBMERSIBLE	CARROL FULMER
OSF-32	282000081344801	282000	813448	02-25E-27E	150	DRILLER	72.5	4	NONE	U.S. GEOLOGICAL SURVEY
OSF-33	281456081161101	281456	811611	01-26S-30E	496	LOGS	224	20	TURBINE	CITY OF ST. CLOUD
OSF-34	281146081211701	281146	812117	30-26S-30E	582	DRILLER	302	10	TURBINE	CEIL WHALEY
OSF-35	281802081352501	281802	813525	14-25S-27E	150	DRILLER	80	4	NONE	U.S. GEOLOGICAL SURVEY
OSF-37	281116081024101	281116	810241	29-26S-33E	513	LOGS	210	12	NONE	DESERET RANCH
OSF-38	281457081172201	281457	811722	02-26S-30E	692	DRILLER	382	16	TURBINE	CITY OF ST. CLOUD
OSF-39	275233080595101	275233	805951	14-30S-33E	516	LOGS	220	3	NONE	OSCEOLA CO. SCHOOLS
OSF-41	274400081043101	274400	810431	36-31S-32E	766	LOGS	200	10	NONE	LATT MAXY CORP.
OSF-42	274307080582401	274307	805824	01-32S-33E	767	LOGS	218	6	NONE	LATT MAXY CORP.
OSF-44	281456081171701	281456	811717	02-26S-36E	614	LOGS	481	8	NONE	CITY OF ST. CLOUD
OSF-45	282046081135801	282046	811358	05-24S-31E	433	DRILLER	217	6	SUBMERSIBLE	MAJESTIC OAKS
OSF-50		280534	810700	33-27S-32E	1035	DRILLER	324	12	TURBINE	GOLDEN BOUGH CITRUS
OSF-52	274806081115501	274806	811155	11-31S-31E	880	LOGS	172	6	NONE	S.F.W.M.D.
OSF-53	280823081210301	280823	812103	18-27S-30E	980	LOGS	160	6	NONE	S.F.W.M.D.
OSF-54		275634	811027	24-29S-31E	869	DRILLER	249	10	NONE	T AND A CORP.
OSF-55		280533	810410	36-27S-32E	891	DRILLER	354	3		CENTRAL FLA. GROVE SERVIC
COUNTY=POLK										
POF- 1	281532081345001	281532	813450	02-26S-27E	247	LOGS	85	6	NONE	U.S. GEOLOGICAL SURVEY
POF- 2	281511081393101	281511	813931	01-26S-26E	447	LOGS	358	6	NONE	U.S. GEOLOGICAL SURVEY
POF- 3	281058081364201	281058	813642	33-26S-27E	180	LOGS	81	10	NONE	P. E. WILLIAMS
POF- 4	280229081325201	280229	813252	18-28S-28E	453	LOGS	146	8	NONE	FLORIDA D.O.T.
POF- 5	274815081130301	274815	811303	10-31S-31E	300	LOGS	187	4	NONE	U.S. GEOLOGICAL SURVEY
POF- 6	280153081274101	280153	812741	19-28S-29E	411	OWNER	178	10	NONE	EXPOSITION COMPANY
POF- 7	275805081321901	275805	813219	17-29S-28E	.		.	3	NONE	POLK COUNTY PARKS
POF- 8	274846081262001	274846	812620	05-31S-29E	194	LOGS	149	3	NONE	POLK COUNTY PARKS
POF- 9	273903081185201	273903	812108	06-33S-30E	1035	OWNER	.	10	CENTRIFUGAL	A.P. CORRECTIONAL INST.
POF-10	273959081215601	273959	812156	30-32S-30E	540	OWNER	.	10	CENTRIFUGAL	A.P. CORRECTIONAL INST.
POF-11	273954081230601	273954	812155	30-32S-30E	930	OWNER	.	10	CENTRIFUGAL	A.P. CORRECTIONAL INST.
POF-12	273924081213601	273924	812136	30-32S-30E	432	LOGS	210	4	CENTRIFUGAL	A.P. CORRECTIONAL INST.

TABLE 3 .--WELL LOCATIONS AND DESCRIPTIONS FOR SFWMD MONITOR WELLS (Continued)

SFWMD STATION NUMBER	USGS STATION NUMBER	LAT-ITUDE	LONG-ITUDE	SECTION-TOWNSHIP-RANGE	DEPTH OF WELL (FT)	SOURCE OF DEPTH	DEPTH OF CASING (FT)	CASING DIAM-ETER (IN)	TYPE OF PUMP	NAME OF OWNER
POF-13	275634081211801	275634	812118	19-29S-30E	560	DRILLER	226	6	SUBMERSIBLE	KISSIMMEE STATE PARK
POF-14	280558081314801	280558	813148	29-27S-28E	396	LOGS	149	4	NONE	C. KIMBLE
POF-15	275622081252301	275622	812523	28-29S-29E	575	DRILLER	.	6	SUBMERSIBLE	WILLIAM LACK
POF-17	274746081202201	274746	812022	08-31S-30E	800	OWNER	.	.	TURBINE	INDIAN LAKE ESTATES
POF-18	274553081115601	274553	811156	23-31S-31E	854	DRILLER	231	12	TURBINE	RIVER RANCH RESORT
POF-19	275137081252501	275137	812525	21-30S-29E	837	DRILLER	.	8	TURBINE	E. LAKE WALES UTILITIES
POF-20	273929081080601	273929	810806	28-32S-32E	1000	LOGS	260	6	NONE	S.F.W.M.D.

TABLE 4. WELL LOCATIONS AND DESCRIPTIONS FOR BOG WELLS

BOG WELL NUMBER	LATITUDE	LONGITUDE	SECTION TOWNSHIP RANGE	DEPTH OF WELL	NAME OF OWNER
W- 519	813200	274350	33-31S-28E	1060	L. Maxcy, Inc.
W- 623	813140	275030	28-30S-28E	968	Fla. High. Lt. & Water
W- 696	812640	281700	30-25S-29E	398	U.S. Army
W- 697	812650	281730	19-25S-29E	394	Sun Oil Co.
W- 894	812650	272900	23-34S-29E	1278	
W- 965	813200	294220	09-32S-28E	1023	S.W Keen
W- 1411	805900	274700	12-31S-33E	8798	Humble Oil
W- 1464	812500	272320	02-36S-29E	1455	L. Maxcy, Inc.
W- 1754	813440	275225	18-30S-28E	1080	Village of Highlands Pk.
W- 1770	805040	281640	27-25S-34E	5856	Hunt Oil Co.
W- 1882	811440	281500	05-26S-31E	470	L. Mussman
W- 1949	812840	275310	12-30S-28E	743	Dr. Phillips and Sons
W- 2163	812220	281140	25-26S-29E	2000	Kissimmee Oil Co.
W- 2397	812800	273420	30-33S-29E	1439	
W- 2398	813000	273530	14-33S-28E	1230	R.H. Lawhon
W- 2399	812100	270900	17-38S-30E	1550	
W- 2859	812800	273040	18-34S-29E	1400	
W- 4750	811720	265450	01-41S-30E	10993	Amerada Petroleum Co.
W- 4896	805450	271030	02-38S-34E	1313	Parker Bros., Inc.
W- 6282	812230	270540	06-39S-30E	1250	Andrew Jackson
W- 9127	805850	273900	30-32S-34E	697	Humble Oil
W- 9129	805850	274210	06-32S-34E	677	Humble Oil
W- 9130	810120	274300	03-32S-33E	634	Humble Oil
W- 9145	810400	274320	31-31S-33E	510	Humble Oil
W- 9151	810830	274840	05-31S-32E	610	Humble Oil
W- 9156	810628	274409	34-31S-32E	690	Humble Oil
W-11366	811230	275840	03-29S-31E	540	Atlantic Richfield Co.
W-11369	812550	280655	29-27S-29E	620	Irlo Bronson
W-11954	810410	280530	36-27S-32E	380	Mohawk Groves, Inc.
W-13942	805950	275610	23-29S-33E	432	Bureau of Geology

TABLE 5 .--WELL LOCATIONS AND DESCRIPTIONS FOR USGS WELLS

SFWMD STATION NUMBER	USGS STATION NUMBER	LAT-ITUDE	LONG-ITUDE	SECTION-TOWNSHIP-RANGE	DEPTH OF WELL (FT)	SOURCE OF DEPTH	DEPTH OF CASING (FT)	CASING DIAM-ETER (IN)	TYPE OF PUMP	NAME OF OWNER
X- 1	283326081262101	283326	812621		109	USGS	84	18		
X- 2	283307081300801	283307	813008		450	USGS	118	24		
X- 3	283144081254201	283144	812542		400	USGS				
X- 4	283134081364801	283134	813648		142	USGS		4		
X- 5	283121081311601	283121	813116		498	USGS	344	12		
X- 6	283011081360001	283011	813600		240	USGS	100	4		
X- 7	282955081181801	282955	811818		422	USGS	137	12		
X- 8	282945081255001	282945	812550		417	USGS	211	12		
X- 9	282936081340201	282936	813402		280	USGS	180	4		
X-10	282923081282801	282923	812828		337	USGS	168	4		
X-11	282911081243601	282911	812436			USGS		8		
X-12	282749081315801	282749	813158		347	USGS	120	6		
X-13	282649081262301	282649	812623		450	USGS	120	18		
X-14	282543081385801	282543	813858			USGS		4		
X-15	282534081220601	282534	812206		455	USGS	202	12		
X-16	282531081095701	282531	810957		300	USGS	226	4		
X-17	282510081054501	282510	810545		710	USGS	316	20		
X-18	281630080591001	281630	805910			USGS	245	4		
X-19	281630081024401	281630	810244			USGS	288	4		
X-20	281440081431701	281440	814317		285	USGS	80	6		
X-21	281354080563301	281354	805633		373	USGS	173	4		
X-22	281105080541401	281105	805414			USGS		12		
X-23	281008081441801	281008	814418		425	USGS	102	6		
X-24	280829080574001	280829	805740		425	USGS	220	4		
X-25	280531081431601	280531	814316		555	USGS	282	12		
X-26	280526080543001	280526	805430		660	USGS	272	8		
X-27	280456081374301	280456	813743		549	USGS		10		
X-28	280229080565501	280229	805655		329	USGS	202	4		
X-29	275852081030501	275852	810305		405	USGS	242	4		
X-30	275840081391101	275840	813911		612	USGS		12		
X-31	275826080554701	275826	805547		500	USGS		2		
X-32	275729081404701	275729	814047		663	USGS		12		
X-33	275620081355901	275620	813559		798	USGS		15		
X-34	275403081391301	275403	813913		1500	USGS				

TABLE 5 .--WELL LOCATIONS AND DESCRIPTIONS FOR USGS WELLS (Continued)

SFWMD STATION NUMBER	USGS STATION NUMBER	LAT-ITUDE	LONG-ITUDE	SECTION-TOWNSHIP-RANGE	DEPTH OF WELL (FT)	SOURCE OF DEPTH	DEPTH OF CASING (FT)	CASING DIAM-ETER (IN)	TYPE OF PUMP	NAME OF OWNER
X-35	275207081411301	275207	814113		783	USGS		10		
X-36	275047080524301	275047	805243		605	USGS	229	6		
X-37	275016081370401	275016	813704		540	USGS		10		
X-38	274742081375601	274742	813756		959	USGS		10		
X-39	274530081404501	274530	814045		773	USGS		10		
X-40	274440081314801	274440	813148		319	USGS	208	6		
X-41	274411081360401	274411	813604		963	USGS		12		
X-42	274353081415001	274353	814150		982	USGS		10		
X-43	273929081363801	273929	813638		700	USGS		6		
X-44	273127080481401	273127	804814		960	USGS		8		
X-45	273114080533601	273114	805336			USGS		8		
X-46	273007081263901	273007	812639		1152	USGS		6		
X-47	272835081251701	272835	812517		841	USGS		6		
X-48	271730081160501	271730	811605		580	USGS		6		
X-49	271729081090001	271729	810900		900	USGS		6		
X-50	271503081080901	271503	810309		647	USGS	315	4		
X-51	271455081054301	271455	810543		900	USGS		6		
X-52	271324081325801	271324	813258		620	USGS		10		
X-53	270948081081101	270948	810811		900	USGS		12		
X-54	270547081050501	270547	810505		763	USGS	282	6		
X-55	270435081234101	270435	812341		1600	USGS		10		
X-56	275326081341201	275326	813412		795	USGS		12		
X-57	274725081333601	274725	813336		628	USGS	187			
X-58	273845081321901	273845	813219		1050	USGS	227	10		
X-59	272326081240201	272326	812402			USGS		10		

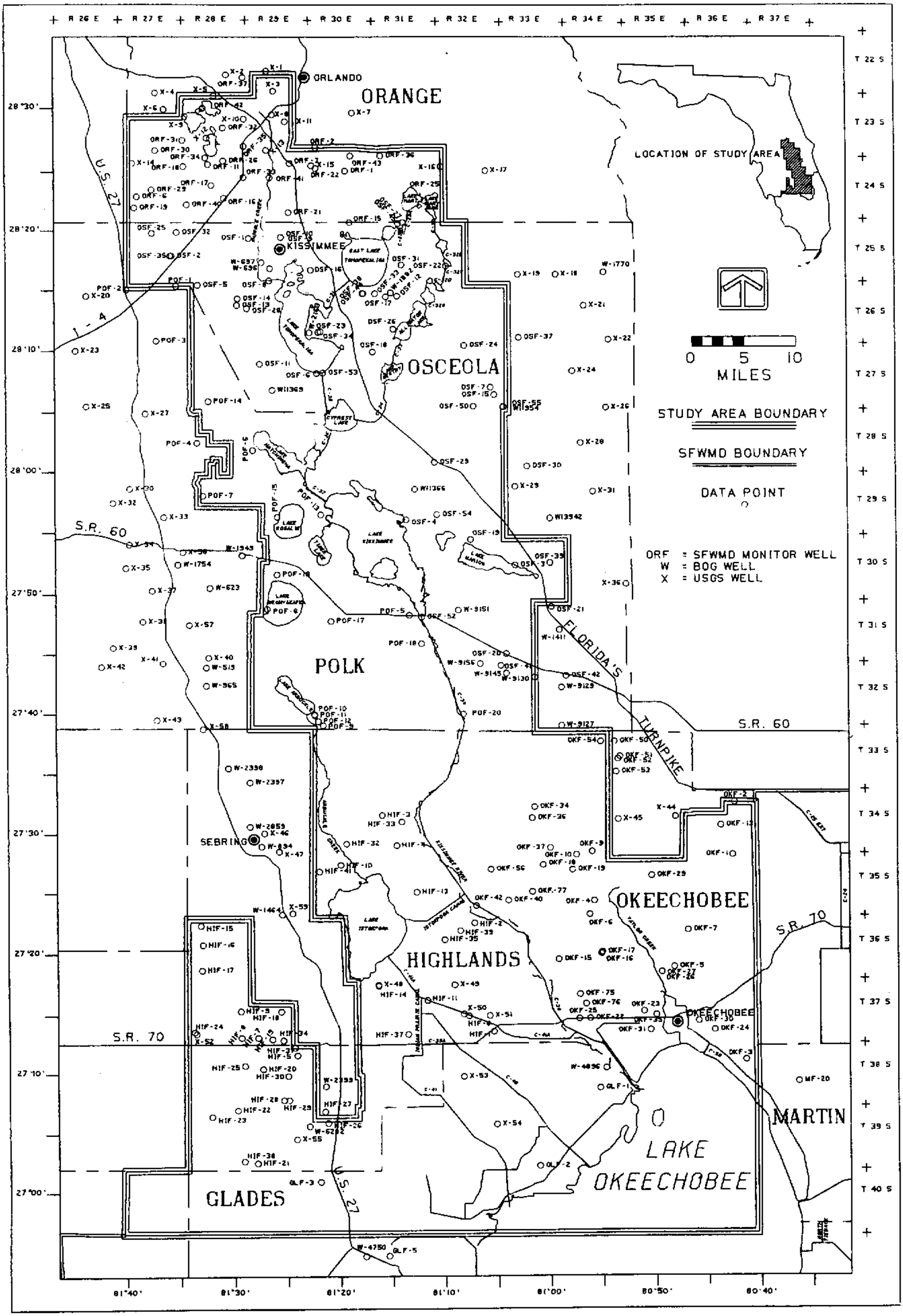


Figure 3 LOCATION OF DATA COLLECTION SITES

Water Level Network and Methods

SFWMD personnel collected water level readings from each monitor well station south of Lake Kissimmee during May and September of 1978, 1979, 1980, 1981 and 1982 to represent dry and wet season conditions respectively. U. S. Geological Survey personnel collected concurrent water level readings on wells in the monitoring network that were north of Lake Kissimmee. Additional water levels were collected at various times during the reconnaissance study. Vertical control referenced to NGVD was established by SFWMD survey crews.

Water level data for each station, including date and time of measurement and well identification number are listed in the KPA data report (Reece and others, 1984) and Appendix I of this report. Wells for which water level data are available are shown on Figure 4.

Water level measurements of non-flowing wells were made with steel tapes or electric tapes. Pressure readings of flowing wells were taken with calibrated mechanical pressure gauges or manometers.

The problem of measuring hydraulic head in different zones of the Floridan Aquifer System due to varying depths of penetration of monitoring wells will be addressed in a later section of this report.

Water Quality Network and Methods

Various water sample collection methods were used throughout the study area. Non-flowing wells with installed pumps were sampled utilizing the existing pump. After the pump was turned on, the sample was collected when the discharging water reached a constant temperature, such that borehole water would be flushed out and the sample would be representative of water within the aquifer.

In the case of flowing wells, the valve on the well head was opened and the sample was collected when the discharging water reached a constant

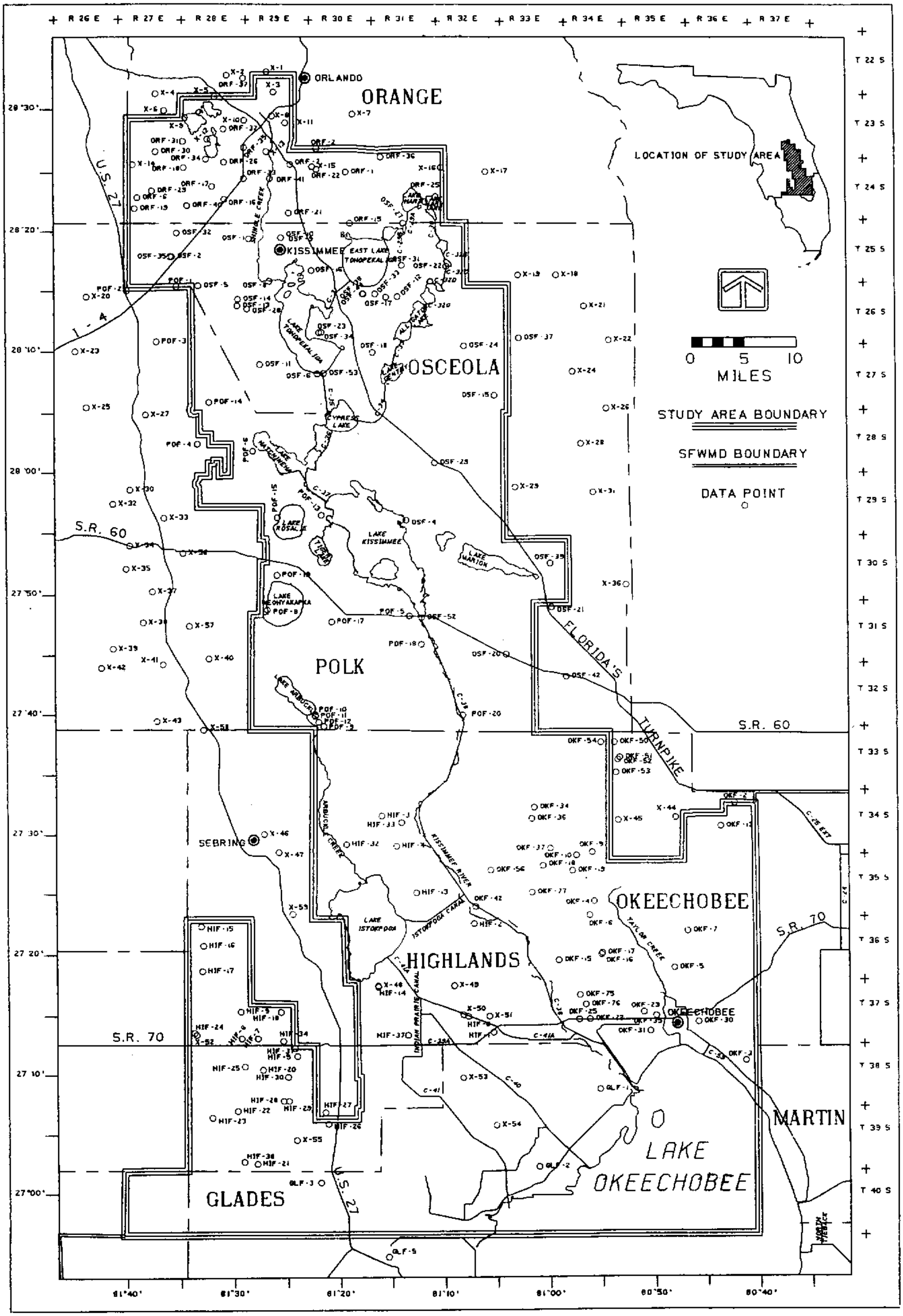


Figure 4 WELLS WITH AVAILABLE WATER LEVEL DATA

temperature. Non-flowing wells without installed pumps were sampled with a 2 inch centrifugal pump when water levels were less than 25 feet below land surface. If the water level was greater than 25 feet below land surface a 3, 4, 6, or 8 inch submersible pump was used. In some cases, water was lifted by air.

After the sample was collected, temperature was recorded and field values of pH and specific conductance were obtained using a digital pH meter and conductivity bridge, respectively. In some cases, a portion of the sample was analyzed immediately for field alkalinity. A portion of each sample was filtered through a 0.45 micron filter using a portable peristaltic sampling pump. A small aliquot of the filtered sample was acidified with concentrated nitric acid in order to prepare the sample for analysis of trace metals such as strontium and total dissolved iron. Water samples were then tagged, chilled on ice, and transported to the SFWMD laboratory for immediate analysis. The following parameters were analyzed: field and laboratory pH and specific conductance, temperature, sodium, calcium, potassium, magnesium, chloride, sulfate, bicarbonate alkalinity, total dissolved solids, strontium, and iron. The methods of analysis are described in Table 6. Analyses of these samples were performed from 1977 through 1983 by the Water Chemistry Laboratory of SFWMD utilizing standard analytical methods. All prior analyses were conducted at the USGS laboratories.

Results of water quality analyses up to 1979, including units of measurements for each parameter are listed in Table 3 of the data report (Reece and others, 1984). Results of water quality analyses, including the number of samples and mean and standard deviation of each parameter by well number, through 1983, are listed in Appendix II.

According to Reece and others, (1984), the variety of sampling methods may result in water samples being collected under varying degrees of stress on

TABLE 6. LABORATORY ANALYTICAL METHODS USED IN KPA STUDY

PARAMETER	ANALYTICAL METHOD
pH	Electrometric, EPA Method #150.1.
Specific Conductance	Electrometric, Specific Conductance at 25°C, modified Standard Methods #205, 14th Ed., pp. 71, 1975, modified EPA Method #120.1.
Dissolved Solids	Gravimetric, with drying at 105°C Standard Methods, #208A, 14th Ed., 1975.
Sodium	Atomic Absorption, Direct Aspiration with Dual Capillary System (DCS), EPA Method #273.1.
Potassium	Atomic Absorption, Direct Aspiration with Dual Capillary System (DCS), EPA Method #258.7.
Calcium	Atomic Absorption, Direct Aspiration with Dual Capillary System (DCS), Samples are treated with La_2O_3/HCl with DCS, EPA Method #215.1.
Magnesium	Atomic Absorption, Direct Aspiration with Dual Capillary System (DCS), Same treatment as calcium, EPA Method #242.1.
Strontium	Atomic Absorption, Direct Aspiration, Standard Methods #321A, 14th ed., 1975.
Total Dissolved Iron	Colorimetric, Automated TPTZ Complex with thioglycolic acid pretreatment, Technicon AA II Method #109-71W.
Chloride	Colorimetric, Automated Ferricyanide, Technicon AA II Method #99-70W, modified EPA Method #325.2.
Sulfate	Colorimetric, Automated Methylthymol Blue, Technicon AA II Method #118-71W, modified EPA Method #375.2.
Alkalinity	Technicon Auto Analyzer: Methyl Orange Technicon AA II Industrial Method #111-071W.
Bicarbonate	Derived from alkalinity and pH.

the aquifer system. Sampling methods may affect analytical results, especially with respect to alkalinity and pH. This will be discussed in the water quality section of this report.

Nearly all of the water samples collected were wellhead or composite samples, in which water from different zones of the aquifer may have been present. In some cases, it was possible to obtain discrete point samples at different depths in various wells with the use of the geophysical logger. The occurrence of producing zones and variations in water quality throughout the study area will be discussed later in this report.

The availability of water quality information in the KPA well monitoring network is displayed in Figure 5.

Geophysical Data Network and Methods

The SFWMD owns and operates a Gearhart-Owen "Widco" Model 3500 portable geophysical logging system. The unit is capable of performing the following geophysical surveys:

(1) 16- and 64-inch Short and Long Normal Resistivity

(2) 6-foot Lateral Resistivity.

(3) Spontaneous Potential

(4) Flowmeter

(5) Fluid Resistivity

(6) Fluid Temperature

(7) Differential Temperature

(8) Natural Gamma Ray

(9) Neutron Porosity

(10) Casing Collar Locator

(11) Caliper

(12) Fluid Point Sampler

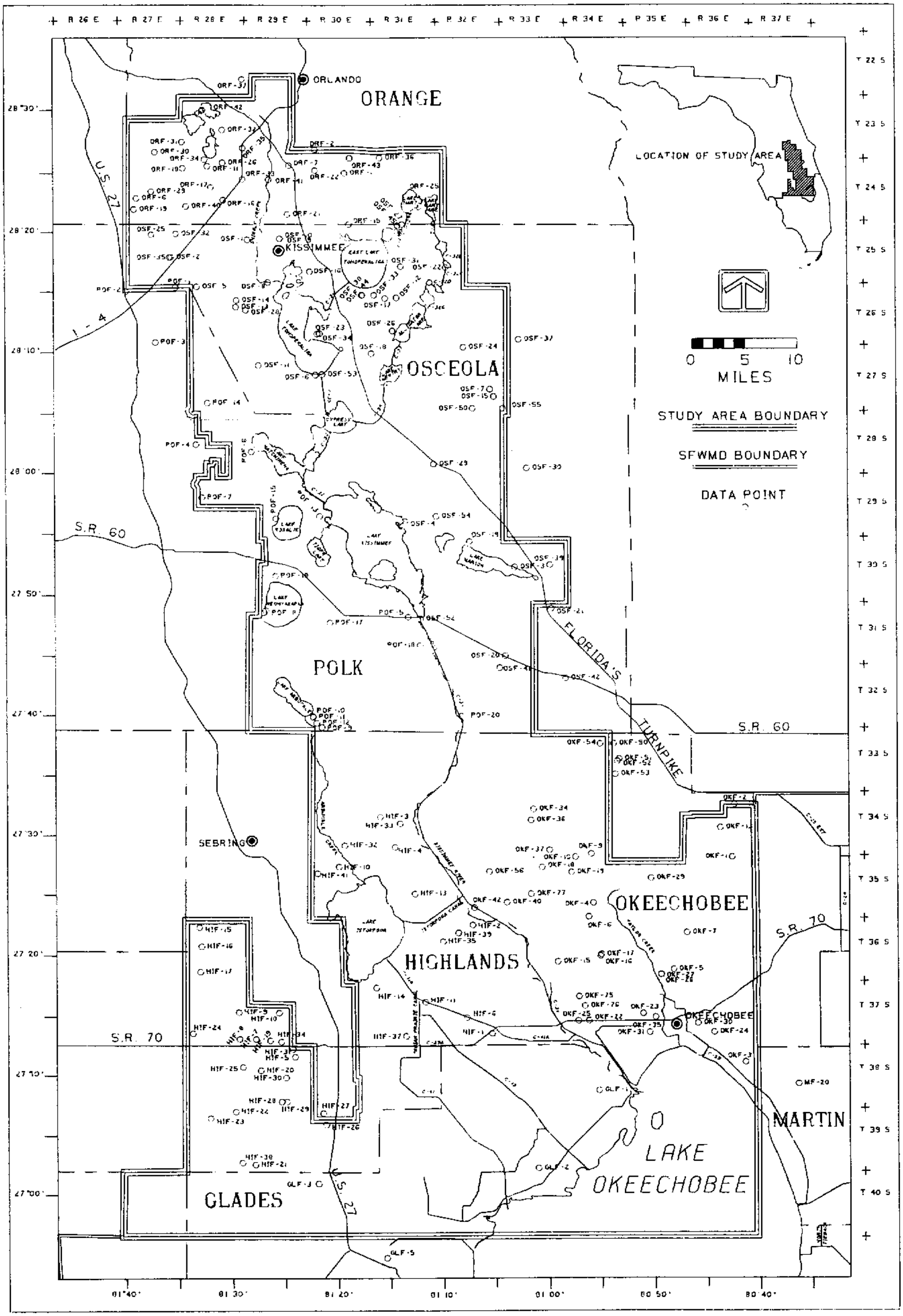


Figure 5 WELLS WITH AVAILABLE WATER QUALITY DATA

The survey data can be recorded in an analog format using the strip chart recorder and/or in a digital format on magnetic cassette tapes using an SIE Geosource, Inc., Data Acquisition System (DAS).

All geophysical data are input into the District's Control Data Corporation Cyber 170 computer using the Well Log Analysis System (WLAS) software devised by SFWMD personnel. Input into the computer may be in the form of:

(1) Magnetic tape from the DAS system.

(2) Paper tape from the machine digitized data.

(3) Computer cards from other manual digitizing.

Output from the WLAS is achieved through six programs which manipulate and list the data, and plot the surveys on a Calcomp plotter using either 12 or 30 inch paper. One of the programs allows calculations to be performed on the survey data. The calculations include correcting the Flowmeter Survey data for borehole diameter, converting resistivity to conductivity, temperature conversions, log transformations, and converting the units of the Natural Gamma Ray and Neutron Porosity Surveys. The Gamma Ray and Neutron Porosity Surveys are initially recorded in counts per second (cps). The American Petroleum Institute (API) adopted standard units of measurement for these surveys, called the "API Gamma-Ray Unit" and "API Neutron Unit." The WLAS program converts the measured survey units from cps into API units. The conversions are based on field calibrations of the neutron porosity and natural-gamma radiation probes by utilizing a neutron collar which simulates 19% limestone porosity and a constant gamma emitting radium source. These sources are calibrated annually at the University of Houston API test pits for standardization and quality control.

The following paragraphs describe the use of the various geophysical surveys. The interpretation of geophysical survey data will be detailed in a later section of this report. Table 7 lists available survey data at various well sites throughout the study area.

According to Keys and MacCary (1971) the 16- and 64-inch Short and Long Normal Resistivity Surveys measure the apparent electrical resistivity of a volume of rock surrounding the invaded zone. The Short Normal Resistivity Survey yields limited vertical detail and records the apparent resistivity of the invaded zone, while the long normal records the apparent resistivity beyond the invaded zone. The 6-foot Lateral Log measures the formation resistivity beyond the invaded zone through the use of widely spaced electrodes. These three surveys are recorded in units of ohm-meters.

The Spontaneous Potential Log, measured in millivolts, is a record of natural potentials developed between the borehole fluid and surrounding lithology. The magnitude and direction of the Spontaneous Potential Log deflections are controlled by the relative salinities of the borehole fluid (drilling mud), formation water, and surrounding lithology.

The Flowmeter Survey measures and records vertical components of fluid flow within the borehole. This is accomplished by using a low inertia impeller which, as it rotates, generates an electrical impulse. A continual record of the fluid velocity within both the uncased and cased portions of a well can be recorded. The measured velocity is affected by varying borehole diameters. The units for the uncorrected flow survey are in counts per second (cps).

Fluid Resistivity surveys measure the resistivity in ohm-meters of the borehole fluid relative to a constant electrical current. The resistivity values measured and recorded on the log are dependent on the ionic concentration and temperature of the borehole fluid.

The Fluid Temperature and Differential Temperature Surveys record the temperature of the fluid at a thermistor which detects changes in temperature.

TABLE 7. GEOPHYSICAL SURVEYS PERFORMED AT WELL SITES IN THE KPA MONITORING NETWORK

WELL NUMBER	CALIPER	FLOW METER	16-,64-INCH NORMAL RESISTIVITY	NEUTRON POROSITY	NATURAL GAMMA	FLUID RESISTIVITY	CCL	TEMP. GRAD.	DELTA TEMP.	SPON. POTEN.	6-FT. LATERAL RESISTIVITY
GLF- 1	X	X	X	X	X	X		X	X	X	
GLF- 2	X	X	X	X	X			X	X		
GLF- 5	X		X	X	X	X	X	X	X	X	
HIF- 5	X	X	X	X	X	X		X	X	X	
HIF- 6	X	X	X	X	X	X		X	X	X	
HIF-11	X	X	X	X	X	X		X	X	X	X
HIF-25	X		X		X						X
HIF-35	X	X	X		X	X		X	X	X	X
HIF-38	X	X	X	X	X	X		X	X	X	
HIF-39	X	X	X	X	X	X		X	X	X	X
OKF- 2	X	X	X	X	X	X		X		X	X
OKF- 3	X			X	X	X		X			
OKF- 5	X	X	X	X	X	X	X	X	X	X	X
OKF- 6	X		X	X	X	X		X		X	X
OKF- 7		X		X	X	X		X	X	X	X
OKF-16					X		X	X	X		
OKF-17	X	X	X	X	X	X		X	X		
OKF-18	X	X	X		X	X		X	X	X	X
OKF-19	X	X	X	X	X	X		X	X	X	X
OKF-29	X	X	X	X	X	X		X		X	
OKF-34	X		X	X	X				X	X	X
OKF-36	X	X	X	X	X	X		X	X	X	
OKF-37	X	X	X	X	X	X		X	X	X	X
OKF-42	X	X	X		X	X		X	X	X	
OKF-54	X	X	X	X	X	X		X	X	X	X
ORF- 7	X			X	X						X
ORF-15	X		X	X	X					X	X
ORF-21	X		X	X	X					X	X
ORF-25	X		X	X	X					X	X
ORF-31	X			X	X						
ORF-34	X			X	X						X

TABLE 7. GEOPHYSICAL SURVEYS PERFORMED AT WELL SITES IN THE KPA MONITORING NETWORK (Continued)

WELL NUMBER	CALIPER	FLOW METER	16-,64-INCH NORMAL RESISTIVITY	NEUTRON POROSITY	NATURAL GAMMA	FLUID RESISTIVITY	CCL	TEMP. GRAD.	DELTA TEMP.	SPON. POTEN.	6-FT. LATERAL RESISTIVITY
OSF- 2		X									
OSF- 3	X		X	X	X					X	
OSF- 5	X	X	X	X	X	X		X		X	X
OSF- 9	X	X	X	X	X	X		X	X	X	X
OSF-11	X	X	X	X	X	X		X	X	X	X
OSF-19	X			X	X						
OSF-22	X	X	X	X	X	X		X	X		
OSF-24	X	X	X	X	X	X		X	X	X	X
OSF-25	X		X	X	X			X	X	X	X
OSF-26	X		X	X	X	X		X		X	X
OSF-27	X		X	X	X	X		X		X	X
OSF-33	X		X	X	X					X	
OSF-39	X		X	X	X			X	X	X	X
OSF-41	X		X							X	X
OSF-42	X	X	X	X	X	X		X	X	X	X
OSF-44	X	X	X	X	X						X
OSF-52	X	X	X	X	X	X		X	X	X	X
OSF-53	X	X	X	X	X	X		X	X	X	
POF- 1	X		X	X	X	X		X	X	X	X
POF- 2	X		X	X	X					X	X
POF- 3	X	X	X	X	X	X		X		X	X
POF- 4	X	X	X	X	X	X		X	X	X	X
POF- 5	X		X	X	X	X		X		X	X
POF-12	X	X	X	X	X	X		X	X	X	X
POF-14	X	X	X	X	X	X		X	X	X	X
POF-20	X	X	X	X	X	X		X	X	X	
MF -20	X	X	X	X	X		X	X	X	X	

The Fluid Temperature Log records the actual temperatures while the Differential Temperature Log detects and records the difference in temperature over a predetermined time interval. The Fluid Temperature is recorded in degrees Fahrenheit (^{o}F), or degrees Centigrade (^{o}C), and the Differential Temperature is a unitless number.

The Natural Gamma Log is a record of the amount of natural-gamma radiation emitted by the rock formation. The radiation detector is a high sensitivity scintillation counter with a sodium iodide crystal emitting light pulses which are optically coupled to a photomultiplier tube which produces an amplified pulse of electrical current. This pulse is sent to the surface equipment where the pulses are integrated over a preset time constant. A DC-voltage output is used to drive the recorder pen on a strip chart to reflect the formations natural gamma radiation intensity. The initial units of measurement are in cps.

The Neutron Porosity Survey measures the effect of the borehole environment on introduced neutrons. The tool consists of a neutron source and a radiation detector spaced 13 inches from the source. As the neutrons from the source bombard the environment they lose energy by colliding with hydrogen nuclei. Neutron logs record parameters which are related to the energy reduction of the neutron and are therefore indices of the "hydrogen richness" of the formation. Since hydrogen atoms are found principally in the water within the borehole and rock interstices, hydrogen richness is an index of porosity, for a constant borehole diameter. The neutron radiation returned to the detector is integrated over a preset time constant and recorded in units of cps.

The Casing Collar Locator, which indicates anomalies in a self-generated magnetic flux, locates variations in metal casing thickness, and is principally used to locate casing collars for depth calibration and length of casing.

The Caliper Survey supplies an estimate of the diameter of the borehole. The caliper tool consists of a probe with three spring-loaded arms which follow along the sides of the borehole as the tool is raised. The signal recorded indicates the extension of the arms and is shown as the borehole diameter in inches.

The Fluid Point Sampler is a tool that enables the collection of a water sample at discrete depths within the borehole.

Figure 6 shows the availability of geophysical data in the KPA well monitoring network. Geophysical surveys conducted prior to 1981 are shown in Reece and others, (1984). Those conducted after 1981 are in Appendix III.

Geologic Data Network and Methods

Geologic information for well sites throughout the study area was compiled from several sources. Drill cuttings were collected from newly drilled wells by SFWMD personnel or cooperating drillers at 10 or 20 foot intervals and at observed lithologic changes. All cuttings, with the exception of those from some wells described by the Florida Bureau of Geology, were examined by SFWMD personnel or Florida State University staff utilizing a binocular microscope. The cuttings were then forwarded to the Florida Bureau of Geology, Tallahassee, Florida.

The SFWMD utilizes a computer data base system, "LITHOLOG", which was modified from an existing Florida Bureau of Geology program, for storage and retrieval of geologic sample descriptions from coded input. This system facilitates standardized sample descriptions which are usually more complete and less time consuming than a conventional written description.

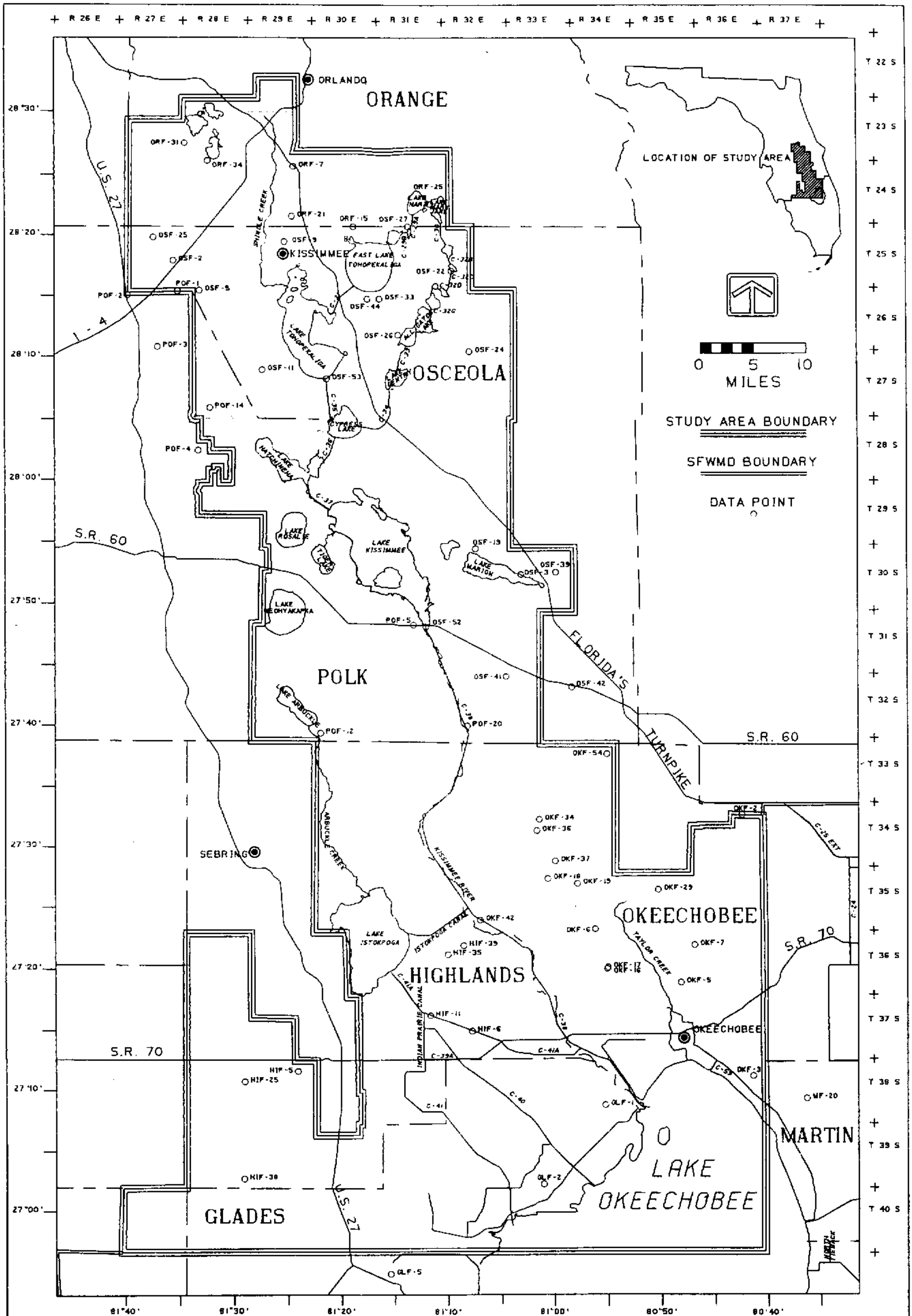


Figure 6 WELLS WITH AVAILABLE GEOPHYSICAL DATA

Selected driller's logs which contain geologic or other useful data are tabulated in Appendix IV. The geologic descriptions of the Florida Bureau of Geology wells, as well as cutting descriptions made by SFWMD personnel, are also compiled in Appendix IV. Figure 7 denotes the sites in the study area for which geologic information is available.

Aquifer Test Network and Methods

Twelve production tests were run on 11 wells in the study area utilizing the USGS submersible pump test rig. Water levels in the pumped wells were measured with electric and steel tapes. Discharge from the pumped wells was measured with a flowmeter.

SFWMD personnel performed 6 pump/recovery tests and 9 flow/recovery tests, depending upon conditions at each site. When the water level in the well was less than 20 feet below land surface, a 6 X 6 centripetal pump was used to pump the well. An orifice tube and manometer were set up at each test to monitor the discharge from the pumped well. Drawdown in the pumped wells was measured with electric tapes. When pumping stopped, recovery water level data were obtained using either an electric or a steel tape.

Recovery tests were run on flowing wells in which water levels ranged from about 5 feet to 20 feet above land surface. The wells were tapped and clear plastic tubing was attached to a spigot. A static measurement of shut-in head was obtained using a manometer or calibrated mechanical pressure gauge. The well valves were opened, so that full flowing natural discharge occurred. Discharge from the wells was measured using the trajectory method (Anderson, 1971). After allowing the well to flow for a specified period of time (usually 12-16 hours) the plastic tubing was extended vertically using PVC pipe for support. A steel tape attached to the pipe was aligned with the zero measuring point located at the height of the discharging water. The well

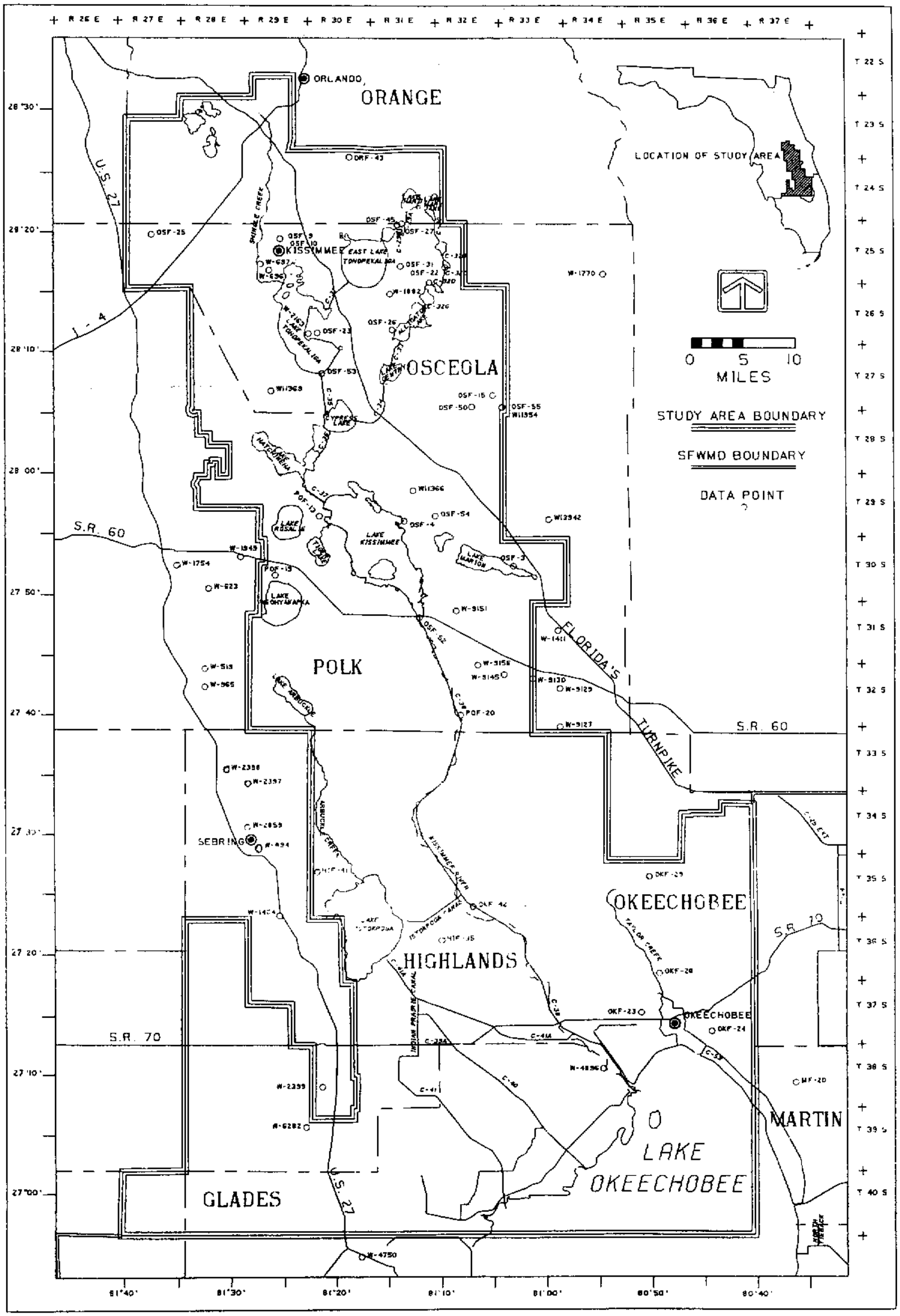


Figure 7 WELLS WITH AVAILABLE GEOLOGIC DATA

valves were then shut, and the recovery water levels were read directly from the steel tape until the static water level observed before flowing the wells was reached.

In most cases, the water levels rose so rapidly in the first few moments of recovery that a tape recorder had to be used to record the water level measurements at predetermined time in intervals. The tape was later played back and the readings were transposed to data sheets for analysis. The data from these recovery tests are plotted in Appendix V. The methods of analysis of the pump/recovery test data are described in a later section of this report.

Additional aquifer characteristic data were collected from a number of sources, including published reports by consultants, the USGS, the Florida Bureau of Geology, and drillers' reports. The well locations for which aquifer parameters are available are shown in Figure 8.

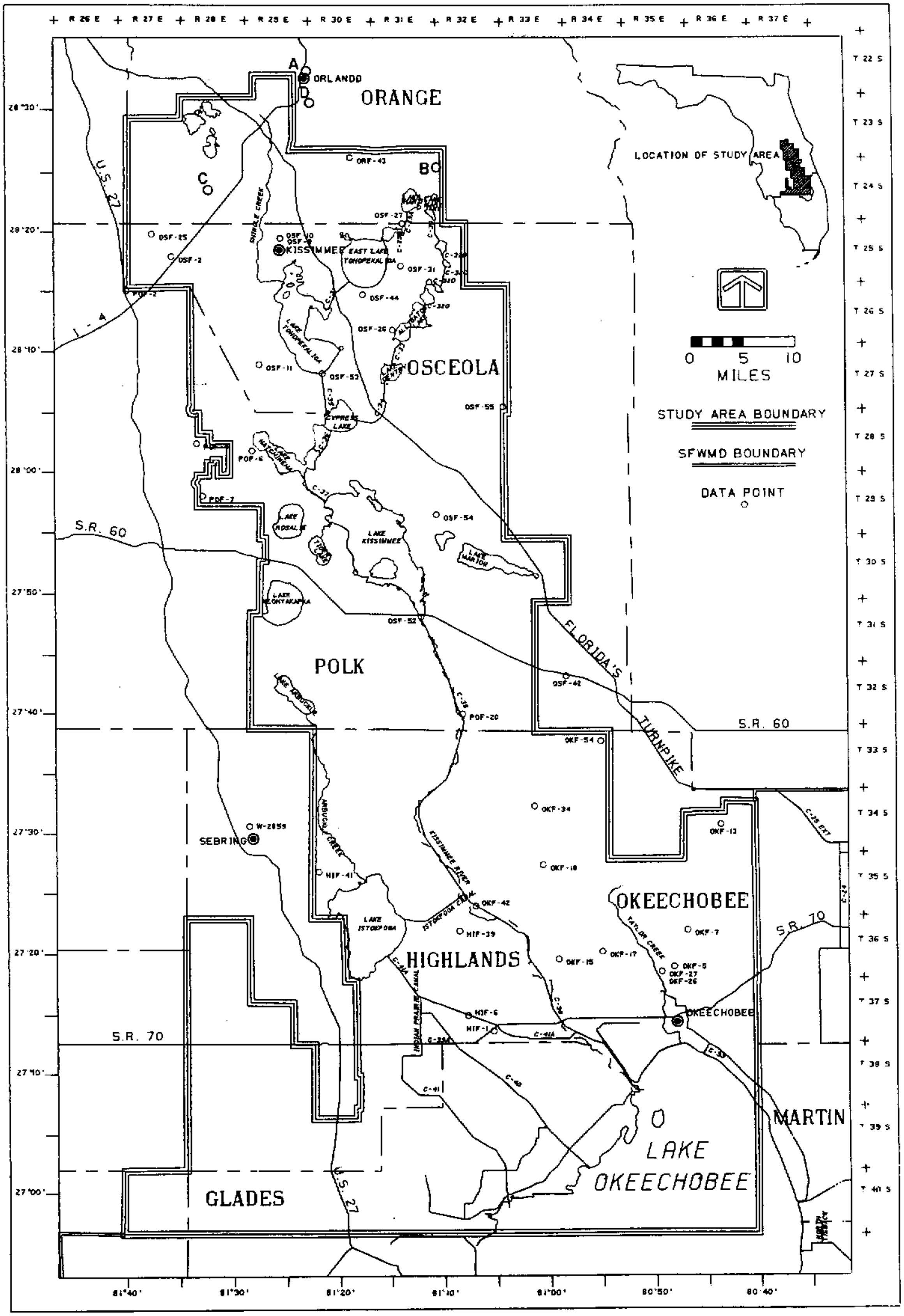


Figure 8 AVAILABILITY OF AQUIFER PARAMETER DATA

GEOLOGY

Introduction

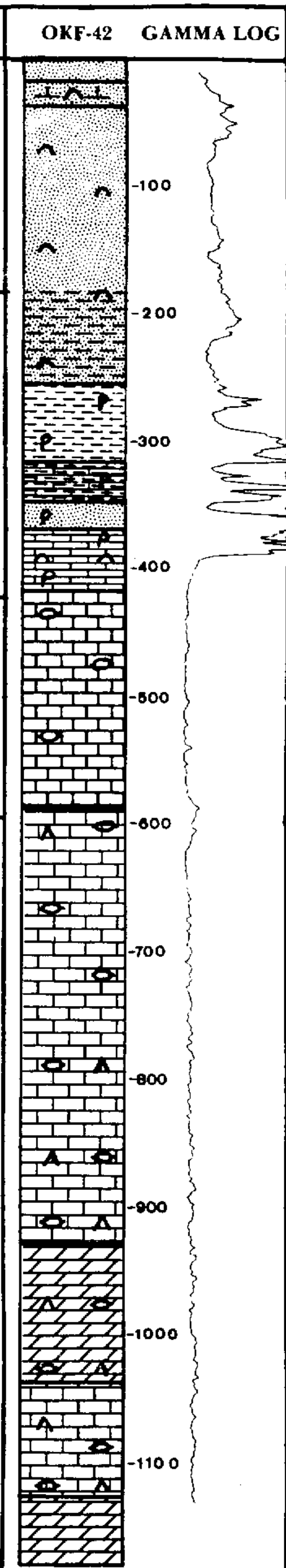
Peninsular Florida and the adjacent continental shelves have been tectonically stable throughout the Mesozoic and Cenozoic Eras. Regional subsidence has been the dominant movement, and more than 10,000 feet of Cretaceous and Tertiary shallow marine sediments, mainly carbonates, were deposited in southern Florida. In the more northern areas of the State, subsidence was slower, and a thinner section of mixed carbonate and terrigenous sediments accumulated in the shallow marine and coastal plain environment.

In the south, bank-type carbonates were deposited throughout the Paleocene. In Eocene time this southern reef was discontinuous, as little evaporite deposition occurred (Puri and Winston, 1974).

Following the deposition of the Eocene rocks, a large unconformity developed. During Oligocene, Miocene, Pliocene, and Pleistocene time, several major and minor unconformities with corresponding transgressions and regressions of the sea occurred (Puri and Winston, 1974).

The entire Floridan Aquifer System ranges in age from Paleocene to Early Miocene and forms a continuous carbonate sequence that is hydraulically connected to varying degrees (Miller, 1982a). The rocks of greatest concern in this study are of Early Eocene age and younger. Emphasis is on the rocks of the Upper Floridan Aquifer System which range in age from Early Eocene to Early Miocene.

Figure 9 shows the major geologic formations present in well OKF-42 as distinguished by the Gamma Ray Log and lithology. The Avon Park Limestone is lithologically similar to the overlying Ocala Group; however, the contact is unconformable. It is recognized by the presence of the distinctive fossil *Dictyoconus cookei*, by a small gamma ray peak followed by a general increase



SERIES	FORMATION	GEOLOGIC CHARACTERISTICS
HOLOCENE	Undifferentiated SAND and SHELL	Unconsolidated medium grained quartz sand with clay and shell; white to brown.
PLEISTOCENE		Shell beds intermixed with sand.
MIOCENE	HAWTHORN FORMATION	Sand, moderate induration grayish-yellow with shell, some clays; calcareous Olive gray sandy clay. High natural gamma radiation; Black phosphorite grains or pebbles.
EOCENE	OCALA GROUP	White to cream phosphatic limestone. Fine to pebble size quartz sand and phosphorite. Becomes dense limestone with large phosphorite pebbles at approximately 400 feet. Light gray to cream, soft, chalky foraminiferal limestone. *Lepidocyclina sp.* and *Camerina sp.* abundant.
	AVON PARK LIMESTONE	Light gray to light brown, soft to hard dolomitic limestone. Secondary calcite, void filling. *Dictyoconus cookei* characteristic fossil. Slight increase in gamma ray activity. Cavity at 1152 feet filled with dolosilt.

Figure 9 GEOLOGY OF WELL OKF-42

in gamma ray activity, and a lithologic change. The top of the Ocala Group is easily recognizable by the abundance of larger foraminifera including Lepidocyclina species and Camerina species. There is also a marked reduction in the gamma ray activity which is greatest at the base of the overlying Hawthorn Formation. The top of the Hawthorn Formation is characterized by a sandy limestone and clay. The clays are light green to dark green and contain abundant phosphorite grains. Gamma ray activity increases greatly towards the base of the Hawthorn Formation. The undifferentiated deposits overlie the Hawthorn Formation and consist of sand with some shell and clay. Undifferentiated deposits may include units of the Tamiami Formation and the Anastasia Formation.

Eocene Series

Oldsmar Limestone

Applin and Applin (1944) named the lower Eocene limestone facies the Oldsmar Limestone. It is lithologically similar to the overlying Lake City Limestone. Gypsum is commonly present and some chert also occurs.

The formation contains a number of thin rubble zones caused by wave action which transported bottom sediments which were then redeposited and cemented. Evaporites are abundant in the Oldsmar Limestone and usually occur in the form of gypsum following the hydration of anhydrite. The gypsum nodules are embedded in pore spaces of hard dense dolomite. Stringers of dolomitic sand also occur (Stewart, 1966).

The Oldsmar Limestone underlies all of south Florida and ranges in thickness from 300 to 1200 feet. It is believed to unconformably underlie the Lake City Limestone (Vernon, 1951; Cooke, 1945).

Applin and Applin (1944) showed the Oldsmar Limestone to occur between 1960 and 2630 feet below NGVD in Polk County. The Oldsmar Limestone was also encountered in Highlands County at a depth of 1240 feet below NGVD, and in Osceola County at 1795 feet below NGVD.

Stewart (1966) states that the contact of the Oldsmar with the overlying Lake City Limestone is indefinite and appears to be a disconformable zone, rather than an erosional unconformity. The disconformable zone consists of marine peats. "The presence of gypsum and anhydrite nodules in the disconformable zone... indicate the absence of fresh water erosion or circulation of fresh groundwater after deposition" (Stewart, 1966, p. 27).

Abundant specimens of the foraminifera Helicostegina gyralis commonly occur near the top of the Oldsmar Limestone. This species has a narrow stratigraphic range and a wide geographic distribution. The bottom of the unit is defined by the contact with the Cedar Keys Limestone (Applin and Applin, 1944). The Oldsmar Limestone does not contain potable water and is here considered to underlie the Floridan Aquifer System. Since these early Eocene rocks are highly transmissive and are overlain by a confining layer of low permeability rock, the unit is used for the disposal of injected wastes.

Lake City Limestone

Applin and Applin (1944) gave the name Lake City Limestone to an Early Middle Eocene limestone facies of Claiborne age. The Lake City Limestone underlying south Florida is composed of alternating layers of brown, hard, crystalline dolomite and dolomitic limestone, and a cream colored, soft to hard, chalky fossiliferous limestone. Applin and Applin (1944) report that scattered chert nodules and thin chert layers also occur.

The Lake City Limestone occurs at depths ranging from 900 feet to 1350 feet below NGVD, in the KPA. The formation was totally penetrated in one well (W-1464) in Highlands County where it was first encountered at 1015 feet below NGVD and had a thickness of 230 feet. It dips downward from north to south and is conformably overlain by the Avon Park Limestone.

Few wells in the KPA actually penetrate the Lake City Limestone except in Highlands and Glades Counties. Lichtler and others (1968), state that the Lake City Limestone is the oldest (about 50 million years old) formation penetrated by water wells in Orange County. One well in Osceola County completely penetrated the Lake City Limestone between 1040 and 1795 feet below NGVD. The overall dip of the formation throughout the planning area is approximately 9 feet per mile. However, it dips more gradually in Highlands County, averaging approximately 5 feet per mile (Bishop, 1956), while in Glades County the dip is steeper, averaging approximately 20 feet per mile.

The Lake City Limestone is characteristic of an offshore depositional environment and is relatively free of intraclastic sediments. Characteristic fossils of the Lake City Limestone include; Dictyoconus americanus, Fabularia gunteri, Fabularia vaughani, and Discorbis inornatus (Stewart, 1966).

The Lake City Limestone is distinguished from the overlying Avon Park Limestone by the occurrence of the fossil Dictyoconus americanus. In many areas of the KPA this fossil is very hard to identify due to dolomitization. Vernon (1951) indicates that the Lake City Limestone may rest unconformably on the Oldsmar Limestone and is unconformable with the overlying Avon Park Limestone. Stewart (1966) states that while the contact with the Avon Park Limestone is not obvious, the continuity of the lithology suggests it is transitional. Bishop (1956) states that this contact is conformable in Highlands County.

As previously mentioned, few wells in the KPA penetrate the Lake City Limestone. This is primarily because water of better quality can be found at shallower depths, especially in the northern part of the KPA, and to the higher cost of drilling a deeper well. However, as stated by Bishop (1956, p. 18), "The Lake City Limestone, because of its high permeability, is a highly productive aquifer in Highlands County and is utilized to a large extent wherever large quantities (500 to 1500 gallons per minute) of groundwater are needed for municipal and irrigation supplies." This formation, as well as other Eocene rocks, has developed a cavernous network of solution channels due to the acidity of circulating groundwater (Parker and others, 1955). These caverns yield large quantities of water and result in very high transmissivity values from tests on wells which intercept these cavities. The occurrence of cavities is very important hydrostratigraphically and will be discussed further in that section.

Avon Park Limestone

The Avon Park Limestone is a distinct microfaunal unit underlying the Ocala Group. The type sample was described from a well in southeast Polk County at the Avon Park Bombing range which is situated in the KPA. According to Applin and Applin (1944) the Avon Park Limestone underlies all of southern Florida.

The Avon Park Limestone is similar lithologically to the underlying Lake City Limestone. It is dark brown to cream, very hard to soft, finely crystalline to chalky, fossiliferous dolomite and limestone. When drillers encounter the top of this formation they will commonly refer to it as "hard brown lime."

The Avon Park Limestone is found throughout the KPA and occurs at depths very near 0 feet NGVD in Orange County, to just over 1000 feet below NGVD in southern Glades County. The top of the formation gradually dips to the south at approximately 9 feet per mile. Thicknesses range up to 600 feet with very few wells in the northern portion of the KPA penetrating the total thickness of the Avon Park Limestone. Through solution of limestone and the formation of dolomite, solution channels and caverns are formed within the Avon Park Limestone. Well OKF-42 (see Appendix I), appeared to have a cavern at the bottom. While drilling, drillers will often notice the bit 'falling' through these caverns, although this was not reported at well OKF-42. Instead, the cavern was full of a fine dolosilt that had winnowed its way into the cavern. Well HIF-35, which is approximately 5 miles to the southwest also had a cavern at the bottom, but it occurred at a depth 160 feet greater than that at well OKF-42 and did not contain any silt material.

Stewart (1966) suggested several possibilities for the origin of thin porous, granular, sand like zones in the Avon Park Limestone; "1) Some zones may be a depositional dolomite-sand in solution cavities, 2) some zones may be an ultra-fine honeycomb developed along fractures and other openings by solution, and 3) some of the zones may be a result of precipitation of ultra-fine dolomitic crystalline limestone. Such zones are also found in the dolomitized zones of the underlying Lake City and Oldsmar Limestone."

Cooke (1945) states that the Avon Park Limestone was a shallow marine deposit which received little clastic material. The formation is distinguished from overlying formations by the abundance of sand-sized, cone-shaped forams.

The characteristic fauna of the Avon Park Limestone are Dictyoconus cookei, Coskinolina floridana, Rotalia avonparkensis, and Lituonella floridana. Coskinolina floridana is probably the most abundant and persistent fossil, while Dictyoconus cookei is in some places common at the top of the Avon Park and also appears at the base, at the conformable contact with the Lake City Limestone (Applin and Applin, 1944; Bishop, 1956).

The permeability of the formation ranges greatly but is particularly high in areas of solution and channelization. In portions of Highlands, Glades, Okeechobee, and Polk Counties, wells penetrating the Avon Park Limestone will yield flowing artesian water. In Polk County the Avon Park Limestone contains the most productive zones in the Floridan Aquifer System. Most wells in the KPA which penetrate the aquifer are open to the Avon Park Limestone.

Ocala Group

Cooke (1945) placed deposits of the "Ocala Limestone" into the Eocene series. Vernon (1951) divided the Ocala Limestone into two easily recognizable units: the Ocala Limestone (restricted) and the Moody Branch Formation. He then divided the Moody Branch Formation into two members; the lower unit was named the Inglis, and the upper unit the Williston. Puri (1953, 1957) raised the Ocala to Group status and assigned three formations to it: the Crystal River Formation, the Williston Formation and the Inglis Formation. This usage comforms with stratigraphic nomenclature of the Florida Bureau of Geology.

The Inglis Formation is not believed to occur in south Florida. Since differentiating between the Williston Formation and the Crystal River Formation is of little importance hydrostratigraphically, this report deals only with the Ocala Group. The group is composed of a white to cream, chalky, soft, coquina of foraminifera. The Ocala Group ranges in thickness from 35 to 300 feet in the KPA. It is found at depths ranging from 60 to 650 feet below NGVD. The average dip is 8 feet per mile from north to south. The Ocala Group lies unconformably on the Avon Park Limestone. The top of the Ocala Group is an eroded surface which underlies Oligocene sediments, where present, or the Miocene deposits of the Hawthorn Formation. The deposition of the Ocala Group is believed to have occurred in an open, shallow, marine environment. The Ocala Group is easily recognizable by the abundance of flat and saddle shaped foraminifera. These are the Lepidocyclina sp. which occur in such abundance as to be referred to as a "coquina of leps" (Applin and Applin, 1944), or a coquinoidal limestone. Drillers may refer to this formation as 'button rock' due to appearance of the "leps."

The Ocala Group is not a major water producer within the Floridan Aquifer System in south Florida. Due to its soft chalky nature, the unit has a relatively low permeability; however, it does yield some water to wells.

Oligocene Series

Suwannee Limestone

Klein and others (1964) state that the Suwannee Limestone underlies all of Glades and Hendry Counties with the exception of northeastern Glades County. Stewart (1966) states that in the northern part of Polk County the formation thins considerably and is absent in much of the northern and eastern part of the county. There is no evidence from this study that the Suwannee Limestone occurs anywhere in the KPA north of Lake Okeechobee. Mooney (1980) discusses the presence of a gray, sandy, unfossiliferous calcilutite which did not fit the definitions of the Suwannee Limestone or Tampa Limestone. Therefore, he refers to it as an Unnamed Limestone. This limestone occurs in eastern Okeechobee County and is approximately 30-35 feet thick. Much of the Florida peninsula included in the KPA was probably above mean sea level during the Oligocene, when the Ocala Group was being eroded. The Suwannee Limestone is a white, porous limestone with minor percentages of quartz sand and sometimes contains phosphatic limestone and dolomite. The Suwannee Limestone, where present, may yield artesian water; however, the water contained in the formation is brackish in most of Glades, Hendry, and Lee Counties (Klein, 1964; Wedderburn and others, 1982).

Miocene Series

Hawthorn Formation

The Hawthorn Formation was originally named by Dall and Harris (1892) but the name was supressed by Matson and Clapp (1909) in favor of the more widely accepted name Alum Bluff. The Alum Bluff was then raised to the rank of Group, so Cooke and Mossom (1929) restored the name Hawthorn Formation.

The Hawthorn Formation is made up of sandy phosphatic limestones and sandy calcareous clays. The calcareous clays are light greenish-gray to dark green with black to brown phosphoritic sand. Drillers may refer to this unit as 'blue gumbo'. The limestone is white to yellow, becomes harder and more phosphatic towards the base. The Hawthorn Formation ranges in thickness from about 80 feet to over 600 feet in the KPA. The top of the formation occurs between +35 to -215 feet NGVD and the bottom contact has a range of 60 to 644 feet below NGVD.

These thick sequences of marine clays act as the confining layer for the Floridan Aquifer System. Only the basal permeable limestone unit acts as an aquifer. Based on the definition by Parker and others (1955), this limestone unit is considered to form the upper part of the Floridan Aquifer System. These lower units contain a high percentage of phosphorite and sand and are referred to by drillers as 'salt and pepper' rock. In the northern part of the planning area the contact with the underlying Eocene sediment is quite distinct. The basal unit consists of a sandy green clay with a distinct contact with the underlying coquinoid limestones of the Ocala Group. This contact is not as distinct in the southern portion of the KPA where thin units of Oligocene sediments separate the Hawthorn Formation from the Ocala Group. Beds at the top of the Hawthorn Formation may contain casts and molds of mollusks.

Plio-Pleistocene Series

Undifferentiated Sand, Clay and Shell

Overlying the Hawthorn sediments are undifferentiated deposits of sand, clay, and shell ranging in age from Pliocene to Recent, and possibly late Miocene. The upper unit is composed of fine to medium grained quartz sand with organic material and iron staining. Below this there are shell beds intermixed with clay layers. In some portions of the KPA the lowermost unit is a sandstone which may act as an aquifer for small water supplies. The thickness ranges from approximately 35 to 250 feet.

Geologic Cross Sections

To illustrate the occurrence and distribution of geologic formations a series of geologic cross sections were constructed. Figure 10 shows the locations of the cross sections. The first cross section is divided into 3 parts; A - A', A'- AA, and AA to AA' (Figures 11 to 13). The cross section trends southeast from Orlando to Okeechobee and then at well OKF-23 there is a change in direction to the southwest. The top of the Hawthorn Formation dips gently to the south over the entire cross section (A - AA') ranging from 33 feet above NGVD at ORF-7 to 210 feet below NGVD at GLF-2. However, the Hawthorn Formation thickens substantially from north to south. At ORF-7 it is 80 feet thick while at GLF-2 it is 434 feet thick. This gradual thickening accounts for a wedge shape description of the Hawthorn Formation. The Ocala Group dips rapidly as it underlies the Hawthorn Formation. Along this entire cross section the top of the Ocala Group ranges from 60 feet below NGVD at ORF-7 to 644 feet below NGVD at GLF-2. The distance from A - AA' is approximately 120 miles, therefore the average dip is approximately 5 feet per mile. All the wells shown in A - AA' terminate in the Avon Park Limestone. The top of the Avon Park Limestone is at 176 feet below NGVD at ORF-2 and at 753 feet below NGVD at GLF-1. Since none of the wells penetrated the underlying Lake City Limestone, the total thickness of the Avon Park Limestone is unknown.

The second cross section is divided into two parts; B - B' and B' - BB (Figures 14 to 15). Cross section B' - BB begins near Lake Hart in Orange County and extends southward into Martin County. The stratigraphy is similar to that shown in cross section A - AA', with the undifferentiated sediments remaining approximately 100 feet thick and the Hawthorn Formation thickening and dipping to the south. The Ocala Group is thin in the south having a minimum thickness of 30 feet at OSF-50 and a maximum thickness to the south of

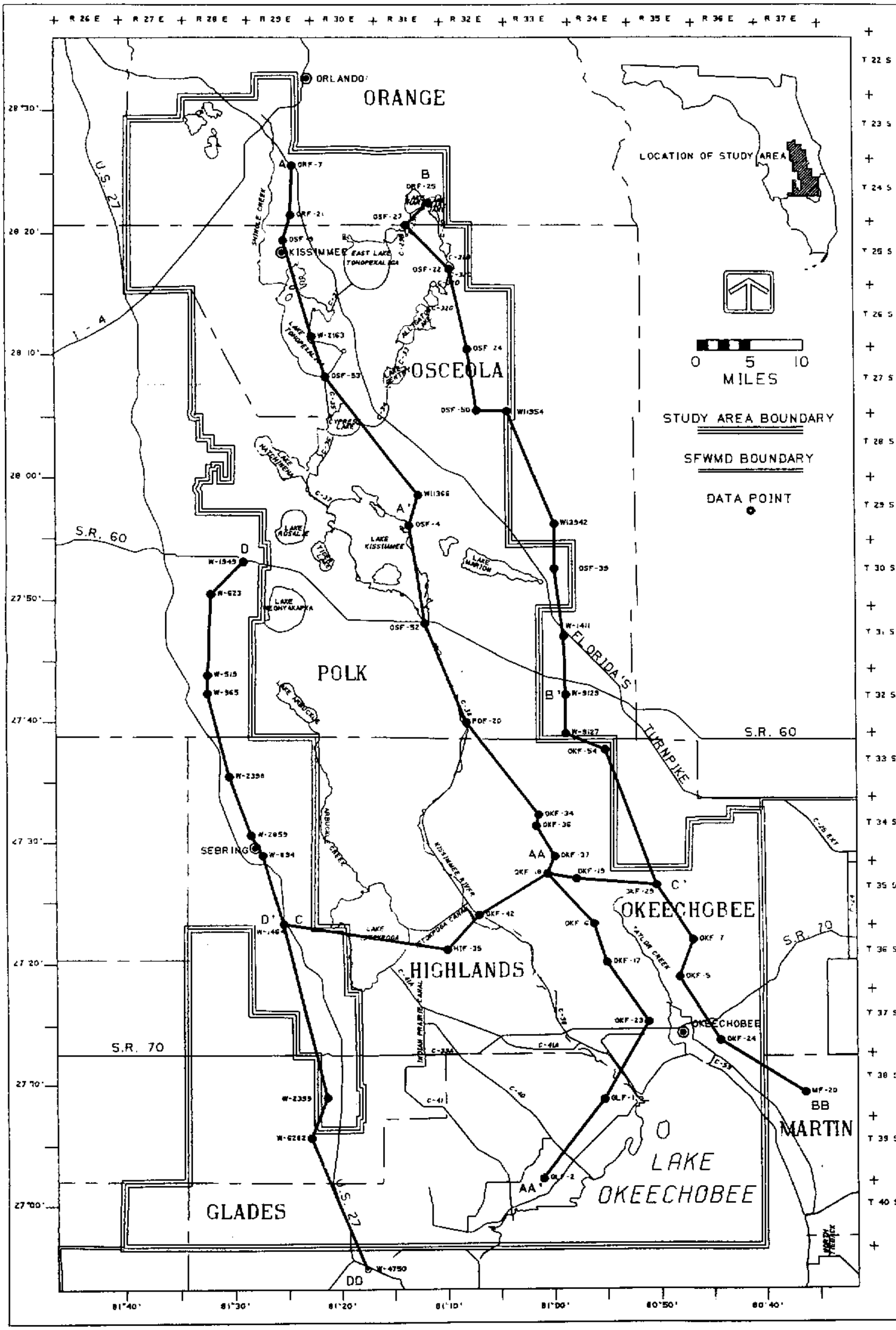


Figure 10 LOCATION OF GEOLOGIC CROSS SECTIONS

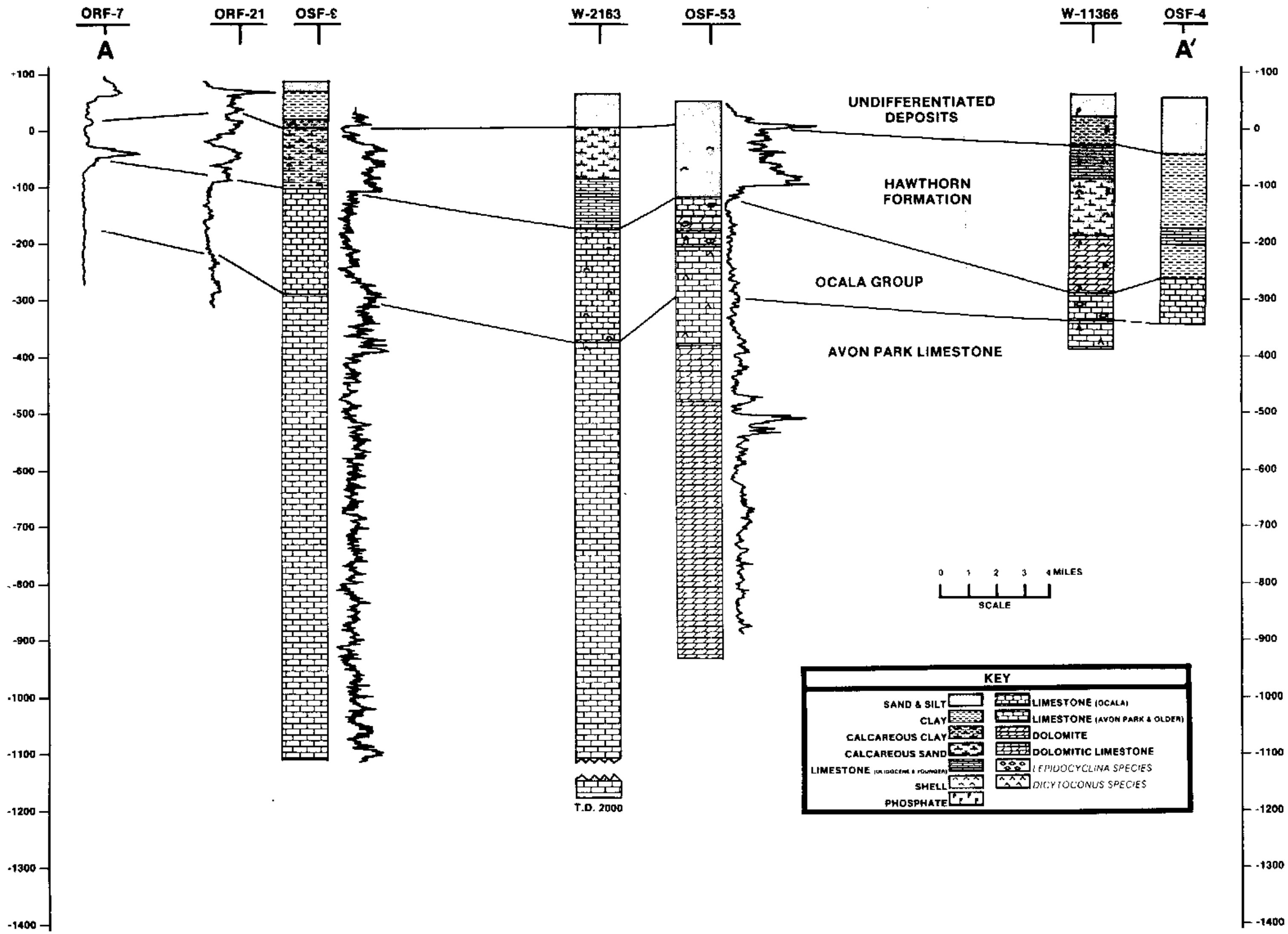


Figure 11 GEOLOGIC CROSS SECTION, A-A'

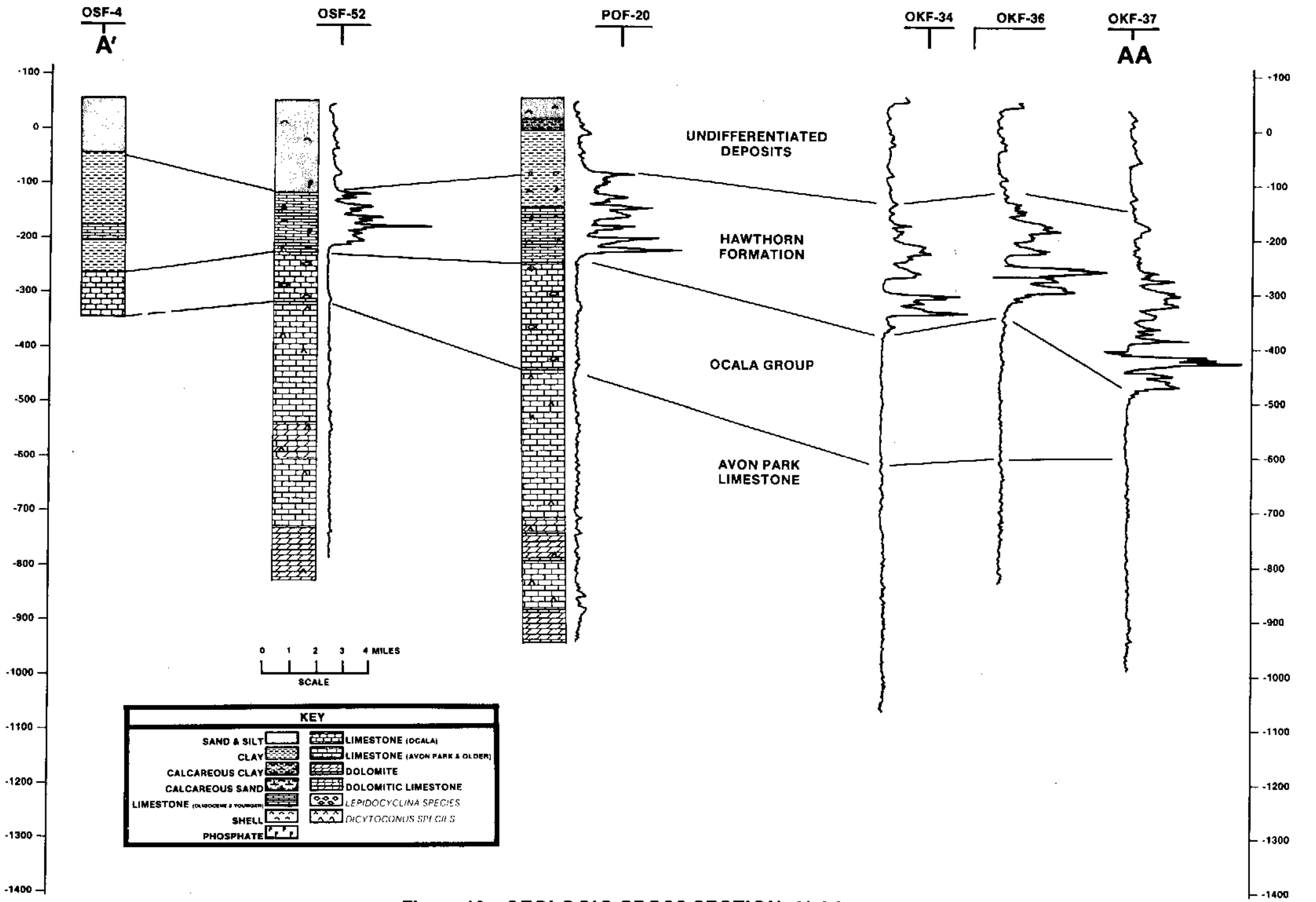


Figure 12 GEOLOGIC CROSS SECTION, A'-AA

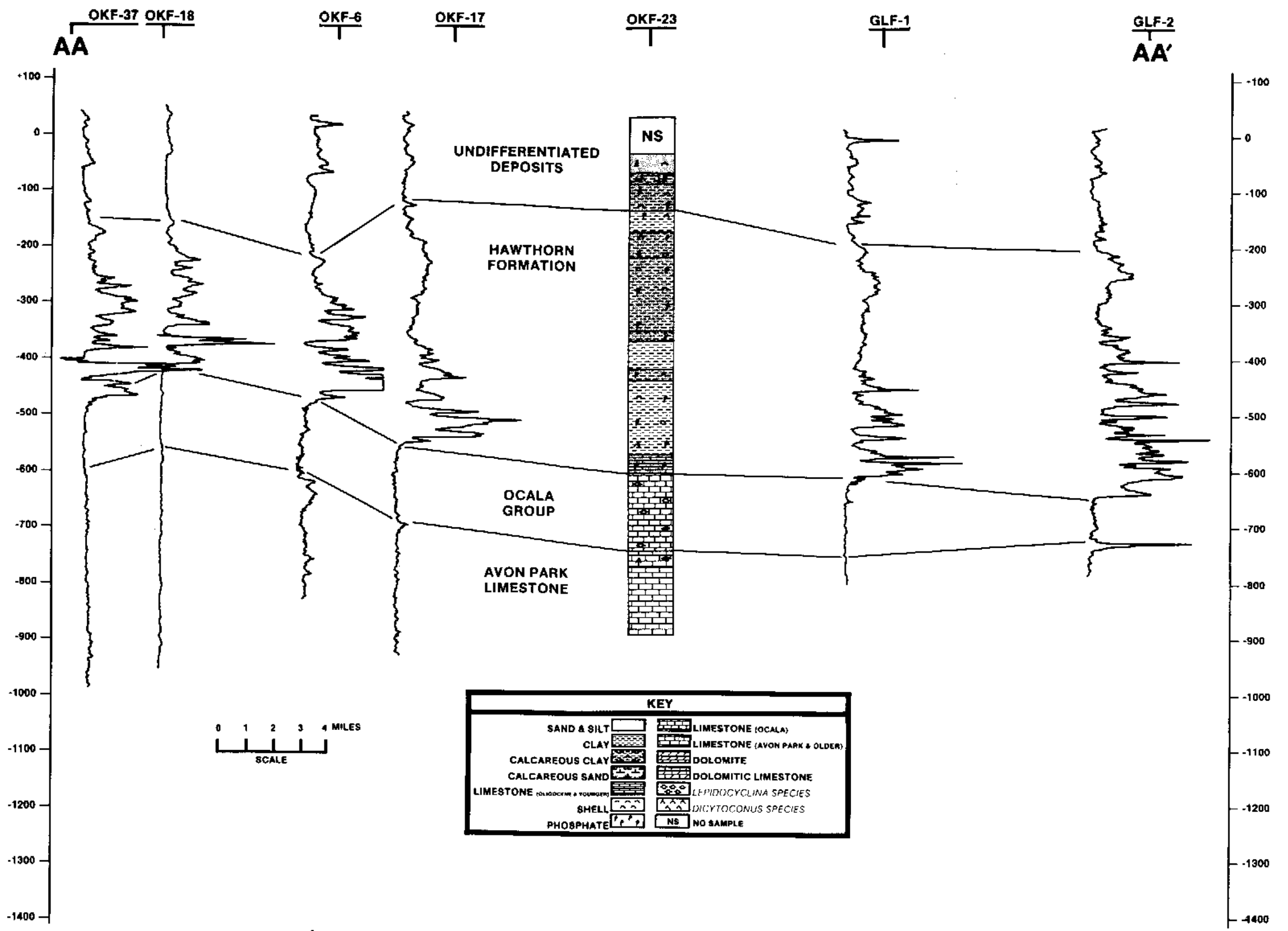


Figure 13 GEOLOGIC CROSS SECTION, AA-AA'

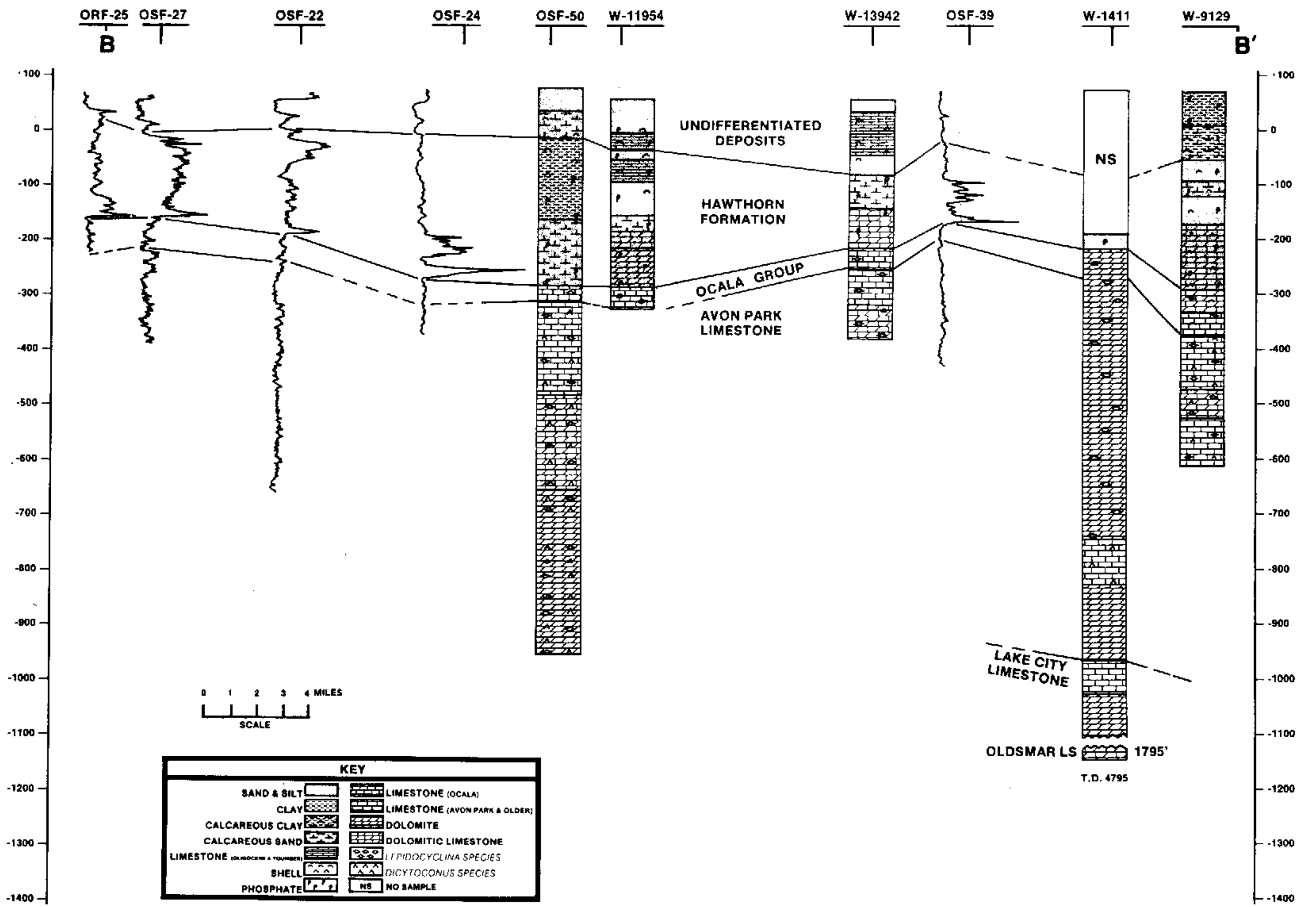


Figure 14 GEOLOGIC CROSS SECTION, B-B'

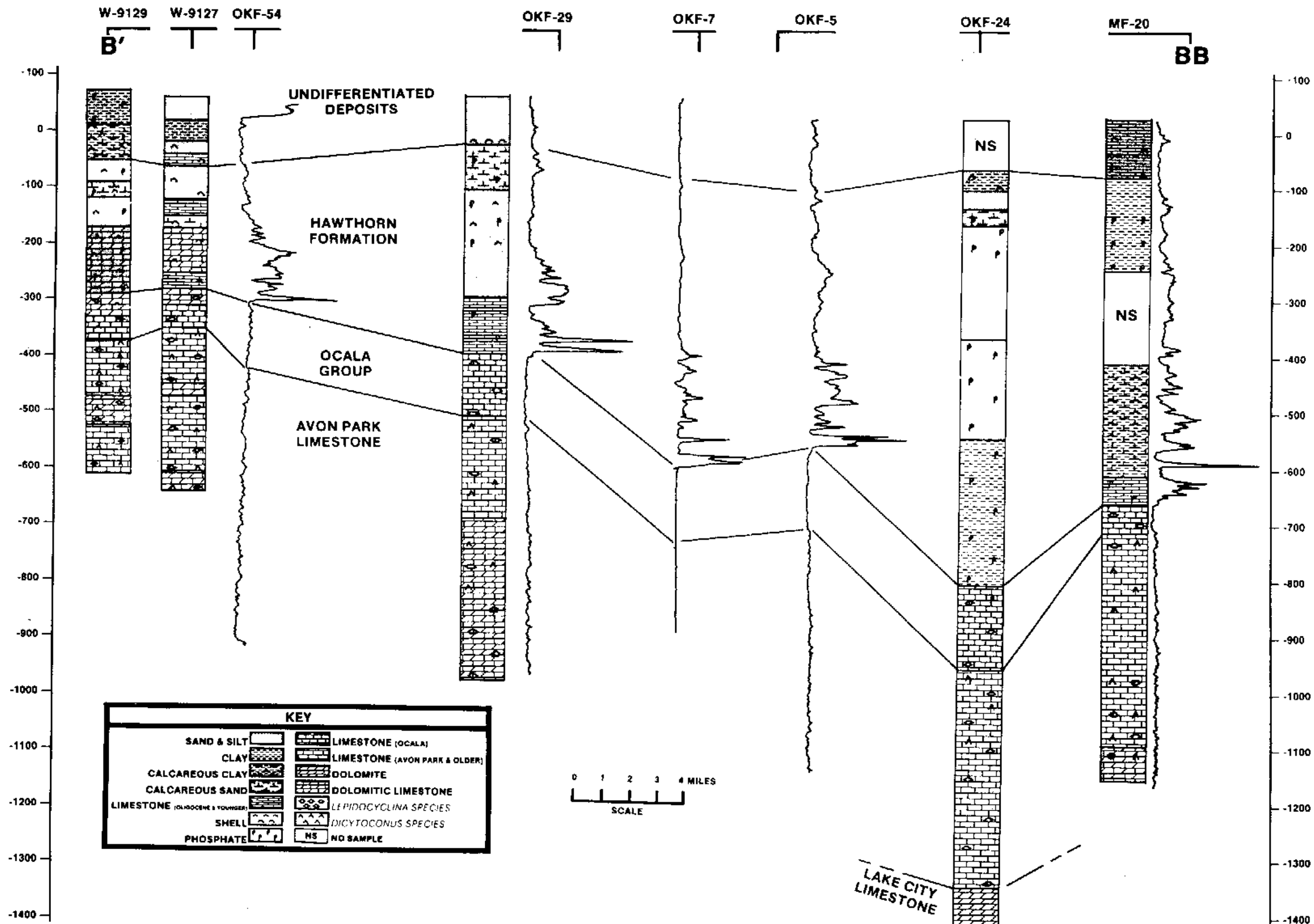


Figure 15 GEOLOGIC CROSS SECTION, B'-BB

170 feet at OKF-24. Wells W-1411 and OKF-24 fully penetrate the Avon Park Limestone with thicknesses of 700 feet and 380 feet, respectively. At W-1411 the Oldsmar Limestone was encountered at a depth of 1795 feet below NGVD. The Lake City Limestone is 755 feet thick at this point.

The third cross section, C-C' (Figure 16), is a west to east cross section that begins along the Lake Wales Ridge and extends to the east through Okeechobee County. Well W-1464, located along the ridge, penetrated 185 feet of undifferentiated sediments. To the east at well OKF-29 there are only 94 feet of undifferentiated sediments overlying the Hawthorn Formation. The Hawthorn Formation ranges in thickness from 372 feet to 240 feet. The Ocala Group thins to the east where it is 290 feet and 118 feet thick at W-1464 and OKF-29, respectively. The top of the Avon Park Limestone is at 765 feet below NGVD at W-1464, which penetrates the top of the Lake City Limestone at 1015 feet below NGVD and the top of the Oldsmar Limestone at 1240 feet below NGVD.

Cross section D-DD (Figure 17) lies wholly outside the KPA and the SFWMD boundary, and was constructed entirely with data from Bureau of Geology wells. These wells are all located close to route U.S. 27 which follows the Lake Wales Ridge through Polk and Highlands Counties. The cross section extends from near Lake Wales south to approximately 9 miles south of Lake Placid. Even though the cross section lies outside the KPA boundary, it has been included to aid in understanding the regional geologic framework along the western boundary of the planning area where little data currently exists. A fairly uniform layer of undifferentiated deposits overlie the Hawthorn Formation. The Hawthorn Formation forms a very distinct wedge, being only 50 feet thick to the north at W-1949. It thickens and deepens to the south where it is 645 feet thick at W-4750. A very thin sequence of Tampa Formation occurs in the northern section and pinches out between W-519 and W-965. To the south, the Suwannee Limestone underlies the ridge and ranges from 70 to 15

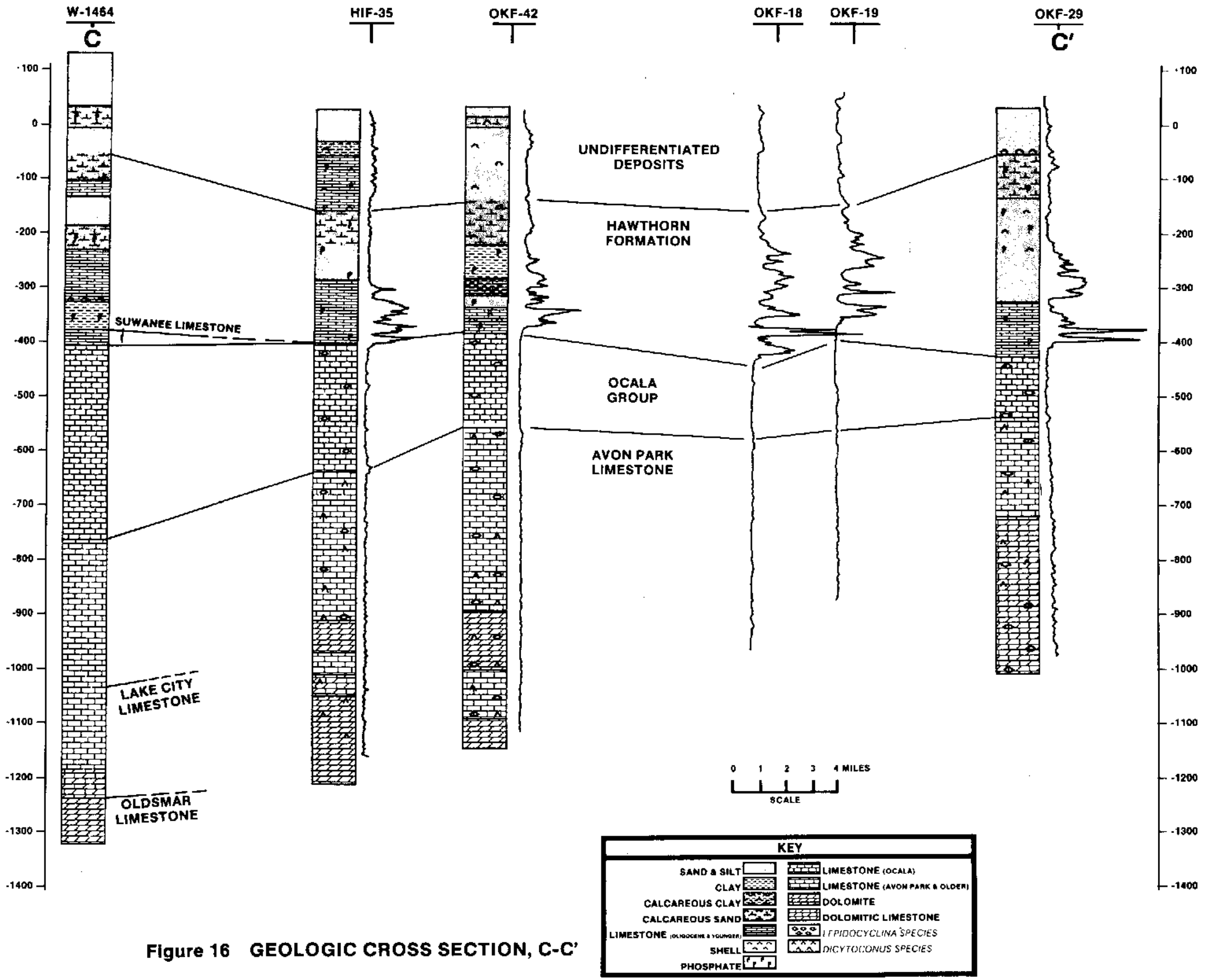


Figure 16 GEOLOGIC CROSS SECTION, C-C'

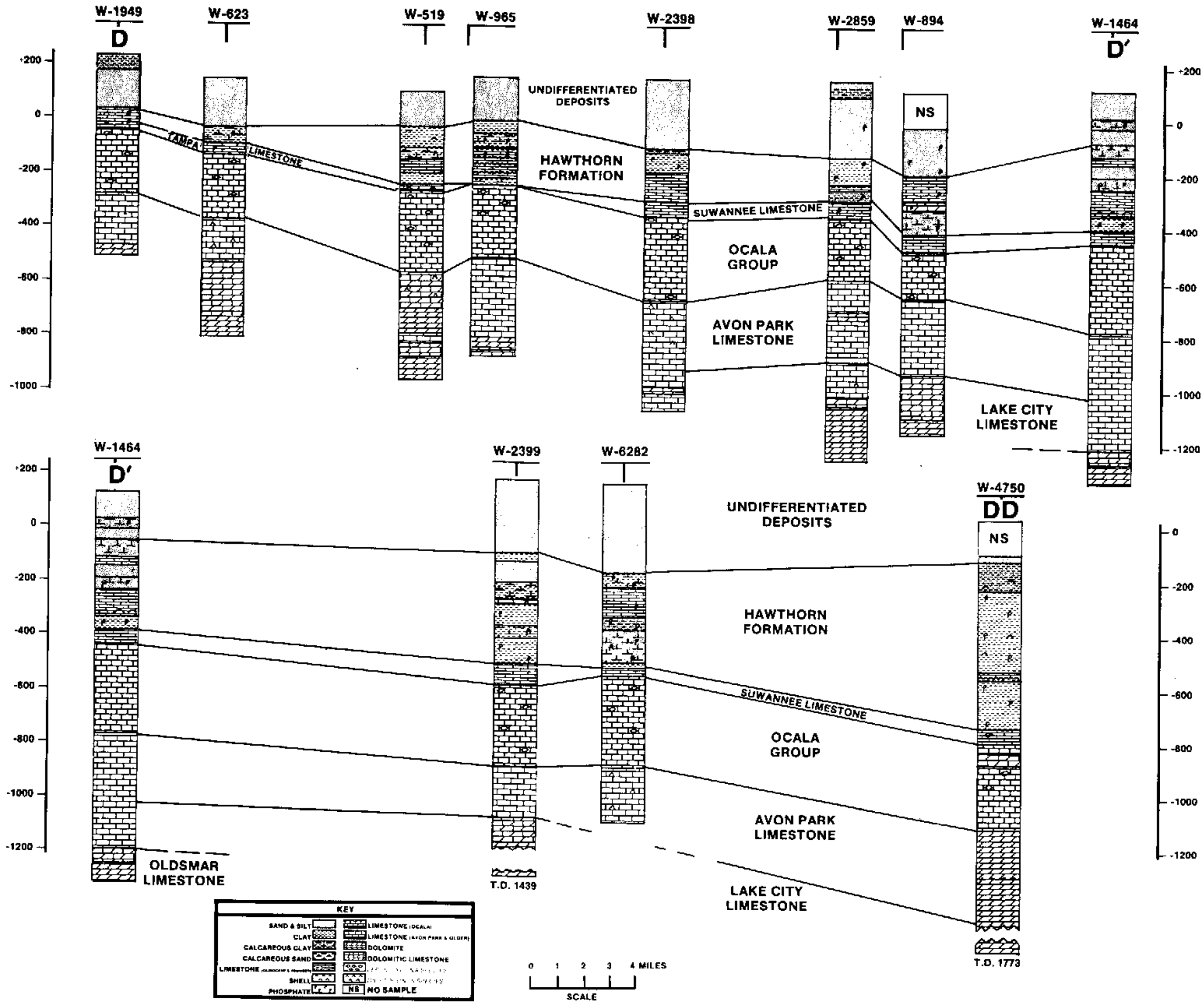


Figure 17 GEOLOGIC CROSS SECTION, D-DD

feet thick. This formation thickens to the west and thins out completely to the east. The Eocene deposits of the Ocala Group, Avon Park Limestone, and the Lake City Limestone all slope gradually to the south.

HYDROSTRATIGRAPHY

Introduction

Commonly used terms in this report include; hydrostratigraphic unit, aquifer, confining bed, aquitard, semi-permeable layer, aquifer system, and producing zone. The term "hydrostratigraphic unit" is applied to a body of rock having considerable lateral extent and composing "a geologic framework for a reasonably distinct hydrologic system" (Maxey, 1964). An aquifer is any water saturated geologic strata that will yield economically significant quantities of groundwater to a well or spring. A confining bed is a body of impermeable or distinctly less permeable strata adjacent to one or more aquifers. There are various terms used to define semi-confining strata based upon their ability to absorb, store, or retard the flow of water to and from adjacent aquifers. Terms used in this report are aquitard and semi-permeable layer. An aquitard is a leaky confining bed that does not readily yield water to a well but may act as a storage unit for groundwater. Semi-permeable layers have a relatively low hydraulic permeability and are bounded by more permeable strata. In this report there are numerous references made to the "Floridan Aquifer System." Poland (1972) defines an "aquifer system" as a heterogeneous body of permeable material interlayered with less permeable material that acts as a water yielding hydraulic unit of regional extent. The term "producing zone" has only recently entered into the literature of groundwater hydrology, (Brown and Reece, 1979; Wedderburn and others, 1982; Meyer, 1983). Originally this term was used by petroleum geologists to define the rock stratum of an oil field that will produce petroleum or gas when penetrated by a well. In this report, "producing zone" is defined as a rock stratum within an aquifer or aquifer system which exhibits a marked increase in permeability and water productivity compared to overlying and underlying strata.

Identification of Hydrostratigraphic Units

Three hydrostratigraphic units were identified based on observed differences in lithologic and hydrogeologic characteristics as interpreted from examination of drill cutting and geophysical logs. Drill cuttings submitted to the District or collected by the District are closely examined for hydraulic characteristics and water bearing properties. A given rock type will generally have distinct porosity and permeability. Water will be found in zones having suitable hydrologic characteristics. The porosity determines the amount of water that can be stored within the rock, and permeability determines the flow rate of water within the aquifer and consequently the ease of withdrawing the water for use. Certain ranges of porosity and permeability are associated with certain rock types as shown in Figure 18.

Geophysical methods have proven quite useful in gathering needed hydrologic data. With the use of a borehole geophysical logger, interpretation of the lithology, permeability, and porosity of strata penetrated by a well can be made even in the absence of geologic samples. Since the majority of the wells in the study area were drilled prior to the initiation of this program, geophysical surveys were used in many cases to identify hydrostratigraphic units. Geophysical signatures of known rock types were used to infer similar lithologic and hydrologic conditions where no direct geologic evidence existed.

The three hydrostratigraphic units which were defined are the Surficial Aquifer System, the Hawthorn confining beds, and the Floridan Aquifer System. Figure 19 refers to these three units and indicates their geologic age and hydrogeologic characteristics. Hydrostratigraphic units were identified along two cross sectional areas shown in Figure 20. Figures 21 and 22 illustrate the vertical relationships of the units in feet NGVD while no horizontal scale is inferred.

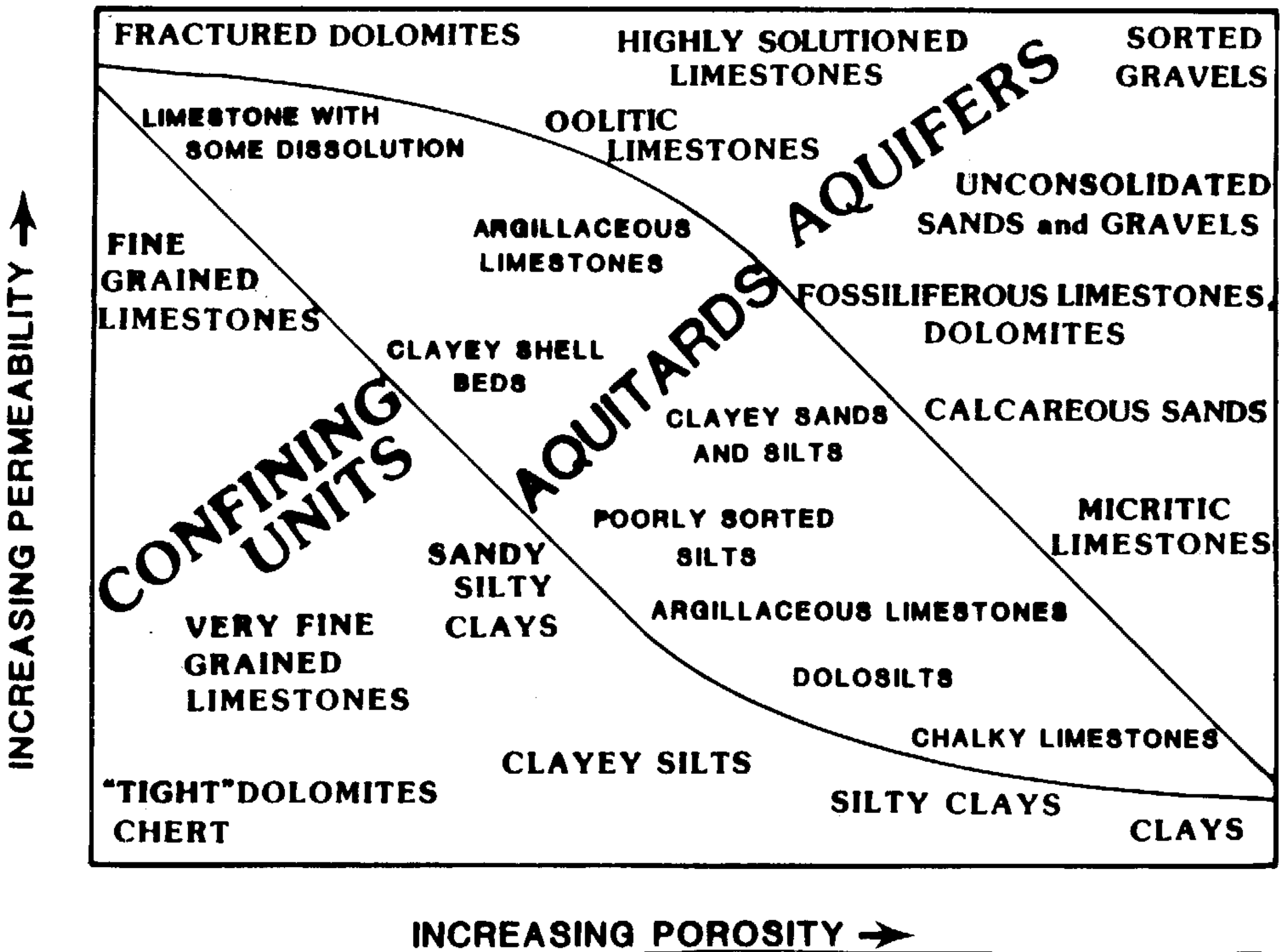


Figure 18 PERMEABILITY AND POROSITY OF VARIOUS ROCK TYPES (FROM KWADER, 1983, WITH PERMISSION)

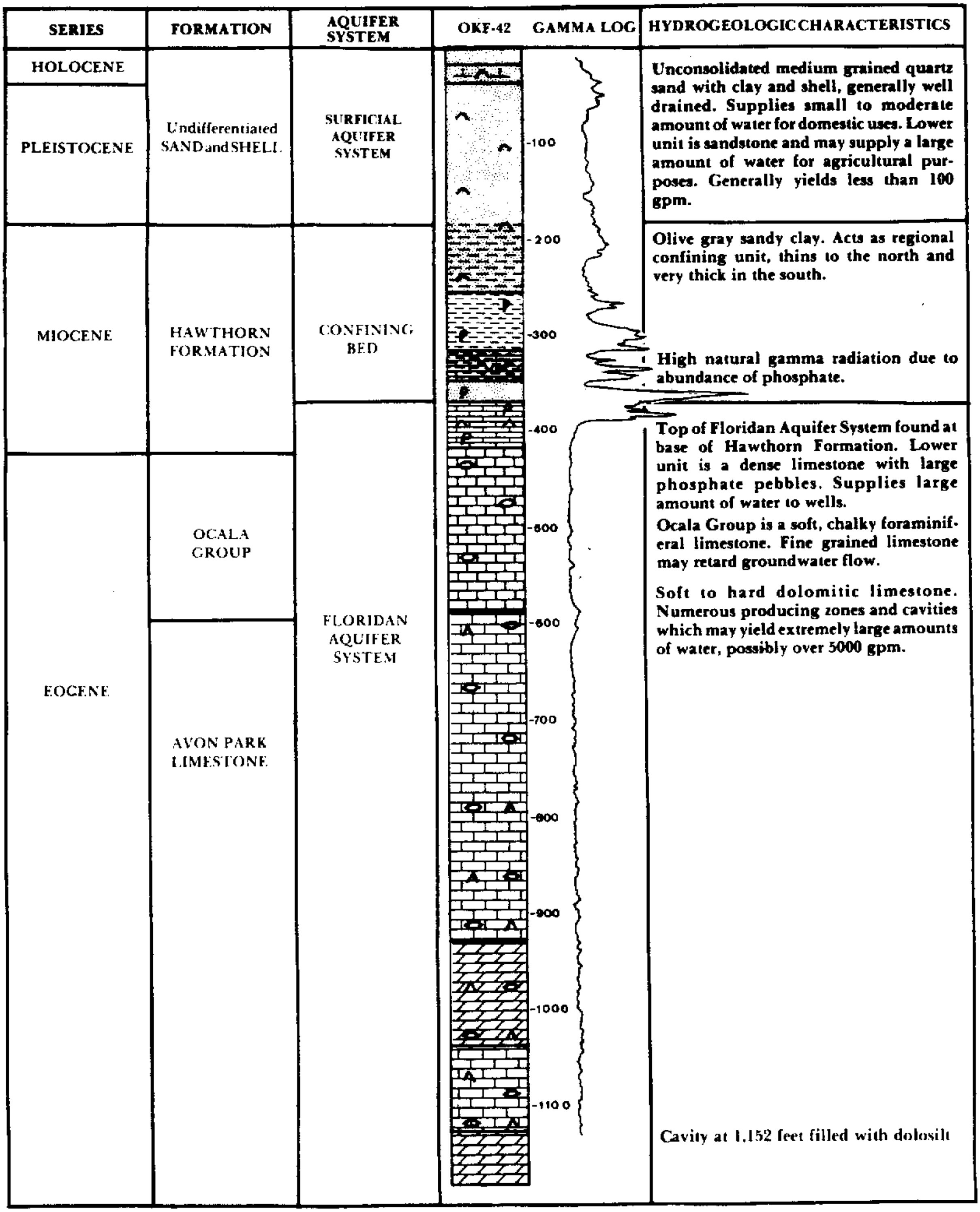


Figure 19 HYDROSTRATIGRAPHY OF WELL OKF-42

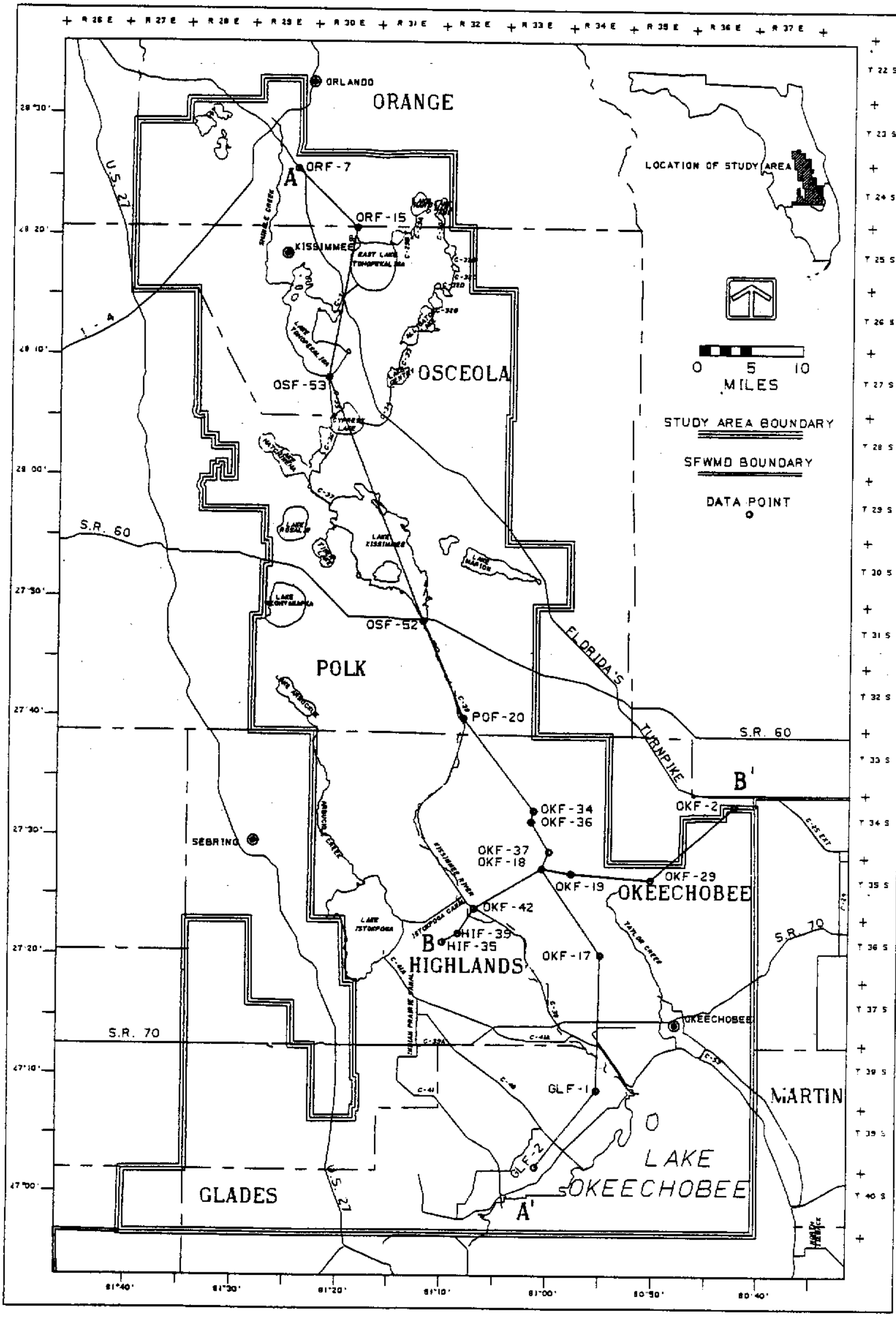


Figure 20 LOCATION OF HYDROSTRATIGRAPHIC CROSS SECTIONS

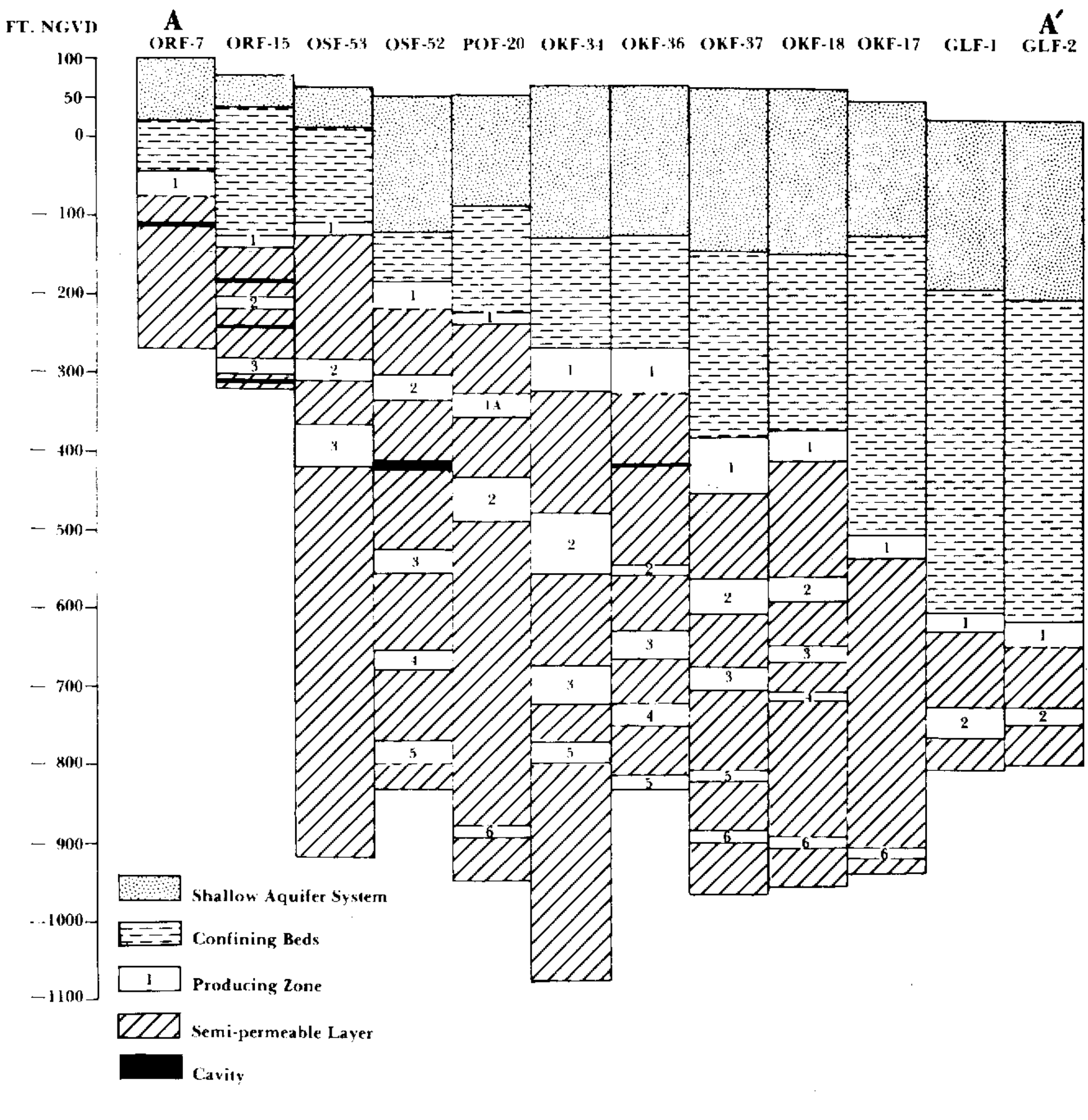


Figure 21 DISTRIBUTION OF HYDROSTRATIGRAPHIC UNITS AND PRODUCING ZONES, A-A' (NO HORIZONTAL SCALE)

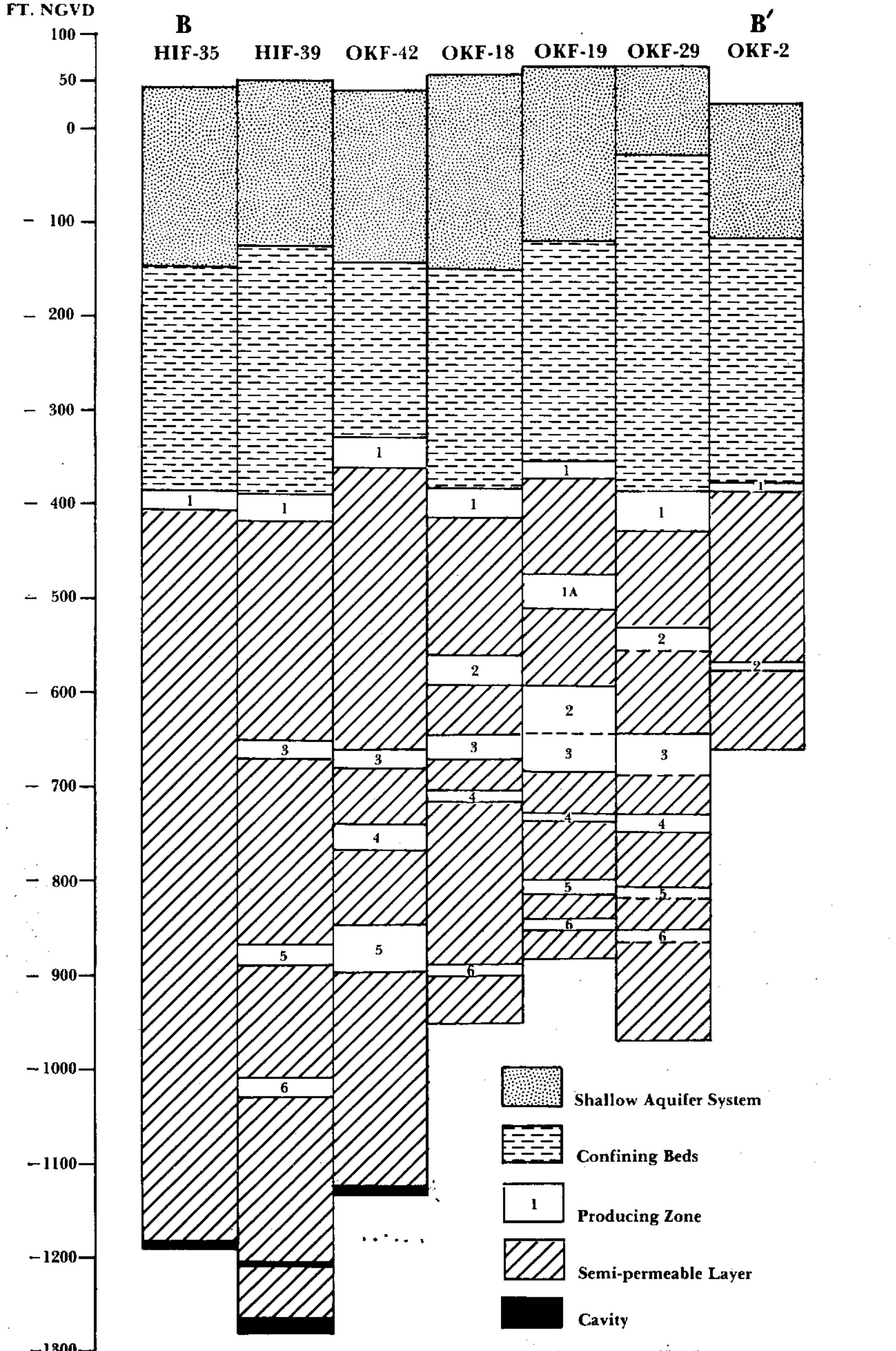


Figure 22 DISTRIBUTION OF HYDROSTRATIGRAPHIC UNITS AND PRODUCING ZONES, B-B' (NO HORIZONTAL SCALE)

Surficial Aquifer System

The Surficial Aquifer System in the KPA consists mainly of sand interbedded units consisting of gravel, shell, sandstone, and limestone of Late Miocene and Pleistocene age. Within the KPA, these surficial units have not been given formal names as they are areally discontinuous. Small to moderate yields of water are generally available from these units with the sandstone units being the most prolific where encountered. The water level in the Surficial Aquifer System is represented by the water table, which is the surface in an unconfined aquifer where the hydrostatic pressure is equal to atmospheric pressure. The confining layers of the Hawthorn Formation form the base of the Surficial Aquifer System. The base of the Surficial Aquifer System varies between 34 feet above NGVD and 215 feet below NGVD. The thickness varies from 38 feet to 225 feet.

In Orange County, the Surficial (nonartesian or water table) Aquifer System extends over most of the county (Lichtler and others, 1968). The base of the aquifer system is at approximately 40 feet below land surface. Most domestic wells are screened to a depth of 20 to 30 feet and yield 5 to 10 gallons per minute (gpm) of water.

Stewart (1966) reports that the Surficial (nonartesian) Aquifer System underlies all of Polk County. The normal thickness ranges from a few inches to 250 feet; however, along the eastern portion of the county and on the crest of the Lake Wales ridge, maximum thicknesses of 300-600 feet are reported. The normal well yield is approximately 20-30 gpm, but in some cases well yields may exceed 100 gpm.

In Glades and Hendry Counties, the Surficial Aquifer System is found in the permeable beds of shell, limestone, or mixtures of sand and gravel (Klein and others, 1964). Wells penetrating the aquifer system range from 10 to 300 feet in depth. According to Klein and others (1964), "the shallow sediments in Glades County generally have low to moderate permeability. Thus most large capacity wells penetrate the Floridan aquifer even though the quality of the water is usually poorer."

In Highlands County, Bishop (1956) refers to the Surficial Aquifer System (Shallow aquifer) occurring in the Hawthorn Formation, the Tamiami Formation, and Undifferentiated deposits. Studies for this report indicate that the base of the Surficial Aquifer System is located in the lower beds of the undifferentiated sand and shell deposits. This commonly occurs at a depth ranging from 40 to 200 feet below NGVD. Well yields are generally low, less than 100 gpm, but are adequate for domestic or small agricultural needs.

In Okeechobee County, the basal unit is a moderately consolidated sandstone. The base of the Surficial Aquifer System is located approximately 180 to 200 feet below land surface. Like other wells open to the shallow sediments, these wells supply only small amounts of water most suitable for domestic use. To supply larger quantities of water (over 100 gpm), wells must penetrate the confining layers and tap the artesian zones in the Floridan Aquifer System.

Hawthorn Confining Beds

Overlying the entire Floridan Aquifer System in the KPA are confining sands and clays of Miocene age. These sediments are part of the Hawthorn Formation. Water in a well drilled through the bottom of this confining zone into the underlying aquifer system will rise above the base of the confining layer due to the artesian conditions of the underlying aquifer system.

The Hawthorn confining sequence is wedge-shaped, being thin in the north and thicker and deeper towards the south. The low permeability of the clays retards vertical movement of water between the Floridan Aquifer System and the overlying Surficial Aquifer System. Where the confining layer is thin (approximately 60 feet or less), as in part of western Orange and eastern Polk Counties, recharge may occur through sinkholes or lakes where the water level of the Surficial Aquifer System is above the potentiometric surface of the Floridan Aquifer System. In parts of Okeechobee and Glades Counties, the confining layer is over 400 feet thick and the potentiometric surface of the Floridan Aquifer System is well above land surface. No downward recharge occurs through these clays. Wells which penetrate the Floridan Aquifer System are under flowing artesian (or discharging) conditions in this area.

The base of the confining unit is near the base of the Hawthorn Formation. It is a grayish green, sandy clay with stringers of quartz sand embedded with brown to black phosphorite pebbles and coarse sand. This unit is identified geophysically by high counts in the gamma ray log, caused by large concentrations of phosphorite, as high as 30 percent.

Underlying the Hawthorn confining bed is a sandy, chalky, white limestone with some recrystallized sparry calcite and dolomite, and abundant phosphorite which marks the top of the Floridan Aquifer System.

Floridan Aquifer System

The term "Floridan aquifer" was originally used by Parker (Parker and others, 1955) to include all or parts of the Lake City Limestone, Avon Park Limestone, Ocala Group, Suwannee Limestone, Tampa Limestone, and "permeable parts of the Hawthorn Formation that are in hydrologic contact with the rest of the aquifer." Other authors have used terms such as "Tertiary Limestone Aquifer System" (Miller, 1982a&b), "Principal Artesian Aquifer" (Stringfield, 1966), and "Southeastern Limestone Regional Aquifer System" (Frazee, 1982), when describing essentially the same sequence of rocks. In this report the term "Floridan Aquifer System" is used. The top of the Floridan Aquifer

System is defined as being located in the basal limestone units of the Hawthorn Formation. According to Meyer (personal communication, 1984), current work suggests that the limestones of Miocene age (basal beds of the Hawthorn Formation) may represent a separate aquifer from the limestone sequence of Eocene age. This proposal is based upon differences in head values between the Miocene limestones and the Eocene limestones. However, conclusive evidence from straddle-packer tests would be required to verify this hypothesis.

Since few wells penetrate the Lake City Limestone in the study area, the base of the aquifer has not been determined. The stratigraphic location of the base of the aquifer is variously defined by different authors. The presence of gypsum and anhydrite located in the Lake City Limestone and the Oldsmar Limestone has been used to indicate that these beds would coincide with the bottom of the Floridan Aquifer System (Stewart, 1966; Vernon, 1951). However, Miller (1982b) indicates that the base of the Floridan Aquifer System (Tertiary Limestone Aquifer System) is stratigraphically located within the Cedar Keys Limestone and ranges from approximately 2250 to 4000 feet below NGVD in the KPA.

The Floridan Aquifer System, as defined in this report, is composed of a thick sequence of carbonate rocks. The high permeability results from the fractured nature of the limestone, dolomitization, and dissolution. Producing zones occur where the limestone is more dense or where dolomitization has occured. Voids in the rock, such as caverns or cavities, occur due to dissolution or dolomitization of the limestone and produce large amounts of water. Well yields may exceed 5000 gpm. Producing zones and cavities may be lithologically indistinct, however; they are usually apparent in borehole geophysical surveys. By locating these producing zones and cavities, the maximum beneficial use of the aquifer may be achieved at minimal cost.

Borehole Geophysical Applications

The borehole geophysical surveys that are most applicable to the delineation of hydrostratigraphic units, especially producing zones, in order of usefulness are: Flowmeter, Differential Temperature, Temperature, Neutron Porosity, 16-and 64-inch Normal Resistivity, 6-foot Lateral Resistivity, Caliper, and in some cases, Spontaneous Potential and Fluid Resistivity.

The Flowmeter Survey is most valuable since it measures the flow of water into the well from strata adjacent to the borehole. Increased flow into a well causes a deflection to the right on the log, which indicates a producing zone. In most cases, the Flowmeter Log shows considerable noise due to variations in line speed during logging, inconsistencies in the tool, or obstruction of the impellers by particles in the water. This noise may mask the effects of increased flow into the borehole. The principal factor, which affects the reliability of the logs in detecting inflow to the well, is the variation in borehole diameter. A Corrected Flow Log, which takes into account changes in velocity due to variations in borehole diameter, generally gives a more accurate picture of inflows to the well.

Figure 23 shows a Flowmeter Log, a Caliper Log, and a Corrected Flow Log for well number OKF-29. It illustrates the method used to obtain both a corrected flow log and estimates of the relative contributions from individual producing zones. Once the location of producing zones has been determined, points are picked above and below each zone on the Caliper Log and the diameter in inches is noted. The counts per second (cps) are noted at corresponding depths on the Flowmeter Log. In order to determine the relative contribution of each zone, the flowmeter value (cps) is first multiplied by the cross sectional area of the borehole at a given point. These new values are replotted to form a Corrected Flow Log. The relative horizontal distances between points gives the percent contribution of each zone, assuming zero

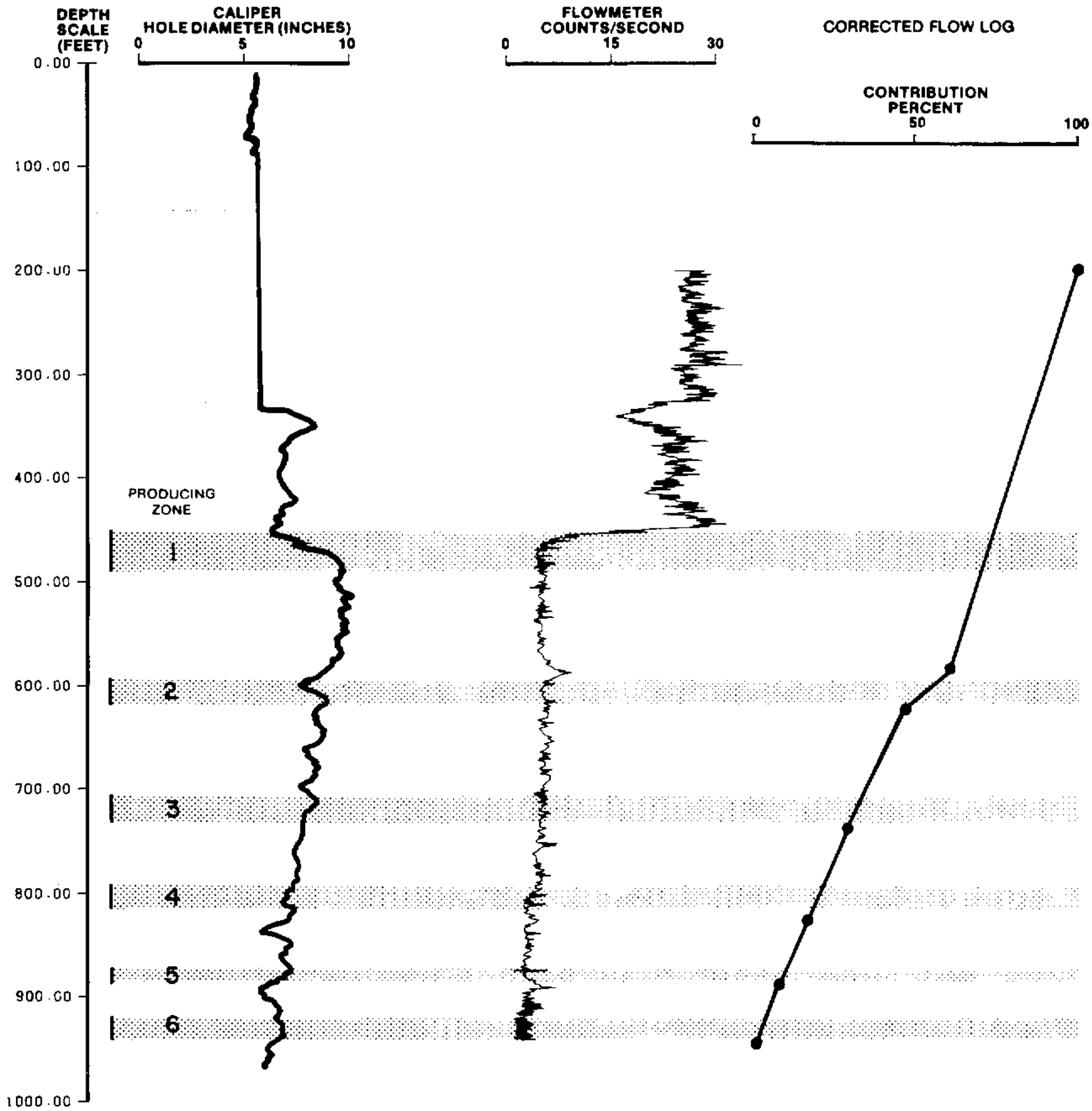


Figure 23 CALIPER LOG, FLOWMETER LOG, AND CORRECTED FLOW LOG FOR WELL OKF-29, WITH PRODUCING ZONES SHOWN

-80-

inflow to the well at the base of the borehole and 100 percent flow in the casing. For well number OKF-29, producing zone number 1 accounted for 41 percent of the flow to the well, while producing zones number 2, 3, 4, 5 and 6 accounted for 13 percent, 18 percent, 12 percent, 9 percent and 7 percent, respectively. Eighty-four percent of the water produced in the well came from producing zone number 4 or above.

Producing zones may also be identified based on small but significant differences in temperature of the water produced from these zones. The Differential Temperature measures a change in temperature over a predetermined length of borehole. Normally the temperature gradient will increase with depth due to the normal geothermal gradient. A normal geothermal gradient is an increase of approximately $1^{o}C$ for every 100 feet of depth. While the temperature gradient measures the actual temperature, the temperature differences are accentuated on the Differential Temperature Log and consequently, this log is more applicable for detecting these zones.

The Neutron Porosity Log is an indirect measure of the porosity of the surrounding strata. This information is also useful in delineating producing zones. High porosity rocks will produce little deflection on the log. Low porosity rocks will cause a deflection to the right when adjacent to a relatively more porous stratum due to the higher number of neutron emissions returning to the detector.

Like the Neutron Porosity Log, the 16- and 64-inch Normal Resistivity and Spontaneous Potential Surveys are also useful in delineating producing zones. However, the electric logs generally lack definition due to the absence of a mudcake along the borehole wall, and are more appropriately used to confirm the presence of producing zones.

The information on borehole diameter generated from the Caliper Survey may be correlated to lithology, stratigraphy, or the presence of fracture and solution openings. The relationship of variations in borehole diameter to the presence of producing zones may be examined in two ways. First, a smaller borehole diameter is evidence of a more competent rock. Experience has shown that it is these very hard, possibly dolomitized zones that are the major water producers and are indicated by a smaller hole diameter on the log. Second, sharp increases in hole diameter may indicate the presence of a cavity. In south Florida, it has been found that these cavities are common and can produce large quantities of water. Thus, a relatively large hole diameter may also indicate the presence of a "producing zone." In cases where the production of water over an interval of the borehole is from a single large cavity or multiple cavities, these are separately identified. The Caliper Survey is also used to correct other surveys i.e., the Flowmeter Survey for influence of borehole diameter.

Figure 24 is a multiple survey plot for well OKF-54 which penetrates the Floridan Aquifer System. The producing zones which are identified from the geophysical logs are highlighted. The depths are shown in feet below land surface. In this well, five producing zones were identified in addition to a cavity near the bottom. The producing zones are located at depths of: 1) 334-366 feet; 2) 418-426 feet; 3) 548-566 feet; 4) 685-715 feet; 5) 788-798. The cavity is at 955-961 feet.

The top of the first producing zone marks the top of the Floridan Aquifer System. The Flowmeter Log shows an increased inflow entering the borehole at this depth. The Differential Temperature Log also shows a noticeable change. The Neutron Porosity Log indicates high porosity and high permeability which is indicative of limestone solutional features. The Resistivity Survey must be examined, bearing in mind that the borehole is not mud filled. In a mud free hole, the 16-inch Normal Resistivity Log measures the formational water resistivity. Producing zone waters tend to be lower in ionic concentration,

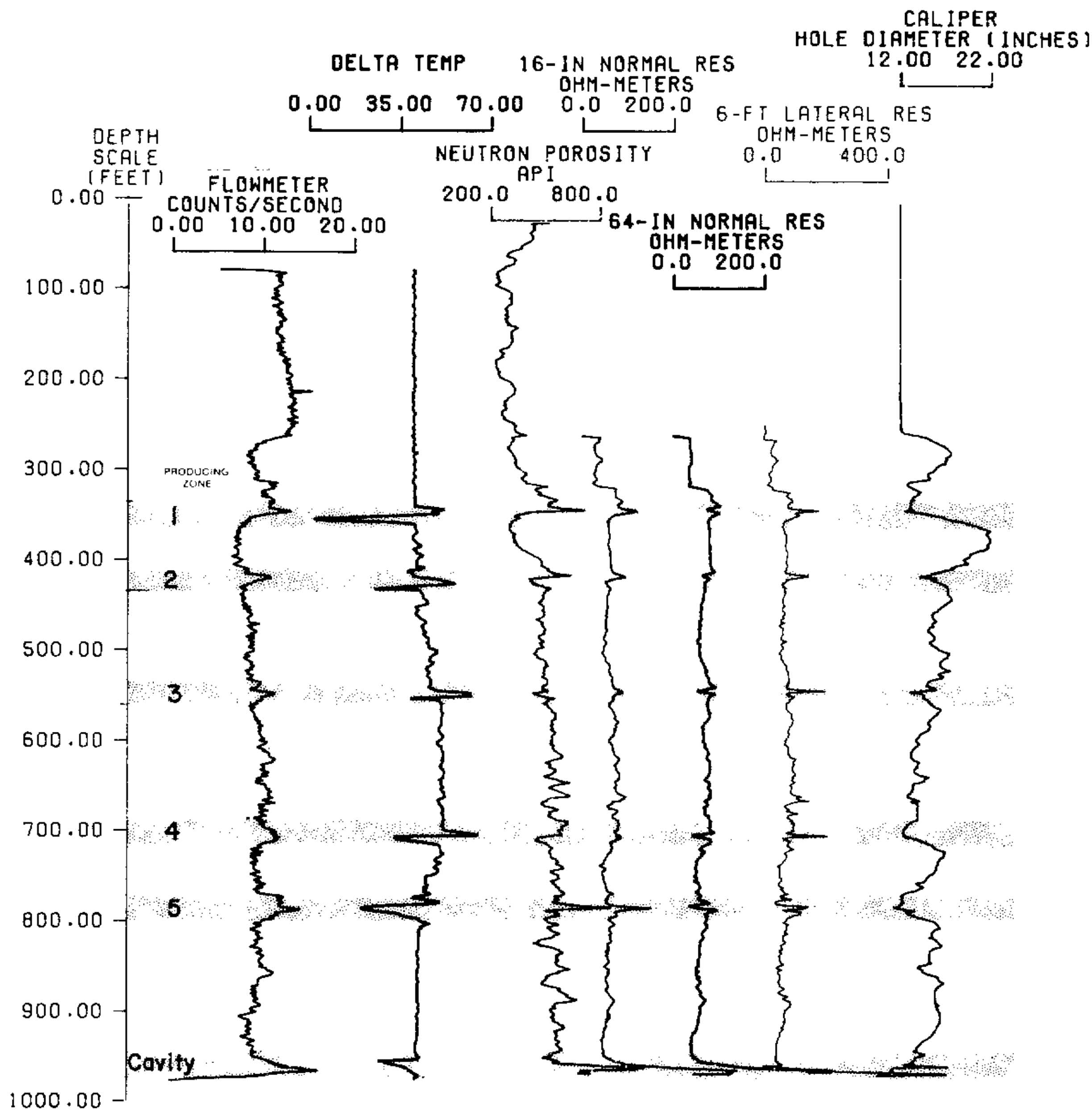


Figure 24 MULTIPLE SURVEY PLOT FOR WELL OKF-54 WITH PRODUCING ZONES AND CAVITY SHOWN

as a result of water travelling faster through the formation. In theory, resistivity should increase in a producing zone since the formation is saturated with resistive waters. In practice, however, the current tends to travel along the borehole in fresh water environments yielding an apparent lower resistivity, as evidenced with the 64-inch Normal Resistivity Log. A better approximation of formation resistivity is recorded with the deeper penetration of the 6-foot Lateral Resistivity Log. More dense, possibly dolomitized producing zones are characterized by an increased response on the 6-foot Lateral Resistivity Log. The Caliper Survey indicates a smaller borehole diameter in the vicinity of the producing zone. This suggests a very competent rock from which water is being produced.

The next four producing zones, 2, 3, 4 and 5, all follow the same pattern as producing zone 1. The Flowmeter, Neutron Porosity, 16-inch Normal Resistivity and 6-foot Lateral Resistivity Logs all show deflections to the right. The 64-inch Normal Resistivity and Caliper Logs show a deflection to the left, and the Differential Temperature Log is deflected back and forth.

The sixth zone is actually a cavity. Instead of the usual Caliper Log shift to the left, there is a marked deflection to the right, clearly indicating the presence of a cavity. It is not unusual for a driller to drill until he encounters one of these cavities, which is usually detected by the bit falling concurrently with a loss of circulation of drilling fluid. At this point, it is assumed that the well will produce all of the water needed by a user. As seen on the Caliper Log, the driller continued approximately 10 feet below this cavity into a very hard rock. This is a good practice, because it reduces the possibility of obstructing the cavity by debris which may accumulate in the well and constrict the flow of water into the borehole. The only other log that deviates from the original pattern is the 64-inch Normal Resistivity Log, which does not provide a valid reading with such a large borehole diameter.

Figures 21 and 22 also show the depth and thicknesses of the various producing zones. Producing zone 1 occurs throughout the KPA and represents the lower beds of the Hawthorn Formation which form the top of the Floridan Aquifer System. The rock is a grayish orange to grayish brown sparry calcite. The spar is void filling and has replaced many fossils. Phosphatic material is also present. The depth to the top of producing zone 1 increases in a southerly direction. The elevation of the top of the Floridan Aquifer System in feet NGVD is shown in Figure 25. This map can be used to determine how deep to drill in order to penetrate the top of the Floridan Aquifer System. The depth is the sum of the land surface elevation at a given location and the depth below NGVD at which the top of the Floridan Aquifer System is encountered. The depth from land surface to the top of the Floridan Aquifer System corresponds with the length of casing which should be installed in a well. To better understand this relationship, a 3-dimensional graphical representation is shown in Figure 26. The study area boundary is superimposed on the surface. It is apparent that the top of the aquifer is at its highest elevations in the north and northwestern portions of the KPA. A rapid drop off in this surface occurs in the middle of Okeechobee County. This causes an increased thickness in the overlying confining beds and places the water in the aquifer under greater pressure. Many of these structural changes are also reflected in the water quality and will be discussed in a latter section.

Producing Zone 1A underlies the top of the Floridan Aquifer System and is located below the Hawthorn Formation. Zone 1A is a rarely occurring zone that is located in the Ocala Group. In general, the chalky nature of the Ocala Group causes the formation to act as a semi-permeable layer. However, in some instances the limestone becomes highly crystallized and will act as a producing zone. Zone 1A may be the contact between the Crystal River and the Williston Formations.

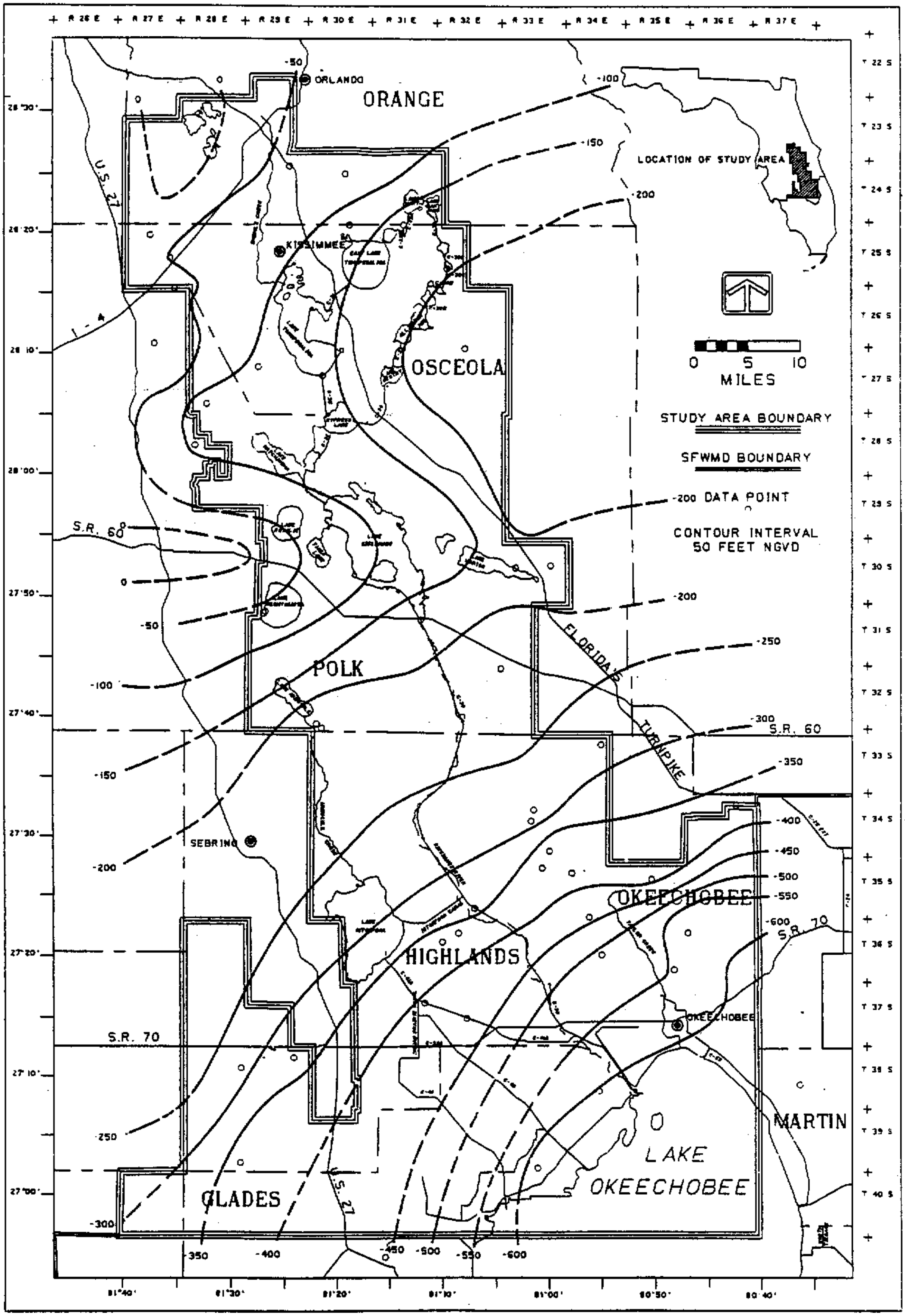


Figure 25 TOP OF THE FLORIDAN AQUIFER SYSTEM

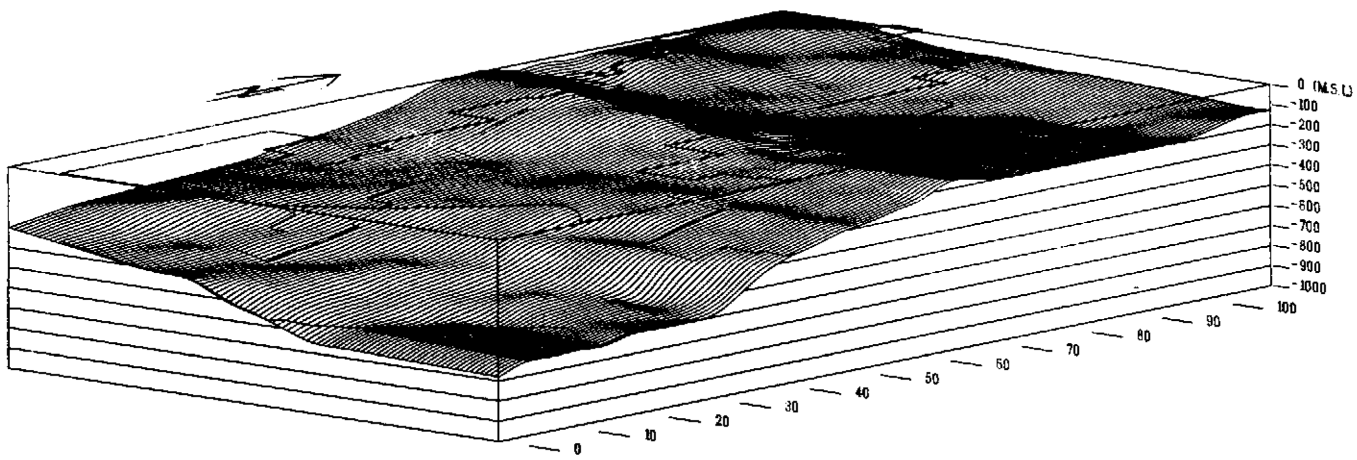


Figure 26 THREE-DIMENSIONAL REPRESENTATION OF THE SURFACE OF THE FLORIDAN AQUIFER SYSTEM

Producing Zone 2 occurs at the contact between the Ocala Group and the Avon Park Limestone. This erosional contact yields a rock matrix suitable for transmitting water. Producing zone 2 is usually a major water producer in the Floridan Aquifer System, and consequently, it is good practice to penetrate this zone before terminating a well.

The remainder of the producing zones delineated in Figures 21 and 22 are located within the Avon Park Limestone. Some are easily traceable laterally while others are not. Because of possible fracturing and preferential dissolution of the rocks over such large distances, it might be improper to assume that Producing Zones 3, 4, 5, and 6 are found within the same stratigraphic sequence in the northern portion of the planning area as in the southern portion. However, the fact that a certain number of producing zones are encountered at varying depths in a given area is important.

Cavities are prevalent in the Floridan Aquifer System and can play an important role in the productivity of a well. Of the 58 wells geophysically logged in the KPA, cavities were detected in 25. Of the 25 wells, 8 wells had cavities at or near the bottom. As a general rule, aquifer tests in wells with cavities indicate a higher transmissivity than nearby wells without cavities.

GROUNDWATER LEVELS

Introduction

The water levels measured in individual wells within the Floridan Aquifer System monitoring network in the KPA were studied by means of potentiometric surface maps. The potentiometric surface maps constructed in this study are water-level contour maps which depict the elevations in feet NGVD to which water levels will rise in tightly cased wells that penetrate the Floridan Aquifer System.

A potentiometric surface map is a representation of the hydraulic head in an aquifer at a given time; and it also provides an indication of the directions of groundwater flow within the aquifer. Semi-annual maps were used to indicate both seasonal (wet and dry season) and annual variations in water levels.

Configuration of the Potentiometric Surface of the Floridan Aquifer System

Potentiometric maps of the Floridan Aquifer System in the KPA were constructed by determining the potentiometric levels, or hydraulic head, at 206 individual wells throughout the study area according to the following relationship:

$$h = z + \psi \tag{1}$$

Where,

h = hydraulic head in feet of water

z = elevation head at point of measurement in feet NGVD

ψ = pressure head in feet of water above or below the measuring point.

The procedures used for determining the pressure head and elevation head are outlined in the methods section of this report.

The individual values of hydraulic head were determined at monitor wells in the KPA every May and September throughout the duration of this study. The

May hydraulic head values represent the "dry season" conditions and the September values represent "wet season" conditions in the Floridan Aquifer System. These data were tabulated for May and September of 1977 through 1982. Values of hydraulic head recorded prior to 1980 are tabulated in Reece and others (1984). Individual values of hydraulic head for May and September of 1980 through 1982 were plotted on maps of the study area and lines of equal head were contoured. All data on which these maps are based are presented in Appendix I.

In addition to examining areal variations in hydraulic head through the use of potentiometric surface maps, several attempts were made to determine differences in hydraulic head with differing degrees of aquifer penetration in an individual well utilizing packer tests. A packer test was performed on well OKF-42. A Tam single-set packer was used for this test. Borehole geophysical logs for the Fluid Temperature, Flowmeter, and Caliper Surveys were examined prior to the test to determine where to set the packer. The packer was set below a delineated producing zone and then inflated. The top of the well casing was used as the datum level. A head measurement was then taken in the drill stem, which represented the hydraulic head value for the aquifer system below the bottom of the packer. A head measurement was also taken in the annular space between the well casing and the drill stem which represented the hydraulic head of the aquifer system above the packer.

The packer test performed at well OKF-42 in the southern portion of the study area showed that the hydraulic head in the well from the top of producing zone number 3 to the bottom of the well (Figure 22) measured 7.12 feet above the top of the well casing. The hydraulic head in the annular space, representing the aquifer material above producing zone number 3, measured approximately 0.25 feet above the top of the casing. This result was verified when the packer was re-set in the middle of producing zone number 1, and the hydraulic head in the drill stem again reached 7.12 feet above the top of the casing, while the head in the annular space (representing the contribution the aquifer material between the bottom of the casing and the middle of producing zone 1) measured 0.28 feet above the top of the casing.

This 6.84 foot difference in hydraulic head in well OKF-42 implies that the bottom 470 feet of the well, including producing zones 3, 4, and 5, contributes much of the total head of the well. The test results indicate that producing zone 1 had a head value of approximately 0.25 to 0.28 feet above the top of the casing. The individual heads of the other producing zones could not be determined, since the packer was not set below each of these zones and no straddle type packer was available. The higher head value (7.12 feet above the top of the casing) obtained from the top of producing zone 3 to the bottom of the well indicates that different head values of the Floridan Aquifer System may be encountered at different depths or in different producing zones. These producing zones may be hydraulically isolated to some degree by the intervening lower permeability beds. The degree of isolation may vary from zone to zone or from well to well.

Areal variations in hydraulic head in the Floridan Aquifer System throughout the KPA can be examined through the use of potentiometric surface maps. The potentiometric surface in May of 1980, shown on Figure 27, exhibits a high of 100 feet above NGVD in western Orange County and northwestern Polk County. The potentiometric surface slopes to the east, decreasing to about 50 feet above NGVD in central Orange County, which indicates an average hydraulic gradient of about 2.8 feet/mile. The potentiometric surface slopes more gently to the southeast, decreasing to 50 feet above NGVD in north-central Highlands County, which represents a hydraulic gradient of about 1.0

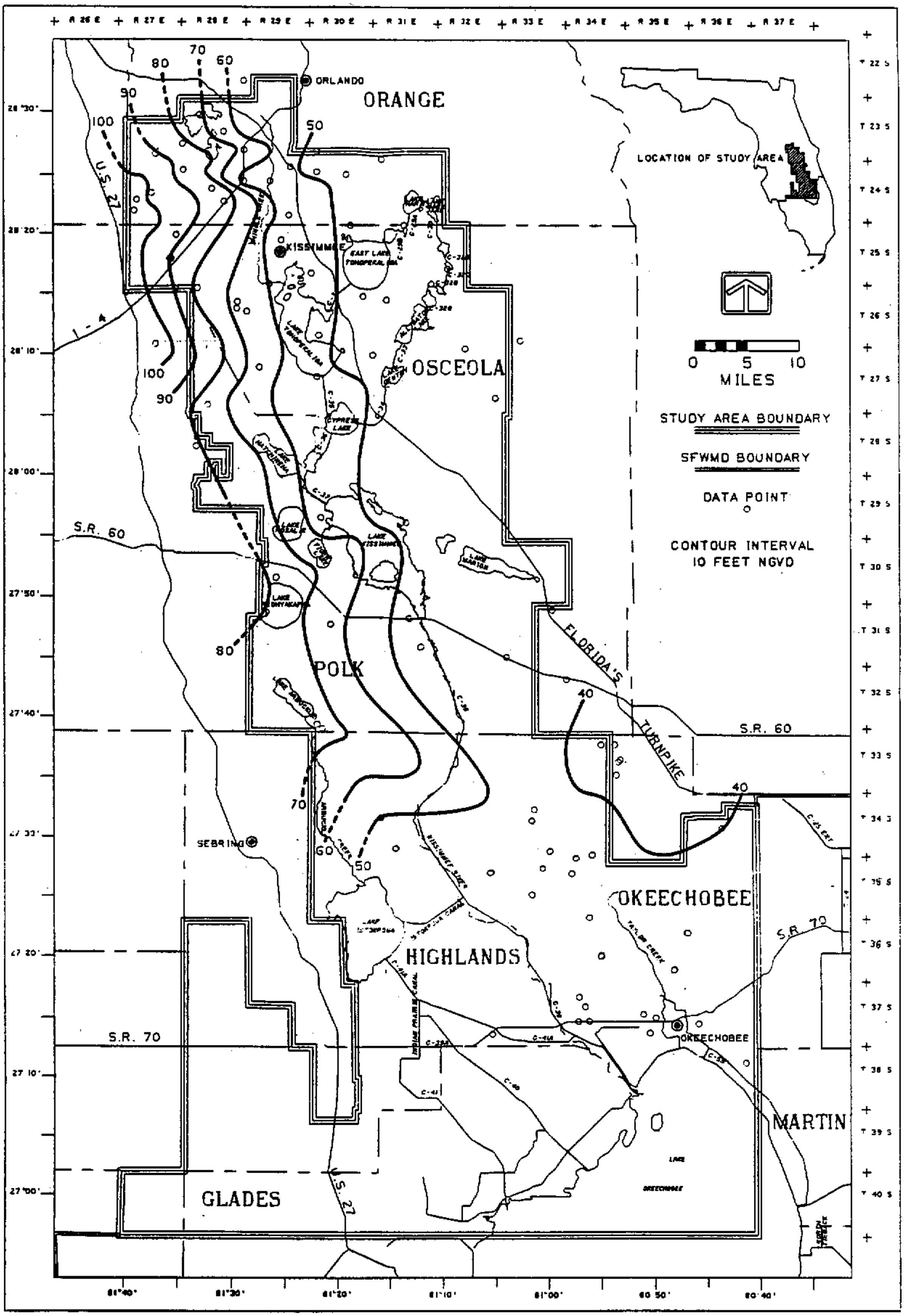


Figure 27 POTENTIOMETRIC SURFACE OF THE FLORIDAN AQUIFER SYSTEM, MAY 1980

feet/mile. A low of about 40 feet above NGVD occurs in northeastern Okeechobee County.

Examination of the September 1980 potentiometric surface map (Figure 28) reveals a very similar configuration to the May 1980 potentiometric surface map (Figure 27). The general shape of the potentiometric contours and the hydraulic head gradients have not changed to a great extent; however, the potentiometric contours have shifted slightly to the east in the southern portion of the planning area. The head values are higher in September 1980 than in May 1980 for most of the wells in Okeechobee County (Appendix I).

In May and September of 1981, a more complete representation of the potentiometric surface in the study area was achieved due to the addition of wells to the monitoring network in Highlands and Glades Counties, and the use of data from the USGS monitor well network (X-wells in Appendix I) along the western portion of the study area. The May 1981 potentiometric surface map (Figure 29) exhibits a high of 120 feet above NGVD in western Polk County outside the boundary of the planning area. With the additional data now available to the west of the KPA boundary, a lobate shape of the potentiometric surface which trends along the Lake Wales Ridge region of the study area is observed. The direction of groundwater flow in the Floridan Aquifer System from the high of 120 feet above NGVD is to the east across Osceola and Orange Counties, and to the southeast across Polk, Highlands, and Okeechobee Counties along the eastern side of the Lake Wales Ridge. Groundwater flows in a southwesterly direction outside the KPA boundary through Hardee and DeSoto Counties on the western side of the Lake Wales Ridge. The potentiometric contour lines have shifted to the west from September 1980 to May 1981. Examination of the data in Appendix I reveals that the hydraulic head values recorded in May 1981 were the lowest values recorded for a period of record between May 1978 to September 1982. May 1981

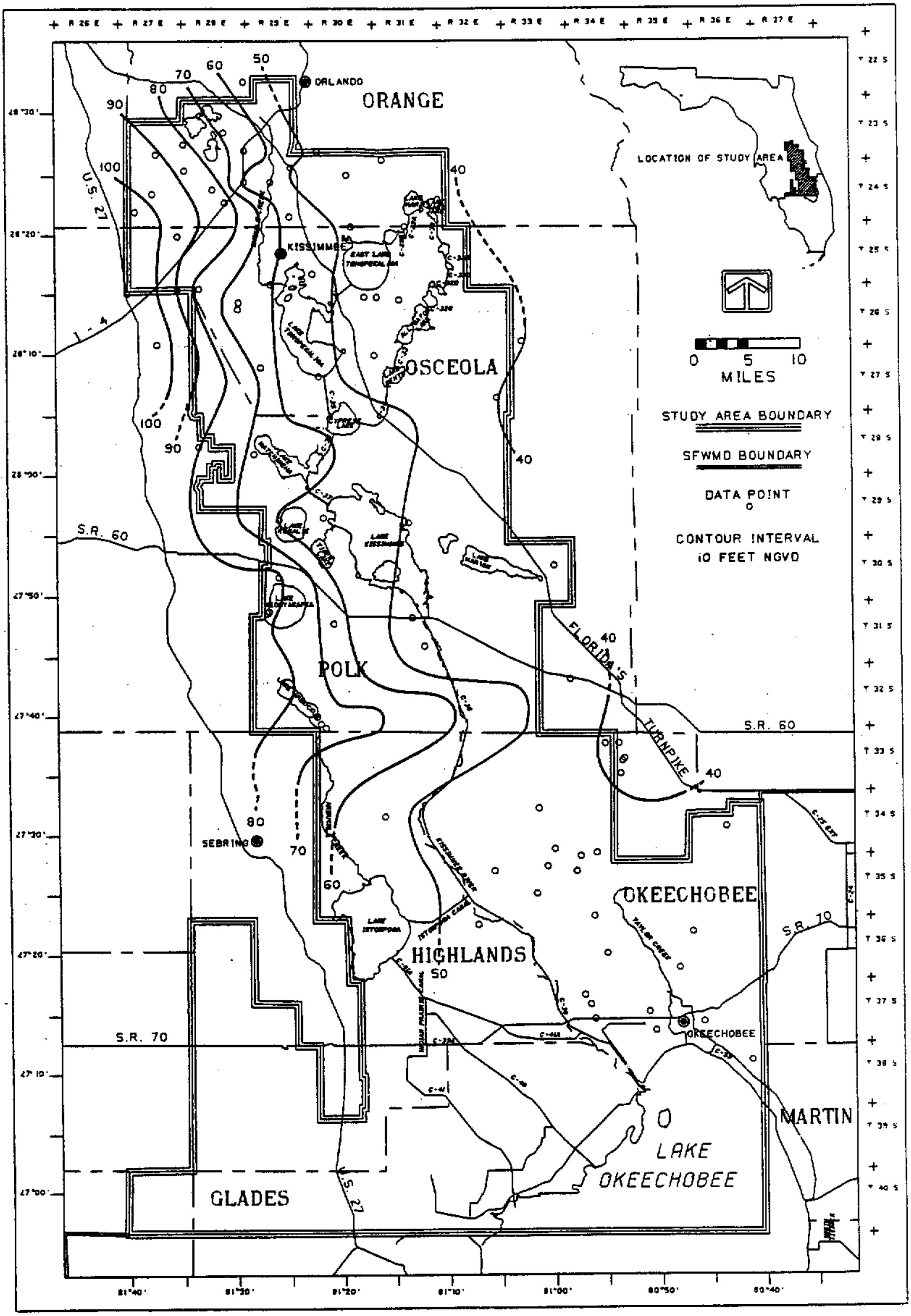


Figure 28 POTENTIOMETRIC SURFACE OF THE FLORIDAN AQUIFER SYSTEM, SEPTEMBER 1980

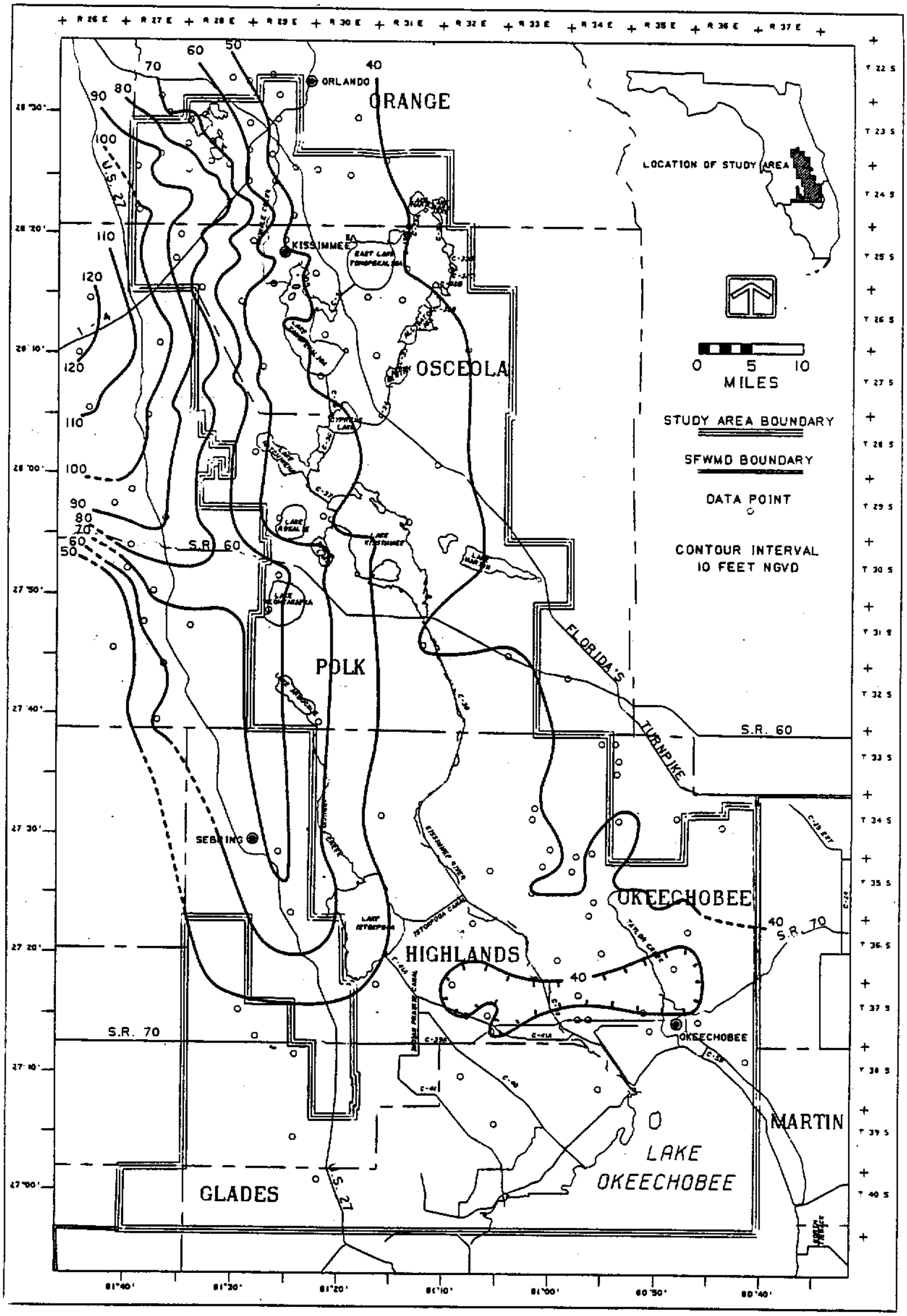


Figure 29 POTENTIOMETRIC SURFACE OF THE FLORIDAN AQUIFER SYSTEM, MAY 1981

hydraulic heads were as much as 10 feet lower than May 1980 hydraulic heads, but were generally 3 to 5 feet below the May 1980 water levels. The May 1981 hydraulic heads were as much as 13 feet but generally 3 to 5 feet lower than September 1980 heads. The May 1981 potentiometric surface map shows a depression in Okeechobee and Highlands Counties just north of Lake Okeechobee. This depression is probably due to localized heavy pumping during the dry season.

The September 1981 potentiometric surface map (Figure 30) has a similar configuration to the May 1981 map (Figure 29). However, the lobate portion of the potentiometric surface which trends along the Lake Wales Ridge extends further to the south than it did in May of 1981. For example, the southernmost portion or "tip" of the 50 foot NGVD hydraulic head contour line for September 1981 is located about 19 miles to the south compared to the May 1981 condition. The southernmost extent of the 60, 70, 80, and 90 foot NGVD hydraulic head contour lines have increased by 4, 5, 29, and 6 miles, respectively. In addition, the September 1981 contour lines are further to the east and the west of the Lake Wales Ridge than the May 1981 contours. The greatest change in these hydraulic head contour lines in the east-west direction occurs between Lake Kissimmee and Lake Istokpoga. In general, the imaginary "ridge" which can be represented by the hydraulic head contour lines for September 1981 in the KPA appears to be longer, wider, and flatter than that of the May 1981 head configuration.

The final set of potentiometric surface contour maps included in this study represent conditions in the Floridan Aquifer System in the KPA in May and September of 1982. The May 1982 potentiometric surface map (Figure 31) exhibits a similar configuration to the September 1981 map (Figure 30). In the southern portion of the KPA, most of the contour lines parallel to the east of the Lake Wales Ridge appear to have shifted about 5 miles to the west.

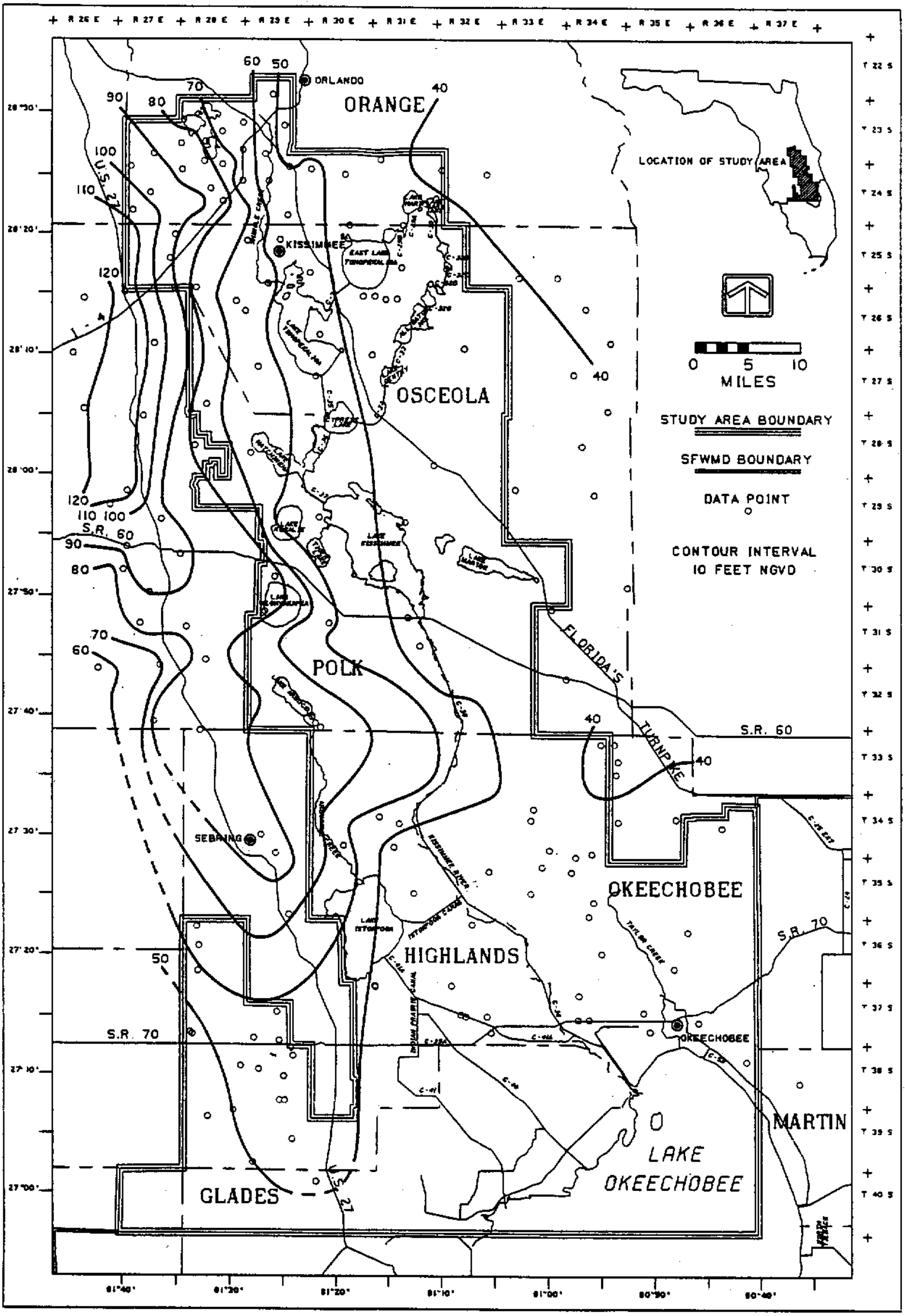


Figure 30 POTENTIOMETRIC SURFACE OF THE FLORIDAN AQUIFER SYSTEM, SEPTEMBER 1981

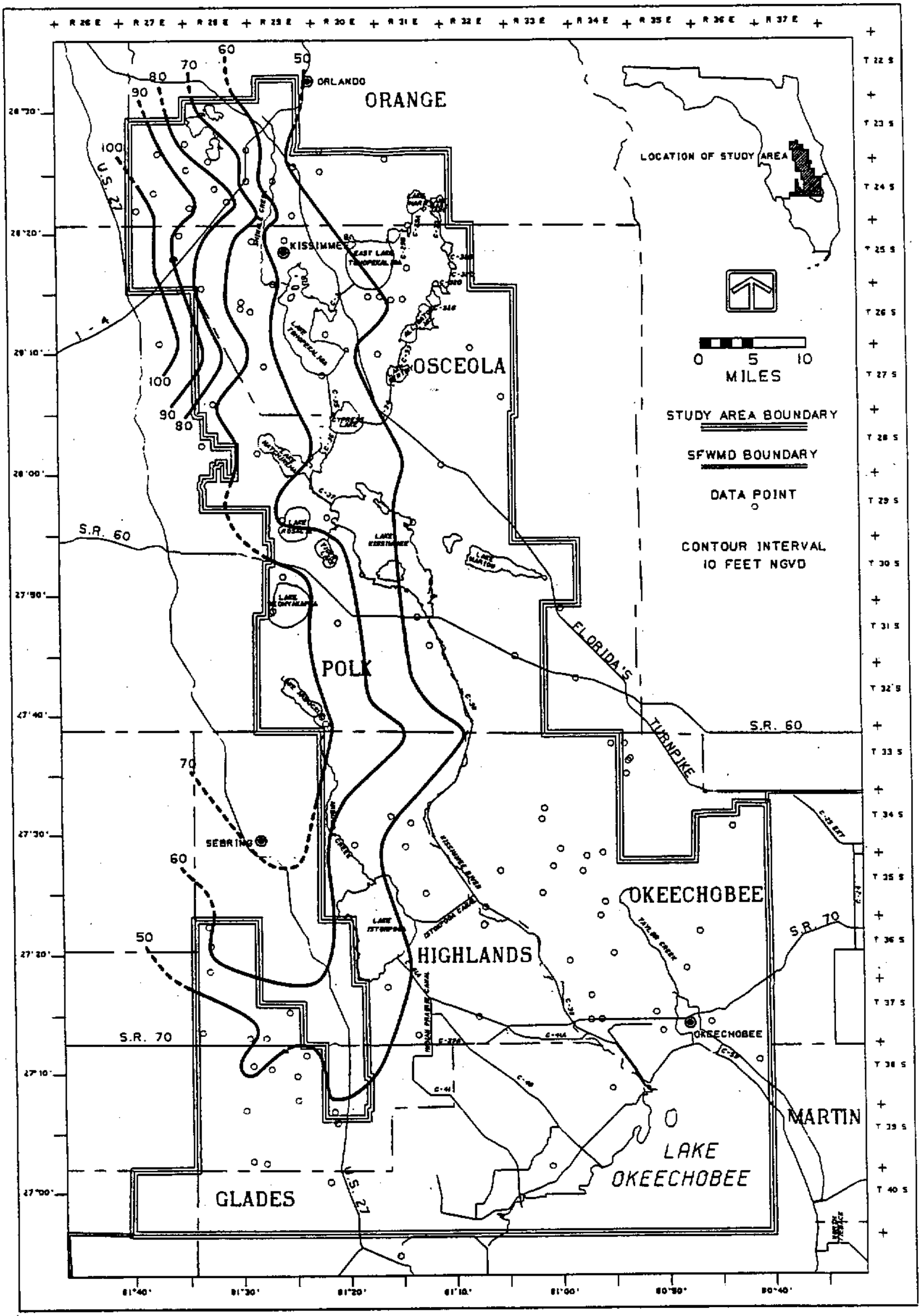


Figure 31 POTENTIOMETRIC SURFACE OF THE FLORIDAN AQUIFER SYSTEM, MAY 1982

Since the data from the "X-wells" were not available for May 1982, the potentiometric contour lines on the west side of the Lake Wales Ridge could not be extended as far as those for 1981, and changes in the configuration of the potentiometric surface could not be inferred in this area. The southernmost "tip" of the lobate configuration of the potentiometric contour lines appears to have shifted to the north between September 1981 and May 1982. The configuration of the potentiometric surface of the Floridan Aquifer System in September 1982 (Figure 32) was very similar to that of September 1981 (Figure 30).

Figure 33 is a three dimensional representation of the potentiometric surface of the Floridan Aquifer System in May 1981. The highest hydraulic heads are in the northwestern portion of the study area, reaching a maximum of greater than 120 feet above NGVD. The potentiometric surface high in western Polk County, which trends along the Lake Wales Ridge, is evident. The depression north of lake Okeechobee and the extreme eastern boundary of the KPA have hydraulic heads less than 40 feet above NGVD. In the remainder of the KPA the potentiometric surface is located between 50 and 40 feet above NGVD.

Water Level Fluctuations

Short Term Water Level Fluctuations

The locations of data collection sites for well hydrographs and rainfall records are shown on Figure 34. Examples of short term fluctuations in the potentiometric surface of the Floridan Aquifer System can be seen in Figures 35 and 36, which are annual hydrographs for wells ORF-18 and OSF-22 for the water year October 1980 to September 1981. At the base of each well hydrograph, the daily rainfall for the same period of record at the nearest rain gauge station is shown. The water level in well ORF-18 fluctuates nearly five feet throughout the year, with a high of approximately 89 feet above NGVD

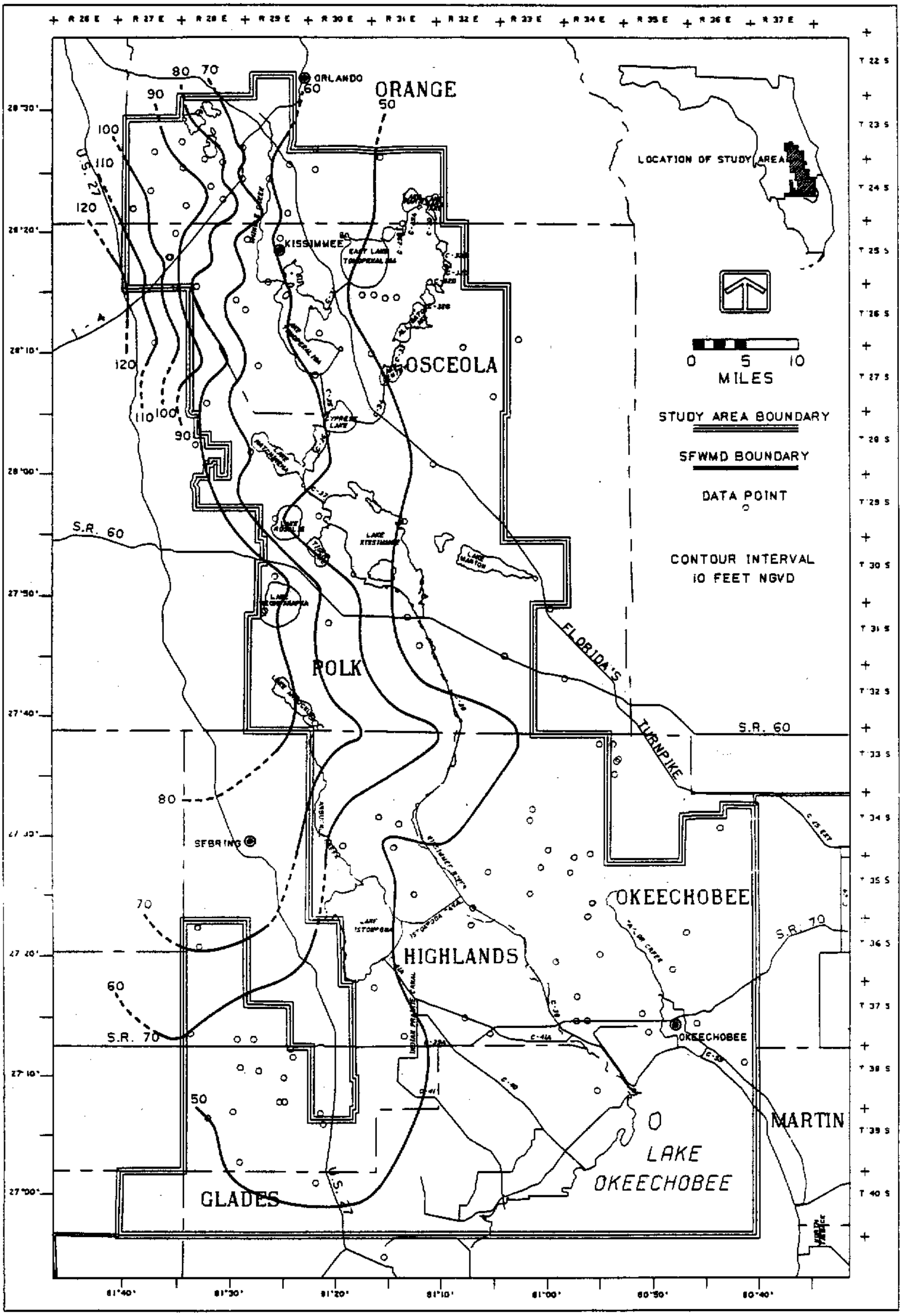


Figure 32 POTENTIOMETRIC SURFACE OF THE FLORIDAN AQUIFER SYSTEM, SEPTEMBER 1982

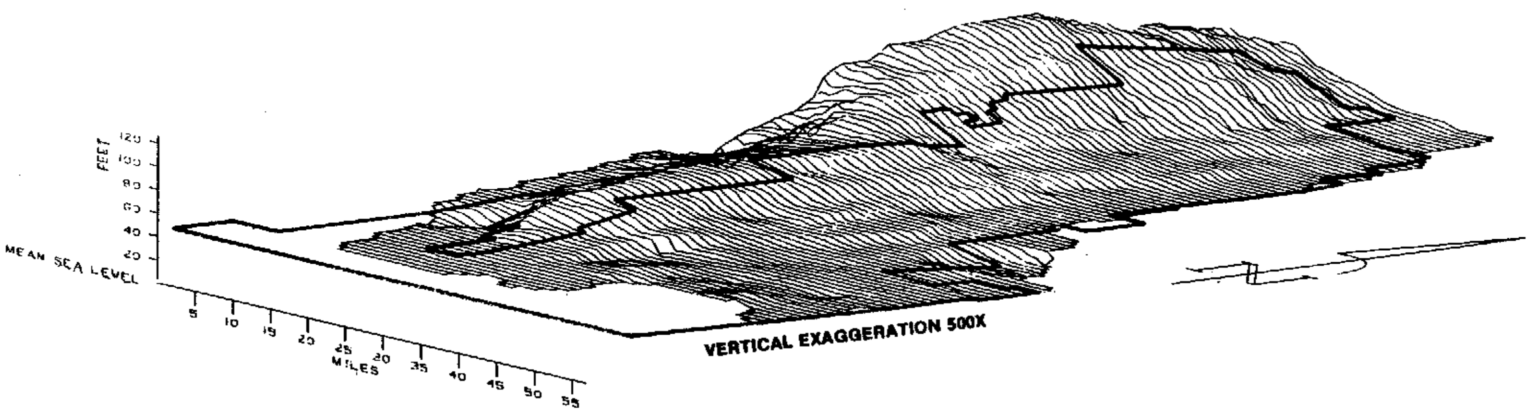


Figure 33 THREE-DIMENSIONAL REPRESENTATION OF THE POTENTIOMETRIC SURFACE OF THE FLORIDAN AQUIFER SYSTEM, MAY 1981

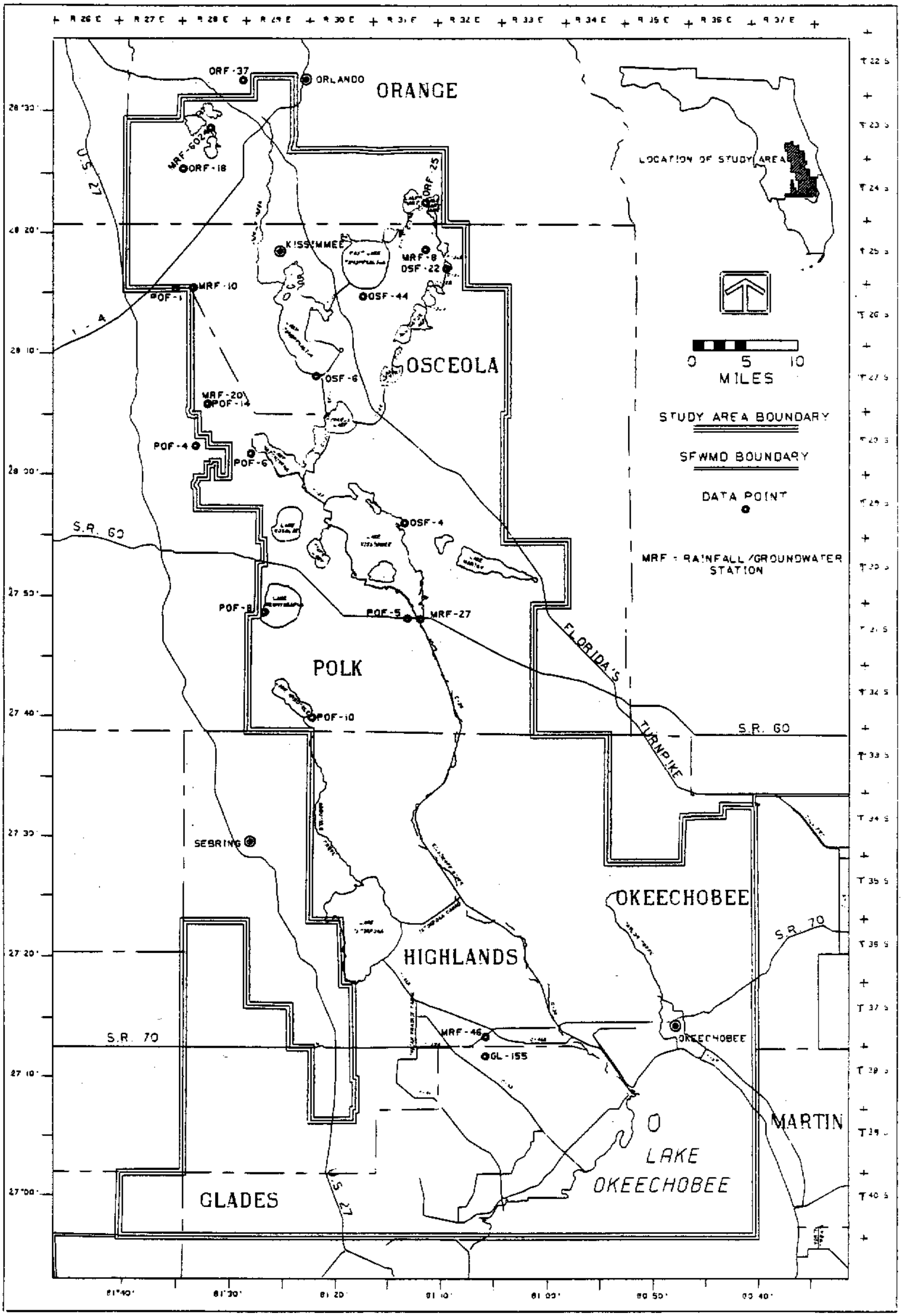
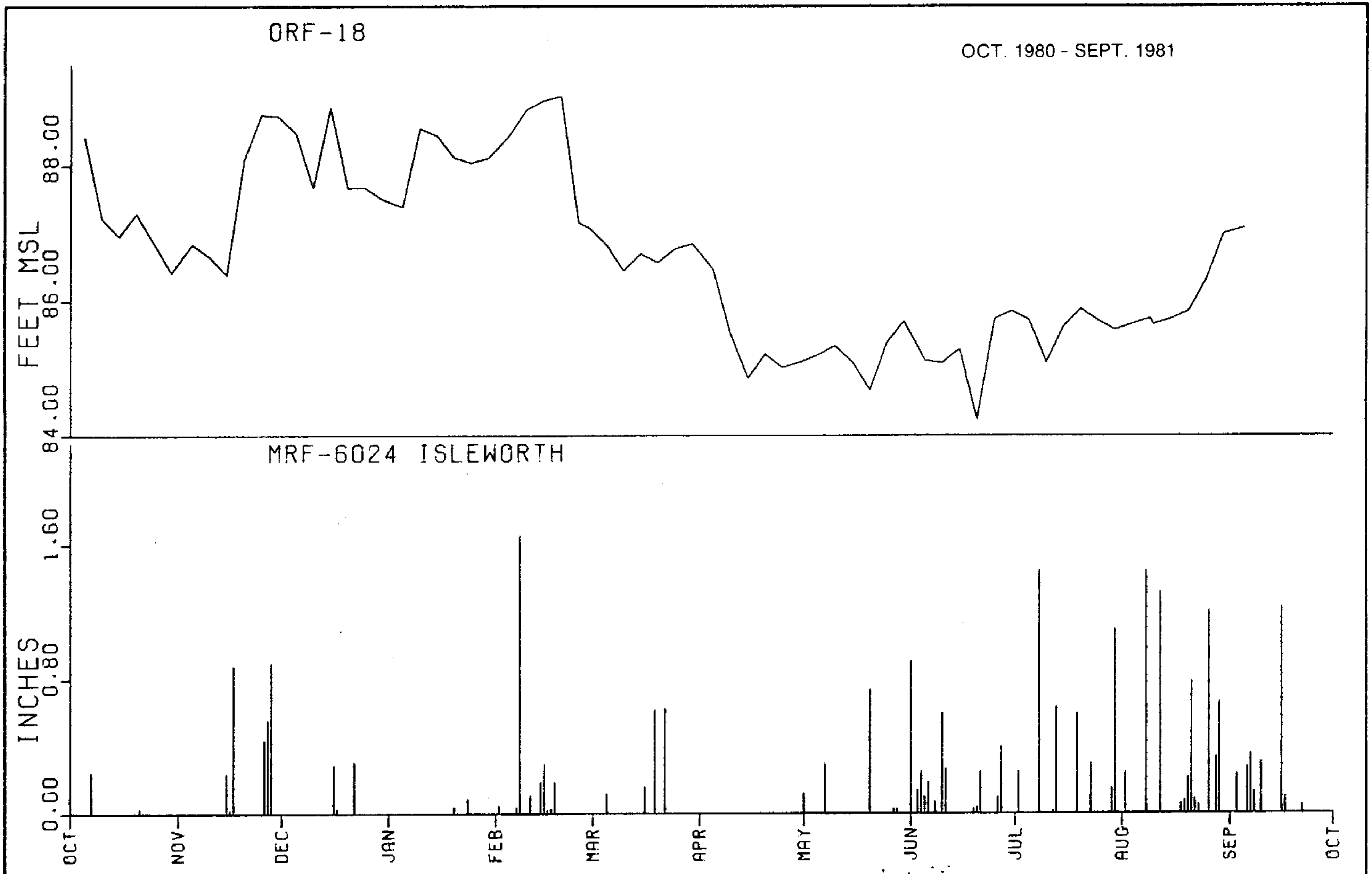


Figure 34 DATA COLLECTION SITES FOR WELL HYDROGRAPHS AND RAINFALL RECORDS



gure 35 HYDROGRAPH OF WELL ORF-18, FLORIDAN AQUIFER SYSTEM AND

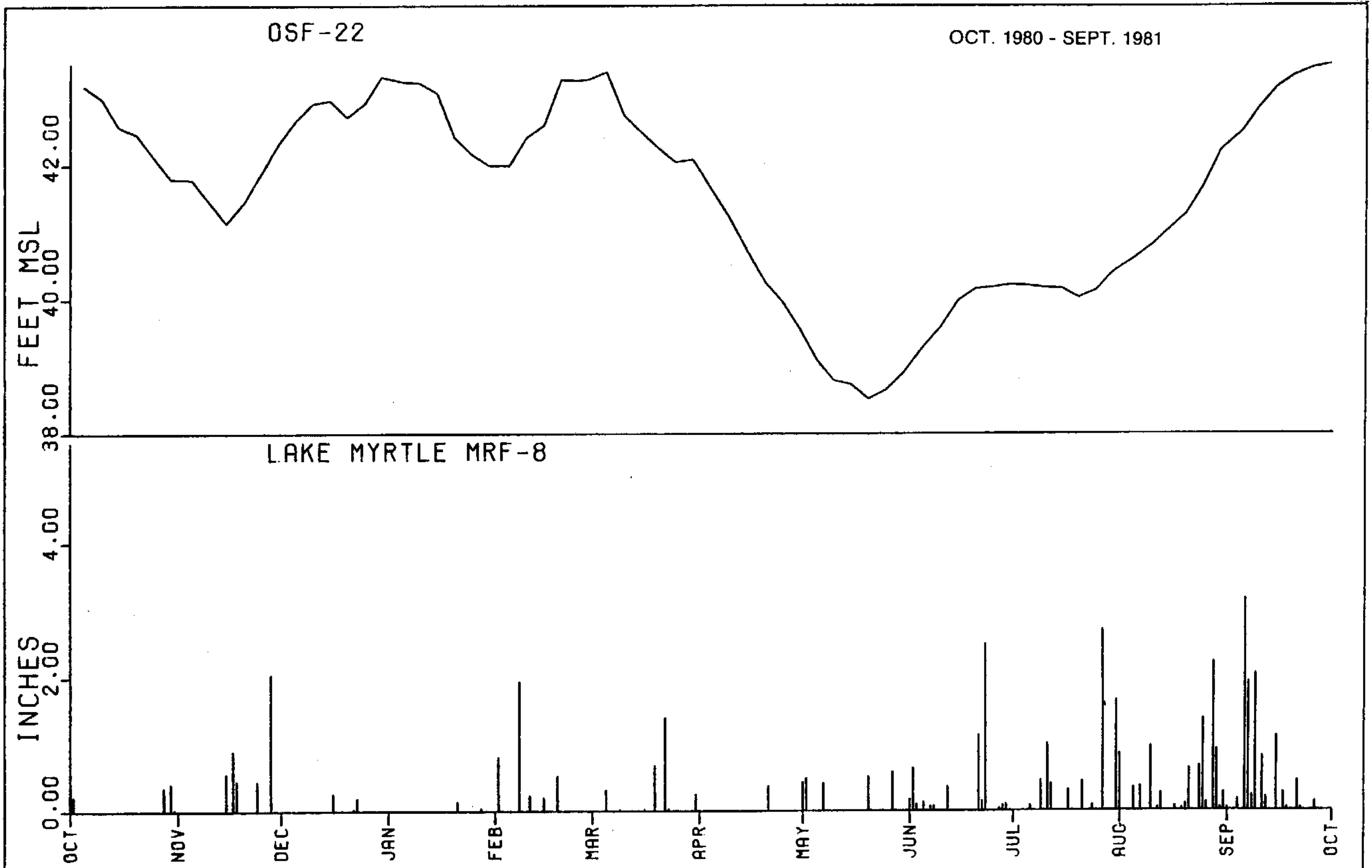


Figure 36 HYDROGRAPH OF WELL OSF-22, FLORIDAN AQUIFER SYSTEM, AND DAILY RAINFALL AT STATION MRF-8, OSCEOLA COUNTY

in mid-February 1981, and a low of approximately 84.25 feet occurring in mid-June 1981.

The response of the water level in well ORF-18 (Figure 35) to rainfall events is apparent. The water level was dropping in October and November of 1980 which corresponded with a lack of precipitation at the rain gauge station. In late November, several storm events were recorded and a rapid increase in the water level was observed. The water level then begins to drop through early December. Isolated peaks in the well hydrograh in mid-December and early January 1981, with no apparent corresponding rainfall events, may be due to localized thunderstorms in the vicinity of the well which were not recorded at rain gauge station MRF-6024. The rain gauge station used for comparison here is nearly 6 miles from well ORF-18. An increase in the water level in February seems to correspond with a large storm event recorded at the rain gauge station. Water levels decreased over the next several months, corresponding with an extremely severe dry season. The lowest water levels were recorded in May and June. Water levels began to rise in July 1981 through September, apparently in response to numerous storm events recorded at MRF-6024.

The annual hydrograph for well OSF-22 (Figure 36) shows a general correlation between rainfall events recorded at station MRF-8, approximately 4 miles from the well, and water levels in the well. A variation of about 5 feet was observed for water year 1981, with a minimum water level of 38.5 feet above NGVD recorded in late May 1981, and a maximum of 42.5 feet above NGVD recorded in late September 1981. Water levels were lowest in May 1981, reflecting the District-wide drought conditions. Several peaks of relatively higher water levels occurred from mid-December 1980, through mid-January 1981. However, no major rainfall events were recorded at station MRF-8 during that time period. This may be due to localized thunderstorm activity which was not recorded at the rain gauge as previously mentioned.

Water levels in the Floridan Aquifer System fluctuate between the "dry season" values in May and the "wet season" values in September. In general, the water levels measured at individual wells throughout the study area are higher in September than in May of each year. For example, the magnitude of seasonal water level fluctuations at an individual well in the monitoring network was determined for the calendar years 1980, 1981, and 1982, by subtracting the May hydraulic head value from the September value and taking the absolute value of that number. In the vast majority of cases, the September head value was greater than the May value. The average magnitudes of water level fluctuations throughout the study area were then computed. The average fluctuation in water levels in the KPA between May and September of 1980 was 1.14 feet. The average water level fluctuations for the same time periods in 1981 and 1982 were 4.97 feet and 3.15 feet, respectively. The relatively high average water level fluctuation of 4.97 feet between May and September 1981 is probably due to the record low hydraulic heads recorded throughout the planning area in May 1981.

An example of annual fluctuations of the potentiometric surface in the KPA is illustrated in Figure 37, which depicts the difference in hydraulic head between September 1981 and September 1982. At a given well, the hydraulic head value in September 1981 was subtracted from the value obtained in September 1982. These differences in hydraulic head were plotted for each well, and contour lines of equal head difference were drawn. A positive value on this map indicates that the hydraulic head value in September 1982 was greater than that of September 1981. In a few areas, in western Highlands County and southern Okeechobee County, contour lines were constructed with hatch marks that point inward, indicating a depression. In these cases, where the contour lines have been labelled with a value of zero, the head difference value obtained was negative, indicating higher hydraulic heads at the wells within the contour lines in September 1981 than in September 1982.

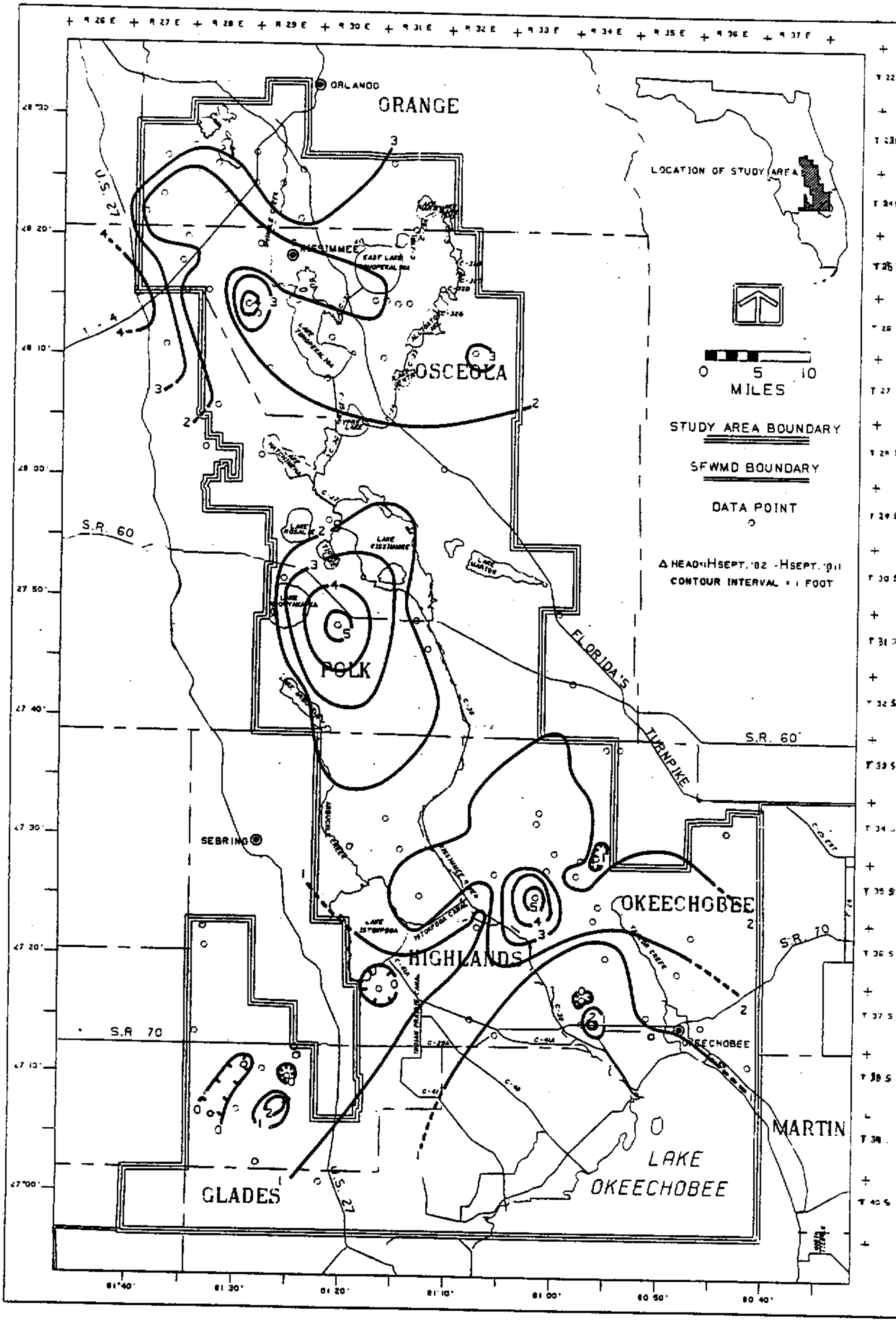


Figure 37 CHANGE IN POTENTIOMETRIC SURFACE OF THE FLORIDAN AQUIFER SYSTEM FROM SEPTEMBER 1981 TO SEPTEMBER 1982

Annual fluctuations in water levels between 2 and 4 feet in magnitude occur over a large area in western Orange and Osceola Counties and northeastern Polk County. Another area of water level fluctuations between 2 and 5 feet in magnitude can be found in central Polk County, south of Lake Kissimmee. These two areas are relatively close to the Lake Wales Ridge area of the KPA, which exhibits potentiometric surface highs. In addition, the confining beds of the Hawthorn Formation are thin along the northern portion of the Lake Wales Ridge, indicating good potential for recharge in this area. The higher water levels noted in September 1982 in these areas probably reflect the response of the Floridan Aquifer System to rainfall which occurred in the recharge area in the previous years.

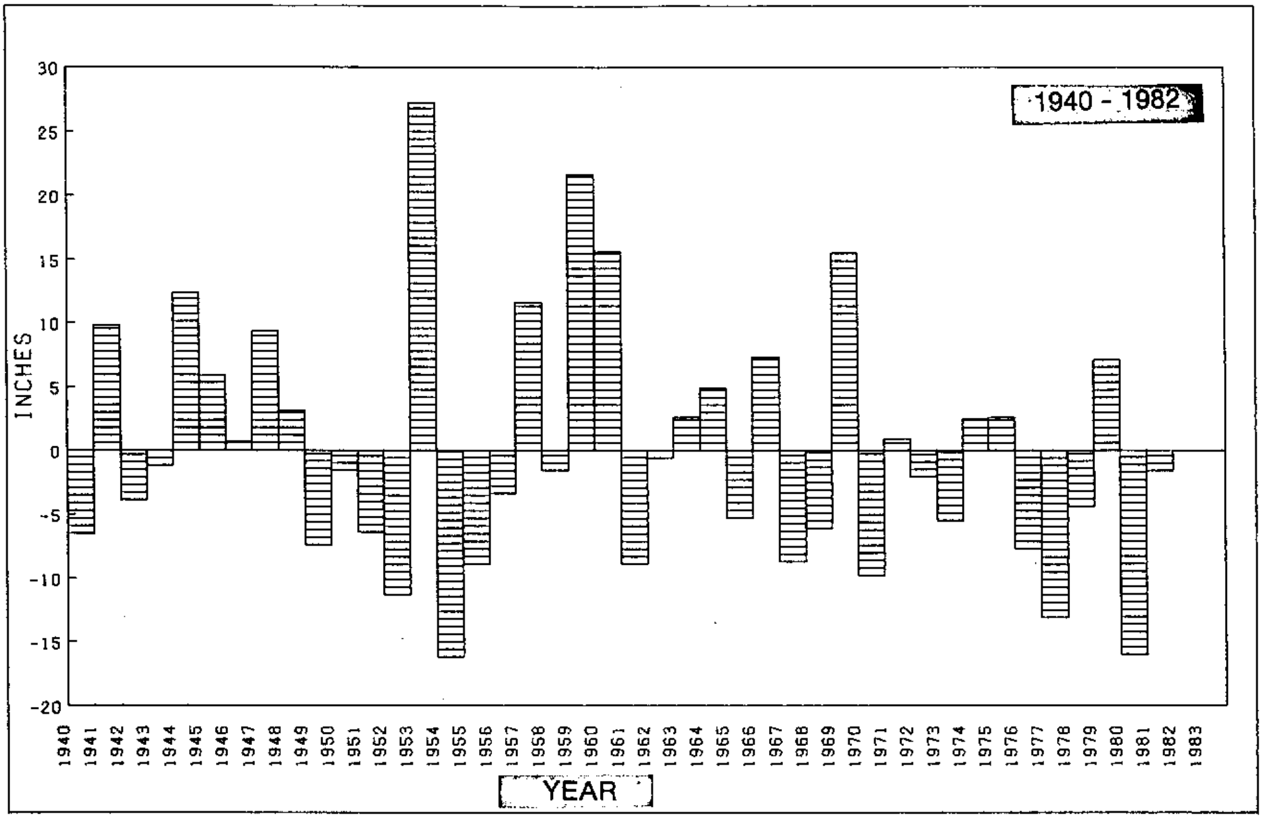
In the southern portion of the planning area, a third region of water level fluctuations is apparent. Throughout most of this area in Okeechobee County and eastern Highlands County, the magnitude of water level fluctuations varies between 1 and 3 feet. The higher hydraulic head values in September 1982 probably represents recovery in this area from heavy localized withdrawals from the Floridan Aquifer System during the "dry" year of 1981. The potentiometric surface of the aquifer system fluctuated 5.8 feet at well OKF-77 between September 1981 and September 1982, creating an apparent contoured "mound" of limited areal extent around that well.

Long Term Water Level Fluctuations

Several hydrographs of wells penetrating the Floridan Aquifer System were utilized to examine long term water level fluctuations in the KPA. These hydrographs were accompanied by local rainfall records, and in some cases, by hydrographs of wells penetrating the Surficial Aquifer System. This data was included in order to examine the relationship between rainfall, water table fluctuations, and water levels in the Floridan Aquifer System. If a hydrograph of a water table well was not available, stage data from a nearby lake was used to approximate water levels in the Surficial Aquifer System.

Nearly forty years of record is available for well ORF-37 which is located in central Orange County, just north of the study area boundary. Figure 38 shows water levels in well ORF-37 from 1943 to 1980, as well as monthly rainfall at station MRF-6024 from 1940 to 1980. The deviation from average annual rainfall at station MRF-6024 is also shown at the top of the figure. The general downward trend in water levels in the well is due to pumpage. The well is owned by Orange County, and is one of several in the area used by the Orlando Utilities Commission for public water supply for the City of Orlando. The average water level in the well has dropped approximately 15 feet throughout the period of record. Most of the higher water level peaks in the well correspond to years with greater than average rainfall at station MRF-6024, which is about 6 miles southwest of the well. Conversely, lower water levels in well ORF-37 appear to correspond with years of below average or average rainfall at the nearby rain gauge. The effects of pumpage are superimposed over the long term water level fluctuations, but rainfall does seem to influence water levels in the Floridan Aquifer System at this site. Water level data in the Surficial Aquifer System was not available in this area.

Figure 39 shows water levels in the Floridan Aquifer System at well POF-1, along with monthly rainfall and water levels in the Surficial Aquifer System at dual recorder MRF-10, located about 2 miles east of well POF-1 in northwestern Polk County. Well POF-1 is owned by the U. S. Geological Survey and is used for water level monitoring, such that effects of local pumpage are non-existent and natural fluctuations of the potentiometric surface of the Floridan Aquifer System can be observed. The maximum annual water level fluctuations in this well measured about 2 feet per year, with lower water levels generally recorded in April, May, and June, and higher water levels observed in August, September, and October of each year. The higher levels



DEVIATION FROM AVERAGE ANNUAL RAINFALL, STATION MRF-6024

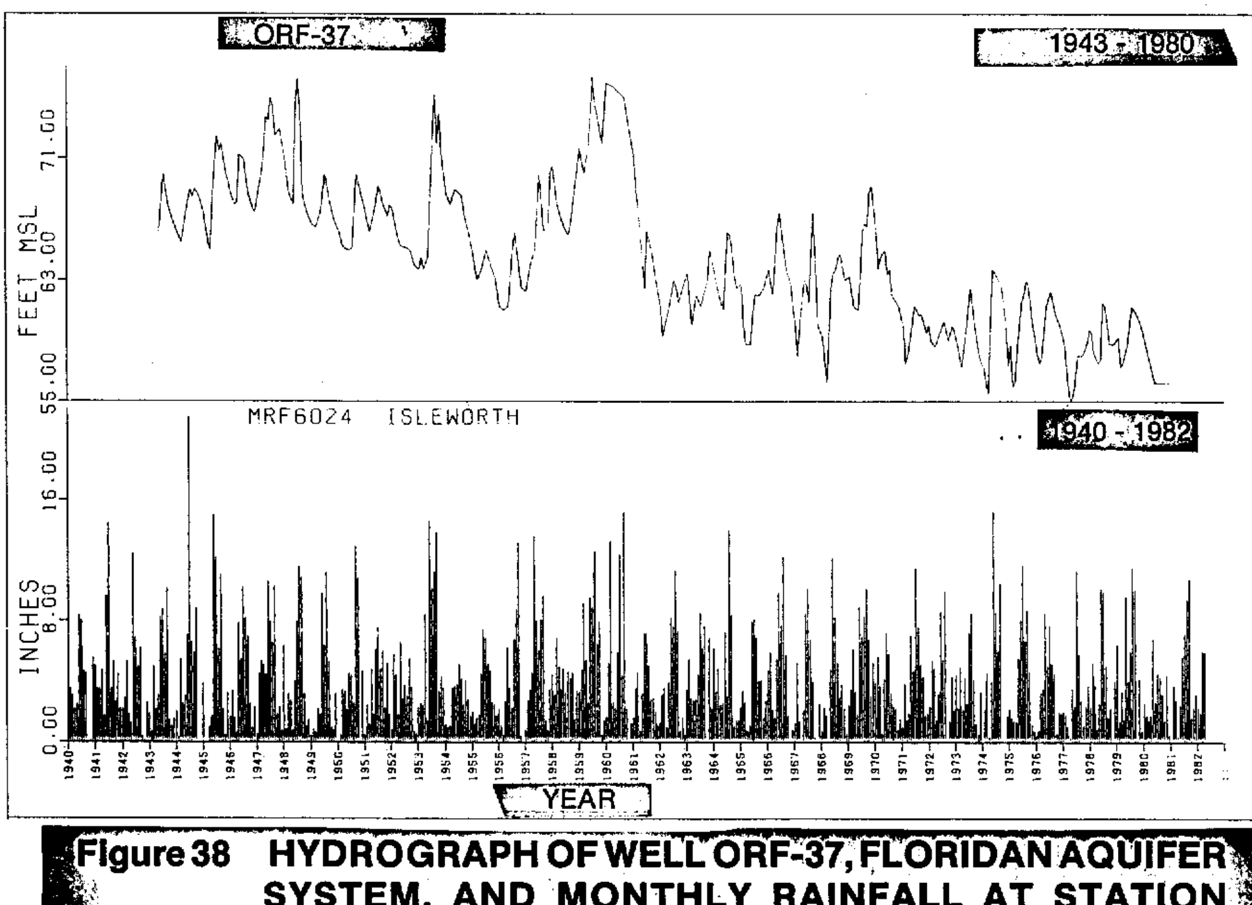
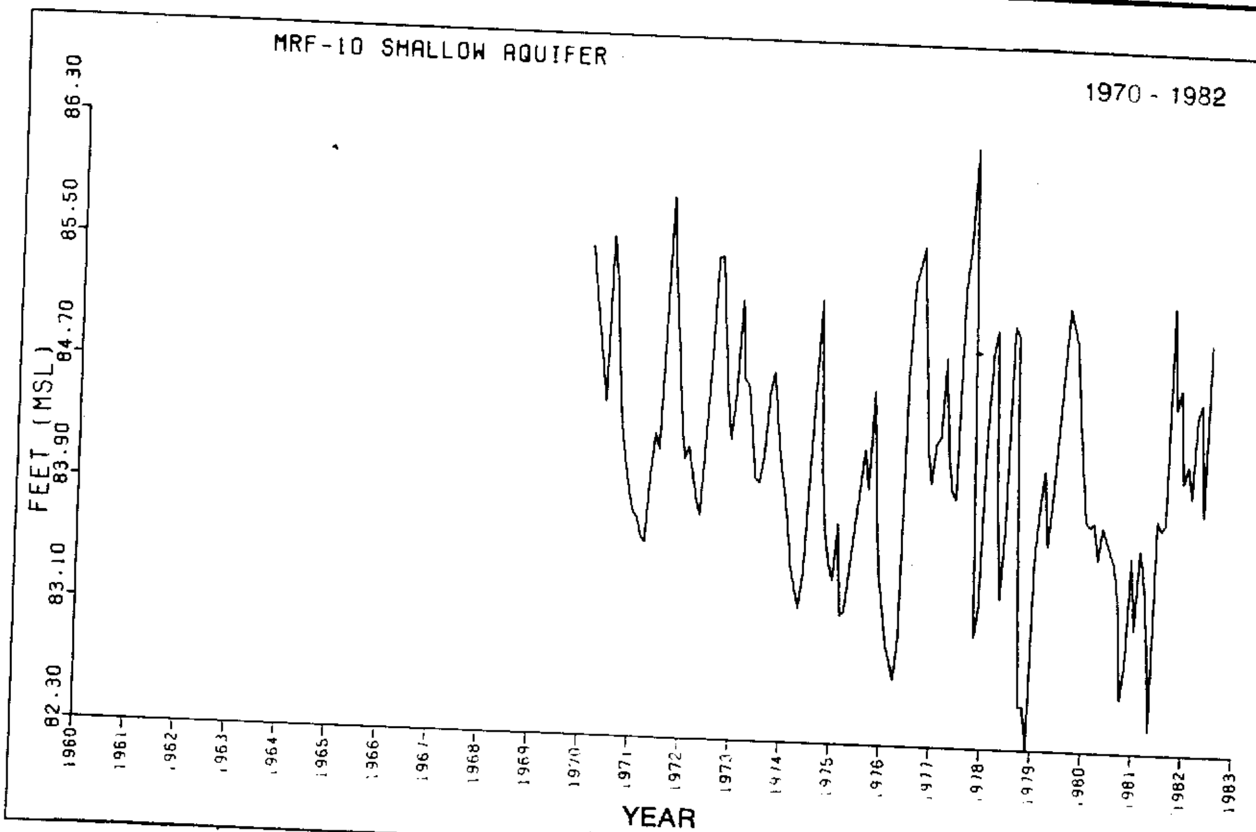


Figure 38 HYDROGRAPH OF WELL ORF-37, FLORIDAN AQUIFER SYSTEM, AND MONTHLY RAINFALL AT STATION MRF-6024, ORANGE COUNTY



MONTHLY WATER LEVELS IN SHALLOW AQUIFER SYSTEM, STATION MRF-10.

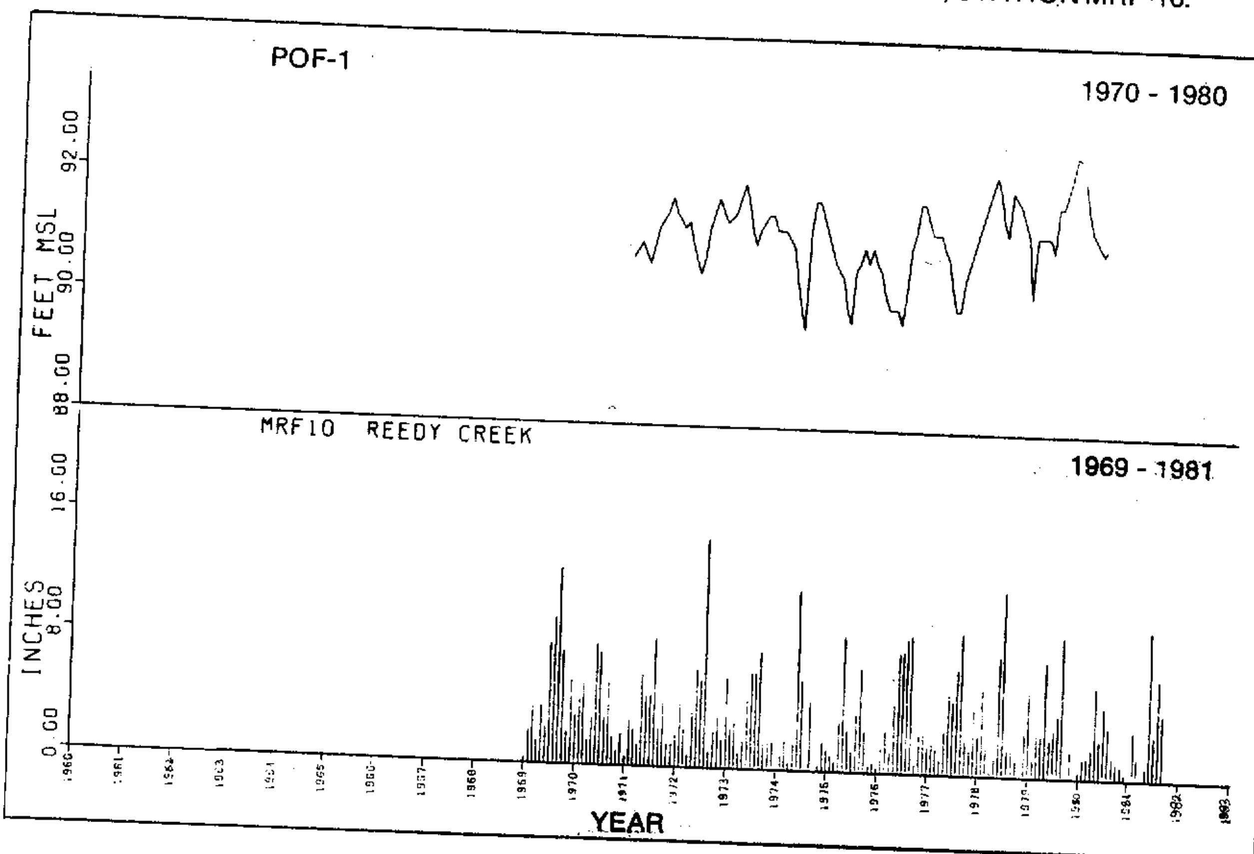
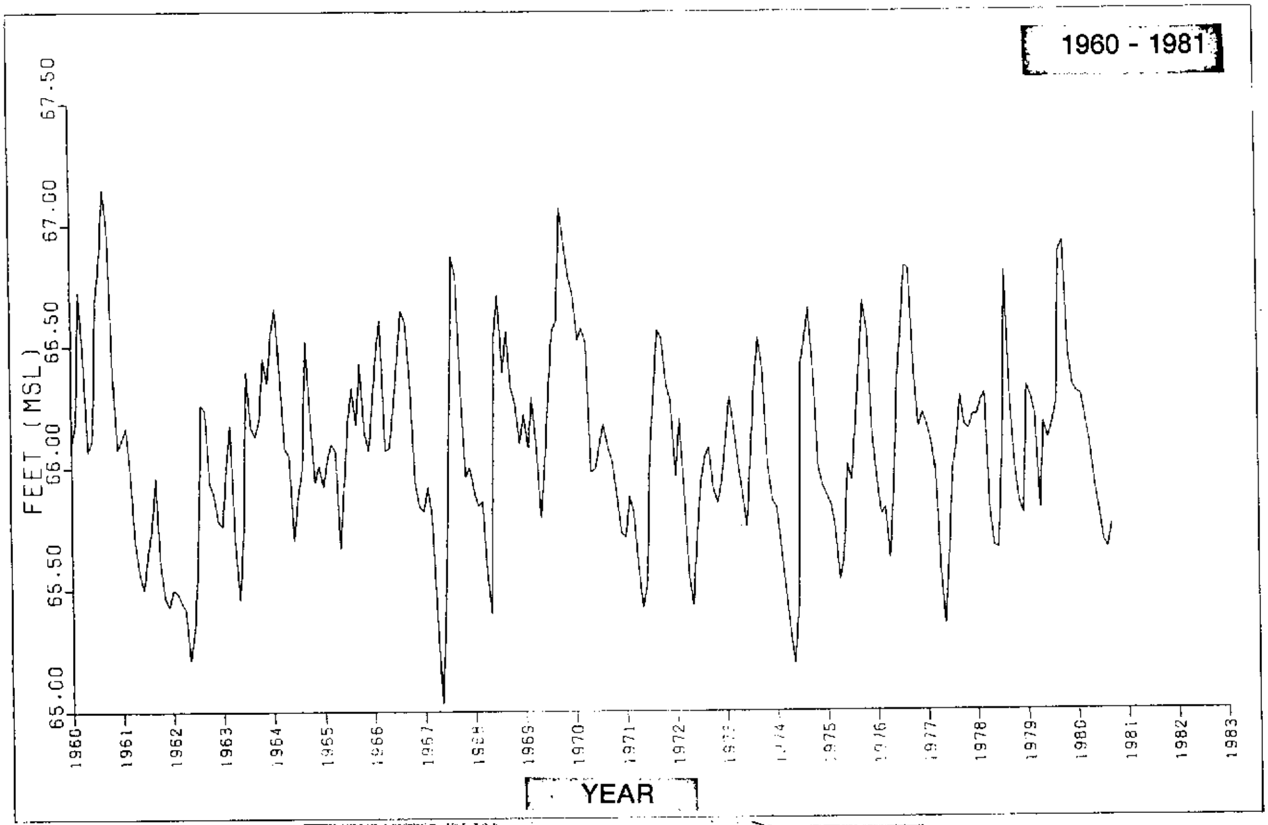


Figure 39 HYDROGRAPH OF WELL POF-1, FLORIDAN AQUIFER SYSTEM, AND MONTHLY RAINFALL STATION MRF-10, POLK COUNTY

reflect the fact that the majority of rainfall events in a given calendar year appear to occur in May through September.

Throughout the ten-year period, water levels in well POF-1 fluctuated about 3.25 feet, from a low of about 89.5 feet above NGVD in 1974, to a high of about 92.75 feet above NGVD in 1979. Water levels in the Surficial Aquifer System varied by as much as 4 feet over the same period of record. A high of about 86.3 feet above NGVD was recorded in 1977, and a low of about 82.3 feet above NGVD was recorded in 1978. The Surficial Aquifer System in this region responds more dramatically to rainfall events, and greater water level fluctuations are recorded within it than in the Floridan Aquifer System. The altitude of the water table at station MRF-10 is below that of the potentiometric surface of the Floridan Aquifer System at nearby well POF-1. This implies that in this area, the Surficial Aquifer System is not actively recharging the Floridan Aquifer System.

A hydrograph of well POF-4, accompanied by monthly rainfall at station MRF-20 and monthly stage data at Lake Marion, is shown on Figure 40. Lake Marion is located midway between well POF-4 and rain gauge station MRF-20. Maximum annual water level fluctuations in well POF-4 measured about 6 feet in magnitude. Average water levels in the well appear to have dropped from about 83 feet above NGVD in 1963 to approximately 77 feet above NGVD in 1982. This general decline in the water level is probably due to localized pumping. The yearly fluctuations in this well appear to correspond to the "wet" and "dry" season patterns evident in the long term rainfall record at station MRF-20, located about 5 miles north of well POF-4. Rainfall data is missing at this station in late 1975 and from mid-1977 to early 1978. Water levels in the Surficial Aquifer System, which have been roughly approximated by utilizing the stage hydrograph for Lake Marion, do not appear to vary by more than 2 feet in a given year.



MONTHLY STAGE DATA AT LAKE MARION

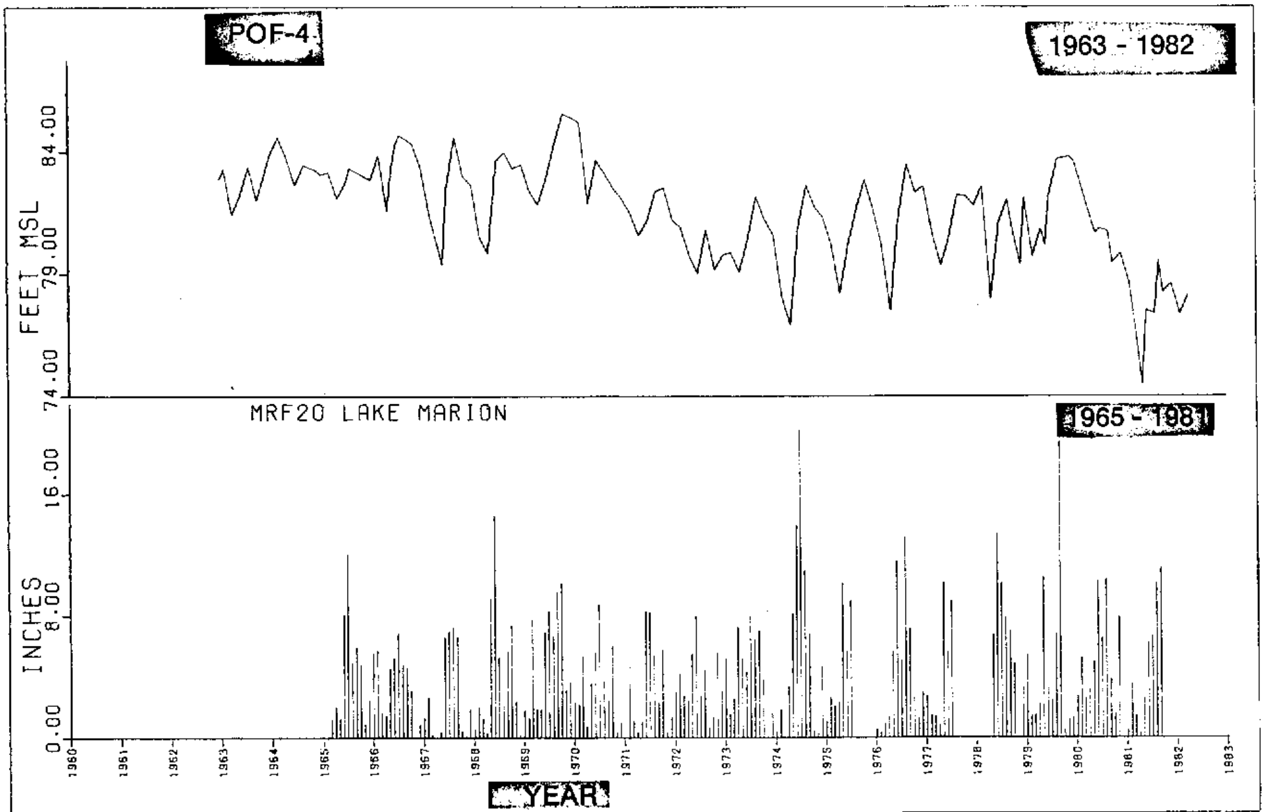
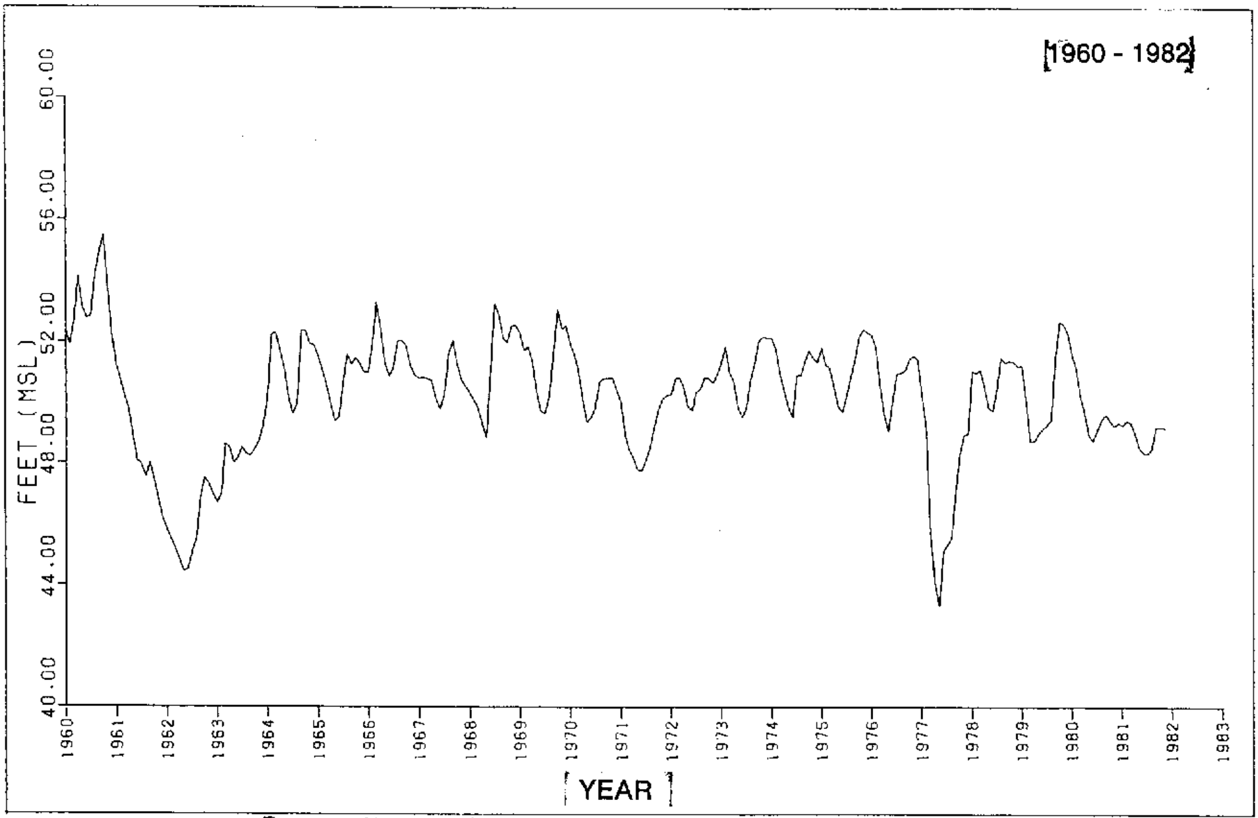


Figure 40 HYDROGRAPH OF WELL POF-4, FLORIDAN AQUIFER SYSTEM, AND MONTHLY RAINFALL AT STATION MRF-20, POLK COUNTY

There are differences in the magnitudes of water level fluctuations in a lake and those in a well penetrating the Surficial Aquifer System. A lake is a surface water body, which obtains water from rainfall, runoff, and seepage, and which loses water due to evaporation, withdrawals, and regulatory releases. The Surficial Aquifer System acts as a porous medium reservoir, and infiltration from relatively small rainfall events may increase the water level in this aquifer system by a much greater magnitude than that of the rainfall event, depending upon the porosity and permeability of the aquifer material. Other factors influencing water levels in the Surficial Aquifer System include groundwater inflow from upgradient areas and discharge due to pumping wells or seepage along the banks of surface water bodies.

Water levels in Lake Marion appear to respond more rapidly than water levels in well POF-4 to rainfall events recorded at station MRF-20. The stage altitude of Lake Marion is less than the water level altitude in well POF-4, inferring an area of little or no recharge to the Floridan Aquifer System from the Surficial Aquifer System.

A hydrograph for well POF-5, located approximately 25 miles southeast of well POF-4, along with monthly rainfall at station MRF-27 and monthly stage data at Lake Kissimmee, is shown on Figure 41. The water level in well POF-5 seems to have fluctuated slightly less than 6 feet per year, ranging from about 42 feet above NGVD to approximately 48 feet above NGVD. Unlike wells POF-4 and ORF-37, no general downward trend in the water level throughout the period of record in well POF-5 is seen. This well is not pumped extensively. The magnitude of the water level peak in 1980 through late 1981 is less than that of previous years, and is probably due to the relatively dry conditions experienced during that period. The "peaks" and "valleys" observed in the well hydrograph appear to correspond to the seasonal variations in rainfall recorded at station MRF-27, located about 1 mile east of the well. The stage



MONTHLY STAGE DATA AT LAKE KISSIMMEE

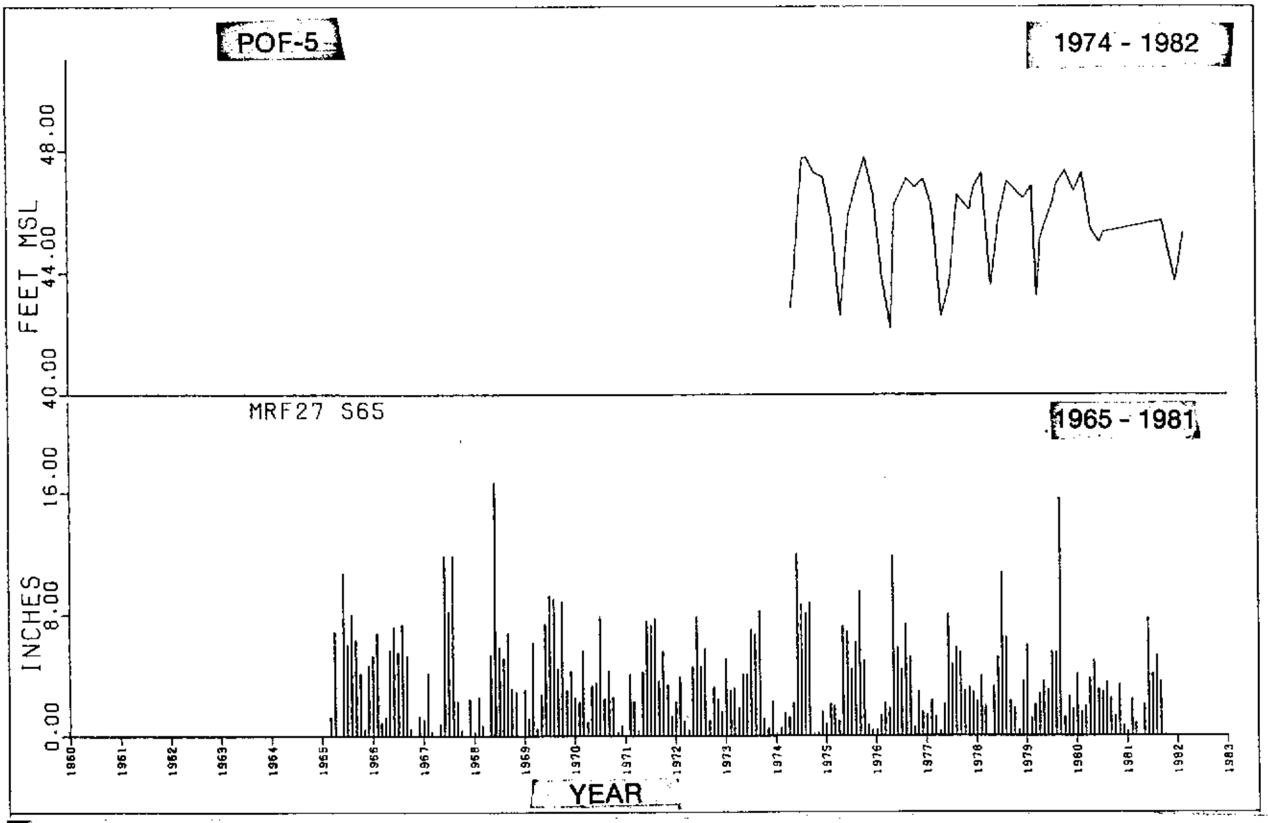
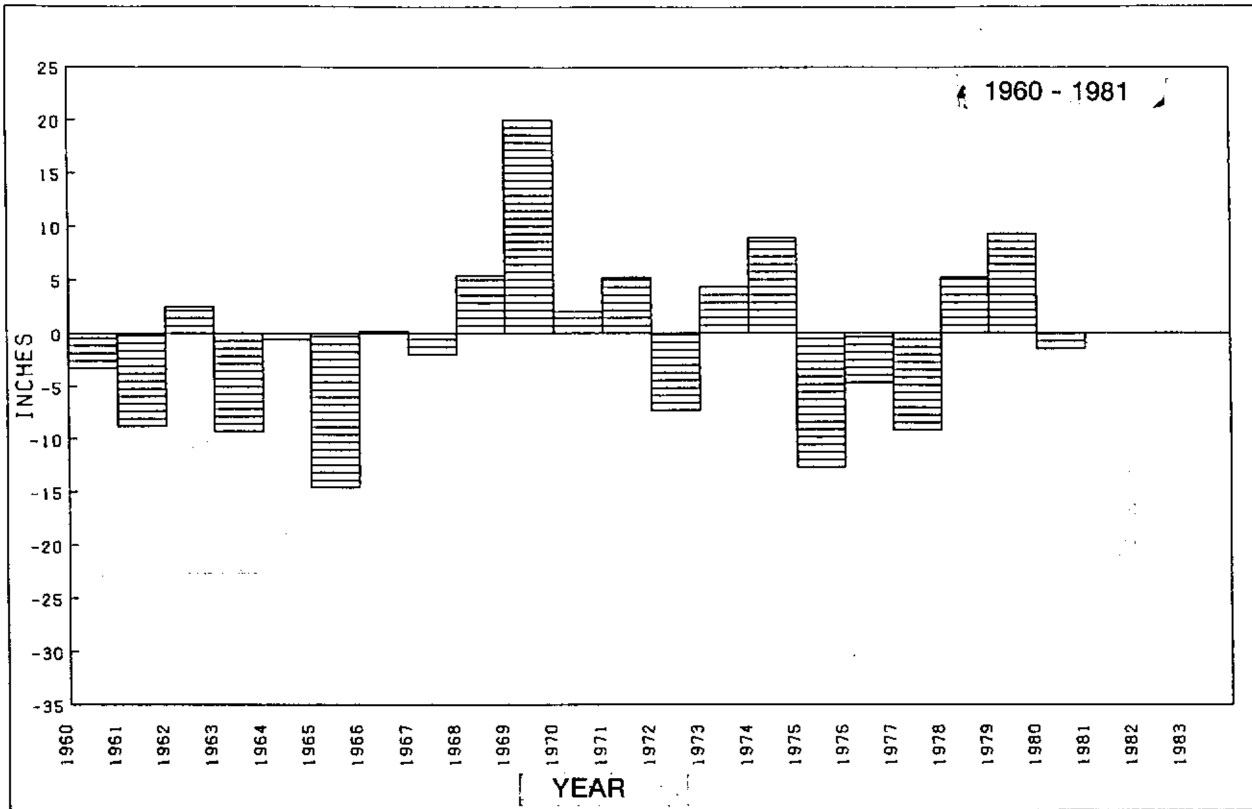


Figure 41 HYDROGRAPH OF WELL POF-5, FLORIDAN AQUIFER SYSTEM, AND MONTHLY RAINFALL AT STATION MRF-27, POLK COUNTY

of Lake Kissimmee, representing Surficial Aquifer System conditions in the vicinity of the well, fluctuated approximately 3 feet per year on the average, with a high of 55.5 feet above NGVD recorded in late 1960 and a low of 43.3 feet above NGVD recorded in 1977. In general, lake stages appear to have been higher than water levels in the Floridan Aquifer System throughout the period of record, inferring possible downward leakage of water from the Surficial Aquifer System to recharge the Floridan Aquifer System in the vicinity of this site.

The final Floridan Aquifer System well hydrograph is located in Glades County about 43 miles south of well POF-5. Well GL155 is a U. S. Geological Survey monitoring well and is not included in the KPA monitoring network. Figure 42 includes a hydrograph of well GL155, monthly rainfall at station MRF-46 (located about 2 miles north of well GL155), and a histogram depicting the deviation from average annual rainfall at station MRF-46. The magnitude of annual water level fluctuations in well GL155 does not appear to be consistent. Water levels fluctuated as little as 1.5 feet in 1980, and as much as 8.75 feet in 1976. A low of 38.15 feet above NGVD and a high of 50.00 feet above NGVD were recorded in 1976 and 1978, respectively. Water levels in well GL155 do not appear to correlate consistently with rainfall recorded at station MRF-46. For example, rainfall at station MRF-46 in 1974 appeared to be greater than the average recorded rainfall, but no corresponding "peak" appears on the well hydrograph. Conversely, rainfall in 1975 appeared to be lower than the norm at station MRF-46, and a small peak appears on the well hydrograph.

The rainfall deviation histogram may be misleading, and could result in an artificially low average value, since the average annual rainfall at each station is calculated using years with no missing data. This is due to the fact that a few days of missing data could occur in a relatively wet year,



DEVIATION FROM AVERAGE ANNUAL RAINFALL, STATION MRF-46

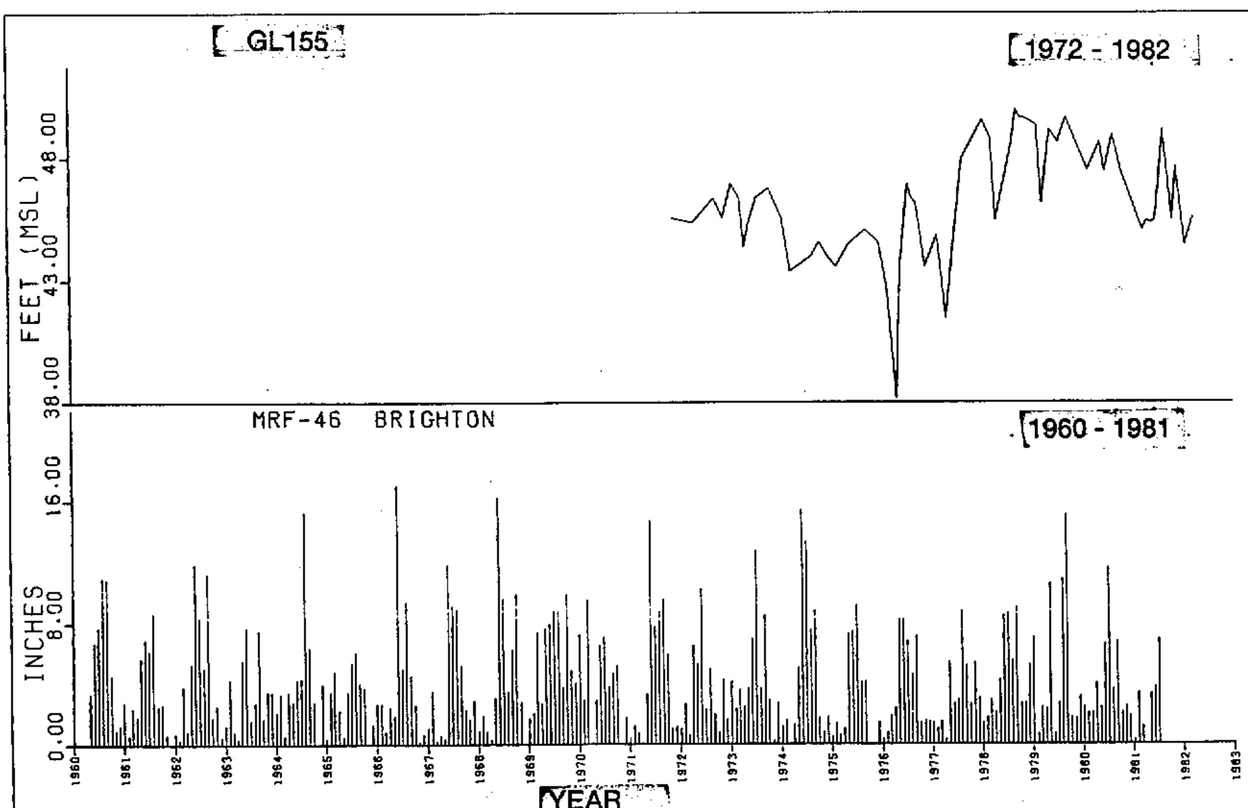


Figure 42 HYDROGRAPH OF WELL GL155, FLORIDAN AQUIFER SYSTEM, AND MONTHLY RAINFALL AT STATION MRF-46, GLADES COUNTY

but the overall rainfall value for that year would not be included when computing a long-term rainfall average.

One possible explanation for the lack of direct correlation between rainfall station MRF-46 and water levels in Floridan Aquifer System well GL155, could be that a "lag" time may exist between rainfall events and Floridan Aquifer System response in this region. This proposed "lag" time could be due to the fact that in this portion of Glades County, the potentiometric surface of the Floridan Aquifer System is above land surface, precluding any recharge from the Surficial Aquifer System. In addition, the confining beds of the Hawthorn Formation are nearly 400 feet thick in the area. Finally, the great distance of this well from the probable recharge area in northwestern Polk County may delay the response of Floridan Aquifer System wells in the southern KPA to rainfall events in the recharge area.

Long term variations in the potentiometric surface of the Floridan Aquifer System can also be observed through comparison of current potentiometric surface configurations with the estimated pre-development potentiometric surface. Johnston and others (1980) produced a map of the estimated pre-development potentiometric surface of the tertiary limestone aquifer in the southeastern United States, which is synonymous with the Floridan Aquifer System. A portion of this map is shown in Figure 43. Comparison of the potentiometric surface of the Floridan Aquifer System in September 1982 (Figure 32) with the estimated pre-development potentiometric surface indicates that, although the general configuration of both maps is similar, several shifts of the potentiometric contour lines have occurred.

The 70 and 80 foot above NGVD potentiometric contour lines within the study area appear to be in nearly the same position in September 1982 (Figure 32) as they were on the pre-development map, which represent conditions in the early 1930's (Figure 43). However, the 60 foot above NGVD contour line

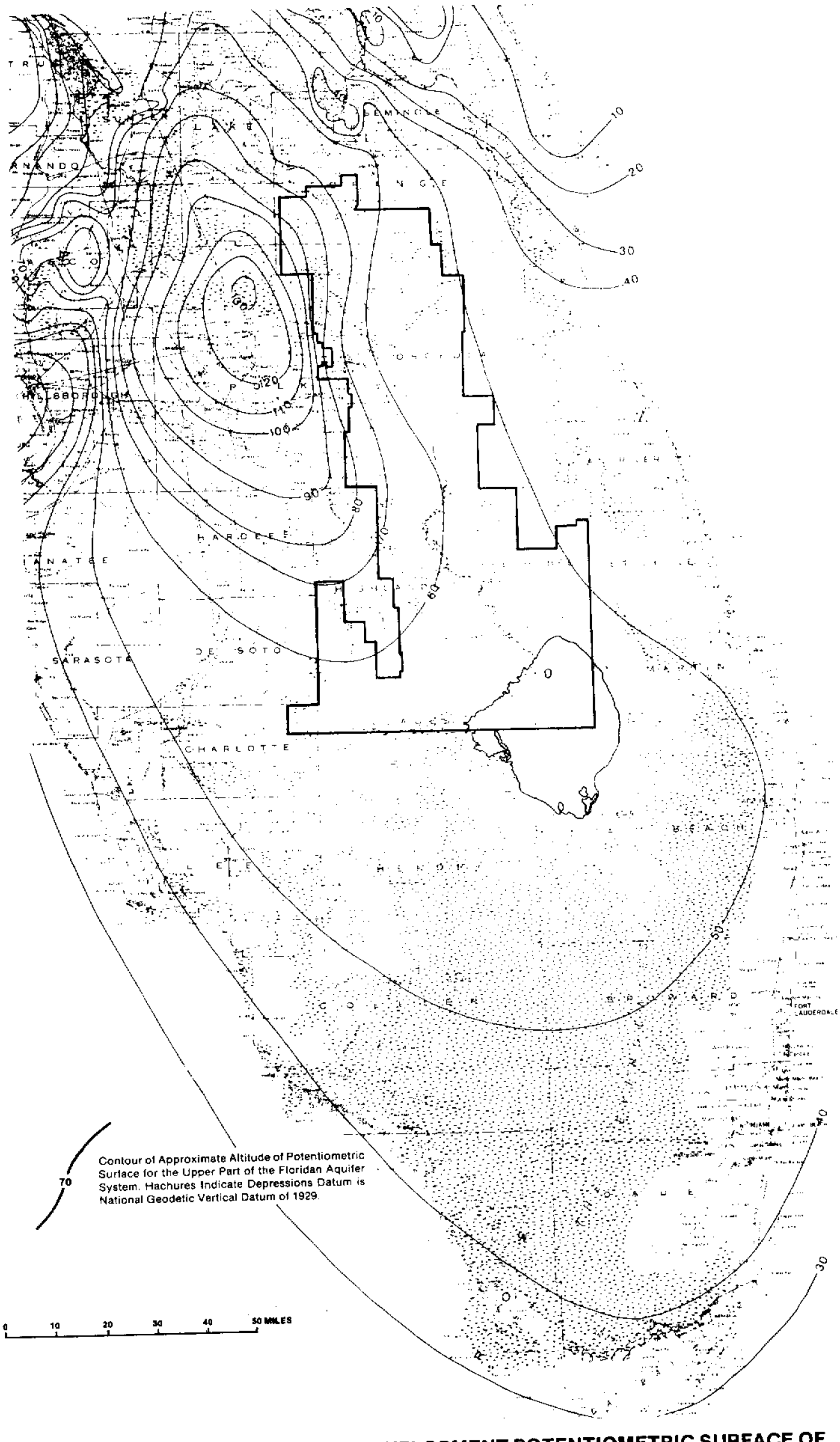


Figure 43 ESTIMATED PRE-DEVELOPMENT POTENTIOMETRIC SURFACE OF THE FLORIDAN AQUIFER SYSTEM (FROM JOHNSTON AND OTHERS, 1980)

appears west and north in September 1982 when compared to the position held during pre-development conditions. The most striking difference between the two configurations, however, is the position of the 50 foot above NGVD contour line. The southernmost extent of the 50 foot above NGVD contour line is now located 60 miles north of the position held in pre-development conditions. In reference to the north/south axis of the planning area, the 50 foot above NGVD contour line is currently located nearly 20 miles west of the estimated position held in the 1930's. In fact, the current 50 foot above NGVD potentiometric contour line now occupies a position remarkably similar to the pre-development 60 foot above NGVD contour line, indicating that throughout the eastern and southeastern portions of the planning area, hydraulic head values were as much as 10 feet lower in September of 1982 than the values prior to development of the Floridan Aquifer System.

Recharge to the Floridan Aquifer System

Possible mechanisms of recharge to the Floridan Aquifer System in the KPA include: a) downward percolation of water from the Surficial Aquifer System through the confining beds, b) subsurface inflow from adjacent areas, c) through drainage wells, and d) downward leakage from lake bottoms where good hydraulic connection exists between sand filled sinkholes which originally formed the chain of lakes and the limestone of the Floridan Aquifer System.

According to Lichtler and others (1968) and Stewart (1966), the major mechanism of recharge to the Floridan Aquifer System appears to be direct infiltration of precipitation to the Surficial Aquifer System with subsequent downward percolation through confining beds to the Floridan Aquifer System. In order for this to take place, the potentiometric surface of the Floridan Aquifer System must be below the water table. In addition, the confining beds must be relatively thin and must have sufficient hydraulic conductivity to permit the percolation of large quantities of water within a reasonable time frame. According to Lichtler and others (1968), "...lake levels and the water table are above the piezometric (potentiometric) surface in most of Orange County... and rain will infiltrate and recharge the Floridan aquifer in most parts of the county if the confining bed overlying the aquifer is not impermeable." Stewart (1966) states that widespread recharge is occurring through this mechanism in Polk County in all areas which are not areas of artesian discharge. Stewart (1966) also mentions that some recharge to the Floridan Aquifer System occurs through sinkholes, "but that the amount is a relatively small part of the total annual recharge to the aquifer."

Klein and others (1964) claim that recharge to the Floridan Aquifer System by downward infiltration from the Shallow Aquifer System may occur in "much of the Highlands Ridge area of central Florida."

Due to the lack of an extensive, established Surficial Aquifer System monitoring network, it is not possible to delineate every area where the water table is above the potentiometric surface of the Floridan Aquifer System in a region the size of the KPA. A map of this sort, coupled with detailed information about the thickness and vertical hydraulic conductivity of the confining beds, would be required to pinpoint areas of probable recharge to the Floridan Aquifer System through the mechanism of downward percolation of water from the Surficial Aquifer System, through confining beds, and into the Floridan Aquifer System. This detailed data collection and analysis is beyond the scope of this study.

Stewart (1980) published a map delineating areas of natural recharge to the Floridan Aquifer System in Florida (Appendix VI). This map indicates that the areas with high recharge in the KPA are located in western Orange County, northeastern Polk County, and a small area in southeastern Polk County. Most of the areas of high recharge are "well-drained upland areas characterized by poorly developed stream drainage systems and many closed depressions, some of which contain water perenially." These areas are found along the western fringes of the KPA, from Orange County to southern Polk County. Areas of very low to moderate recharge in the KPA are found in central Orange County. According to Stewart, the confining beds in this area are either thick enough to restrict movement of water into the Floridan Aquifer System, resulting in low recharge, or the confining beds may be thin or breached and the water table considerably higher than the potentiometric surface, resulting in moderate recharge.

A comparison of lake stages in the chain of lakes in the northern KPA with water levels in nearby Floridan Aquifer System wells is shown on Table 8. The potentiometric surface of the Floridan Aquifer System near Lakes Marion, Hatchineha, Weohyakapka, and Arbuckle is above the respective lake stages, inferring that generally no recharge to the Floridan Aquifer System is occurring at those sites. However, lake stages in Lakes Hart, East Tohopekaliga, Tohopekaliga, and Kissimmee are above the potentiometric surface of the Floridan Aquifer System at those sites, indicating a potential for low to moderate recharge depending upon the thickness of the confining beds at the sites.

Current studies by the District indicate that water levels in piezometers that penetrate approximately 10-20 feet of the Surficial Aquifer System are higher than the stages of Lake Tohopekaliga and Lake Kissimmee. During periods of low rainfall in the area, lake stages remained relatively constant, and did not seem to be affected by evaporation losses. This may indicate recharge from some source. The recharge to the lakes may occur as inflow from the Surficial Aquifer System. However, since there is little known about the hydraulic conditions of the lake bottoms, and there is little difference between the lake stages and water levels at nearby Floridan Aquifer System

TABLE 8. COMPARISON OF SELECTED LAKE STAGES WITH THE POTENTIOMETRIC LEVELS IN NEARBY FLORIDAN AQUIFER SYSTEM WELLS

STATION	MAY '80	SEPT '80	MAY '81	SEPT '81	MAY '82	SEPT '82
Lake Marion	65.93	65.76	65.04	65.96	65.88	66.52
POF-14	72.05	-	-	71.29	70.35	73.01
Lake Hatchineha	49.10	49.46	48.30	49.20	50.20	51.60
POF-6	-	68.69	63.00	68.39	65.89	70.09
Lake Weohyakapka	60.73	61.08	59.20	60.18	59.96	61.88
POF-8	79.20	81.35	72.00	81.25	74.45	82.75
Lake Arbuckle	53.07	53.41	51.56	53.47	52.35	55.47
POF-10	74.73	78.64	-	76.64	71.94	78.84
Lake Hart	59.76	58.74	57.26	58.88	59.95	60.45
ORF-25	42.02	42.60	38.00	43.06	43.47	55.51
E. Lake Tohopekaliga	54.87	54.34	53.75	55.15	55.75	57.00
OSF-44	-	-	42.00	46.58	53.40	48.43
Lake Tohopekaliga	52.29	52.31	52.06	53.43	52.25	53.95
OSF-6	52.89	51.61	48.00	52.95	52.83	59.82
Lake Kissimmee	48.94	49.61	48.54	49.18	50.25	51.65
OSF-4	46.24	49.37	42.00	47.17	47.57	49.17
POF-5	45.85	45.49	-	45.47	46.03	47.30

wells, there is a possibility that if lake levels dropped low enough, upward leakance from the Floridan Aquifer System could recharge Lakes Tohopekaliga and Kissimmee.

Stewart's (1980) map indicates a large area of known very low recharge from central Orange County to central Okeechobee County, east of the Kissimmee River extending beyond the eastern boundary of the KPA. Stewart (1980) characterizes areas of low recharge as those areas where "the Floridan is known to be overlain by relatively impermeable confining beds generally more than 25 feet thick and unbreached."

The other possible modes of recharge to the Floridan Aquifer System in the KPA include drainage wells and downward leakage through lake bottoms, where good hydraulic connection exists with the Floridan Aquifer System through the sands and fine grained materials which fill the sinkholes. Kimrey and Fayard (1982) indicate that over 300 drainage wells in Orange County contribute approximately 50 million gallons of water per day to the Floridan Aquifer System in the area.

Kohout and Meyer (1959) indicated that significant amounts of recharge to the Floridan Aquifer System occur through downward leakage through the bottom of Lake Placid in Highlands County, located just outside the KPA. Lichtler and others (1968) indicate that this mechanism is also occurring in Orange County. Stewart (1966) stated that "evidence of major, widespread recharge to the Floridan aquifer through lakes and sinkholes is still lacking." However, he did indicate that the likelihood of areal recharge by slow downward percolation of water from the Shallow Aquifer System "through the confining beds, in both sinkhole and inter-sink areas is substantial in Polk County."

Discharge from the Floridan Aquifer System

The modes of discharge from the Floridan Aquifer System within the KPA are upward leakage through confining beds, discharge from pumping or freely flowing wells, and subsurface outflow into adjacent areas. In the northwestern part of the planning area where confining beds are thin or breached and the potentiometric surface of the Floridan Aquifer System is above the elevation of the water table, upward leakage of water from the Floridan Aquifer System to the Surficial Aquifer System can occur. According to Stewart (1966), many of the large lakes east of the Lake Wales Ridge, including Lake Hatchineha, Lake Weohyakapka, and Lake Arbuckle, are partially supplied by upward leakage from the Floridan Aquifer System.

In the southern portion of the KPA, the confining beds are much thicker, and although there may be some upward leakage in lowland areas where the potentiometric surface is higher than the water table, this amount of natural discharge is probably small compared to pumpage. Figure 44 depicts areas of flowing artesian conditions in the KPA for September of 1982. The area where the potentiometric surface of the Floridan Aquifer System is above land surface includes parts of Polk and Orange Counties east of the Lake Wales Ridge and west of the Kissimmee River, southern Okeechobee and Highlands Counties, and eastern Glades County. The area of flowing artesian conditions extends east of the KPA boundary into Martin and St. Lucie Counties, where all of the wells which penetrate the Floridan Aquifer System flow at land surface.

A large portion of the natural discharge of water from the Floridan Aquifer System probably occurs as subsurface outflow of water east and south into Brevard, Indian River, St. Lucie, and Martin Counties. The water that is not "captured" by man through pumpage eventually discharges into the Atlantic Ocean.

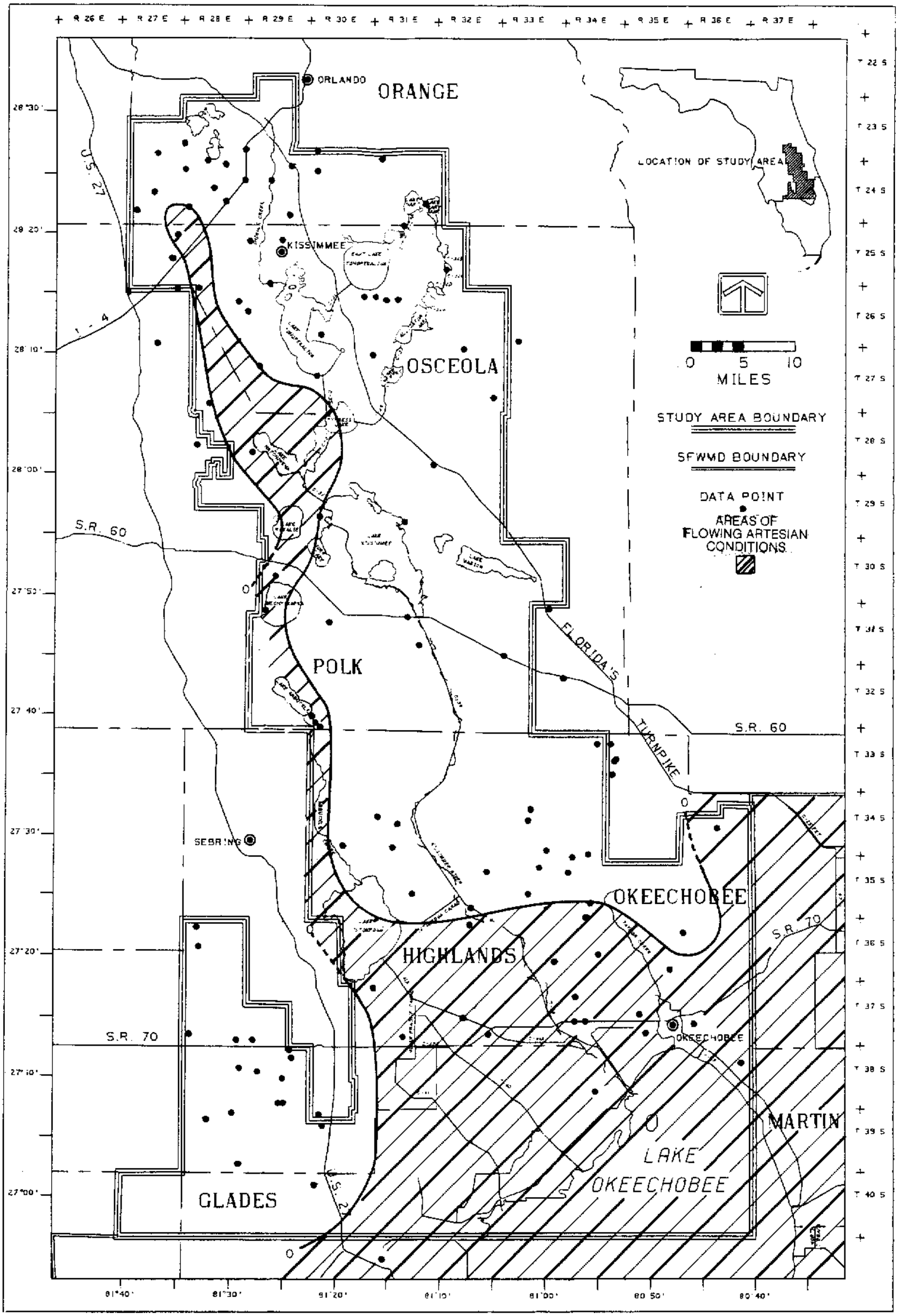


Figure 44 AREA OF FLOWING ARTESIAN CONDITIONS, SEPTEMBER 1982, FLORIDAN AQUIFER SYSTEM

Figure 45 is a graphical representation of the probable directions of flow as groundwater moves through the Floridan Aquifer System in the direction of decreasing head in May of 1981. The solid lines are the potentiometric contour lines, and the dashed lines are flowlines. These lines are constructed perpendicular to the lines of equal head and represent the direction of the maximum head gradient. The area bounded by two given flow lines in a flownet is called a streamtube. The amount of flow through a given streamtube is constant from one end of the tube to the other if no pumpage or loss due to leakage occurs. The driving force for most of the flow within the Floridan Aquifer System in the KPA originates in an area of potentiometric surface highs in northwestern Polk County, outside the study area boundary. The groundwater flows eastward from this potentiometric surface high, across Orange County and Polk County, into Osceola County and eastward, outside the study area. Groundwater flows in several directions from the imaginary "ridge" depicted by the potentiometric contour lines along the western boundary of the planning area. Flowlines that originate to the west of this "ridge" indicate groundwater flow into portions of Polk, Highlands, and Hardee Counties which are not included in the study area. Some water appears to flow southward into Highlands County, down the southern extent of the potentiometric surface ridge. The depression in the potentiometric surface of the Floridan Aquifer System in Okeechobee County and eastern Highlands County is caused by localized pumpage. Groundwater flows radially into this depression from upgradient areas, although only one flowline is shown on Figure 45.

Figure 45 is not a unique representation of the given flownet or flow system. A flownet could be drawn with an infinite number of streamtubes, and there is a subjective influence upon the final configuration of the flownet depending upon the approach of the individual constructing it. If the aquifer

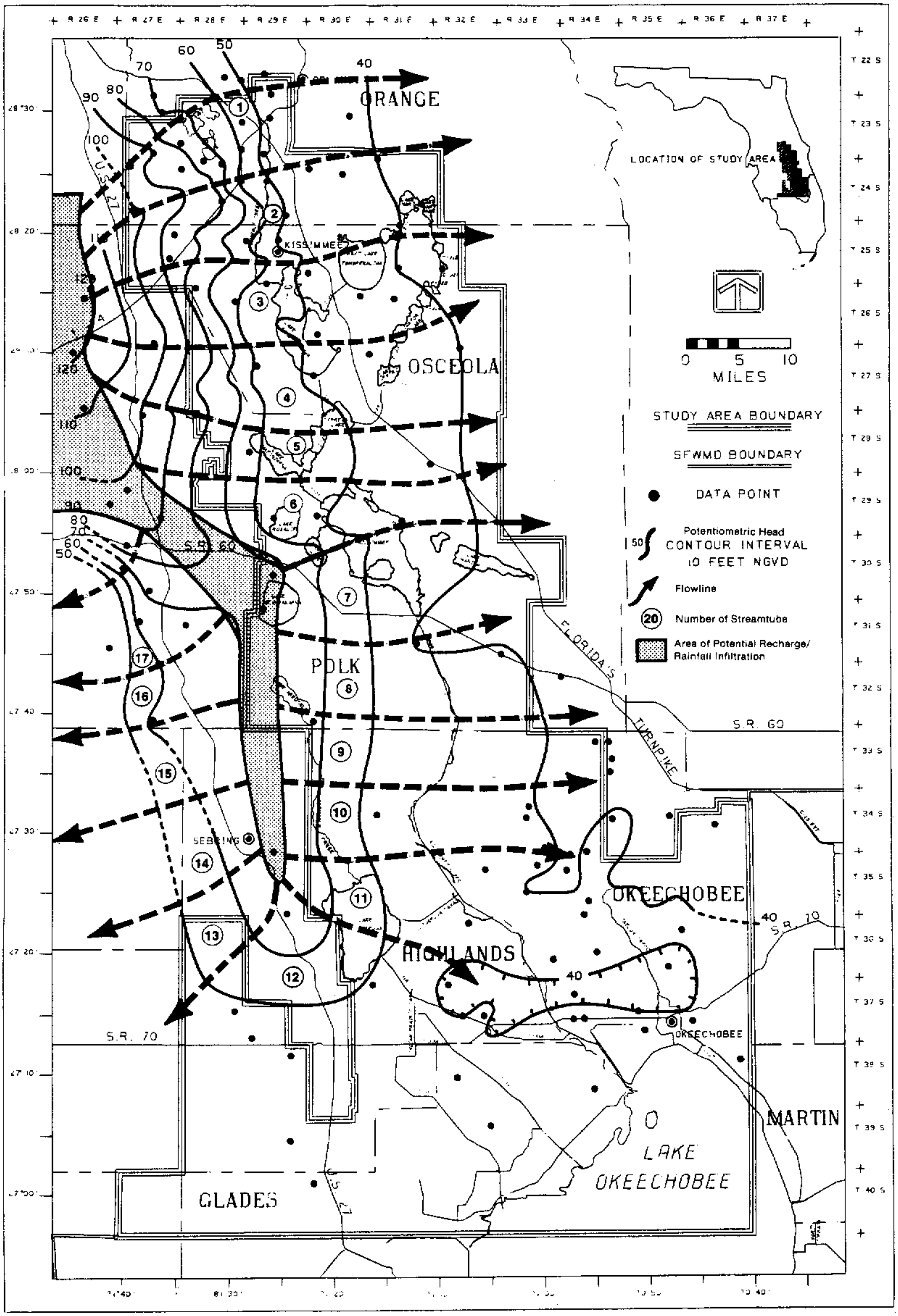


Figure 45 FLOWNET REPRESENTATION OF THE FLORIDAN AQUIFER SYSTEM, MAY 1981

material is homogeneous and isotropic, groundwater flow is horizontal, and the hydraulic gradient is uniform, a flownet can be used to analytically determine the transmissivity of the aquifer system or the amount of water moving through an individual streamtube by utilizing Darcy's Law. In the case of the flownet constructed to represent conditions in the Floridan Aquifer System in the KPA, areal estimates of transmissivity are known, and estimates of the subsurface horizontal flow through a given cross section of the aquifer delineated by two flow lines and two potentiometric surface contours can be made.

An analytical estimate of the flow through a given streamtube shown on Figure 45 can be made utilizing the following modification of Darcy's Law:

$$Q = T \quad i \quad W \qquad (2)$$

Where,

Q = rate of flow of water through cross section of aquifer, in gpd.

T = coefficient of transmissivity, in gpd/ft

i = hydraulic gradient, in ft/mile

W = average width of cross section of aquifer, in miles

The flow, Q, through a given streamtube is constant if no water is recharged or removed through infiltration, pumpage, or leakage. In the KPA, variations in the hydraulic gradient in individual streamtubes are apparent. These are reflected in variations in the spacing of the potentiometric contour lines. For example, in the northeastern part of the KPA in streamtube #1, the distance between the 10-foot interval contour lines from 100 feet above NGVD to 50 feet above NGVD is approximately equal. However, the spacing between the 50-foot above NGVD contour and the 40 foot above NGVD contour is much greater.

A rough approximation of the volume of groundwater flow between the 60-foot and 50-foot above NGVD potentiometric contour lines for streamtubes 1 through 17 on Figure 45 was determined using equation (2) above. The estimate of total flow through the Floridan Aquifer System in this area was approximately 81 mgd. A volume of 71.1 mgd subsurface flow in the Floridan Aquifer System which moves from west to east through the planning area in streamtubes 1 through 12 was determined. A volume of 9.4 mgd flows through streamtubes 13 through 17 from the potentiometric surface highs along the Lake Wales Ridge into the neighboring Southwest Florida Water Management District.

Variations in hydraulic gradient in a flow field without recharge or discharge may be due to variations in transmissivity. In this area, the Floridan Aquifer System is thicker towards the east and south and regional transmissivities may be higher where the aquifer is thicker. However, the transmissivity data were not sufficiently detailed to confirm this. In the northwestern part of the planning area the closer spacing of the potentiometric contour lines may be due to the mounding effect caused by recharge to the Floridan Aquifer System.

In order to check the relative accuracy of the estimate of groundwater flow derived from the flownet analysis, an estimate of the volume of water entering the Floridan Aquifer System in the area of potentiometric surface highs was made. Stewart (1966) estimated that in 1959, the average rainfall over the Kissimmee River basin was 65 inches. Stewart (1966) assumed that 20 inches of the precipitation was lost to runoff and 40 inches was lost to evapotranspiration, arriving at a rough estimate of 5 inches of water per year over the area of the Kissimmee River basin as potential recharge to the Floridan Aquifer System.

Assuming that downward percolation of rainfall throughout the shaded area on Figure 45 represents recharge to the Floridan Aquifer System and the total volume of water available to the flownet, and applying an estimate of 5 inches of water per year over this 329 square mile area, results in an estimated volume of approximately 78 mgd entering the system in that area. This volume of water compares favorably with the 81 mgd figure obtained from the flownet analysis. Discharge from wells was not taken into account in the recharge estimate analysis due to a lack of agricultural water use data in the area. In addition, the flownet analysis used transmissivity estimates. These factors may affect the accuracy of the volume estimates obtained in these analyses.

In addition, the assumption of 5 inches per year in the recharge estimate analysis may be inaccurate. The average rainfall in the area for October 1980 through September 1981 was approximately 42 inches in comparison with the 65 inches of rainfall recorded in 1959. The amount of rainfall available for infiltration after runoff and evapotranspiration losses in early 1981 may have been substantially less than the 5 inches of water estimated by Stewart (1966). However, although these volume estimates are only approximations, it appears that they are of the proper order of magnitude.

WATER QUALITY

Introduction

The quality of groundwater is controlled by chemical reactions that occur in various parts of the hydrologic cycle. In general, surface water heated by the sun and water transpired by plants is converted into atmospheric vapor which contains small amounts of several dissolved ions such as chlorides and sulfates of sodium, magnesium, calcium, and potassium. The water vapor then condenses to form precipitation. Rain falls through the atmosphere, enters the soil, and is mixed with carbon dioxide (CO_2) to produce carbonic acid. Reactions of soil minerals with carbonic acid form solutions containing bicarbonate and iron, aluminum, and silica ions. As groundwater flows through an aquifer, further alteration of the water quality occurs. The groundwater is eventually reconverted to water vapor through the processes of evaporation or transpiration, either over the land mass or from the ocean, to continue the hydrologic cycle.

The resultant products from these various reactions determine whether the groundwater will be of usable quality for particular purposes. For example, water which is high in concentrations of sodium and potassium chloride may be too salty for direct potable or agricultural use. If the water is high in total dissolved solids, it may also be unsuitable for many potable and industrial uses. High concentrations of particular ions in water which otherwise has low overall mineralization may also be undesirable. For many uses, water quality standards have been established which set concentration limits for the suitability of the water for particular uses. A knowledge of the variations in water quality within the aquifer and of the physical and chemical processes which control water quality is essential in assessing the availability of water for municipal, industrial, agricultural, and other uses.

The municipal water supplier who treats water for a large population, and the individual who has a well, are primarily interested in obtaining potable water at minimum expense. Potable water may be defined simply as water suitable for human consumption, and the term could be loosely applied to any water free from toxic or disease causing constituents. The substances listed in Table 9 are maximum contaminant levels for primary drinking water regulations and are applicable to community water systems in Florida. Primary standards are enforceable under the Safe Drinking Water Act and therefore concentrations higher than those listed would lead to the water supply being considered unsuitable unless subjected to treatment to lower the concentration of the undesirable constituent below the set limits. The term 'potable' as used in this report indicates water which meets these criteria. The concentrations listed in Table 10 are the maximum contaminant levels for secondary drinking water regulations. Concentration levels for secondary standards are desired goals. Other properties that are important for domestic use are that the water should be colorless and have no unpleasant odors or taste. Chloride concentrations in excess of 400 mg/l will impart a salty taste to water (Hem, 1970). Many of the effects of dissolved ions in water vary among individuals. For example, water which may be considered unpleasant tasting to one person may be palatable to another.

TABLE 9. PRIMARY DRINKING WATER REGULATIONS, FLORIDA ADMINISTRATIVE CODE, 1982

Substance	Concentration (mg/l)
Arsenic (As)	0.05
Barium (Ba)	1
Cadmium (Cd)	0.010
Chromium (hexavalent, as Cr)	0.05
Lead (Pb)	0.05
Mercury (Hg)	0.002
Nitrate (as N)	10
Selenium (Se)	.01
Silver (Ag)	.05
Sodium	160

TABLE 10. SECONDARY DRINKING WATER REGULATIONS, FLORIDA ADMINISTRATIVE CODE, 1982

Substance	Concentration (mg/l)
Chloride (Cl)	250
Color	15 color units
Copper (Cu)	1
Iron (Fe)	0.3
Manganese (Mn)	0.05
Odor	3
pH	6.5 min.
Sulfate (SO_4)	250
Total dissolved solids (TDS)	500
Zinc (Zn)	5

Agricultural water supply is primarily used for irrigation purposes or the watering of livestock. Of secondary importance is the use of water for frost control, cleaning, and mixing chemical sprays. Water used in irrigation is taken up by plants relatively free of dissolved cations and anions regardless of the original content. The minerals shown to be retained in plants are calcium and magnesium salts, while the other minerals are retained in the soil. High solute concentration can interfere with osmotic activity of the plant. When a high soluble salt content is found in the soil it may be removed by leaching the top soil and allowing the solution to percolate downward to the water table. This is useful in areas with deep water tables. However, in most of south Florida the water table is only 5-10 feet below land surface. This may place the leached water, which is high in ion concentration, in contact with the root system of the plant, leaving the land unsuitable for most agricultural purposes (Hem, 1970). Such waters may be pumped out, at some expense, and they must be completely removed from the basin so that subsequent pumping does not draw the contaminated water back to the irrigated fields. Table 11 lists the upper limits for total dissolved solid concentrations in water that may safely be used for livestock. It has been recorded that some livestock may get accustomed to drinking water with dissolved solids concentrations in excess of 10,000 mg/l. Well OKF-30 in Okeechobee County is used daily to supply drinking water to dairy cattle, although the water has a total dissolved solids concentration that averages 4280 mg/l.

TABLE 11. UPPER LIMIT OF TOTAL DISSOLVED SOLIDS CONTENT FOR STOCK WATER

Stock	Concentration (mg/l)
Poultry	2,860
Pigs	4,290
Horses	6,435
Cattle (dairy)	7,150
Cattle (beef)	10,100
Sheep (adult)	12,900

The quality of water needed for industrial purposes varies greatly, depending on the type of industrial use for which the water is needed (for example, cooling, bleaching, and drying of paper and textiles, pharmaceuticals, or canning or bottling of food products, etc). Water used for boiler feedwater should be relatively free of impurities, and concentrations of dissolved constituents must be significantly lower the higher the steam pressure. Cooling water may have a wide range of ion concentrations, but temperature is one parameter that should remain relatively constant. For this reason many industries use groundwater for cooling purposes because of its relatively constant temperature. After water is used for cooling, the heated water must be properly disposed of to avoid thermal pollution. Thermal pollution of surface waters depletes the dissolved oxygen content in the water and harms fish and other aquatic life. Evaporation of water during use will result in a build up of dissolved solids concentrations (Hem, 1970). Another important industrial use of water is the commercial sale of bottled drinking water. Usually the water is distilled or spring water which is used for drinking purposes in place of tap water. To be acceptable in taste to the user, water which is bottled and sold should be low in total ion concentrations. In many portions of the KPA, Floridan Aquifer System wells meet drinking water standards and would require little treatment to be acceptable bottled drinking water.

Water Quality Parameters

Various water quality parameters are measured when a groundwater sample is analyzed. In groundwater studies a "standard complete" analysis measures the physical properties of water as well as the concentration of major ions. Table 12 lists those parameters used in this study with appropriate units and the range of values found in the KPA. Each one of these parameters will be discussed as to their source and significance in groundwater.

TABLE 12. WATER QUALITY PARAMETERS WITH APPROPRIATE UNITS AND RANGE OF VALUES IN THE KPA

Parameter	Units	Range
Conductivity	μmhos/cm	112. - 6879.
pH	-	6.80 - 8.65
Temperature	^{o}C	22.0 - 35.0
Sodium	mg/l	3.00* - 1073.70
Potassium	mg/l	.48 - 28.96
Calcium	mg/l	13.38 - 267.88
Magnesium	mg/l	2.24 - 171.79
Chloride	mg/l	4.00* - 2057.70
Sulfate	mg/l	5.00* - 625.10
Iron	mg/l	.02* - .82
Strontium	mg/l	.198 - 43.188
Total Dissolved Solids	mg/l	65.00 - 4769.20
Hardness	mg/l	48.1 - 1363.1
Alkalinity	meq/l	.64 - 6.25
Field Alkalinity	mg/l	45.40 - 374.00
Saturation Index	-	1.31 - .23

*Lower detectable limit.

Physical Parameters

Rather than an analysis for the concentration of a specific ion in solution, physical parameters indirectly measure properties of water. These parameters generally are conductivity, pH, and temperature and are measured in the field since they may change as the environment changes.

Conductivity: Specific conductance and conductivity are synonymous terms at 25°C. They are a measurement of the ability of water to conduct electricity. Electrical resistance is measured in ohms and is the reciprocal of electric conductance which is measured in mhos. However, for convenience, the value of conductivity is in mhos per centimeter which is multiplied by 10^{-6} to convert the conductivity to units of micro mhos per centimeter (μmhos/cm). Specific conductance is a measure of the conductance when the conductor is at 25°C. The value for conductivity is dependent upon the total concentration and type of dissolved ions in solution at the temperature at which the measurement is made. In general, calcium bicarbonate and calcium sulfate waters have a low conductivity, while sodium chloride waters have a high conductivity.

Distilled water has an extremely low conductivity of 0.5 to 2 μmhos/cm. Rainwater ranges from 5.0 to 30 μmhos/cm, potable water from 50 to 1,500 μmhos/cm, seawater approximately 50,000 μmhos/cm, and oilfield brines may be in excess of 100,000 μmhos/cm. The conductivity of groundwater from the Floridan Aquifer System in the KPA ranged from 112 to 6,879 μmhos/cm. Conductivity measurements are a good indicator of the degree of mineralization of groundwater. Conductivity measurements are taken both in the field and in the lab. The lab conductivity value is generally slightly higher due to the absorption of atmospheric carbon dioxide (APHA, 1980).

pH: The pH is a measurement of the acidity or alkalinity of a solution based on the concentration of H^+ and OH^- ions. The pH of a solution represents the negative logarithm to the base 10 of the concentration of the hydrogen ion in moles per liter at a given temperature. Mathematically this is represented by the formula:

$$pH = -\log [H^+] \qquad (3)$$

Thus, if the concentration of hydrogen ions is 10^{-8} the pH is 8.00. The pH of pure water at $25^{o}C$ is 7.00.

Changes in pH occur due to the dissociation of water which reacts to form new species. For example, the reaction of water with dissolved carbon dioxide is one of the most important in determining the pH, and is shown in the following equations;

$$H_2O + CO_2 = H_2CO_3 \qquad (4)$$

$$H_2CO_3 = H^+ + HCO_3^- \qquad (5)$$

$$HCO_3^- = H^+ + CO_3 2^- \qquad (6)$$

The release of H^+ in the last two steps controls the pH of the solution.

The major control carbon dioxide has on pH causes a problem in sampling groundwater. Since the solubility of carbon dioxiode changes with temperature and pressure, the pH will also change when samples are collected at the surface from a pumped or flowing well. Stored samples will release additional carbon dioxide altering the pH even further. For these reasons a field pH determination is preferred. Since the loss of carbon dioxide will cause the pH to increase, lab pH values are generally slightly higher than those taken in the field. In general, sodium-carbonate-bicarbonate water has pH values in the 7.8 - 8.5 range. Values of pH of groundwater in the Floridan Aquifer System in the study area range from 6.80 to 8.65.

Saturation Index: The method for determining calcium carbonate saturation is taken from APHA (1980). Normally this method is used in determining whether corrosion or deposition of a carbonate scale will occur for industrial purposes. However, the same reactions are occurring in the Floridan Aquifer System and the saturation index is indicative of whether calcium carbonate is being dissolved or precipitated from the groundwater.

The saturation index is defined as the actual pH minus the pH of saturation (pH_S). It is calculated using the alkalinity, calcium concentration, pH, temperature, and total dissolved solids. The pH is calculated by adding a constant that is a function of water temperature with a constant that is a function of total dissolved solids and subtracting the log of the calcium ion and the log of the alkalinity concentration. The calculated pHs is then subtracted from the measured pH of the water to determine the calcium carbonate saturation index. If the index is positive it indicates that precipation of calcium carbonate is occurring while a negative index indicates dissolution. Saturation indices range from -1.31 to .23 in the KPA.

Temperature: Temperature is generally measured in degrees Celsius (^{o}C) and must be taken at the time the sample is collected. Occasionally temperature is reported in degrees Fahrenheit (^{o}F). The following equations may be used to convert Centigrade to Fahrenheit and vice versa.

$$^{o}F = 9/5\ ^{o}C + 32 \qquad (7)$$

$$^{o}C = 5/9\ (^{o}F - 32) \qquad (8)$$

Shallow groundwater temperatures usually vary in accordance with the overlying surface environment. Below this surface zone of influence, groundwater temperatures should increase approximately 2.9^{o}C for each 300 feet of depth in accordance with earth's geothermal gradient (Todd, 1980). Thus water pumped from deep wells is usually warmer than the shallow groundwater. However, anomalous temperature difference may result from density difference or fractures causing the mixing of different waters. Temperature readings are also necessary for the calculation of chemical parameters such as alkalinity, saturation, and stability with respect to calcium carbonate and salinity calculations (APHA, 1980).

Major Anions and Cations and Other Chemical Parameters

An anion is a negatively charged ion and a cation is a positively charged ion. Eight major anions and cations are found in groundwater in south Florida. They are sodium, potassium, calcium, magnesium, chloride, sulfate, iron, and strontium. Concentration values for the parameters are reported in milligrams per liter (mg/l) which is synonymous with parts per million (ppm) in dilute waters. Each ion will be discussed as to the form of the dissolved species, source of the material, concentration ranges expected in groundwater, and their environmental influences. In addition, total dissolved solids, hardness, alkalinity, and saturation index, which are calculated or defined on the basis of different ion concentrations, are discussed.

Sodium (Na): Sodium is derived in south Florida chiefly from unflushed residual seawater, modern seawater intrusion, clay minerals, evaporites, and precipitation. Sodium is readily adsorbed on clays through cation exchange. Very high concentrations of sodium can be present in solution before precipitation takes place. Therefore, the range of sodium concentration in groundwater is widely variable. In the Floridan Aquifer System in the KPA, concentrations of sodium range from a low of 3.00 mg/l (lower detectable limit) to a high of 1073.70 mg/l. The reuse of irrigation water will often lead to high sodium concentrations since sodium from the soil will go back into solution. The values of sodium and potassium are often added together as they have the same occurrences, and potassium concentrations are generally overshadowed by those of sodium. Thus, in the Stiff patterns and the Piper trilinear diagrams discussed later in this section, the one axis is represented by the milliequivalents of sodium plus potassium. Sodium and potassium concentrations greater than 50 mg/l will cause foaming and accelerate scale formation and corrosion in boilers. Sodium and potassium carbonate can cause deterioration of wood in cooling towers. Concentrations of sodium in excess of 65 mg/l can cause problems in ice manufacturing (Todd, 1980).

Potassium (K): Potassium is derived from sources similar to that of sodium. In groundwater the concentration of potassium is much lower than the concentration of sodium. In the KPA, potassium concentrations range from a low of 0.48 mg/l to a high of 28.96 mg/l. Potassium is found in such low concentrations in groundwater due to the ions size such that it readily enters into the structure of clay minerals. Potassium is used in fertilizer and is taken up by plants.

Calcium (Ca): The calcium ion is a divalent cation and is represented by Ca^{2+}. Calcium is abundant in the groundwater of south Florida as it is derived from the limestone material. These carbonates consist of calcite and aragonite, both having the formula $CaCO_3$, and the mineral dolomite, represented as $Ca\,Mg\,(CO_3)_2$. Limestone consists primarily of calcite with some magnesium and other impurities. If the rock has a ratio approaching 1:1 of magnesium to calcium, it is termed dolomite. Other calcium minerals common in sediments include the sulfates, gypsum ($CaSO_4 \cdot 2H_2O$) and anhydrite ($CaSO_4$), and the fluoride, fluorite (CaF_2). Calcium is also a component of smectite clays (Hem, 1970). The calcium ion is liberated from calcite by the presence of the hydronium ion H^+.

$$CaCO_3 + H^+ = Ca^{2+} + HCO_3^- \qquad (9)$$

This occurs when water and carbon dioxide react to form carbonic acid (as in rain) which disassociates releasing H^+ ions.

$$\underset{\text{(Water)}}{H_2O} + \underset{\text{(Carbon Dioxide)}}{CO_2} \leftrightarrow \underset{\text{(Carbonic Acid)}}{H_2CO_3} \qquad (10)$$

$$\underset{\text{(limestone)}}{CaCO_3} + \underset{\text{(carbonic acid)}}{H_2CO_3} \leftrightarrow \underset{\text{(calcium)}}{Ca^{2+}} + \underset{\text{(bicarbonate)}}{2HCO_3^-} \qquad (11)$$

The amount of carbon dioxide in the system controls whether calcium carbonate is dissolved or precipitated. If carbon dioxide is added, solution continues; if it is removed, deposition will occur (Davis and Dewiest, 1966). Calcium concentrations in the KPA range from a low of 13.38 mg/l to a high of 267.88 mg/l. Calcium is the main cause of hardness in water which leads to scale forming in boilers and inhibits soap lathering.

Magnesium (Mg): The most common source of magnesium ions in Florida groundwaters is dolomite. Calcite also contains some magnesium, thus the solution of limestone yields magnesium as well as calcium ions. The reactions with magnesium are similar to those of calcium. The solubility of magnesium carbonate is also controlled by the presence of carbon dioxide. Magnesium is generally found in lower concentrations than calcium in groundwater. This is probably due to the greater abundance of calcium in the earth's crust and the slow dissolution of dolomite. However, seawater contains about five times as much magnesium as calcium probably due to the uptake of calcium by sea plants and animals which use it for hard parts of calcite and aragonite (Davis and Dewiest, 1966). Magnesium concentrations in the KPA range from a low of 2.24

mg/l to a high of 171.79 mg/l. Magnesium, like calcium, acts to form scale and inhibits soap lathering. The sum of calcium and magnesium is usually called hardness (see hardness).

Chloride (Cl): Chloride is generally present as the chloride ion, Cl^-. Chloride occurs when porous rocks are submerged and seawater enters and impregnates the rock with soluble salts, usually in the form of chloride crystals, or as a solution of sodium and chloride ions. Chloride is also associated with evaporites halite (NaCl) and sylvite (Kcl), and from connate brine sources (Hem, 1970). The chloride ion is considered a "conservative" ion in that it reacts very little with the surrounding environment. Conservative ions are unaffected by changes in the environment such as pH, temperature, and pressure. Some chloride ions may be retained as water passes through clays, due primarily to the larger size of the chloride molecule. This may lead to the concentration of chlorides. Chloride concentrations in the KPA range from a low of 4 mg/l (lower detectable limit) to a high of 2057.70 mg/l. When the major cation is sodium, water with chloride concentrations in excess of 250 mg/l has a salty taste. In water, where the predominant cations are calcium and magnesium, the chloride concentration may be as high as 1000 mg/l before the water tastes salty (APHA, 1980).

Sulfate (SO_4): Sulfur, when dissolved in water, usually occurs with oxygen as the anion sulfate, SO_4^{2-}. Most sulfate present in the groundwater is from the solution of sulfate minerals in sedimentary rocks. These include gypsum ($CaSO_4 \cdot H_2O$) and anhydrite ($CaSO_4$) and to a lesser extent celestite ($SrSO_4$). Sulfate compounds are readily soluble and most water in contact with them will be high in dissolved solids. Bacteria play an important role in the reduction of sulfur ions and produce hydrogen sulfide (H_2S) gas as a by-product. This release of hydrogen sulfide accounts for the "rotten egg" smell of water high in sulfate. Concentrations of sulfate in the KPA range from a low of 5 mg/l (lower detectable limit) to a high of 625.10 mg/l. Sulfate in combination with calcium causes scale deposits on boilers. Water containing 500 mg/l of sulfate tastes bitter and water containing approximately 1000 mg/l sulfate may be cathartic (Todd, 1980).

Iron (Fe): The concentration of ferrous ions in groundwater is limited by the solubility of ferrous carbonate. Iron species in groundwater from the Surficial Aquifer System will occur predominantly as ferric hydroxides and sulfides. Bacteria in wells may remove some iron by precipitation of ferric hydroxide before the water gets to the ground surface. Iron concentrations are generally quite low in the Floridan Aquifer System. In the KPA the concentration of iron ranges from a low of 0.02 mg/l (lower detectable limit) to a high of 0.82 mg/l. Concentrations in excess of 0.2 mg/l will precipitate after exposure to air. Iron also adds objectional taste and color to drinking water and will stain plumbing fixtures, laundry, and buildings.

Strontium (Sr): Strontium is chemically similar to calcium and occurs structurally where calcium occurs. Strontium in groundwater occurs from the dissolution of strontium and calcium carbonates and strontium sulfate ($SrSO_4$), or celestite. The strontium to calcium ratio in most limestones is less than 1:1000, although fossils in limestones tend to be enriched in strontium (Hem, 1970). Davis (1966) states that the concentration of strontium in groundwater ranges between 0.01 and 1.0 mg/l. However, in the KPA, the concentration in the Floridan Aquifer System ranges from a low of 0.20 mg/l (lower detectable limit) to a high of 43.19 mg/l.

Total Dissolved Solids (TDS): Values of TDS represent all of the solid minerals in solution. It does not include suspended sediment, colloids or dissolved gases. In the Floridan Aquifer System in the KPA concentrations of TDS range from a low of 65.00 mg/l to a high of 4769.2 mg/l. TDS in water for domestic and industrial use should be less than 1000 mg/l, and water for agricultural purposes less than 3000 mg/l. However, the suitability of water for a particular use generally depends more on the concentrations of specific ions rather than the TDS concentration (Davis, 1966).

Hardness: Hardness is a rather loosely defined term. The property of hardness is associated with observed effects by the use of soap or with scaling left when certain waters are used. Since the effectiveness of soap is attributable mainly to the presence of calcium and magnesium, hardness is generally defined on the basis of those two constituents. In fact, the hardness values reported here are merely calculated by multiplying the concentration in mg/l of Ca and Mg by factors of 2.447 and 4.118, respectively, and then summing to two values. The value is then reported as hardness in mg/l of $CaCO_3$. Table 13 shows the relative hardness that describes certain waters (Hem, 1970).

TABLE 13. DESCRIPTIONS USED FOR VARIOUS HARDNESS RANGES

Hardness Range (mg/l)	Description
0-60	soft
61-120	moderately hard
121-180	hard
>180	very hard

Values for hardness in the KPA range from a low of 48.1 mg/l to a high of 1363.1 mg/l.

Alkalinity: Alkalinity is defined as the capacity of a solution to neutralize acid, at a specified pH. The total alkalinity is calculated from a titration using methyl orange indicator and reported in milliequivalents per liter. Field titrations to the methyl orange end point are reported in milligrams per liter of $CaCO_3$. To convert alkalinity in milliequivalents per liter to milligrams per liter, multiply the former by 50. When alkalinity is expressed as milligrams per liter of $CaCO_3$ it can be converted to an equivalent concentration of HCO^{-3} in milligrams per liter by dividing the former by 0.8202. Alkalinity measurements are useful in the intepretation and control of water and wastewater processes. Concentrations of alkalinity in the Floridan Aquifer System in the KPA vary from a low of 45.4 mg/l to a high of 374.0 mg/l. High alkalinity values usually indicate high pH, hardness, and TDS which may be detrimental for certain water uses.

Water Quality of Wellhead Samples from the Floridan Aquifer System

The vast majority of water samples collected for this report consist of wellhead samples. These samples are collected from the pump discharge, or in the case of a flowing well, from the overflow after opening the valve flushing and the well. The sample consists of water derived from the open hole section of the borehole, and may therefore be a mixture of waters from a number of different producing zones. Variations in water quality with depth will be discussed later.

Table 14 lists the water quality parameters previously discussed along with the mean, standard deviation, and number of analyses available for each parameter for the wellhead samples. The data clearly indicate that there is a great deal of variability in a given parameter throughout the Floridan Aquifer System in the KPA. These differences in water quality are due to: 1) geographic location relative to the recharge area; 2) the distance away from the recharge area along the flow path; 3) well depth both in depth from the surface and relative to NGVD; 4) casing depth; 5) whether the well is free flowing or not; 6) age of the well; 7) degree of penetration into the Floridan Aquifer System; and 8) analytical error.

TABLE 14. MEAN, STANDARD DEVIATION, AND NUMBERS OF CASES FOR EACH PARAMETER

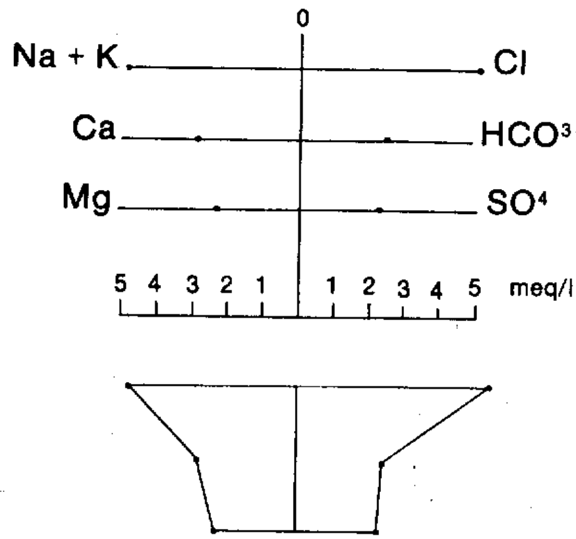
VARIABLE	MEAN	STANDARD DEVIATION	CASES
Conductivity	992.66	1376.77	111
pH	7.76	.32	111
Temperature	25.95	2.37	115
Sodium	108.72	212.29	124
Potassium	4.32	5.89	124
Calcium	57.37	45.22	124
Magnesium	27.68	31.26	124
Chloride	197.13	411.45	124
Sulfate	109.06	131.81	122
Iron	.15	.16	92
Strontium	9.75	11.47	113
Total Dissolved Solids	638.59	878.90	121
Total Hardness	117.52	49.17	122
Alkalinity	2.37	.96	122
Field Alkalinity	143.29	58.78	84
Saturation Index	-.32	.31	116

The overall water types, as determined by the concentrations of various constituents and how they change, may be examined by a number of different methods. Four of these techniques are applied to the water quality data collected for this study and will be discussed individually. The first method is contour mapping where raw data values are plotted areally on a map and then contoured. The second method is a graphical method using Stiff patterns (Stiff, 1951) which affords a quick visual representation of seven of the major ions found in a sample. The third method is the Piper trilinear diagram (Piper, 1953), also a graphical technique which allows one to plot the analysis for a large number of samples on one graph. The fourth method is factor analysis. Factor analysis is a statistical method that reduces a large number of parameters to a few factors with common characteristics.

Appendix II lists all of the water quality analyses by well and sample. The number of values, mean, and standard deviation for each parameter measured for each well are shown. These mean, or average, values for wellhead samples are used to plot the areal contour maps, Stiff patterns, Piper trilinear diagrams, and as input in the factor analysis program.

Contour mapping involves plotting the raw data for a given parameter on the base map. Lines of equal value, or isoliths, are drawn to show the areally distributed concentration of that parameter. This was done for the following parameters: chloride, total dissolved solids, conductivity, temperature, hardness, and sulfate.

Figure 46 shows how a Stiff pattern is constructed using the mean data values that are listed in Table 14. The data are plotted based on the scales shown on the three horizontal lines. However, the data listed in Table 14 must first be converted from milligrams per liter to milliequivalents per liter (meq/l), using the conversion factors shown for each parameter. The meq/l of Na and K are added together, and plotted on the appropriate axis. The points are then connected to give an irregular polygon with the zero vertical axis shown for reference. These patterns, when consistent axes are used, may be recognizable on a universal basis. If similar scales are used the width of the pattern is an approximate indication of total ionic content of the sample (Hem, 1970). Water types may then be classified on the basis of the shape of the Stiff pattern. In the example shown (Figure 46), the upper axis is elongated indicating a sodium-chloride type water. If the middle axis was elongated beyond the other two, the water would be enriched with calcium-bicarbonate. An elongation of the bottom axis would indicate a magnesium sulfate type water. The points on an individual axis do not necessarily have to be equidistant from the zero axis. For example, a pattern could have an elongated top left axis and middle right axis which would indicate a sodium-bicarbonate type water. However, the total milliequivalents per liter of the 3 points to the right should approximately equal the total of the points on the left such that the anion-cation mass balance exists.



Average Sample (See Table 14)

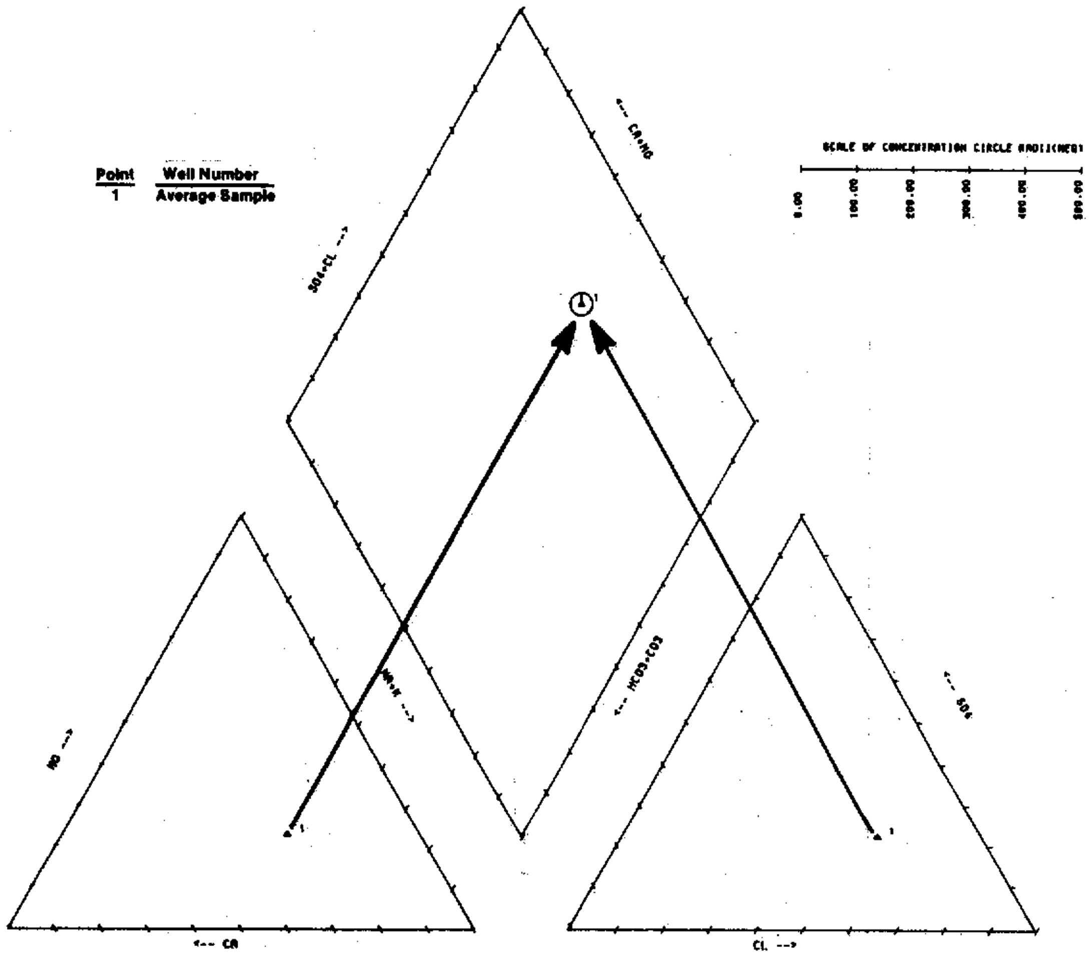
Na = 108.72 mg/l x .0435 = 4.73 meq/l
K = 4.32 mg/l x .02557 = .11 meq/l
Ca = 57.36 mg/l x .0499 = 2.86 meq/l
Mg = 27.68 mg/l x .08226 = 2.28 meq/l

Cl = 197.13 mg/l x .02821. = 5.56 meq/l
HCO^{3} = Alkalinity = 2.27 meq/l
SO^{4} = 109.06 mg/l x .02082 = 2.27 meq/l

Figure 46 CONSTRUCTION OF A STIFF PATTERN

A graphical method which allows for the closer study of a number of waters samples is the Piper trilinear diagram. Figure 47 shows the construction of a Piper trilinear diagram using the same mean data values that are listed in Table 14 and shown in Figure 46. The same values in milliequivalents per liter used in the Stiff patterns are used in the Piper diagram. However, the concentrations are expressed as a percentage of the total ionic concentration of the sample. The percent of calcium and magnesium of the total cations are calculated and plotted in the lower left triangle. The percent of sulfate and chloride of the total anions are calculated and plotted in the lower right triangle. These two points are extended into the central diamond along lines parallel to the outside edge of the triangles. The intersection of the two lines is the point of interest. Each point may be interpreted by its position in the diamond relative to the four sides. For this study the plots were computer generated using a code modified from Morris and others (1983). In the example illustrated in Figure 47, the average samples plot at approximately 23 percent carbonate and bicarbonate, 52 percent calcium and magnesium, 77 percent sulfate and chloride, and 48 percent sodium and potassium. This equals 200 percent or 100 percent from each of the lower triangles. Thus our average sample has nearly equal amounts of cations with sulfate and chloride the dominant anions. Piper trilinear diagrams are particularly applicable to the study of temporal or spatial variations in water quality. The changes in water quality as the groundwater moves down the groundwater gradient will be discussed later in this section.

Factor analysis is a statistical method of data reduction and interpretation. The three main objectives in factor analysis are: 1) to study the correlation of a large number of variables and to cluster those variables which are highly correlatable into factors, 2) to interpret each



	Na	K	Ca	Mg	Cl	SO4	HCO3
mg/l	108.42	4.32	57.36	27.68	197.13	109.06	140.00
meq/l	4.73	.11	2.86	2.28	5.56	2.27	2.29
%	*48.50		28.82	22.82	54.92	22.42	22.66
*Na + K							

Figure 47 CONSTRUCTION OF PIPER TRILINEAR DIAGRAM

factor based on the variables belonging to it, and 3) to condense a large number of variables into a few factors (Frane and Hill, 1976).

While factor analysis has been used in the past primarily for social studies (Guttman, 1954; Harris, 1963; Kaiser and Caffry, 1965; Rao, 1955; Rummel, 1970) it has only recently been applied to hydrogeologic studies (Dawdy and Feth, 1967; Lawrence and Upchurch, 1976; Dalton and Upchurch, 1978; Lawrence and Upchurch, 1982).

In the initial analysis 16 variables were used. These are listed along with their units of measurement and range of values (Table 14). Iron concentration was subsequently dropped from the final analysis due to a low variance.

The data were then normalized such that each of the 15 variables had a mean of zero and a standard deviation of one. This is done to ensure a linear correlation between variables. The normalized data set was then used as input into the factor analysis subroutine called FACTOR of the Statistical Package for the Social Sciences (Nie and others, 1975). The method of factoring used was PA1 which does a principal factor solution without interactions. The final factor solution was achieved using Varimax rotation after Kaiser normalization. Factor scores are then calculated for each time factor for each of the 125 cases. For an in-depth account of the factor analysis procedure the reader should refer to Nie and others (1975).

Contour Mapping

Figure 48 is a contour map showing the areal distribution of the average wellhead chloride concentration. Chloride concentrations of the Floridan Aquifer System in the KPA averaged approximately 197 mg/l. Chloride concentrations are low in the northwestern portion of the planning area (less than 10 mg/l). Almost the entire area north of latitude $27^{0}10'$ contains groundwater with less than the recommended maximum allowable concentration of

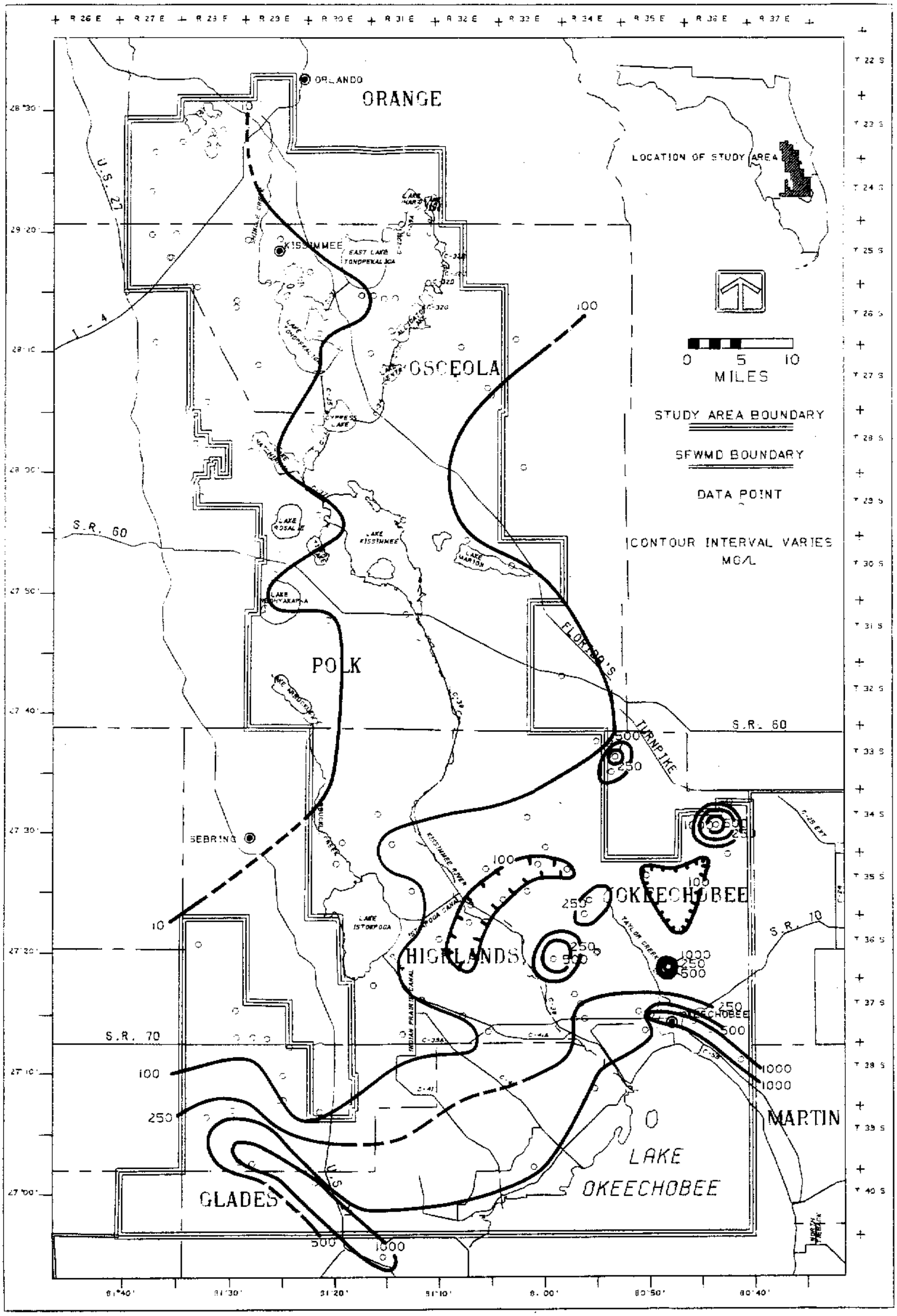


Figure 48 AVERAGE WELLHEAD CHLORIDE CONCENTRATION, FLORIDAN ÅQUIFER SYSTEM

250 mg/l chloride in drinking water (Table 10). There are, however, a few areas with concentrations exceeding this level, such as at wells OKF-5, OKF-15, OKF-4, OKF-6, OKF-13, OKF-51, and OKF-53. These wells repeatedly show high values for most of the water quality parameters. All of these wells are flowing artesian wells with the exception of OKF-51 and OKF-53. Of the flowing wells, OKF-15, OKF-4, and OKF-6 do not have valves and are continually free flowing (although OKF-6 was occasionally capped). This could be causing the upconing of more brackish waters from greater depths. OKF-5 and OKF-13 are drilled deeper than the surrounding wells and are used heavily during parts of the year for citrus irrigation. It is interesting to note the change of almost an order of magnitude in the chloride concentrations between OKF-26 and OKF-27 as compared to OKF-5. They are located only one mile apart. However, OKF-26 and OKF-27 are 825 and 725 feet deep, respectively, while OKF-5 is 1181 feet deep. The large ranges of chloride concentrations are not apparent in the northern portion of the KPA. For example, OSF-9 and OSF-10 are drilled to depths of 1195 feet and 458 feet, respectively, and have the same average chloride concentration of 5.3 mg/l. They are located less than 1 mile apart. In Okeechobee County there is a band of wells which have average chloride concentrations greater than 1000 mg/l. The band extends from the southeastern Okeechobee County border and parallels C-59 to the west to the center of the City of Okeechobee. It includes wells OKF-3, OKF-24, OKF-30, and OKF-35. Unfortunately, all attempts to geophysically log these wells have failed due to the highly corroded casings and blockages in the wells. Well OKF-3 was partially logged but the tool was stuck at 433 feet, 3 feet below the bottom of casing. A lithologic log for well OKF-24 indicated a depth of 1448 feet (Appendix V). Information given by the other well owners indicate these wells range in depth from 1200 to 1400 feet. Most of the wells in

southern Highlands and northern Glades Counties have average chloride concentrations greater than 500 mg/l.

Areal contour maps for total dissolved solids, conductivity, temperature, hardness, and sulfate concentrations are shown in Figures 49 to 53, respectively. These show a similar pattern to that shown on the chloride map.

Stiff Patterns

Stiff patterns representing wellhead samples for selected wells penetrating the Floridan Aquifer System in the KPA are shown in Figure 54. Lines indicating the saturation index are also shown in this figure and will be discussed later. It is apparent from this diagram that the samples from wells to the north, which are closest to the recharge area (i.e. OSF-2), have a much lower total ionic content than those from wells which are downgradient to the south. The pattern for OKF-30 was drawn to one-half its actual width. The Stiff pattern also indicate that the groundwater nearest the recharge area are sodium-bicarbonate type waters. The pattern for OSF-27 indicates that, although the ionic content has increased, the groundwater remains a sodium-bicarbonate type. In Okeechobee County there is an apparent change in water type. OKF-37 and OKF-17 are transitional water types. Wells OKF-30, OKF-22, HIF-22, and GLF-2 clearly show sodium-chloride type groundwater as evidenced by the extension of the sodium-chloride axis beyond that of the calcium-bicarbonate. Also the magnesium and sulfate concentrations have greatly increased in these samples compared to groundwater to the north. Samples from well OKF-30 have the highest ionic content in the KPA. Wells in Highlands County contain calcium-bicarbonate water (HIF-9), transitional water (HIF-6), and sodium-chloride waters (HIF-22).

To explain how and why changes in groundwater quality occur in the Floridan Aquifer System one must study the relationship between carbonate

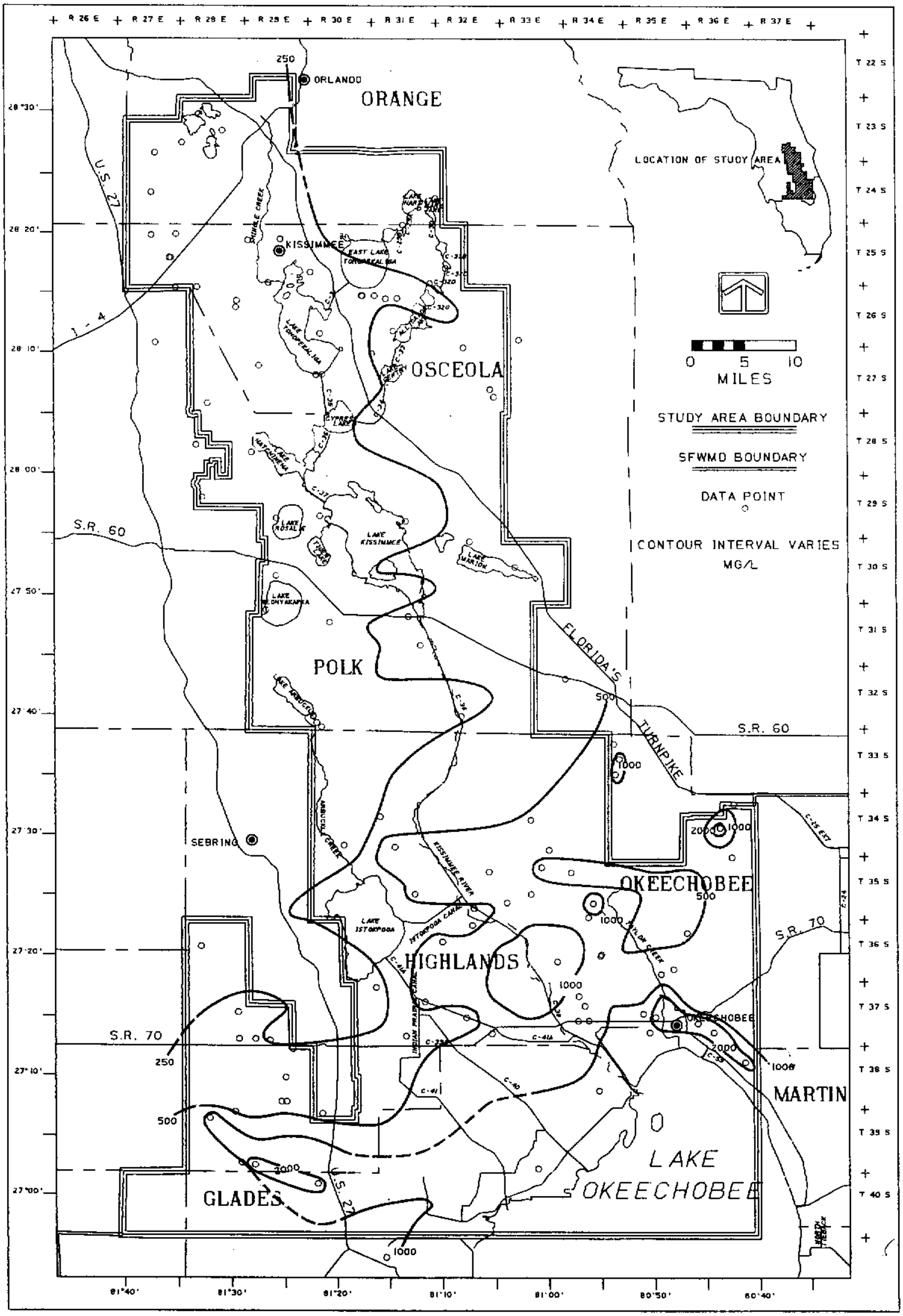


Figure 49 AVERAGE WELLHEAD TOTAL DISSOLVED SOLIDS CONCENTRATION, FLORIDAN AQUIFER SYSTEM

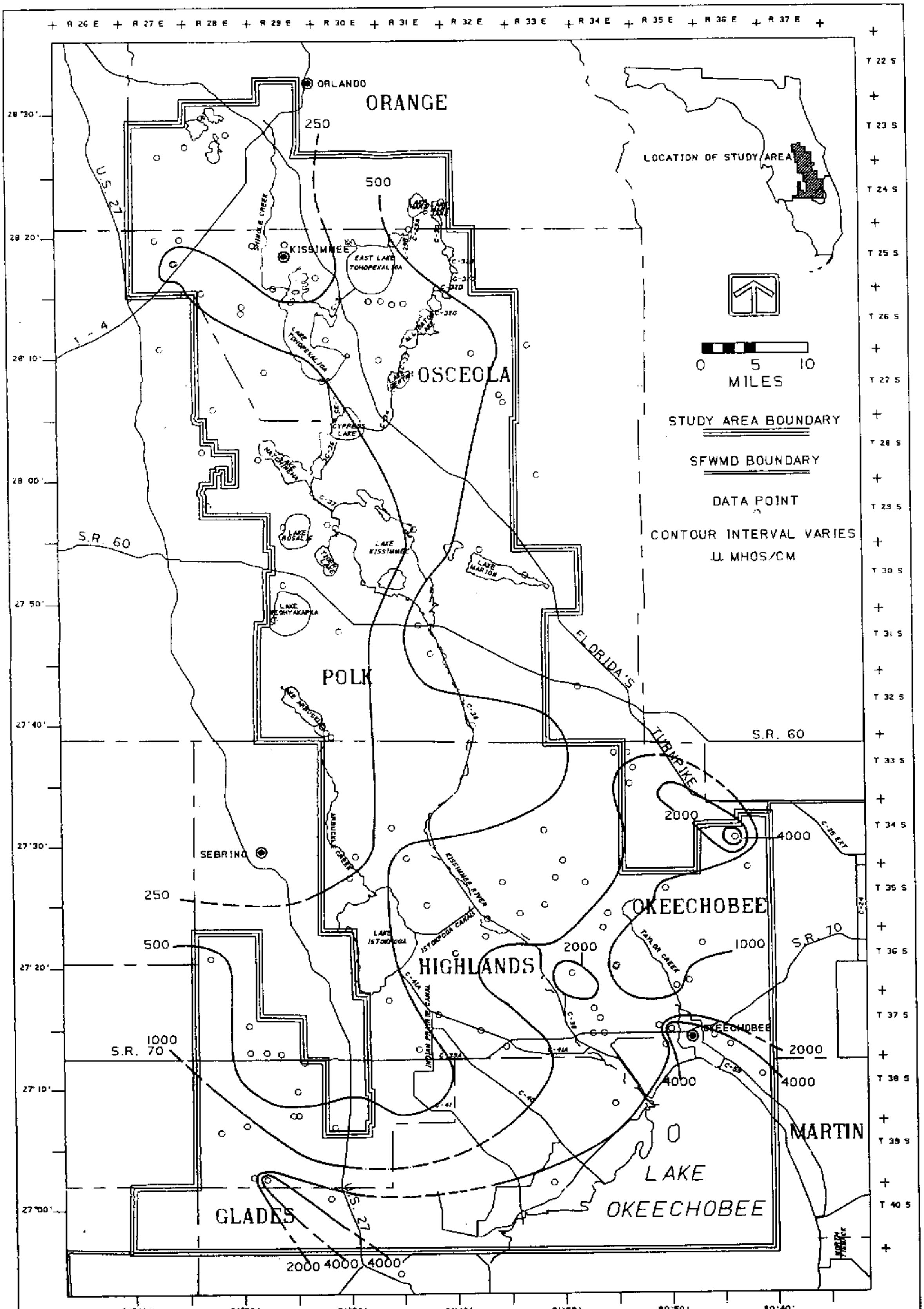


Figure 50 AVERAGE WELLHEAD CONDUCTIVITY, FLORIDAN AQUIFER SYSTEM

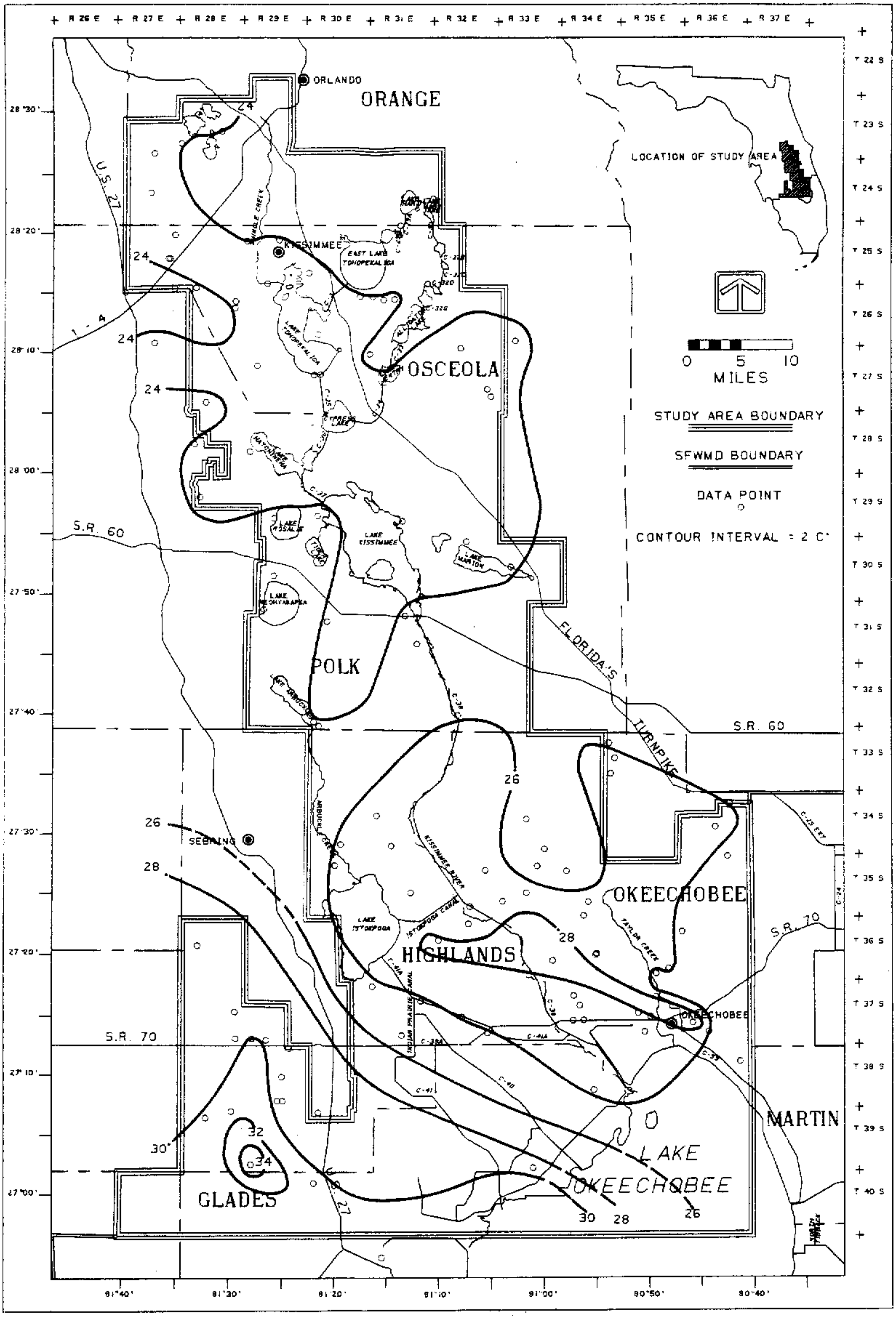


Figure 51 AVERAGE WELLHEAD TEMPERATURE, FLORIDAN AQUIFER SYSTEM

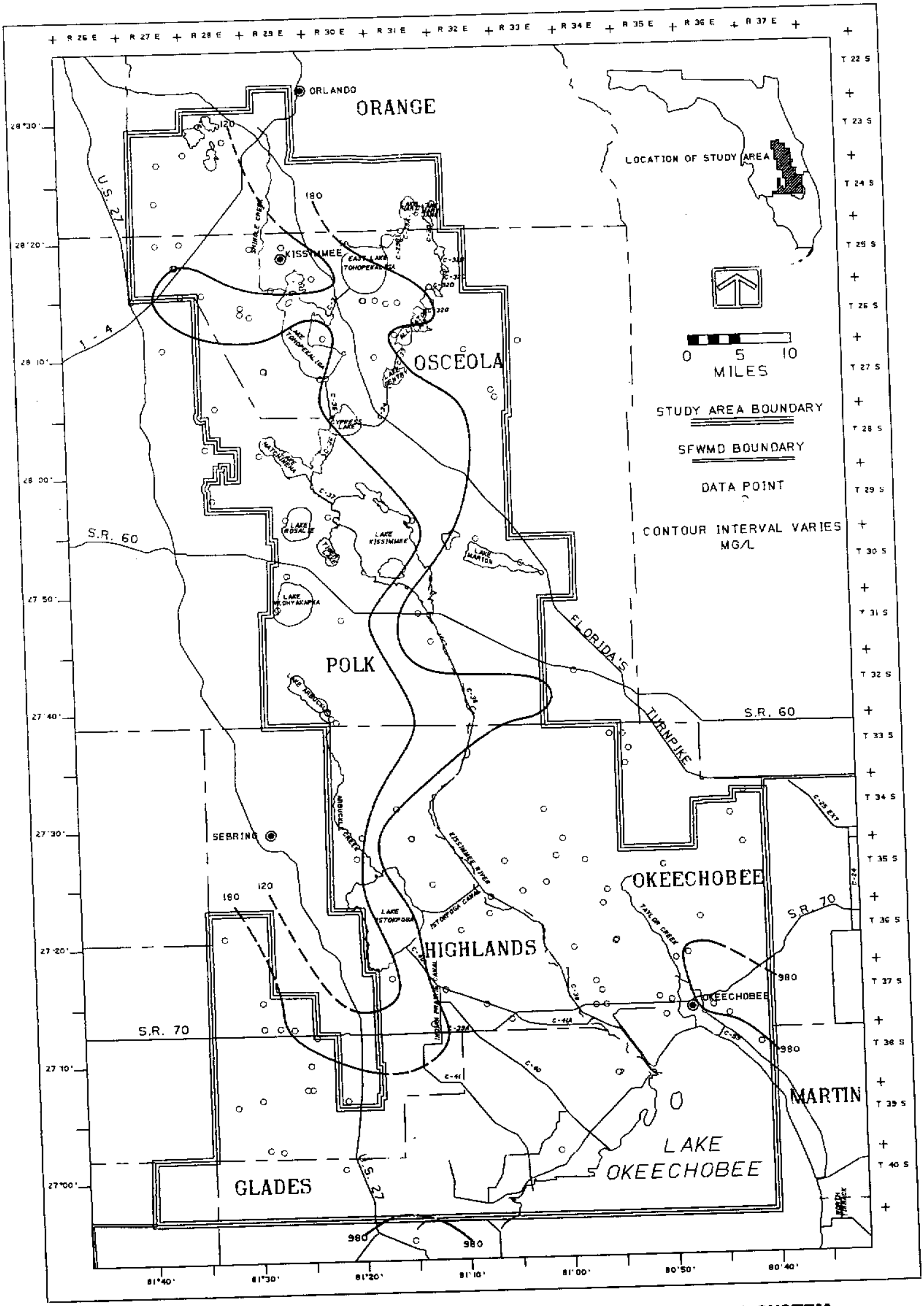


Figure 52 AVERAGE WELLHEAD HARDNESS, FLORIDAN AQUIFER SYSTEM

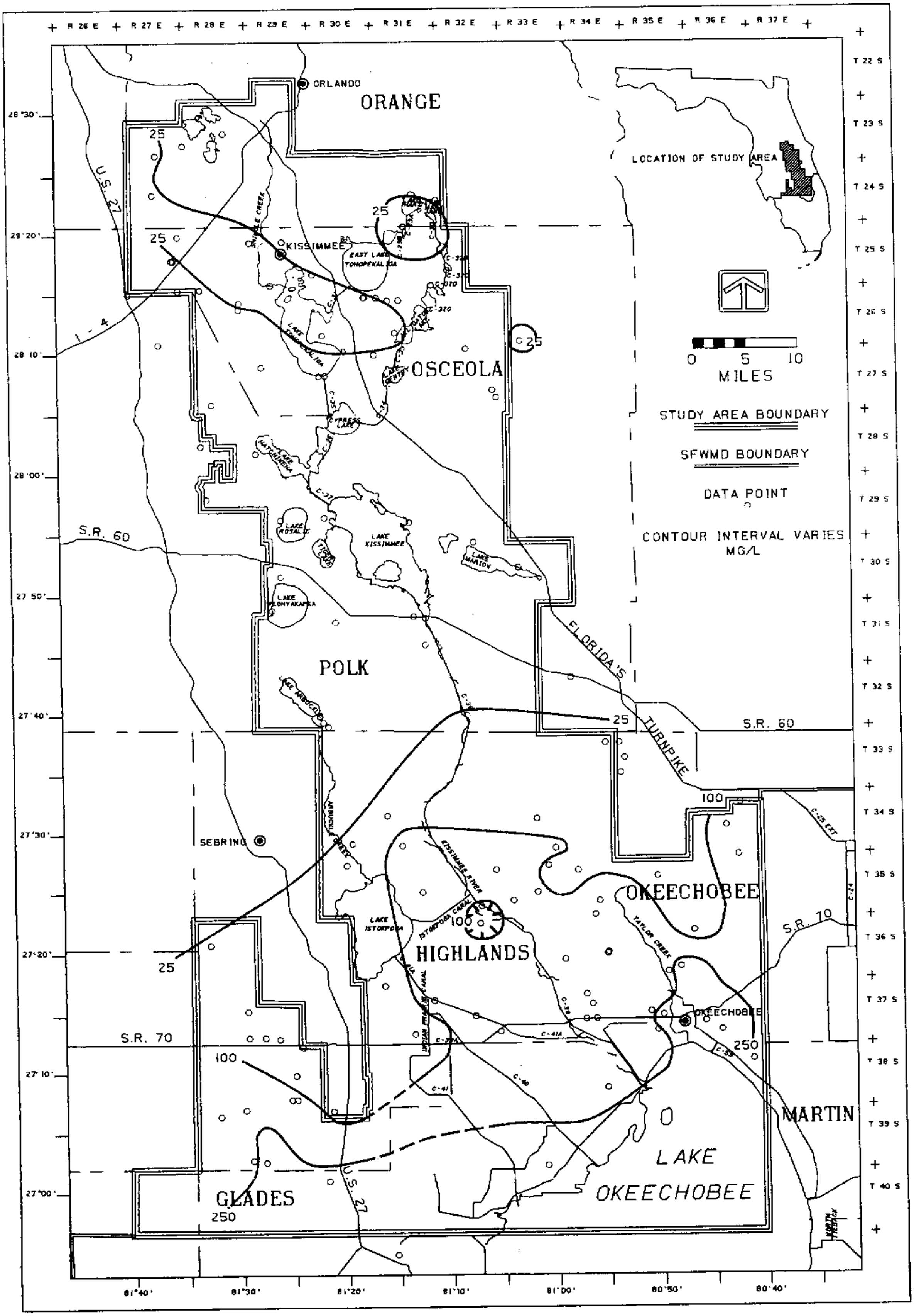


Figure 53 AVERAGE WELLHEAD SULFATE CONCENTRATION, FLORIDAN AQUIFER SYSTEM

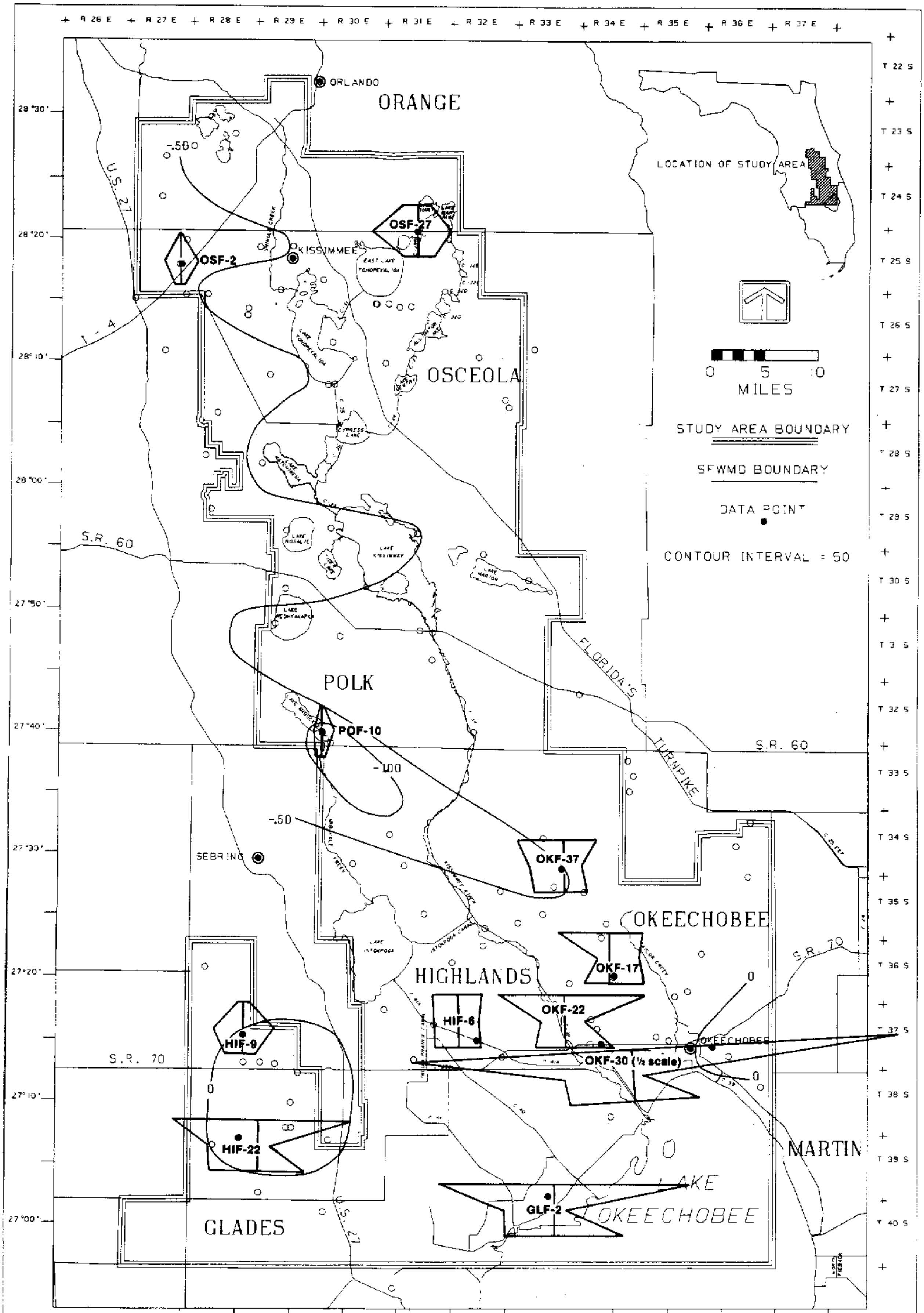


Figure 54 STIFF PATTERNS FOR SELECTED WELLS AND SATURATION INDEX, FLORIDAN AQUIFER SYSTEM

rocks and water quality. One method for examining this relationship is the determination of calcium carbonate saturation.

The distribution of the calcium carbonate saturation index for the Floridan Aquifer System in the KPA is plotted in Figure 54, along with the Stiff patterns previously discussed. The highest degree of undersaturation with respect to calcium carbonate is in northwestern Osceola County and in Polk County along the Lake Arbuckle region. Indeed, the saturation index of groundwater for the entire northwest portion of the planning area is less than -.50, indicating an undersaturation with respect to calcium carbonate and thus the potential for dissolution of the limestone. This area is associated with the movement of the freshly recharged groundwater. The groundwater in a major portion of Highlands County, where the potentiometric contours are more widely spaced, is in equilibrium with the rock indicated by a saturation index of zero. It is possible that within this zero contour calcium carbonate is precipitating. Waters from wells OKF-30 and OKF-24 also show zero or near zero saturation indices.

Since groundwater from wells OSF-2 and POF-10 have the highest potential for dissolving limestone they must therefore have the least amount already dissolved. This is indicated by the Stiff patterns which show a slight calcium-bicarbonate type water but with a very low total ionic content. Wells with near zero or greater saturation indices tend to be sodium-chloride types. The calcium-bicarbonate species are being precipitated as is indicated by a narrow middle axis of the Stiff pattern.

Since the saturation indices indicate limestone dissolution it may be indicative of sinkhole formation. Since many of these deep wells indicate an undersaturation with respect to calcite, dissolution may be occurring hundreds of feet below the land surface to form channels and cavities. This is the case for wells HIF-35 and HIF-40 which have negative saturation indices and cavities at great depths.

Piper Trilinear Diagrams

The Piper trilinear diagrams indicate different water types by the location of the point plotted in the diamond. Figure 55 is a Piper trilinear diagram using the same selected wells from Figure 54 and additional wells. The radius of the circle indicates ionic concentration. The large arrow indicates the direction of groundwater flow from the recharge area to the discharge area. The general trend is then to move from the lower left to the upper right of the diagram. This direction indicates increases in sulfate, chloride, sodium, and potassium and decreases in calcium, magnesium, carbonate, and bicarbonate. Near the recharge area to the left of the diamond (i.e. at well OSF-2), the dominant water type is calcium bicarbonate water. The samples plotted in the middle represent transitional waters. Those on the right become predominantly sodium chloride waters. One can see that OKF-30, which has the highest ionic content, plots the highest chloride and sulfate and the highest sodium and potassium of all the samples. These samples are indicative of connate water which has high chloride and total dissolved solids concentrations (Frazee, 1982).

By examining Figures 56 to 61 which show water quality trends for each county in the KPA, regional trends may be better appreciated. In Orange County (Figure 56), the samples cluster closely to the high calcium bicarbonate area representative of recharge waters. Osceola County (Figure 57) has many points which fall in the recharge waters zone. However, there are a number of points indicative of increased calcium relative to sodium and the chloride concentrations also begin to increase. Polk County wells (Figure 58) also show characteristics of the recharge area. Well POF-20 is considerably deeper than the other Polk County wells and this is reflected in

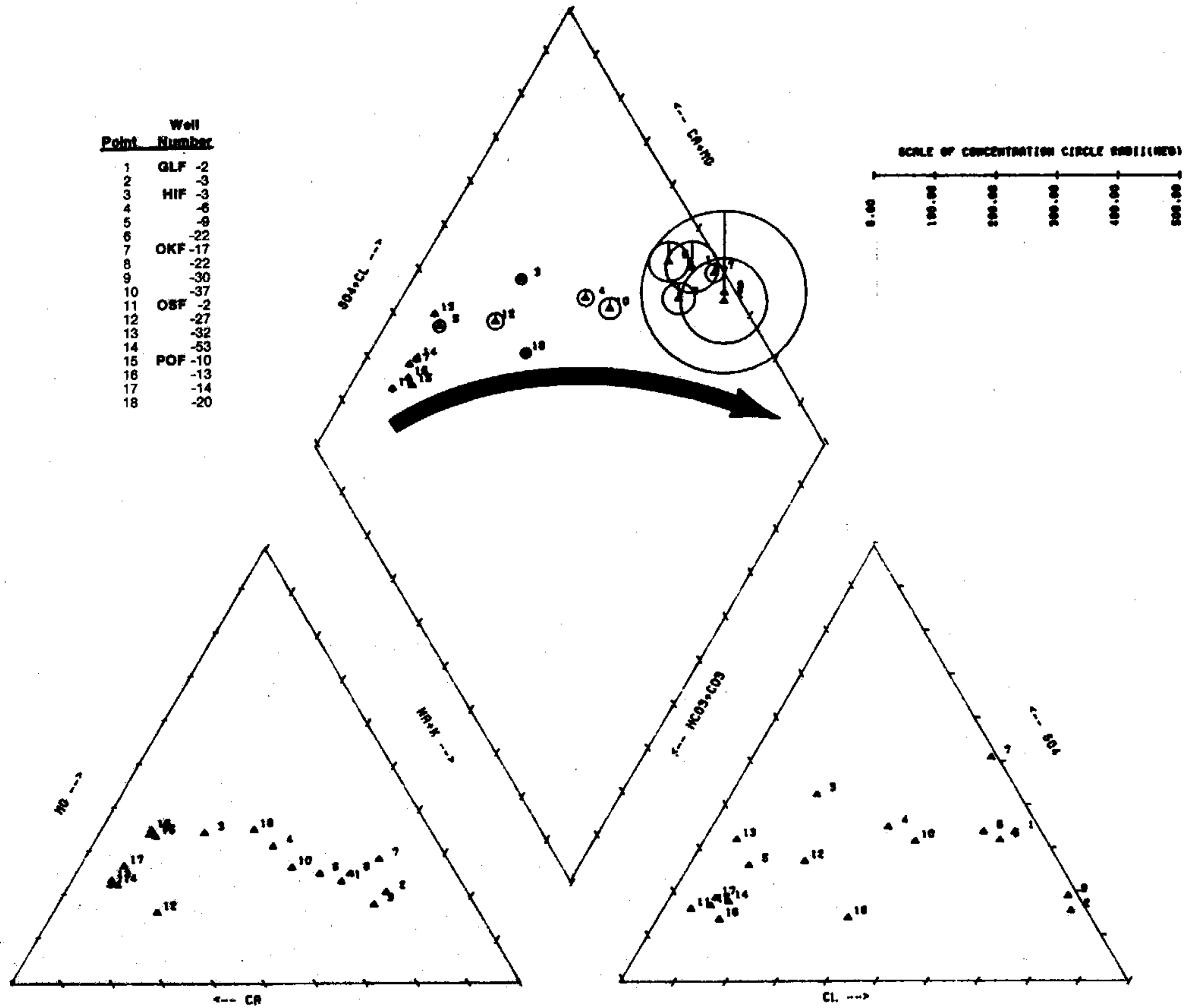


Figure 55 PIPER TRILINEAR DIAGRAM FOR SELECTED WELLS, FLORIDAN AQUIFER SYSTEM

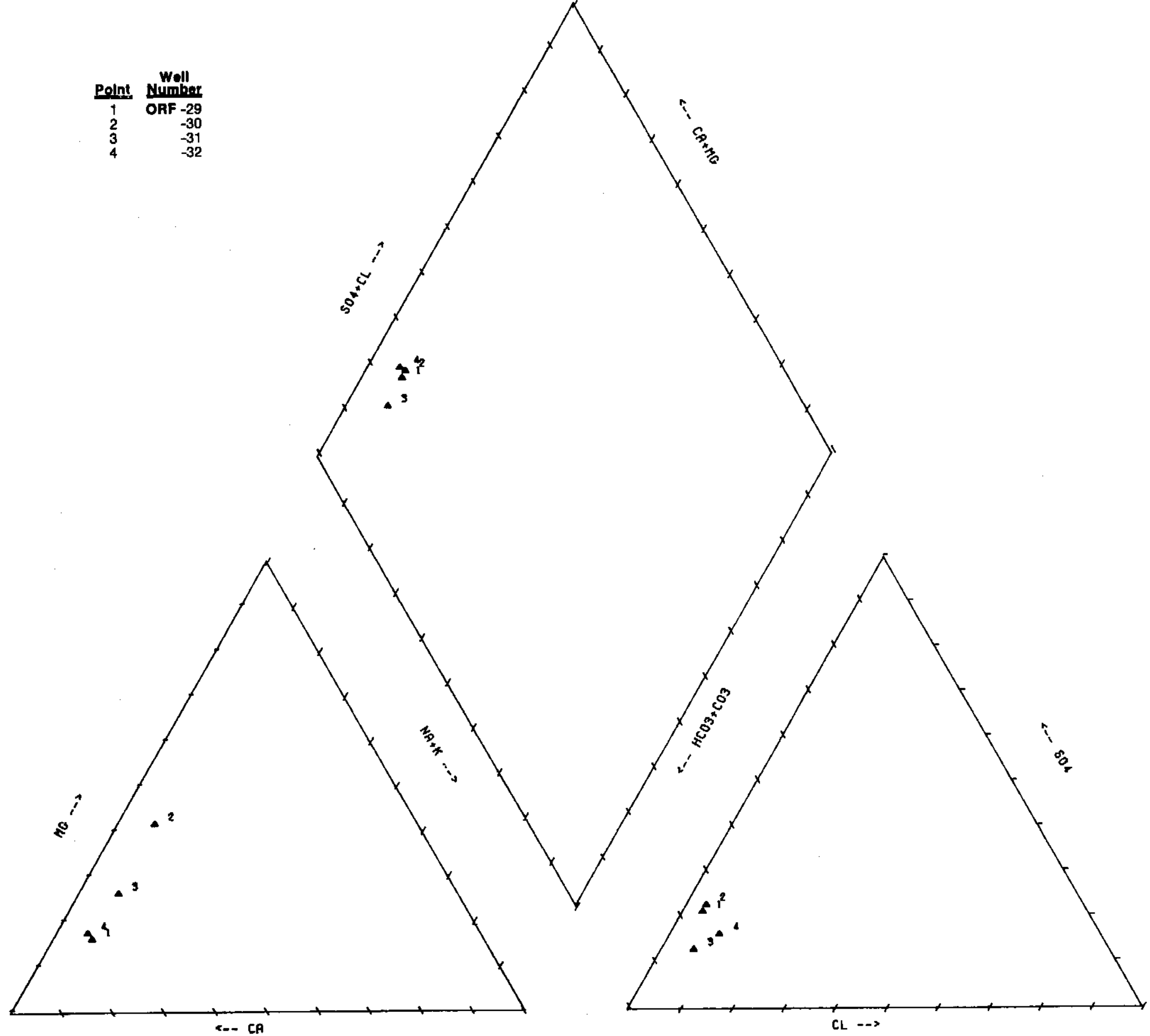


Figure 56 PIPER TRILINEAR DIAGRAM FOR ORANGE COUNTY

Point	Well Number
1	OSF -1
2	-2
3	-3
4	-4
5	-5
6	-6
7	-7
8	-8
9	-9
10	-10
11	-11
12	-12
13	-14
14	-15
15	-16
16	-17
17	-18
18	-19
19	-22
20	-24
21	-25
22	-27
23	-32
24	-33
25	-34
26	-35
27	-37
28	-42
29	-44
30	-53

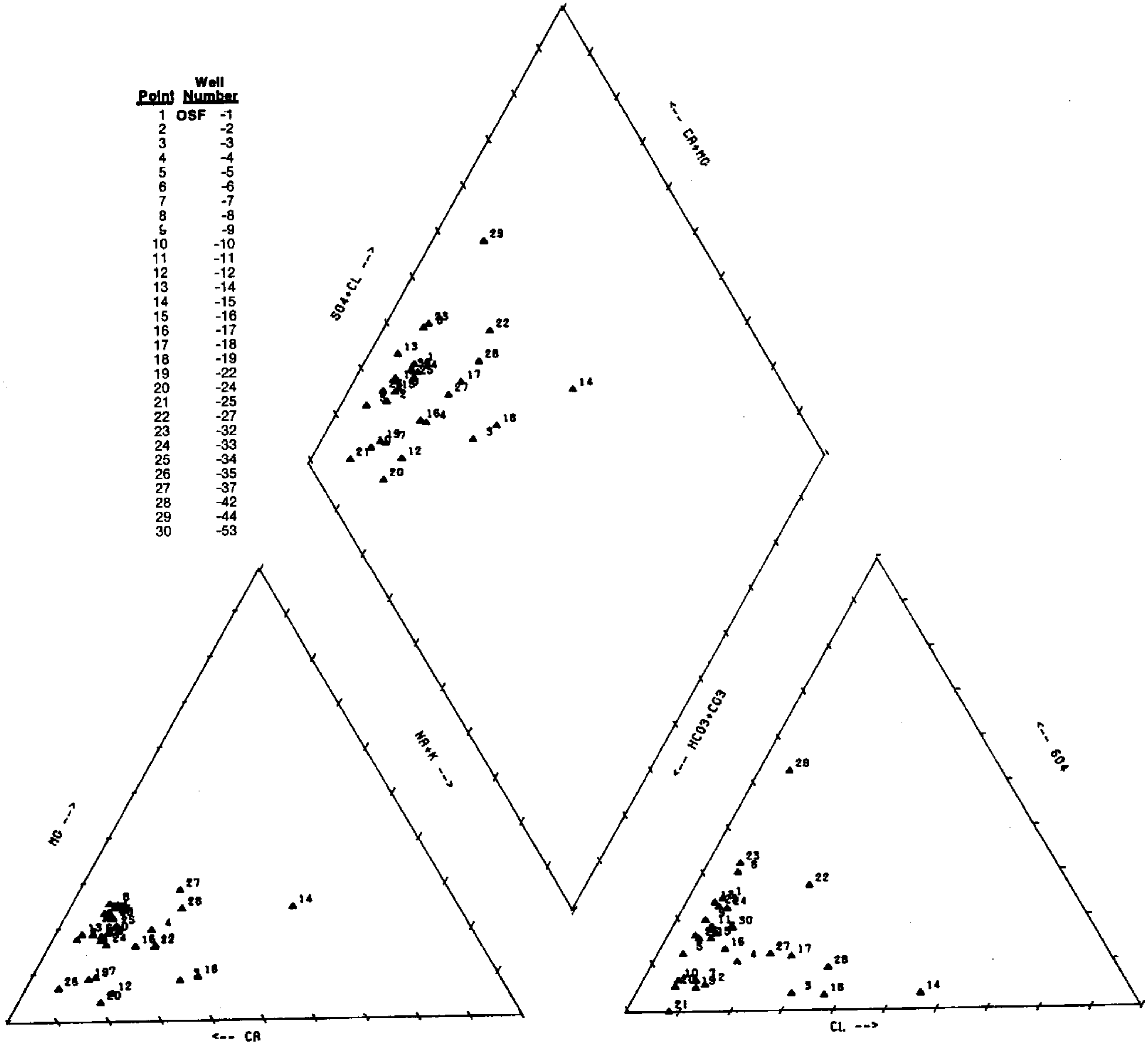
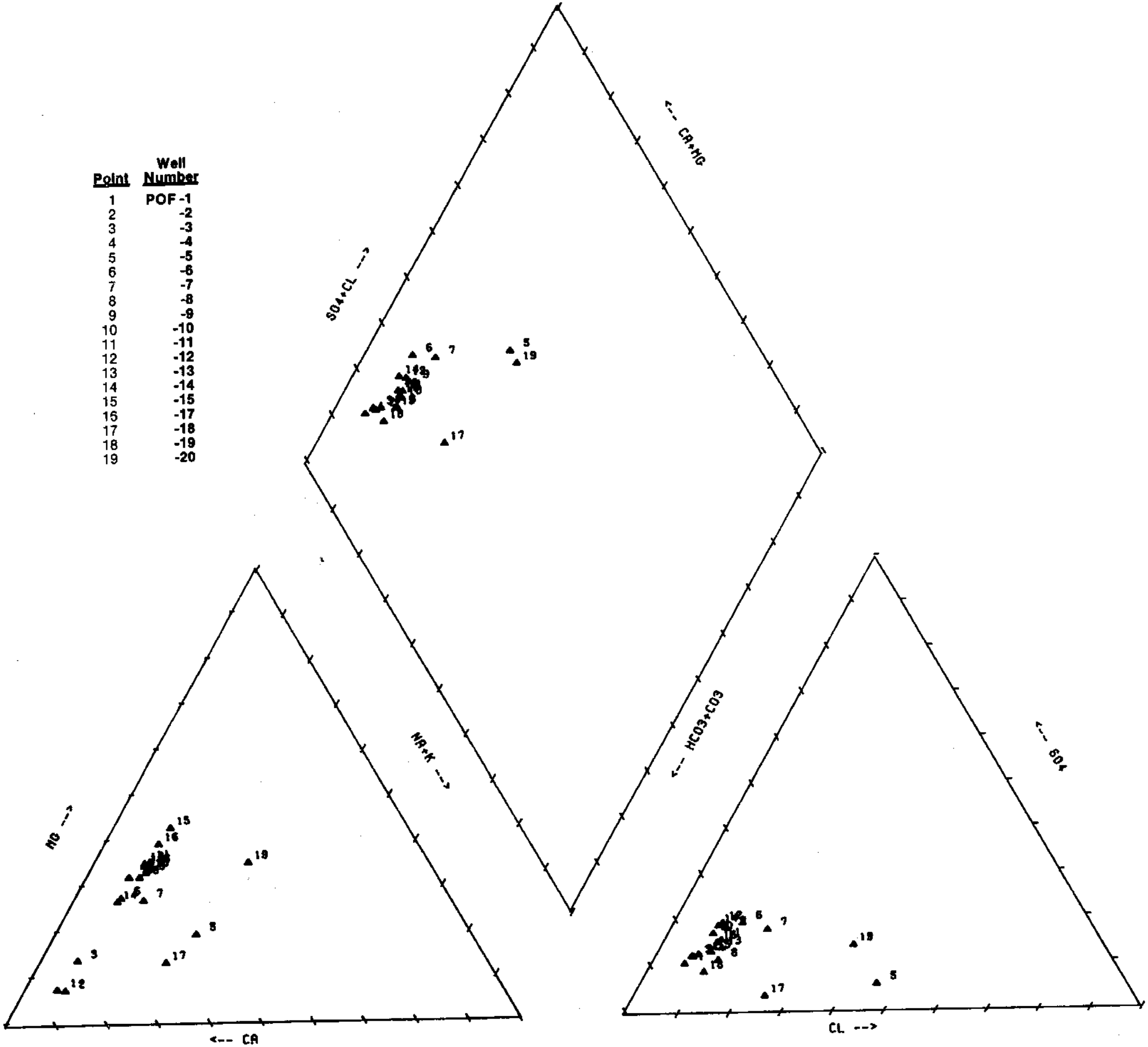


Figure 57 PIPER TRILINEAR DIAGRAM FOR OSCEOLA COUNTY



Point	Well Number
1	POF-1
2	-2
3	-3
4	-4
5	-5
6	-6
7	-7
8	-8
9	-9
10	-10
11	-11
12	-12
13	-13
14	-14
15	-15
16	-17
17	-18
18	-19
19	-20

Figure 58 PIPER TRILINEAR DIAGRAM FOR POLK COUNTY

Point	Well Number
1	OKF -42
2	-1
3	-2
4	-3
5	-4
6	-5
7	-6
8	-7
9	-8
10	-13
11	-15
12	-16
13	-17
14	-18
15	-19
16	-22
17	-23
18	-24
19	-25
20	-26
21	-27
22	-29
23	-30
24	-31
25	-35
26	-36
27	-37
28	-40
29	-50
30	-51
31	-53
32	-54
33	-56
34	-75
35	-76
36	-77

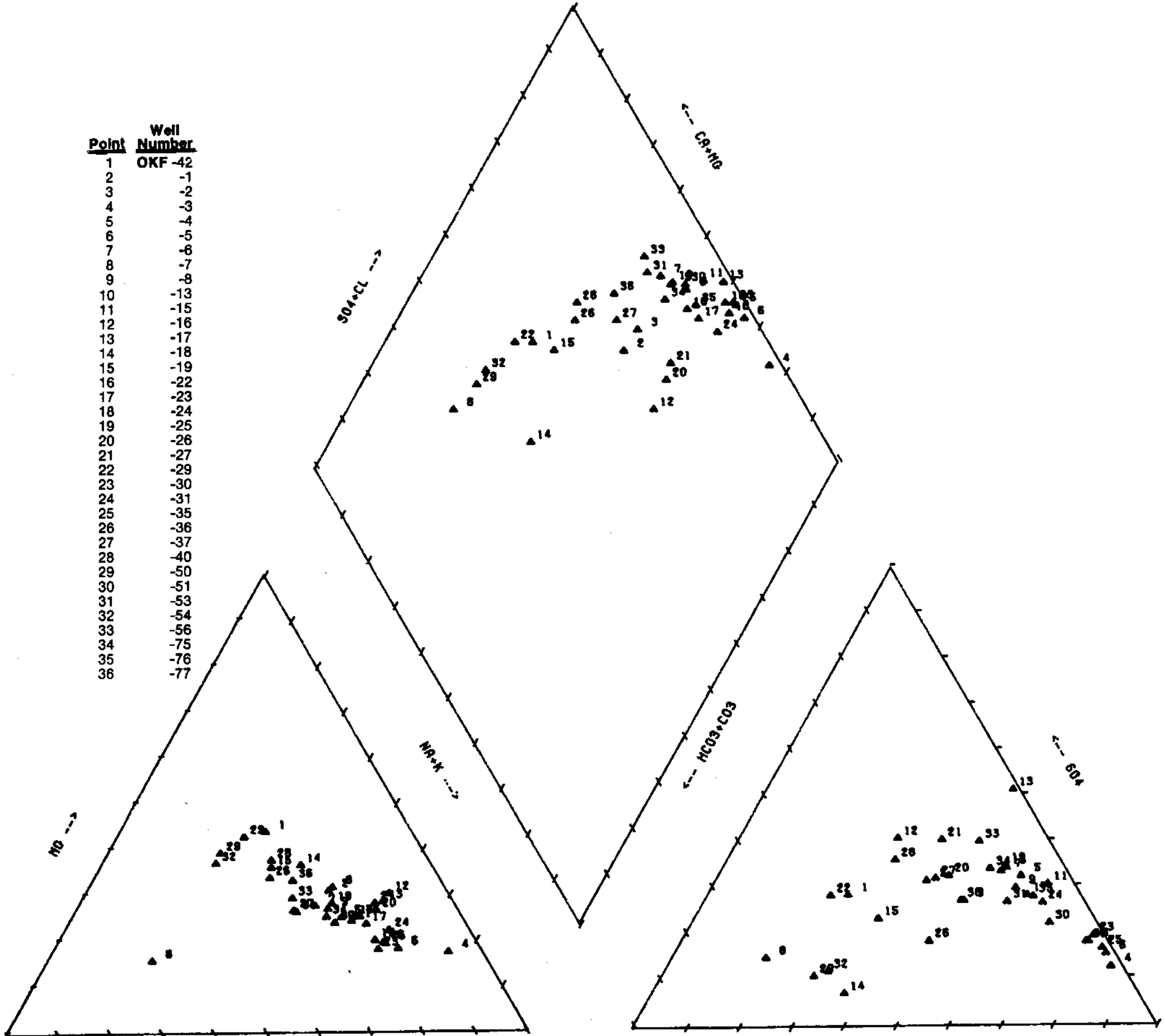


Figure 59 PIPER TRILINEAR DIAGRAM FOR OKEECHOBEE COUNTY

Point	Well Number
1	HIF-1
2	-2
3	-3
4	-4
5	-6
6	-7
7	-8
8	-9
9	-10
10	-11
11	-13
12	-14
13	-16
14	-19
15	-21
16	-22
17	-23
18	-27
19	-28
20	-29
21	-30
22	-31
23	-32
24	-35
25	-36
26	-37
27	-38

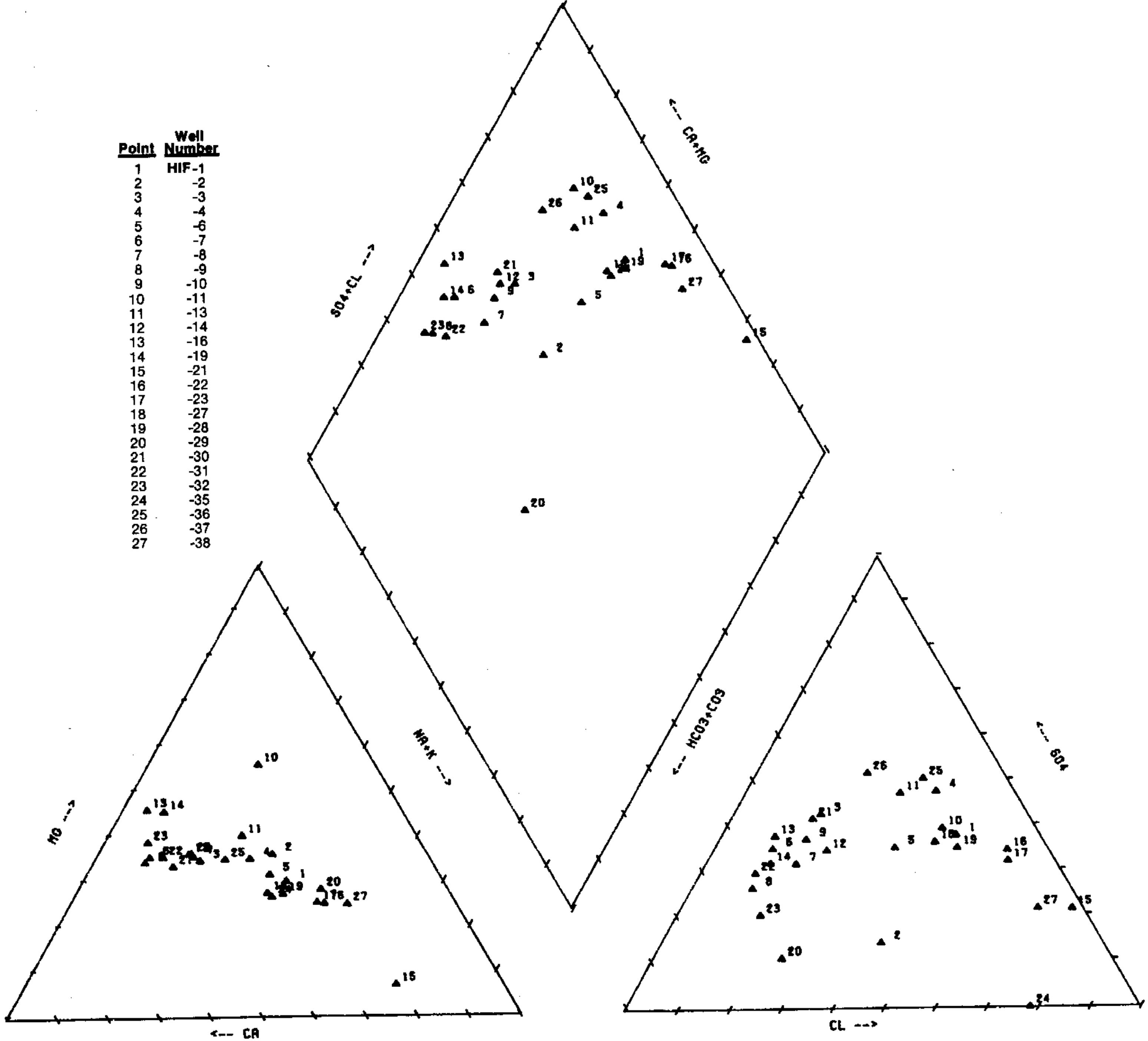


Figure 60 PIPER TRILINEAR DIAGRAM FOR HIGHLANDS COUNTY

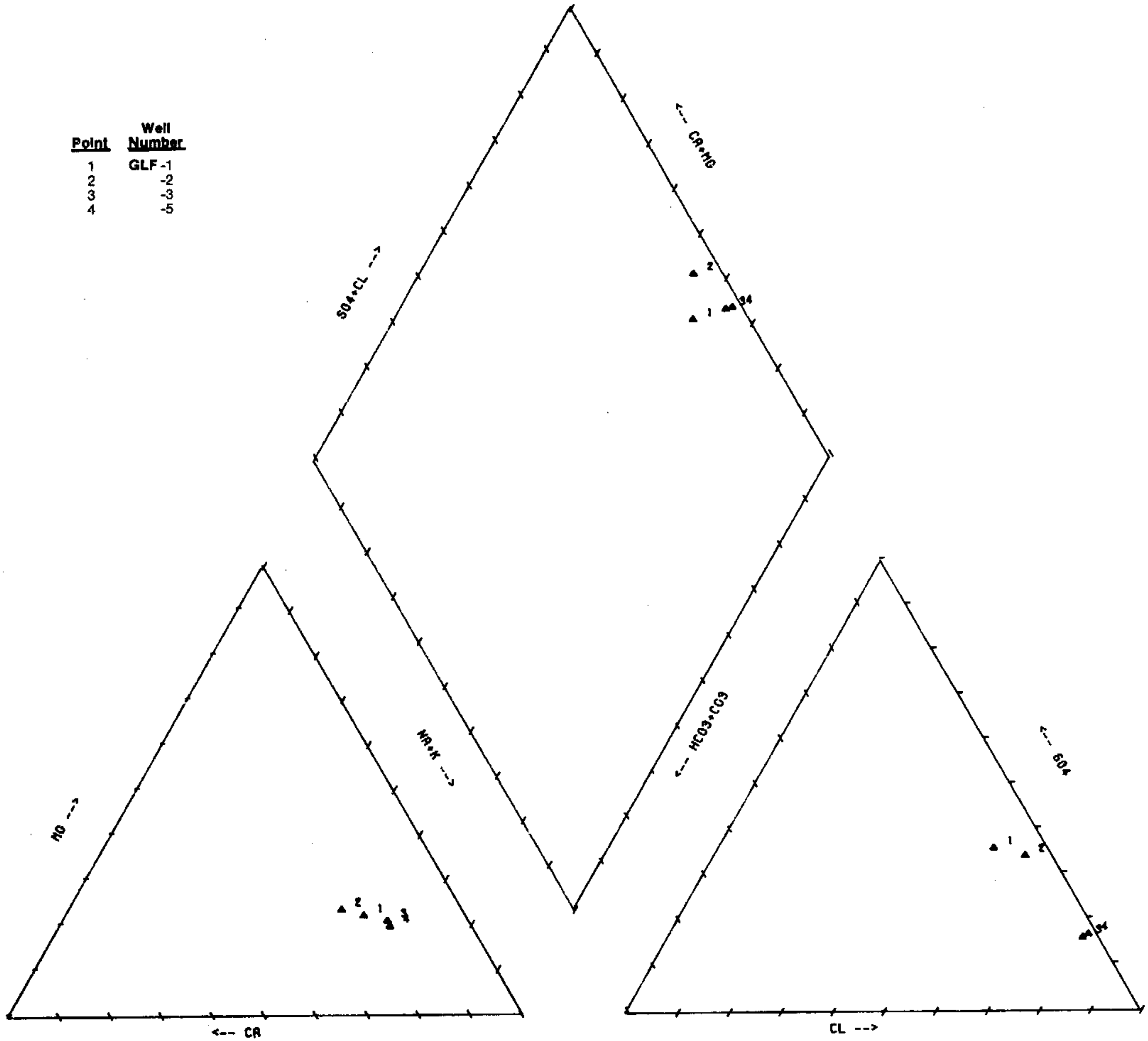


Figure 61 PIPER TRILINEAR DIAGRAM FOR GLADES COUNTY

higher sodium chloride values. Okeechobee County wells (Figure 59) cluster from transitional wells to the right of the diagram representing connate waters. As mentioned earlier in this section many of these wells are flowing artesian wells. The upwelling of these connate waters are indicated by the fact that they plot towards the 100 percent sodium chloride point. Highlands County (Figure 60) has probably the most widely scattered points as is expected from the high variability shown in other water quality analyses for this county. Glades County wells (Figure 61) cluster at the sodium chloride area of the diagram. This is to be expected since these wells are the farthest from the recharge area.

Factor Analysis

The factor analysis solution resulted in three factors which accounted for 90.2 percent of the total variability. The factors with their factor loadings are listed in Table 15. Factor scores are a measure of the intensity of each factor with respect to each station. The factor scores are similar to standard normal scores in that they have a mean of zero, a standard deviation of one, and a range of ± 3. Figures 62, 63, and 64 are contour maps of the factor scores for factors 1, 2, and 3, respectively.

Factor I accounts for 58.1 percent of the variance. It is made up of the following variables: conductivity, temperature, sodium, potassium, calcium, magnesium, chloride, sulfate, total dissolved solids, strontium, saturation index, and negative pH. It would be expected that the major ions would factor together with TDS and conductivity. Factor I therefore represents waters that are a product of dissolution of limestone. Figure 62 shows the areal distribution of the factor scores for factor I. It is quite apparent that the wells which are high in chloride and other dissolved ions show high factor scores for factor I. These include wells OKF-51, OKF-13, OKF-15, OKF-5, OKF-35, OKF-30, OKF-24, and OKF-3, as well as HIF-21, GLF-3, and GLF-5. All

TABLE 15. FACTORS AND FACTOR LOADINGS FOR AVERAGE WELLHEAD SAMPLES, FLORIDAN AQUIFER SYSTEM

FACTOR LOADINGS

	I	II	III
FACTOR I			
Conductivity	.99	-.07	.01
Temperature	.58	-.26	.46
Sodium	.97	-.10	-.04
Potassium	.95	-.07	-.03
Calcium	.93	.20	-.04
Magnesium	.94	-.09	.11
Chloride	.97	-.10	-.04
Sulfate	.94	-.17	.10
Total Dissolved Solids	.99	-.06	-.01
Strontium	.75	-.18	.34
Saturation Index	.31	.47	.81
pH	-.33	-.33	.81
FACTOR II			
Alkalinity	-.11	.96	-.07
Field Alkalinity	-.13	.98	.02
Hardness ($CaCo_3$)	-.11	.95	.06
Saturation Index	.31	.47	.81
pH	-.33	-.33	.81
Temperature	.58	-.26	.46
FACTOR III			
Saturation Index	.31	.47	.81
pH	-.33	-.33	.81
Temperature	.58	-.26	.46
Strontium	.75	-.18	.34

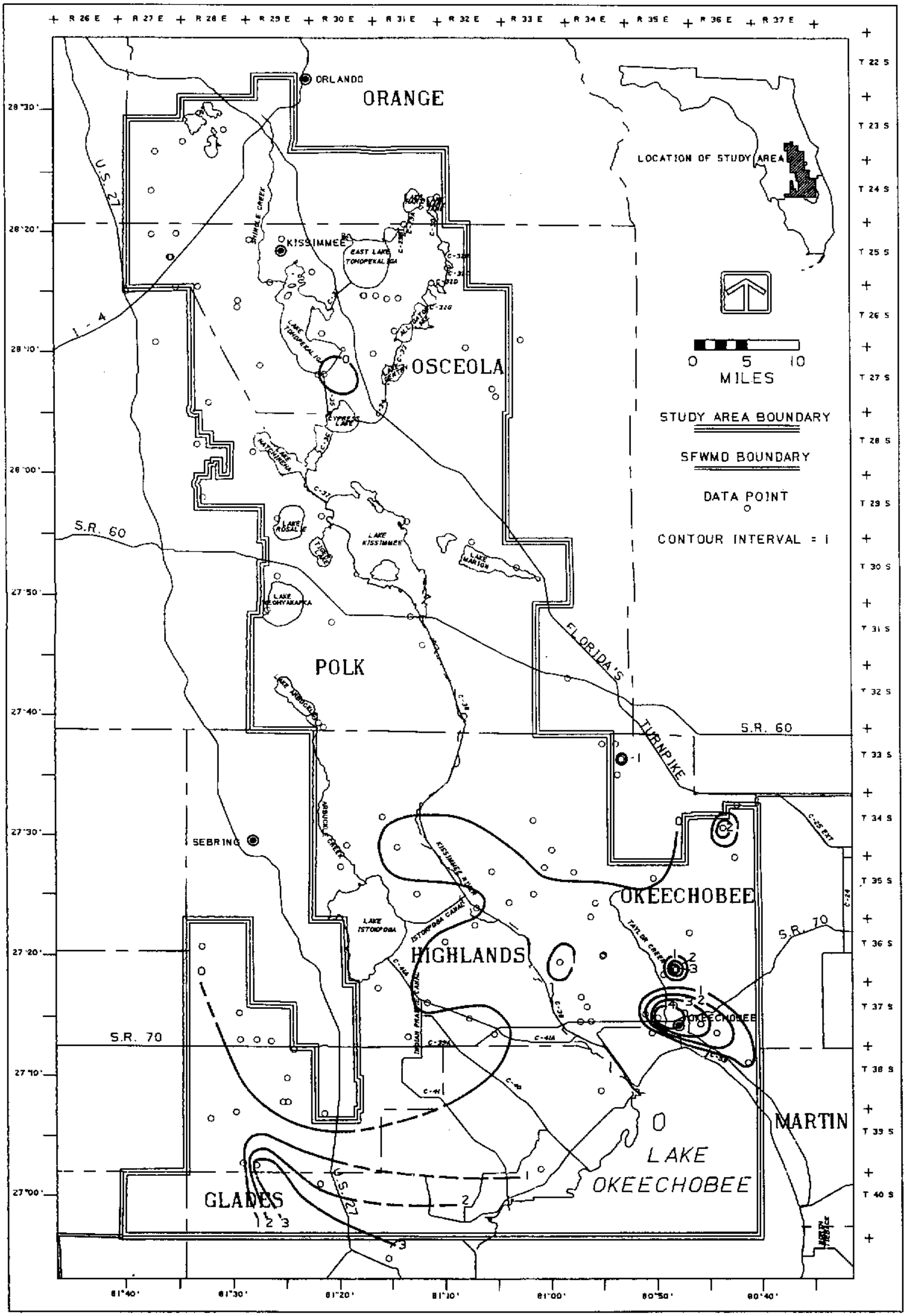


Figure 62 DISTRIBUTION OF FACTOR 1

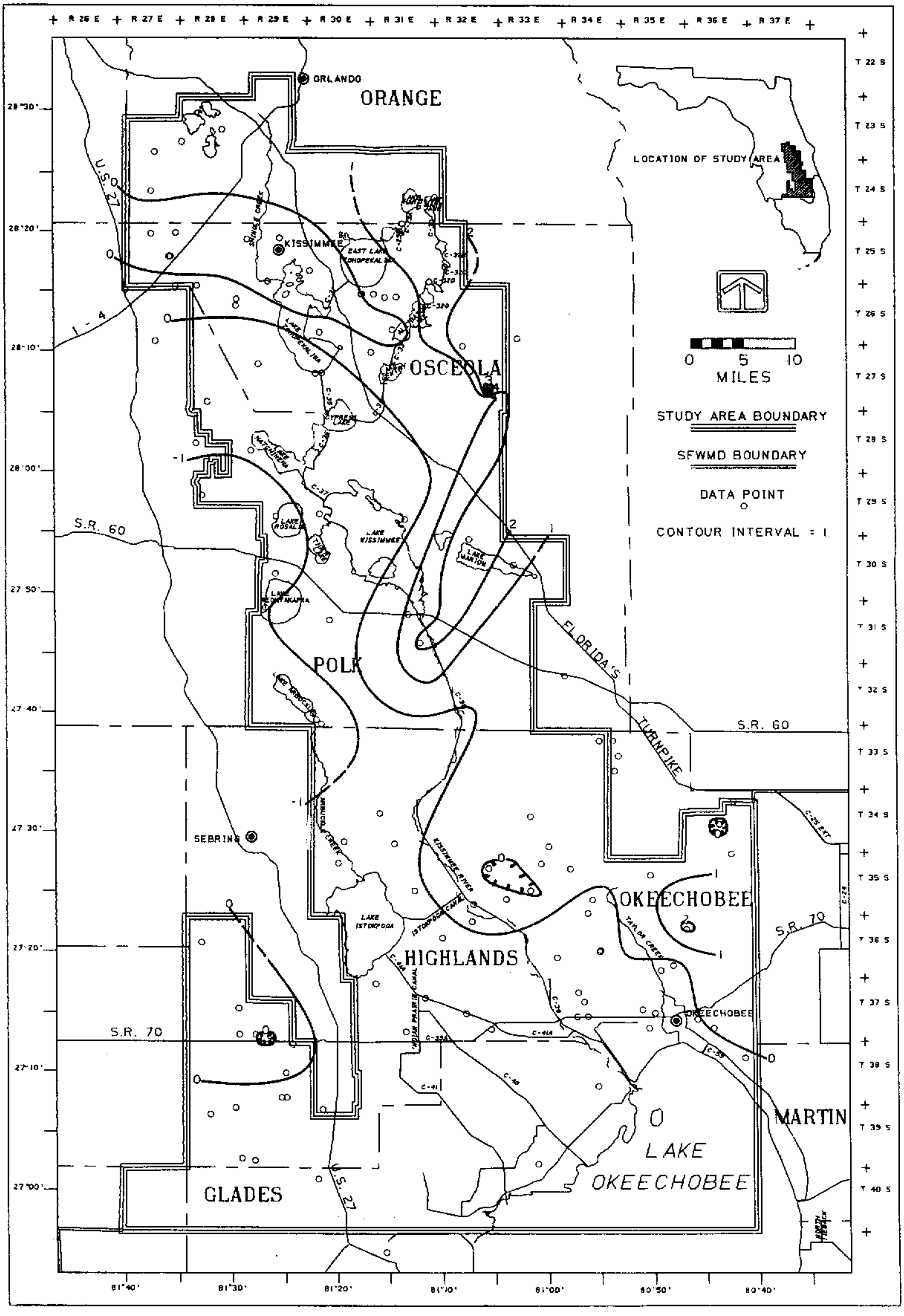


Figure 63 DISTRIBUTION OF FACTOR 2

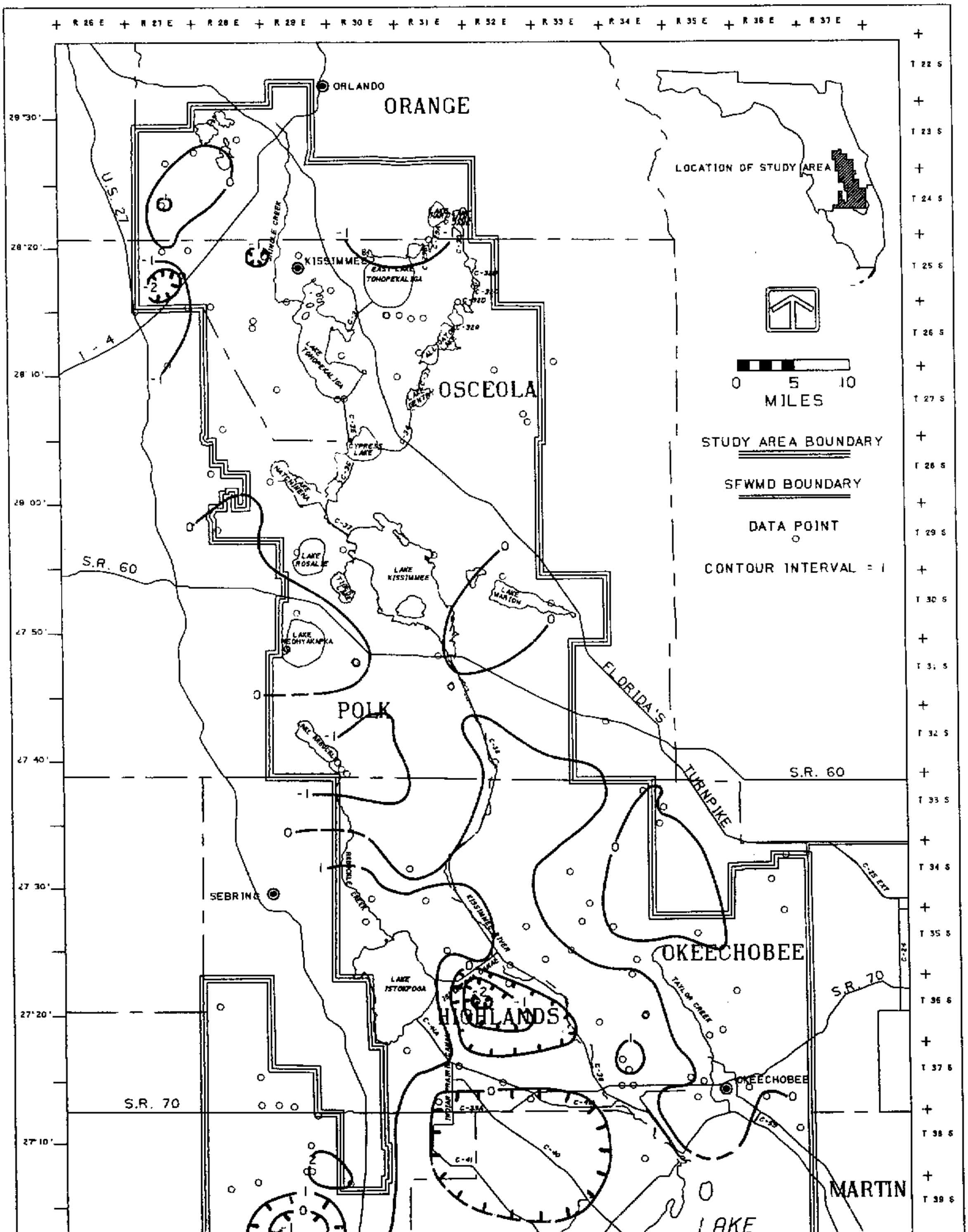


Figure 64 DISTRIBUTION OF FACTOR 3

of Polk, Osceola, and Orange Counties have factor scores less than zero indicating little influence of highly ionic or connate waters.

Factor II accounts for 21.4 percent of the variance. It is made up of the following variables: alkalinity, field alkalinity, carbonate hardness, saturation index, pH, and temperature. These variables are reflective of the concentration of dissolved carbonate species. Therefore, Factor II represents waters of dissolved limestone in the absence of connate waters. Figure 63 shows the areal distribution of the factor scores for Factor II.

Note that for the most part, the recharge area is near zero or below zero. Lawrence and Upchurch (1982) suggest that the factor score less than -1 indicates areas where dissolution has not yet reached its maximum. This hypothesis strongly agrees with the saturation index for wells along the central and western boundary of the KPA. Here we have factor scores less than -1 and also where the increases in saturation were the highest, indicating the greatest potential for limestone dissolution. This, again, is due to the rapid infiltration of fresh water in or near the recharge area. The high factor scores in the central and eastern portion of the KPA represent waters high in carbonates and bicarbonates. Other portions of the planning area are near zero and therefore not indicative of bicarbonate waters.

Factor III accounts for 10.8 percent of the variability. It is made up of the following variables: saturation index, pH, temperature, and strontium. Factor III appears to represent the transitional waters. The waters are very near saturation with respect to calcium carbonate, indicated by the high factoring together of the saturation index and the pH. Wells with transitional waters are concentrated in northern Highlands County and between Osceola and Okeechobee Counties and shown in Figure 64.

Factor analysis was capable of distinguishing three broad water types: carbonate waters, transitional waters, and connate waters. However, there was a general overlapping of certain variables. The pH, temperature, and saturation index factored out into all three factors. Strontium appeared in both Factor I and III. These redundancies may have occurred for several reasons. Temperature and pH are variables used in the calculation of the saturation index. Therefore, the three variables would be expected to factor together. These variables are also dependent upon characteristics of both Factors I and II so they factor with them even though they most strongly factor out in Factor III. These overlaps may also be due to mixing of waters from different depths within the borehole. Therefore, some samples represent a homogeneous mass that will not have distinct characteristics (i.e. factors). Factor analysis is probably more applicable to defining different aquifers or aquifers where the changes in water quality are more clearly distinguished.

Table 16 lists four methods of interpreting water quality along with their advantages and disadvantages. In regional studies such as this one, the author finds that the Piper trilinear diagram has the greatest advantages over the disadvantages for interpreting trends in water quality. It is the easiest method for plotting each sample location with the highly variable data found in the KPA. Not only can an individual sample be classified by its position in the triangle, but the trend for the entire aquifer is apparent. The movement of groundwater can be traced from the recharge area, through the transitional water, to the areas of connate water as the points plot from the left to right on the diamond. Using a classification scheme such as Frazee (1982) any water quality sample may be easily classified.

Water Quality With Depth

The samples previously discussed represent a mixture of water from all zones penetrated by individual wells. Water quality variations with well depth are masked by mixing of water from different zones. To determine water

TABLE 16. ADVANTAGES AND DISADVANTAGES TO DIFFERENT METHODS USED IN INTERPRETING WATER QUALITY DATA

METHODOLOGY	ADVANTAGES	DISADVANTAGES
Contour mapping of raw data	No data manipulation. Actual measurements may be plotted. May plot desired contour interval. Water masses are identifiable in some cases. Good areal perspective.	Must plot each variable for each sample site separately. Must plot numerous maps. Anomalous data difficult to contour.
Stiff pattern	Considers multiple variables on one pattern. Pattern recognized universally. Ionic content inferred. Easily interpreted by laymen.	Must convert data to milli-equivalents. Large differences in ionic content must be plotted at different scales. Includes only the seven major ions. Each sample must be plotted separately.
Piper trilinear diagram	Considers multiple variables on one diagram. May plot a large number of samples on one diagram. Indicates trends in water quality. May be used a classification scheme.	Must convert data to milli-equivalents. Must convert data to relative percent proportions No indication of concentrations. Includes only the seven major ions.
Factor analysis	All available water quality data may be used allowing for a large number of variables. Water types are identifiable. A large number of samples may be used. Reduces data to a smaller number of factors. Factor scores may be plotted. Raw data is input.	Strong statistical background needed. Results not always easily interpretable. Not always applicable to water quality studies. Must plot factor scores for each sample site for each factor separately.

quality in specific zones, samples were collected at predetermined depths using a downhole fluid sampler. The sampling tool, which is operated with the geophysical logger, is lowered to a particular depth and the ports are then electronically opened to allow water to fill a hollow chamber. The ports are then closed and the water sample, which is indicative of the quality at the depth it was collected, is brought to the surface for analysis. Changes in various water quality parameters can be plotted to give a profile with depth. Figure 65 shows a profile of the chloride concentration for point samples at well HIF-38. Values ranged from a low of 187.7 mg/l at the wellhead to a high of 518.2 mg/l at a depth of 1380 feet. Although this is an excellent method for determining water quality trends with depth, data collection is somewhat tedious since the tool must be raised and lowered for each sample.

An indirect method of determining water quality variations with depth on a continuous basis involves use of the Fluid Resistivity Log. Figure 65 also shows the Fluid Resistivity Log for well HIF-38. The Fluid Resistivity Survey measures the resistivity of borehole fluid directly in ohm-meters. Kwader (1983) shows that in Florida the resistivity of formation water (Rw) is highly correlated with the chloride concentration. By comparing the point sample values for chloride concentration to the resistivity of the formation water from the Fluid Resistivity Log (Figure 66), a linear relationship can be derived.

Since Rw and conductivity are related by the equation:

$$\text{Conductivity} = 10{,}000/R_w \qquad (12)$$

The data can be plotted in terms of both Rw and conductivity. In the case of HIF-38 the equations are:

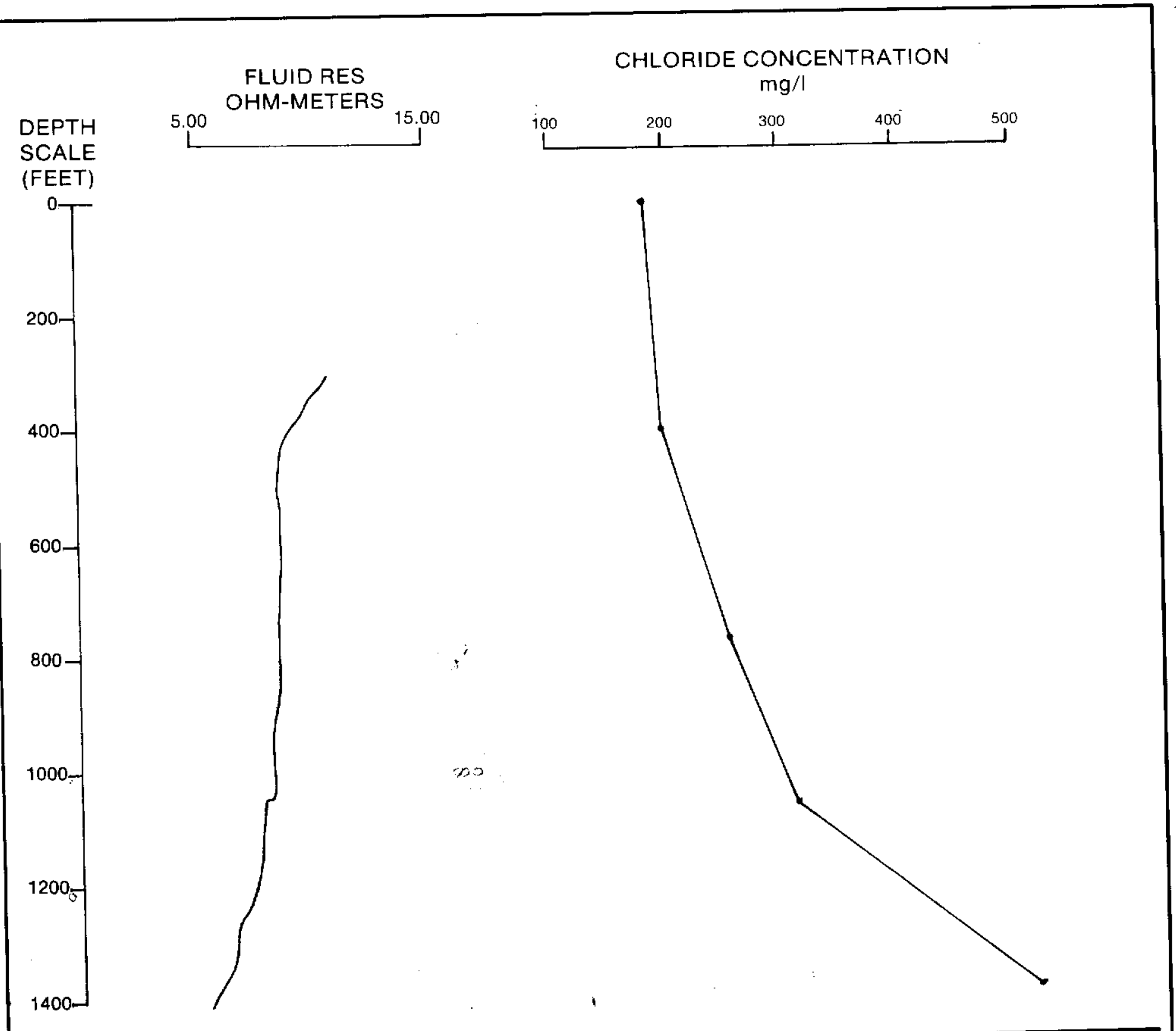


Figure 65 FLUID RESISTIVITY AND CHLORIDE CONCENTRATION WITH DEPTH, WELL HIF-38

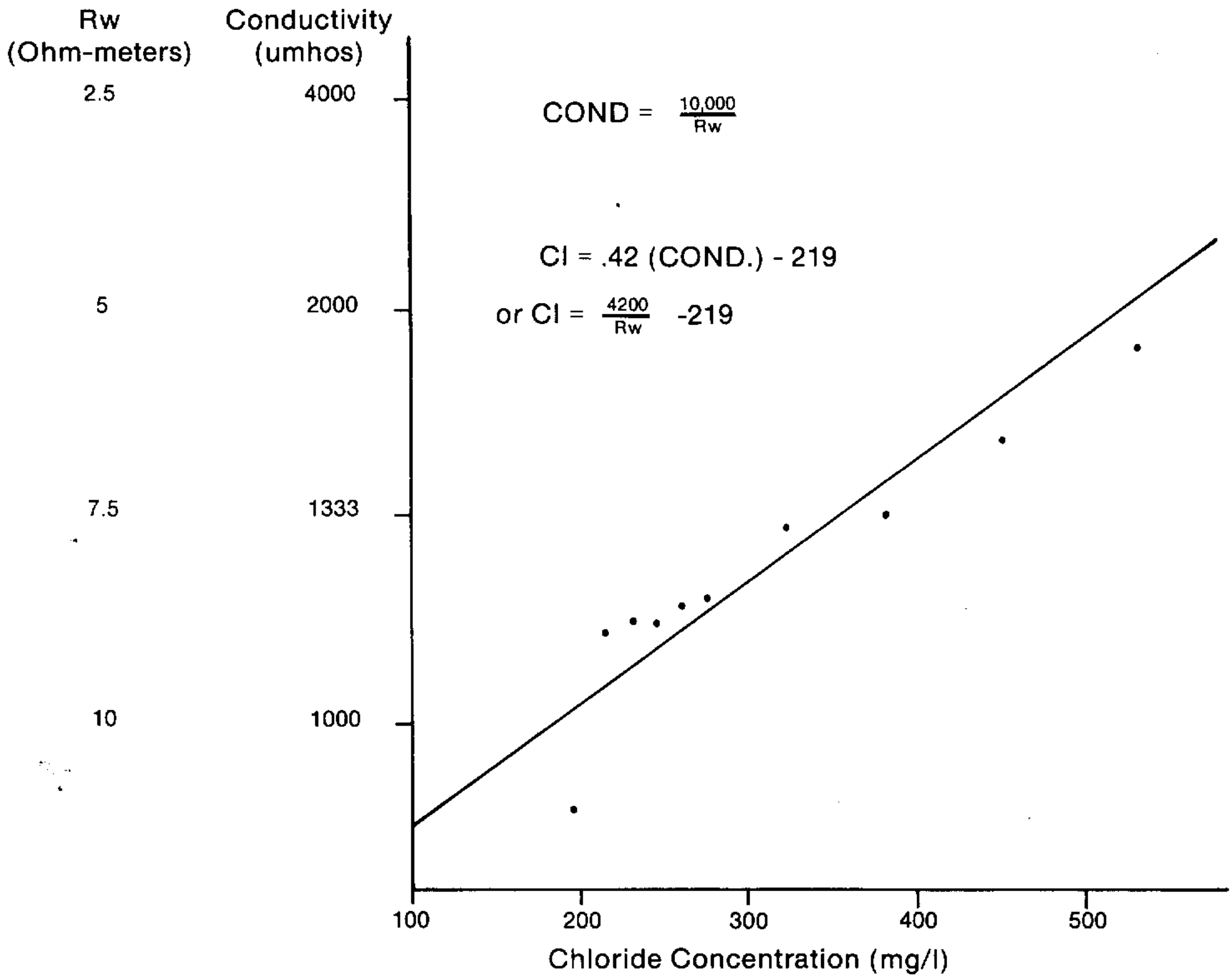


Figure 66 CHLORIDE CONCENTRATION VERSUS FLUID RESISTIVITY, WELL HIF-38

$$Cl = .42\ (Cond.) - 219 \qquad (13)$$

Or,

$$Cl = \frac{4200}{Rw} - 219 \qquad (14)$$

The equation closely resembles that of Kwader (1983) which is:

$$Cl = .35\ (Cond.) - 153,$$

for a Floridan aquifer well in Seminole County.

Using the relationship in Equations 13 or 14, data from the Conductivity or Fluid Resistivity Survey measurements can be used to determine chloride concentration. Examination of Fluid Resistivity Logs from a number of wells in the KPA indicates that chloride concentration increases with increased well depth. In addition, a comparison between depth of penetration of the Floridan Aquifer System and chloride concentration from wellhead samples yields a statistically significant correlation coefficient; $r = .4041$ at 99 percent confidence.

The potentiometric maps presented in Figures 27 through 32 show the direction of groundwater movement from the recharge areas in the west and northwest towards the east and south. Adjacent to the recharge areas, the potentiometric contours are close together, indicating a steep groundwater gradient and possible rapid movement of groundwater away from the recharge area perpendicular to the contours. In the eastern and southern portion of the KPA, potentiometric contours are more widely spaced, indicating a gentle groundwater gradient and possibly slower movement of groundwater. Longer residence time for groundwater within the aquifer generally results in more dissolved ions being put into solution as the rocks are slowly dissolved. It was noted in the geology section of this report that wells which penetrate the Floridan Aquifer System in the southern portion of the KPA are generally deeper than those to the north, due to the increased thickness of the overlying confining beds. The three-dimensional illustration (Figure 26) shows that a major depression occurs in the top of the Floridan Aquifer System in Okeechobee County. The occurrence of poorer quality water in the southern portion of the area may therefore be due to sluggish groundwater movement down dip of the potentiometric surface high, and possibly the presence of connate water trapped in the stratigraphic depression. In addition, since many of the wells are free-flowing in Okeechobee County, the continuous discharge may have caused upwelling of waters of possibly poorer quality from deeper zones. The length of time the well is in operation may also be a contributing factor to poor water quality, since the extended period of use may have resulted in increased drawdowns and consequently increased upward leakage of saline or brackish water.

AQUIFER PARAMETERS AND WELL YIELDS

Introduction

Assessment of the potential of an aquifer to store and supply water is based on a knowledge of the hydraulic characteristics of the rocks which compose the aquifer and adjacent confining and semi-confining strata. The aquifer parameters of particular relevance are transmissivity (T), storage coefficient (S) and leakage coefficient (L). These parameters are used to quantify the availability of groundwater, to determine regional and local water level and water quality impacts due to withdrawal of water from the aquifer, and to formulate water management strategies for long term exploitation of the aquifer system.

The above aquifer coefficients can be determined by analyzing the changes in water levels in observation wells at known distances from a well from which water is withdrawn at a constant rate. However, observation wells were not available for aquifer tests during this study to monitor water level changes. Consequently, water level recovery data from single production well tests were used for limited calculations of aquifer parameters. With this method, a transmissivity value for the aquifer in the vicinity of the well can be determined. To obtain coefficients of storage and leakage, one or more observation wells must be available.

The coefficient of transmissivity (T), expresses the ability of the aquifer to transmit water. Transmissivity is defined (Lohman, 1972) as the rate at which water of a prevailing kinematic viscosity is transmitted through a unit width of the aquifer at a unit hydraulic gradient. In this report the coefficient of transmissivty will be expressed in units of gallons per day per foot (gpd/ft).

The storage coefficient (S), also referred to as storativity, is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head normal to that surface. The storage coefficient is expressed as a dimensionless number. The coefficient of leakage is defined by Hantush (1964) as the rate of flow across a unit area of the interface between the main aquifer and the semipervious layer, if the difference between the heads at the top and bottom of the semipervious layer is unity. The coefficient of leakage is often expressed in units of gpd/ft^3, or 1/t, where t is time.

Some of the other common terms relating to pump tests and aquifer tests that are used in this report are defined in the following paragraphs.

The static water level is the level at which water stands in a well when no water is being removed from the aquifer by pumping or free flow. In this report it is expressed as the distance, in feet, from a given measuring point on the well head to the water level in the well. In the case of a flowing well, the static water level, or shut-in head, is above land surface and is measured using a pressure gauge calibrated in feet of water after shutting off the flow of the well.

The pumping level is the level at which water stands at a given moment in a well when the well is discharging. Although in the case of a flowing well, where no pump is actually used, the terminology is retained to avoid confusion. The drawdown (s), is the difference, in feet, between the static water level and the pumping level. The well yield (Q), is the volume of water per unit time that is discharged from a well by pumping or free flow. In this report the well yields are measured in gallons per minute (gpm).

After pumping has stopped, the water level in the well will rise and approach the static water level that was observed before pumping began. This period is called the recovery period. During the recovery period, the difference between the water level in the well at a given time and the original static water level is the residual drawdown, which is measured in feet.

Data used to obtain a regional picture of aquifer characteristics of the Floridan Aquifer System throughout the planning area was obtained from the following sources:

(1) Published values of aquifer parameters.

(2) Analysis of available discharge/drawdown data obtained from tests conducted by SFWMD and the USGS.

(3) Well driller's reports.

(4) Data developed from aquifer tests performed during this study.

No observation wells were available during these tests: therefore, the transmissivity of the aquifer system at the well site was derived from a straight-line method in which the residual drawdown is plotted on semi-log paper against the ratio t/t', where t is the time since pumping began and t' is the time since pumping stopped. This method of analysis was derived from the Theis equation, and does not allow determination of the storage coefficient (S).

In addition to aquifer parameters, data recorded under controlled conditions during field tests at wells in the KPA can give a measure of the productive capacities of the individual wells. This type of well test is called a specific capacity test, or production test.

The specific capacity of a well is defined as the yield per unit drawdown and is represented as:

$$S.C. = \frac{Q}{s} \qquad (15)$$

Where,

S.C. = specific capacity (gpm/ft drawdown)

Q = discharge (gpm)

s = drawdown (ft)

The specific capacity of an individual well is not a constant, as evidenced by the production test data for wells OSF-11, OKF-17, HIF-1, and HIF-39. Since drawdown generally tends to increase during pumping, the specific capacity value for a given well may decrease with continued pumping. In addition, friction losses or well losses generally increase for a particular well as the discharge, Q, increases. Greater friction losses result in larger drawdowns, and hence a lower specific capacity value may be obtained for a well if the discharge is increased unless corrections are made for friction losses. A decline in specific capacity for a given well over time may indicate an inefficient well due to faulty construction, improper well development procedures, deterioration of the well casing, or caving of the borehole material (Bouwer, 1978).

Several authors have utilized specific capacity data from wells in a given aquifer system to estimate the transmissivity of the aquifer. Logan (1964) worked with field data for a confined aquifer system in Illinois and developed an empirical relationship between specific capacity and transmissivity based on the Theim equation. The resulting equation for an aquifer under confined conditions is:

$$T = \frac{1750\ Q}{s} \tag{16}$$

Where,

T = transmissivity (gpd/ft)

Q = discharge (gpm)

s = drawdown (ft)

Logan indicated that transmissivities estimated from this empirical relationship often differed by as much as 50 percent below to about 50 percent above values of transmissivity computed from pump test data. However, the errors of the estimates for several of the given examples in Illinois were less than 10 percent. Logan concluded that using the empirical estimates was useful if the resultant transmissivities were accepted as being only approximations.

According to Walton (1970, p. 315) the theoretical specific capacity of a well discharging at a constant rate in a homogenous, isotropic, nonleaky artesian aquifer infinite in areal extent is given by the following modification of the Theis equation:

$$\frac{Q}{s} = \frac{T}{264 \log \left(\frac{Tt}{2693 r_w^2 S}\right) - 65.5} \tag{17}$$

Where,

$\frac{Q}{s}$ = specific capacity (gpm/ft)

Q = discharge (gpm)

s = drawdown (ft)

T = coefficient of transmissivity (gpd/ft)

S = coefficient of storage (dimensionless)

r_w = nominal radius of well (ft)

t = time in minutes after pumping started

The equation assumes fully penetrating wells, negligible well loss, and an effective radius of the production well unaffected by drilling or well development, and equal to the nominal radius of the production well.

Applying equation (17) above, Walton assumed different values of well radii, storage coefficient, and pumping duration in order to construct graphs which he then used to obtain rough estimates of transmissivity from specific capacity data.

Uhl and Sharma (1978) also used the Theis equation to present theoretical plots of 12-hour specific capacity versus transmissivity for wells drilled in crystalline rocks by assuming several values of the storage coefficient. The actual values of specific capacity (corrected for well loss) and transmissivity determined from pump tests were also plotted. They concluded that for some of the pumping tests that were run, the analytical method used was reasonable.

An empirical relationship between specific capacity and transmissivity for wells penetrating the Floridan Aquifer System in the KPA was developed by performing a regression analysis on 11 values of corrected specific capacity and 11 values of transmissivity determined from recovery tests performed during this study. Drawdown data obtained from drillers reports and from all production tests performed during this study were corrected for friction losses in the well casings. The friction loss along the length of the well casing will result in an apparent drawdown which is greater than the actual drawdown of the potentiometric surface of the aquifer system at the well site. These corrections must be made so that values of specific capacity and transmissivity are not artificially low. Corrections for head losses in valves, elbows, and constrictions near the wellhead or point of discharge of the wells were not performed, since these head losses were not considered signifciant when compared to the total drawdown in the wells.

In addition to corrections for head loss in the wells, logarithmic transformation of the resulting values of corrected specific capacity and transmissivity was performed prior to the regression analysis due to the exponential relationship expressed in the Theis equation between drawdown, discharge, transmissivity, and storage. According to Chow (1964), "the transformation of variables has three basic advantages, which may or may not all occur in a given transformation: (1) a simple linear relationship is obtained among the transformed variables, (2) the marginal distribution of the transformed variables approach more closely to the normal distribution than do those of the untransformed variables, and (3) the variation of the points along the regression line is more homogeneous." A logarithmic transformation is generally used in hydrology more often than others.

<u>Distribution of Aquifer Parameters</u>

Values of aquifer parameters obtained from publications of the USGS or private consulting firms are presented in Table 17 and on Figure 67. The results of 12 production tests performed by the SFWMD and the USGS on non-flowing wells are presented in Table 18, along with the results of 4 production tests conducted by SFWMD personnel on flowing wells in the study area. Data compiled from 13 production tests conducted by well drillers is presented in Table 19. Results of 11 aquifer tests performed on flowing artesian wells during this study are presented in Table 20.

The empirical relationship between specific capacity and transmissivity for wells penetrating the Floridan Aquifer System in the planning area is described by the following equation:

$$\log_{10} (Tp) = 2.9436 + 1.2308 (\log_{10} (S.C_c)) \qquad (18)$$

Where,

Tp = estimated transmissivity value (gpd/ft)

$S.C_c$ = corrected specific capacity value (gpm/ft)

The values of corrected specific capacity and calculated transmissivity are plotted on Figure 68. The solid line on Figure 68 is the best-fit line determined through a regression analysis of the data. Theoretically, this line represents the empirical relationship between the specific capacity and transmissivity of the Floridan Aquifer System in the KPA. The relationships shown in equation (18) and on Figure 68 can be used to estimate aquifer transmissivity using corrected specific capacity data from wells which penetrate the Floridan Aquifer System.

TABLE 17. PUBLISHED VALUES OF AQUIFER PARAMETERS

WELL	LAT/LONG	SEC TWP RNG	TOTAL DEPTH FT	CASING DEPTH FT	DEPTH PENETRATION FT	CASING DIAMETER IN.	HYDRAULIC CHARACTERISTICS OF FLORIDAN AQUIFER SYSTEM	SOURCE OF DATA
A	28 33 43 81 22 27	24-22S-29E	.	.	.	.	$T = 5 \times 10^6$ gpd/ft $S = 2.0 \times 10^{-3}$	"The Effects of Groundwater Withdrawals in the Orlando Area," by CH2M Hill for Orlando Utilities Commission November 1979 (Well #2, Highlands Plant).
B	28 25 31 81 09 57	1-24S-31E	300	226	74	4	T = 445,000 gpd/ft $S = 6.3 \times 10^{-4}$ $L = 4 \times 10^{-3}$ gpd/ft^3	Lichtler, et al., 1968. "Water Resources of Orange County, Florida": State of Florida, Division of Geology, Report of Investigations No. 50 (Observation Well Cocoa D).
C	28 23 52 81 31 32	17-24S-28E	910	237	673	12	T = 590,000 gpd/ft $S = 1.6 \times 10^{-3}$	Dames & Moore, May 1969. "Report - Evaluation of Floridan Aquifer, Pumping Test of Well No. 5, Near Administration Building, Walt Disney World, Near Orlando, Florida for WED Enterprises, Inc." (Observation Well #1).
D	28 31 00 81 22 00	36-22S-29E	350	88	262	12	T = 455,000 gpd/ft $S = 7.1 \times 10^{-4}$ L = 0.131 gpd/ft^3	Lichtler, et al., 1968. "Water Resources of Orange County, Florida": State of Florida, Division of Geology, Report of Investigations No. 50 (Test 1, Well #831-122-15).

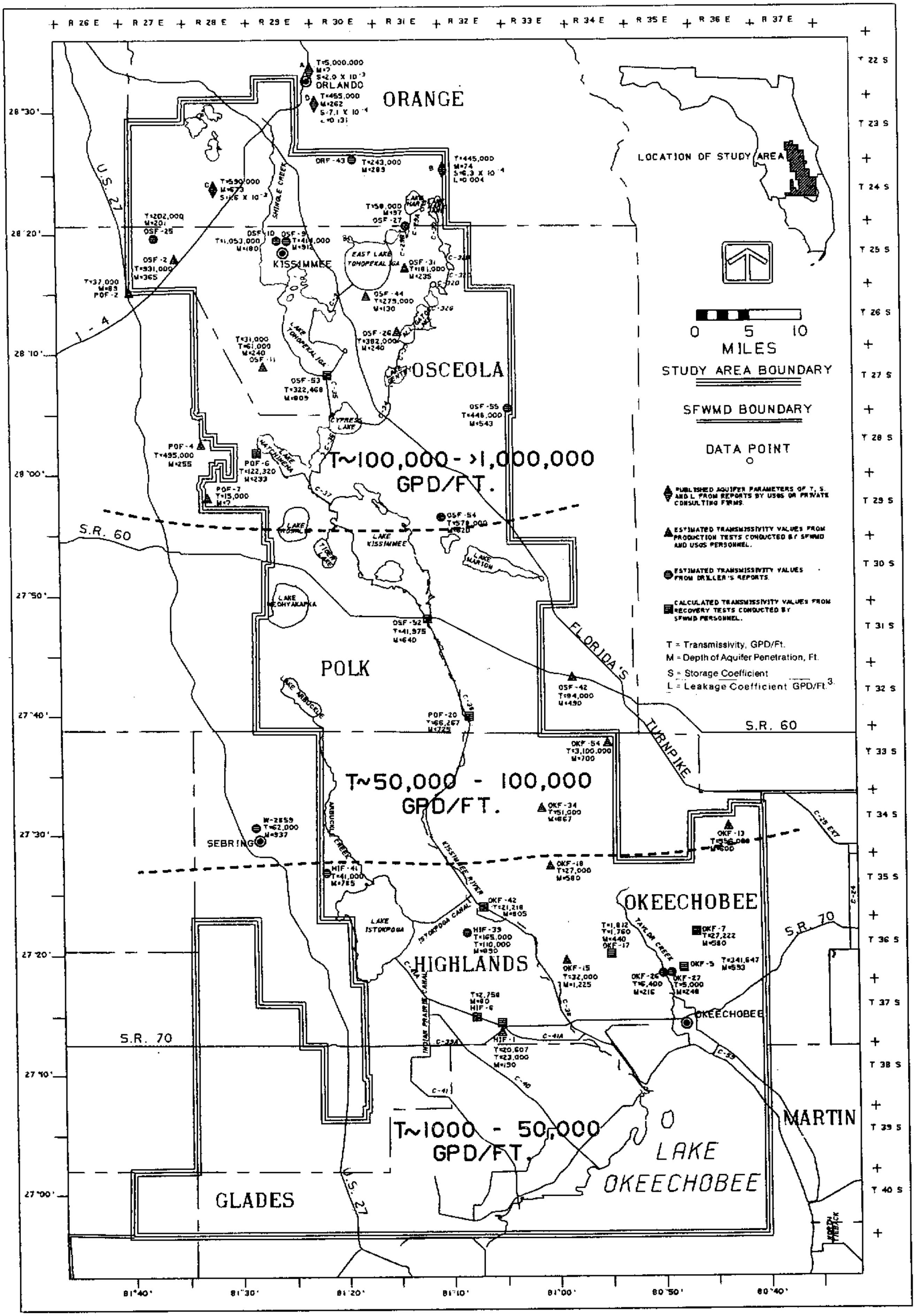


Figure 67 DISTRIBUTION OF AQUIFER PARAMETERS

TABLE 18. SPECIFIC CAPACITY AND ESTIMATED TRANSMISSIVITY VALUES FROM PRODUCTION TESTS CONDUCTED BY SFWMD AND USGS PERSONNEL

WELL	DATE PUMPED	NUMBER OF HOURS PUMPED	DEPTH ft	CASING DEPTH ft	CASING DIAMETER in	AQUIFER PENETRATION ft	DISCHARGE (Q) gpm	DRAWDOWN (s) ft	UNCORRECTED SPECIFIC CAPACITY (S.C.) gpm/ft	CORRECTED DRAWDOWN (s_c) ft	CORRECTED SPECIFIC CAPACITY ($S.C_c$) gpm/ft	ESTIMATED TRANSMISSIVITY (T) gpd/ft
HIF-1[1]	3/09/82	21	640	450[3]	8-6	190	134	10.7	12.51	9.58	13.97	23,000
OKF-13[1]	3/23/82	18	1200[3]	600[3]	10	600	789	7.03	112.2	4.18	188.8	556,000
OKF-15[1]	4/07/82	24	1600	375[3]	8	1225	154	8.68	17.74	8.36	18.42	32,000
OKF-18	11/28/79	1	1015	255	8	580	270	17.19	15.7	16.75	16.11	27,000
OKF-34	11/28/79	1	1143	276	10	867	390	14.75	26.4	14.44	27.01	51,000
OKF-54	11/29/79	2	973	260	12	700	390	0.64	609.4	0.512	764.7	3,100,000
OSF-2	12/05/79	1	450	85	10	365	310	1.12	276.8	1.08	287.03	931,000
OSF-11	7/08/79	5	398	134	6	240	300	17.85	16.8	16.65	18.02	31,000
JSF-11	12/05/79	1	398	134	6	240	115	3.88	29.6	3.65	31.51	61,000
OSF-26	6/12/78	5	622	322	10	240	430	3.56	120.7	3.09	139.16	382,000
OSF-31	3/07/79	1.2	474	239	8	235	326	4.86	67.1	4.29	75.99	181,000
OSF-42	11/29/79	2	767	218	6	490	110	3.02	36.4	2.71	40.59	84,000
OSF-44	11/27/79	5	614	481	8	130	260	3.27	79.5	2.41	107.89	279,000
POF-2	8/01/79	5	447	358	6	89	240	13.49	17.8	11.54	20.79	37,000
POF-4	12/01/79	3	453	146	8	255	390	2.72	143.4	2.27	171.8	495,000
POF-7[1]	4/21/82	9	-	-	3	-	1.63	0.18	9.06	-	-	15,000[2]

[1]Production test conducted by SFWMD personnel (flowing well, natural flow = discharge, Q)
[2]Estimated transmissivity from uncorrected specific capacity data.
[3]Approximation, based on nearby well specifications.

TABLE 19. SPECIFIC CAPACITY AND ESTIMATED TRANSMISSIVITY VALUES FROM DRILLER'S REPORTS

WELL	DEPTH ft	CASING DEPTH ft	CASING DIAMETER in	AQUIFER PENETRATION ft	DISCHARGE (Q) gpm	DRAWDOWN (s) ft	UNCORRECTED SPECIFIC CAPACITY (S.C.) gpm/ft	CORRECTED DRAWDOWN (s_c) ft	CORRECTED SPECIFIC CAPACITY ($S.C_c$) gpm/ft	ESTIMATED TRANSMISSIVITY (T) gpd/ft
HIF-39	1332	370	10	890	236	3.6	65.55	3.36	70.23	165,000
HIF-39	1332	370	10	890	323	6.8	47.5	6.43	50.23	110,000
HIF-41	1205	420	16	785	2118	86.6	24.45	85.44	24.79	41,000
OKF-26	825	625	12	216	400	80	5.0	79.59	5.03	6,400
OKF-27	725	477	12	248	346	85	4.07	84.76	4.08	5,000
ORF-43	500	211	12	289	1000	11	90.91	10.37	96.43	243,000
OSF-9	1195	283	16	912	2513	18	139.6	16.90	148.6	414,000
OSF-10	458	278	16	180	2513	9	279.2	7.92	317.3	1,053,000
OSF-25	300	99	6	201	300	4.7	64.38	3.62	82.87	202,000
OSF-27	470	373	6	97	320	15	21.33	10.59	30.22	58,000
OSF-54	869	249	10	620	1000	7	142.85	5.13	194.82	578,000
OSF-55	891	354	13	543	1650	12	137.5	10.41	158.5	448,000
W-2859	1400	464	14	937	1212	39	31.08	38.02	31.87	62,000

TABLE 20. CALCULATED TRANSMISSIVTY AND SPECIFIC CAPACITY VALUES FROM RECOVERY TESTS CONDUCTED BY SFWMD PERSONNEL

WELL	DATE	TYPE OF TEST	DEPTH ft	CASING DEPTH ft	CASING DIAMETER in	AQUIFER PENETRATION ft	DISCHARGE (Q) gpm	DRAWDOWN (s) ft	UNCORRECTED SPECIFIC CAPACITY (S.C.) gpm/ft	CORRECTED DRAWDOWN (s_c) ft	CORRECTED SPECIFIC CAPACITY ($S.C_c$) gpm/ft	CALCULATED TRANSMISSIVITY (T) gpd/ft
HIF-1	8/19/82	flow/recovery	640	450*	8-6	190	151	8.70	17.36	7.31	20.6	20,607
HIF-6	3/10/82	flow/recovery	520	440	4	80	47	17.23	2.72	15.82	2.97	2,758
OKF-5	3/24/82	flow/recovery	1181	440	8	593	176	1.48	118.9	1.02	172.5	341,647
OKF-7	7/14/79	pump/recovery	927	412	6	580	265	26.12	10.15	22.78	11.63	27,222
OKF-17	1/12/82	pump/recovery	983	448	6	440	70	25.31	2.77	24.94	2.81	1,812
OKF-17	6/23/82	pump/recovery	983	448	6	440	35	17.99	1.95	17.88	1.96	1,760
OKF-42	8/18/82	flow/recovery	1152	370	6	805	43	5.68	7.57	5.55	7.75	21,218
OSF-52	3/9/83	pump/recovery	880	172	12-6	640	475	23.67	20.07	20.35	23.34	41,975
OSF-53	3/24/83	pump/recovery	980	160	12-6	809	838	14.57	57.45	7.01	119.4	322,468
POF-6	5/26/82	flow/recovery	411	178	10	233	347	10.11	34.32	9.89	35.06	122,320
POF-20	3/7/83	pump/recovery	1000	260	12-6	725	446	18.08	24.66	13.2	33.78	66,267

*Approximation, based on nearby well specifications.

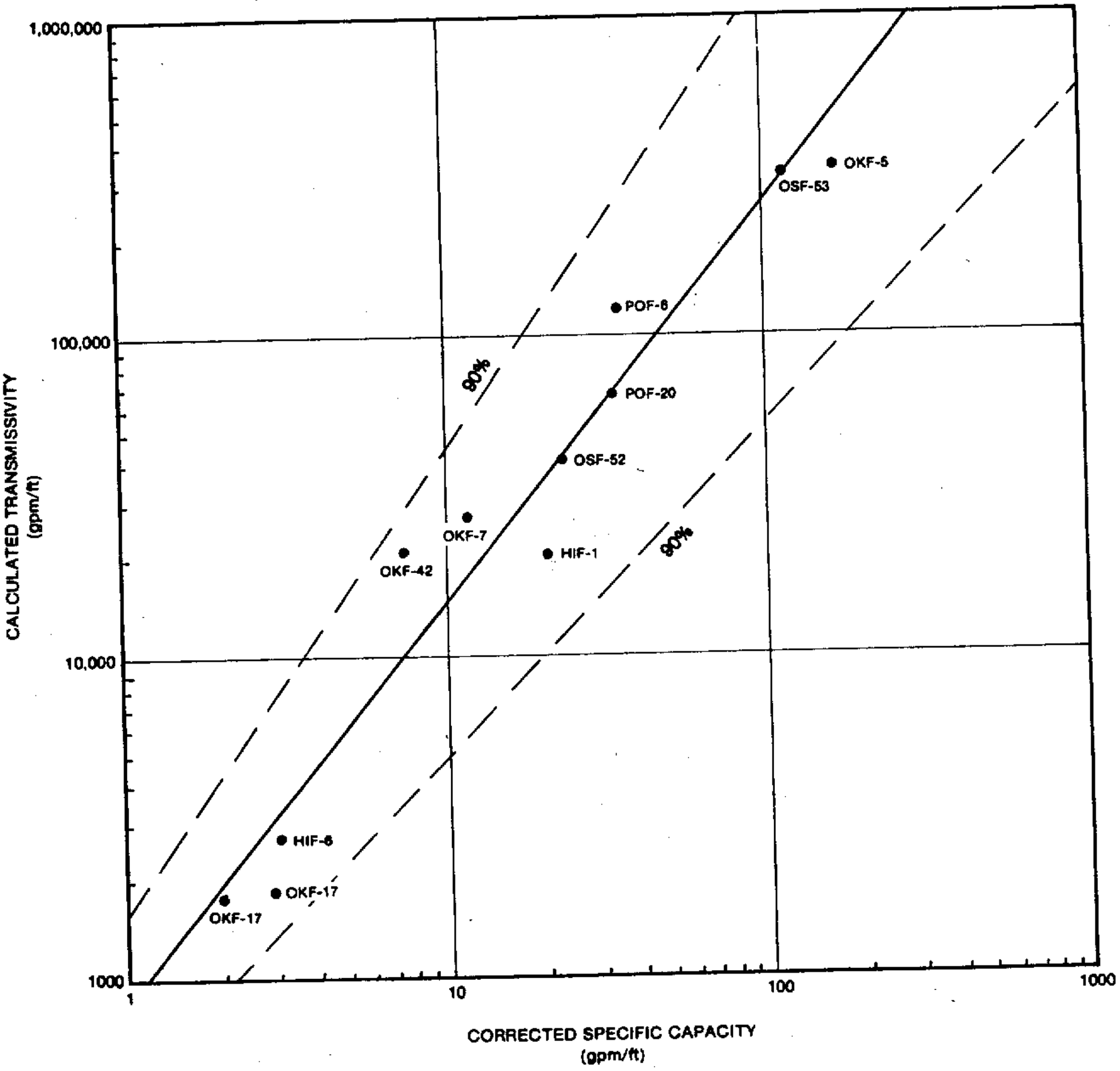


Figure 68 CORRECTED SPECIFIC CAPACITY VERSUS CALCULATED TRANSMISSIVITY FROM RESIDUAL RECOVERY ANALYSIS FOR SELECTED WELLS

Although it would be desirable to use a larger sample size when developing an empirical relationship, these were the only cases in which specific capacity values, as well as calculated transmissivity values, were available. This relationship has been applied to the specific capacity values obtained from the production tests performed by USGS personnel, SFWMD personnel, and well drillers to obtain an estimate of the transmissivity of the Floridan Aquifer System at the test sites. The estimated transmissivity values derived from equation (18) above are presented in Tables 18 and 19, and on Figure 67.

For example, if a corrected specific capacity value of 50 gpm/ft is obtained for a well, one would locate 50 gpm/ft on the x-axis of Figure 68 and move vertically along this line until intersecting the solid line fitted to the data points. The corresponding value of the y-axis at this intersection point represents the estimated transmissivity, which in this case is approximately 108,000 gpd/ft. Corrected specific capacity values can also be substituted into equation (18) above to obtain transmissivity estimates. Substituting a specific capacity of 50 gpm/ft into equation (18) yields an estimated transmissivity of 108,315 gpd/ft.

The dashed lines on either side of the solid line in Figure 68 represent the confidence interval around the computed parameter (in this case, the relationship between specific capacity and predicted transmissivity) at the 90 percent level. This means that out of 100 specific capacity values, it is expected that 90 values of predicted transmissivity would fall inside this interval. The confidence limits are numerical values describing the boundaries of the confidence interval. For a specific capacity value of 50 gpm/ft, the 90 percent confidence limits of estimated transmissivity are roughly 26,000 gpd/ft and 440,000 gpd/ft.

Transmissivity

The distribution of calculated and estimated transmissivity values of the Floridan Aquifer System shown on Figure 67 exhibits a recognizable trend on a regional scale. In general, transmissivity values are lowest in the southern portion of the KPA, namely Okeechobee and Highlands Counties, and range from about 1000 to 50,000 gpd/ft. In the central portion of the planning area, including northern Okeechobee and Highlands Counties and southern Polk and Osceola Counties, transmissivity values range from 50,000 to 100,000 gpd/ft. In the northern part of the KPA, including Orange County and northern Polk and Osceola Counties, the transmissivity values of the Floridan Aquifer System are generally the highest, ranging from 100,000 to over 1,000,000 gpd/ft.

Although a regional trend appears to exist, closer examination of these three regional trends in the northern, central, and southern portions of the KPA reveal a few transmissivity values that do not fall within the ranges cited for the areas. These variations are probably due to the fact that the well may penetrate a cavity or a different number of producing zones than other wells in the area, or the discrepancies may be due to differences in well efficiency. Older wells may have corroded casings or some collapse of borehole materials, resulting in a lower specific capacity or transmissivity value. It is important to remember that the bulk of the transmissivity data was obtained from corrected specific capacity data. These projected values of transmissivity should only be considered rough approximations of the true transmissivity of the Floridan Aquifer System at those well sites.

For example, wells HIF-39 and OKF-5 in the southern region of the KPA, where the transmissivity of the Floridan Aquifer System appears to range from 1,000 to 50,000 gpd/ft, exhibit noticeably higher transmissivities. Examination of borehole geophysical logs reveals that HIF-39 has 2 cavities; one at 1212 feet below NGVD and the second at 1264 feet below NGVD which continues to the bottom of the well. Well OKF-5 has a cavity at 517 feet below NGVD.

In the central region of the study area, wells OKF-13 and OKF-54 have exceptionally high values of transmissivity when compared to the expected range of 50,000 to 100,000 gpd/ft. A transmissivity of over 3 million gpd/ft was obtained in the production test at well OKF-54, which has a cavity from 902 feet below NGVD to the bottom of the well at 907 feet below NGVD. There is no geophysical data available for well OKF-13, but it is known to be over 1000 feet deep, and the relatively high natural flow of 790 gpm indicates that this well may penetrate a cavity.

In the northern portion of the KPA, transmissivity values range from 100,000 to over 1 million gpd/ft. This area, including Orange County and northern Osceola and Polk Counties also exhibits the greatest occurrence of cavities. Wells POF-2, POF-7, OSF-11, and OSF-27 exhibit transmissivity values that fall below the range of 100,000 to over 1 million gpd/ft. Well POF-2 penetrates only 89 feet of the Floridan Aquifer System and probably encounters only 1 producing zone. Well POF-7 was affected during the flow/recovery test by a nearby well with a pump which ran on and off several times and affected the drawdown. According to the drillers report, although well OSF-27 penetrates a cavity, it penetrates a total of only 97 feet of the Floridan Aquifer System and, therefore, the transmissivity value is lower than expected. Neither borehole geophysical data nor drillers logs are available for OSF-11, which makes the interpretation of the lower transmissivity values obtained from the two production tests that were conducted on this well very difficult.

The transmissivity values derived from the methods outlined above reflect the hydrogeologic and well construction factors at the particular sites. A number of factors should be considered when applying the data to regional hydrogeologic assessments. Whenever possible, it is desirable to utilize data from wells that penetrate the full saturated thickness of the aquifer system. The thickness of the Floridan Aquifer System in the KPA ranges from 2200 to 3400 feet (Miller, 1982a). Throughout most of the KPA, full penetration of the Floridan Aquifer System is constrained by drilling costs and changes in water quality with depth, and is not feasible from an economic point of view.

In the northern portion of the study area, the top of the Floridan Aquifer System is encountered at relatively shallow depths, approximately 150 feet below land surface. Most of the wells in the northern KPA do not penetrate more than 300 feet of the Floridan Aquifer System, since adequate quantities of water for most purposes can be obtained from the upper portion of the Floridan Aquifer System in this area.

In the southern portion of the KPA, the top of the Floridan Aquifer System is encountered at much greater depths; often 600 to 700 feet below land surface. In addition, the water quality in this region is much poorer than in the northern part of the study area. Therefore, drilling costs are higher due to the greater depth of the aquifer system and a balance must be reached between the desired productivity of the well and the desired water quality. The water quality in the southern KPA generally degrades with depth. Depending upon the proposed use of the water, a well driller may install a deeper well, hoping to increase productivity so that an additional well would not be needed, even though water from a deeper well may be of poorer quality. According to Todd (1980), when partial penetration of the aquifer system occurs, "the flow pattern to the well differs from the radial horizontal flow assumed to exist around fully penetrating wells. The average length of a flow line into a partially penetrating well exceeds that into a fully penetrating well so greater resistance to flow is encountered." Huisman (1972) notes that with partial penetration, groundwater velocities in the immediate vicinity of the well are higher than accounted for, resulting in an additional loss of head. The additional drawdown due to the effects of partial penetration is larger at the well face, while it reduces with increasing distance from the well.

In the KPA, no simple relationship may exist between the depth of penetration and the transmissivity of the aquifer system at a particular site due to the presence of cavities and solution channels randomly distributed through a vertical section of the aquifer system. Vertical anisotropy of the Floridan Aquifer System is a major factor in controlling the apparent transmissivity calculated from partially penetrating wells. As discussed in the hydrostratigraphy section of this report, the permeability of the Floridan Aquifer System varies greatly throughout the saturated thickness. The term producing zone is used in this report to describe zones of greater permeability within the aquifer system. The presence of several producing zones has been mapped both areally and vertically throughout many areas in the KPA through the use of borehole geophysical logs and well cuttings. Since the depth at which a cavity or a particular producing zone is encountered can vary by as much as 100 feet over a distance of 4 or 5 miles, production tests performed on wells within a few miles of each other that penetrate the Floridan Aquifer System equally may result in transmissivity values that differ by an order of magnitude, due to one well penetrating more producing zones or cavities than another. For example, wells OSF-9 and OSF-10 are located within 1500 feet of each other. OSF-9 penetrates 912 feet of the Floridan Aquifer System, and the estimated transmissivity at the site is 414,000 gpd/ft. A production test performed at well OSF-10, which penetrates only 180 feet of the Floridan Aquifer System, yielded an estimated transmissivity of over 1,050,000 gpd/ft. Examination of the drillers reports for these wells showed that two cavities were present in well OSF-10 at depths of 407-409 and 412-416 feet below land surface which produced water.

As mentioned above, many factors such as the presence of producing zones or cavities and the construction of the well appear to affect the transmissivity values of the Floridan Aquifer System obtained at well sites in the study area. The calculated or estimated transmissivity of the Floridan Aquifer System at 36 well sites throughout the KPA has been plotted against the amount of aquifer penetration at those sites in Figure 69. The transmissivity of the Floridan Aquifer System does not appear to be a function of depth of penetration overall. Note that several wells penetrate approximately 200 feet of the Floridan Aquifer, with transmissivity values ranging from 6500 gpd/ft to over 1,000,000 gpd/ft; a variation of two orders of magnitude.

Storage Coefficients and Leakage

Several values of the coefficients of storage and leakage that were obtained from pump tests conducted by the USGS and consulting firms in the northern portion of the KPA, where observation wells were available, are presented on Figure 67 and on Table 17. The storage coefficients of the Floridan Aquifer System obtained in these tests range from 6.3×10^{-4} to 2.0×10^{-3}. The results of additional pumping tests conducted in Orange and Polk Counties (Lichtler and others, 1968; Stewart, 1966) but not included here indicate that values of storage coefficient on the order of magnitude of 1×10^{-4} are generally representative of the storativity of the Floridan Aquifer System in the northern portion of the planning area. Storativity values in the range of 10^{-4} to 10^{-5} appear to be characteristic of the Floridan Aquifer System in St. Lucie and Martin Counties, to the south and east of the KPA, according to Brown (1980) and Wedderburn and Knapp (1983).

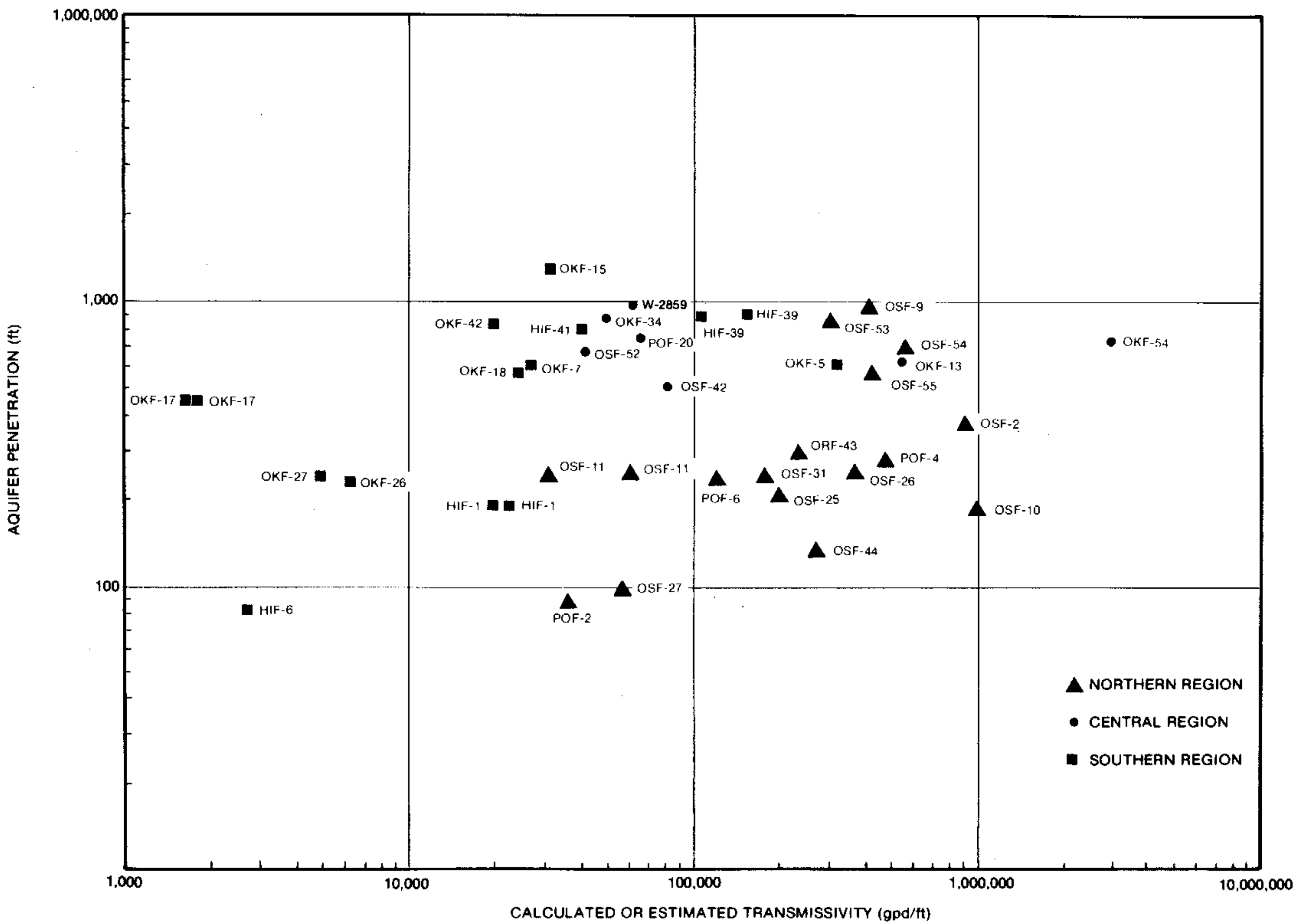


Figure 69 CALCULATED OR ESTIMATED TRANSMISSIVITY VERSUS AQUIFER PENETRATION FOR SELECTED WELLS

Leakage from adjacent strata, such as from the overlying unconfined aquifer in the northern portion of the KPA where the confining beds of the Hawthorn Formation are thin, as well as upward leakage from the lower zones in the Floridan Aquifer System in the southern portion of the KPA, seems to be an important contribution to the yields from wells which penetrate the Floridan Aquifer System throughout the study area. This premise appears to be supported by the fact that for most of the Floridan Aquifer System wells that were discharged or pumped in the planning area, the maximum drawdowns were attained in the first 1 to 5 minutes of the tests and remained virtually stable throughout the duration of pumping. Leakance values of 0.131 gpd/ft^3 and 0.004 gpd/ft^3 (Table 17) were obtained from pump tests conducted by the USGS at two well sites in Orange County (see Figure 67). The leakance value of 0.131 gpd/ft^3 obtained at well D (Figure 67) indicates that this well is in a more effective part of the recharge area of the Floridan Aquifer System than well site B, where the leakance was 0.004 gpd/ft^3. The average coefficient of leakage from the nine determinations made in the upper zone of the Floridan Aquifer System in Orange County (Lichtler and others, 1968) was 0.107 gpd/ft^3. Wedderburn and Knapp (1983) obtained a leakage coefficient of approximately 0.336 gpd/ft^3 for the Floridan Aquifer System in central St. Lucie County.

Well Productivity

In addition to the parameters discussed above, the specific capacity of wells can be used as an indicator of the productivity of wells penetrating the aquifer system. As shown on the histogram in Figure 70, there is a large variability in corrected specific capacity within the study area, with most of the values ranging from less than 2 to approximately 50 gpm/ft. According to Davis and Deweist (1966), "Frequency distributions of specific capacities of wells in most moderately indurated sedimentary rocks show a strong right, or

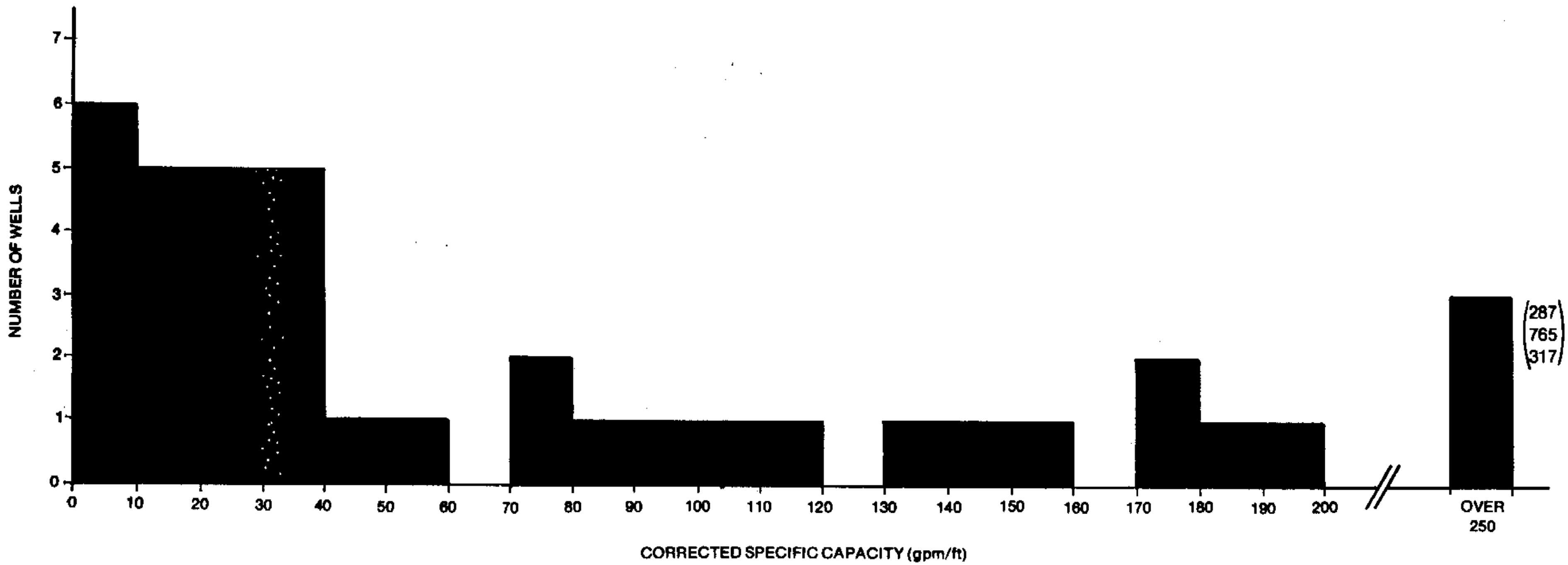


Figure 70 FREQUENCY DISTRIBUTION OF THE CORRECTED SPECIFIC CAPACITIES OF 39 WELLS IN THE FLORIDAN AQUIFER SYSTEM

positive, skewed distribution. This skewed relation is most pronounced in limestone and fractured orthoquartzites." The skewed distribution of the wells tested in the KPA is probably due to the presence of the producing zones, as well as fracturing and solution channels in the limestones and dolomites that compose the Floridan Aquifer System.

The cumulative frequency distribution curves of corrected and uncorrected specific capacities shown on Figure 71 indicate that 50 percent of the wells tested had a specific capacity greater than 30 gpm/ft. Approximately 30 percent of the wells had specific capacities greater than 100 gpm/ft, while approximately 20% of the wells had specific capacities less than 10 gpm/ft.

The variations in specific capacities throughout the area may be due to areal or vertical variations in aquifer properties. In general, higher specific capacities are found in the northern portion of the study area, with values decreasing towards the south. This pattern corresponds to the variations in transmissivity indicated on Figure 69.

Figure 72 illustrates the variability of specific capacities from both an areal and vertical perspective. Wells in Osceola and Polk Counties exhibit generally higher specific capacities than those in Okeechobee and Highlands Counties. Wells in Okeechobee County show the lowest overall specific capacities, although there are notable exceptions. No distinct relationship between depth of penetration of the aquifer and productivity of the well is indicated on Figure 72. This is probably due to the fact that although distinct producing zones are identifiable, the relative productivitity of these zones is unpredictable. In practice, therefore, wells are drilled until a satisfactory yield is obtained. This may be obtained from the first producing zone penetrated or from deeper producing zones.

In order to examine in greater detail the relation between variations in specific capacity with depth of penetration, a method outlined by Walton (1970) was applied.

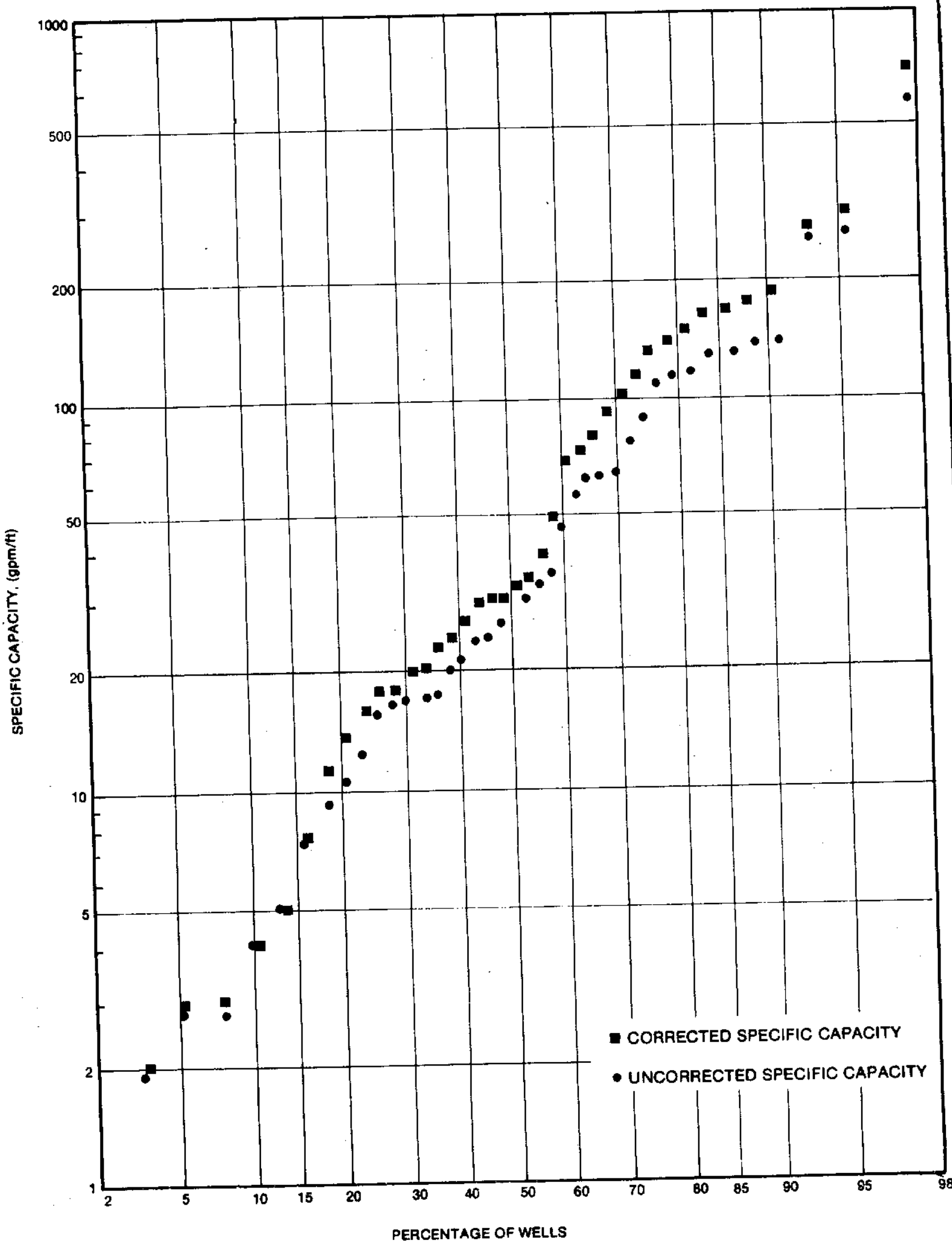


Figure 71 CUMULATIVE FREQUENCY DISTRIBUTION OF CORRECTED AND UNCORRECTED SPECIFIC CAPACITY DATA

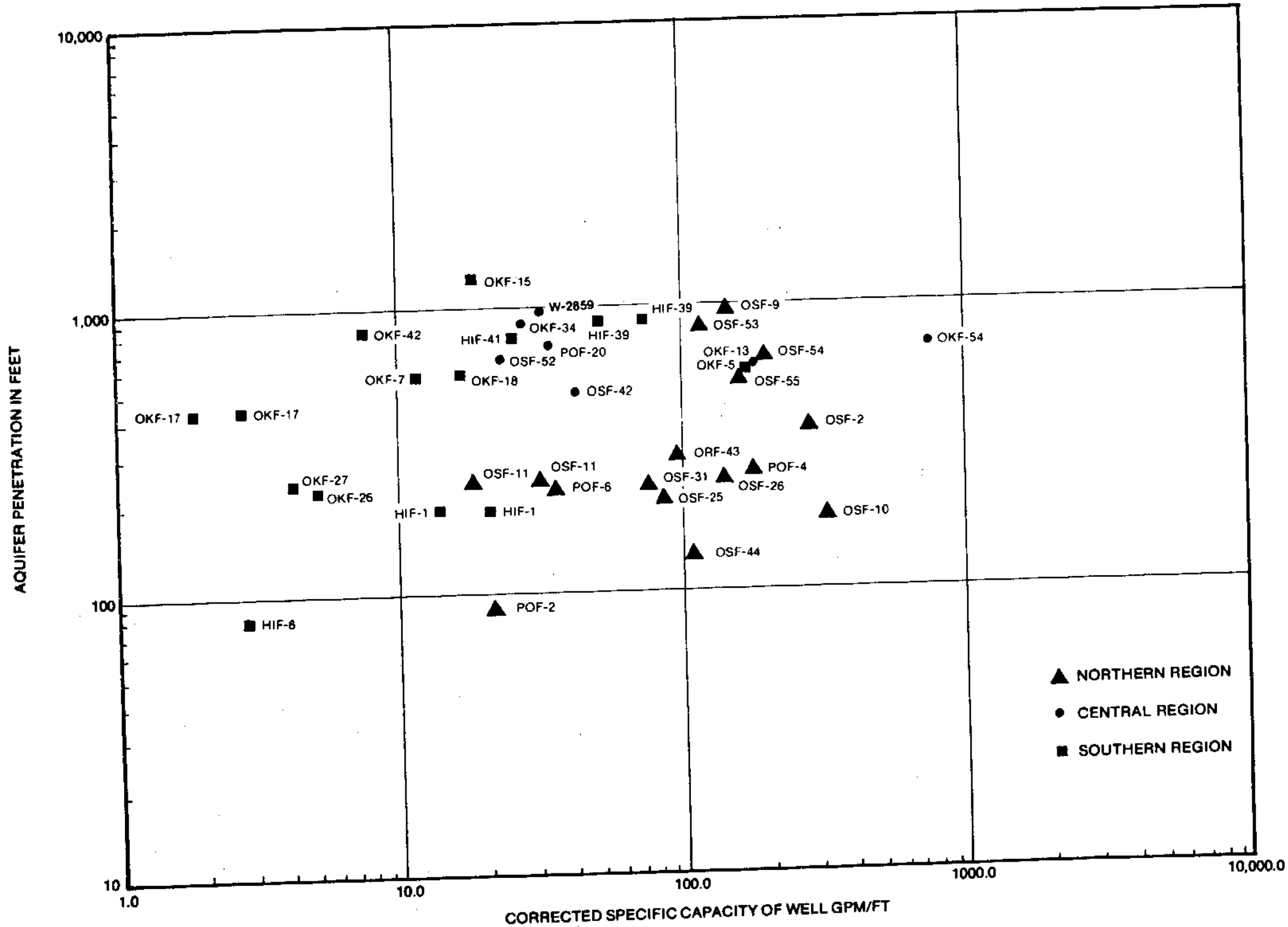


Figure 72 CORRECTED SPECIFIC CAPACITY VERSUS AQUIFER PENETRATION FOR SELECTED WELLS

Specific capacities of wells penetrating one or several units of a multiunit aquifer can be divided by the thickness of aquifer penetration to obtain a parameter to predict well yields (Walton, 1970). This relationship can be used at sites for which little data is available. This prediction is based upon the assumption of areal homogeneity of the aquifer material.

Values of specific capacity per foot of aquifer penetration for each well within a given zone of an aquifer are ranked from largest to smallest, and a frequency distribution is calculated as follows:

$$Fs = \frac{Mo}{Nw+1}(100) \tag{19}$$

Where,

M_o = rank order

N_w = total number of wells

F_s = percentage of wells whose specific capacities are greater than or equal to the specific capacity of order number M_o.

According to Walton (1970, p. 321), "Values of specific capacity per foot of penetration are then plotted against the percentage of wells on logarithmic probability paper. Straight lines are fitted to the data. If specific capacities per foot of penetraton decrease as the depth of wells and number of units penetrated increase...," the upper units of the aquifer are considered to be more productive than the lower units. The slope of the line plotted for each zone varies with the inconsistency of production, such that a steeper line indicates a greater range in productivity.

This analysis has been performed on the corrected specific capacity data compiled for the KPA. Due to the apparent regional trend in transmissivity values of the Floridan Aquifer System, the corrected specific capacity data for wells in the northern, central, and southern regions of the planning area were examined separately. The wells in each region were divided into two groups as follows:

0 - 400 ft penetration

> 400 ft penetration

These divisions were chosen because the varying degrees of aquifer penetration in both the northern and southern regions appeared to have a natural "breakpoint" or obvious grouping into wells with less than 400 feet of aquifer penetration and wells with greater than 400 feet of aquifer penetration. Another reason for selection of these divisions was that in the northern region of the KPA, it was apparent that wells penetrating the aquifer approximately 400 feet always encountered producing zones 1 and 2; and in many cases, encountered producing zone 3 as well (Figure 22). Wells that penetrated less than 400 feet were nearly always completed through producing zone 2. Wells penetrating greater than 400 feet in the northern region encountered zones 1 through 3 along with zones 4, 5, and 6 if the well was drilled deep enough.

In the central region of the KPA, all of the wells for which corrected specific capacity data was available penetrated the Floridan Aquifer System in varying amounts greater than 400 feet. Therefore, in this region, there was no real basis for comparison and the analysis was performed only on wells in the northern and southern regions of the study area.

In the southern region of the KPA, nearly the same type of situation exists as in the northern region. Producing zone 1 is encountered in all of the wells since it represents the contact between the basal beds of the Hawthorn Formation and the top of the Floridan Aquifer System. Nearly all of the wells penetrating the Floridan Aquifer System approximately 400 feet encountered producing zones 1, 2, and 3. Wells which penetrated more than 400 feet of the Floridan Aquifer System encountered these zones in addition to zones 4, 5, and 6.

The data presented on Figure 73 for the northern portion of the KPA confirms the inconsistency of the relationship between specific capacity and depth of penetration of the aquifer. The overlap in plotted points indicates that in most cases, upper units are more productive, while in a few cases the lower units may be more productive. In general, however, wells which penetrate the Floridan Aquifer System from 0 - 400 feet appear to be the most productive, indicating that in the northern region, penetration of up to 400 feet of the aquifer may be the most favorable range for completion of production wells. Very shallow wells (less than 100 feet of aquifer penetration) would therefore not maximize the productive capacity of the aquifer, while in general, penetrating the Floridan Aquifer System more than 400 feet would not add significantly to productivity.

Figure 74, representing conditions in the southern portion of the KPA, indicates the same concepts apparent in Figure 73. In most cases, wells which penetrate less than 400 feet of the Floridan Aquifer System appear to be the most productive. Well OKF-5, which penetrates 593 feet of the aquifer system, appears highly productive, but as mentioned previously, this well penetrated a cavity which greatly enhanced productivity.

After examination of Figures 73 and 74, one could conclude that penetrating more than 400 feet of the Floridan Aquifer System in order to encounter producing zones 4, 5, and 6 may not enhance productivity enough to justify additional drilling costs.

In conclusion, it appears that no firm prediction can be made regarding the productivity of individual wells in the Kissimmee Planning Area due to the presence of producing zones and cavities, the random distribution of fracturing and varying degrees of solution channelling in the Floridan Aquifer System, and differences in well construction. In general, the transmissivity of the Floridan Aquifer System in the KPA is the greatest in the north,

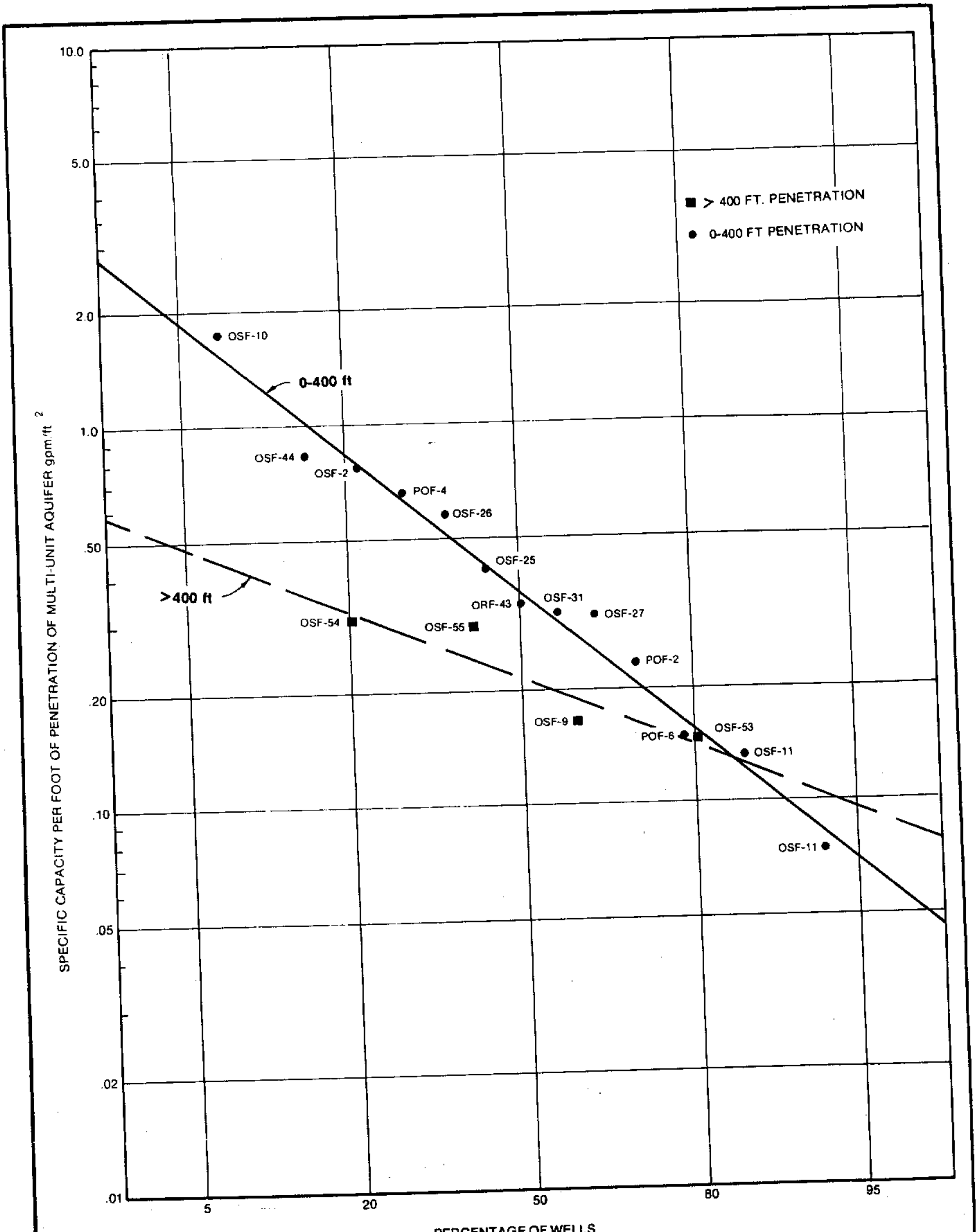


Figure 73 RANGE IN PRODUCTIVITY OF WELLS IN THE NORTHERN REGION OF THE KPA

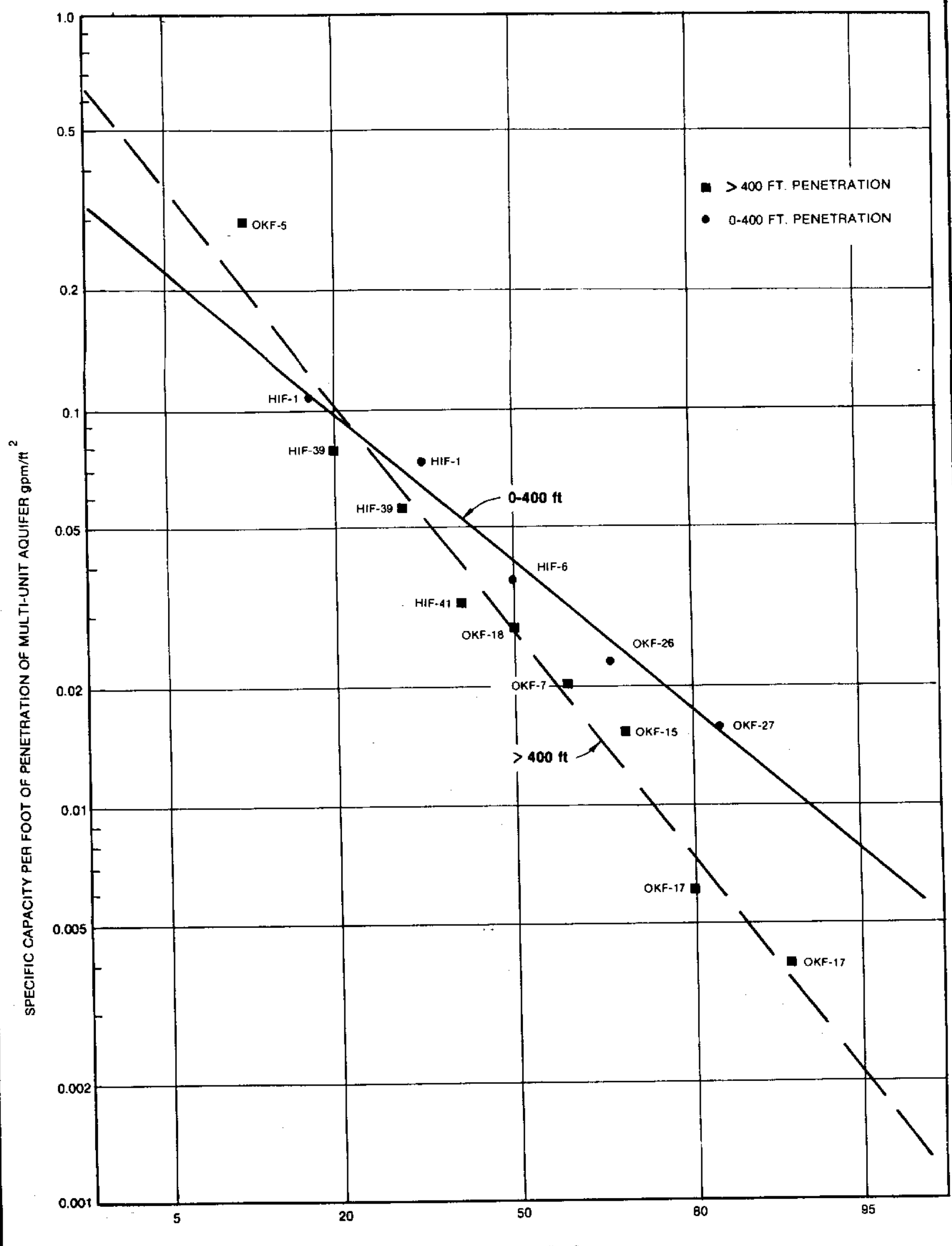


Figure 74 RANGE IN PRODUCTIVITY OF WELLS IN THE SOUTHERN REGION OF THE KPA

ranging from 100,000 to over 1,000,000 gpd/ft and gradually decreases as the southern border of the planning area is reached. In the southern portion of the KPA, the transmissivity values ranged from 1,000 to 50,000 gpd/ft.

GROUNDWATER DEVELOPMENT POTENTIAL

Introduction

The major sources of groundwater in the Kissimmee Planning Area are the Surficial Aquifer System and the Floridan Aquifer System. Although this study did not focus on the Surficial Aquifer System, previous studies indicate that throughout the KPA, the Surficial Aquifer System will yield sufficient water for small domestic and irrigation requirements. However, the quality of the water obtained may be undesirable for certain uses due to pollution from fertilizers, surface runoff, organic contaminants, and suspended. solids present depending upon the local lithology.

The Floridan Aquifer System is the principal source of groundwater throughout the planning area. The usage of groundwater from the Floridan Aquifer System varies in different regions of the planning area due to differences in water quality and depth to water-bearing zones within the aquifer system.

Use of Water from the Surficial Aquifer System and the Floridan Aquifer System

In Polk and Orange Counties and in northern Osceola County according to Stewart (1966) and Lichtler and others (1968), nearly all municipal, domestic, and industrial supplies and about half of agricultural supplies of water are obtained from wells. The majority of the wells are open only to the Floridan Aquifer System. Lake water is used to some extent to irrigate citrus crops and pastures, but the majority of agricultural supplies, including livestock and dairies, are obtained from the Floridan Aquifer System. For example, the citrus industry utilizes water from the Floridan Aquifer System for packaging and processing, and in over half of the citrus irrigation uses.

Groundwater from the Floridan Aquifer System in the northern portion of the planning area (Orange, Polk, and northern Osceola County) is potable and usually only requires chlorination for disinfection or chlorination and aeration for removal of hydrogen sulfide gas as treatment for public water supply. The least mineralized water in the Floridan Aquifer System occurs in the northern and northwestern portions of the planning area where the recharge rate of the aquifer is highest. Mineralization in the aquifer within the KPA generally increases to the south, and with depth. Sources of increased mineralization include mixing with connate saltwater, and contact with soluable minerals (mostly gypsum) near the base of the aquifer (Stewart, 1966).

The largest user of groundwater in Orange County is the Orlando Utilities Commission, which delivered an average of about 50 mgd from March 1982 to February 1983 to users in and around Orlando.

In Polk County, the phosphate industry represents a large user of water from the Floridan Aquifer System, although considerable amounts of water are obtained from seepage into mine pits which penetrate much of the Shallow Aquifer System (Stewart, 1966).

According to Bishop (1956), four towns in Highlands County (which are located just outside planning area boundaries) have public water supply systems. Avon Park and Sebring obtain supplies from wells tapping the Floridan Aquifer System. The water supply for DeSoto City is obtained from wells completed in the Hawthorn Formation. The town of Lake Placid obtains its water supply from a nearby lake.

Smaller towns and rural areas of Highlands and Osceola Counties without public water systems obtain most of their domestic water supplies from shallow wells. In some areas, high iron content and organic impurities may be encountered at shallow depths. According to Bishop (1956), the present trend in drilling domestic wells in the ridge section of Highlands County is to tap zones of the Hawthorn Formation, which furnish better quality water than the Surficial Aquifer System. A few domestic supplies are obtained from lakes.

Where sufficient water is not available from lakes and streams in Highlands County, southwestern Osceola County, and northwestern Okeechobee County, groundwater is utilized from both the Shallow Aquifer System and the Floridan Aquifer System. Nearly all of the large citrus groves, cattle ranches, and dairies withdraw water from the Floridan Aquifer System.

In Okeechobee County and throughout most of Glades County, the water from the Floridan Aquifer System is highly mineralized in comparison to the rest of the KPA, and is not potable. In the southern portion of the KPA, most domestic supplies are derived from individual shallow wells or surface water supplies, with water treatment when needed. The City of Okeechobee obtains its municipal supply from Lake Okeechobee. In areas near surface water bodies in the southern portion of the KPA, irrigation is practiced by the use of shallow ditches from the surface sources. Other areas depend upon groundwater from the Floridan Aquifer System. Many crops will not tolerate the relatively high chloride concentration in southern Okeechobee County and Glades County, which ranges from 700 mg/l to more than 1500 mg/l. For this reason, in the past twenty years irrigation by shallow wells has increased greatly in areas without nearby surface water bodies.

All of the Floridan Aquifer System wells in southern Okeechobee County and eastern Glades County flow above land surface. In many cases (e.g., OKF-13, natural flow of over 700 gpm), the natural discharge of these wells is more than adequate for the pasture irrigation or livestock watering needs of dairy farmers or cattle ranches in the area, and pumps are not utilized.

Suitable Areas for Water Supply Development

The development potential for the Floridan Aquifer System in the KPA can be assessed after examining areal variations in water quality and transmissivity. Figure 75 depicts areas of good, moderate, and poor water

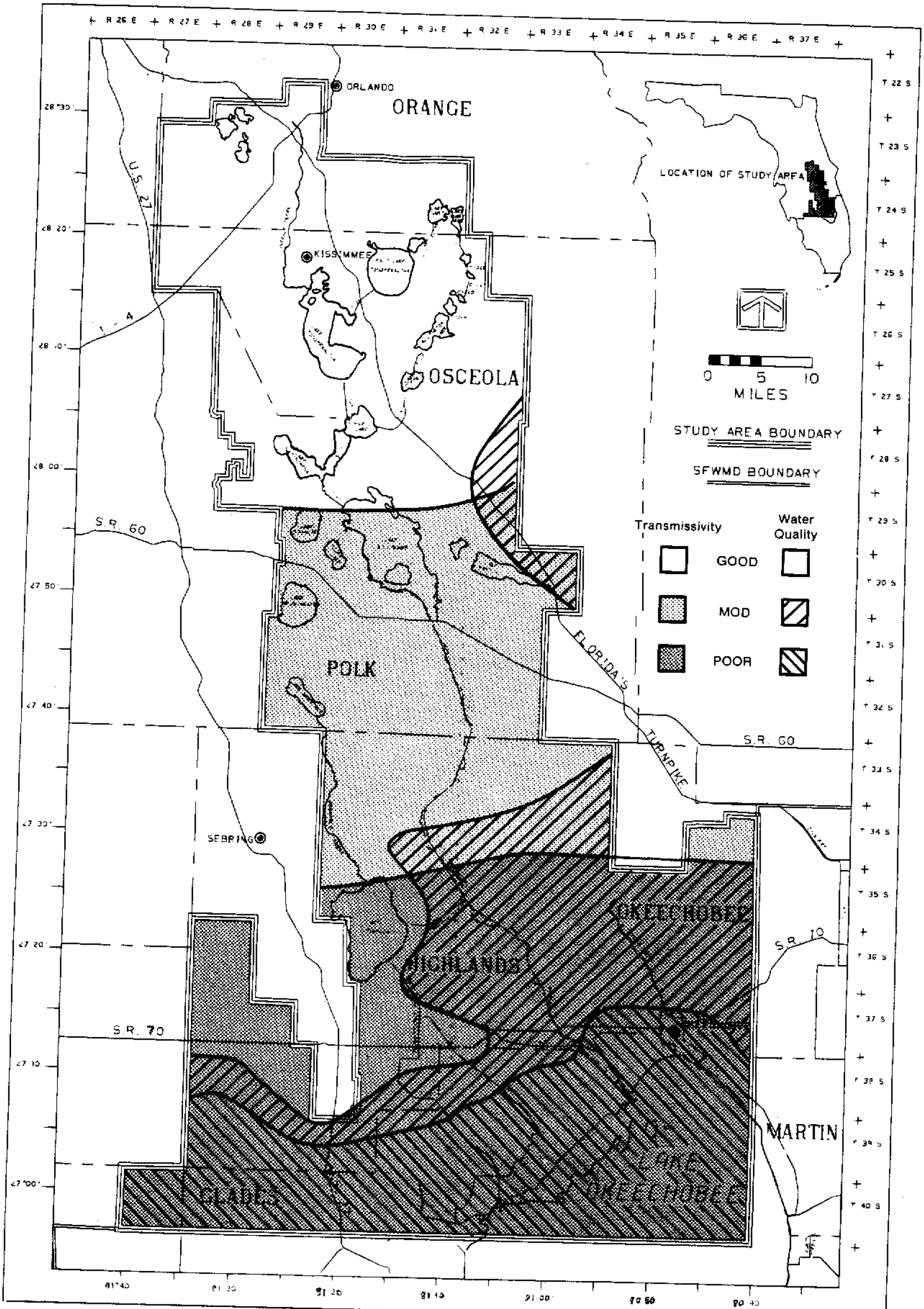


Figure 75 SUITABILITY OF AREAS FOR WATER SUPPLY DEVELOPMENT

quality and transmissivity. The variation in wellhead chloride concentrations was chosen as criterion of water supply development potential based upon water quality. Areas of good development potential were selected as those areas with less than 100 mg/l chloride concentration. Wells penetrating the Floridan Aquifer System in most of the study area, from Orlando to northern Highlands and Okeechobee Counties and parts of western Highlands County, yield water with less than 100 mg/l chloride. Areas of moderate water supply development potential of the Floridan Aquifer System, based on water quality considerations, are found in a small portion of central Osceola County, most of Okeechobee County, eastern Highlands County, and a small part of southern Highlands County. In these areas, wells yield water with chloride concentrations between 100 and 250 mg/l. Areas with poor potential for water supply development from the Floridan Aquifer System, due to water quality considerations, are found in southern Okeechobee and Highlands Counties, and in Glades County. In these areas, in the southernmost portion of the KPA, chloride concentrations are greater than 250 mg/l and the water from the Floridan Aquifer System is not potable. Chloride concentrations in excess of 1000 mg/l have been noted in parts of Glades and Okeechobee Counties.

Aquifer parameters such as transmissivity are important indicators of the availability of water in an area. The highest transmissivity values obtained for the Floridan Aquifer System were found in the northern portion of the KPA. The transmissivity of the Floridan Aquifer System ranged from 100,000 gpd/ft to over 1,000,000 gpd/ft in Orange County and northern Osceola and Polk Counties. This area is considered to have good potential for water supply development from the Floridan Aquifer System based upon the relatively high transmissivity values. Moving further south in the KPA, an area of moderately high transmissivity is encountered in southern Polk and Osceola Counties and in northern Highlands and Okeechobee Counties. The transmissivity of the

Floridan Aquifer System ranges from 50,000 to 100,000 gpd/ft in this area, which is believed to have a moderate potential for water supply development based upon these values. In the southernmost portion of the KPA, in southern Highlands and Okeechobee Counties and in northern Glades County, the lowest values of transmissivity of the Floridan Aquifer System are encountered. In this region, transmissivity ranged from about 1000 gpd/ft to 50,000 gpd/ft. Based upon transmissivity values, this area is considered to have a poor potential for water supply development in comparison to the central and northern regions of the study area.

Figure 75 superimposes the areal variations in water quality and transmissivity within the study area. It is apparent that the northern portion of the KPA has the best overall potential for water supply development from the Floridan Aquifer System, since the transmissivity of the aquifer system is relatively high and the water quality is also good. The water supply development potential of the central region of the KPA is considered moderate to good, due to the relatively moderate range in transmissivity values coupled with good water quality in this area. Finally, the development potential of the Floridan Aquifer System in the southern portion of the KPA is considered poor in comparison with the rest of the area. The water quality in this region is the poorest in the study area and has a chloride concentration ranging from 100 mg/l to greater than 1000 mg/l. In addition, the lowest values of transmissivity of the Floridan Aquifer System were found in this area. A growing trend towards the use of surface water sources and the Surficial Aquifer System in this area, due to the poor water quality and generally lower well yields from the Floridan Aquifer System, has become apparent over the past 20 years. Another factor which may further hinder water supply development is the greater depth at which the Floridan Aquifer System is encountered in this area. The top of the Floridan Aquifer System is located over 600 feet below land surface throughout much of the southern portion of the KPA, and these greater depths signify increased drilling costs.

Available information from drillers reports, specific capacity data, and analyses of geophysical logs suggests that the majority of the yield of an individual well is obtained in the upper 2 producing zones within the Floridan Aquifer System. Figure 76 shows the average total well depth necessary to intercept these upper producing zones. This figure could be used as a guide when completing wells in the Floridan Aquifer System. Interception of the upper zones of the Floridan Aquifer System may result in maximum well yields with minimized depths and drilling costs. However, in many cases, deeper penetration of the Floridan Aquifer System may be necessary depending upon the desired yield and water quality. For example, well productivity may be greater if a cavity is penetrated. However, it is difficult to predict the locations of cavities with any degree of certainty.

Other factors which need to be considered when assessing the groundwater development potential of the study area are neighboring water management districts, water quality ramifications of artificial recharge, and expanding urban development. Withdrawals from the Floridan Aquifer System in neighboring water managements districts could have an effect upon the water supply of the SFWMD. Kimrey and Fayard (1982) stated "some caution is suggested in regard to the water-quality aspects of this (drainage wells and inter-aquifer connector wells) artificial recharge practice." Further urban development and growth in the KPA could lead to overdrainage of the land and cause adverse impacts upon the water quality of the Surficial and Floridan Aquifer Systems.

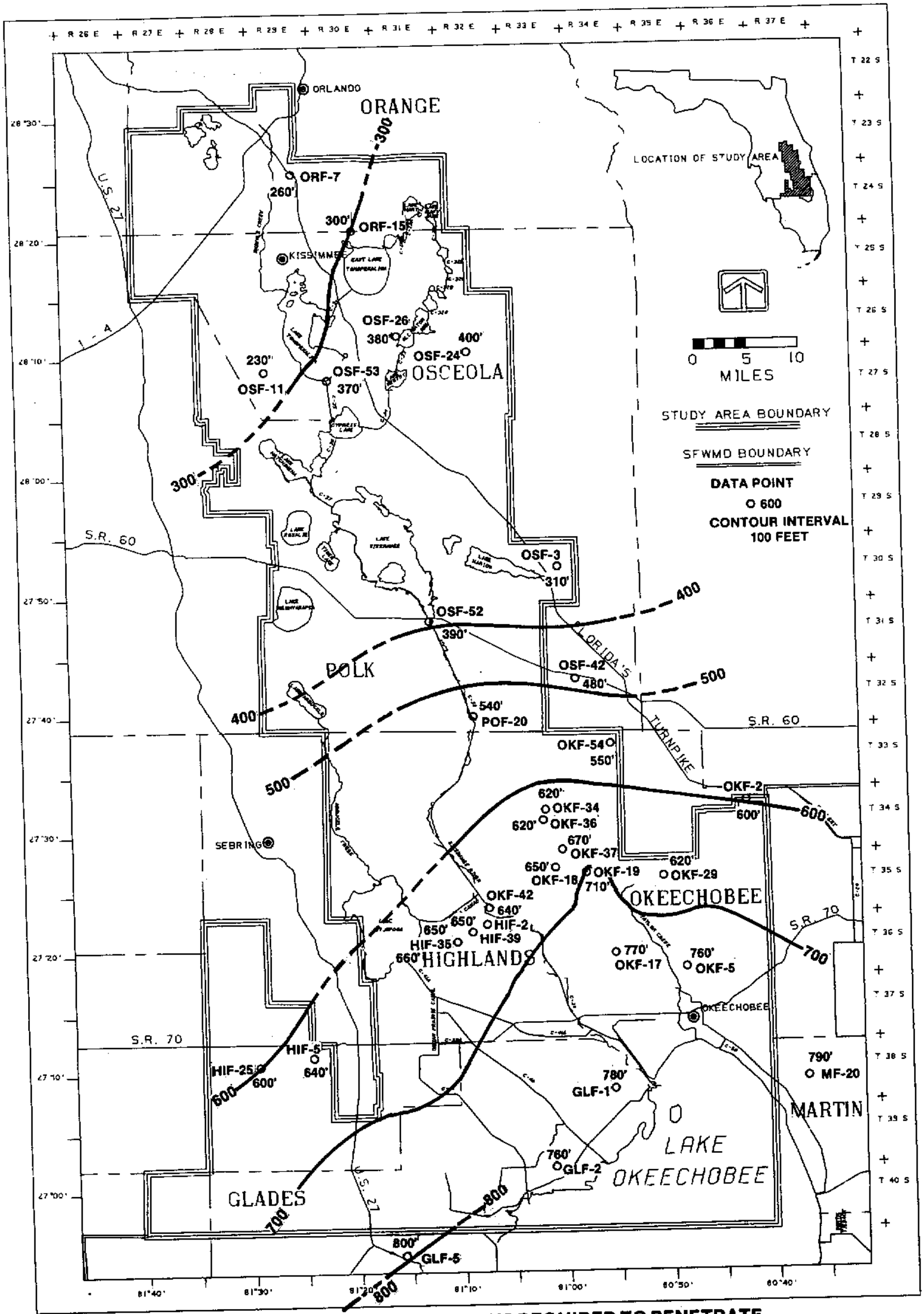


Figure 76 AVERAGE WELL DEPTHS REQUIRED TO PENETRATE THE MOST PRODUCTIVE ZONES OF THE FLORIDAN AQUIFER SYSTEM

CONCLUSIONS

1. By combining the resources of the District, the U. S. Geological Survey, and the Florida Bureau of Geology, data from 265 wells were collected including information on the well descriptions, water levels, water quality, geophysical logs, geologic logs, and aquifer characteristics. These data form the basis of the report and allow for an assessment of the groundwater resources from both a quality and quantity standpoint.
2. The KPA is divided into three hydrostratigraphic units; the Floridan Aquifer System, the confining beds of the Hawthorn Formation, and the Surficial Aquifer System. The Floridan Aquifer System is composed of Eocene and Late Miocene age sediments including, but not limited to, the Avon Park Limestone, the Ocala Group, and the basal units of the Hawthorn Formation. The confining beds are composed of Miocene age sediment of the Hawthorn Formation. The Shallow Aquifer System is composed of Plio-Pleistocene age undifferentiated deposits.
3. Most of the water obtained from wells penetrating the Floridan Aquifer System is contributed by relatively thin producing zones and cavities. Geophysical logs can be used to identify both producing zones and cavities. Up to six producing zones were delineated in the KPA. In general, the upper two producing zones appear to be the most productive.
4. The depth to the top of the Floridan Aquifer System increases from the north to the south. The altitude of the top of the Floridan Aquifer System ranges from 0 feet above NGVD to greater than 600 feet below NGVD.
5. In the southern portion of the KPA, the total head in a given well in the Floridan Aquifer System appeared to increase with depth. Individual producing zones appear to effect the greatest changes in pressure head, with little or no apparent contribution from adjacent semi-permeable layers.

6. Hydraulic head values ranged from greater than 110 to less than 40 feet above NGVD in the study area. They were highest in the northwest and decreased to the south and east. The average magnitudes of seasonal and annual fluctuations in head for all monitor wells ranged from about 1 to 5 feet from 1980 through 1982, with maximum fluctuations at certain individual wells of 10-13 feet. Record low water levels were observed in May 1981.
7. Many wells penetrating the Floridan Aquifer System exhibit relatively constant long-term water levels. Some wells which were pumped extensively, such as those used for public water supply, showed noticeable downward trends in water levels over the periods of record.
8. The recharge area for the Floridan Aquifer System in the KPA lies in the northwestern part of the planning area and along upland portions of the Lake Wales Ridge which are located within the Southwest Florida Water Management District. This recharge area is indicated by potentiometric surface highs, relatively rapid responses of water levels in Floridan Aquifer System wells to nearby rainfall events, and the elevation of the water table in the Surficial Aquifer System above that of the potentiometric surface of the Floridan Aquifer System in the area.
9. The major mode of recharge to the Floridan Aquifer System in the KPA appears to be direct infiltration of rainfall into the Surficial Aquifer System with subsequent downward percolation to the Floridan Aquifer System, where confining beds are thin or breached by solution features.
10. The major modes of discharge from the Floridan Aquifer System in the KPA are pumpage, uncontrolled flowing wells, subsurface flow into adjacent counties, and upward leakage through the confining layers.
11. It was estimated that approximately 78 mgd of water derived from rainfall infiltrates the Surficial Aquifer System and percolates downward to

recharge the Floridan Aquifer System in the region of potentiometric surface highs near the northwestern boundary of the planning area. From a flownet analysis, it was calculated that approximately 81.5 mgd of groundwater of the Floridan Aquifer System flowed between the 60 and 50 foot potentiometric contours in May 1981.

12. The best quality water in the Floridan Aquifer System is found closest to the recharge area in the western portion of the planning area. In the western region chloride concentrations are below 10 mg/l. In southern Okeechobee and Glades Counties chloride concentrations exceed 250 mg/l and in some cases exceed 1000 mg/l.

13. Groundwater quality degrades with distance away from the recharge area and with depth of penetration of the Floridan Aquifer System.

14. Piper trilinear diagrams are useful for tracing the groundwater migration as it passes from recharge water to transitional water and then to sodium chloride type waters.

15. The Surficial Aquifer System will yield sufficient water for domestic and small irrigation requirements. Well yields from the Surficial Aquifer System range from about 2 gpm to over 100 gpm. The water quality of the Surficial Aquifer System may be undesirable for certain uses due to pollution from fertilizers, organic contaminants, agricultural and surface runoff, and suspended solids which may be present depending upon local lithology.

16. The Floridan Aquifer System is the principal source of groundwater throughout the KPA. The use of water from the Floridan Aquifer System varies in different regions of the study area, due to differences in quality and depth to water bearing zones. Well yields range from over 100 gpm to over 5000 gpm, depending upon the number of producing zones penetrated and differences in well construction. Most of the wells in

the monitoring network yield between 100 and 2000 gpm utilizing centrifugal or turbine pumps. Measured natural flow varied from about 2 gpm to approximately 800 gpm.

17. Most municipal, industrial, and agricultural water needs in Polk, Orange, and Osceola Counties are supplied by the Floridan Aquifer System.
18. Domestic supplies in Highlands, Glades, and Okeechobee Counties are obtained from the Surficial Aquifer System or surface water sources. The water quality of the Floridan Aquifer System is adequate for most irrigation and livestock needs in these counties, but there is a growing trend in parts of Okeechobee and Glades Counties to drill shallow wells or utilize surface water resources due to poor water quality in the Floridan Aquifer System.
19. An empirical equation which was developed in this study can be utilized to estimate the transmissivity of the Floridan Aquifer System if specific capacity data are available.
20. No firm predictions can be made regarding the transmissivity of the Floridan Aquifer System in the vicinity of an individual well due to the presence of producing zones, cavities, varying degrees of fracturing and solution channeling in the Floridan Aquifer System, and differences in well construction. However, the distribution of transmissivity values of the Floridan Aquifer System exhibited a recognizable trend on a regional scale, with values of 100,000 to over 1,000,000 gpd/ft determined for the northern region of the study area, values of 50,000 to 100,000 gpd/ft in the central region, and the lowest transmissivity values of 1,000 to 50,000 gpd/ft recorded in the southern region.
21. Storage coefficients in the Floridan Aquifer System in the study area are on the order of $1X10^{-4}$. The average coefficient of leakage determined from several aquifer tests performed by Lichtler and others (1968) in the

upper zone of the Floridan Aquifer System in Orange County was 0.107 gpd/ft^3. In St. Lucie County, adjacent to the southeast portion of the KPA, an average leakage coefficient of 0.336 gpd/ft^3 was determined by Wedderburn and Knapp (1983).

22. Wells which penetrate approximately 400 feet or less of the Floridan Aquifer System appear to be more productive per foot of penetration than wells penetrating more than 400 feet. To maximize well productivity and minimize drilling costs, it is advisable to penetrate at least the first four producing zones of the Floridan Aquifer System. This requires at least 400 feet of penetration of the Floridan Aquifer System. In some cases, depending upon the desired yield of the well, sufficient water can be obtained after penetration of the first two producing zones.

23. The potential for groundwater development appears to be the greatest in the northern portion of the study area, based upon considerations of good water quality and high values of transmissivity of the Floridan Aquifer System. The southern portion of the KPA seems to have the poorest potential for development of groundwater from the Floridan Aquifer System due to lower transmissivity values and poorer water quality of the Floridan Aquifer System.

WATER MANAGEMENT RECOMMENDATIONS

1. It is recommended that the monitoring network wells continue to be sampled twice annually for water levels and for water quality. These wells may also become part of a statewide water quality monitoring network for the Floridan Aquifer System.
2. It is recommended that continuous water level recorders be installed at SFWMD exploratory wells OKF-42, OSF-52 and 53, and POF-20.
3. Flowing wells in Okeechobee, Highlands, and Glades Counties which have broken valves or no valves should be repaired so that the flow can be controlled. In doing so, the maintenance of flowing artesian conditions and protection of the groundwater quality of the Surficial Aquifer System may be assured.
4. Further study on the Surficial Aquifer System may be needed if the demand on this aquifer system increases.
5. It is recommended that research be conducted on the effects of groundwater withdrawals from the Floridan Aquifer System in the recharge area, and how lower water levels in the Floridan Aquifer System may effect sinkhole formation.
6. Coordination and exchange of data between water management districts should take place where basin boundaries cut across district boundaries. In doing so, the effects of withdrawals from the Floridan and Surficial Aquifer Systems can be evaluated by those districts involved.
7. Changes in groundwater quality of the Floridan Aquifer System due to artificial recharge practices should be evaluated.
8. It is recommended that a well which is open only to the Floridan Aquifer System be constructed in the area north of Lake Okeechobee. A properly constructed well with a complete set of data (including geologic and geophysical logs, and aquifer test results) would be an important

monitoring station for water levels and water quality. Preliminary data collected in this area that upconing of highly mineralized waters may be contaminating the Surficial Aquifer System due to interaquifer exchange.

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