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FLORIDAN AQUIFER TESTING AND ANALYSIS

BULL CREEK WILDLIFE MANAGEMENT AREA
OSCEOLA COUNTY

VOLUME 1 - TEXT

JULY 1990

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Prepared for

SOUTH BREVARD WATER AUTHORITY

Prepared by

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07-348.40

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ENGINEERING
PLANNING
ARCHITECTURE

July 31, 1990

Mr. Robert J. Massarelli
Executive Director
South Brevard Water Authority
P.O. Box 360382
Melbourne, FL 32936-0382

RE: **FLORIDAN AQUIFER TESTING AND ANALYSIS**
BULL CREEK WILDLIFE MANAGEMENT AREA, OSCEOLA COUNTY

Dear Mr. Massarelli:

We are pleased to submit this two volume report describing hydrogeologic conditions at the Bull Creek Wildlife Management Area test site south of Crabgrass Creek and east of Crabgrass Road.

The 200-foot thick dolomite production zone within the upper Floridan aquifer is highly transmissive and can yield large quantities of water without causing excessive water level declines. Thick beds of relatively low-permeable clay and limestone restrict the movement of water between the surficial aquifer and Floridan aquifer production zone.

The production zone at the test site yields water with dissolved mineral concentrations well below maximum levels necessary to meet drinking water standards using conventional membrane technology. Water with higher dissolved mineral content was encountered in the lower Floridan aquifer at a depth of about 550 feet below the production zone. A 400-foot thick sequence of low permeable dolomite retards the movement of water between the upper Floridan production zone and the lower Floridan aquifer.

The time and effort provided by the Authority in support of this challenging project is greatly appreciated.

Sincerely,

POST, BUCKLEY, SCHUH & JERNIGAN, INC.

Roy Silberstein
Project Manager
Hydrogeology Department

P. Fred Biery, P.E.
Deputy Director
Environmental Services

07-348.10

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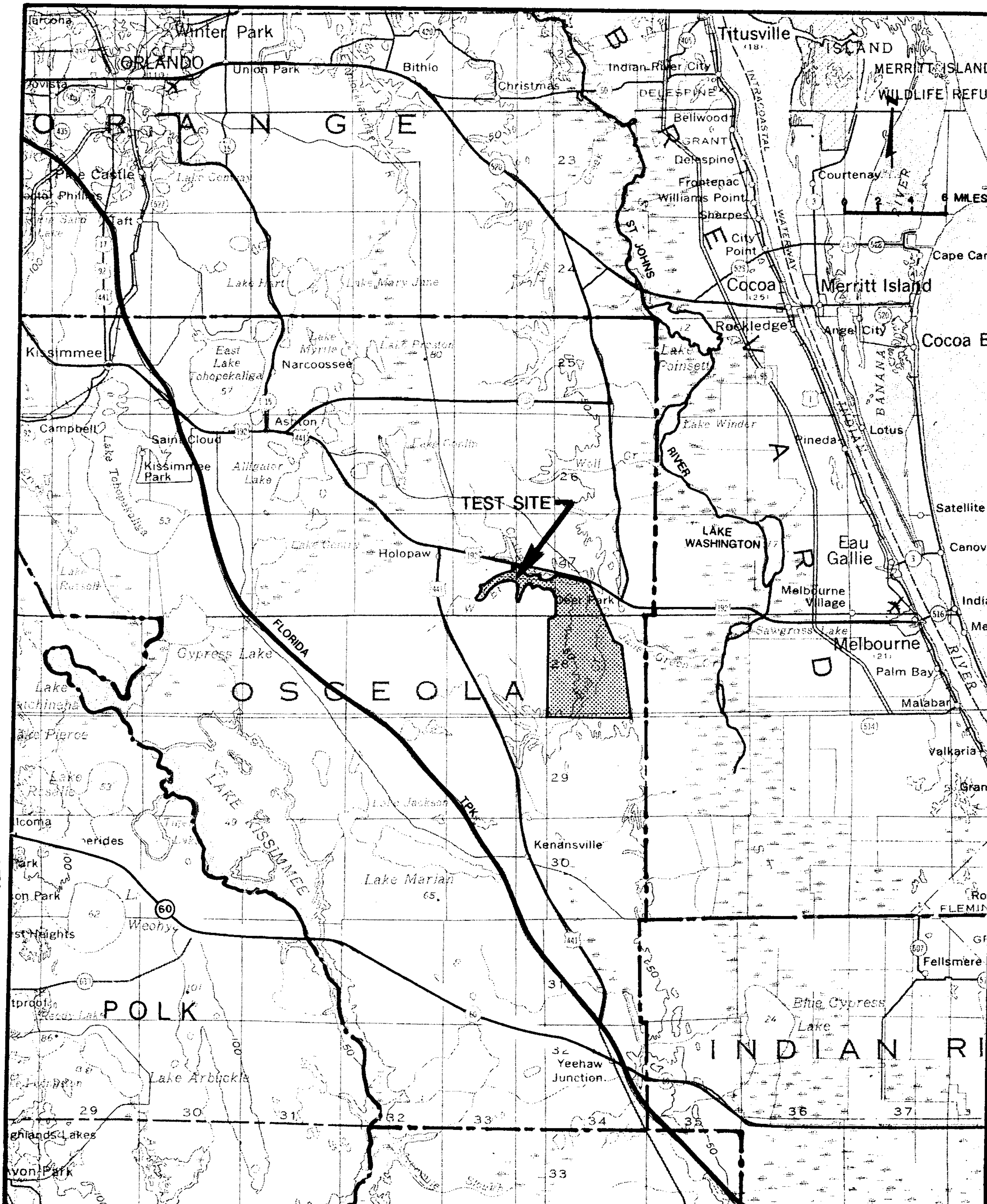
INTRODUCTION

1.1 BACKGROUND

The South Brevard Water Authority (Authority) and St. Johns River Water Management District (SJRWMD) entered into an agreement in November 1988 to evaluate the groundwater resources of the Bull Creek Wildlife Management Area in eastern Osceola County near the Brevard County line (Figure 1-1). The approximately 22,000-acre property is owned by the SJRWMD. The Agreement was developed to assist the Authority in meeting its water supply needs by having both parties participate in the design and performance of an aquifer test.

This report describes the regional hydrogeologic setting of the entire area shown in Figure 1-1, the hydrogeology of the Bull Creek test site and the aquifer test program. Regional conditions, described in Section 2, were established from published reports and updated with recent data collected by SJRWMD, the Authority, and the U.S. Geological Survey (U.S.G.S.). The hydrogeology of the Bull Creek test site is described in Section 3 using data from six wells drilled by the SJRWMD and a deep test well installed by the Authority. Section 4 describes the aquifer test program and includes a discussion of test production and observation wells, the test procedure and data, and the analyses and conclusions.



BULL CREEK WILDLIFE MANAGEMENT AREA

FIGURE 1-1

1.2 PURPOSE AND SCOPE

Well drilling and aquifer testing were performed in the Management Area to determine the groundwater development potential for potable use. Wells were designed and constructed, and the aquifer test was conducted, following guidelines established in the November 1988 Agreement between the SJRWMD and the Authority.

The test program outlined in the Agreement was specifically designed by the SJRWMD to evaluate hydraulic properties of the confining Hawthorn Formation, the Floridan aquifer producing zone, and possible confining units above and below the producing zone. The Agreement also required, as part of the test program, an assessment of the "potential for water quality degradation of the producing zone by either lateral or vertical movement of poorer quality waters in other stratified layers within the Floridan aquifer."

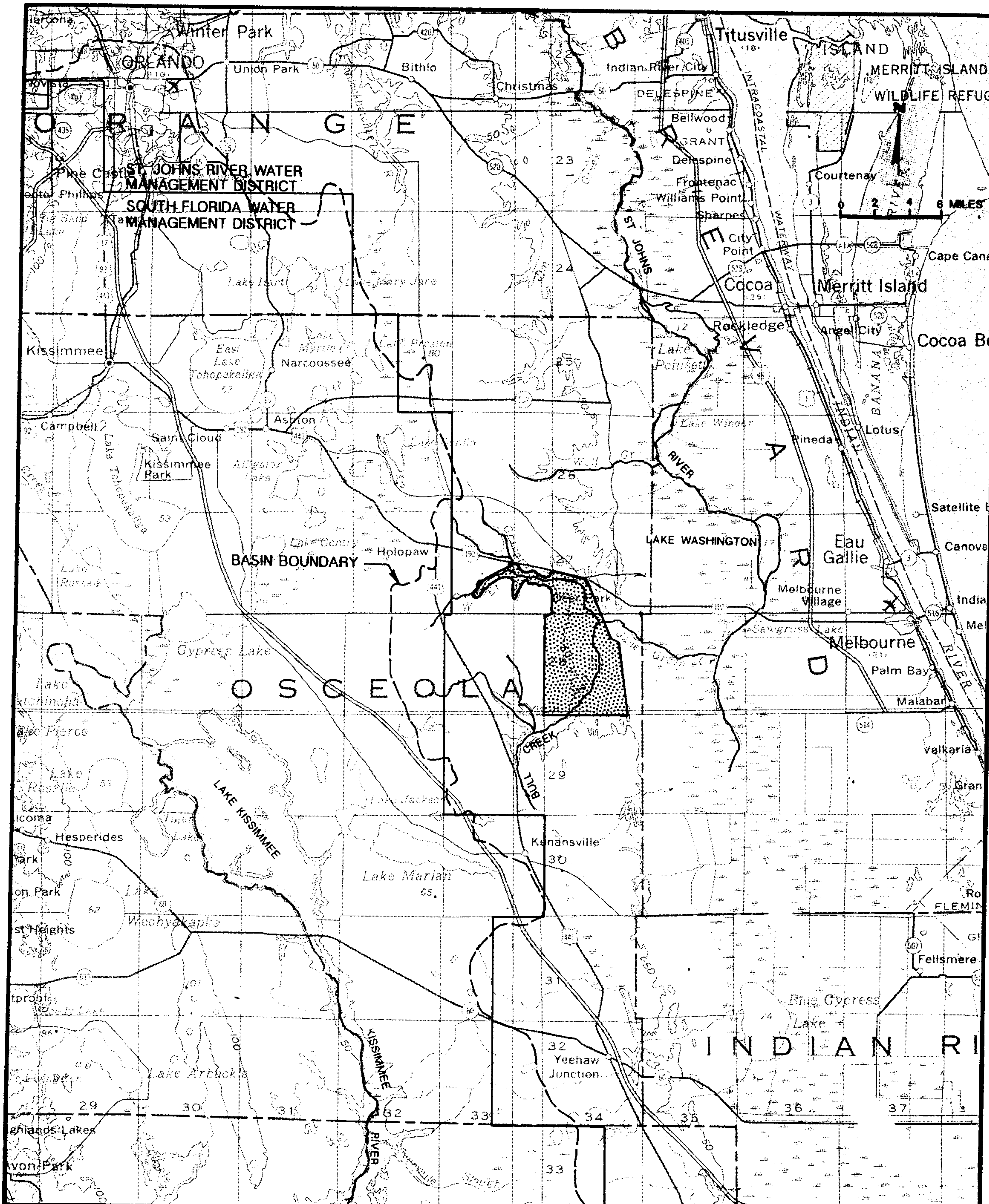
The aquifer test program consisted of four components: construct a test monitor well to obtain hydrogeologic and water quality data; design and construct a test production well and test observation wells; perform the aquifer production test; and prepare an interpretive report evaluating drilling and testing data. Groundwater flow and transport modeling studies required by the Agreement to assess expected water level and water quality impacts associated with development of a wellfield are presented in a separate report.

Well drilling and testing for this investigation were conducted at the Bull Creek test site located in the westernmost reach of the Management Area (Figure 1-1). This site was selected because of its proximity to an existing Floridan aquifer observation well installed by the SJRWMD and its easy access from S.R. 192.

1.3 SURFACE HYDROLOGY

Average yearly rainfall for most of the study area is about 52 inches, but varies greatly from year to year. The study area is drained by the Kissimmee River, about 15 miles southwest of the Management Area and the St. Johns River, about 5 miles to the east (Figure 1-2). The upper Kissimmee River basin includes the area generally west of the Management Area from the City of Orlando to just south of Lake Kissimmee near S.R. 60 where the Kissimmee River begins. The basin drains an area of approximately 1,600 square miles and has an average yearly discharge of about 9.3 inches (Hughes and Frazee, 1979). The St. Johns River drains the area east of the Kissimmee basin from the St. Johns Marsh in Indian River County north through Brevard County. The boundary between the South Florida and St. Johns River Water Management Districts generally follows the surface water drainage divide.

The Bull Creek Wildlife Management Area is located within the drainage area of the St. Johns River and its tributaries. The northern third of the Management Area is drained by Crabgrass Creek, and the southern two-thirds is drained by Bull Creek. Both creeks are tributaries to Jane Green Creek which has a drainage area of approximately 250 square miles and an average yearly discharge of 15 inches. Jane Green Creek discharges into the St. Johns Marsh, the headwaters of the St. Johns River, a distance of approximately six miles from the confluence of Crabgrass and Bull Creeks. Runoff from Jane Green Creek, and Wolf Creek to the north, is much higher than from the upper Kissimmee basin due to the absence of large open water bodies which allow for greater evaporation rates, and because of differences in hydrogeology.



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KISSIMMEE RIVER AND ST. JOHNS RIVER DRAINAGE BASINS

FIGURE 1-2

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Section 2

REGIONAL HYDROGEOLOGIC CONDITIONS

2.1 INTRODUCTION

Regional hydrogeologic conditions of the approximately 3,500 square mile area centered around the Management Area and shown in Figure 1-1 are described by the U.S.G.S. in a report prepared by Planert and Aucott (1985). Recent data collected by the SJRWMD, the Authority, and the U.S.G.S., have been included to update the discussion of regional conditions with emphasis on the Bull Creek Wildlife Management Area.

The SJRWMD drilled six wells, shown in Figure 2-1, between December 1988 and June 1989 as part of a reconnaissance study to determine groundwater quality and water supply potential within the Management Area. Well SJ-1 was drilled to 600 feet and wells SJ-2 through SJ-5 were drilled to approximately 400 feet (Table 2-1). Well SJ-6 was drilled to a depth of 780 feet.

Table 2-1 includes the Holopaw East test well, completed in December 1986, to a depth of 1,100 feet and the Bull Creek test monitor well, completed in August 1989 to a depth of 1,483 feet. Both wells were drilled by the Authority. Well U.S.G.S.-FL drilled by the U.S.G.S. in 1980 to 329 feet is also included. The latitude/longitude given in the U.S.G.S. record places the well in Section 20 near SJ-3. However, the well was found in the field in Section 29 about one mile south of SJ-3.

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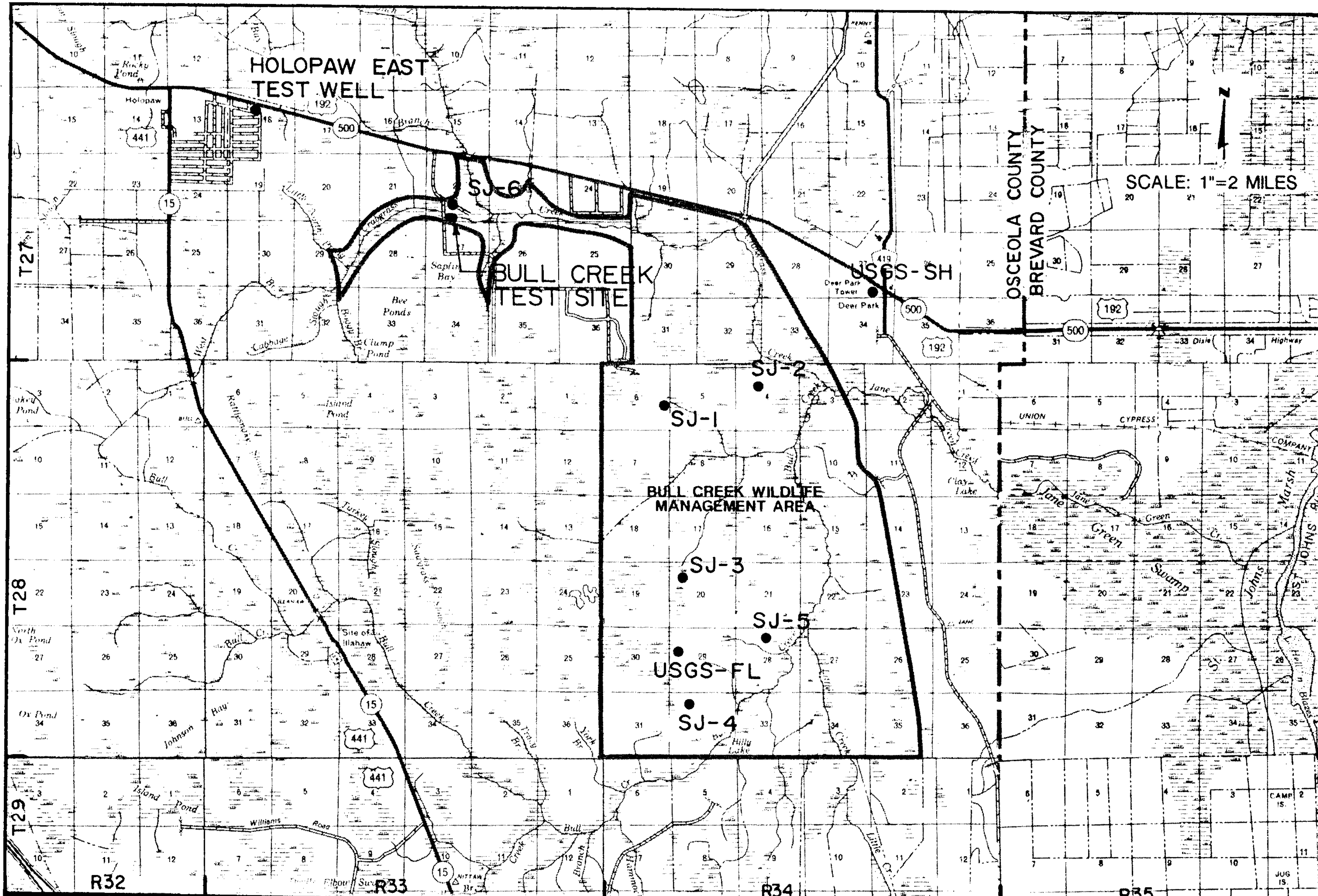


BULL CREEK AREA OBSERVATION WELLS

FIGURE 2-1

Table 2-1

OBSERVATION WELL DESCRIPTIONS

Well I.D.	Casing Depth (ft)	Total Depth (ft)	Land Elev (ft)	Dia. (in)	Township /Range/ Section	Chloride (mg/l)	
SJ-1	240	600	52	4	28/34/06	90	(1)
SJ-2	240	380	33	4	28/34/04	328	
SJ-3	240	400	57	4	28/34/20	78	
SJ-4	240	400	58	4	28/34/32	239	
SJ-5	240	400	35	4	28/34/28	298	
SJ-6	370	780	40	4	27/33/22	373	
Bull Creek Test	1,473	1,483	40	4	27/33/22	375	(2)
Holopaw East Test	320	1,100	75	10	27/33/18	300	(3)
USGS-FL	na	329	60	4	28/34/29	28	(4)

(1) Analyses for wells SJ-1 to SJ-6 by SJRWMD, 1989

(2) Analysis by PBSJ, sampled at 600 feet during drilling, 1989

(3) Analysis by PBSJ, sampled at 600 feet during drilling, 1986

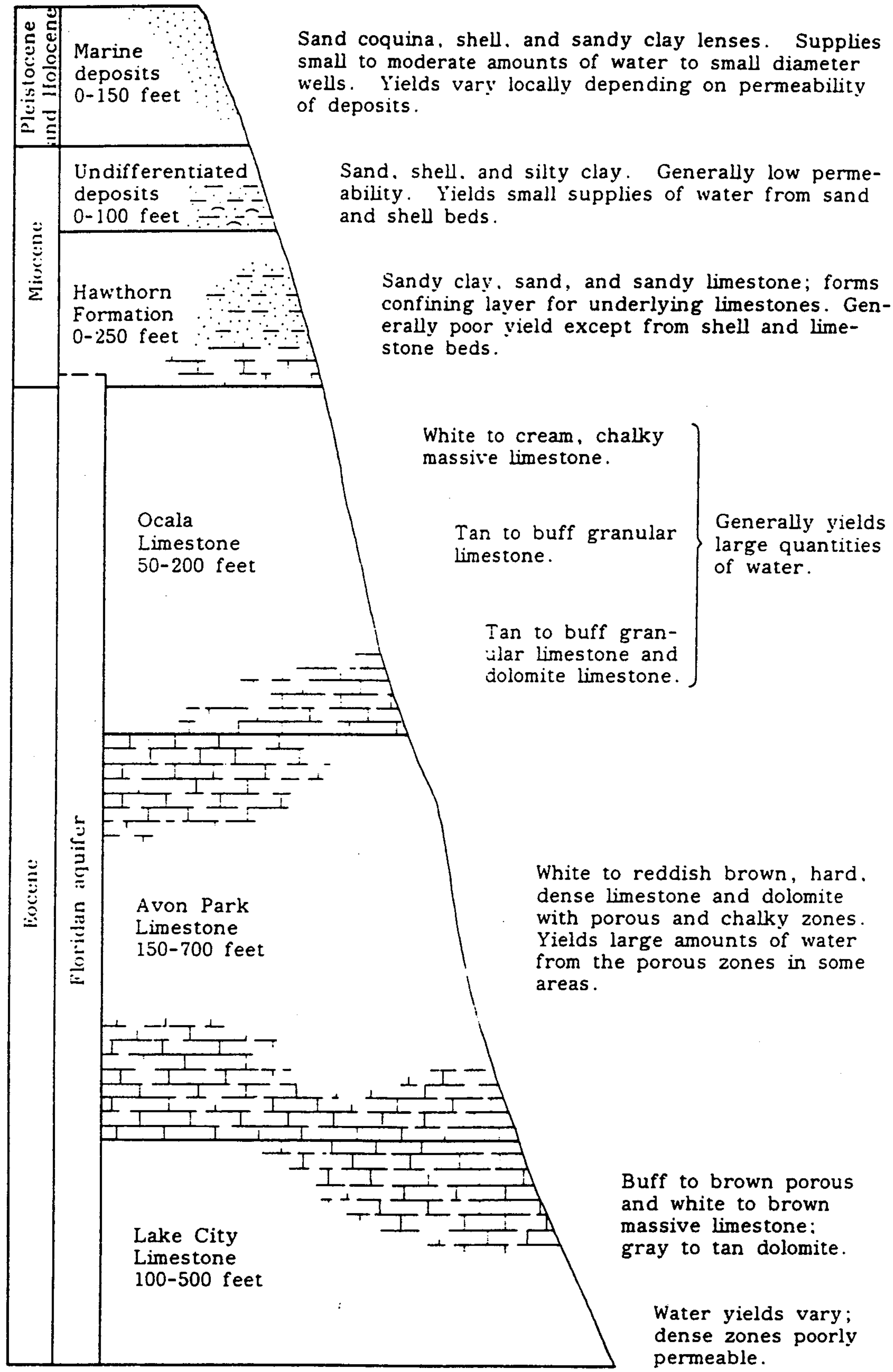
(4) Analysis by USGS, 1980

2.2 HYDROGEOLOGIC FRAMEWORK

The regional study area is underlain, in descending order, by unconsolidated sediments of Holocine and Pleistocene age, the Miocene age Hawthorn Formation, and limestones of Eocene age (Figure 2-2). The groundwater system is represented by three hydrologic layers: a surficial aquifer, a confining unit, and the Floridan aquifer. The surficial aquifer, present throughout the study area, is comprised of sand and some clay and shell. The confining unit which separates the two aquifers and does not readily transmit water is comprised of clays, silts, and dense limestone of the Hawthorn Formation. The Floridan aquifer consists of a series of limestone and dolomite formations which have a total thickness of several thousand feet.

The surficial deposits consist of unconsolidated sand and shells with some silt and clay. The deposits form an aquifer that ranges from less than 20 to over 80 feet in thickness and produces adequate domestic and some irrigation water supplies. Locally thin, discontinuous beds of shell, limestone, or sand and gravel, called secondary artesian aquifers, occur in the surficial sediments or in the upper part of the Hawthorn Formation. Although they can yield as much as 1,000 gpm, secondary artesian aquifers are not areally extensive enough to be considered as a source for major water supplies.

The Hawthorn Formation of Miocene age unconformably overlies the Ocala and Avon Park Limestones in most of the study area. The formation contains clay beds with low hydraulic conductivities which restrict the vertical movement of water to various degrees, depending on its thickness. Thickness of



(From Snell and Anderson, 1970)

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GEOLOGIC FORMATIONS IN THE STUDY AREA

FIGURE 2 - 2

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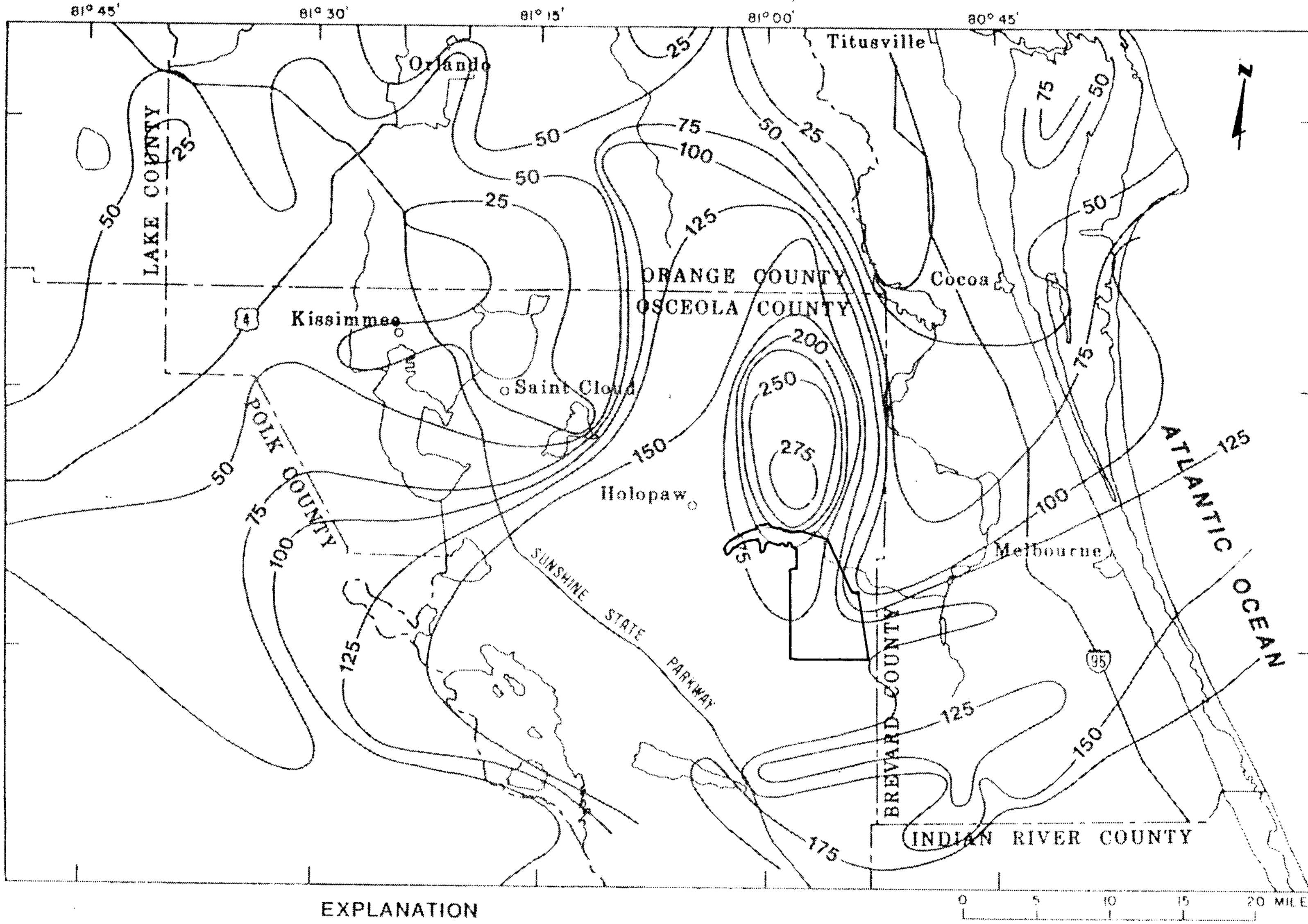
the formation varies from less than 25 feet in northwest Osceola County to over 275 feet in northeast Osceola (Figure 2-3). Recent data verify Hawthorn Formation thickness of 200 to 250 feet in the northern portion of the Management Area as shown in Figure 2-3. However, the formation is approximately 80 to 100 feet thick in the central and southern portions of the Management Area, one-half the 175-foot thickness indicated in Figure 2-3.

The Floridan aquifer is comprised of the Ocala and Avon Park Formations of Eocene age. The Eocene formations contain cavities and solution channels that can yield large quantities of water. Most large capacity irrigation wells west of the Management Area and municipal supply wells for the cities of Kissimmee and St. Cloud are drilled into the dolomites of the Avon Park Formation. Floridan aquifer studies conducted west of Orlando by PBS&J (1989) and in the Management Area indicate that these dolomites are hard and very porous, and produce large quantities of water. Less permeable zones which restrict the movement of water between the upper and lower portions of the Floridan aquifer are known to exist in central Florida. However, a comprehensive investigation has never been conducted to determine the areal extent and to characterize the hydraulic properties of the less permeable zones.

Most Floridan aquifer wells in east central Florida penetrate only the Ocala Formation, which consists of white to cream, fossiliferous limestones. The Ocala Formation ranges up to 200 feet thick in the study area, but is relatively thin or absent in the Management Area. The top of the Ocala Limestone varies in altitude as depicted by Figure 2-4. Wells can produce large quantities of water from cavities and solution channels in the Ocala Limestone. However, the Ocala Limestone and the limestones of the underlying Avon Park produce little water in the Management Area.



EXPLANATION

—125— LINE OF EQUAL THICKNESS, of Hawthorn Formation. Interval is 25 feet.

(From Planert and Aucott, 1984)

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THICKNESS OF THE HAWTHORN FORMATION

FIGURE 2-3

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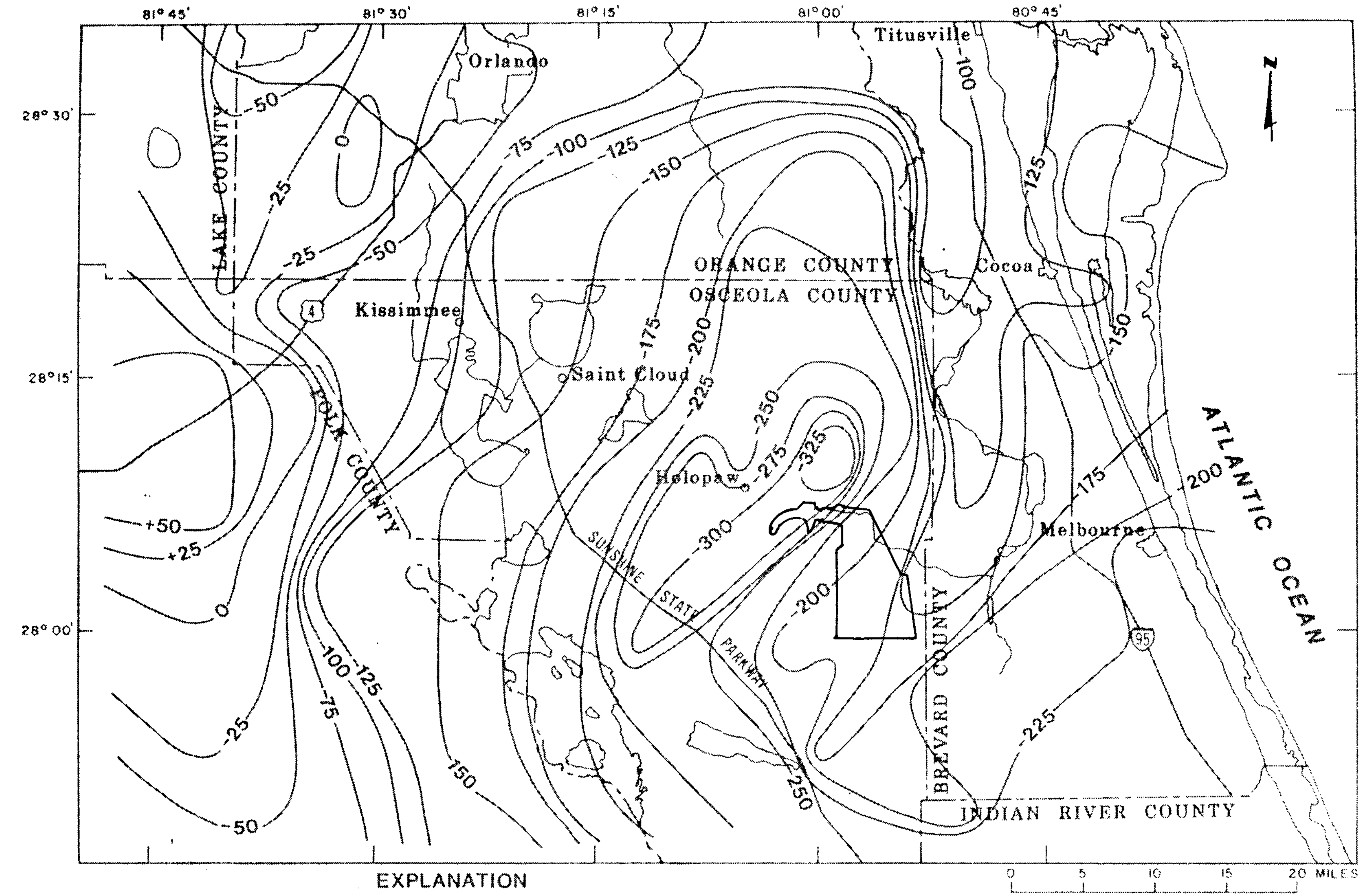

EXPLANATION

—— -50 —— STRUCTURE CONTOUR, shows altitude of the top of the Floridan aquifer. Contour interval is 25 feet. Datum is sea level.

(From Planert and Aucott, 1984)

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TOP OF THE FLORIDAN AQUIFER

FIGURE 2-4

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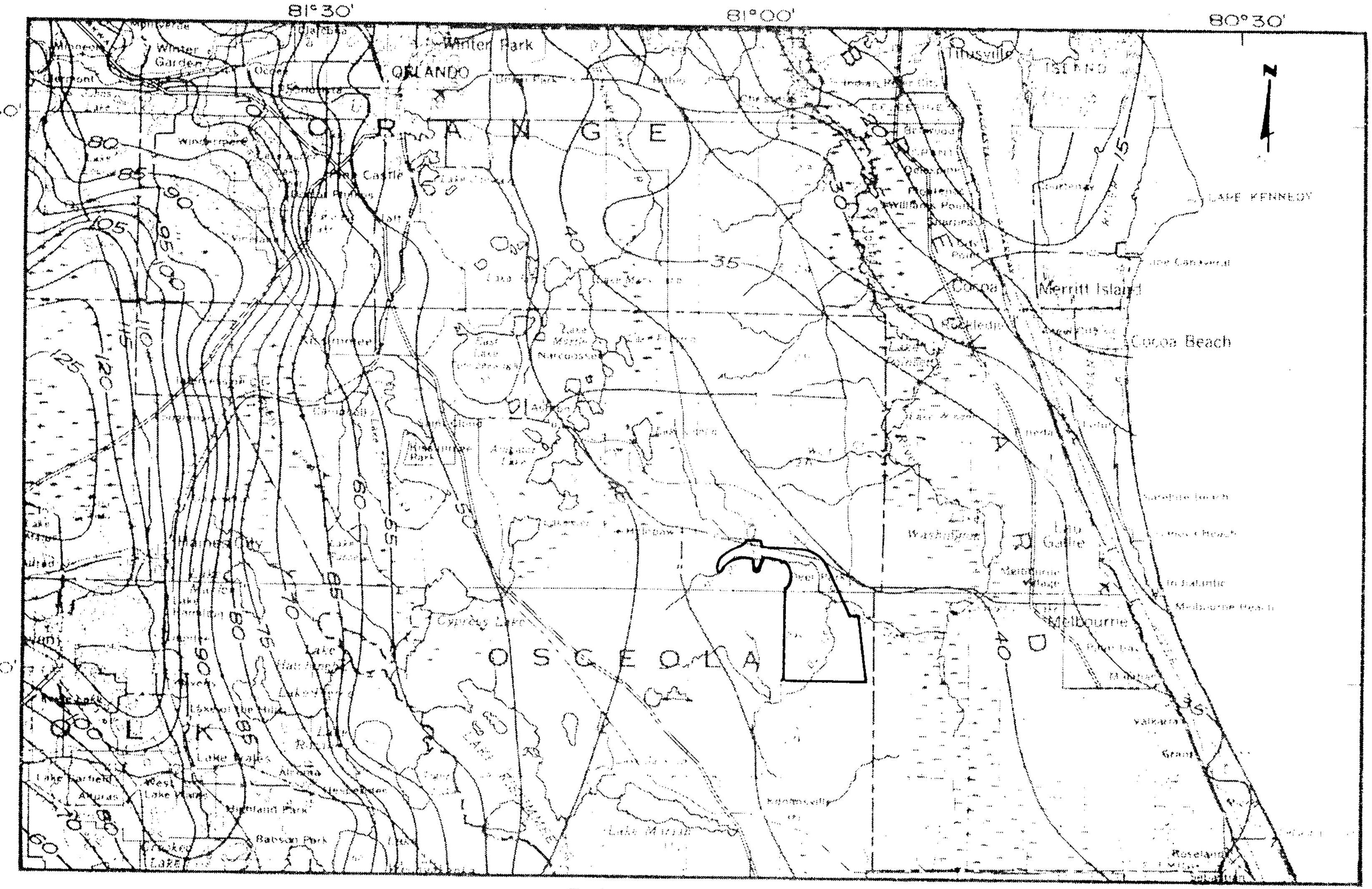
2.3 GROUNDWATER LEVELS AND FLOW

Water in the Floridan aquifer in under artesian pressure and rises to its potentiometric level in wells open to the aquifer. Figure 2-5 depicts the potentiometric surface of the Floridan aquifer in September 1980. The potentiometric map for September 1988, the most recent available, is nearly identical, except for a ten-mile radius centered near Deer Park where water levels appear to be 2 to 3 feet higher.

The potentiometric high in Polk County (Figure 2-5) acts as a groundwater divide which separates groundwater flow in the Floridan aquifer toward the east and west coasts. In the study area, groundwater moves generally from the groundwater divide to the east in the direction of decreasing potentiometric levels, and locally toward major discharge points, such as springs and areas of heavy pumpage. A predominant discharge feature, created by withdrawals of about 20 million gallons per day at the City of Cocoa wellfield, can be seen along the 35-feet contour near the Econlockhatchee River in eastern Orange County. The dramatic eastward shift of the 40-foot contour, south of Deer Park, is probably due to recharge to the Floridan aquifer to the west of the contour.

Recharge to the Floridan aquifer primarily occurs along the Lake Wales ridge where the confining unit is thin or absent (Figure 2-6). Some recharge does occur beneath topographically high areas where the water table is above the potentiometric surface as in central Osceola County. However, the presence of a thick confining unit and a potentiometric surface generally close to land surface limits the overall recharge rates in eastern Osceola County. The similarity of the 1980 and 1988 potentiometric maps indicates that the amount of



EXPLANATION

SEPTEMBER 1980

—80— POTENTIOMETRIC CONTOUR--Shows elevation at which water levels would have stood in tightly cased wells. Interval 5 feet. Datum is sea level.

(From Planert and Aucott, 1984)

0 5 10 15 20 MILES

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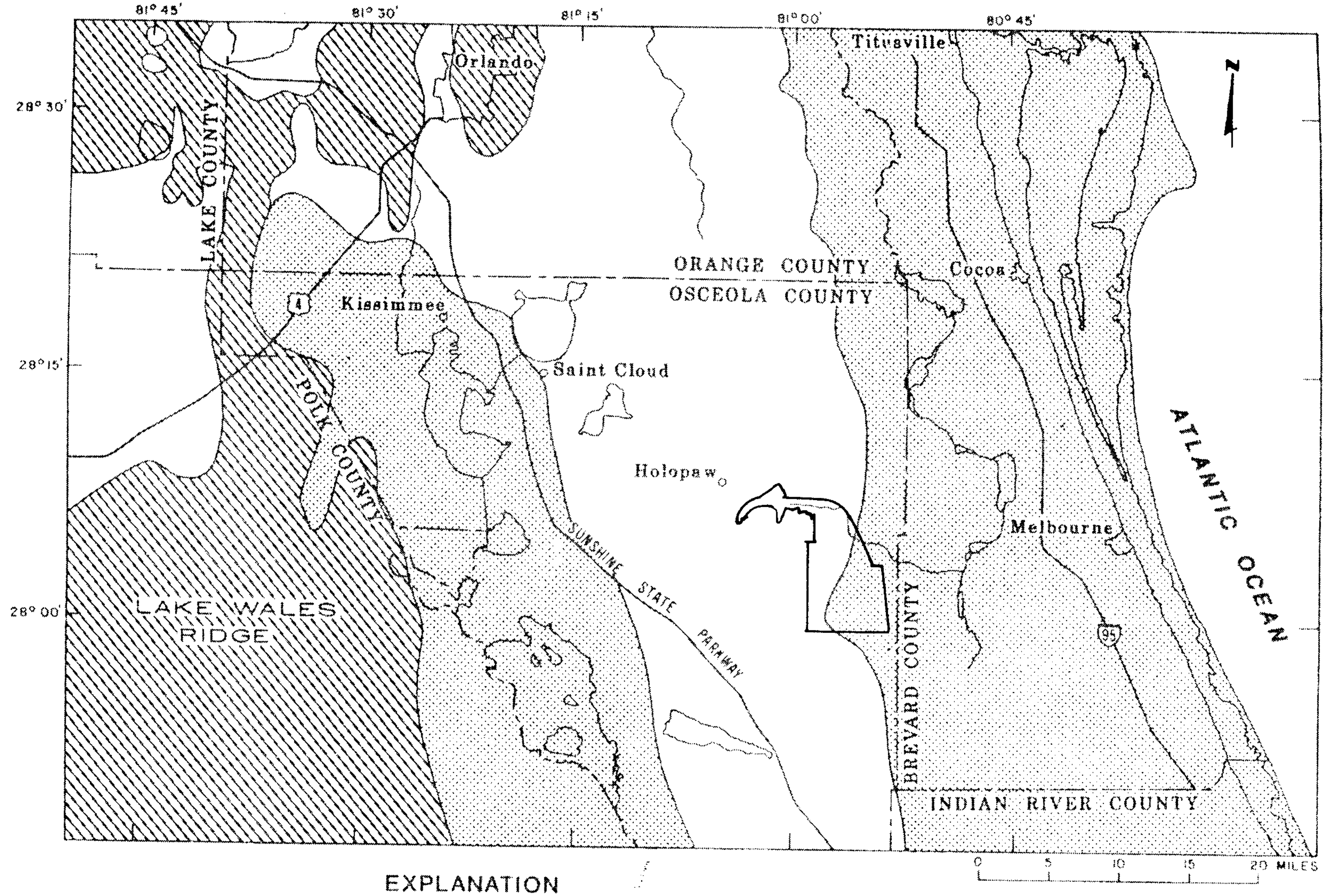
POTENTIOMETRIC SURFACE OF THE FLORIDAN AQUIFER

FIGURE 2-5



EXPLANATION

- Areas of high recharge.
- Areas of low to moderate recharge.
- Areas of generally no recharge.

(From Planert and Aucott, 1984)

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AREAS OF RECHARGE TO THE FLORIDAN AQUIFER

FIGURE 2-6

water stored in the Floridan aquifer has not changed significantly during this period because the rate of recharge and discharge were in equilibrium.

2.4 FLORIDAN AQUIFER PROPERTIES

Planert and Aucott (1985) conducted tests on 19 irrigation wells within the study area to determine transmissivity of the Floridan aquifer. The transmissivity data were obtained from specific capacity tests conducted on the upper 300 to 400 feet of the aquifer, composed of soft limestone. Eleven (11) data points are located near the Osceola/Brevard County line. Transmissivity ranged from about 50,000 to 500,000 gpd/ft. and averaged about 185,000 gpd/ft. Aquifer transmissivities estimated at six wells in the Management Area (Figure 2-1) from tests performed by the SJRWMD (1989) ranged from about 10,000 to 50,000 gpd/ft. The values were obtained from specific capacity tests of wells which penetrated from 100 to 350 feet of the Floridan aquifer. Transmissivities for the upper 350 feet of the Floridan aquifer at the Bull Creek test site (Figure 2-1 and Table 3-1), determined from step drawdown tests conducted by the Authority, are consistent with these studies.

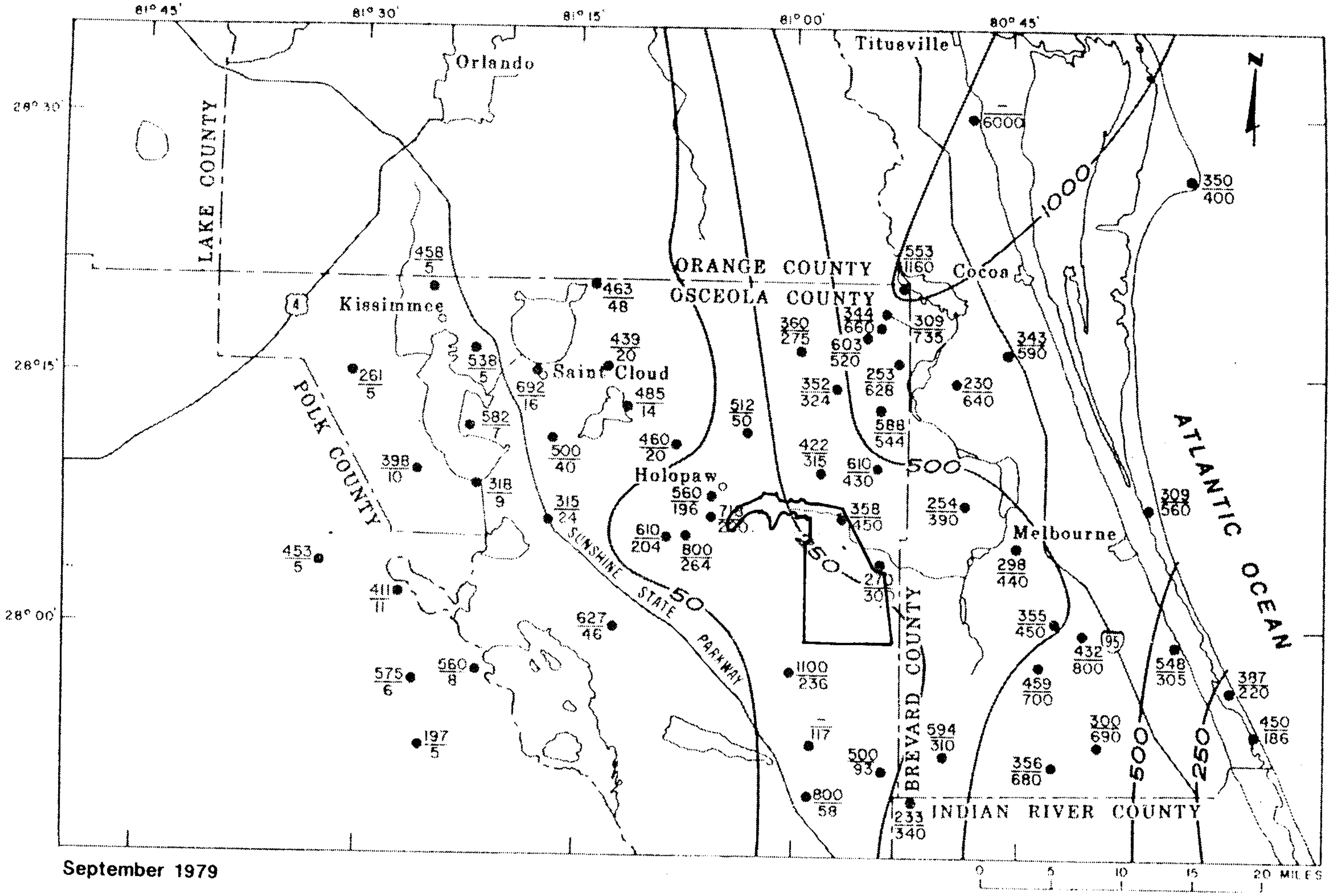
Published data indicate that the dolomite of the Avon Park Formation which underlies the soft limestone is 10 to 20 times more transmissive. Shaw and Trost (1984) report transmissivities of about 300,000 gpd/ft. to more than 1,000,000 gpd/ft. determined from 12 wells penetrating the dolomite in the western half of the study area which lies in the South Florida Water Management District (Figure 1-2). A transmissivity of about 450,000 gpd/ft. was estimated from a drillers report for Well OSF-55, about four miles southwest of the Bull Creek test site. This well has about 350 feet of casing and a total depth of about 900 feet.

Few data are available to determine the transmissivity of the thick sequence of dolomite from the Avon Park Limestone in isolation from the overlying soft limestone. Most large diameter irrigation wells in Osceola County are cased to the first limestone, for economic reasons, and are open to both the limestone and underlying dolomite sequence. Few irrigation wells in Brevard County penetrate the Avon Park dolomite (verbal comment from Bud Timmons, Brevard County hydrogeologist). A test production well at the Bull Creek test site, constructed with 200 feet of borehole open almost entirely within the Avon Park dolomite, has a transmissivity of approximately 2,000,000 gpd/ft.

Regional flow modeling studies report transmissivities for the upper Floridan aquifer of about 500,000 gpd/ft (Planert and Aucott, 1985) and from about 750,000 to 1,500,000 gpd/ft. (Tibbals, 1981) within the study area. Values within Brevard County average about 350,000 gpd/ft. Leakance values derived from modeling studies average about 1×10^{-5} day^{-1}, but vary throughout the study area depending upon the vertical hydraulic conductivity and thickness of the confining unit.

2.5 GROUNDWATER QUALITY

Figure 2-7, from Planert and Aucott (1985), depicts the areal distribution of chloride concentration within the Floridan aquifer. The general pattern indicates that groundwater is freshest upgradient of the 45-foot potentiometric contour (Figure 2-5), about 20 miles west of the Osceola-Brevard County line, and increases in dissolved mineral content towards the east. This pattern is partially explained by changes in quality due to chemical reactions that occur as groundwater flows through the Floridan aquifer. Areas where potentiometric con-



September 1979

EXPLANATION

—50— LINE OF EQUAL CHLORIDE CONCENTRATION, in milligrams per liter. Contour interval varies.

●197/5 WELL LOCATION, upper number is depth of well below land surface, in feet. Lower number is chloride concentration in milligrams per liter.

(From Planert and Aucott, 1984)

CHLORIDE CONCENTRATIONS IN THE FLORIDAN AQUIFER

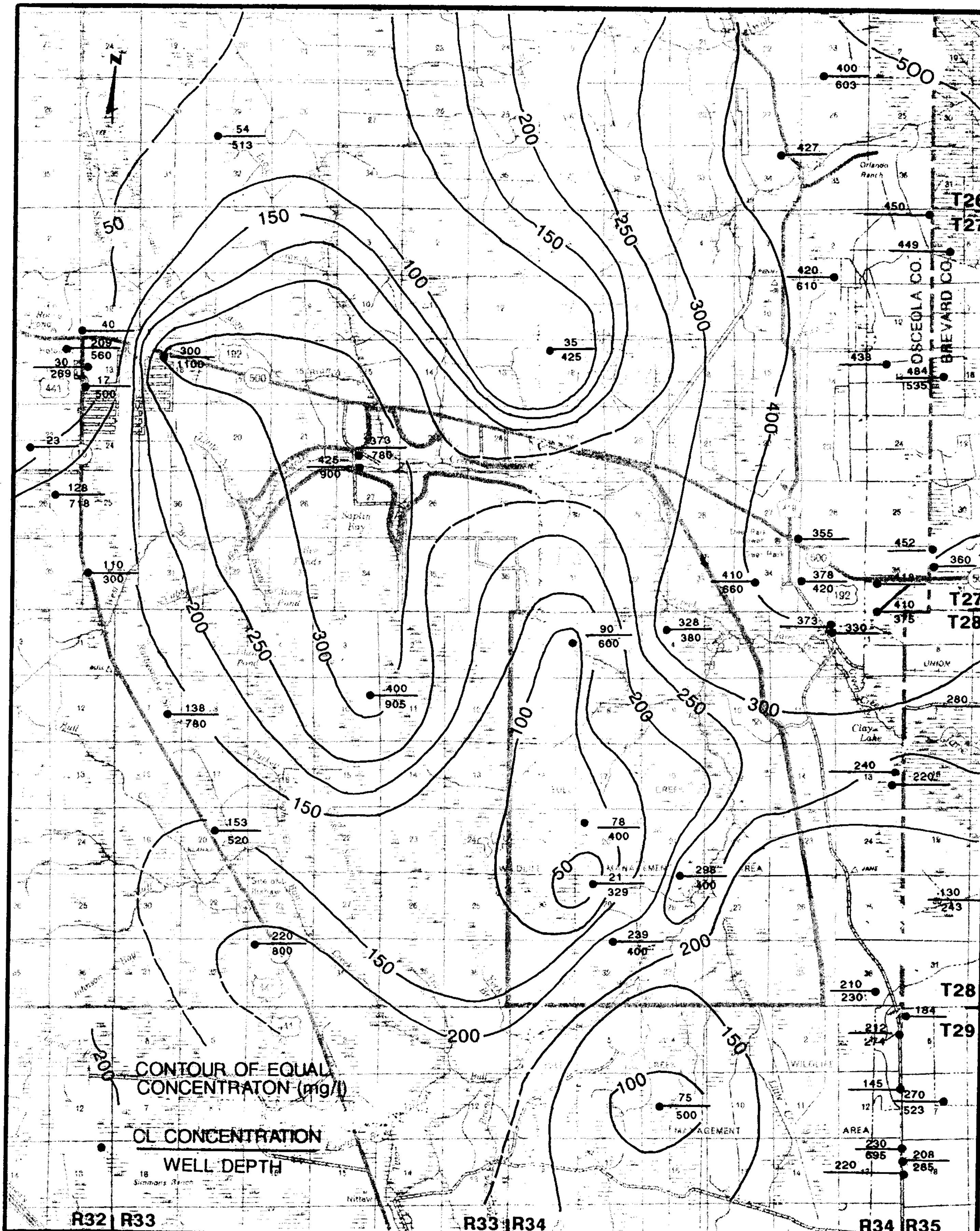
FIGURE 2-7

tours are more widely spaced in Figure 2-5 indicate a gentle groundwater gradient and possibly slower groundwater movement which results in more dissolved ions in solution as the carbonate rocks are slowly dissolved.

SJRWMD (1989) prepared a detailed contour drawing of chloride concentrations within the study area, using data compiled from the U.S.G.S., the Authority, and their own records. Chloride data are from the upper 100 to 500 feet of the Floridan aquifer, as are data in Figure 2-7. A similar regional pattern is depicted, but with an unexplained shift in concentration to the west in the vicinity of the Management Area. The SJRWMD data set was revised to resolve inconsistencies in the data and to correct possible errors. Removal of a surficial aquifer data point near Deer Park (Well 280620805426) substantially changed the orientation of the contours in the northern portion of the Management Area. Minor corrections were made in the position of three data points. A chloride of 425 mg/l from Well TP at the Bull Creek test site was added to the data set, and a concentration of 12 mg/l from Well 280107810201 was removed. Contouring was intially performed using a computer to obtain a general representation of the distribution. Manual refinements and adjustments were made to better fit the data. Figure 2-8 shows the westward shift in the 250 mg/l contour parallel to Crabgrass Creek and Jane Green Creek, also depicted in the original SJRWMD drawing. The lense of relatively fresh water shown by the 50 and 100 mg/l isochlors in the western portion of Management Area may be the result of local recharge due to somewhat higher land elevations and a relatively thin confining unit. A concentration of 209 mg/l reported by the USGS from a well in Section 14 southwest of Holopaw is much greater than other nearby values and may be the result of measurement or sampling error.

The 250 mg/l contour in Figure 2-8 shows a pronounced relationship to the lower land surface elevations adjacent to Crabgrass Creek, Bull Creek, and their tributaries. A similar relationship was proposed by Barraclough (1962) in Seminole County near the St. Johns River and its tributaries. The higher mineral content near stream channels appears to be the result of seawater infiltrating into the Floridan aquifer during the Pleistocene age when the sea stood above its present level. Table 2-1 illustrates how wells drilled at or below elevation 40 feet generally have the highest chloride concentrations. Wells SJ-4 and the Holopaw East well, at elevations 58 and 75 feet, appear to be exceptions. However, well SJ-4 is less than 2,500 feet from Bull Creek on one of its steepest banks, and physiographic information indicates that the Holopaw test well is located on a relict beach ridge.

Few data are available within the study area to areally define the depth of the transition zone between fresher water and more highly mineralized water below. Data from the Cocoa wellfield, about 20 miles north of the Management Area, indicate a rapid transition to more mineralized water with chloride concentrations increasing from about 100 mg/l to about 2,200 mg/l between 1,350 and 1,360 feet. A more gradual transition to mineralized water was encountered at the Bull Creek test site where chloride concentrations increased from about 400 mg/l at 1,450 feel to about 1,000 mg/l at 1,480 feet. Data from the City of Melbourne test well at Lake Washington, about 18 miles east of the Bull Creek test site, indicate that chloride concentrations remain relatively constant at about 550 mg/l from the top of the Floridan aquifer to total depth at 1,200 feet. Concentrations also were relatively constant, about 275 to 325 mg/l, to a total depth of 1100 feet at the Holopaw East Well about 3.5 miles west of the test site.



CHLORIDE CONCENTRATIONS
IN THE UPPER FLORIDAN AQUIFER
REVISED FROM SJRWMD (1989)

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Section 3

HYDROGEOLOGY OF THE BULL CREEK TEST SITE

3.1 INTRODUCTION

Hydrogeologic data at the Bull Creek test site were collected from wells drilled by the Authority in cooperation with the SJRWMD. The SJRWMD drilled six wells, described in Table 2-1, as part of the reconnaissance study to determine groundwater quality and water supply potential within the Bull Creek Wildlife Management Area. Well SJ-6 was drilled in the northwestern portion of the Management Area (Figure 2-1).

Wells drilled by the Authority from August to November 1989, discussed in Section 2.1, provided data to describe the hydrogeologic conditions at the test site. The Authority installed a deep test monitor well approximately 950 feet south of SJ-6 which provided hydrogeologic data to design the test production and observation wells for aquifer testing. Data collected during construction of the production well and eight observation wells augmented the geologic information from the test monitor well. Borehole geophysics assisted in delineating hydrogeologic units and water producing zones. Water quality data were collected during drilling and from completed wells to characterize the geochemistry of water at increasing depths in the Floridan aquifer. Step drawdown tests were conducted to determine the yield of various zones within the Floridan aquifer and to estimate aquifer transmissivity.

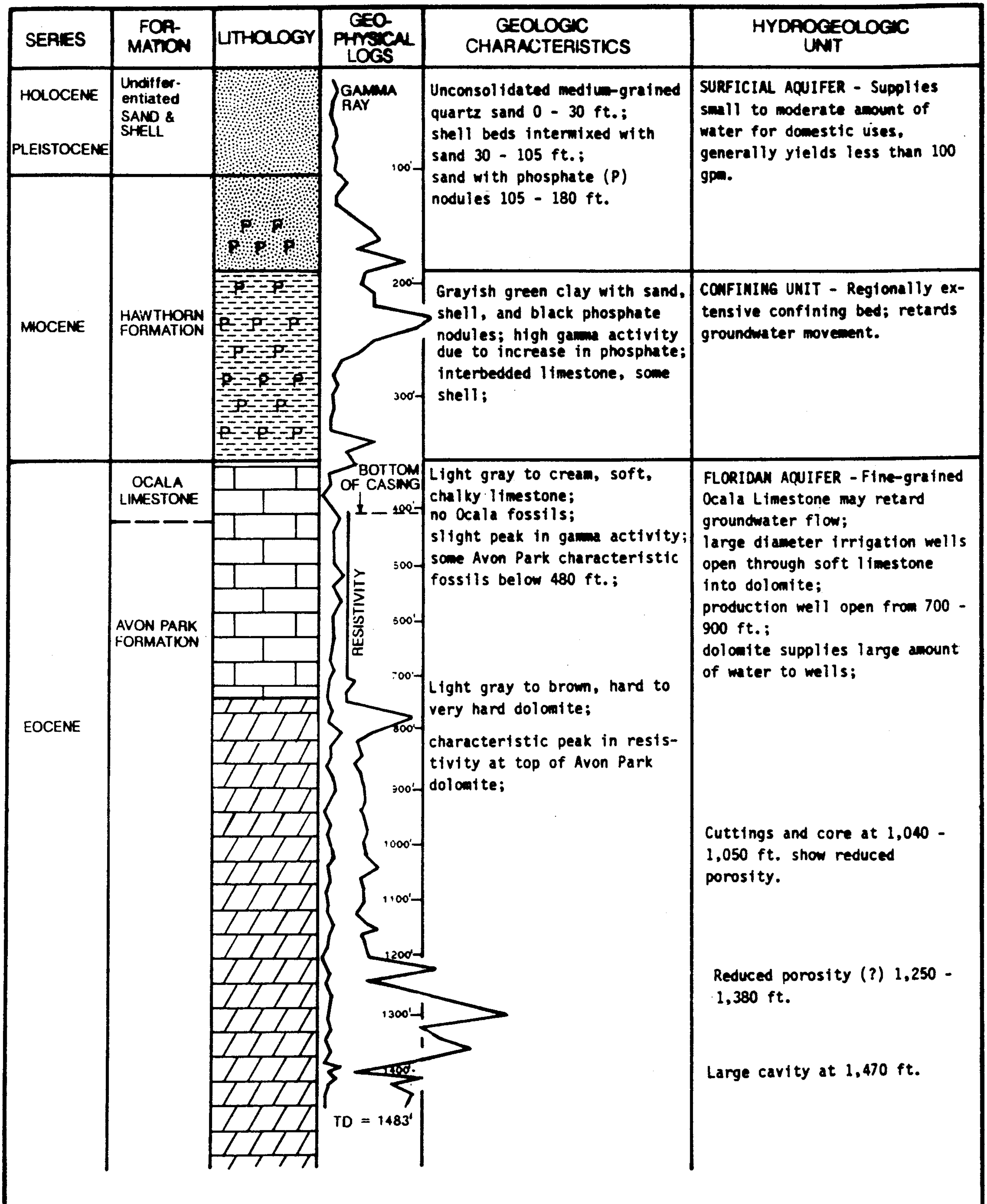
3.2 HYDROGEOLOGY

3.2.1 Geology

The Bull Creek test site is underlain, in descending order, by undifferentiated deposits of sand and shell ranging in age from Holocene to Pleistocene; Miocene phosphatic clays with varying amounts of sand, shell, and limestone; relatively soft, chalky limestone of Eocene age; and a thick sequence of hard, porous dolomite also of Eocene age. Figures 3-1 and 3-2 show the major geologic formations present in the test monitor well (TM) and in the dual zone well (D) as distinguished by geophysical logs and lithology.

The undifferentiated sand and shell deposits extend from land surface to 180 feet in well TM and to about 100 feet in well D. The Hawthorn Formation, composed principally of phosphatic clays with interbedded sand and limestone, extends to a depth of approximately 370 feet in both wells. The Hawthorn Formation is underlain by a thick sequence of limestone and dolomite which extends from 370 feet to total depth in both wells. The Ocala Limestone, the uppermost limestone unit commonly identified by foraminifera Lepidocyclina, is lithologically similar to and lies unconformably above the Avon Park Formation. The absence of characteristic fossils suggests that the Ocala Limestone may be missing at the test site.

The Avon Park Formation, recognized by the presence of the fossil Dictyoconus cookei and by a small peak in gamma activity (Shaw and Trost, 1984), occurs at a depth of about 420 feet at the test site. This indicates that the overlying Ocala Limestone is about 50 feet thick at the site. Descriptions of



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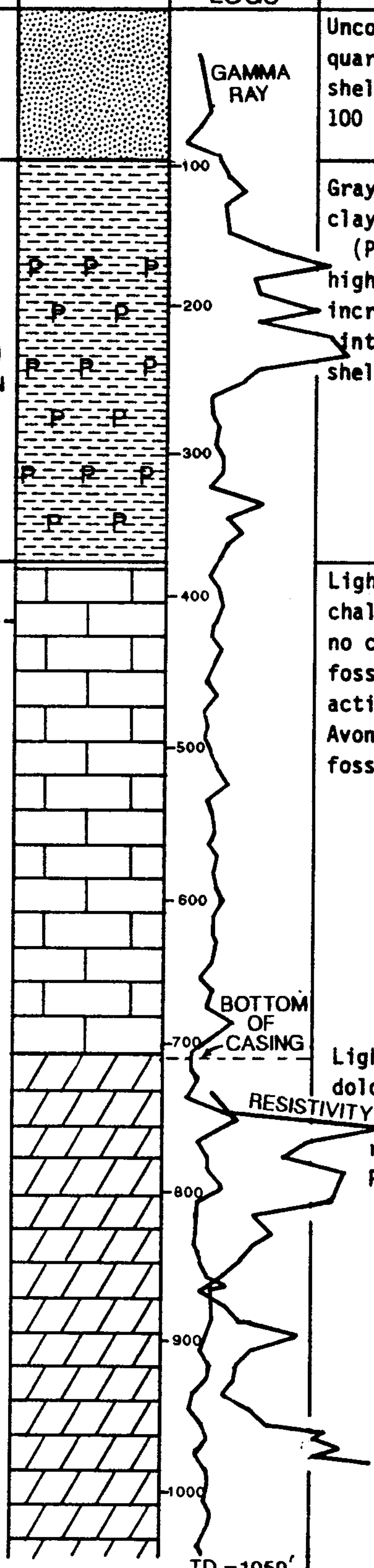
GEOLOGIC FORMATIONS AND HYDROGEOLOGIC UNITS FROM WELL TM

FIGURE 3-1

SERIES	FORMATION	LITHOLOGY	GEOPHYSICAL LOGS	GEOLOGIC CHARACTERISTIC	HYDROGEOLOGIC UNIT
HOLOCENE PLEISTOCENE	Undifferentiated SAND & SHELL			Unconsolidated medium-grained quartz sand 0 - 30 ft.; shell beds with limestone 30 - 100 ft.	SURFICIAL AQUIFER - Supplies small to moderate amount of water for domestic uses, generally yields less than 100 gpm.
MIOCENE	HAWTHORN FORMATION			Grayish green clay 100 - 160 ft clay with abundant phosphate (P) 160 - 370 ft.; high gamma activity due to increase in phosphate; inter-bedded limestone, some shell;	CONFINING UNIT - Regionally extensive confining bed; retards grounwater movement.
EOCENE	OCALA LIMESTONE AVON PARK FORMATION			Light gray to creamy, soft, chalky limestone; no characteristic Ocala fossils; slight peak in gamma activity at 520 ft.; some Avon Park characteristic fossils below 430 ft.; Light gray to brown, hard dolomite to total depth; characteristic peak in resistivity at top of Avon Park dolomite; Core cut at 1,040 - 1,050 ft.	FLORIDAN AQUIFER - Fine-grained Ocala Limestone may retard groundwater flow; large diameter irrigation wells open through soft limestone into dolomite; production well open from 700 - 900 ft.; dolomite supplies large amount of water to wells;



GEOLOGIC FORMATIONS AND HYDROGEOLOGIC UNITS FROM WELL D

FIGURE 3-2

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drill cuttings by Scott (1988) show the Ocala to be about 50 feet thick near the Management Area. Limestones from the Ocala Limestone and Avon Park Formation are underlain by hard dolomite from the Avon Park Formation. Resistivity logs show the characteristic deflections as dolomite is encountered at about 730 feet, and indicate that dolomite density increases significantly below about 1,200 feet.

3.2.2 Hydrogeologic Units

Three hydrogeologic units having distinct hydrologic characteristics were identified from geologic and geophysical data collected during this investigation. The hydrogeologic units, shown in Figures 3-1 and 3-2, include the surficial aquifer, the Hawthorn confining unit, and the Floridan aquifer. The surficial aquifer at the test site is about 100 feet thick and is composed of approximately 30 feet of unconsolidated quartz sand and 70 feet of shell with sand and limestone. Domestic wells tapping the surficial aquifer generally yield small to moderate amounts of water.

Underlying the surficial aquifer are the regionally extensive confining clays of the Hawthorn Formation. The grayish green clays and sands contain abundant phosphate nodules greatly increasing gamma activities from about 125 to 375 feet. The 200- to 250-foot thick, low-permeability clays act as a confining unit to retard vertical movement of groundwater through the Hawthorn Formation.

The Floridan aquifer at the test site is composed of a thick sequence of carbonate rocks beginning about 370 feet and extending to more than 1,485 feet. A soft, fine-grained limestone, with relatively low permeability, was encountered from the top of the Floridan aquifer to a depth of approximately 730 feet. This soft limestone sequence produces relatively small quantities of water at the test site.

Below 730 feet, the limestone has been altered into a hard brown dolomite. Dolomitization of the limestone produces voids in the rock which yield large amounts of water to wells at the test site. Porosity appears to be greatest from 730 to 950 feet and below 1,400 feet. A reduction in porosity was observed in cuttings collected from approximately 1,000 to 1,400 feet and from a 10-foot core cut at 1,040 feet. Most large-diameter irrigation wells in the area are cased into the top of the soft limestone and are open into the underlying dolomite to about 1,000 feet.

3.2.3 Borehole Geophysics

Borehole geophysics were used to delineate hydrogeologic units, to identify potential producing zones, and to identify changes in water quality with depth. Gamma, electric, acoustic, temperature, caliper and flow velocity logs were conducted in wells TM and SJ-6 (except acoustic) by Southern Resources Exploration. Copies of all geophysical logs are provided in Volume 2. The SJRWMD conducted caliper, gamma, flowmeter and electric logs in wells TM and D, and a gamma log in well MC. With the exception of the gamma log, all logs were conducted in the uncased borehole section of the wells.

Gamma ray, resistivity, and acoustic logs aided in delineating the hydrogeologic units described in Section 3.2.2. Gamma and resistivity deflections, depicted in Figures 3-1 and 3-2, show good correlation in wells TM and D, about 250 feet apart. Gamma activity is greatest in the Hawthorn Formation between 125 and 375 feet, where phosphate nodules are common, and is lowest above 125 feet and below 375 feet. Resistivity logs measure apparent resistivity of the formation and surrounding fluid and can be related directly to porosity when water quality is relatively constant (Keys, 1989). Acoustic velocity, or sonic, logs record the travel time and velocity of a refracted acoustic wave and is dependent upon porosity and density of the formation.

Four distinct porosity changes are apparent from the resistivity and sonic logs: low porosity soft limestone from 380 to 730 feet; porous dolomite from 730 to 1,000 feet; very dense, low-porosity dolomite from 1,000 to 1,400 feet; and porous dolomite below 1,400 feet. An increase in formation hardness with depth is demonstrated by the reduction in borehole diameter depicted in the caliper log. The greater spacing between the 16-inch and 64-inch resistivity logs shown in Volume 2 for well TM indicates that the porosity of the formation is greatly reduced from 1,200 to 1,380 feet. Formation and borehole fluid resistivities are the same from 1,385 to 1,405 feet due apparently to an increase in formation porosity shown on the sonic log. Porosity remains relatively high below 1,410 feet to total depth.

Fluid logging was conducted in well TM to measure characteristics of the fluid column in the borehole. These logs included temperature, flow, and resistivity logs. Caliper logs provided a record of borehole diameter for use in the interpretation of the temperature and flow logs. Borehole temperature increases from 27.4 degrees C. at 400 feet, the bottom of the casing, to 27.9 degrees C. at 1,470 feet near the bottom of the hole. This small geothermal gradient indicates mixing of lower temperature water from higher in the aquifer.

The differential temperature log identified apparent water producing zones from 500 to 530 feet, 740 to 760 feet, 790 to 800 feet, and 820 to 830 feet. However, when corrected for changes in velocity due to variations in borehole diameter, the flow log suggests very little inflow to the borehole occurs between 500 and 530 feet. Water within the borehole appears to move between a large cavity encountered at 745 feet and a second cavity at 1,195 feet. Decreasing flow velocity from 1,200 to 1,470 feet is related to the uniform borehole diameter and lack of flow contribution from above.

The fluid resistivity response is relatively constant to about 1,350 feet, indicating no change in dissolved solids concentration. The abrupt decrease in fluid resistivity from 1,350 to 1,400 feet is directly related to an increase in dissolved solids concentration caused by the mixing of freshwater from above with mineralized water from below. Fluid resistivity is relatively constant from 1,390 to 1,420 feet where a decrease in porosity also is shown on the formation resistivity log. A relatively flat resistivity gradient indicates a constant concentration of mineralized water in the high-porosity zone between 1,400 and 1,450 feet.

3.2.4 Core Samples

Core samples were collected in well TM and in well D using a 4-inch diameter core barrel attached to the end of the drill rod. Ten-foot cores were cut in expected low-permeability zones beginning at depths of approximately 335, 940, and 1,090 feet in well TM, and at 1,040 feet in well D. The hydraulic properties of representative sections of the four cores were analyzed by Ardaman & Associates, Inc. of Orlando and are summarized in Table 3-1. A 12-inch clay

Table 3-1

HYDRAULIC PROPERTIES OF SELECTED CORES

Depth (feet)	Description	Porosity (percent)	Hydraulic Conductivity Vertical (feet/day)	Hydraulic Conductivity Horizontal (feet/day)	Specific Storage ($feet^{-1}$)
240	Sandy Clay	0.45	0.0007	-	-
342	Sandy Clay	0.45	0.0003	-	$7X10^{-7}$
946	Dolomite	0.32	0.1560	-	$5X10^{-7}$
1,046	Dolomite	0.16	0.0002	0.00001	$2X10^{-7}$
1,100	Dolomite	0.16	0.0002	-	$2X10^{-7}$

sample collected at 240 feet by the SJRWMD was analyzed by Westinghouse Environmental.

The hydraulic conductivities determined in the laboratory are much lower than field values obtained from aquifer testing because only properties of the rock are measured in the laboratory (Navoy, 1986). Values determined in the field by pumping wells are based on a much larger and, therefore, more representative sample of the Floridan aquifer and include the effect of fractures and interconnected pores. Laboratory data should be used only in a comparative sense and should not be considered to represent true hydraulic conductivity.

Porosity and hydraulic conductivity values verify visual observation that the dolomite core collected from 940 to 950 feet is very porous. The difference in vertical hydraulic conductivity of the 946-foot sample and dolomite samples tested at 1,046 and 1,100 feet is significantly large to indicate that the hydraulic conductivity is substantially reduced from at least 1,046 to 1,100 feet. The vertical conductivity of the low-porosity dolomite appears to be somewhat less than the confining Hawthorn Formation clay. The laboratory stated that the horizontal conductivity for the 1,046-foot core was not expected to be less than the vertical and may be the result of experimental error. The horizontal hydraulic conductivity of the 1,046-foot sample, however, is extremely low when compared to the vertical conductivity of the 946-foot sample. Specific storage, calculated from an equation developed by Lohman (1970), is used in Section 4 to estimate storage coefficient of the aquifer.

3.3 GROUNDWATER LEVELS

Water level hydrographs were generated to illustrate how water stored in the surficial and Floridan aquifers responds to recharge and discharge, and to identify the vertical direction and rate of groundwater flow at the test site. Water level data were collected as each well at the test site was completed from August 1989 through February 1990. Data were also obtained from the U.S.G.S. for the Floridan aquifer at the Holopaw East test well three miles west of the Bull Creek test site and at the surficial aquifer well at Deer Park seven miles east of the test site (Figure 2-1). In addition to rainfall data obtained from the Florida Division of Forestry station at Deer Park, data were collected at the test site by the SJRWMD. Water level data, hydrographs, and rainfall records are included in Volume 2.

Figure 3-3 depicts the water level in the upper sands of the surficial aquifer (Well S-1) and in the upper limestone (TM1) and lower dolomite (TM2) units of the Floridan aquifer. Water levels decrease with depth, indicating that water moves downward from the the surficial aquifer to the Floridan aquifer, and downward through the Floridan aquifer. The 0.5 foot difference in water level elevation between the surficial and the upper Floridan aquifer, and from the upper to lower Floridan aquifer, indicates that the rate of downward movement through the Hawthorn confining unit and through the Floridan aquifer is very slow under normal conditions of recharge and discharge. The water level of the Floridan aquifer does not respond to local recharge from major storms, such as on October 9 when six inches of precipitation was recorded nearby. This also suggests that recharge to the Floridan aquifer occurs very slowly near the test site.

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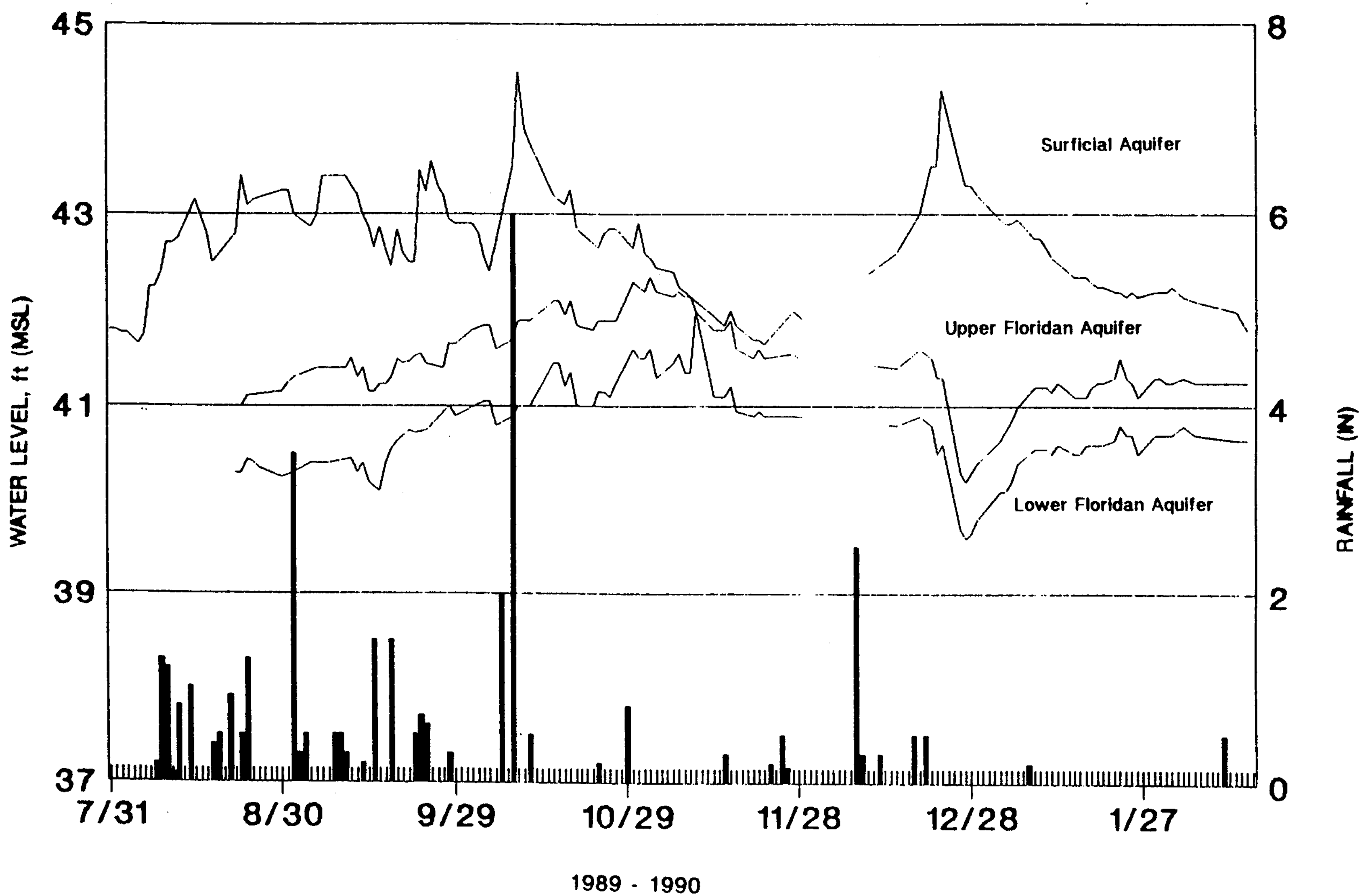

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WATER LEVEL HYDROGRAPHS

FIGURE 3-3

Water levels in the surficial aquifer rise and fall in response to recharge and discharge much more rapidly than in the Floridan aquifer. During the wet season, the water table in the surficial aquifer is two feet or more above the level in the Floridan, but is nearly coincident with the Floridan during the dry season (Figure 3-3). The water table remained relatively constant from mid-August to late-October, while levels in the Floridan aquifer steadily increased approximately one foot. A one-foot decline was recorded in the water level in both zones of the Floridan aquifer in late December as a result of areawide pumping to protect crops from below freezing temperatures. The water-level decline was 30 percent slower in the lower portion which suggests the vertical hydraulic conductivity is less than the horizontal within or between the upper and lower portions of the Floridan aquifer.

3.4 GROUNDWATER QUALITY

Water samples from the Floridan aquifer were tested in the field for chloride, conductivity, temperature, and pH during drilling of wells TM, TP, and D at approximately 30-foot intervals. Laboratory analyses of chloride, conductivity, total dissolved solids, and sulfate were also performed on water samples collected every 30 feet during drilling of well TM. Field and laboratory results for chloride and conductivity, given in Volume 2, are generally in close agreement.

Chloride concentrations of water in well TM ranges from 325 to 375 mg/l in samples collected during drilling in the limestone section of the Floridan aquifer from 350 to 730 feet. Concentrations range from 375 to 425 mg/l in the dolomite section from 730 to 1,460 feet. Between 1,460 to 1,483 feet, chloride concentrations increased from about 450 to 1,080 mg/l and dissolved solids increased from approximately 1,300 to 2,150 mg/l. Water quality variations with depth do not appear to be greatly affected by mixing of waters from above or below the sample depth, except near the bottom of well TM.

Standard complete analyses, which measure the concentration of major ions in water and some physical properties, were conducted to explain variations in water quality with depth. Table 3-2 lists standard complete data from 7 samples collected during drilling of well TM from 410 to 1,473 feet and while pumping the well after it was completed with an open borehole from 1,473 to 1,483 feet. At all depths sampled, sodium and chloride are the predominant ions in solution. Calcium, magnesium, sodium, chloride and sulfate concentrations increase gradually throughout the Floridan aquifer to about 1,443 feet.

A gradual transition to more mineralized water occurs below 1,443 feet in well TM where freshwater from above mixes with mineralized water below. Above the transition zone, dissolved solids range from about 800 to 1,100 mg/l, chloride ranges from 325 to 425 mg/l, and hardness ranges from about 250 to 350 mg/l. In the bottom hole sample, dissolved solids, chloride, and hardness increased to about 2,150, 1,080, and 450 mg/l, respectively. This transition is confirmed by the fluid resistivity log which shows an abrupt increase in conductivity from approximately 1,350 to 1,400 feet and again from 1,450 to 1,470 feet.

The charge balance and comparing reported with calculated dissolved solids are common procedures for checking analytical accuracy (Hem, 1970). A balance of five percent or less is generally acceptable for waters of moderate concentra-

TABLE 3-2

STANDARD COMPLETE ANALYSES OF WATER FROM WELL TM

Sample Depth	410 ft		565 ft		595 ft		848 ft		940 ft		1443 ft		1473 ft		1483 ft	
	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Calcium	85.5	4.28	65.1	3.26	75.2	3.76	160.7	8.04	76.4	3.82	134.0	6.70	77.2	3.86	91.0	4.55
Magnesium	23.8	1.95	25.7	2.11	26.0	2.13	29.7	2.43	26.8	2.20	27.2	2.23	39.1	3.20	55.0	4.51
Sodium	142.2	6.18	167.2	7.27	165.9	7.21	179.2	7.79	174.0	7.57	197.4	8.58	472.0	20.52	717.0	31.17
Potassium	6.1	0.16	8.2	0.21	7.1	0.18	7.5	0.19	8.3	0.21	9.2	0.23	11.1	0.28	26.0	0.66
Iron	0.9	0.03	0.4	0.01	0.2	0.01	1.0	0.04	0.1	0.00	0.9	0.03	0.8	0.03	0.2	0.01
Strontium	3.4	0.08	3.4	0.08	4.0	0.09	4.9	0.11	4.7	0.11	4.7	0.11	7.2	0.16	7.8	0.18
Total cations		12.60		12.85		13.29		18.49		13.80		17.78		27.90		40.90
Bicarbonate	252.0	4.13	153.8	2.52	206.0	3.38	174.4	2.86	164.8	2.70	134.8	2.21	129.5	2.12	132.9	2.18
Chloride	306.0	8.64	376.0	10.62	375.0	10.59	426.0	12.02	414.0	11.68	421.0	11.88	658.1	18.56	1080.0	30.47 (1)
Sulfate	59.6	1.24	74.3	1.55	74.5	1.55	85.6	1.78	83.5	1.74	239.5	4.99	166.0	3.46	194.0	4.04
Total anions		14.02		14.69		15.52		16.66		16.12		19.08		24.15		36.69
Charge balance		5.3%		6.7%		7.7%		5.2%		7.8%		3.5%		7.2%		5.4%
Dissolved solids:																
Reported	814		838		842		992		920		1092		1512		2152	
Calculated	880		899		934		1088		972		1186		1574		2309	
Hydrogen sulfide	0.5		0.6		0.3		0.6				0.9		1.0			
Silica (SiO2)			24.0				18.6		18.9		16.7		12.4		5.0	
Cond. (umhos/cm)	1370		1496		1614		1770		1596		1580		2070		2900	
Hardness (CaCO3)	312		269		295		524		301		447		354		454	
Calcite saturation	1.2		1.3		1.1		1.8		0.7		0.9		0.8		1.3	
pH (field)	8.3		8.7		8.3		8.7		8.0		8.0		8.2		8.6	
Temp. (C) (field)	27.0		27.5		27.5		25.5		26.5		26.5		26.5		28.5	

(1) chloride at 1483 ft reported by SJRWMD, collected with downhole fluid sampler while pumping 100 gpm

tion (250 to 1,000 mg/l dissolved solids). When possible, samples were rechecked for those constituents whose concentrations appeared to fall outside the expected range. Most data in Table 3-2 fall within the range of expected values for Floridan aquifer waters in the area. However, charge balances vary from 3.5 to 7.8 percent. The charge imbalance of samples from 210 to 940 feet is related to higher than expected bicarbonate ion concentrations. SJRWMD (1989) reported bicarbonate concentrations of 110 to 150 mg/l at Bull Creek. Calcium concentrations at 843 feet and 1,443 feet are twice the expected concentration due possibly to small particles of carbonate rock in the sample. Corrections for calcium and bicarbonate ions to average values (about 75 mg/l and 130 mg/l) brings all charge balances to less than five percent.

Field and laboratory analyses for chloride and conductivity of samples collected from well TP, completed with an open borehole from 700 to 900 feet, showed no increase in concentration during 6 hours of pumping at rates up to 2,800 gpm. Conductivity of samples collected from well TM, which has an open borehole from 1,473 to 1,483 feet, remained constant at about 3,000 umhos/cm while pumping 100 gpm for six hours.

3.5 WELL YIELD AND AQUIFER TRANSMISSIVITY

Single well tests were conducted to determine the specific capacity of each well constructed at the test site and to estimate the transmissivity of the Floridan aquifer. Specific capacity is calculated by dividing the discharge rate by the water level drawdown measured in the well, and is commonly used to estimate aquifer transmissivity and potential well yields when aquifer test data are not available.

Step drawdown testing was conducted by measuring drawdown in the well during three pumping rates. Pumping rates were increased after water level drawdown stabilized during the previous step. Different methods were used, depending on the diameter of the well casing, to measure water level and discharge. Water levels stabilized generally within the first few minutes of each pumping rate and recovered is less than 15 minutes when pumping ceased. Water-level recovery could not be accurately measured because water rose over the top of the well casing and oscillated continuously during the recovery phase. Water level and discharge data collected during step drawdown testing are included in Volume 2.

Table 3-3 summarizes the results of seven step drawdown tests conducted at the test site from 600 to 1,483 feet in the Floridan aquifer. Construction details of wells discussed here are described in Section 4. The specific capacity of well TM increased five-fold when the borehole was deepened through the soft limestone into hard dolomite to a depth of 940 feet. This substantial improvement in specific capacity indicates that the upper 240 feet of the Floridan aquifer in the area produces very little water. Test results from well TP demonstrate that the Floridan aquifer is highly productive from 700 to 900 feet.

When the discharge rate is increased, the specific capacity of wells tapping the Floridan aquifer generally decrease due to greater friction losses inside the pump column pipe. The measured drawdown is corrected for friction losses using a method described by Walton (1970). A linear relationship developed by Logan (1964) is used to estimate aquifer transmissivity. Transmissivity of the Floridan aquifer from 700 to 900 feet is very high, ranging from about 500,000

TABLE 3-3

STEP-DRAWDOWN TEST RESULTS

Well iden. / Borehole depth / Casing diameter	Discharge Q (gpm)	Drawdown s (ft)	Specific Capacity Q/s (gpm/ft)	(1) Corrected Drawdown (ft)	(2) Corrected Specific Capacity (gpm/ft)	(3) Estimated Transmissivity T (gpd/ft)	Hydraulic Conductivity K (ft/day)
TM	280	9.6	29	8.6	33		
400-600 ft	402	14.4	28	12.4	32		
8 inch	448	16.3	27	13.8	32	57,000	40
MC	5	2.2	2.3	1.8	2.8		
583-587 ft	10	5.2	1.9	3.8	2.6		
4 inch	20	12.7	1.6	7.4	2.7	4,700	3
TM	350	1.9	184	1.0	350		
400-940 ft	548	3.8	146	1.5	365		
8 inch	781	6.8	116	2.1	372	634,000	160
TM	estimated using a weighted						
740-940 ft	average (4) of the above						
8 inch	well TM data					539,000	360
TP	1760	4.5	391	1.5	1173		
700-900 ft	2450	7.8	314	2.0	1225		
16 inch	2790	9.8	285	2.2	1268	2,139,000	1,400
D	395	5.2	76	1.3	304		
700-915 ft	475	7.2	66	1.6	297		
8 inch	600	12.0	50	3.0	200	467,000	290
D	20	2.5	8.2	1.0	20		
1050-1054 ft	31	6.0	5.2	2.5	12		
4 inch	60	16.7	3.6	3.7	16	28,000	10
TM	75	5.0	15	2.0	38		
1473-1483 ft	100	8.0	13	2.6	38		
4 inch						66,000	90

(1) Corrected Drawdown = Drawdown - Well Loss
from Walton (1970):
Well Loss = CQ^2
C = well loss coefficient in sec^2/ft^5
Q = well discharge rate in cfs

(2) Corrected Specific Capapcity = Discharge / (1)

(3) Estimated Transmissivity = 1750 X (2) from Logan (1964)

(4) K for TM(740-940ft): 40ft/day X 340ft + K X 200ft = 160ft/day X 540ft

gpd/ft. at wells D and TM to about 2,000,000 gpd/ft at well TP.

Hydraulic conductivities given in Table 3-3 provide a means of comparing the lateral resistance to groundwater flow at different depths in the Floridan aquifer. Hydraulic conductivity is calculated by dividing transmissivity by the hydrogeologic unit thicknesses defined in Section 3.2.2. Conductivities measured in the dolomite unit from 740 to 940 ft. vary from 290 to 1,400 ft./day. The highest hydraulic conductivity was determined in well TP, the 16-inch diameter production well completed with a borehole from 700 to 900 feet. This value is more representative of the conductivity at that depth because it was determined by pumping at much higher rate which samples a substantially larger portion of the aquifer. Conductivity of the dolomite units below 940 ft. appear to be significantly lower.

Hydraulic conductivity of the clay sediments within the Hawthorn Formation was determined to be 4×10^{-5} ft./day (1×10^{-8} cm/sec) using water level recovery data from well H-1. The SJRWMD completed well H-1 in early November 1989 and developed the well later in the month by removing water from the casing with a bailer. A recorder measured the final 10 feet of recovery over a period of about 30 days beginning on November 28. Dividing the hydraulic conductivity by 200 feet, the approximate thickness of the Hawthorn Formation, results in a leakance of about 1×10^{-7} day^{-1}. The solution for time-lag tests described by Thompson (1987) and water level data from well H-1 are provided in Volume 2.

3.6 SUMMARY

Three hydrogeologic units identified at the test site include the surficial aquifer, the Hawthorn confining unit, and the Floridan aquifer. The surficial aquifer at the test site is approximately 100 feet thick and is composed of about 30 feet of unconsolidated quartz sand and 70 feet of shell with sand and limestone. Underlying the surficial aquifer are the regionally extensive, relatively impermeable confining clays of the Hawthorn Formation. The 200-foot thick low permeable clays act as a confining unit to retard vertical movement of groundwater through the Hawthorn Formation. Leakance of the Hawthorn Formation was determined to be about 1×10^{-7} day^{-1} from a time-lag test conducted at the test site, indicating that the clay is an extremely effective confining unit.

The Floridan aquifer at the test site is composed of a thick sequence of carbonate rocks from the Ocala and Avon Park Formations, beginning at approximately 370 feet and extending to more than 1,485 feet. A soft, fine grained limestone sequence, primarily from the Avon Park Formation, was encountered from the top of the Floridan aquifer to a depth of approximately 730 feet. This low permeable limestone produces relatively little water at the test site. Step drawdown tests demonstrate that the Floridan aquifer is highly productive from a depth of 700 to 900 feet. Transmissivity estimated for this sequence of the Floridan aquifer ranges from about 500,000 gpd/ft. at wells D and TM to about 2,000,000 gpd/ft. at well TP. Most large-diameter irrigation wells in the area are cased into the top of the soft limestone and are open into the underlying dolomite to about 1,000 feet.

In general, hydraulic conductivity in the Floridan aquifer increases with depth to about 940 feet. Below about 1000 feet, conductivities appear to be significantly lower. The highest hydraulic conductivity was determined in well TP, the test production well, completed with a borehole from 700 to 900 feet.

The entire dolomite sequence yields large amounts of water to wells at the test site. Hard porous dolomite was encountered from 730 feet to total depth, about 1,480 feet. The dolomite unit can loosely be divided into three hydrogeologic units: from the top of dolomite to about 1,000 feet; from approximately 1,000 to 1,400 feet; and from approximately 1,400 to total depth. Porosity appears to be greatest from 730 to 950 feet and below 1,400 feet. Core samples and borehole geophysics provide evidence of reduced porosity and hydraulic conductivity from about 950 to 1,400 feet.

Water level relationships indicate that the rate of downward movement through the Hawthorn confining unit is very slow. The rate of vertical flow through the Floridan aquifer is also very slow under normal conditions of recharge and discharge, particularly through the upper limestone unit. Water levels in the Floridan aquifer fluctuate in a typical manner for an area receiving very little local recharge to the aquifer. The water level steadily increases during the wet season and slowly declines during dry periods and does not respond to local recharge from major storms.

The lack of local recharge to the Floridan aquifer greatly affects the quality of water found at the test site and surrounding areas. Water quality is relatively uniform throughout the Floridan aquifer to about 1,440 feet. Chloride concentrations gradually increase from 325 to 425 mg/l from the top of the aquifer to 1,460 feet. Calcium, magnesium, sodium, chloride and sulfate concentrations also gradually increase with depth. At all depths sampled, sodium and chloride are the predominant ions in solution and originate from residual, unflushed seawater trapped in the sediments during periods of higher sea level.

A gradual transition to more mineralized water below 1,443 feet develops where fresh water from above mixes with mineralized water below. Near the bottom of the well, dissolved solids, chloride, and hardness increased to about 2,150, 1,080, and 450 mg/l, respectively.

Section 4

FLORIDAN AQUIFER TEST PROGRAM

4.1 TEST PROGRAM DESIGN

Aquifer testing was conducted at the Bull Creek site (Figure 2-1) to obtain data to design production wells and determine wellfield capacity, and to assess potential hydrologic impacts to existing users and to surrounding water resources. Wells were designed and constructed to meet guidelines established in the November 1988 "Bull Creek Groundwater Evaluation" Agreement between SJRWMD and the Authority. The test program outlined in the Agreement was specifically designed by the SJRWMD to evaluate hydraulic properties of the confining Hawthorn Formation, the Floridan aquifer producing zone, and possible confining units within the Floridan aquifer above and below the producing zone. The Agreement also required, as part of the test program, an assessment of the "potential for water quality degradation of the producing zone by either lateral or vertical movement of poorer quality waters in other stratified layers within the Floridan aquifer."

The aquifer test program consisted of four components: construct a test monitor well to obtain hydrogeologic and water quality data; design and construct a test production well and test observation wells; perform the aquifer test; and prepare an interpretive report evaluating drilling and testing data. Groundwater flow and transport modeling studies required by the Agreement to assess expected water level and water quality impacts associated with development of a wellfield are presented in a separate report.

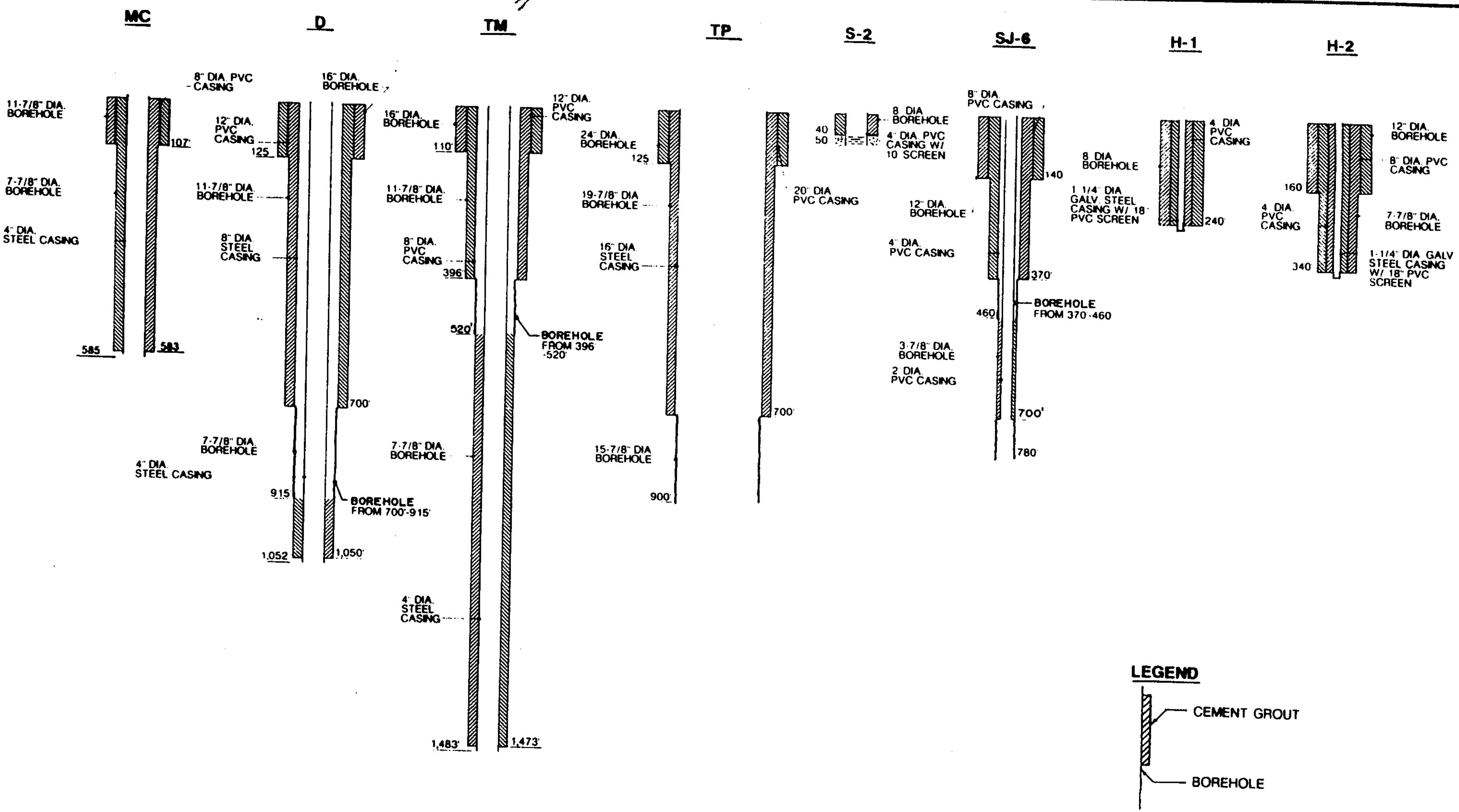
4.2 TEST MONITOR WELL

Much of the data used to describe the hydrogeology of the test site in Section 3 were obtained from the test monitor (TM) well. Data collected during drilling and testing of well TM provided the basis for proceeding with the next phases of the test program. As described in Section 3, data from well TM indicate that the soft limestone in the upper 250 feet of the Floridan aquifer produces very little water but that the hard dolomite underlying the limestone is highly transmissive. The water quality of the dolomite producing zone is well within design limits for membrane treatment processes. Depth to a transition zone between fresher and more mineralized water is at about 1,450 feet, more than 500 below the producing zone.

Well TM was constructed with 1,473 feet of 4-inch diameter steel casing and an open borehole to about 1,483 feet (Figure 4-1). The well was completed as a dual zone monitor leaving an open borehole from about 400 to 520 feet. The upper zone (TM1) is open to the soft, low-permeable limestone from the upper part of the aquifer and the deepest zone (TM2) is open the hard, highly permeable dolomite. Well TM provides water level data from both zones, and zone TM2 provides water quality data from the transition zone between relatively fresh water above and more mineralized water below.

4.3 TEST PRODUCTION AND OBSERVATION WELLS

The test production well (TP) was constructed with 16-inch diameter steel casing to a depth of 700 feet with an open borehole to 900 feet (Figure 4-1). Figure 4-2 shows the location of well TP and the eight observation wells utilized dur-



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TEST-WELL CONSTRUCTION DETAILS

FIGURE 4-1

ing aquifer testing. Most large diameter supply wells in Osceola County are cased to the first limestone. Well TP casing was set at 700 feet, about 300 feet below where limestone was first encountered, to test the dolomite separately from the limestone unit.

In addition to well TM, five observation wells were constructed for the aquifer test (Figure 4-1). Table 4-1 describes the test wells including the distance from well TP, casing and total depth, diameter, and purpose for each observation zone. An existing shallow well (S-1) and well SJ-6 were also utilized during testing. Well SJ-6 was modified by the SJRWMD to isolate the 700 to 780 foot portion of the producing zone from the overlying limestone unit. Table 4-1 shows that in addition to two production zone observation wells (D1 and SJ-6(2)), wells were completed into the limestone unit (MC and TM1), Hawthorn Formation (H-1 and H-2), surficial aquifer (S-1 and S-2), and at two depths beneath the producing zone (D2 and TM2).

4.4 AQUIFER TESTING

The test production (TP) well was equipped with a 12-inch vertical turbine pump powered by a 250 horsepower diesel engine. The flow rate was measured regularly by an 8-inch in-line propeller meter. Water was discharged through about 500 feet of 8-inch diameter PVC line to a small detention basin (Figure 4-2). Water flowed by gravity from the detention basin through a 1,500 foot ditch to an approximately 40-acre impoundment.

Water levels, rainfall, barometric pressure, and flow were recorded by SJRWMD. Water levels during pumping and recovery were scanned in the production zone observation well (D1) every five seconds for the first three minutes, every

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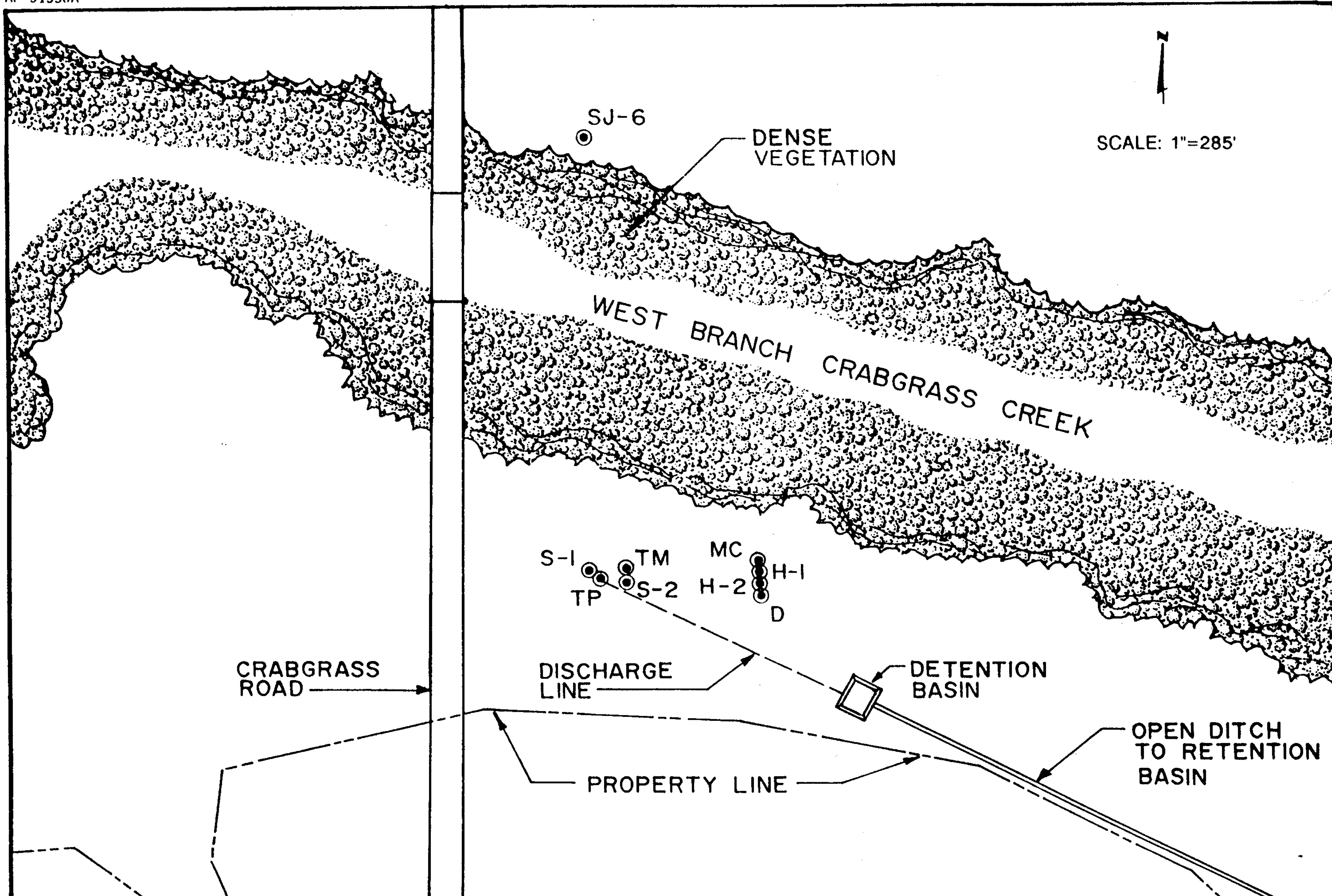

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AQUIFER TEST WELL LOCATIONS

FIGURE 4-2

Table 4-1

TEST WELL DESCRIPTIONS

Well	Casing Depth (ft)	Total Depth (ft)	Well Diameter (ft)	Radial Distance from well TP (ft)	Purpose
TP	700	900	16	0	Test Production
D1	700	915	8	300	FL Aq prod. zone
SJ-6(2)	700	780	2	948	FL Aq prod. zone
S-1	5	8	2	13	Surficial sands
S-2	40	50	4	51	Surficial shells
H-1	240	241	1.25	295	Hawthorn clay
H-2	340	341	1.25	295	Hawthorn clay
MC	583	585	4	289	FL Aq limestone
D2	1,050	1,054	4	300	FL Aq dolomite
TM2	1,473	1,483	4	51	FL Aq dolomite
SJ-6(1)	360	460	4	948	FL Aq limestone
TM1	396	520	8	51	FL Aq limestone

See Figure 4-2 for well positions.

minute for the next hour, and hourly thereafter. All other wells were scanned every minute for the first four hours, then hourly. Conductivity of water from wells TP and TM2 were measured and recorded in a similar manner. A one- to two-hour trial pumping test was conducted on January 24 and 25 to insure that the discharge line and recording equipment were operating properly.

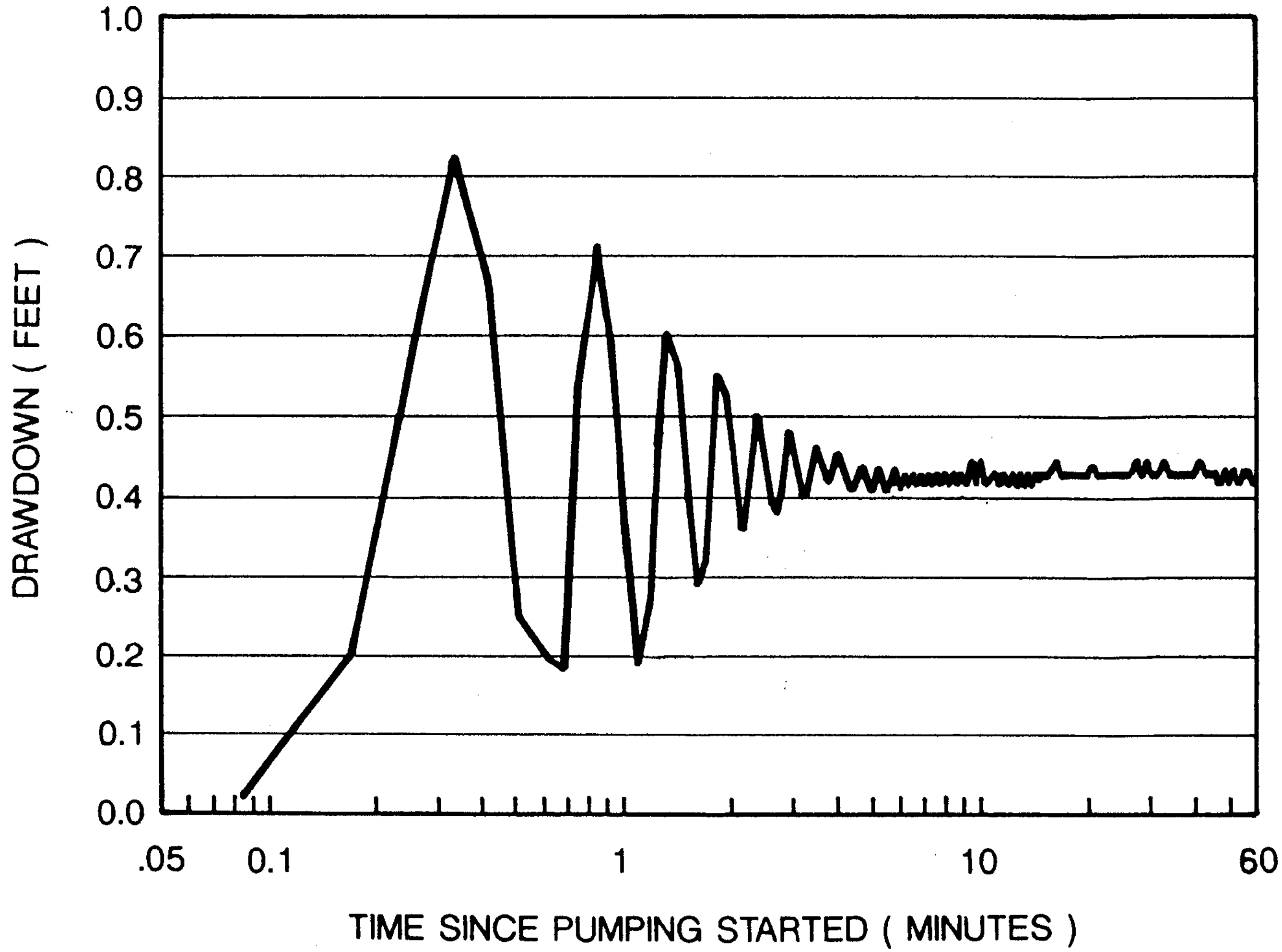
The aquifer test began at 12:00 noon on January 26 and ended at 11:00 a.m. on February 5, ten days after the pump was started. The flow rate fluctuated from 2,200 to 2,400 gpm during the first 24 minutes and remained at 2,080 gpm for the remainder of the test. The water level drawdown in well TP averaged about 6 feet and fluctuated one-half foot due to turbulence in the well. The greatest drawdown measured in an observation well was about 0.4 feet in well D1, the production zone observation well 300 feet from well TP, and occurred in the first minutes after pumping began. Steady state drawdown in all the observation wells generally occurred within the first two hours of pumping. Maximum drawdown in wells MC and D2, which monitored water levels above and below the production zone, was about 0.15 and 0.25 feet respectively. These data indicate that the production zone is highly transmissive. Drawdown was not observed in the surficial aquifer (well S-2) or Hawthorn Formation (wells H-1 and H-2). During the test period, water levels did not decline in private Floridan aquifer wells about seven miles east of the test site. Selected hydrographs of aquifer test data are provided in Volume 2 of the report.

4.5 AQUIFER ANALYSIS

The aquifer test program was designed by SJRWMD to determine aquifer transmissivity and storage using conventional methods and to calculate vertical hydraulic conductivities using the ratio method developed by Neumann and Witherspoon (1972). Water levels in the Floridan aquifer remained relatively constant for three weeks prior to testing. Little rainfall was recorded onsite from late December 1989 until after the test was complete. Barometric pressure dropped slightly prior to testing and rose during the first days of the test. These data show that adjustments to water level data collected during testing are unnecessary.

Water level drawdown data from well D1, the closest production zone observation well, are plotted in Figure 4-3. The water level oscillated during the first seven minutes, typical of the response in highly fractured aquifers, and reached equilibrium shortly after. Conventional time-dependent solutions are not appropriate under these conditions. Non-steady state techniques for solving hydraulic conductivity in discrete fractures requires lengthy analyses and do not necessarily improve the solution when other less complex methods are available.

Theim's steady state flow equation (Lohman, 1972) resulted in an average transmissivity of 2,000,000 gpd/ft for the Avon Park producing zone from 700 to 900 feet. Jacob's unsteady flow equation for confined aquifers (IGWMC, 1986) was used to calculate storage and verify transmissivity of the producing zone. Figure 4-4 shows the distance-drawdown plot at distances of 1 (well TP), 300 (well D1) and 950 (well SJ-6) feet from well TP, 10 minutes after pumping started. Storage resulting from these data was calculated to be about 0.002 and transmissivity was about 2,000,000 gpd/ft (Table 4-2). Although the data at 950 feet do satisfy the assumptions of the solution, omitting this record



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TIME - DRAWDOWN PLOT FOR OBSERVATION WELL D1

FIGURE 4-3

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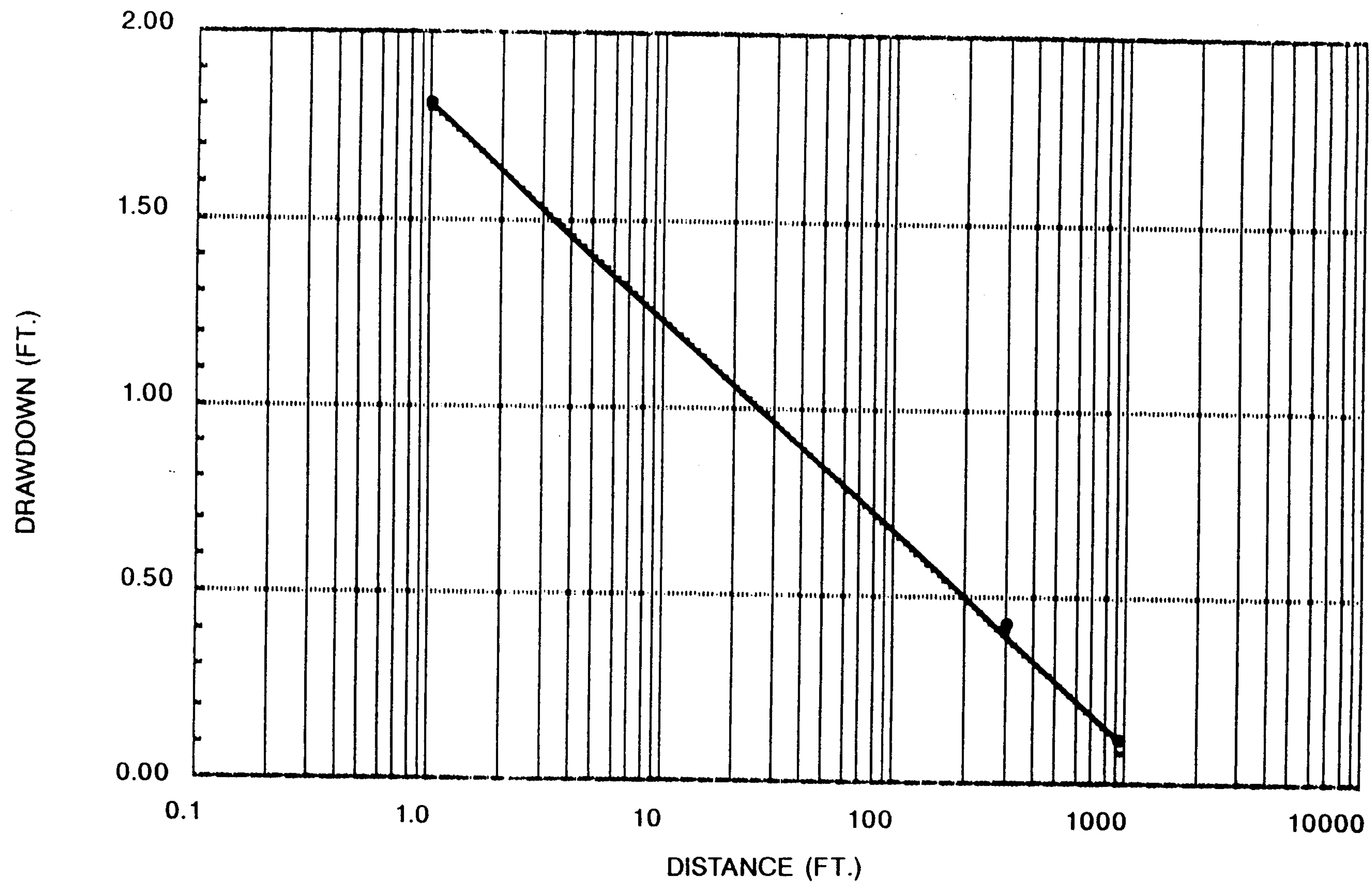

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DISTANCE - DRAWDOWN PLOT AT 10 MINUTES

FIGURE 4-4

TABLE 4-2

DISTANCE-DRAWDOWN ANALYSIS

```
****************************************************
*                                                  *
*          program:  Distance                      *
*          version:  IBM PC 1.0                    *
*                                                  *
*  A PROGRAM FOR PUMP TEST ANALYSIS USING JACOB'S  *
*  FORM OF THEIS EQUATION AND LEAST SQUARES' METHOD. *
*                                                  *
****************************************************
```

PROJECT......... = South Brevard Water Authority
LOCATION........ = Bull Creek Test Site
WELL............ = Test Production (TP)
DATE............ = January 26, 1990

STATIC WATER LEVEL   S.W.L.   = 2 [ft]
DISCHARGE RATE............... = 2200 [gpm]
TIME OF THE OBSERVATION...... = 10 [min]

NO	DISTANCE [ft]	DRAWDOWN [ft]	u	DEVIATION
1	1.00	1.800	.241E-06	-.334E-02
2	300.00	0.420	.217E-01	+.199E-01
3	950.00	0.100	.218E+00	-.165E-01

TRANSMISSIVITY T = .317E+01 [ft2/s]
               T = 2049459 [gpd/ft]
STORATIVITY   S = .184E-02

DATA SEGMENT ANALYZED :
- starting with data pair 1
- ending   with data pair 3

DETERMINATION COEFFICENT = .9995833

****

Formation loss adjacent to well TP (record no. 1) was estimated using well loss factor calculated from step drawdown analyses.

does not change the estimates. Transmissivity values calculated using Jacob's and Theim's methods are in close agreement with single well test results from well TP (Table 3-3).

After the pump was switched off, the water level recovered in about five minutes in the test production well (TP) and in well D1, the closest production zone observation well. This rapid recovery is characteristic of a highly transmissive aquifer. An analysis to determine transmissivity could not be conducted because well D1 recovery data exhibited an oscillation pattern similar to its drawdown response.

Analyses using the ratio method, developed by Newmann and Witherspoon (1972), indicate that the vertical hydraulic conductivity (K') of the soft limestone unit above and of the dense dolomite below the producing zone is relatively low. The K' and leakance (L) of the limestone is less than the underlying dolomite due to lithologic differences described in Section 3. Values for L within the Floridan aquifer are within the expected range when compared with the Hawthorn Formation L of $1X10^{-7}$ day^{-1} reported in Section 3. Ratio method data and analyses are summarized in Table 4-3 and described in Volume 2.

4.6 GROUNDWATER QUALITY

Table 4-4 gives standard complete analyses of water samples from well TP after the first five minutes of pumping, every 12 hours up to 48 hours, at 72 hours, and just prior to the completion of pumping at about 240 hours. The seven analyses are very similar indicating that the water type did not change during testing.

Table 4-3

SUMMARY OF RATIO METHOD DATA

	Well MC	Well SJ-6	Well D2	Well TM2
Lithology	Limestone	Limestone	Dolomite	Dolomite
Open Interval (ft)	583 - 585	370 - 460	1050 - 1052	1423 - 1483
r (ft)	300	948	300	50
t (min)	65	23 and 45	52 and 51.5	213
s'/s (-)	0.048	0.09 and 0.27	0.60 and 0.10	0.048
z (ft)	116	290	102 and 162	528 and 578
T (gpd/ft)	500,000 to 2,000,000	same as MC	same	same
S (-)	0.002 and 0.0002	same as MC	same	same
M' (ft)	400	400	450 and 400	450 and 400
S'_s (ft^{-1})	10^{-7} to 10^{-6}	10^{-7} to 10^{-6}	10^{-7} to $4.4x10^{-6}$	10^{-7} to $4.4x10^{-6}$
K' (ft/day)	0.005 to 0.054	0.147 to 2.55	0.015 to 10.7	0.024 to 1.49
L (day^{-1})	$1.3x10^{-5}$ to $1.4x10^{-4}$	$3.7x10^{-4}$ to $6.4x10^{-3}$	$3.3x10^{-5}$ to $2.4x10^{-2}$	$4.5x10^{-5}$ to $3.7x10^{-3}$

See Neumann and Witherspoon (1972) and Tibbals (1982) for definition of terms.

TABLE 4-4

STANDARD COMPLETE ANALYSES OF WATER FROM WELLS TP AND TM2
DURING AQUIFER TESTING

Sample No.	TP 5min		TP 12hr		TP 24hr		TP 36hr		TP 48hr		TP 72hr		TP 240hr		TM2 72hr		TM2 240hr	
	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Calcium	71.4	3.57	76.7	3.84	62.2	3.11	74.0	3.70	64.9	3.25	72.3	3.61	72.0	3.60	105.7	5.29	72.0	3.60
Magnesium	30.6	2.51	29.3	2.40	31.3	2.57	30.3	2.48	28.3	2.32	30.6	2.51	38.6	3.16	68.0	5.57	73.2	6.00
Sodium	317.0	13.78	278.0	12.09	234.0	10.17	209.0	9.09	222.0	9.65	283.0	12.30	328.0	14.26	601.0	26.13	650.0	28.26
Potassium	9.1	0.23	9.3	0.24	9.1	0.23	9.1	0.23	9.1	0.23	9.2	0.23	9.6	0.24	11.9	0.30	22.0	0.56
Iron	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Strontium	5.5	0.13	4.5	0.10	5.4	0.12	5.9	0.13	5.5	0.13	5.0	0.11	5.2	0.12	7.1	0.16	6.7	0.15
Total cations		20.09		18.56		16.08		15.50		15.45		18.66		21.27		37.29		38.42
Bicarbonate	142.7	2.34	141.7	2.32	143.8	2.36	142.9	2.34	142.7	2.34	141.2	2.31	140.0	2.30	129.9	2.13	130.0	2.13
Chloride	439.0	12.40	451.0	12.74	405.0	11.44	438.0	12.36	426.0	12.02	405.0	11.42	407.0	11.48	939.0	26.49	834.0	23.53
Sulfate	212.0	4.42	191.0	3.98	179.0	3.73	174.0	3.63	171.0	3.56	283.0	5.90	133.0	2.77	239.0	4.98	198.0	4.13
Total anions		19.16		19.04		17.53		18.32		17.92		19.64		16.55		33.60		29.78
Charge balance		2.4%		1.3%		4.3%		8.3%		7.4%		2.5%		12.5%		5.2%		12.7%
Dissolved solids:																		
Reported	1070		1050		1050		1050		1050		997		979		2090		2170	
Calculated	1243		1197		1086		1099		1085		1247		1147		2116		1999	
Hydrogen sulfide											1.3							
Silica (SiO2)	15.4		15.9		16.3		15.4		15.9		16.0		13.3		13.9		13.3	
Cond. (umhos/cm)	1310		1350		1500		1350		1330		1380		1230		2700		2500	
Hardness (CaCO3)	305		312		284		310		279		307		339		544		482	
Calcite saturation	0.9		0.9		0.9		0.9		0.9		0.9		0.9		1.1		0.9	
pH (field)	8.3		8.3		8.3		8.3		8.3		8.3		8.3		8.3		8.3	
Temp. (C) (field)	27.0		27.0		27.0		27.0		27.0		27.0		27.0		27.0		27.0	

The variability in mineral concentrations reflect experimental error typical of repetitive analyses, rather than actual changes in mineral content. For example, samples collected at 5 minutes and 72 hours have similar concentrations and the lowest charge balance differences. However, because intermediate samples collected at 24, 36, and 48 hours have lower than average sodium concentrations they have relatively high charge imbalances. Although repeat laboratory analyses indicated no correction for sodium, a value closer to the average concentration of 280 mg/l for the three samples would bring the charge balance to within one percent. The higher sodium and lower sulfate concentrations, both rechecked in the laboratory, account for the charge imbalance of the 240 hour sample. Conductivity of water from well TP, measured and recorded continuously by the SJRWMD in the field, decreased from 1,680 to 1,670 umhos/cm after about three hours of pumping, and remained constant at 1,670 umhos/cm for the remainder of the test.

Water from well TP meets primary inorganic drinking water standards listed in F.A.C. 17-550 except for sodium. Iron, color, hydrogen sulfide, turbidity, nitrate, orthophosphate and metals concentrations were less than the maximum concentration allowed for primary constituents. The sample was not tested for microbiological or organic constituents. Total dissolved solids and chloride were the only secondary standards to be exceeded. However, the membrane treatment process planned for this system will reduce the concentration of all physical and dissolved constituents to below drinking water standards. A complete drinking water analysis will be conducted in accordance with Department of Environmental Regulation requirements during the well construction phase of the project. The laboratory report for primary inorganic and secondary constituents is given in Volume 2.

Table 4-4 also lists standard complete analyses for the deepest zone (TM2) in well TM sampled after 72 and 240 hours. Water was continuously removed from the bottom of the well at 1,483 feet using a peristaltic pump operated at about 1 gallon per minute. A significant change in concentration occurred during testing. Charge balance calculations for samples from well TM2 would be improved with a chloride concentration of 1,000 to 1,100 mg/l which was obtained from a sample collected with a downhole sampler during pumping (Table 3-2). Results are consistent with data from Table 3-2 for the 1,483 sample.

Conductivity of water from zone TM2, measured continuously and recorded hourly in the field, fluctuated widely between readings due to air bubbles in the intake hose (Volume 2). Values ranged from 2,100 to 3,300 umhos/cm, with the largest amplitudes occurring during the first four days. A weak trend from about 2,600 to 2,800 umhos/cm occurred during the first three days due to mixing of water inside the casing with water from the borehole. Conductivity fluctuated around 2,800 umhos/cm during the final six days of pumping.

4.6 CONCLUSIONS

The 400-foot thick limestone unit and underlying dolomite sequence in the upper 1,000 feet of the Floridan aquifer at the Bull Creek test site are hydraulically connected. Water levels in both units are nearly the same and respond in a similar manner to recharge and discharge. The production zone in the upper portion of the dolomite sequence and a second permable zone below 1,400 feet in the Floridan aquifer are separated by hard, low-porosity, low-permeable dolomite.

Analysis of aquifer test data provides further evidence that the production zone from about 700 to 900 feet is highly transmissive and can yield large quantities without causing excessive water level declines in the Floridan aquifer. Flow to the test production well is predominantly radial because of the extremely high lateral hydraulic conductivity of the production zone compared with the low vertical conductivities above and below the production zone. Water level oscillations and a rapid equilibrium condition during testing indicates that the production zone is highly fractured.

The extremely low vertical hydraulic conductivity and relatively thick clay layers of the Hawthorn Formation reported in Section 3 account for the absence of drawdown in the Hawthorn and surficial aquifer during testing. The presence of about 400 feet of relatively low-permeable limestone overlying the production zone and the overlying Hawthorn Formation provide a large degree of protection against lowering water levels in the surficial aquifer.

Geochemical analyses of water collected prior to and during aquifer testing indicate that water quality remained unchanged in both the production zone from 700 to 900 feet and in the deepest well (TM2) about 500 feet below the production zone. Chloride and TDS was about 425 mg/l and 1,050 mg/l from the production zone and about 950 mg/l and 2,100 mg/l from Well TM2. The processes controlling the movement of different density waters in the Floridan aquifer require large hydraulic gradients over a period of many decades before significant lateral or vertical movement occurs (SJRWMD, 1984). A discussion and analysis of potential water level changes affecting the movement of mineralized waters is presented in a separate groundwater flow and transport modeling report.

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