FLORIDAN AQUIFER WATER SUPPLY
INVESTIGATION.

TURKEY POINT AREA

DADE COUNTY, FLORIDA

DAMES & MOORE

4598-050-26

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August 25, 1975

Florida Power & Light Company
P.O. Box 013100
Miami, Florida 33101

Attention: Mr. Earl C. Weber

Gentlemen:

We are pleased to submit herewith our report, "Floridan Aquifer Water Supply Investigation, Turkey Point Area, Dade County, Florida".

The scope of work undertaken for this report draws together published information and an extensive field testing program. The testing program has provided new quantitative information for evaluation of the Floridan aquifer.

We appreciate the cooperation and assistance provided us during the progress of this study by the Government Advisory Group (Appendix B), Florida Power & Light personnel at Turkey Point, and all other participants. It has been a pleasure performing this investigation for you.

Very truly yours,

DAMES & MOORE

Benjamin S. Persons pck

Benjamin S. Persons, P.E.
Partner

Porter C. Knowles

Porter C. Knowles, P.E.
Associate

BSP/PCK:dld

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1.0 INTRODUCTION

The objective of this study was to evaluate in detail the water supply potential of the brackish Floridan aquifer for large volume, long-term withdrawals for use as a cooling medium. These withdrawals could serve as a possible make-up to Florida Power & Light Company's Turkey Point Cooling Canal System and provide a possible source of cooling water for the proposed South Dade Generating Facility. Prior to this study, information from several wells indicated the Floridan aquifer as a potential source of brackish, unpotable water; however, no large scale pumping tests had been conducted to define the aquifer and its characteristics.

The lack of such tests is easily explained. The Floridan aquifer, although used for fresh water supplies over much of the central and northern part of the state, is contaminated by salt waters in areas generally south of Lake Okeechobee. The contamination of these waters has proved sufficient to prevent their use for drinking supplies and irrigation without expensive desalinization treatment. The lack of an economic impetus together with the lack of apparent use for the brackish waters have limited the number of detailed investigations of the aquifer in southern Florida. As a result, these immense brackish water reserves have remained almost totally unused.

Since the present investigation was the first of its type and magnitude in the south Florida area, if was felt both necessary and desirable to work with the Federal,

State, and local officials responsible for water management in the area. This led to the formation of a Government Advisory Group of leading ground-water professionals. This group was formed during the planning phase of the program to insure that all appropriate concerns of the individual agencies might be considered and their experience utilized in the formation of this project. During program implementation, the Government Advisory Group was kept apprised of progress and developments through a continuing forum of meetings and status reports so that upon completion, the program could withstand technical review of the highest caliber.

Several short-term tests and a long-term 90-day test were conducted using five drilled wells and other previously drilled wells in the area. By analyzing the test results, an evaluation of various withdrawals was made and the hydrologic impact of using the previously undeveloped water supply was also considered. Such use of brackish waters represents a significant step forward in water resource utilization by providing a new supply source while not placing additional stress on existing fresh-water supplies.

The important Findings and Conclusions are summarized in Section 2.0. Section 3.0 outlines Recommendations based on information gathered during this investigation while Section 4.0 outlines the Project Scope. Additional sections and appendices provide the basic data and analyses used in arriving at these evaluations.

2.0 FINDINGS AND CONCLUSIONS

The conclusions reached in this study are based upon evaluation of an extensive pump test program, its data, and extensive literature reviews. The comprehensive efforts expended for this investigation have been necessary for several reasons; they are: the need to identify and utilize large quantities of water to provide electric generating capacity; the importance of the volume and length of withdrawal period required for the water supply; the general lack of aquifer data needed to judge the effects of large withdrawals; and, to take into consideration the overall concern given to water resources management in the State. The magnitude and importance of this project required expenditures of large amounts of money, a significant portion of which was for well construction alone.

Findings and conclusions of two types have been reached. The first are general with regard to the availability and effects of large ground-water withdrawals in the Turkey Point area while others deal specifically with the actual development of a well field to withdraw brackish water from the principal artesian water-bearing zone of the Floridan aquifer.

A. General

1. The principal artesian water-bearing zone of the Floridan aquifer is 800 to 900 feet thick in the Turkey Point area and ranges in depth from about 1000 to 1800 or 1900 feet below ground surface.

2. The principal artesian zone of the Floridan aquifer in Dade County and Southern Florida represents an enormous water reservoir and with sound water resources management is a potentially prolific supplier of that water.

3. The immense quantities of available Floridan water are presently undeveloped in South Florida because of relatively high mineralization. These waters have been and are unsuitable for most municipal, industrial, and irrigation uses without expensive treatment facilities.

4. Large, long-term withdrawals from the Floridan aquifer provide an environmentally acceptable cooling water alternative in Southern Florida.

5. In order to evaluate the feasibility of ground-water withdrawals of sufficient quantity for cooling water at an electric generating facility, 70 million gallons per day withdrawal (approximately 50,000 gallons per minute) was assumed for a test case. Based on this constant withdrawal rate over a 40 year period, the following conclusions were reached:

   a. The quantity of water in the principal artesian zone of the Floridan aquifer is more than adequate to supply the water required for make-up for the present Turkey Point Cooling Canal system and/or provide cooling water for an electric power generating facility.

b. The assumed withdrawals in the Turkey Point area will not affect any users now withdrawing fresh water from the Floridan aquifer.

c. The assumed withdrawals will not have any effect on the supply of fresh water available from the Biscayne aquifer, the primary source of fresh water in Dade County.

d. Under the assumed pumping conditions, drawdown of the potentiometric surface of the principal artesian zone would begin to stabilize after 5-10 years and very little additional decline is expected beyond this time to the end of the 40 year test period.

e. Drawdown, under the assumed pumping conditions, of the potentiometric surface of the principal artesian zone below mean sea level would be confined in all directions to an area less than five miles from a well field at the Turkey Point area.

f. At the Ocean Reef Club on Key Largo (the nearest user of brackish Floridan waters about 10 miles east of the center of pumping) drawdown of the potentiometric surface would be about 15 feet. This drawdown would not cause any of the wells to stop flowing.

g. Movement of the seawater wedge as a result of pumping the assumed amount over a forty year period will not result in a change of water quality in any wells presently withdrawing fresh water from the principal artesian zone of the Floridan. Any increases in chemical concentrations in the already brackish water withdrawn at the Ocean Reef Club on Key Largo should be extremely slight.

h. Based on an extensive literature review and on conservatively estimated engineering properties used in analysis, the possibility of assumed withdrawals causing surface subsidence is judged to be extremely small with the subsidence limited to the well field area.

i. Other present or potential uses of the Floridan aquifer such as (1) fresh water storage in the Miami area or on the Florida Keys and (2) disposal of fluids in the underlying Boulder Zone will not be significantly affected, if at all, by the assumed withdrawals at the Turkey Point area.

6. Large withdrawals from the principal artesian zone of the Floridan aquifer in the Turkey Point area would utilize a previously undeveloped source of water in the area; would provide a basis for future use of these waters as a relief of stress on the fresh water supplies in the Biscayne aquifer; and would represent a cost effective use of brackish waters.

B. Specific

1. Aquifer response is homogeneous based upon pump test results and analysis.

2. Representative, long-term aquifer parameters evaluated from a combination of field tests and computer simulations for the principal artesian zone of the Floridan aquifer at the Turkey Point area are as follows:

Transmissivity	- 500,000 gpd/ft.
Storage coefficient	- 0.005
Leakance	- 0.00005 gpd/cu. ft.

3. The chloride concentrations of ground water within the principal artesian zone of the Floridan aquifer at the Turkey Point area ranges from 3,000 to 4,000 mg/l at depths of about 1000 feet and increases to as much as 17,000 to 19,000 mg/l at depths between 1800 and 1900 feet.

4. Based on lithologic samples and down-hole geophysical data, most of the ground-water flow in the principal artesian zone appears to be from depths between about 1100 and 1400 feet below ground surface in the Turkey Point area.

5. The principal artesian zone of the Floridan aquifer is overlain by a confining bed of relatively impermeable and indurated claystone/siltstone about 100 feet thick at the base of the St. Mark's Formation.

6. Individual production wells penetrating the upper 300 feet of the principal artesian zone of the Floridan aquifer in the Turkey Point area could supply an average of 5,000 gallons per minute for 40 years.
7. Pumping from the principal artesian zone in the Turkey Point area will induce ground water to move both vertically and horizontally toward the well field. Vertical movement would be confined to the well field area where the potentiometric surface would be at the lowest levels.
8. Chemical concentrations in the ground water increase with depth and to the east, therefore, pumping can be expected to result in some deterioration in quality at the Turkey Point area over a forty year period. This increase, however, should be less than about 30 percent over present concentrations. This effect will not occur outside the immediate well field area. The deterioration will be almost entirely a result of upconing of more saline waters and interformational leakage in the near vicinity of the well field.

3.0 RECOMMENDATIONS

Recommendations based on the conclusions of this study are as follows:

1. Producing wells in the Turkey Point area should be of the telescoping type similar to the existing Production Test Well. Prior to final well design, however, studies should be made of the most efficient pump equipment, materials, and configurations. This information would then be considered in conjunction with the final well and casing design.
2. The producing zone should be approximately 300 feet thick at depths between about 1100 feet and 1400 feet below mean sea level. Deepening of the producing wells, for example, to the base of the principal artesian zone, would result in greater deterioration of withdrawal water quality after a relatively short time because of the more saline water present at the base of the aquifer.
3. Because of potential corrosion problems resulting from concentrations of H_2S in the ground water, consideration should be given to the most current applications and development of asbestos cement or fiberglass casing in comparison to other corrosive resistant metal casings or metal casings with liners at the time of pumping well design. Although great care must be exercised in placing and cementing non-metal casings particularly at depth, installa-

tion feasibility of new, higher strength, inert materials may be promising. Small diameter fiberglass and PVC well casings for shallow wells have been used with some success, however, fiberglass and PVC casing required for deep, large diameter wells is not readily available and requires special installation procedures and risks. Several companies, however, are presently evaluating the feasibility of this particular application of fiberglass material.

4. A monitoring and testing program should be performed during well field installation and during subsequent well field withdrawals. The staged evaluation and development of additional information in this fashion will serve to optimize the potential water resource use of the Floridan aquifer in South Florida.

4.0 PROJECT SCOPE

The scope of this study was as follows:

1) Develop and design a "Production Test Well" and Observation Wells for testing. In the planning process, a Governmental Advisory Group (Appendix B) was formed to provide suggestions and recommendations to the program before either the drilling of the wells or the test program was started.

2) Provide specifications for the wells.

3) Review specifications with competent contractors, prepare bid documents, and to aid in the selection of or recommendation of a contractor for drilling of the wells based upon bid documents received.

4) Monitor the drilling of the wells and the collection of data during drilling.

5) Conduct pumping tests on the Production Test Well and monitor the effect of the tests on Observation Wells.

6) For large, long-term withdrawals, evaluate test results to:

a) Provide information as to the effect of pumping on the aquifer;

b) Provide information as to the effect of pumping on other users of the aquifer in the area;

c) Provide information as to the possibility of saline water intrusion;

d) Provide withdrawal water quality information as a function of time;

e) Provide information on the stability of the substrata under the influence of pumping; and

f) Provide information to allow the design of an optimum well field.

5.0 DRILLING PROGRAM

5.1 INTRODUCTION

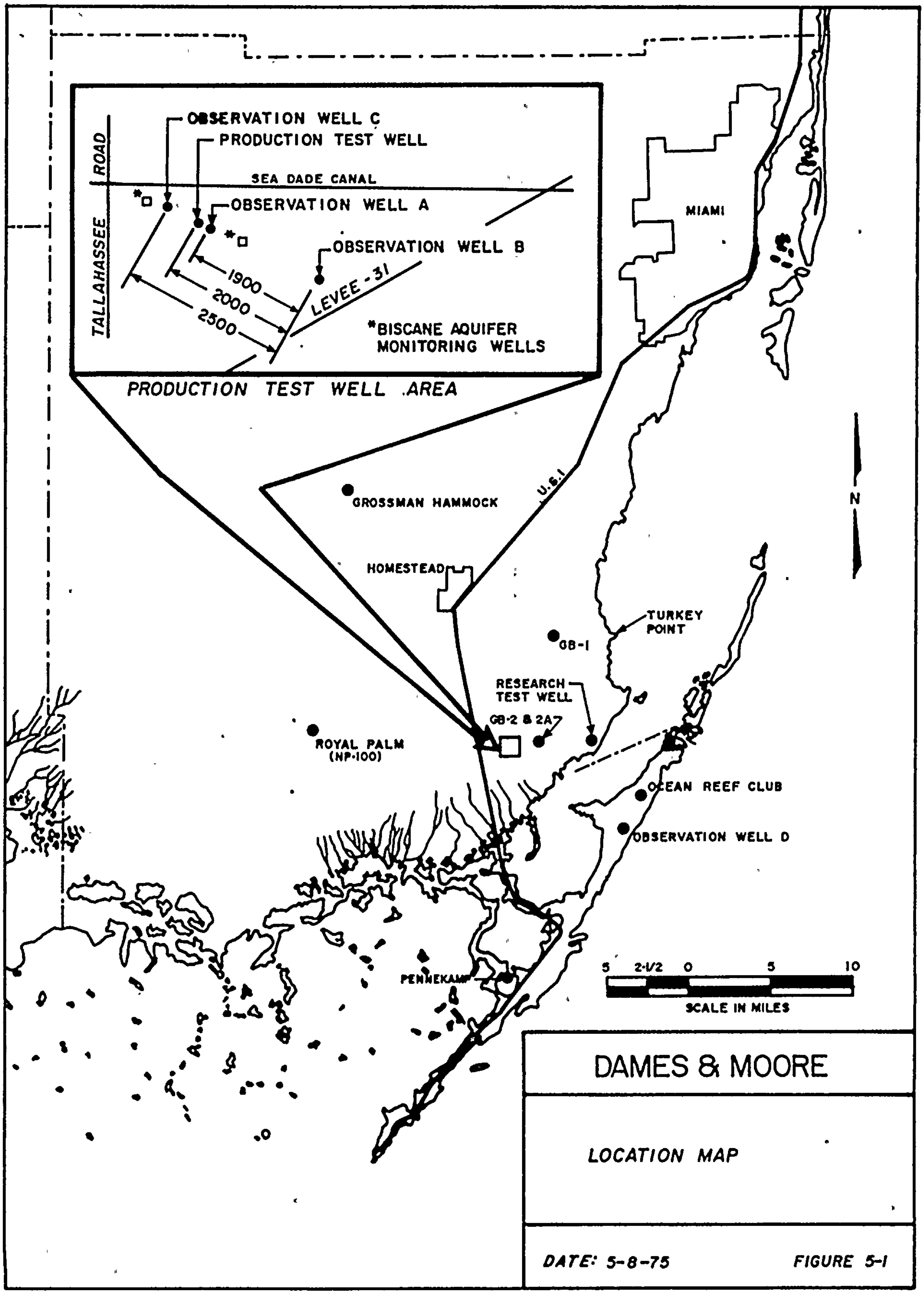
The technical methods of well construction employed during the study are described in this section. The reader may refer to Figures 5-1 through 5-6 for a pictorial and tabular synopsis of the well locations, final well specifications and drilling schedule.

On the basis of preliminary results obtained from water analysis and pump tests performed on the Research Test Well, Florida Power & Light Company authorized construction of a Production Test Well and four observation wells. The purpose of completing these wells was to use them in obtaining additional and substantive information on the characteristics of the Floridan aquifer and to evaluate the effects of withdrawals in the Turkey Point area.

The methods of operation and well construction specifications were generally based on the subsurface conditions that were encountered while drilling the Research Test Well. Modification of the well specifications during drilling operations were dictated by subsurface conditions and availability of materials; however, the scope of modifications was generally within the principal guidelines that had originally been established.

5.2 CONTRACTOR SELECTION

Prior to selective bidding on this project, a list of drilling contractors considered capable of completing deep, large diameter wells as required was compiled. Letters of



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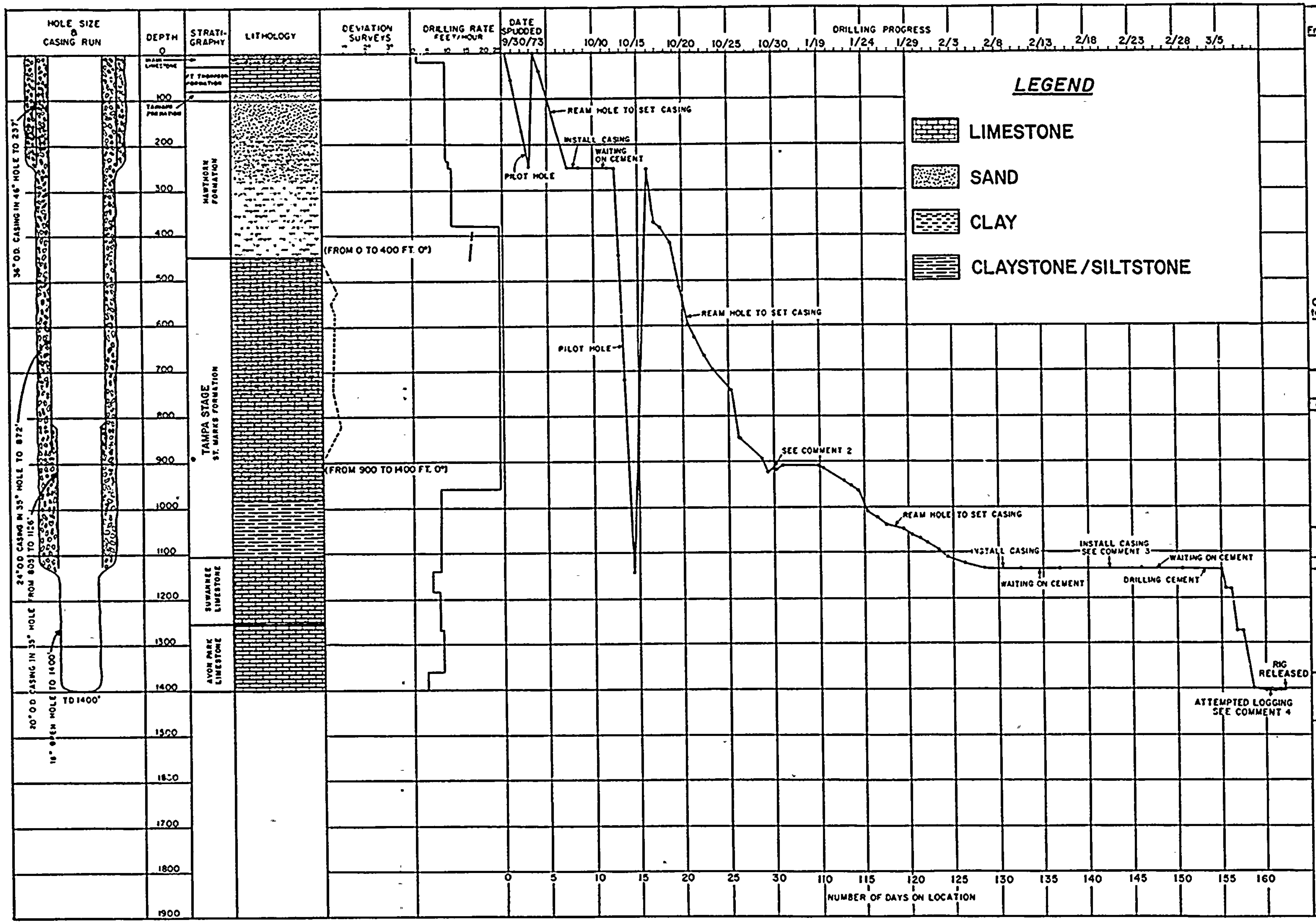
LOCATION MAP

DATE: 5-8-75 *FIGURE 5-1*

PRODUCTION TEST WELL



Well Production Test Well
Owner Florida Power & Light Company
Consultant Dames & Moore
Contractor Alsay Pippin Corp
Address Lake Worth, Florida
Well Location T58S, R39E, Sec. 26, SW 1/4 Turkey Pt., Fla.
Pad elevation 4.23 Ft. MSL

TIME ANALYSIS

From Spud Date to Total Depth

	DAYS	%
Drilling on bottom	9	5.00
Drill trips	14	7.77
Core trips, reaming hole	30	16.66
Downtime maintence & preparation	28	15.55
Conditioning hole	4	2.22
Deviation surveys	3	1.66
Water sampling	-	-
Fishing	48	26.66
Logging	0	-
Test pumping	0	-
Other	16	8.88

CASING SIZE	WALL THICKNESS		DAYS RUN	DAYS W.O.C.		
48"OD	CONDUCTOR PIPE			—	—	—
36"OD	.375	142.68	1	3	4	2.22
24"OD	.500	125.49	1	3	4	2.22
20"OD	.406	85.01	1	3	4	2.22
Totals			3	9	12	6.66

Overall time to total depth	164	91.06
Operations after reaching total depth		
Logging	3	1.66
Well head construction	13	7.22
Total time after TD	16	8.88
Total days on well	180	100.00

RIG DESCRIPTION

0-1400 Ft

Date spudded 9-30-73
Date rig released 3-12-74

MUD PROGRAM

WEEK ENDING	MUD (sks)	ADDITIVES (sks)
10/5	60	2
10/12	102	36
10/19	10	5
10/26	146	66
11/2	119	29
11/9	27	-
1/25	89	-
2/1	55	-
2/15	70	14

BIT and REAMER SUMMARY

OPERATION	SIZE	DEPTH	FOOTAGE
Pilot Hole	11"	0-250'	250'
Ream	46"	0-250'	250'
Pilot	11"	250-1140	890'
Ream	35"	250-1129	879'
Drill	18"	1129-1400	271'

CEMENTING SUMMARY

PIPE SIZE	HOLE SIZE	NO SACKS	TYPE	ADDITIVE
48"OD		24	Ready Mix	-
36"OD	45"	796	H	Neat
24"OD	35"	1500	A	8% gel
		400	A	4% gel
20"OD	23"	1100	A	Neat

WELL LOGGING SUMMARY

Logging company Schlumberger Well Services Inc.

SEE COMMENTS

COMMENTS

1 Contractors Work Schedule
 a From 9/30/73 to 1/4/74 drilling 24 hours seven days/week.
 b From 1/5 to 3/8, drilling 12 hours/day, six days/week
2. Fishing and Drilling Past Lost Bit
 a From 10/30/73 to 12/16 attempted to retreive bit
 b. On 12/19, cemented in lost bit
 c. From 12/19 to 1/4/74 drill rig idle
 d From 1/5 to 1/19, drilling through cement and bypassing lost bit
3 24"OD casing become struck at 872 feet, 321 feet of 20"OD casing was drop set to 1126 feet.
4 Schlumberger unable to obtain logs, due to loggings tools hanging up on casing
5 Well head construction from 3/14 to 3/22 not shown on graph.

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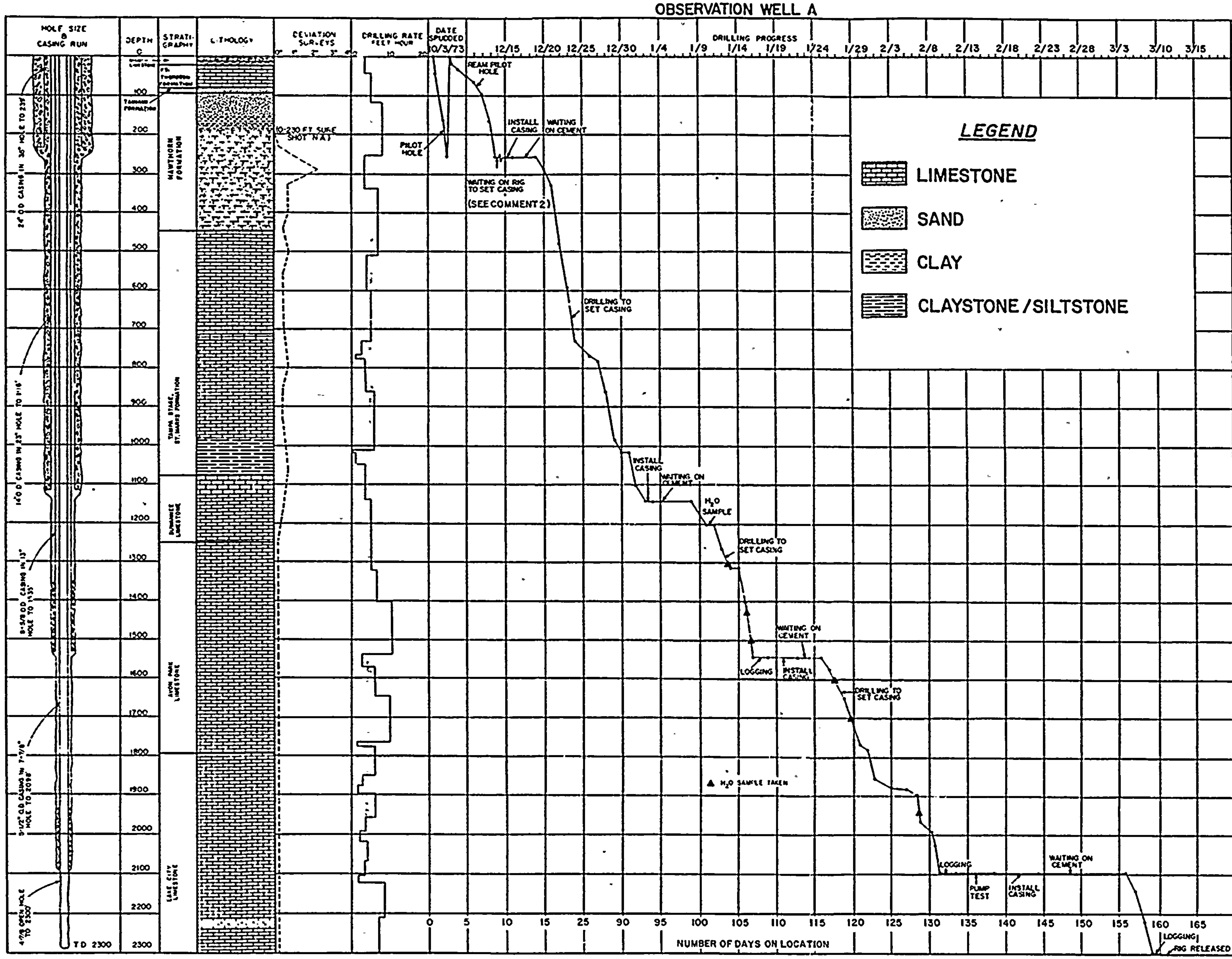
DRILLING TIME ANALYSIS & STRATIGRAPHIC COLUMN FOR PRODUCTION TEST WELL

DATE: 6-10-75 FIGURE 5-2

OBSERVATION WELL A



TIME ANALYSIS
From Spud Date to Total Depth

	DAYS	%
Drilling on bottom	35	22.15
Drill trips	3	1.89
Core trips, reaming hole	10	6.32
Downtime maintenance & preparation	7	4.43
Conditioning hole	1	.63
Deviation surveys	1	.63
Water sampling	5	.31
Fishing	15	.94
Logging	4	2.53
Test pumping	4	2.53
Other	58	36.70

CASING SIZE	WALL THICKNESS	lbs/ft	DAYS RUN	DAYS WOC	DAYS	%
24" OD	.500	125.49	1	3	4	2.53
13-3/8" OD	.375	54.59	1	4	5	3.16
8-5/8" OD	.322	28.55	1	3	4	2.53
5-1/2" OD	.344	19.16	6	12	18	11.39
Totals			9	22	31	19.61

	DAYS	%
Overall time to total depth	156	98.67
Operations after reaching total depth		
Logging	1	.63
Well head construction	1	.63
Total time after TD	2	1.26
Total days on well	158	100.00

Well Observation Well "A"
Owner Florida Power & Light Company
Consultant Dames & Moore
Contractor Alsay-Pippin Corp.
Address Lake Worth, Florida
Well location T56S, R39E, SEC 26 SW 1/4 100 FT SE of Production Test Well, Turkey PT Fla.
Pad elevation 3.13 FT MSL

RIG DESCRIPTION

0-250 FT Failing 1500
250-2300 FT Failing JED "X"

Date spudded 10/3/73
Date rig released 3/11/74

MUD PROGRAM

WEEK ENDING	MUD (sks)	ADDITIVES (sks)
10-5	60	2
10-12	17	5
12-21	107	-
12-28	87	-
1-4	15	29

BIT and REAMER SUMMARY

OPERATION	SIZE	DEPTH	FOOTAGE
Pilot	8-5/8"	0-250'	250'
Ream	35"	0-250'	250'
Drill	23"	250-1135	885'
Drill	13"	1135-1535	400'
Drill	4-7/8"	1535-2098	563'

COMMENTS

1. Contractors Work Schedule
   a. From 10/3/73 to 10/11, drilling 12 hrs/day, seven days/week
   b. From 12/20 to 1/4/74, drilling 24 hrs/day, seven days/week
   c. From 1/5 to 3/16 drilling 12 hrs/day, six day/week
2. Rig moved off site due to size being inadequate for casing installation.

CEMENTING SUMMARY

PIPE SIZE	HOLE SIZE	NO SACKS	TYPE	ADDITIVE
36" OD	34"	70	READYMIX	NEAT
14" OD	23"	1155	A	12% Gel
-	-	900	A	Neat
8-5/8" OD	13"	200	A	Neat
5-1/2" OD	7-7/8"	75	A	Neat

WELL LOGGING SUMMARY

Logging company Schlumberger Well Services Inc.

Type Log	Depth Logged	Date Logged
Gamma	0-1535	1/18/74
CBL	0-1116	1/18/74
Induction	1116-1535	1/18/74
SP	1116-1535	1/18/74
Temp	0-1535	1/18/74
Gradiomanometer	1116-1535	1/18/74
Collarlocator	0-1116	1/18/74
CBL	1116-1535	1/18/74
Flowmeter	1116-1535	1/18/74
Caliper	1116-1535	1/18/74
Sonic	1116-1535	1/18/74
Gamma	1535-2103	2/10/74

Type Log	Depth Logged	Depth Logged
Induction	1535-2103	2/10/74
SP	1535-2103	2/10/74
VDL	1535-2103	2/10/74
Sonic	1535-2103	2/10/74
Flowmeter	1535-2103	2/10/74
Caliper	1535-2103	2/10/74
Gamma	2103-2300	3/10/74
CBL	1535-2098	3/10/74
Induction	2098-2300	3/10/74
SP	2103-2300	3/10/74
Temp	0-2300	3/10/74
Sonic	2098-2300	3/10/74
VDL	1535-2098	3/10/74
Collarlocator	0-2300	3/10/74

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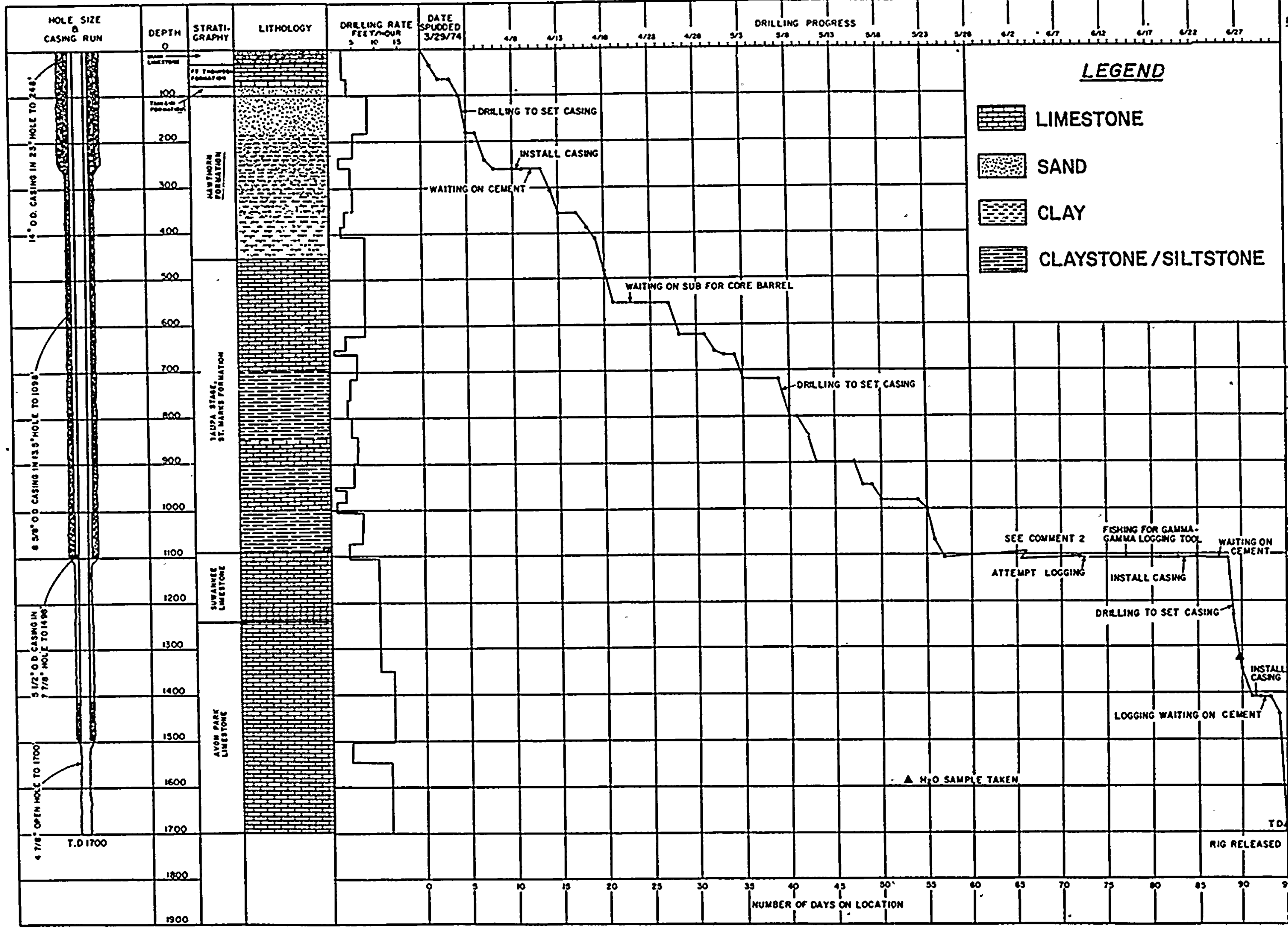
DRILLING TIME ANALYSIS & STRATIGRAPHIC COLUMN FOR OBSERVATION WELL A

DATE 6-10-75 *FIGURE 5-3*

OBSERVATION WELL B



TIME ANALYSIS
From Spud Date to Total Depth

	DAYS	%
Drilling on bottom	28	29.16
Drill trips	1	1.04
Core trips, reaming hole	5	5.20
Downtime maintenance & preparation	4	4.16
Conditioning hole	2	2.08
Deviation surveys	-	-
Water sampling	.5	.52
Fishing	8	8.33
Logging	.5	.52
Test pumping	0	- -
Other	35	36.45

CASING SIZE	WALL THICKNESS	lbs/ft	DAYS RUN	DAYS WOC	DAYS	%
24" OD	CONDUCTOR PIPE					
14" OD	.375	54.57	1	3	4	4.16
8 5/8" OD	.322	28.55	1	3	4	4.16
5 1/2" OD	.344	19.16	1	2	3	3.12
Totals						
Overall time to total depth					95	99.39

Operations after reaching total depth

	DAYS	%
Logging	.5	.52
Well head construction	.5	.52
Total time after TD	1	1.04
Total days on well	96	100.00

BIT and REAMER SUMMARY

OPERATION	SIZE	DEPTH	FOOTAGE
Drill	23"	0-248'	248'
Drill	13 1/2"	248'-1098'	850'
Drill	7 7/8"	1098'-1498'	400'
Drill	4 7/8"	1498-1700	202'

CEMENTING SUMMARY

PIPE SIZE	HOLE SIZE	NO SACKS	TYPE	ADDITIVE
24" OD	-	5	Ready Mix	-
14" OD	23"	100	A	Neat
-	-	288	A	4% gel
8 5/8" OD	13 1/2"	360	A	4% gel
-	-	120	A	Neat
5 1/2" OD	7 7/8"	40	A	Neat

WELL LOGGING SUMMARY

Logging company Schlumberger Well Services Inc

Type Log	Depth Logged	Date Logged
Gamma	0-1505	6/27/74
CBL	0-1104	6/27/74
Induction	1104-1505	6/27/74
S.P.	1104-1505	6/27/74
Caliper	1104-1505	6/27/74
Sonic	1104-1506	6/27/74
Flowmeter	1000-1505	6/27/74
Gamma	1505-1700	7/11/74
CBL	1104-1498	7/11/74

Well Observation Well B
Owner Florida Power & Light Company
Consultant Dames & Moore
Contractor Alsay Pippin Corp.
Address Lake Worth, Florida
Well location T58S, R39E, Sec 26, SW 1/4
2000 Ft SE OF Production Test Well Tky Pt, Fla
Pad elevation 4.41 Ft MSL

RIG DESCRIPTION

0-1105 Feet Failing 1500
1105-1700 Feet Failing JED A

Date spudded 3/29/74
Date rig released 7/29/74

MUD PROGRAM

WEEK ENDING	MUD (sks)	ADDITIVES (sks)
3/29/74	4	11
4/5/74	98	32
4/12/74	19	4
4/19/74	41	30
4/26/74	15	20
5/3/74	17	29
5/10/74	41	34
5/17/74	55	25
5/24/74	25	22

COMMENTS

1. Contractor's Work Schedule
   a. From 3/29/74 to 6/21, drilling 10 hours/day, five days/week.
   b. From 6/21 to 7/2 drilling an average of 12 hours/day, six days/week.
2. Explanation of Delay
   a. From 5/24 to 6/3, job shutdown due to contractor.
3. Logging program of 7/11 not shown on graph

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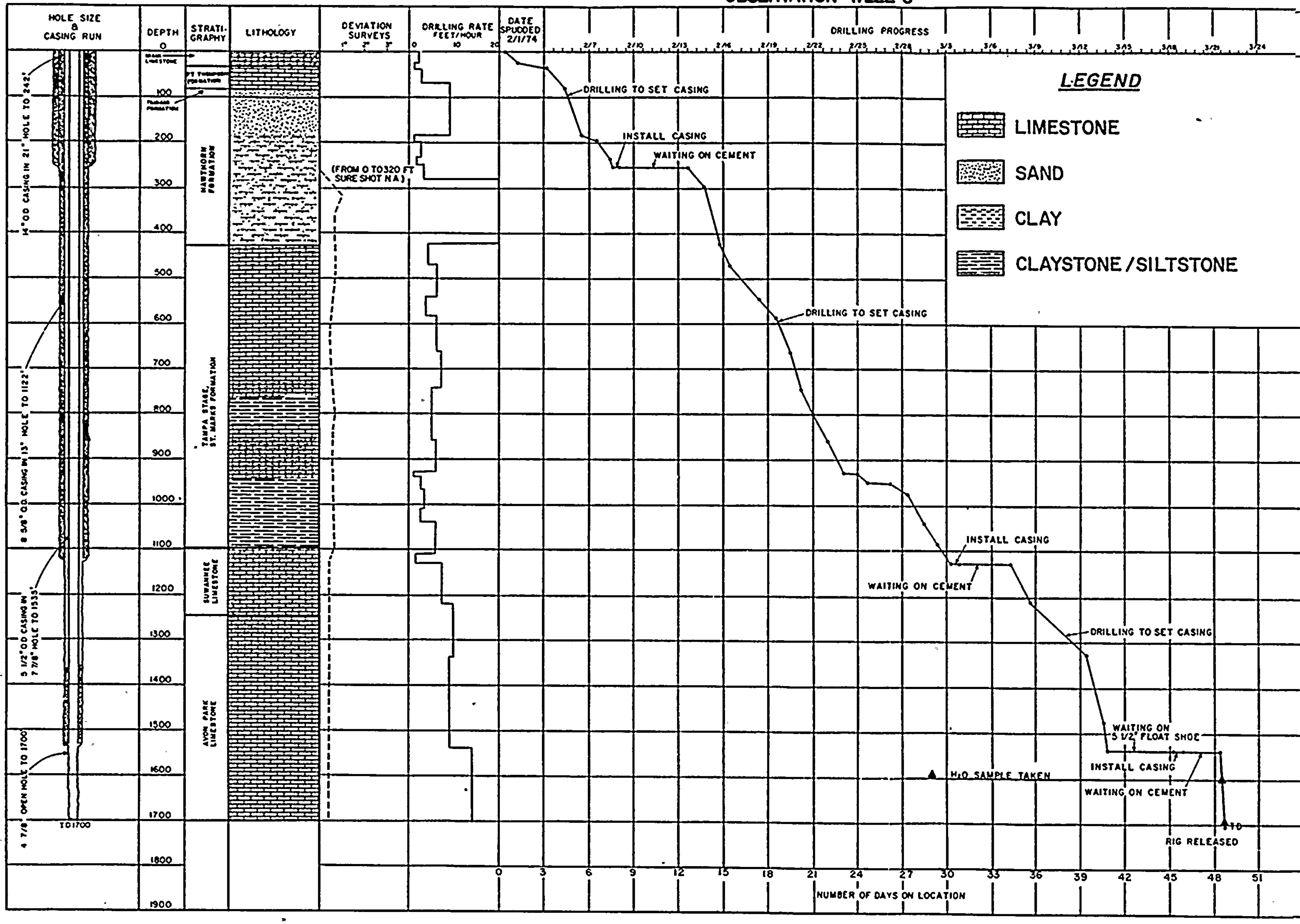
DRILLING TIME ANALYSIS & STRATIGRAPHIC COLUMN FOR OBSERVATION WELL B

DATE 6-10-75 *FIGURE 5-4*

OBSERVATION WELL C



TIME ANALYSIS
From Spud Date to Total Depth

	DAYS	%
Drilling on bottom	27	52.94
Drill trips	1	1.96
Core trips, reaming hole	1	1.96
Downtime maintence & preparation	5	9.80
Conditioning hole	1	1.96
Deviation surveys	1	1.96
Water sampling	1	1.96
Fishing	-	-
Logging	-	-
Test pumping	-	-
Other	-	-

CASING SIZE	WALL THICKNESS	lbs/ft	DAYS RUN	DAYS WOC		
24" OD	CONDUCTOR PIPE					
14" OD	.375	54.57	1	3	4	7.84
8 5/8" OD	.322	28.55	1	3	4	7.84
5 1/2" OD	.344	19.16	1	3	4	7.84
Totals			3	9	12	23.52

	DAYS	%
Overall time to total depth	119	96.06
Operations after reaching total depth		
Logging	1	1.96
Well head construction	1	1.96
Total time after TD	2	3.92
Total days on well	51	100.00

Well Observation Well C
Owner Florida Power & Light Company
Consultant Dames & Moore
Contractor Alsay Pippman Corp.
Address Lake Worth, Fla
Well location T58S, R39E, Sec 26, SW 1/4, 500' NW Of Production Test Well Turkey Pt. Fla
Pad elevation 3.30 Ft. MSL

RIG DESCRIPTION

0-1340 Ft Failing 1500
1340-1700-Ft - Failing JEO A

Date spudded 2/1/74
Date rig released 3/21/74

MUD PROGRAM

WEEK ENDING	MUD (sks)	ADDITIVES (sks)
2/1	32	-
2/8	95	3
2/22	54	23
3/1	43	17
3/8	21	26

BIT and REAMER SUMMARY

OPERATION	SIZE	DEPTH	FOOTAGE
Drill	21"	0-242	242
Drill	13"	242-1122	880
Drill	7 7/8"	1122-1535	413
Drill	4 7/8"	1535-1700	165

COMMENTS

1. Contractors' Work Schedule
   a From 2/1/74 to 3/21, drilling 12 hours/day, six days/week.
2. Logging program of 7/11 not shown on graph

CEMENTING SUMMARY

PIPE SIZE	HOLE SIZE	NO SACKS	TYPE	ADDITIVE
24" OD	-	5	Ready mix	-
14" OD	21"	155	A	4% gel
	-	142	A	Neat
8 5/8" OD	13"	400	A	4% gel
	-	125	A	Neat
5 1/2" OD	7 7/8"	100	A	Neat

WELL LOGGING SUMMARY

Logging company Schlumberger Well Services Inc.

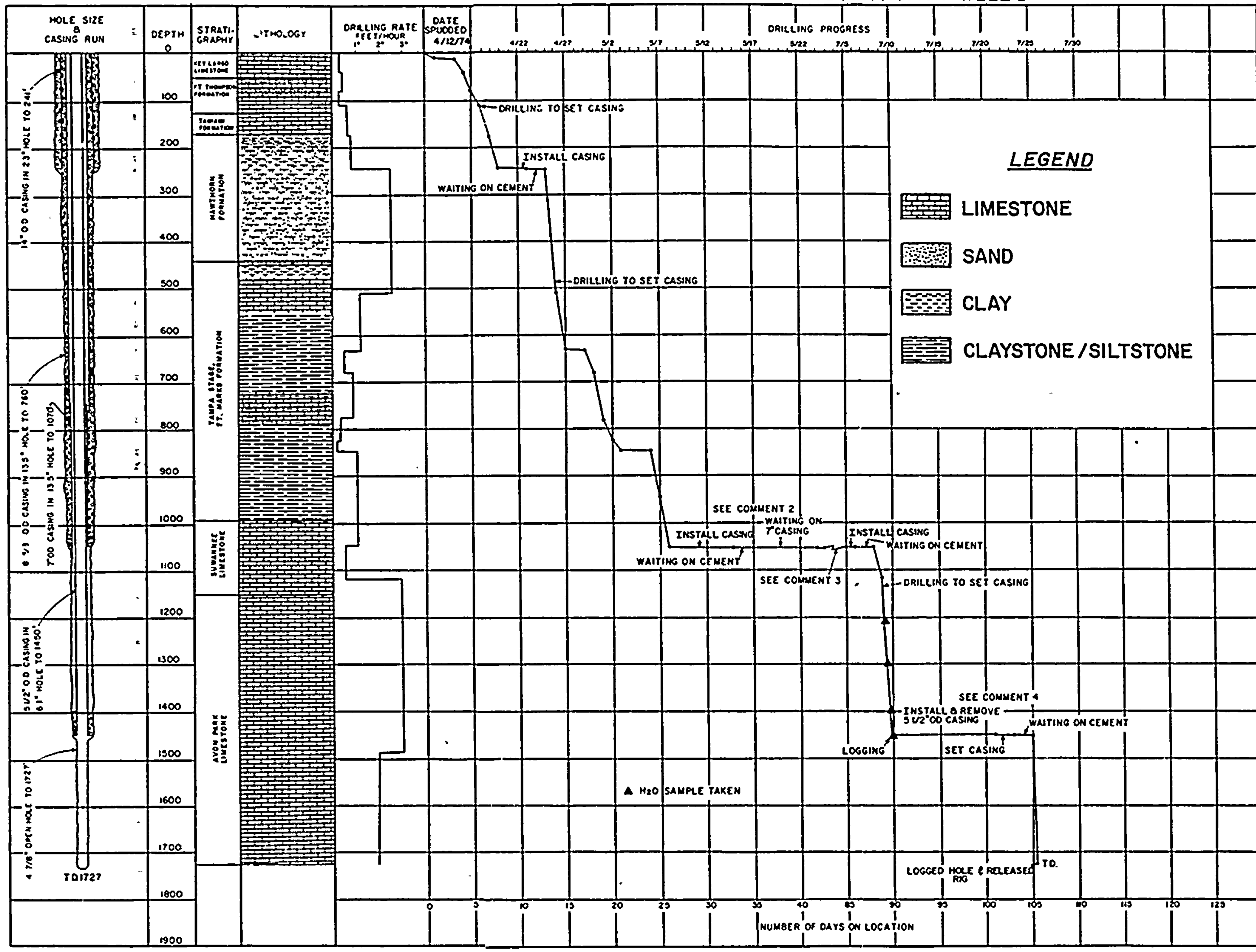
Type Log	Depth Logged	Date Logged
Gamma	0-1700	7/11/74
CBL	0-1535	7/8/74
Induction	1535-1700	7/11/74
S.P.	1535-1700	7/11/74
	SEE COMMENTS	

DAMES & MOORE

DRILLING TIME ANALYSIS & STRATIGRAPHIC COLUMN FOR OBSERVATION WELL C

DATE 6-10-75 FIGURE 5-5

OBSERVATION WELL D



TIME ANALYSIS
From Spud Date to Total Depth

	DAYS	%
Drilling on bottom	17	16.19
Drill trips	1	.95
Core trips, reaming hole	2	1.90
Downtime maintence & preparation	7	6.66
Conditioning hole	1	.95
Deviation surveys	-	-
Water sampling	.5	.47
Fishing	1	.95
Logging	.5	.47
Test pumping	-	-
Other	42	40.00

CASING SIZE	WALL THICKNESS	lbs/ft	DAYS RUN	DAYS WOC		
24" OD	Conductor Pipe					
14" OD	.375	54.57	1	3	4	3.80
8 5/8" OD	.322	28.55	8	3	11	10.47
7" OD	.498	34.58	1	1.5	2.5	2.38
5 1/2" OD	.344	19.16	13	1.5	14.5	13.80
Totals						

	DAYS	%
Overall time to total depth	104	99.00

Operations after reaching total depth

	DAYS	%
Logging	.5	.47
Well head construction	.5	.47
Total time after TD	1	.94
Total days on well	105	100.00

BIT and REAMER SUMMARY

OPERATION	SIZE	DEPTH	FOOTAGE
Drill	23"	0-241	241
Drill	13.5"	241-1050	809
Drill	6.1"	1050-1450	400
Drill	4 7/8"	1450-1727	277

CEMENTING SUMMARY

PIPE SIZE	HOLE SIZE	NO SACKS	TYPE	ADDITIVE
24" OD	-	5	Ready Mix	-
14" OD	23"	160	A	6% gel
	-	150	A	Neat
8 5/8" OD	13.5"	200	A	4% gel
	-	75	A	Neat
7" OD	13.5"	250	A	Neat
5 1/2" OD	6.1"	50	Portland Cement	

WELL LOGGING SUMMARY

Logging company Schlumberger Well Services Inc.

Type Log	Depth Logged	Date Logged
Gamma	0-1455	7/10/74
CBL	0-1053	7/10/74
Induction	1053-1455	7/10/74
Sonic	1053-1455	7/10/74
Caliper	1053-1455	7/10/74
Gamma	1455-1720	7/24/74
CBL	1053-1455	7/25/74
Induction	1455-1727	7/25/74
Sonic	1455-1727	7/24/74
Caliper	1455-1727	7/24/74

Well Observation Well D
Owner Florida Power & Light Company
Consultant Dames & Moore
Contractor Alsay-Pippin Corp.
Address Lake Worth, Florida
Well location T59S, R40E, Sec 35, NW 1/4 44,800 Ft SE From Prod Test Well, Key Largo, Fla
Pad elevation 11.17 Ft MSL

RIG DESCRIPTION

0-1700 Feet Failing JED A

Date spudded 4/12/74
Date rig released 7/25/74

MUD PROGRAM

WEEK ENDING	MUD (sks)	ADDITIVES (sks)
4/12	15	9
4/19	274	65
4/26	26	20
5/3	62	82
5/10	31	174
5/17	100	37

COMMENTS

1. Contractor's Work Schedule
   a From 4/12/74 to 5/12, drilling 10 hours/day, five days/week.
   b From 7/5 to 7/25, drilling an average of 12 hours/day, seven days/week.
2. 8 5/8" OD casing became stuck in hole at 760 ft., 346 feet of 7" OD casing was drop set to 1050 ft
3. Explanation of Delay
   a From 5/24 to 6/3, job shutdown due to contractor.
   b. From 6/3 to 7/5, rig not available, because of use on OWB.
4. 5 1/2" OD casing removed and reinstalled because of inadequate cement job.

DAMES & MOORE

DRILLING TIME ANALYSIS & STRATIGRAPHIC COLUMN FOR OBSERVATION WELL D

DATE 6-10-75 *FIGURE 5-6*

invitation to bid were mailed to each of these companies, with a copy of the Contract Agreement and technical specifications. Four of the eight companies declined to submit bids on the project with the predominant reason being a lack of available drilling equipment in the area.

On August 22, 1973, the bids were opened and compared. Of the four bids received, that of Alsay Drilling, Inc. (now Alsay-Pippin Corporation) of Lake Worth, Florida, was lowest.

Inasmuch as Alsay-Pippin Corporation had been the contractor for the previously drilled Research Test Well, had the most extensive similar deep well experience, and committed large rigs for use, this firm was recommended by Dames & Moore to Florida Power & Light Company for award of the drilling contract. Subsequently, Florida Power & Light Company selected Alsay-Pippin Corporation as drilling contractor for the Floridan aquifer water supply investigation. The contract with Alsay was signed on August 29, 1973, and mobilization of equipment began shortly thereafter.

5.3 SCOPE OF WORK

The scope of work consisted of drilling one production well and four observation wells. The Production Test Well was to be constructed for use as a pumping well. The well was to have initial specifications of a 24-inch outside diameter casing set at a depth of approximately 1050 feet, drawing water from the open hole (18-inch diameter) zone between approximate depths of 1050 to 1350 feet.

Four observation wells were to be constructed for monitoring purposes. Observation Well A was to be located 100 feet from the Production Test Well. Observation Well B was to be located 1500 to 2000 feet southeast of the Production Test Well, and Observation Well C was to be 500 feet northwest of the Production Well. Observation Well D was to be located on Key Largo about nine miles to the southeast of the Production Test Well.

Observation Well A was to be drilled to a total depth of approximately 2200 feet, with four separate strings of casing extending from ground surface to respective depths of approximately 180, 1050, 1425, and 2000 feet. This would allow monitoring of an upper zone from 1050 to 1225 feet, a lower zone from 1425 to 1600 feet as well as a deep zone from 2000 to 2200 feet.

Observation Wells B, C and D were designed to have total depths of 1600 feet, and three separate casing strings set in each hole to respective depths of 180, 1050 and 1425 feet. This would allow monitoring of the producing zone in the upper Floridan from about 1050 to 1225 feet and the lower Floridan from about 1425 to 1600 feet.

5.3.1 Expanded Scope of Work

Due to a concern over potential corrosion resulting from the presence of H_2S in the ground water, coal tar epoxy was applied to both the inside and outside of each section of casing prior to installation in the well. The casing was cleaned by sandblasting just prior to coating in order to provide a clean surface to which the epoxy would adhere. Also, prior to application of the epoxy, each section of casing was masked with tape at each end. This left approximately 2 inches of uncoated metal exposed both inside and out to facilitate welding.

An even coat of coal tar epoxy was desirable in order to reduce the possibility of galvanic cells setting up and corroding the casing. A spray gun was used to coat the outside. A spinner apparatus was used to apply an even coat to the inside. As the tool was pushed along the inside of each section, a spinner revolved pneumatically at a high rpm, depositing the epoxy onto the casing in one even coat.

While the casing was being installed, each welded joint was coated, both inside and out. The inside coat was again applied by the spinner tool. The outside of the joint was coated by hand with a brush.

5.4 SITE PREPARATION

Prior to commencement of drilling, the proposed locations of the wells were surveyed and marked (Figure 5-1). Access roads and drilling pads were constructed of limestone fill for the Production Test Well and Observation Well A. Pad construction for Observation Well B, Observation Well C and Observation Well D was completed while drilling operations were in progress on the Production Test Well. The pads were designed to accommodate the drilling rig and

accessory equipment. The Observation Well D site was cleared of vegetation and leveled with limestone fill. Well location on the pad was determined by the working area available with consideration being given to leaving as much land as possible for other uses subsequent to completion of the well.

5.5 GENERAL DRILLING METHODS

The wells were generally drilled with drilling mud from ground surface to a depth of approximately 1100 feet. From 1100 feet to total depth, the wells were drilled with reverse air.

Briefly, the reverse air method consists of lowering a string of small diameter pipe down the inside of the drill stem and then pumping compressed air down this small pipe. The air bubbles reduce the hydrostatic pressure at the bottom of the drill stem below that of the fluid in the hole and in the surrounding formation, causing water to flow into the drill stem. This in turn forces the rock cutting up the drill pipe and into a pit at the surface. Drilling with reverse air allows the well to be developed to full artesian pressure with no mudcake. In addition, the lithologic samples are clean and have a minimum amount of contamination.

The Production Test Well, however, was drilled from ground surface to total depth with drilling mud. Drilling mud was required to remove the large volume of cuttings produced by cutting the large diameter drill hole. The drilling mud was completely purged from the aquifer soon after completion of drilling, using the drill stem as a wash pipe. Final development and purging of the aquifer was completed with the initial pumping of the well during the pump tests.

5.5.1 Casing Program

Original technical specifications outlined certain diameters, wall thicknesses and coupling requirements. Depths and sizes of open hole for installation of the various strings of casing were also established, based on subsurface conditions encountered while drilling the Research Test Well.

Due to casing availability and initial time schedule restriction, the original specifications were modified in order to expedite the work. The modifications resulted in the wall thickness of the 8-5/8 inch casing being changed from 0.35 inches to 0.322 inches and thickness of the 5-1/2 inch casing being changed from 0.304 inches to 0.344 inches. These modifications are not judged critical to the quality of well construction.

The annular space outside the 8-5/8 inch casing was sealed with cement from ground surface to installation depth in Observation Wells B, C and D to provide a barrier between the well and the aquifer. In addition, the casing which is exposed to artesian flow is coated with 20 millimeters of coal tar epoxy.

Specifications also called for all casing 14 inches or less in diameter to be threaded and coupled. Unfortunately, this type of casing was not available at the time of drilling and consequently, all casing of this size was plain ended. The casing was butt welded with a triple bead weld during installation. The welded joints were also coated with coal tar epoxy.

Deviations from specified casing depths originally estimated were due, in most part, to existant subsurface conditions. Geologic formation tops, for example, were generally deeper than had been expected, thereby requiring a correspondingly deeper setting of the casing strings.

In other cases, subsurface conditions, prevented the installation of the casing to the desired depth. Casing sizes were reduced accordingly in order to allow "drop-set" casing installation. "Drop-set" casing operations were performed successfully on the Production Test Well and Observation Well D.

Initial specifications on all wells called for two strings of casing. Although three casing strings are normally used for wells of this depth, it was felt that by careful mud control and drilling a cost savings could be achieved. Two of the five wells were installed successfully using two casing strings.

5.5.2 Sampling Program

Lithologic - As drilling progressed, two sets of lithologic samples were collected every ten feet. One set was sent to Florida Geological Survey for future paleontological analysis. The other set was retained by Florida Power & Light Company at Turkey Point.

After each sample was obtained, a geologic description was recorded by the field geologist on location. These descriptions were used, in part, to compile a lithologic log for each well and served as a basis for setting casing strings at different depths. Using lithologic and geophysical logs, depths and thicknesses of the subsurface geologic formations were correlated between wells during the drilling operations.

As drilling progressed on the Production Test Well and Observation Well A, rock and soil samples were obtained for correlation with cutting samples and geophysical logs. Coring operations were begun in Observation Well A at a depth of 1642 feet. The intervals from which cores were recovered are 1642 to 1652 feet, 1760 to 1772 feet, 1992 to 2017 feet. Coring and soil sampling operations also were performed on Observation Well B. The intervals from which cores were recovered are 555 to 565 feet, 650 to 656 feet, 950 to 956 feet. Soil samples were recovered at the depths of 181.5 feet, 351.5 feet and 401.5 feet. Core recovery of the limestone generally averaged 30 percent, while soil sample recovery averaged 60 percent.

Water - After each Observation Well had penetrated the Floridan aquifer, water samples were obtained every 10 feet and analyzed for conductivity and temperature. Samples from selected depths were then sent to a laboratory for more detailed chemical analysis. Further discussion of this sampling program is presented in the section on hydrochemistry.

5.5.3 Cementing Program

The objectives of the cementing program were twofold: 1) to prevent potential leakage and contamination of near surface water by vertical migration of deeper more saline waters; 2) to isolate specific intervals within the Floridan aquifer in order to observe and evaluate hydrologic characteristics at various depths.

Class A cement plus litepoz was originally specified to be used in cementing the casing. However, due to the non-availability of this type of cement, a suitable substitute of Class A and Class H cement was utilized. At times, various percentages of bentonite were added to the cement, dependent on the subsurface conditions. The reason for bentonite additive was to increase the yield per cubic feet of the cement. This increased yield aids in cementing geologic formations of high permeability and porosity such as the limestones that were encountered.

The technical specifications for each well indicated volumes of cement for each casing string. These amounts were increased as drilling progressed largely because of the deeper casing depths. At times, however, the waste factor was enlarged in order to take into account cement seepage

into very permeable formations and/or to counter the effect of artesian flow which would tend to wash some of the cement out of the annulus. The quantities of cement used to cement the respective casing strings are shown in Figures 5-2, 5-3, 5-4, 5-5 and 5-6.

In order to properly cement the annulus, all rock cuttings must be removed from the drill hole. This removal was accomplished by pumping drilling mud through the drill hole until all of the rock cuttings had been removed. The time required for this conditioning varied with hole depth and size; however, in most cases the time ranged from 5 to 26 hours. This conditioning was not necessary when artesian flow was present because the natural flow of water served to adequately flush out the cuttings. After cementing, an appropriate curing time, dependent on the class of cement and additives, was allowed before drilling was resumed.

5.5.4 Mud Program

The mud program was designed primarily to reduce down hole problems developing from squeezing clay in the subsurface, particularly within the Hawthorn Formation. As experienced during this project and previously on the Research Test Well, the Hawthorn clays behave unpredictably during drilling. As a result, installation of casing through these clays is equally unpredictable and difficult. Similar well installation problems are common throughout Florida when these clays are encountered.

The type of mud used on this project was Baroid Zeogel. This mud is especially formulated to be used with brackish or saline waters. Additives, such as sodium chloride and caustic soda, were also used to maintain the mud characteristics at maximum effectiveness.

Soon after drilling had begun, a Baroid Mud Engineer was brought on location so that he could make specific recommendations concerning the properties of the mud. The final recommendation was to maintain the mud weight and viscosity at 10 lbs. per cubic foot and approximately 45 seconds respectively. During drilling operations, mud properties were monitored in order to maintain these general characteristics.

The problem of the squeezing clays resulted in the modification of casing programs for the Production Test Well and Observation Well D. The drilling mud performed quite adequately in maintaining an open hole during installation of casing in Observation Wells A, B and C.

In order to adhere to pollution guidelines concerning possible contamination of the surrounding surface waters, all mud and disposal pits were lined with heavy sheet plastic. Subsequent to the completion of drilling operations, all of the pits were filled in and the sites were cleared of excess material.

5.5.5 Hole Deviation Specifications

Hole deviation measurements were taken every 60 feet to assure a maximum deviation of not more than 3° from the

vertical and a maximum difference of not more than 1/2° between any two successive readings. These limits were specified in order to maintain a reasonably straight and plumb hole which was particularly necessary for successful pump column and casing installation in the Production Test Well.

Deviation readings were obtained with an inclinometer manufactured by Geolograph Corporation. During the drilling program, concern existed over the accuracy of the instrument. To meet this concern, a factory representative visited the site and calibrated the instrument. Subsequent utilization, however, produced similar doubtful results and a second new instrument was obtained. This new instrument also produced doubtful results. Nevertheless, drilling of the wells proceeded without excessive hole deviation. Deviations were prevented, in part, by closely controlling the weight on the drill bit. The deviation readings are shown in Figures 5-2, 5-3 and 5-5.

Each rig was also equipped with a Geolograph, an instrument to continually monitor drilling rates and weight on the drill bit. This data indicates the relative "drillability" of the geologic formations and provide an indirect indication of the rock type being drilled. The instrument is also useful in controlling the weight on the bit and provides a continuous record of drilling progress.

5.6 PRODUCTION TEST WELL CONSTRUCTION

Drilling of the Production Test Well began on September 30, 1973, utilizing a Failing 3000 drill rig. The location

of this well is shown on Figure 5-1. Initially, an 11-inch diameter pilot hole was drilled to a depth of 250 feet. A pilot hole provided lithologic samples with minimum contamination, thereby providing information on the subsurface conditions. This information was necessary to determine the depths at which casing should be installed. The pilot hole also served to guide the reaming bit as the hole was being reamed for large diameter casing installation. The pilot hole was enlarged using a 46-inch reaming bit. Casing (36" OD) was installed to a depth of 237 feet and cemented to ground surface.

Following installation of the 36-inch casing, a pilot hole was drilled to a depth of 1140 feet, or about 40 feet into limestone. Again the pilot hole was reamed out, this time with a 35-inch diameter bit. During this reaming operation, however, the drill bit was lost in the well at a depth of approximately 880 feet. From October 30 to November 29, the driller attempted without success to recover the bit from the hole. From November 29 to December 16, the services of a professional tool recovery specialist were employed in a final but unsuccessful effort.

Inclination surveys indicated that the lost bit was located in a deviated section of the hole approximately 3.0^{o} from the vertical. A redrilled pilot hole successfully bypassed the lost bit and was extended on to a depth of 1129 feet. The entire hole was then completely rereamed and drilling mud was circulated for 16 hours to remove all cuttings. As soon as the hole was clean, a 24-inch diameter casing was started in the hole. At a depth of 350 to 400 feet, it became obvious that the silty clays of the Hawthorn Formation had squeezed in enough to exert a drag on the casing as it went into the hole. Although an effort was made to get the casing in the hole as quickly as possible, the drag presumably exerted by the Hawthorn Formation allowed installation of only 872 feet of the 24-inch casing. Efforts to work the casing loose either up or down were unsuccessful; consequently, the 24-inch casing was installed to a depth of 872 feet and the annulus was cemented to ground surface.

In order to correct the situation of having an uncased hole from 872 to 1129 feet, 321 feet of 20-inch OD casing was obtained and set in the hole from 805 feet to 1126 feet. This provided full casing of the hole from ground surface to 1126 feet. The annulus between the two strings of casing was also cemented to prevent leakage. Following cementing of this string, the Production Test Well was drilled with an 18-inch bit to completion at a total depth of 1400 feet. The drilling operations for the Production Test Well are summarized on Figure 5-2.

From March 14 to March 22, 1974, the pumps and engine drive units on the Production Test Well were installed. First, 180 feet of 12-inch OD pump column were installed. Second, a discharge head and an Amarillo double right angle drive unit were placed on top of the 24-inch OD casing. Two cement pedestals were constructed, and one V-12 GMC diesel

engine was installed on each pedestal. An orifice weir was used to monitor the flow rate from the aquifer during the pump test.

5.7 OBSERVATION WELL A CONSTRUCTION

Observation Well A is located 100 feet southeast of the Production Test Well (Figure 5-1). A Failing 1500 was used to drill from ground surface to 250 feet and a Failing Jed A was utilized to drill the interval between 250 - 2300 feet.

Drilling of an 8-5/8 inch pilot hole to 250 feet began on October 3, 1973. A 35-inch bit was used to ream the hole for installation of the 24-inch OD casing. The rig was then removed from the well because it was too small to adequately handle the 24-inch casing. In December, the Failing Jed A arrived on location to complete the well. The 24-inch casing was installed to a depth of 239 feet and the annulus was cemented to ground surface. Below that depth, a 23-inch bit was used to drill to a depth of 1135 feet. This operation was followed by the installation of the 14-inch OD casing to a depth of 1116 feet, which was cemented to ground surface. Drilling continued using a 13-inch bit to a depth of 1535 feet. Casing (8-5/8 inch OD) was installed from ground surface to 1535 feet. Afterwards, the casing annulus was cemented from 1350 feet to 1535 feet. Following casing installation, the hole was drilled to 2098 feet with a 7-7/8 inch bit. Casing (5-1/2 inch OD) was installed to a depth of 2098 feet and cemented from 1930 feet to 2098 feet. The

last section of the well was drilled to a total depth of 2300 feet using a 4-7/8 inch bit. This portion of the well was left uncased. Drilling operations are summarized on Figure 5-3.

5.8 OBSERVATION WELL B CONSTRUCTION

Observation Well B is located 2000 feet southeast of the Production Test Well (Figure 5-1). Two rigs, a Failing 1500 and a Failing Jed A, were utilized during the construction of the well.

Drilling operations began on March 29, 1974. Initially, a 23-inch hole was drilled to a depth of 248 feet. Casing (14-inch OD) was installed to 248 feet and cemented to ground surface. This was followed with a 13-1/2 inch hole drilled from 248 feet to 1105 feet for the installation of 8-5/8 inch casing.

A geophysical logging operation was conducted subsequent to drilling the 13-1/2 inch hole and prior to installing the 8-5/8 inch casing, in order to define the rock properties through the interval from 248 feet to 1105 feet. During the logging operation on June 9, the gamma-gamma geophysical logging tool became stuck in the well at 906 feet. Initial efforts by the driller to pull the tool free were unsuccessful; therefore, a professional "fishing" tool specialist was contracted to retrieve the lost tool. The "fishing" tool contractor was successful in extracting the tool from the hole on June 17th. To avoid further risks

involved with logging this unpredictable subsurface section of the well, logging operations were abandoned.

The 13-1/2 inch hole was rereamed. An 8-5/8 inch casing was installed to a depth of 1098 feet and cemented to ground surface. A 7-7/8 inch hole was drilled to 1498 feet and 5-1/2 inch casing was installed from ground surface to 1498 feet and cemented from 1410 feet to 1498 feet. The well was completed by drilling a 4-7/8 inch open hole to 1700 feet. Drilling operations are summarized on Figure 5-4.

5.9 OBSERVATION WELL C CONSTRUCTION

Observation Well C is located 500 feet northwest of the Production Test Well (Figure 5-1). Two rigs, a Failing 1500 and a Failing Jed A, were utilized in the construction of the well.

Drilling began on February 2, 1974. Initially, a 21-inch hole was drilled to a depth of 242 feet. At this depth, 14-inch OD casing was installed and cemented to ground surface. From 242 feet to 1122 feet, a 13-inch hole was drilled and 8-5/8 inch casing installed from ground surface to 1122 feet and cemented to ground surface. A 7-7/8 inch hole was drilled from 1122 feet and 5-1/2 inch casing was installed from ground surface to 1535 feet. This was followed by cementing the annulus from 1360 feet to 1535 feet. The well was completed by drilling a 4-7/8 inch open hole to 1700 feet. Drilling operations are summarized on Figure 5-5.

5.10 OBSERVATION WELL D CONSTRUCTION

Observation Well D is located on Key Largo approximately 45,000 feet southeast of the Production Test Well (Figure 5-1). A Failing Jed A was utilized to drill the well.

From ground surface to a depth of 241 feet, a 23-inch hole was drilled for installation of 14-inch casing. This casing was installed to 241 feet and cemented to ground surface. A 13-1/2 inch hole was drilled to 1050 feet for installation of 8-5/8 inch casing. Despite careful hole conditioning prior to casing installation, squeezing and drag apparently from the Hawthorn silty clays caused the casing to become stuck with only 760 feet of the 8-5/8 inch casing in the hole. Continued efforts to dislodge the casing were futile.

The casing was set at 760 feet and cemented to ground surface. In order to completely seal the zone from 760 feet to 1070 feet, 341 feet of 7-inch casing was installed in the well from 729 feet to 1070 feet; thereby providing an overlap of 31 feet between the 7-inch and the 8-5/8 inch casing. This annular space was then cemented providing a completely cemented section from ground surface to 1070 feet.

A 6-1/8 inch hole was drilled to 1450 feet and 5-1/2 inch casing was installed to that depth. The subsequent cementing operation was unsuccessful, even though standard procedures were followed and no apparent malfunctions occurred during the pumping of the cement. Subsequent inspection

showed that all of the cement had remained inside of the 5-1/2 inch casing. During an effort to drill the cement out of the casing, the drill pipe was broken off and left in the casing. The entire string of 5-1/2 inch casing had to be removed from the well. New 5-1/2 inch casing was installed from ground surface to 1450 feet and cemented from 1400 feet to 1450 feet. The well was completed with the drilling of a 4-7/8 inch open hole to 1727 feet. Drilling operations are summarized on Figure 5-6.

6.0 GEOPHYSICAL LOGGING

6.1 INTRODUCTION

Geophysical well logging may be loosely defined as including all techniques of lowering a sensing device into a well to make a record that can be interpreted in terms of rock characteristics, nature of contained fluids, and well construction. No single type of geophysical log gives a complete picture of rock-aquifer characteristics. However, information from several common logging tools can be combined and used to evaluate geologic and hydrologic conditions that are present in the subsurface and also the condition of the completed well. Various combined parameters applicable to each log must be considered in conjunction with standard interpretation techniques so that a qualitative and/or quantitative assessment can be made.

Data obtained from the geophysical logs run by Schlumberger Well Logging Service, and Dames & Moore during this investigation were used in conjunction with lithologic logs to assist in correlation of geologic formations between wells, to provide data for evaluation of well completion methods, and in certain cases to obtain qualitative hydrologic information about the subsurface lithic material. A listing of individual logs run on each well is given in Figures 5-2 through 5-6.

The phrase, "Production Test Well Area", is used in this report to present or discuss data obtained from a combination of the Production Test Well, Observation Well A,

Observation Well B, and Observation Well C. The term indicates that data obtained from these particular wells are similar or that the data have been adjusted to reflect an average for the area.

6.2 ELECTRIC LOGS

In electrical logging, measurements are made in an uncased hole filled with drilling mud. A system of electrodes (known as a sonde) is lowered into the hole on a multiconductor cable, and the readings are recorded on film or by other means. During this study, two types of electric logs were run: spontaneous-potential and resistivity.

6.2.1 Spontaneous-Potential Log

The Spontaneous-Potential (usually called SP) log records the difference between the potential of a surface electrode and of a moving electrode in the hole. In general, the SP log is used (in conjunction with other logs) to locate permeable formations, define their boundaries, aid in correlation, and to determine the resistivity of formation waters.

The SP logs run for wells during this investigation showed little deflection, and were relatively featureless. This was probably due to two factors: (1) the similarity of sediment type in the carbonate section of the Floridan aquifer, and (2) the similarity of the mud filtrate and formation water. The resistivities of water in the bore hole and in the surrounding formation are about equal, indicating a chemical similarity of the two waters thereby at least partially accounting for the lack of difference in potential. An SP log that shows little deflection has relatively little value in locating permeable formations or in stratigraphic correlation.

6.2.2 Resistivity Log

The resistivity of a substance, in this case sedimentary rock, is its ability to impede the flow of electric current through that substance. In conventional resistivity logs, currents are passed through the formation via certain electrodes, and voltages are measured within certain others. These measured voltages provide the resistivity determinations. The logging probe must be run in holes containing electrically conductive mud or water so that there will be a current path between electrodes and the formation.

Electrical conductivity of a substance is the reciprocal of resistivity; that is, if resistivity is high, conductivity is low. In general, the higher the concentration of salts in the water, the higher the conductivity and the lower the resistivity.

The resistivity logs for the Production Test Well area indicated that the interval with the highest and most varied resistivity occurs between 1100 and 1400 feet. This would tend to suggest that the lithology is varied and the formational waters are relatively fresh. Below 1400 feet, the resistivity gradually decreased with depth indicating a corresponding increase in salinity of the water.

Examination of the resistivity logs taken at Observation Well D on Key Largo showed that the same trend was present. However, the interval of the highest resistivity was from 1050 to 1140 feet, with a steady decrease with depth below this interval.

6.3 GAMMA RAY LOG

The gamma ray log can be recorded in cased wells, which makes it very useful for correlation purposes. The log indicates the natural radioactivity of the sediments penetrated by the well. In general, radioactive elements tend to be concentrated in shales and clays. Sedimentary rocks such as limestone usually have a very low level of radioactivity and a corresponding increase in the gamma ray curve value. For this study, gamma ray logs were used primarily in conjunction with lithologic samples for the purpose of correlating subsurface geology between wells.

In each of the wells, the gamma ray logs indicated that from ground surface to approximately 1400 feet the changes in lithology were more numerous than at greater depths. The upper 1400 feet consist principally of clays, claystone, siltstone, and limestones with some sand. Below 1400 feet, the gamma ray logs consistently measured decreasing amounts of natural radioactivity with depth. This suggests that the lithology, in this case limestone, remains relatively constant, to a depth of at least 2300 feet.

6.4 CEMENT BOND LOG

A cement bond log is designed to show how effectively the cement grouting has bonded to the casing. This log indicates the quality of the seal between the casing and the bore hole, and the thickness of the seal. The cement bond log is based on the principle that the amplitude of the acoustic signal travelling along the casing is greatly reduced where the cement is well bonded to the pipe. A signal of constant strength is transmitted and a continuous recording of the return signal versus depth is made at the receiver.

Each of the five wells contain casing strings extending from the ground surface to approximately 1100 feet. Information from the cement bond logs indicated that in each of the wells the cement bond was adequate to prevent the vertical migration of deeper saline waters. In each observation well where casing extends to approximately 1500 feet and/or 2100 feet, the cement bond log indicated that a substantial grout-to-casing bond was present. The possibility of contamination of isolated flow zones, therefore, by vertical migration of saline water is very remote with good cement bonding.

6.5 SONIC LOG

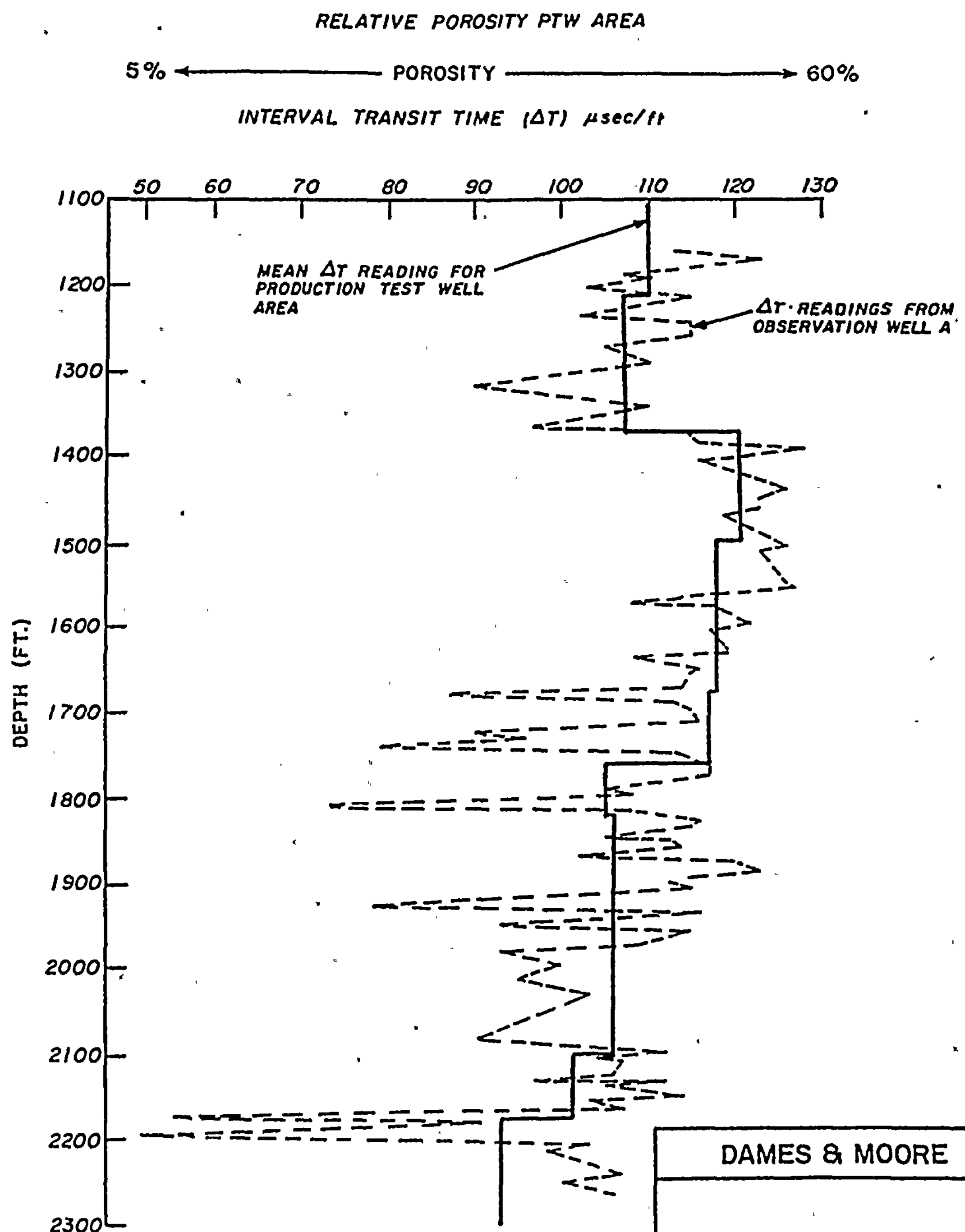
The sonic log records the depth versus the time required for a compressional sound wave to travel through one foot of rock along the bore hole. This length of time,

called interval transit time (ΔT), is the reciprocal of the velocity of the compressional sound wave (Schlumberger, 1972b, p. 32). The interval transit time for a given formation depends upon its lithology and porosity. Where the lithology is known, as from well cuttings, data from the sonic log may be useful in evaluating formation porosity.

Figure 6-1 presents information about the relative porosities of material on OW-A (dashed line) and mean values for the Production Test Well Area (solid line). Interval transit times (ΔT) taken from the sonic logs are plotted versus depth. Using charts from Schlumberger (1972a) together with lithologic information determined from well cuttings, qualitative interpretations of porosity values for the subsurface material at the indicated depths were made. Porosities calculated range from as high as 50 percent near the top of the section to less than 10% at the base. The mean ΔT readings for the Production Test Well area show a porosity on the order of 40% for the major part of the section. A trend of decreasing porosity with depth can also be observed. Because the sonic log tends to ignore such things as secondary porosity and since shale and/or fractures complicate the response, the information presented should be judged as qualitative and values taken to represent only an estimate.

6.6 CALIPER LOGS

The caliper log is a highly sensitive device which measures the diameter of the drill hole. This log is nor-



DAMES & MOORE

RELATIVE POROSITIES AT THE PRODUCTION TEST WELL AREA

6-22-75 FIGURE 6-1

mally the initial tool used in the hole because it provides data useful in casing installation and in determining required cement volumes. The caliper log may be used in conjunction with the flowmeter to determine quantitative flow measurements.

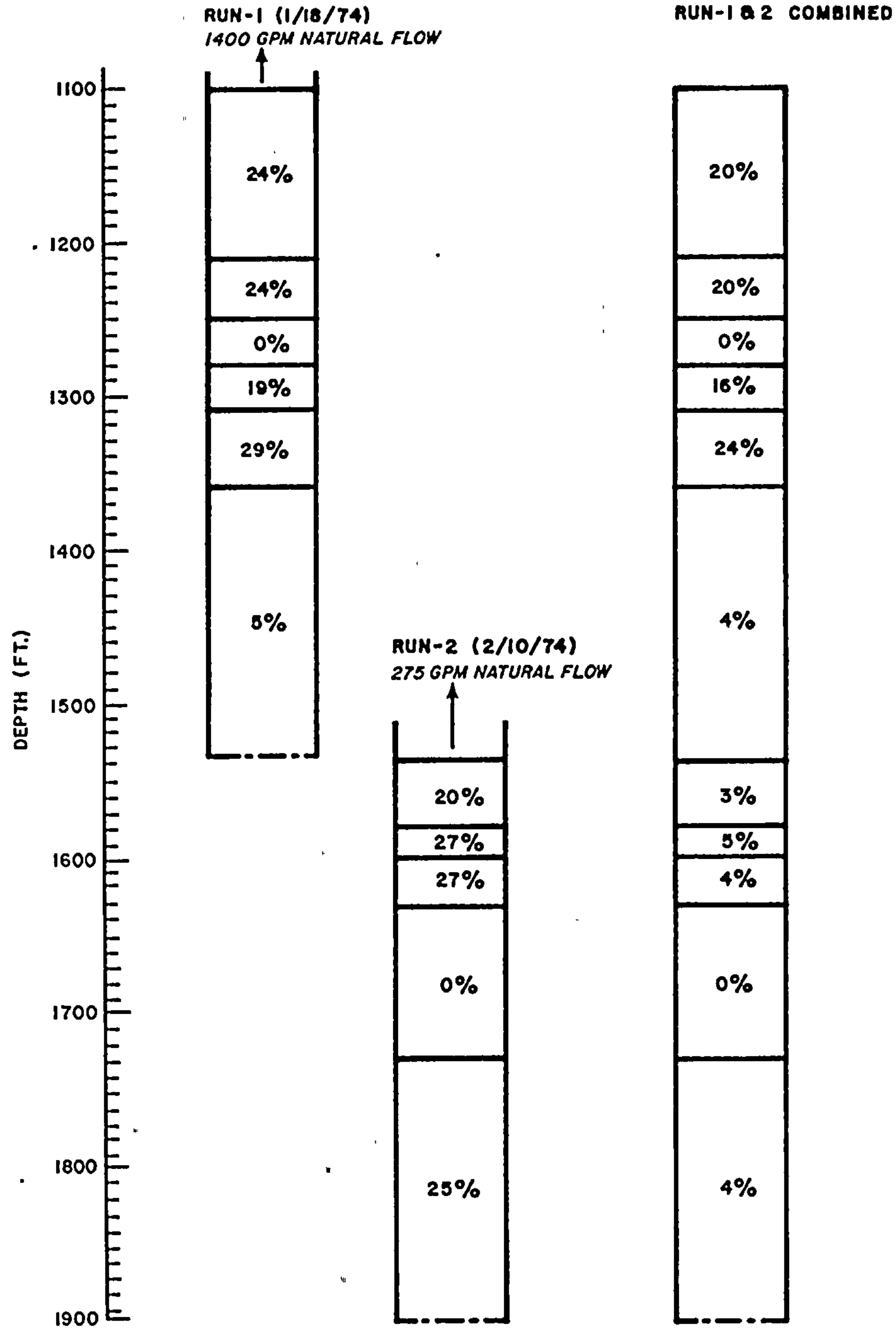
In all observation wells the greatest increase in hole size, as compared to the original size of the drilling bit, occurred from 1000 feet to approximately 1500 feet. The increase in hole diameter ranged from two to six inches. Below 1500 feet, the caliper log indicated that the hole diameter remained close to the drill bit diameter.

Significant increases in hole diameters suggest that the limestone between 1000 and 1500 feet may be more porous and possibly less cemented than overlying or underlying material. Hole sizes remaining relatively constant with bit sizes suggest a somewhat more consolidated rock material.

6.7 FLOWMETER LOG

The flowmeter log provides information on the stratigraphic origin of artesian flow in the well. The rate of water flow at a particular depth or depth interval is recorded in terms of revolutions per second (rps) of the spinner on the probe.

Figure 6-2 is a generalized presentation of the flowmeter data collected for Observation Well A. Two separate logging runs were made in this well, both in uncased hole and both under conditions of natural artesian flow. The



FLOW PERCENTAGE FOR INDIVIDUAL DEPTH INTERVALS CALCULATED UNDER NATURAL FLOW CONDITIONS AND NOT ADJUSTED FOR DENSITY CHANGES.

DAMES & MOORE

APPROXIMATE PERCENTAGE OF TOTAL ARTESIAN FLOW AT VARIOUS DEPTHS IN OBSERVATION WELL A

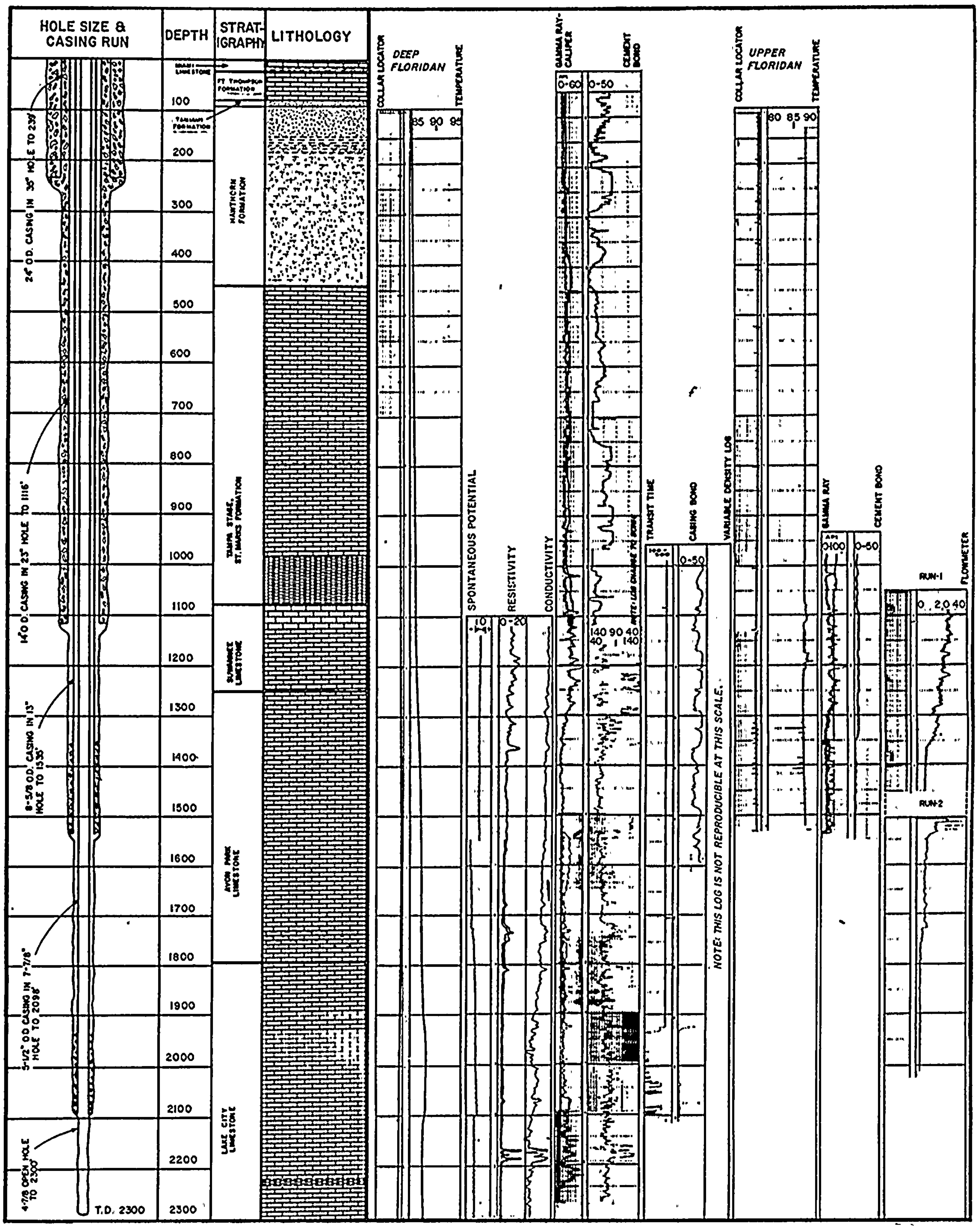
6-22-75 FIGURE 6-2

first log was made from depths between about 1100 and 1535 feet below land surface. The flowmeter reading at the base of the installed casing indicated a total natural flow of about 1400 gallons per minute. The percentage of flow from various intervals is graphically shown under Run #1.

Following installation of 8-5/8 inch OD casing to 1535 feet, a 7-7/8 inch hole was drilled to about 2100 feet. A second flowmeter log was made between depths of about 1530 feet and 1900 feet below ground surface. The flowmeter indicated a total natural flow of about 275 gallons per minute from the second test interval. The percentage of this flow from various depths is shown under Run #2.

Results from Run #1 and #2 are combined in Figure 6-2 to show a qualitative picture of artesian flow contribution from various zones within the Floridan aquifer at the Turkey Point area. Because of such uncertainties as tool position in the hole, variable head and density relationships in the water column and the effects of changes in hole size, the data from particular depths or intervals should not be considered as strictly quantitative. It does appear, however, that a major portion of the artesian flow is derived from the 250 foot interval between 1100 and 1350 feet below ground surface.

The flowmeter log together with other well construction and geophysical logs for Observation Well A are presented in Figure 6-3.



LEGEND

- LIMESTONE
- SAND
- CLAY
- CLAYSTONE / SILTSTONE

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SUMMARY OF DRILLING AND LOGGING OPERATIONS FOR OBSERVATION WELL A

6-22-75 FIGURE 6-3

6.8 TEMPERATURE LOG

The temperature log provides a continuous recording of water temperature versus depth. During the study, the temperature log was run in Observation Well A. Well construction was complete with the well being cased from ground surface to 2100 feet. Water temperature in OW-A increases from 79.5°F. at the ground surface to 82.5°F. at 1900 feet. From 1900 to 2110 feet the temperature increases to 83.5°F. and remains constant below this level down to 2300 feet.

6.9 COLLAR LOCATOR LOG

The collar locator log can provide information regarding the effects of corrosion upon casing, along with providing depth measurements where each section of casing has been welded.

This tool provides baseline data regarding the quality of casing in the well and can be compared with future logs to determine corrosion rates with time.

6.10 GRADIOMANOMETER LOG

The gradiomanometer log is utilized to determine fluid interfaces within a well. This is accomplished by measuring pressure gradient changes of the fluid versus depth.

This log was run on Observation Well A. It was noticed, however, that as the tool was being run in the well it was malfunctioning. Attempts to repair the tool on site failed; consequently, no reliable data were obtained from this log.

7.0 GEOLOGY

7.1 INTRODUCTION

A discussion of the surface and subsurface geologic formations encountered during the drilling program is presented in this section to provide a background for the hydrologic investigation presented in Section 8.0. Particular attention is given to the methods of study and correlations and to the lithic characteristics of the individual formations in the vicinity of the Turkey Point area. A more generalized and regional geologic setting is discussed in connection with the regional ground-water hydrology of the Floridan aquifer in Section 8.0.

The geologic formations studied during this investigation range in age from middle Eocene to Holocene. Permeable rocks of the Eocene Lake City and Avon Park Limestones and the overlying Oligocene Suwannee Limestone comprise the principal artesian water-bearing zone of the Floridan aquifer in the Turkey Point area. The near surface Biscayne aquifer is composed of highly permeable rocks within the Fort Thompson Formation and the Miami and Key Largo Limestones. The less permeable limestones, clays, silts, claystones, and siltstones within the Miocene St. Marks and Hawthorn Formations yield minimal amounts of water and act as confining beds separating the two major aquifers.

7.2 ANALYTICAL METHODS

Wash cuttings, rock cores and geophysical logs were the

main sources of information utilized to interpret the local geology within the study area. Wash cuttings were collected every ten feet, examined and described as to lithologic composition, and placed in labeled bags for future reference. One complete set of wash cuttings was furnished to the Florida Bureau of Geology for their examination. Rock core samples were also taken at intervals from the Hawthorn Formation to the Lake City Limestone.

Geophysical logs of the wells, particularly the gamma ray logs, were used in conjunction with cuttings and cores to identify the positions of lithologic changes and formational contacts.

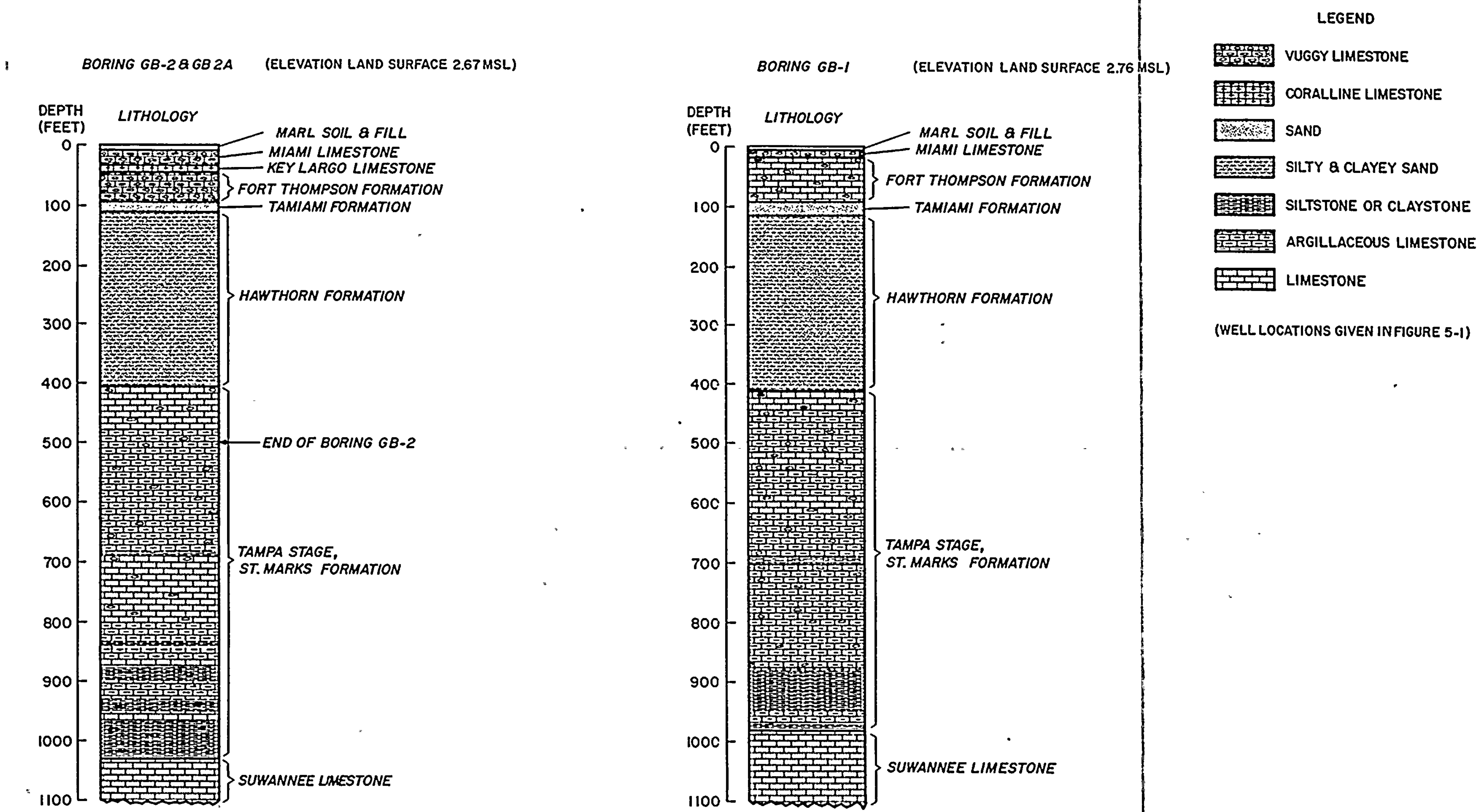
The geologic data obtained during the drilling of the wells in this program were originally analyzed and correlated with the Research Test Well data and other well information in the area. The Research Test Well served, because of its proximity and extensive testing data base, as a primary basis for interpretation and correlation of the newly acquired data. Formational contacts and lithologic changes were defined in the Research Test Well utilizing lithologic, geophysical and paleontologic data. The establishment of the correlation of the five new wells with the Research Test Well provided a relatively complete geologic section extending from Key Largo to the Production Test Well.

Subsequent to the completion of the subsurface geologic investigation for this project, additional geologic data

were generated from detailed studies of two deep core borings (greater than 1000 feet) and nine medium depth core borings (from 150 to 300 feet deep) drilled near the Production Test Well area in conjunction with PSAR studies for the FP&L Company's proposed South Dade site. Boring GB-1 was drilled 7.1 miles NNE of the Production Test Well, whereas GB-2 and GB-2A were drilled 1.7 miles east of Production Test Well (Figure 5-1). Their logs are shown on Figure 7-1.

Borings GB-1 and GB-2, 2A were continuously cored to a depth approximately 30 feet into the Suwannee Limestone. Borings GB-2 and 2A are located 10 feet apart and, for the purposes of this study, are considered one boring. Additional geologic and engineering borings were drilled approximately 3 to 4 miles east of the Production Test Well area. This new information, although part of a separate study, has been incorporated within this report because of its close proximity to the Production Test Well area, and its provision of extensive core data. These additional data have been utilized to reclassify the lithologies where required, and in general supplement the data collected during this study. Analysis of these cores enabled more accurate definition of the formations and their corresponding boundaries. The lithologic descriptions and formational contact elevations provided are the result of analysis of all the assimilated data.

Gamma ray geophysical logs were also obtained from these new boring locations. When the analysis of the logs



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STRATIGRAPHIC COLUMNS FOR BORINGS GB-1, GB-2 AND GB-2A

DATE: 5-9-75

FIGURE 7-1

and cores was complete, a more direct relationship between the gamma ray activity and the core samples was established. To check previous information and for better direct correlation, all the observation wells and the Research Test Well were logged again in detail with the same geophysical equipment.

Correlation of new information with the previously existing data was then performed and, where appropriate, some refinements of formational boundaries and lithologies were made. The adjustments of data that are reflected in this report include: minor changes in boundaries and revised lithologic descriptions of the Miocene and Pleistocene formations. Confirmation of the presence of the Key Largo Limestone within the study area was also made. These changes are discussed, as appropriate, under Lithostratigraphy.

7.3 STRATIGRAPHIC CORRELATION

Correlation is essentially the logical extrapolation of geologic formations from outside areas (described by previous studies) to the well site being studied, based on similarity of lithology, paleontology, geophysical logs, and other data. In areas where lithologic difference between formations tend to be minimal, paleontological differences, for example, may be helpful in identifying the depths and boundaries of the formations. Correlation of such formations from one area to another can be done based on the occurrence of similar index fossils or fossil assemblages at both locations.

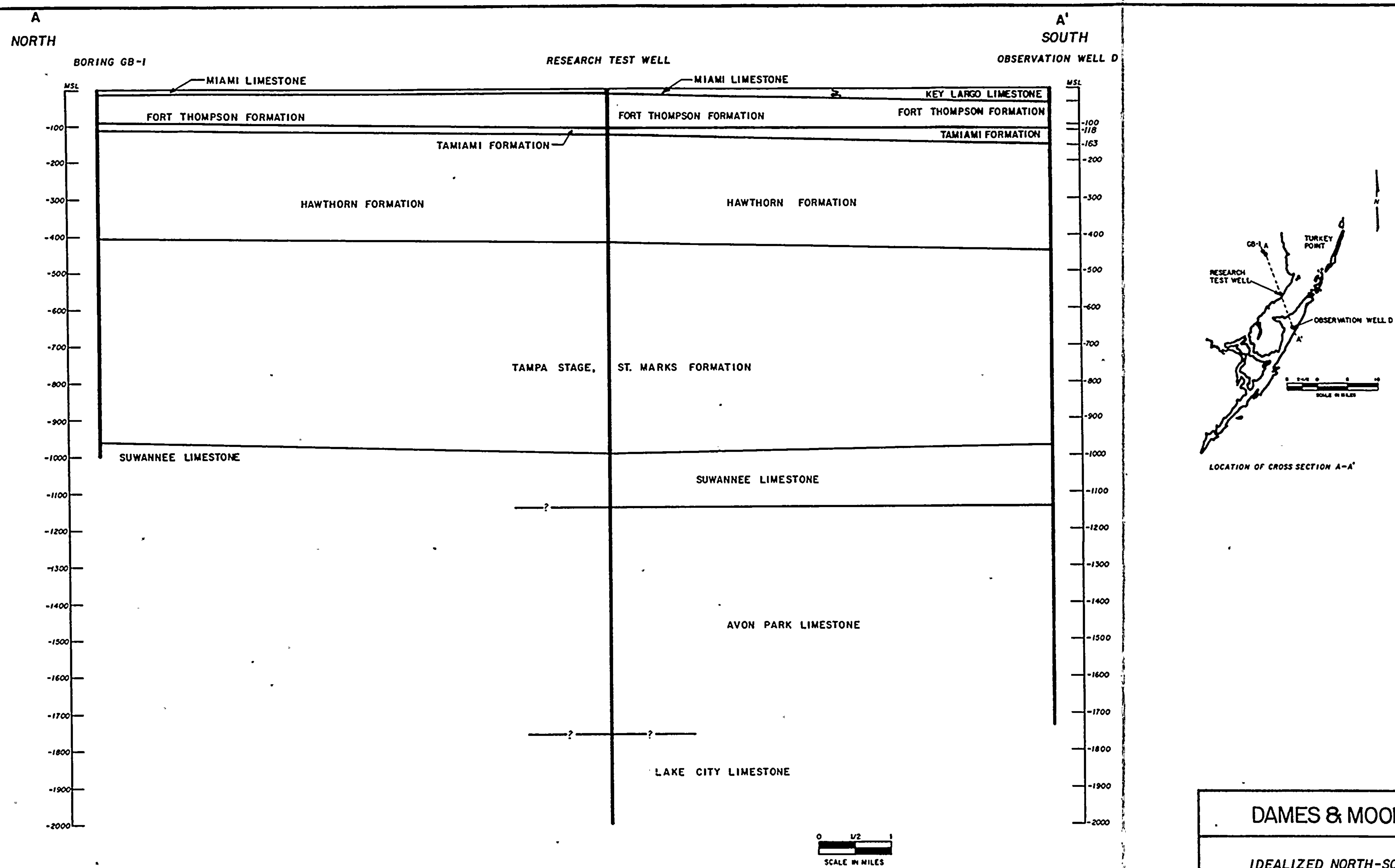
Vertical differentiation and lateral correlation may also be accomplished, in some instances, by the use of gamma ray logs and other logging techniques. Correlation of gamma ray activity, for example, with a particular formation or formational contact may be accomplished by comparison of core samples or cuttings from a well with its gamma ray log. Once this gamma ray-lithologic correlation is established, other gamma ray logs or other wells in the area may then be used to identify particular formations or formational contacts. Gamma ray logs, as compared to many other geophysical logs, are most useful in subsurface correlation because gamma ray activity can be measured in a cased hole and the variables affecting such measurements are generally negligible. A major advantage is that older cased wells, never logged when drilled, may now be gamma ray logged and utilized for correlation. However, gamma ray correlation of the upper 150 feet of the Production Test Well area borings and the Research Test Well was not possible due to the presence of several strings of casing which decreased the signal/noise ratio. Deeper strata provided excellent data and correlation.

Present correlations of formations encountered in the Production Test Well and Observation Wells with the formations encountered in the Research Test Well and in the GB and EB core borings were primarily based on lithology and gamma ray logs.

The general geology of the Turkey Point area is shown in Figures 7-2 and 7-3. The exact depth of the contacts and thicknesses of the Miami Limestone, Key Largo Limestone, Fort Thompson Formation, Tamiami Formation and the Hawthorn Formation were difficult to determine precisely during well completion by analysis of the rotary wash cuttings. However, correlation of gamma ray activity associated with the St. Marks Formation, Suwannee Limestone and to some extent the Avon Park Limestone was distinct, and thereby permitted good verification of the boundaries of these formations throughout the study area. The formational boundaries are generally planar across this site with slight undulations and dip seaward with slopes of a few feet per mile. This dip is common throughout the southeastern United States and is due to normal sedimentary depositional processes and not to tectonic activity or other structural deformation.

7.4 LITHOSTRATIGRAPHY

The formations penetrated during the drilling phase of this study range in age from Eocene to Holocene. In ascending order, the formations encountered are: the Lake City Limestone and the Avon Park Limestone of Eocene age; the Suwannee Limestone of Oligocene age; the St. Marks Formation, Hawthorn Formation and Tamiami Formation of Miocene age; and the Fort Thompson Formation, Key Largo Limestone, and Miami Limestone of Pleistocene age. In addition, surficial marl soil deposits of Holocene (or

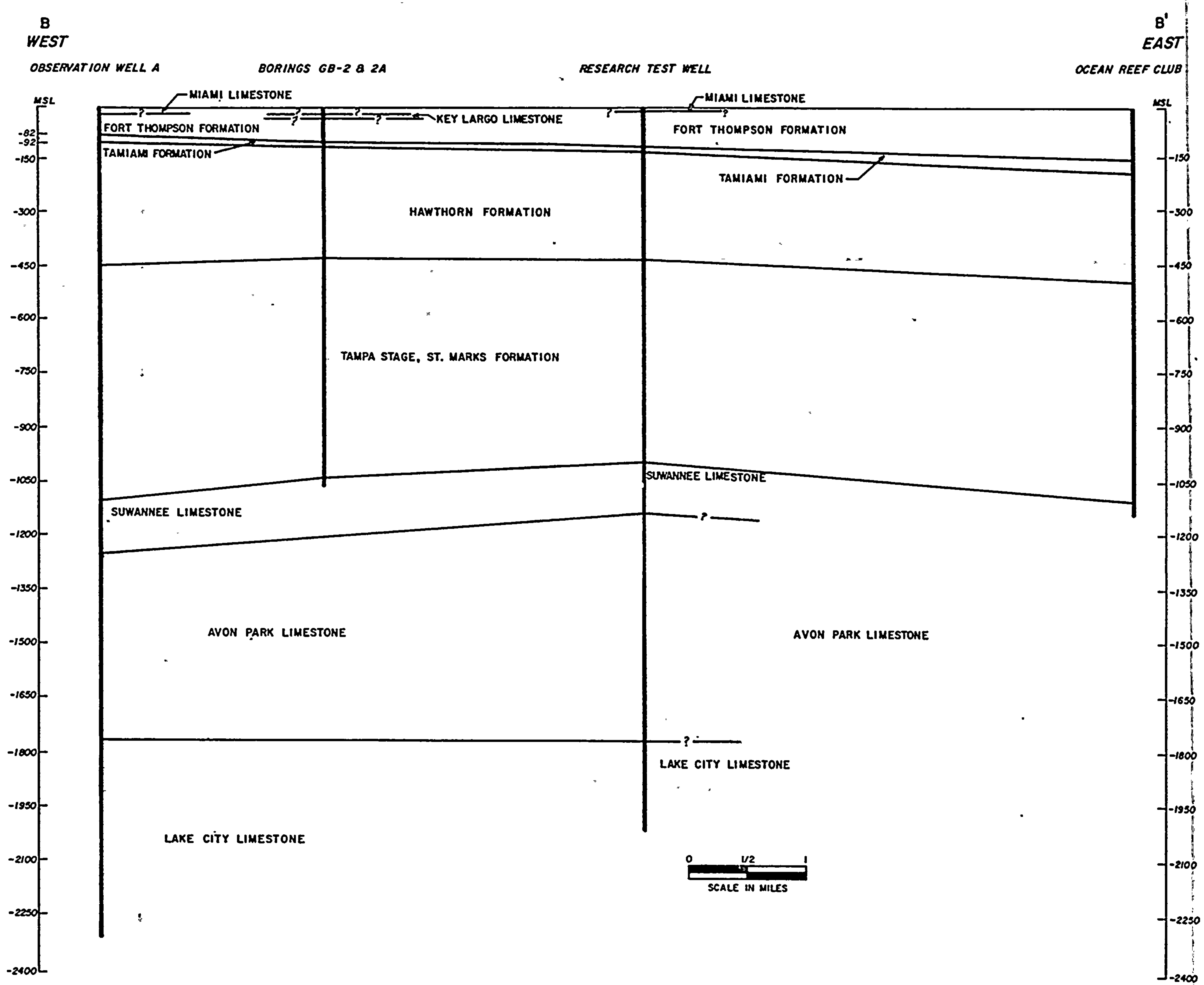


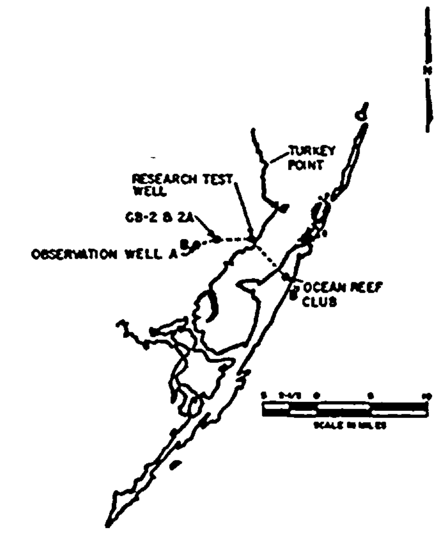
DAMES & MOORE

IDEALIZED NORTH-SOUTH CROSS SECTION OF GENERAL SITE VICINITY

DATE: 5-9-75

FIGURE 7-2





LOCATION OF CROSS SECTION B-B'

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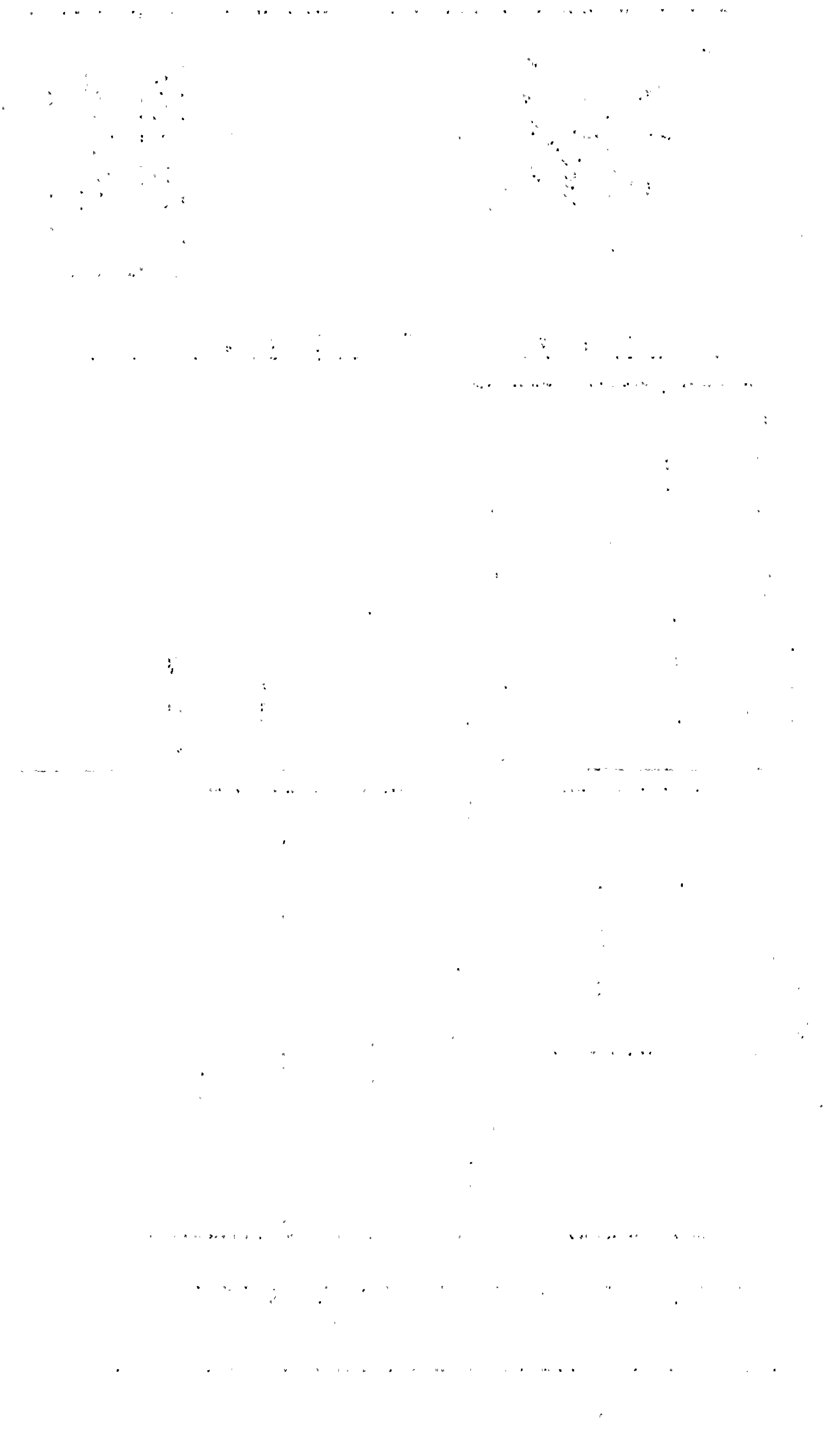
IDEALIZED WEST-EAST CROSS SECTION OF GENERAL SITE VICINITY

DATE: 5-9-75

FIGURE 7-3



recent) age are present in the study area. Stratigraphic columns for each well are presented on Figures 5-2, 5-3, 5-4, 5-5, 5-6. Figure 7-1 presents the stratigraphy of Borings GB-1, GB-2 and GB-2A. Lithologic logs are presented in Appendix A.

7.4.1 Lake City Limestone

The Lake City Limestone is the oldest geologic formation penetrated during the drilling of the six deep wells at the site. The top of this formation was penetrated by the Research Test Well and Observation Well A; however, the base was not encountered by either well.

The Lake City Limestone is overlain conformably by the Avon Park Limestone; consequently, the exact location of the formation top is difficult to determine. Based on correlations of gamma ray logs from Observation Well A and Research Test Well, the top of the Lake City Limestone is at a depth of about 1760 feet below ground surface.

The lithologic characteristics of the Lake City Limestone are similar to those of the overlying Avon Park Limestone. The formation consists of limestone which ranges in color from buff to brown, is abundantly to sparsely fossiliferous, porous and vuggy, but occasionally consolidated and dense.

7.4.2 Avon Park Limestone

Chen (1965, Page 59) describes the lithology of the Avon Park as consisting mainly of fossiliferous limestone

and dolomite with a very small amount of evaporite. The Avon Park in the study area consists entirely of limestone and is overlain by the Suwannee Limestone of Oligocene age.

The Avon Park is very similar in lithology to the overlying Suwannee Limestone. On the basis of lithology alone, the contact of these formations is difficult to determine. The Avon Park is, however, distinguished from the Suwannee by fossil content, with the Avon Park being the more fossiliferous. The top of the Avon Park occurs in the study area at respective depths of about 1255 feet, 1150 feet, and 1150 feet in Observation Well A, Research Test Well, and Observation Well D, respectively. The base of the Avon Park, coincident with the top of the Lake City Limestone, is at respective depths of about 1760 feet and 1770 feet in Observation Well A and Research Test Well. The thickness of the Avon Park Limestone ranges from about 505 feet in Observation Well A to about 620 feet in the Research Test Well.

At the site, the Avon Park is composed of limestone that is white to brown and sparsely to highly fossiliferous. The formation is highly vugular and very porous as determined with the aid of geophysical logs.

7.4.3 Suwannee Limestone

The depth to the top of the Suwannee Limestone has been a matter of question in the study area. Disagreements among various workers exist in placement of the formation top in

wells previously drilled in this area because of lithologic and paleontologic similarities. Meyer (1971) places the top of the Suwannee Limestone at a depth of approximately 970 feet in Well NP-100 in the Everglades National Park (Figure 5-1). The top of this formation was placed by Meyer (1971) at a depth of approximately 760 feet in Well G-1273 in Pennekamp State Park, Key Largo. Included within the Suwannee Limestone in these wells are several claystone/siltstone zones of varying thickness. Dames & Moore, in consultation with Puri (1972), placed the top of the Suwannee Limestone at 1038 feet in the Research Test Well and, in doing so, excluded the above mentioned claystone/siltstone zones from the Suwannee by placing them in the overlying St. Marks Formation of Miocene age. The same method for delineation is followed in this report i.e., the top of the Suwannee is considered to be at the base of the lowest claystone/siltstone in the St. Marks Formation. However, gamma ray data obtained subsequently from the Research Test Well during the PSAR studies show this contact to occur at a depth of 995 feet.

The Suwannee Limestone, as defined here, consists entirely of limestone. The limestone is light brown to light gray, fine to medium grained. It is generally well cemented and fossiliferous.

During the present study, the top of the Suwannee Limestone was found at depths of 1098, 995 and 986 feet, respectively, in Observation Well A, Research Test Well, and

Observation Well D. Thus, in these wells, the thickness of the formation varies from 157 feet, to 155 feet, to 164 feet respectively.

7.4.4 Tampa Stage, St. Marks Formation

Within the study area, the St. Marks Formation was thought to consist of alternating limestone and clays. Subsequent analysis of core samples obtained from this formation in borings GB-1 and GB-2A indicate that the so-called clay zones have textured characteristics more similar to a siltstone and/or claystone.

This material was initially logged as clay by Dames & Moore personnel based on the appearance of the wash cuttings obtained during drilling with a roller-cone drill bit. The cuttings that are brought to the surface resemble a clay/silt. Core samples, however, have shown that the material is not clay/silt but consolidated rock material. The close similarity of the cored material in GB-1 and GB-2, which are about seven miles apart, indicates continuity of this particular lithic material throughout the vicinity of the Turkey Point area. This is supported by the similarity of gamma ray log patterns in the various observation wells.

The St. Marks Formation, Tampa Stage occurs in Observation Well A from a depth of 446 feet to a depth of approximately 1098 feet below ground surface. The St. Marks is present at the Research Test Well between depths of 428 and 995 feet. At Observation Well D this formation occurs at depths of 437 to 986 feet.

At the Production Test Well area, (vicinity of PTW, OW-A, OW-B, and OW-C; Figure 5-1) and at Observation Well D, the St. Marks Formation generally can be segregated into two lithologic types. The upper part is predominantly limestone. The limestone is light gray to light olive gray and generally well cemented. Fossil content is variable and consists mainly of large shell fragments. The limestone is essentially nonvuggy; however, there are scattered zones in which the occurrence of vugs varies from a trace to moderate amounts. The second, lower part consists dominantly of alternating beds of limestones and claystone/siltstone. The limestone strata are generally more argillaceous than those in the upper portion. The claystone/siltstone strata are commonly pale green to light greenish gray. This material is generally indurated and cemented. The occurrence of fossils and vugs is similar to that of the limestone.

7.4.5 Hawthorn Formation

Throughout the study area, the Hawthorn Formation consists almost entirely of clayey and silty sands. The sands are typically olive green, but local zones of light gray to gray sands do occur. Occasional zones containing cemented sand fragments are also present. Locally the formation contains small grains of phosphate.

The sands of the Hawthorn Formation tend to be more argillaceous (clayey) with depth. The formation generally contains some shell fragments, though rarely in any quantity.

The top of the Hawthorn Formation in the study area occurs at depths of approximately 95 feet, 135 feet and 175 feet in Observation Well A, Research Test Well and Observation Well D, respectively. The base of the formation is coincident with the top of the St. Marks Formation. Thus, the thickness of the Hawthorn Formation at the three respective locations is about 351 feet, 293 feet and 262 feet.

7.4.6 Tamiami Formation

The lithic description of the Tamiami Formation has been revised since the Research Test Well report was written (1972). As presented in the earlier report (Dames & Moore, 1972), the Tamiami Formation consisted of limestone grading to sand. This interpretation was based mostly on well cuttings. It has now been determined, based on core information, that the Tamiami Formation in the Turkey Point area consists almost entirely of a tan to gray, medium dense to dense unconsolidated, fine grain quartz sand which is occasionally cemented forming a calcareous sandstone. The Tamiami has an average thickness of 10 to 20 feet and generally occurs between 85 and 115 feet below ground surface.

7.4.7 Fort Thompson Formation

The Fort Thompson Formation consists of limestone that is light gray to white, fine to medium grained and moderately to abundantly fossiliferous, particularly in the lower portion. Vugs within the medium to massively bedded limestone are abundant in certain zones. The formation is usually moderately to well cemented and extends from about 35 feet to 90 feet below ground surface in the Production Test Well area (Figure 5-1).

7.4.8 Miami Limestone

The Miami Limestone is generally a white to light brown poorly to moderately well cemented rock with occasional oolites. It is abundantly vuggy. Minor surface weathering is also recognized throughout the upper portion of formation.

The Miami Limestone at the Production Test Well area occurs between depths of approximately 7 and 20 feet. At the Research Test Well, it is present in the interval from approximately 10 to 20 feet.

7.4.9 Key Largo Limestone

It was originally thought that the Key Largo Limestone was not present within the Production Test Well area. However, examination of core samples in Well GB-2, obtained subsequent to this study, confirms that this formation is present.

The Key Largo Limestone consists of tan to white coralline limestone, intermixed with gray to brown, fine to medium grained cemented reef detritus. Scattered vugs are also present. Due to the depositional environment associated with coral reef morphology, the depth and thickness of the formation vary. In general, this formation is between depths of approximately 20 and 35 feet below ground surface.

At Observation Well D, located on Key Largo, the formation is exposed at the surface.

7.4.10 Marl Soil

The marl soil is a soft, dark brown and black material containing silt, sand, clay and abundant organic debris. Surficial deposits span the area from Observation Well A to the Research Test Well. The thickness of this material varies with location. In the area of Observation Well A, where four wells are located, the marl soil ranges in thickness from 2 to 5 feet. At the Research Test Well, approximately 5 feet of marl soil was encountered. Marl soil deposits are not present at Observation Well D on Key Largo.

8.0 HYDROGEOLOGY

8.1 INTRODUCTION

Ground water in the Dade County area of southern Florida is present to some degree in each of the geologic formations discussed in the previous chapter. However, ground water that may be developed in sufficient quantity for large municipal, industrial, or irrigation supply is known to be available from only two sources: the shallow Biscayne water-table aquifer and the deeper Floridan artesian aquifer.

Water from the Biscayne is normally of good quality and relatively inexpensive to produce, whereas water from the Floridan is brackish to saline and the exploration, development, and production costs are high. Almost all of the fresh water used in Dade County, therefore, is produced from the Biscayne aquifer.

A third major hydrologic system, locally known as the Boulder Zone, is located within limestone or dolomite formations several hundreds of feet below the base of the Floridan aquifer. The Boulder Zone, which contains water of extremely high salinity, is not used for supply but is presently used for injection of treated waste water from treatment plants and industrial facilities in the Miami area.

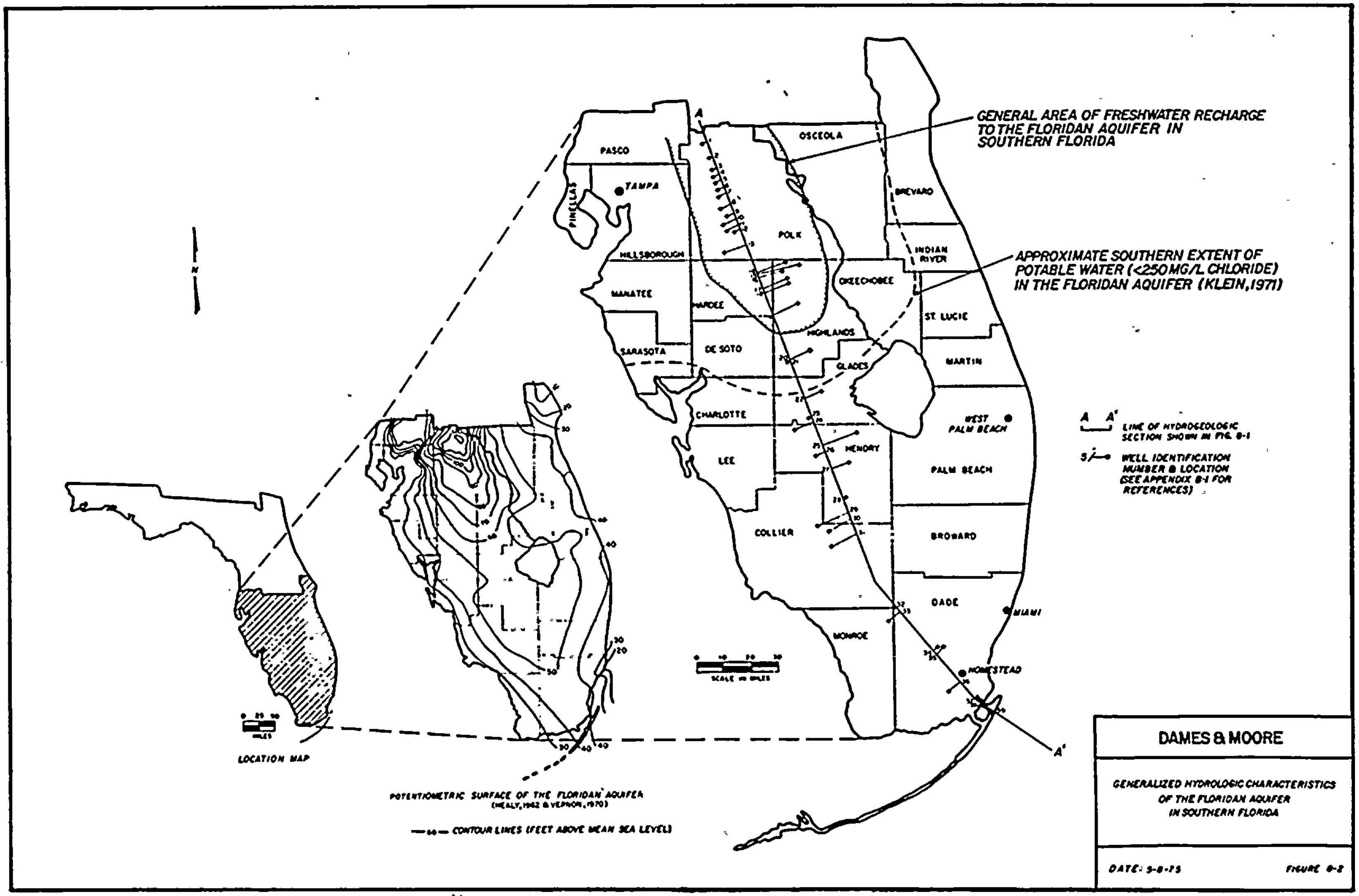
Previous studies in the Turkey Point area of Dade County by Dames & Moore (1972, 1973) for Florida Power & Light Company indicated that, for the purposes of a supplemental source of water supply for the Turkey Point cooling canal system, ground-water withdrawal from the Floridan aquifer was the most viable alternative. These recommendations were based on a number of geologic, hydrologic and economic considerations. It was a major purpose of the present investigation, therefore, to confirm these recommendations by additional field testing and analysis of the aquifer.

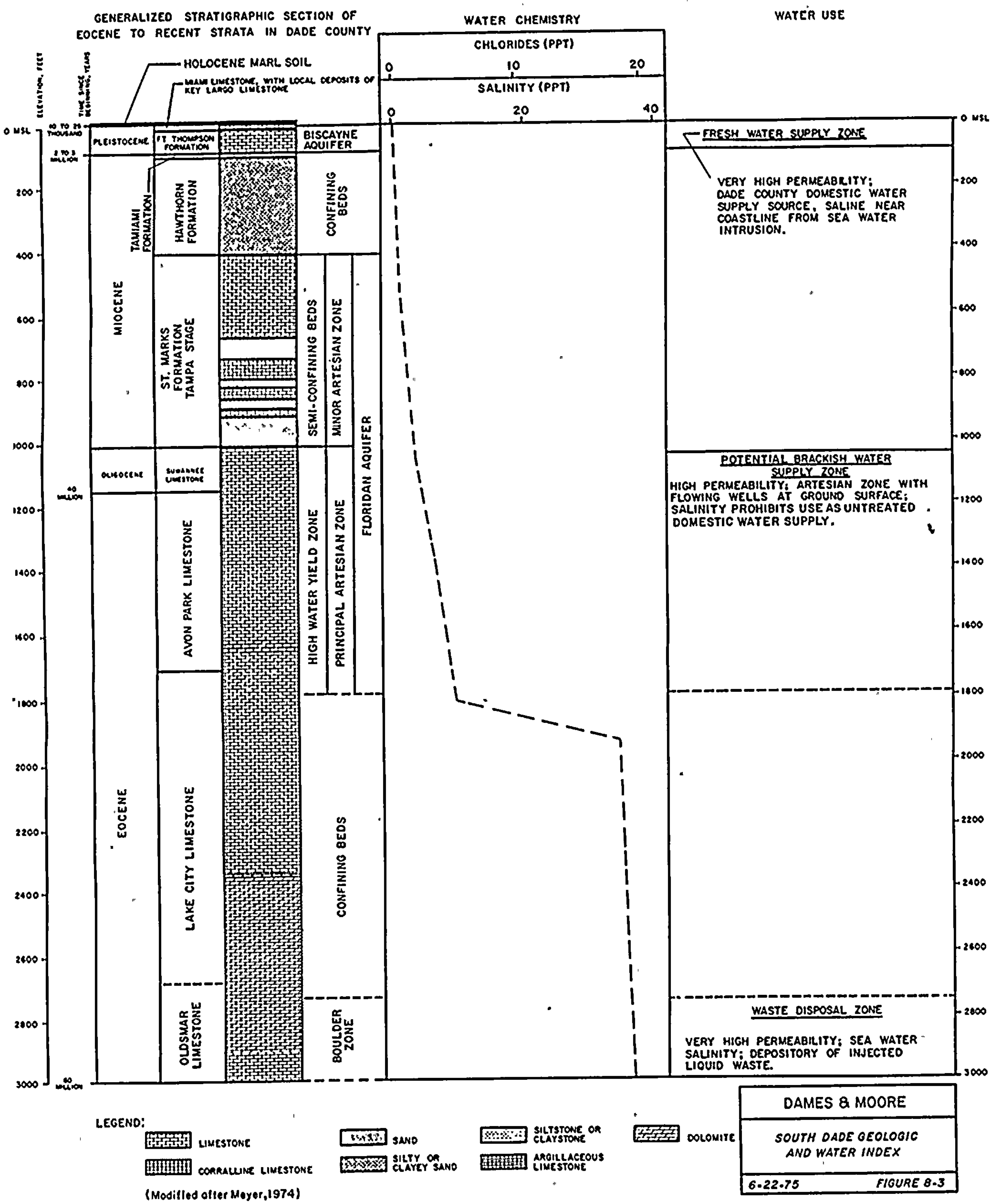
In the following sections, the Floridan aquifer is discussed in terms of regional, local and site characteristics. The aquifer testing program is described, and a computer simulation model, used for calculating the effects of ground-water withdrawals, is discussed.

8.2 REGIONAL

The regional hydrogeology of the Floridan aquifer, as presented in the following subsections, is based on an extensive search of the literature relating to the overall ground-water regime in southern Florida. Published information from a number of sources has been reviewed and schematically presented in Figures 8-1, 8-2, and 8-3. The purpose of this particular phase of the investigation was to provide an understanding of the physical framework of the Floridan from which certain assumptions required for aquifer evaluation in the Turkey Point area could be made.

Previous detailed studies of the Floridan aquifer have been concentrated in the areas of greatest use such as in the mining areas of Polk and Hillsborough Counties in


GENERAL AREA OF FRESHWATER RECHARGE TO THE FLORIDAN AQUIFER IN SOUTHERN FLORIDA
APPROXIMATE SOUTHERN EXTENT OF POTABLE WATER (<250 MG/L CHLORIDE) IN THE FLORIDAN AQUIFER (KLEIN, 1971)
PASCO
OSCEOLA
TAMPA
PINELLAS
HILLSBOROUGH
POLK
BREVARD
INDIAN RIVER
OKEECHOBEE
MANATEE
HARDEE
ST. LUCIE
HIGHLANDS
SARASOTA
DE SOTO
GLADES
MARTIN
CHARLOTTE
WEST PALM BEACH
LEE
HENDRY
PALM BEACH
COLLIER
BROWARD
DADE
MIAMI
MONROE
HOMESTEAD
A
A'
LINE OF HYDROGEOLOGIC SECTION SHOWN IN FIG. 8-1
WELL IDENTIFICATION NUMBER & LOCATION (SEE APPENDIX 8-1 FOR REFERENCES)
SCALE IN MILES
LOCATION MAP
POTENTIOMETRIC SURFACE OF THE FLORIDAN AQUIFER (HEALY, 1962 & VERNON, 1970)
CONTOUR LINES (FEET ABOVE MEAN SEA LEVEL)
DAMES & MOORE
GENERALIZED HYDROLOGIC CHARACTERISTICS OF THE FLORIDAN AQUIFER IN SOUTHERN FLORIDA
DATE: 5-8-75
FIGURE 8-2



DAMES & MOORE

SOUTH DADE GEOLOGIC AND WATER INDEX

6-22-75 *FIGURE 8-3*

central Florida and around large metropolitan areas such as Jacksonville in the north. Only a few investigations (Dames & Moore, 1972, 1973; Meyer, 1971, 1974; and Black, Crow and Eidsness, 1970, 1972) have dealt specifically with the Floridan aquifer in Dade County and the extreme southeastern part of the state. Therefore, most of the information presented in Figure 8-1 for the Floridan aquifer between Polk and Dade Counties represents an interpretation and extrapolation of data from less detailed, more regional studies throughout southern Florida.

The major hydrologic features shown on Figures 8-1, 8-2, and 8-3 are discussed in the following subsections.

8.2.1 Aquifers, Confining Beds and the Boulder Zone

In Dade County, ground water is available from two major aquifers: the Biscayne and the Floridan. These aquifers are composed of geologic formations that contain sufficient saturated permeable material to yield significant quantities of ground water to wells.

Biscayne Aquifer

The shallow Biscayne aquifer underlies eastern Dade County to depths ranging from about 70 to 100 feet. The aquifer, which becomes thinner to the northwest and eventually pinches out, is dominantly composed of sandy limestone and calcareous sandstone riddled with solution cavities that are generally filled with sand. Water in the aquifer is unconfined and is in direct contact vertically with the atmosphere through open spaces in permeable material.

Confining Bed I

Underlying the Biscayne aquifer in southeastern Florida and separating it from the principal artesian water-bearing zone of the Floridan aquifer (Meyer, 1974) are approximately two hundred feet of sandy clay and siltstone of the Miocene Hawthorn Formation and about six hundred feet of alternating limestones, siltstones and claystones of the Miocene St. Mark's Formation. This entire lithic interval is designated as Confining Bed I on Figure 8-1.

A confining bed is defined as a body of "impermeable" material stratigraphically adjacent to one or more aquifers (Lohman and others, 1972). In nature, however, the permeability of the confining bed may range from nearly zero to some value distinctly lower than that of the aquifer itself. Confining beds retard, if not prevent, the upward or downward movement of water from an adjacent aquifer.

The presence of the overlying, relatively impermeable beds may cause water in an underlying aquifer to be confined. Water levels in wells drilled into a confined or artesian aquifer rise above the top of the artesian water body they tap. If the water level in an artesian well stands above land surface as is the case in most of southern Florida, the well is a flowing artesian well. The level to which water will rise in tightly cased wells penetrating the Floridan aquifer in southern Florida is indicated by the potentiometric surface shown in Figures 8-1 and 8-2.

Floridan Aquifer

The Floridan aquifer is a heterogeneous body of intercalated permeable and less permeable material that acts as a water-yielding hydrologic unit of regional extent. Parker (1955, p. 189) applied the name "Floridan" to the stratigraphic interval in southern Florida that included parts or all of the middle Eocene (Avon Park and Lake City Limestones), upper Eocene (Ocala Limestone), Oligocene (Suwannee Limestone), and Miocene (Tampa Limestone), and permeable parts of the Hawthorn Formation that are in hydraulic contact with the rest of the aquifer.

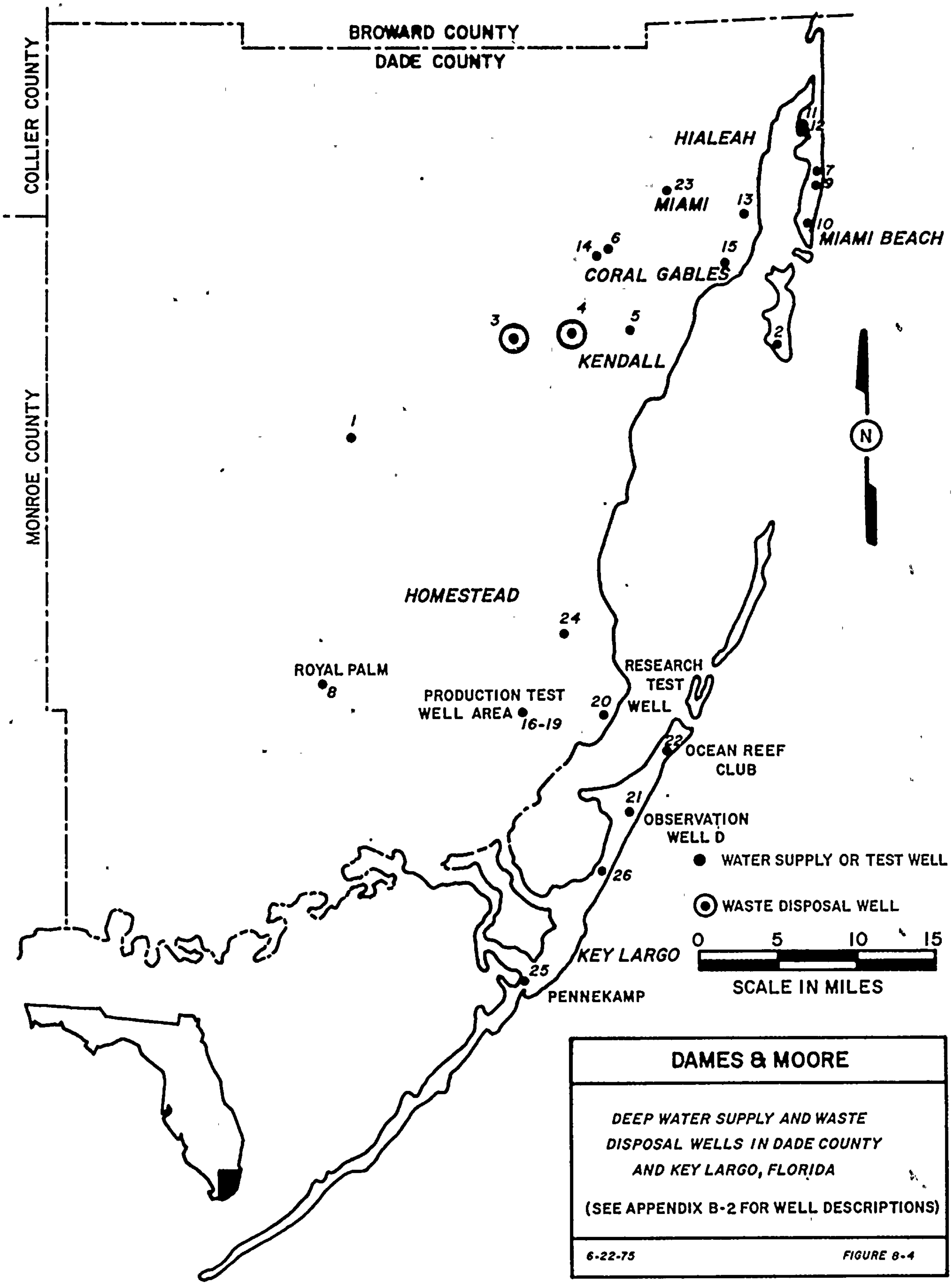
Stringfield (1966, p. 1) included the geologic formations of the Floridan within a major Tertiary artesian system which extended into northern Florida, southern Georgia, and adjacent parts of Alabama and South Carolina. This aquifer system as discussed by Stringfield includes as many as eight formations, chiefly limestone, and is the source of some of the largest ground-water supplies in the United States.

A recent study by Meyer (1974) in Dade County shows two zones within the Floridan aquifer system: a minor artesian water-bearing zone and a principal artesian water-bearing zone (Figure 8-3). The minor artesian zone is approximately six hundred feet thick and is comprised of alternating limestones, siltstones and claystones mostly within the St. Mark's Formation. Previous studies of the Floridan aquifer in Dade and Monroe Counties (Meyer, 1971) showed that con-

fined ground water was present within this lithic section, however, the amount appeared small compared to that available from the underlying Suwannee and Avon Park Limestones which constitute the principal artesian zone. Meyer (1971, p. 68) also indicated that the artesian pressures or potentiometric head at the Royal Palm Well (Figure 8-4) was significantly greater at depths below about 1100 feet than it was in the overlying material. Subsequent investigations by Dames & Moore for Florida Power & Light Company have confirmed the presence of a relatively impermeable claystone bed at the base of the St. Mark's in the Turkey Point area.

The lithologic data from the coring of wells GB-1 and GB-2 (see Section 7) together with hydrologic data from the Royal Palm Well and from the present study indicate that the lithic material at the base of the St. Mark's Formation and overlying the Suwannee Limestone significantly retards, if not prevents, the upward movement of confined water from the principal artesian zone of the Floridan aquifer in the Dade County area. Data from Vernon (1970, pp. 6-7; 1973) appear to support this interpretation and are used in Figure 8-1 to extrapolate depths to the top of the principal artesian zone throughout southern Florida.

Geologic formations within the principal artesian zone of the Floridan aquifer are relatively shallow in the Polk County area and gradually increase in depth to the south (Figure 8-1). Klein (1971) indicates that the depth to the base of potable water in the Floridan aquifer in Polk


BROWARD COUNTY
DADE COUNTY
COLLIER COUNTY
MONROE COUNTY
HIALEAH
MIAMI
MIAMI BEACH
CORAL GABLES
KENDALL
HOMESTEAD
ROYAL PALM
PRODUCTION TEST WELL AREA 16-19
RESEARCH TEST WELL
OCEAN REEF CLUB
OBSERVATION WELL D
KEY LARGO
PENNEKAMP
WATER SUPPLY OR TEST WELL
WASTE DISPOSAL WELL
0 5 10 15
SCALE IN MILES
N
DAMES & MOORE
DEEP WATER SUPPLY AND WASTE DISPOSAL WELLS IN DADE COUNTY AND KEY LARGO, FLORIDA
(SEE APPENDIX B-2 FOR WELL DESCRIPTIONS)
6-22-75
FIGURE 8-4

County in central Florida may be as much as 2000 feet which corresponds approximately to the base of the Lake City Limestone. Stewart (1966, p. 1) states, however, that studies near Lakeland also in Polk County show that the Avon Park Limestone appears to be the lowest unit of the Floridan aquifer. Although the thickness of the aquifer in central Florida is not of major concern to the present investigations, the apparently conflicting results and interpretations do point out the problems and uncertainties involved in giving definite physical boundaries for such a large and complex hydrologic system.

Based on geologic correlation, the thickness of the principal artesian zone of the Floridan aquifer ranges from about 800 to 1400 feet in southern Florida. Site information in Dade County indicates that the portion of the aquifer capable of supplying significant amounts of water is 800 to 900 feet thick with most of the flow probably coming from a part of the zone about 300 feet thick (Figure 6-2).

Generalized boundaries of the principal artesian zone of the Floridan aquifer in southern Florida are given in Figure 8-1. A more detailed presentation of the aquifer system in Dade County and the Turkey Point area is shown in Figure 8-3. Differences between the two figures with respect to the hydrologic characteristics of Confining Bed I are more likely a function of the location and extent of detailed studies than of a significant difference in the hydrogeologic characteristics of the stratigraphic interval.

Confining Bed II

Underlying the principal artesian zone of the Floridan aquifer and separating it from the Boulder Zone are approximately 800 to 1100 feet of interbedded limestones and dolomite of the Lake City and Oldsmar Limestones. Vernon (1970, p. 10) states that an interval of dense dolostone restricts the vertical movement of water between the Boulder Zone and the Floridan aquifer. Studies in the Miami area (Black, Crow and Eidsness, 1972; Meyer, 1974) have also indicated the presence of a thick section of dense carbonate material having relatively low vertical permeability directly below the principal artesian zone of the Floridan aquifer.

Boulder Zone

The beds referred to as the "Boulder Zone" contain no boulders. The zone was named by well drillers in the early days of south Florida oil exploration for a lithic interval ranging between about 2000 to 3500 feet deep through southern Florida. It is a zone of great permeability and characterized by an intricate vug and large cavity porosity. Pieces of the rock forming the roof of an occasional cavity, collapse breccia, or cavern are broken off by drilling activity and these fragments fall into the hole, are rolled between the drill rod and the walls of the hole to create real "boulders" (Puri and Winston, 1974, p. 33).

"High transmissivity zone" (Figure 8-1) is a hydrologic term implying the ability of a thick vertical section to transmit large volumes of fluids. Five discreet zones of high transmissivity have been mapped by Puri and Winston (1974, p. 33) within Cretaceous, Paleocene and Eocene Formations in southern Florida. One of these zones below about 2800 ft. MSL is presently used for injection of treated wastes in the area (Black, Crow and Eidsness, 1970, 1972).

8.2.2 Recharge and Movement of Ground Water in the Principal Artesian Zone

Fresh water enters the principal artesian zone of the Floridan aquifer in areas of relatively higher altitude where the overlying impervious beds that confine the aquifer in down-dip areas are absent or have been breached. Such recharge may occur: where sinkholes penetrate the confining beds; where the aquifer is at or near land surface; or where the aquifer is overlain by permeable material.

From these intake or recharge areas (Figures 8-1 and 8-2), the water infiltrates the aquifer and flows in the direction of the hydraulic gradient, eventually reaching areas where overlying beds confine the water under artesian pressure.

Stringfield (1966, p. 96) provides a map which delineates those areas in Florida where sinkholes breach the Hawthorn and overlying younger deposits and where the Floridan aquifer is at or near the land surface. When this information is considered in combination with the potentiometric surface map of the Floridan aquifer (Figure 8-2; Healy, 1962; Vernon, 1970), it appears that the major recharge area for the aquifer affecting southern Florida is within Polk, Hardee and Highlands Counties.

Recharge to the principal artesian zone may also occur as a result of vertical movement of water from underlying and overlying confining beds. If the artesian pressures either below or above the principal artesian zone are greater than that in the zone itself, water may move through the confining beds and into the aquifer. Although this vertical movement is extremely slow, the amount contributed in this manner could be significant over a large area.

The velocity of ground water is directly proportional to the aquifer permeability and the hydraulic gradient and inversely proportional to the effective porosity. Hanshaw and others (1965, p. 494-495) estimated the velocity of water movement in the Floridan aquifer in central Florida to be on the order of 20 to 30 feet per year. These results were derived by carbon-14 dating of the water and by using the velocity equation as a check.

The flow is in the direction of the hydraulic gradient along lines perpendicular to the lines of equal potentiometric head (Figure 8-2). The orientation of the potentiometric contours indicates that in Dade County, the Floridan ground water moves from northwest to southeast in which direction it ultimately discharges into the ocean (Figures 8-1 and 8-2).

8.2.3 Discharge of Ground Water from the Principal Artesian Zone

Discharge of ground water from the principal artesian zone of the Floridan aquifer occurs in several ways. These include: pumpage, spring flow, upward leakage and outflow to the ocean.

Large quantities of fresh water are withdrawn annually from the Floridan aquifer for public supply, irrigation and industrial uses. In the Lakeland Ridge area of Polk County, ground-water withdrawals were estimated at 27 billion gallons in 1970, or about 74 million gallons per day (Robertson, 1973, p. 15). Withdrawals in Polk County during 1959 for the combined municipal, domestic, industrial, irrigation and other uses averaged 217 million gallons per day (Stewart, 1966, p. 141). Further south in Florida, however, little use is made of water from the principal artesian zone because of its relatively poor quality.

The discharge of some of the larger limestone springs in central Florida rank among the highest in the world. Among the largest of these springs discharging from the principal artesian aquifer is the Silver Springs Group. Stringfield (1966, p. 193) reports that the combined flow of springs in the area is equal to a discharge of about 3700 million gallons per day.

Upward leakage of water from the principal artesian zone may take place through the relatively impervious formations that overlie the aquifer. The amount of this type of discharge is difficult to estimate since it is a function of the head differences between the head in the aquifer and that in the overlying materials and the vertical permeability of the overlying confining unit. Over a large area, however, the quantity of vertical leakage could be considerable.

Discharge into the ocean occurs where the aquifer and ocean are hydraulically connected and the artesian head exceeds the back pressure of the ocean water. Evidence for subsea connection and discharge includes changes of buoyance in submarines as they encounter abrupt changes in density and temperature along the northern and central Florida Coast (Manheim, 1967, p. 844); conspicuous depressions of the potentiometric surface along central Florida coastal areas (Brooks, 1961, p. 132); and karst solution features on the Pourtales Terrace off southern Florida (Manheim, 1967, p. 845). Malloy and Hurley (1970, p. 1947) suggest that submerged karst features (sinkholes) found on the east slope of the Straits of Florida may be kept free of sediment by submarine flow from the Floridan aquifer.

8.3 TURKEY POINT AREA

8.3.1 Introduction

A detailed field investigation of the principal artesian zone of the Floridan aquifer in the Turkey Point area was initiated in August, 1973. The purposes of the study were: 1) to evaluate the potential of the principal artesian zone to supply water of sufficient quantity to supplement the existing cooling canal system; 2) to evaluate the impact of the pumping on existing users of the Floridan aquifer; and 3) to evaluate the possibility of future changes in water quality that might result from pumping.

A Production Test Well and four associated Observation Wells were completed to allow pumping and monitoring of the high water-yield zone in the Suwannee and Avon Park Limestones (Figure 8-3). In addition, a second, lower monitoring zone was isolated in each of the Observation Wells so that possible changes in artesian head and hydrochemistry below the pumped zone could be observed during testing. (See Figures 5-2 through 5-6 and Table 8-1).

8.3.2 Advisory Groups

Due to the complexity of this project, close cooperation with leading experts was desired to develop the best possible research program through a free flow of ideas. Two advisory groups were organized to meet this need. One, the Government Advisory Group, consisting of members from interested Federal, state, regional, county and local organizations, was to advise in the planning and execution of the "Production Test Well Program". This committee was also kept apprised of the program as it developed to provide a forum for the type of field program appropriate and to identify any particular concerns at an early date. A second group, the Internal Advisory Group, consisted of a team of

TABLE 8-1

DESCRIPTION OF WELLS

	Well	Location	Distances from PTW	Well Pad Elevation*	Zone	Elevation of Monitoring Zones
Production Test Well Area	PTW	T 58 S R 39 E Sec 26		+4.23 ft	Upper	-1116 ft -1396 ft
Production Test Well Area	OW-A	T 58 S R 39 E Sec 26	100 ft SE	+3.13 ft	Upper	-1113 ft -1345 ft
					Lower	-1532 ft -1915 ft
					Deep	-2095 ft -2301 ft
Production Test Well Area	OW-B	T 58 S R 39 E Sec 26	2000 ft SE	+4.41 ft	Upper	-1100 ft -1403 ft
					Lower	-1496 ft -1696 ft
Production Test Well Area	OW-C	T 58 S R 39 E Sec 26	500 ft NW	+3.30 ft	Upper	-1117 ft -1357 ft
					Lower	-1529 ft -1693
	OW-D	T 59 S R 30 E Sec 35	44800 ft SE	+11.17 ft	Upper	-1042 ft -1379 ft
					Lower	-1436 ft -1714 ft
	RTW	T 58 S R 40 E Sec 28	22600 ft E	+9.70 ft		-990 ft -1990 ft
	Royal Palm	T 58 S R 37 E Sec 14	63200 ft N 77° W		Upper	-620 ft -1333 ft

*All elevations are based on mean sea level.

(Figures 5-1 and 8-4 show locations of these wells.)

professional ground-water hydrologists within Dames & Moore and Mr. Ross Sproul of the firm, Black, Crow and Eidsness, Inc. (see Appendices B-7 and B-8).

8.3.3 Definition of Terms

The value of an aquifer as a fully developed source of water depends on primary characteristics such as its ability to store and transmit water. Also, availability of a source of recharge or a means by which water may be replenished is of fundamental importance. One of the most reliable methods to evaluate these characteristics is to conduct an aquifer test.

Aquifer Test

An aquifer test is conducted by pumping one well and recording either the water level drawdown or the decrease in artesian head in both the pumped well and nearby observation wells. Measurements of dynamic water levels after cessation of pumping are also valuable for a study of the water-level recovery. Data collected during the test are used in conjunction with particular mathematical equations, selected on the basis of existing boundary conditions, to develop values for the transmissivity and storage coefficient.

Transmissivity

The transmissivity (T) presented in the following sections indicates the capacity of the Floridan aquifer, as a unit, to transmit water. Transmissivity, in units as used herein, is a measure of the volume of water in gallons which will flow each day under a hydraulic gradient of unity through a vertical strip of the aquifer that is one foot wide and extends the full saturated thickness of the aquifer. The transmissivity is the product of the hydraulic conductivity and the saturated thickness of the aquifer (after Theis, 1935, p. 520). Hydraulic conductivity is expressed in meinzer units which are defined as the flow of water in gallons per day through a cross-sectional area of one square foot under a hydraulic gradient of one foot per foot (Davis and De Wiest, 1966, p. 163).

Storage Coefficient

The storage coefficient (S), a dimensionless term, 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 (Lohman, 1972, p. 13). In a confined aquifer, such as the principal artesian water-bearing zone of the Floridan, the water derived from storage with decline in head comes from expansion of the water and compression of the aquifer; similarly, water added to storage with a rise in head is accommodated partly by compression of the water and partly by expansion of the aquifer.

Leakage and Leakance

Artesian aquifers are not always perfectly confined between completely impervious strata because of variations in the original depositional processes. The percolation of water into or out of an aquifer through confining strata has been termed leakage (De Wiest, 1965, p. 271).

To characterize the amount of leakage, values of another coefficient called the leakance or leakage coefficient (hydraulic conductivity of the confining bed divided by the thickness of the confining bed) are usually given numerically. This coefficient may be defined as the quantity of water that flows across a unit area of the boundary between the main aquifer and its semiconfining bed, if the difference between the head in the main aquifer and that of the ponded water supplying leakage is unity (Davis and De Wiest, 1966, p. 226). Leakance as used in this report is discussed in units of gallons per day per cubic foot.

Well Loss

The water level decline in a pumped well is due to both laminar flow losses within the aquifer and turbulent flow losses that are encountered as water flows into the well. The water level decline component due to turbulence, is called well loss.

When designing well fields, the well loss is added to the calculated drawdown caused by laminar flow in order to assign depth of pump setting and calculate cost of pumping water.

8.3.4 Aquifer Testing

Four aquifer pumping tests and one recovery test were conducted at the Turkey Point area between February 14, 1974 and January 28, 1975. The first two were preliminary, relatively short term tests while the later two pumping

tests and recovery test were longer and included more extensive data collection programs.

Pumping Test - Observation Well A (OW-A) (2/14/74)

The pumping test program began on February 14, 1974 with a short-term (4 hour) test at Observation Well A. The two major purposes of this test were: to verify the effectiveness of the cement seal between the upper and lower monitoring zones (Figure 5-3); and, it was felt that the test might provide qualitative information about the vertical permeability of the lithic interval between the two monitoring zones.

In order to test the cement seal, water was pumped from the lower zone at a rate of about 880 gallons per minute. Salinity, conductivity and temperature of the discharged waters from the lower zone were measured as was the artesian head in the upper monitoring zone. For this and each of the succeeding tests, artesian head was observed using either 15 or 30 psi calibrated gauges and discharge was measured using a pipe orifice.

Data from this test, presented in Appendix B-3, indicate that the pumping did not induce any change of head in the upper monitoring zone. Salinities and conductivities of the discharged water showed a slight decrease during the first two hours of pumping but appeared to remain constant thereafter. The effectiveness of the cement seal between the two monitoring zones was determined to be satisfactory since the artesian head remained constant in the upper

monitoring zone. It was felt, however, that an evaluation of the vertical permeability in the lithic material between the two monitoring zones could not be made because the pumping rate for this test was too low and the length of pumping was for too short a time.

Pumping Test - Production Test Well (PTW) (3/27/74)

The Production Test Well pumping program was begun on March 27, 1974. The duration of the test was 20 hours and was terminated because of pump engine difficulties.

The Production Test Well had, prior to testing, an estimated artesian flow of 1000 to 1100 gallons per minute. During the test, the well was pumped at a constant rate of 6500 gallons per minute for the 20 hour period. Observation Wells A and C, located 100 feet and 500 feet respectively from the test well, were used to define the decline in the potentiometric surface with distance from the pumped well. Time and pressure-decline data are presented in Appendix B-4.

The head decline versus time data show that the total drawdown after pumping the PTW for 20 hours was about 32 feet at OW-A and 14 feet at OW-C. About 50 percent of the total drawdown in Observation Well A occurred within the first 3 minutes and 90 percent occurred within the first 2-1/2 hours. The water level in the pumped well declined 230 feet. Of this amount 120 feet is estimated to be well loss.

Although the length of the test was less than the planned 72 hours, the main objective of determining a desirable location for Observation Well B was achieved. Examination of the drawdown data indicated that an optimal location for a third observation well in the area would be at a distance of 2000 feet from the pumped well. This decision was based on distance-drawdown data which indicated that at a distance of 2000 feet from PTW the observation well would be far enough away for the effects of turbulence and possible partial penetration of the aquifer by the well to be minimal and yet close enough to be useful for observation of head declines in future tests.

<u>Pumping Test - Production Test Well (PTW) (7/30/74-8/7/74)</u>

The third aquifer pumping test was begun July 30, 1974 and continued for 8 days until August 7, 1974. The major objectives of this test were to evaluate the hydrologic characteristics of the principal artesian zone of the Floridan aquifer (Figure 8-3).

The aquifer test commenced on July 30, 1974, at 0900 hours with the start of pumping of the Production Test Well at a constant rate of approximately 5000 gallons per minute. Prior to the test, natural artesian flow was estimated to be 1000 to 1100 gallons per minute. The test was stopped 8 days later on August 7, 1974, when a universal joint failed between the engine drive unit and the Amarillo gear drive.

Before, during and after the test, artesian head was measured in the upper and lower monitoring zones of OW-A, OW-B, OW-C, and OW-D and in the composite zones of the Research Test Well and Royal Palm Well (Appendix B-5).

Maximum drawdowns in the upper monitoring zones of OW-A, OW-C, and OW-B were about 22 feet, 9 feet and 5 feet respectively. No significant changes were observed in the upper monitoring zone at OW-D or in the composite zones of the Research Test Well and Royal Palm Well. Slight changes in artesian head were observed, however, in the lower monitoring zones of OW-A, OW-B, OW-C, and OW-D. Artesian heads in the lower monitoring zones of OW-A and OW-D showed a slight increase of .7 ft. and .3 ft., respectively. While the heads in OW-B and OW-C showed a slight decrease of 1.1 feet and .9 feet, respectively.

The total drawdown in the pumped well was 175 feet, of which 90 feet is estimated to be well loss.

Conductivity measurements of water from the various monitoring zones were also made before and after the test. Only the upper and lower monitoring zones of Observation Well A showed any change. These were an increase of 1.3 millimhos/cm in the upper monitoring zone and an increase of 3.0 millimhos/cm in the lower zone.

Ninety-day Pumping Test - Production Test Well (10/16/74-1/14/75)

A long-term pumping test was begun on October 16, 1974, and continued for 90 days until January 14, 1975. The objectives of this test were to monitor long-term declines of artesian heads and possible water quality changes. The water quality data are discussed in Section 9.0.

Data collection procedures were similar to those of the previous test. Continuous pressure recorders used for monitoring the upper monitoring zone on Observation Wells A, B and C were checked daily during the test. Pressure declines in both the upper and lower zones were monitored for Observation Wells A, B, C and D. The Research Test Well and the Royal Palm Well were also monitored for pressure changes during the test.

The pumping test started at 10:00 a.m. on October 16, 1974. The upper part of the principal artesian zone of the Floridan aquifer at the Production Test Well was pumped at a constant rate of 5000 gpm throughout the test. Prior to the test the natural artesian flow was 1050 gpm. Pressure decline and time data are presented in Appendix B-6.

Several factors that could affect pressures in the wells during the test were evaluated. These included barometric changes, interfering wells, seasonal water level changes, and water sampling.

During the 90-day test period the greatest barometric pressure difference encountered was .46 inches of mercury. This is equivalent in pressure to less than 1/2 foot of water. This is not sufficient to significantly affect results, even assuming the aquifer had a 100 percent barometric efficiency.

About 5 miles north of Observation Well D, on Key Largo, wells at the Ocean Reef Club have been pumping at a steady rate of about 1100 gallons per minute for several years. The wells are the only ones close enough to have any conceivable influence on the test well. The fact that they have been pumping for a relatively long period of time prior to the 90-day test suggests that they had reached an apparent equilibrium and would, therefore, have little effect on OW-D during the test.

Because the test was conducted over a 90-day period, seasonal changes in water level, which are common in Florida, were considered in the analysis of test data. Ground-water levels normally begin to decline in October at the beginning of the dry season. An unsuccessful attempt was made to locate long-term water level records of water-level fluctuations in the Floridan aquifer in the south Dade County area. Because these were unavailable, a long-term monitoring program was initiated by Florida Power & Light beginning in October 1974. As of the time of this report, minor fluctuations have been observed but no consistent or significant trends are apparent.

There are water-level data for locations approximately 150 miles north near Sarasota where the Floridan aquifer water levels fluctuate on the order of 5 feet annually (Healy, 1962). The Floridan is confined from this area to the south and within this confined reach the aquifer would not be subject to seasonal climate influences. Therefore, the investigation of seasonal influences on water levels was confined to a study of the possibility of the transmitting of significant seasonal water level fluctuations from Sara-

sota south to the site, using a technique described by Ferris and others (1962, p. 133). From this analysis, it appears the seasonal water level fluctuations at the South Dade area would be substantially less than 0.001 foot, a negligible amount.

During the test, the water level observation wells were sampled periodically by allowing the observation wells to free flow for a sufficient length of time to collect a representative sample in a particular monitoring zone. This produced a temporary drop in aquifer pressure at the observation wells and is the principal reason for some anomalously low pressures recorded during the test (Appendix B-6). In an effort to remove this influence from the evaluation of test data, any anomalously low measurements were not considered.

The maximum drawdown in the upper monitoring zone at Observation Wells A, C, B and D was about 24 feet, 12 feet, 6 feet, and .8 feet, respectively. Drawdown observed in the lower monitoring zone for Observation Wells A, B, C and D was about 2.6 feet, 2.5 feet, 1.7 feet and 1.4 feet, respectively. A decrease in artesian head equal to about 2.3 feet was observed in the composite zone of the Research Test well, however, problems with a leaky gate valve prevented quantitative interpretation of the drawdown at the Royal Palm Well. Graphical plots of the drawdown data versus time indicated that although the test had been run for an extensive period of 90 days, the aquifer system had not yet reached an equilibrium condition (Appendix B-6).

Pressure Recovery Test (1/14/75-1/28/75)

After completion of the 90-day period of monitoring artesian head decline, the pump was shut off and pressure recovery data were collected from Observation Wells A, B and C for two weeks until January 28, 1975 (Appendix B-6). Values obtained from analyses of the recovery record serve as an independent means to calculate and check results based on the pumping record.

Recovery of artesian head in Observation Wells A and C was faster than in Observation Well B. Both the upper and lower monitoring zones in each well showed recovery although at the end of the 2 week observation period none of the monitoring zones had returned to the pre-pump test pressures. It was felt, however, that during the two week period sufficient data had been collected to evaluate the aquifer characteristics.

8.3.5 Analysis of Data

Data collected during the 90-day pumping test and the 14-day recovery test were used to calculate aquifer hydraulic coefficients. Water levels continued to decline at an extremely small rate throughout the 90-day test indicating that a stable, equilibrium condition was not attained, yet the principal artesian zone of the Floridan aquifer appeared to respond during the tests as a leaky artesian aquifer rather than one totally confined.

Aquifer Coefficients

The pumping test and recovery test data were first analyzed using graphical techniques described in texts by Walton (1962) and Johnson Division UOP (1972). Observation Wells B and C at distances of 500 and 2,000 feet were analyzed and believed to be representative of the principal artesian zone.

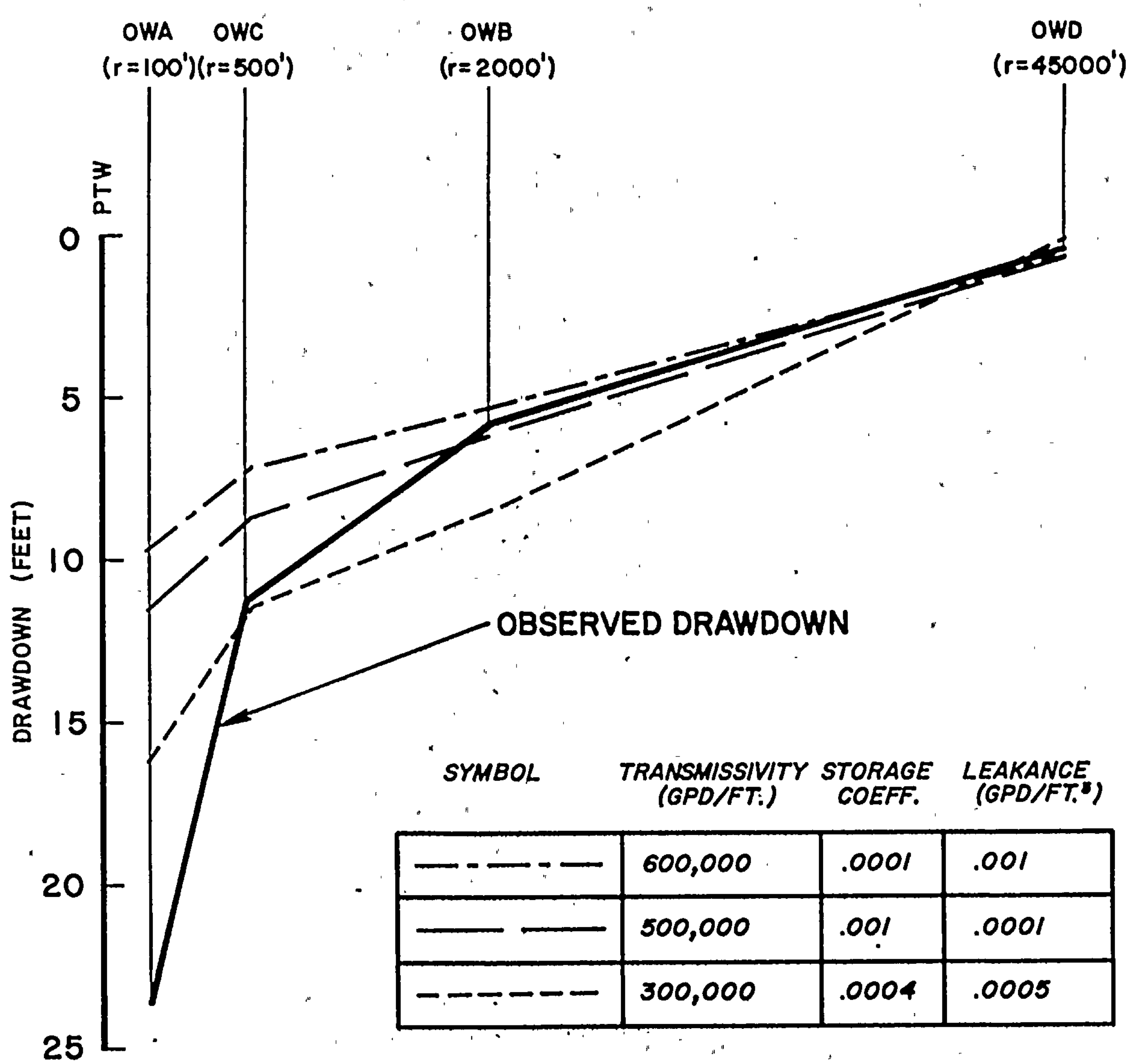
Average values of coefficients obtained by use of the graphical techniques for these wells were as follows:

Transmissivity	= 400,000 gpd/ft.
Storage Coefficient	= 0.0006
Leakance	= 0.002 gpd/cu. ft.

A check on the accuracy of the graphic techniques was made of an iterative procedure, that consisted of successive computational trials using various values of the hydraulic coefficients. The procedure was aided through the use of a digital computer. Comparison of the results of the graphical and computer iterative techniques were favorable. The iterative procedure produced a good fit between computed and observed drawdown values when used with the following values:

Transmissivity	= 500,000 gpd/ft.
Storage Coefficient	= .001
Leakance	= 0.0001 gpd/cu. ft.

Comparisons of profiles of computed cones of depression using these and other experimental parameters in the interactive process are presented graphically on Figure 8-5.



SYMBOL	TRANSMISSIVITY (GPD/FT.)	STORAGE COEFF.	LEAKANCE (GPD/FT.³)
— - — - —	600,000	.0001	.001
—— ——	500,000	.001	.0001
- - - - - -	300,000	.0004	.0005

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NINETY-DAY COMPUTED VS. OBSERVED DRAWDOWNS IN OBSERVATION WELLS

JULY 1975 *FIGURE 8-5*

Using these best-fit parameters, an acceptably close match between computed and observed water level declines was obtained for the distant observation wells OW-B and OW-D. The large drawdowns in OW-A and OW-C are believed to be indicative of localized aquifer conditions, whereas the water levels in the more distant wells should respond to aquifer hydraulic properties averaged over a large area.

As wells are drilled, localized variations in aquifer properties will probably be discovered. But the net projected effect of pumping within the well field should be based on data from OW-B. Regional homogeneity is further indicated by geologic data on formations thickness and lithology.

The selected aquifer hydraulic coefficients used to project pumping effects were as follows:

Transmissivity	= 500,000 gpd/ft.
Storage Coefficient	= 0.005
Leakance	= .00005 gpd/cu. ft.

These coefficient values were based on the coefficients discussed above which were derived from analyses of the 90-day pumping test. The storage coefficient was increased slightly to account for the long-term release of water that could result from consolidation that accompanies a decline of aquifer pressure. This release of water is a delayed phenomena. It will require several years for its effects to be observed. Leakance was reduced as a conservative measure and the transmissivity was selected by averaging the results of the two methods of analysis.

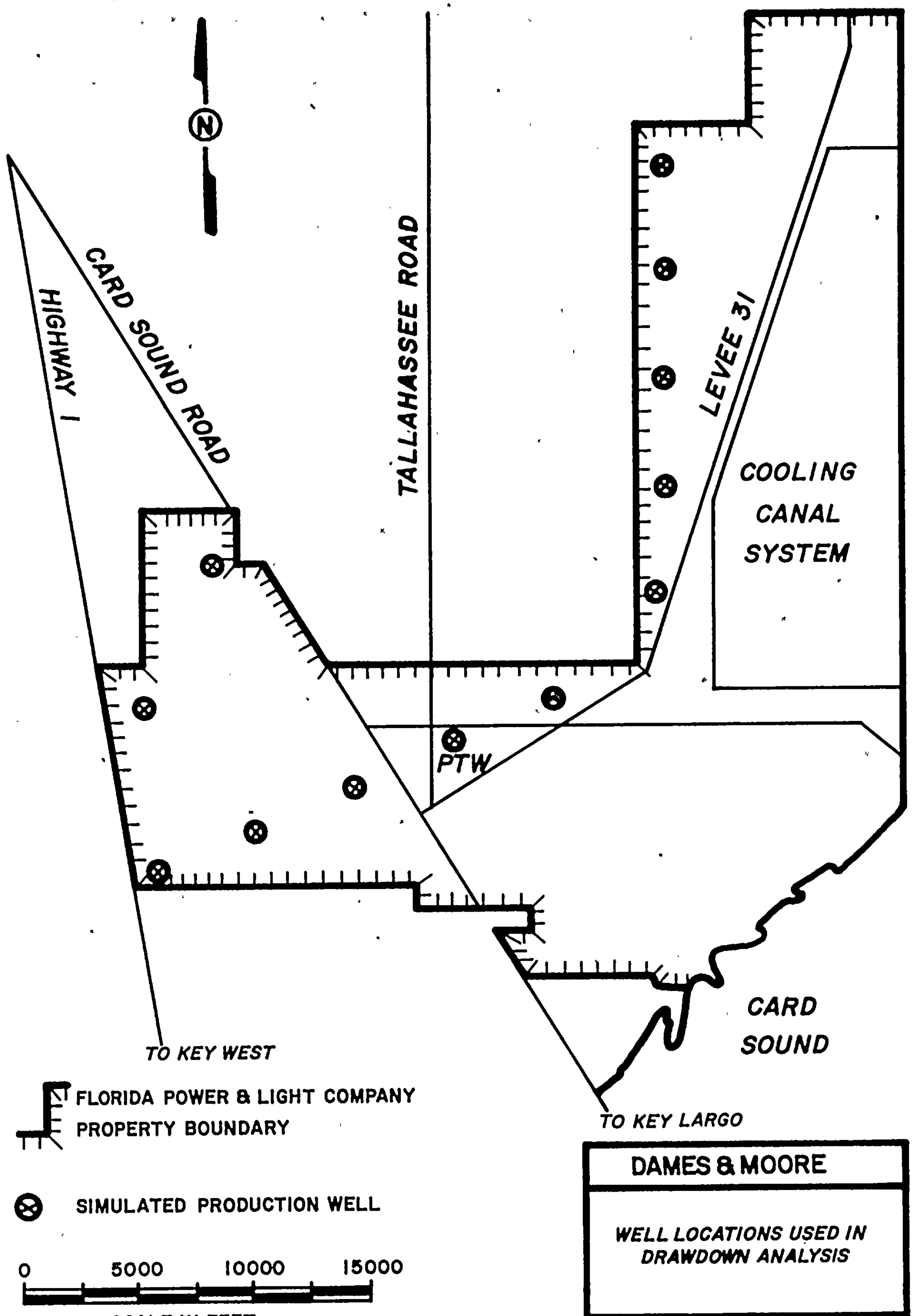
Aquifer Response to Projected Pumping

The leaky radial flow formula (Hantush and Jacob, 1955) was used to evaluate the response of the aquifer to multiple well pumping and to calculate the depth and extent of a cone of depression created by pumping at various rates. For purposes of this analysis, the aquifer is assumed to be homogeneous and continuous in all directions except to the southeast, where it probably crops out in the Straits of Florida (Figure 8-1). The existence of this out-crop area potentially allows seawater to recharge the aquifer. The mathematical model uses a line of image recharge wells to simulate this recharge boundary. The analysis is also based on the following aquifer coefficients:

Transmissivity	= 500,000 gpd/ft.
Storage Coefficient	= 0.005
Leakance	= .00005 gpd/cu. ft.

The configuration assumed for a test well field is as shown on Figure 8.6. This configuration was based on a desire to locate wells within Florida Power & Light Company property boundaries. The full extent of the property is used in order to minimize drawdowns in head due to interference between wells. A total withdrawal rate of 70 million gallons per day (mgd) was used as an example.

Head declines calculated using the foregoing coefficients and well layout were superimposed on the present potentiometric surface of the Floridan aquifer in Dade County to schematically illustrate the changes that would



DAMES & MOORE

WELL LOCATIONS USED IN DRAWDOWN ANALYSIS

JULY 1975 *FIGURE 8-6*

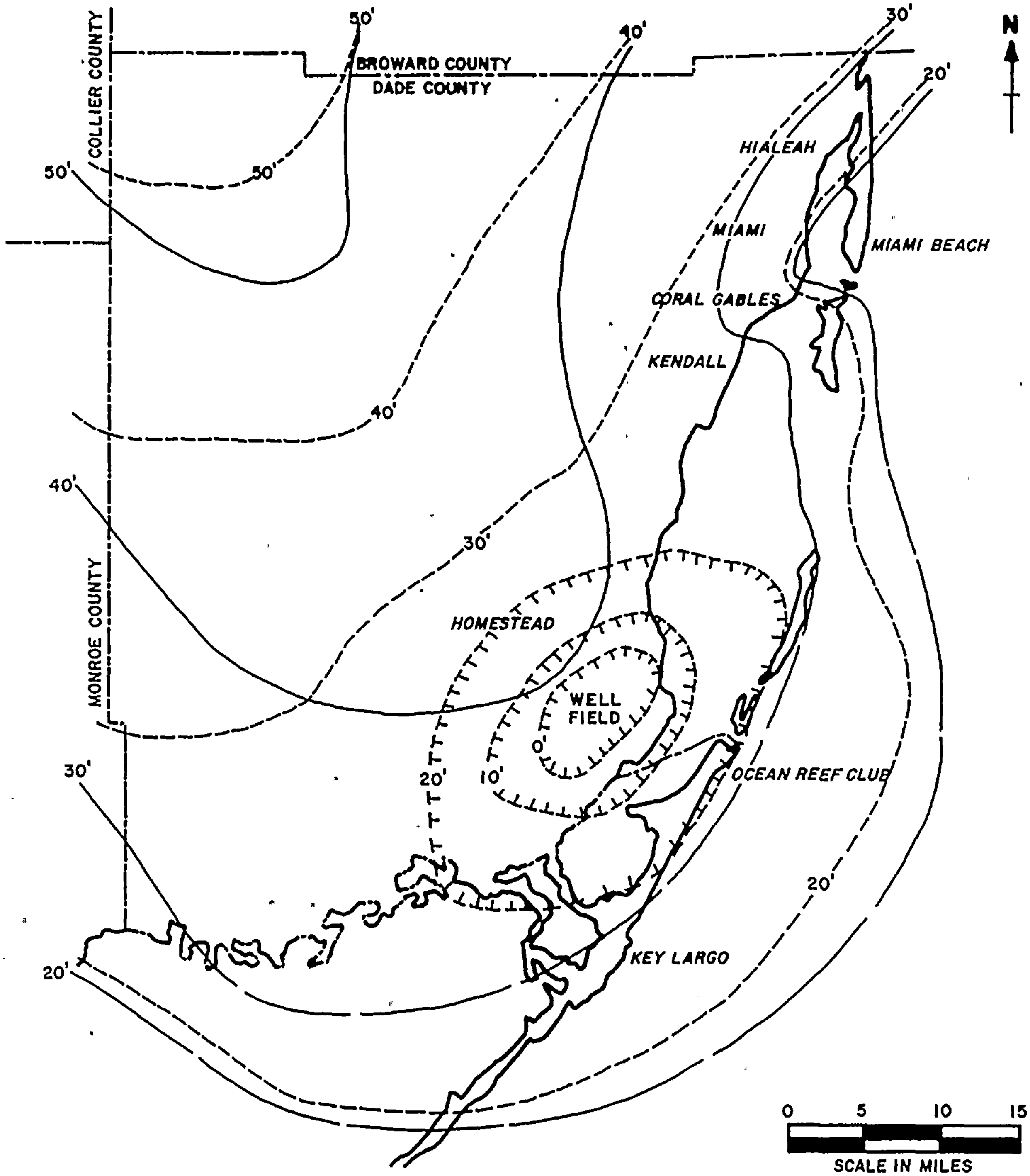
take place after a 40-year pumping period. The response of the aquifer to this pumping is presented in Figure 8-7. Maximum drawdown calculated adjacent to a pumping well was 64 feet. This drawdown, which is only 24 feet below MSL, decreases rapidly with increasing distance from the well. The artesian head decline would begin to stabilize after 5-10 years and very little additional decline is expected beyond this time to the end of the 40-year project life. A well loss of about 100 feet can be expected, but would vary somewhat from well to well, owing to changes in rock openings.

Well Field Design Considerations

The leaky radial flow formula was used to evaluate well spacings, and to determine the regional influence of the cone of depression created by pumping at projected rates.

The well field design aspect was approached with the understanding that there was a physical limitation to the area in which the well field could be located. First, it was desirable to locate the wells on the existing FP&L property. Second, in considering additional land for well field development, it was considered as a practical matter that the area of investigation would be bounded on the south and east by the coastline, on the west by the National Park, and on the north by the developments of the Town of Homestead and the airbase.

The number and spacing of wells considered also the economics of pumping, investment and maintenance, and the threat of salt water intrusion from the ocean. The closer



40' 40' APPROXIMATE HEIGHT (ABOVE MSL) TO WHICH WATER WILL RISE IN WELLS PENETRATING THE FLORIDAN AQUIFER-1975 (MODIFIED AFTER VERNON, 1970)

40' APPROXIMATE HEIGHT (ABOVE MSL) TO WHICH WATER WILL RISE IN WELLS PENETRATING THE FLORIDAN AQUIFER AFTER PUMPING 50,000 GPM FOR 40 YEARS IN THE THE TURKEY POINT AREA

20' CLOSED POTENTIOMETRIC CONTOURS AROUND THE CENTER OF MAXIMUM DRAWDOWN IN THE FLORIDAN AQUIFER

DAMES & MOORE

APPROXIMATE POTENTIOMETRIC SURFACE OF THE FLORIDAN AQUIFER IN 1975 AND AFTER PUMPING 70 MGD FOR 40 YEARS IN THE TURKEY POINT AREA

6-22-75 FIGURE 8-7

the wells are to the Straits, the greater the threat of salt water intrusion. Wide spacing of wells results in lower pumping costs due to decreased interference between wells. But offsetting this is an increase in costs such as pipeline expense, booster stations and related maintenance. In addition, other expenses could be incurred in acquiring right-of-way and extended property.

Through the use of the computer it was possible to rapidly evaluate alternative well field patterns. It was discovered that owing to high transmissivity, drawdown in the Turkey Point area is not greatly affected by local changes in well spacing. Consequently, a well field extending over the property boundary was chosen as adequate for evaluating future ground-water levels and water quality changes.

Recommendations on well specifications for individual wells would be as follows:

1) Producing wells would be of the telescoping type similar to the existing Production Test Well.

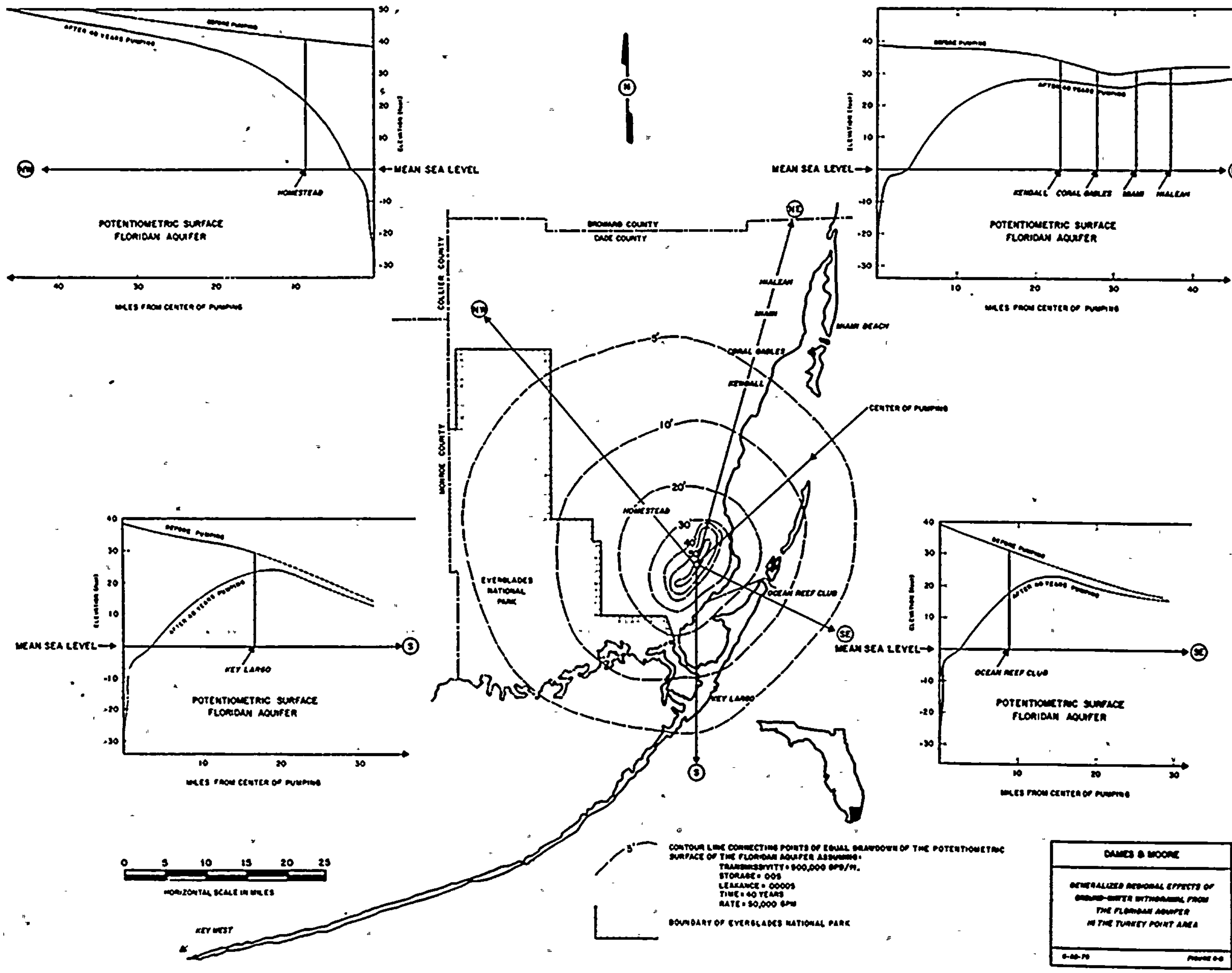
2) The producing zone would be approximately 300 feet thick at depths between about 1100 feet and 1400 feet below MSL. Deepening of the producing wells, for example, to the base of the principal artesian zone, would result in greater deterioration of water quality after a relatively short time because of the more saline water present at the base of the aquifer.

3) Serious consideration should be given at the time

of pumping well design to the alternative use of asbestos cement or fiberglass casing on the producing wells in comparison to using other corrosive resistant metal casings or metal casings with liners. Although great care must be exercised in placing and cementing such casings particularly at depth, installation feasibility of new higher strength inert materials may be promising. Small diameter fiberglass well casings for shallow wells have been used with success in other areas, however, fiberglass casing required for deep, large diameter wells is not readily available. Several companies, however, are presently researching this application of the fiberglass material. At the time of any well installation, design using the most promising of inert materials should be made. Use of such products provides an answer to potentially severe long term H_2S, corrosion problems inherent in Floridan waters. Long term corrosion studies have been and are still being conducted by Florida Power & Light Company.

Effects of Pumping on Existing Users

The regional effects of the assumed withdrawals of 70 mgd over a 40-year period are illustrated in Figure 8-8. The figure shows the amount of drawdown which could be expected under the assumed condition in various directions radiating from the center of pumping at the Turkey Point area. The effects are not symmetrical around the well field because of the presence of a potential recharge area in the Straits of Florida, about 30-35 miles to the east.



POTENTIOMETRIC SURFACE
FLORIDAN AQUIFER
MEAN SEA LEVEL
HOMESTEAD
MILES FROM CENTER OF PUMPING
KENDALL
CORAL GABLES
MIAMI
HIALEAH
BROWARD COUNTY
DADE COUNTY
COLLIER COUNTY
MONROE COUNTY
MIAMI BEACH
CENTER OF PUMPING
EVERGLADES NATIONAL PARK
OCEAN REEF CLUB
KEY LARGO
KEY WEST
HORIZONTAL SCALE IN MILES
CONTOUR LINE CONNECTING POINTS OF EQUAL DRAWDOWN OF THE POTENTIOMETRIC SURFACE OF THE FLORIDAN AQUIFER ASSUMING:
TRANSMISSIVITY = 500,000 GPD/FT.
STORAGE = .005
LEAKANCE = .00005
TIME = 40 YEARS
RATE = 50,000 GPM
BOUNDARY OF EVERGLADES NATIONAL PARK
DAMES & MOORE
GENERALIZED REGIONAL EFFECTS OF GROUND-WATER WITHDRAWAL FROM THE FLORIDAN AQUIFER IN THE TURKEY POINT AREA

A comparison of the potentiometric surface before pumping and after pumping for 40 years is shown for regions to the northwest (NW), northeast (NE), southeast (SE), and south (S). Future development to the west has been precluded by the presence of Everglades National Park. Drawdown of the potentiometric surface below mean sea level is confined in all directions to an area less than five miles from the center of the well field at the Turkey Point area.

The only user of the Floridan aquifer within 10 miles of the center of pumping is the Ocean Reef Club on Key Largo. At the Ocean Reef Club, brackish water is presently withdrawn from the upper part of the principal artesian zone, treated using the reverse osmosis process and then used for irrigation and drinking. Pumping of 70 mgd over a 40-year period at the Turkey Point area could produce a modest decline in head about 15 feet at the Ocean Reef Club, however, the artesian head of the principal artesian zone would still remain above land surface.

Pumping from the Floridan would not adversely affect the overlying Biscayne aquifer. The potentiometric levels in the Floridan are now and, except in the center of the well field, will continue to be higher than those in the Biscayne, therefore, water in the Biscayne would not be induced to move downward and deplete any potential fresh water supplies. Furthermore, the thick sequence of relatively impermeable material in the Hawthorn Formation between the two aquifers would restrict such movement even if the hydraulic gradients were reversed over a larger area.

8.3.6 Changes in Water Quality

Pumping from the Floridan will induce water to move both vertically and horizontally toward the well field. Vertical movement would be confined to the well field area where the potentiometric surface would be at the lowest levels. Because the water quality of the Floridan varies in both vertical and lateral directions, the pumping can be expected to cause some water quality changes in the area over the life of the project. The existing water quality is presented in Section 9.

Waters more saline than the water in the zone tested in the Turkey Point area have been identified in deeper strata and could potentially migrate into the production zone through vertical leakage. This upconing would be concentrated in the near vicinity of the pumping well. Also, since salinity of the Floridan aquifer water increases rapidly southeastward toward Biscayne Bay, withdrawals could cause this more saline water to move towards the well field possibly affecting to a slight extent the water withdrawn to the east of the Turkey Point area.

Lateral Salt Water Intrusion

The time of travel of seawater from its present or equilibrium position about 9 miles to the east can be approximated by assuming that all pumping occurs in a single well located at the Production Test Well area. This method assumes radial flow in a homogeneous aquifer with no natural hydraulic gradient. This assumption is conservative as water at a high head to the north-northwest will move faster due to pumping imposed on a natural gradient. It is further assumed that the confining beds of the formation are not leaky. Effective porosities of about 0.30 were estimated in a zone about 300 feet thick. Using the above assumptions, it is calculated that water nine miles away from PTW would move toward the well field in response to 70 mgd pumping a distance of not more than 3 miles during the proposed 40-year life. It is, therefore, reasonable to assume that deterioration of the well water quality at the Turkey Point area by lateral seawater intrusion is not likely to occur within this time period under the assumed pumping rate of 70 mgd.

Interformational Leakage

Under leaky aquifer conditions, inferred from pumping test data, water would move from adjacent units into the production zone. Although the leakage rate is identified, the net chemical composition of the water that enters the aquifer by the leakage is speculative. Water in overlying beds is less mineralized than the production zone water but water below the production zone is more saline. Depending on the relative proportion of the leakage water contributed by the two respective sources, the net dissolved solids concentration of the leakage water would range between 5000 and 30,000 mg/l.

The area of leakage and related water quality effects are estimated using the following: a) the well-configuration

pattern shown on Figure 8-6, b) the selected aquifer hydraulic properties, and c) the distance of water travel toward the well field.

The mathematical model was developed on the assumption that water quality changes can be simulated by convection and mixing. The procedure involves segmenting the production zone of the upper Floridan into cells. Each cell receives flows of formation water laterally and saline water vertically. The flow rates are calculated on the basis of Darcy's law (Davis and De Wiest, 1966, p. 156). Each cell has a vertical dimension equal to an aquifer thickness of 300 feet. The lateral dimensions, in the direction of flow, are such that average particle travel time across each cell is identical for all cells. The flow rate calculations assumed that stabilized drawdown conditions would be attained after about 5 years of pumping.

Since the purpose of the model was to evaluate whether water quality degradation due to interformational leakage would be substantial, conservative assumptions were used. Initial water levels were assumed to be at their equilibrium position. In order to show the greatest possible percent increase, it was also assumed that initially the concentration of dissolved solids in the upper Floridan would be 5000 mg/l (present concentrations are about 6000). The contributing interformational leakage source was assumed to have a dissolved solids content equivalent to seawater.

Under the foregoing assumptions, the model calculations indicated a gradual increase in dissolved solids of about 20-30% in 40 years. It then can be concluded that future water quality changes that might be expected should not result in more than a 30 percent increase over present concentrations.

8.3.7 Subsidence

Surface subsidence is sometimes associated with decline in artesian heads resulting from withdrawal of large quantities of ground water from an artesian aquifer. Recognizing the potential for this problem, an exhaustive search of the literature was undertaken during this investigation to locate case histories and methods of analysis that would be applicable to the geologic and hydrologic conditions at the Turkey Point area. Methods of analysis used in other areas of known subsidence have been evaluated and compared to local conditions. The methods used for analysis in this report represent a conservative approach to the problem in that low elastic moduli were assumed, deformation was computed for the maximum piezometric decline near the wells, the pressure changes were assumed to propagate upward as a function of time, and that deformation damping factors such as beam action or arching would not prevail. This analysis computed the deformation of the rock materials at depth and not the subsidence of ground surface.

The artesian head and the soil or rock skeletal structure of the aquifer system support the load of the overlying deposits. Deep-well pumping, as proposed at the Turkey Point Area, will reduce the artesian pressure within the aquifer and, in time, possibly within the confining stratum, thereby increasing the effective stress on the soil and rock structures by an amount equal to the pressure decline. An increase in effective stress could produce deformation of the aquifer and the confining stratum. Any deformation at depth of the aquifer-confining bed system is ultimately responsible for surface subsidence.

A conservative estimate has been made of the order of magnitude of possible surface subsidence in the Turkey Point area due to deep well pumping from the Floridan aquifer at a depth of about 1000 feet. The wells will penetrate approximately 900 feet of overburden deposits consisting of horizontally bedded sands, clayey sands, claystones, siltstones, and limestones from the Miami Limestone, Key Largo, Fort Thompson, Tamiami, Hawthorn and St. Marks geologic formations. Approximately 100 feet of indurated claystone lies immediately above the upper zone of the aquifer at the approximate 1000 foot depth. The wells would be terminated in the Suwannee Limestone. The claystone functions as a confining stratum due to its relatively impermeable characteristics as compared to the underlying aquifer.

Boring GB-2 (Figure 7-1) was selected to represent a typical soil/rock profile for this analysis. Values of

Young's modulus were estimated based on previous testing of the shallow, near surface materials, values given in the literature and on recent geophysical measurements. It must be noted that the parameters used for the zone undergoing deformation are considered conservative estimates that have not been verified by actual testing. The profile and elastic parameters used were:

Depth Interval and Material		Young's Modulus, E, psi
0 to 97'	Limestone	1×10^6
97 to 428'	Clayey Sand (Hawthorn)	2×10^4
428' to 681'	Limestone (silty) St. Marks	1×10^6
681' to 932'	Limestone/siltstone layered	5×10^5
932' to 1032'	Indurated Claystone	5×10^5
1032' +	Suwannee Limestone (Aquifer)	2×10^5

The artesian head declines were determined from extensive pumping tests at the proposed pumping rates at the Dade County site and analytical considerations. A maximum artesian head decline of 64 feet was used for the case of minimal leakance. These maximum declines occur outside the well casing and decrease with distance from the well as dictated by the cone of depresssion. The artesian head decline will cause an increase in effective stress within both the Suwannee Limestone aquifer and, depending upon the vertical permeability of the claystone, the effective stress increase may eventually migrate upward into the overlying strata.

Other data used in the analysis include:

1. Artesian head 40 feet above ground surface prior to pumping;
2. Depth to top of aquifer: 1032 feet;
3. Aquifer storage coefficient: 5×10^{-3};
4. Aquifer Porosity: 35%;
5. Aquifer thickness: 900 feet.

From the high core recovery, obvious soundness and low permeability of the claystone confining stratum and the potentiometric head distribution measured through similar strata (Meyer, 1971), it is concluded that the claystone is an effective confining stratum that will retard the upward migration of changes in head within the aquifer. In fact, it is considered most unlikely that head changes above the claystone will occur during the life of the plant. However, to provide a conservative estimate of subsidence, it has been assumed that, at 40 years, the head decrease at the top of the claystone would be 50% of that within the aquifer and that the head decrease within the claystone would decrease linearly to zero at the base of the Hawthorn Formation.

The elastic compression of the aquifer was calculated using the concepts shown in "Compression of Elastic Artesian Aquifers", (Lohman, 1961). A maximum elastic aquifer deformation of 3.8 inches was calculated for the maximum artesian head decline of 64 feet in the vicinity of a pumping well.

Evaluation of the compressive deformation of the rock confining beds was estimated by the method presented by

Domenico (1972), and is also considered conservative. These estimates consider the deformation of each stratum with the total deformation equal to the sum of the deformation of the individual layers. The effects of arching and strain compatibility (layered system with varying moduli) have not been included but are considered to cause a reduction in the estimated deformation.

Using a conservative distribution of the increase in effective stress within the overlying materials due to the decline in artesian pressure within the aquifer as previously described, a maximum compressive deformation of the overlying materials of 4.4 inches was calculated for a maximum artesian head decline of 64 feet.

The total compressive deformation at depth of the aquifer/confining bed system was estimated for the life expectance of the plant. A maximum deformation at depth, not surface subsidence, of 8.2 inches (i.e., 3.8" + 4.4") was computed for the maximum artesian head decline of 64 feet. The maximum head decline represents the drawdown in the near vicinity of the producing wells and is significantly greater than the average drawdown across the entire well field. Areal subsidence would reflect the average drawdown; consequently, the estimated deformation is highly conservative with regard to areal subsidence. It should be clearly understood that this estimated deformation would occur within the rocks below the Hawthorn Formation and that this deformation must be propagated upward to the ground surface before the ground surface would subside. The rocks undergoing deformation and the overlying soils and rocks are continuous for large distances horizontally and are relatively stiff and, consequently, will tend to spread and to dampen the deformation so that the ground surface subsidence would be substantially less than the computed deformation at depth. Even with completely flexible overlying materials, the ground surface subsidence cannot be greater than the sum of the deformations at depth.

Considering the nature of the subsurface materials and the magnitude and vertical distribution of the estimated deformations, the subsidence of the ground surface would be most likely quite small, appreciably less than the estimated deformation at depth, and limited to the near vicinity of the well field. Also, the extensive literature search provided no indication that subsidence due to ground-water withdrawal from the Floridan aquifer has been a problem anywhere in the state of Florida.

9.0 HYDROCHEMISTRY

9.1 INTRODUCTION

The principal artesian water-bearing zone of the Floridan aquifer contains large amounts of mineralized water throughout most of southern Florida. Little use has been made of this source of supply, however, because water of better quality is usually available from shallower aquifers. At present only a few wells within the study area, located at the Ocean Reef Club on Key Largo (Figure 5-1), consumptively use water from the Floridan. The water from these wells is desalinized before use as a supply for irrigation and drinking.

9.2 REGIONAL

Variations in the chemical composition of water in the principal artesian zone occur laterally across the State and vertically within the aquifer section. Figure 8-1, a northwest-southeast cross section through southern Florida, shows the lateral variation of chloride concentrations within the aquifer. The 19,000 mg/l isochlor in the extreme southeast represents a chloride concentration close to that of seawater (Hem, 1970; Appendix C-1), while the 250 mg/l isochlor in the northwest represents the approximate location for the southern extent of potable water in the aquifer (Klein, 1971). A third isochlor, 5000 mg/l, is included on the Figure to point out the relatively small distance over which the chloride concentration decreases from 19,000 to 5,000

mg/l as compared with the relatively large distance over which the chloride concentration decreases from 5,000 to 250 mg/l chlorides.

A generalized picture of the vertical variations in hydrochemical concentrations within the aquifer is presented in Figure 8-3. This chloride and salinity versus depth profile shows relatively fresh water near the top of the Floridan aquifer and an increase in the chemical constituent towards the base particularly between 1800 and 2000 feet. The mineral content of water overlying the Floridan in the Biscayne aquifer in Dade County, for example, is normally very low except in near-coastal areas where the chemical concentration may approach that of seawater. Below the principal artesian zone of the Floridan aquifer, the water usually has chemical concentrations equal to or greater than seawater.

In general, the water quality of the principal artesian zone deteriorates in a down gradient direction toward the coasts and also with depth in the aquifer. Further discussions of the regional hydrochemistry of the Floridan aquifer are presented by Meyer (1971) and Shampine (1965).

9.3 FLORIDAN AQUIFER, TURKEY POINT AREA

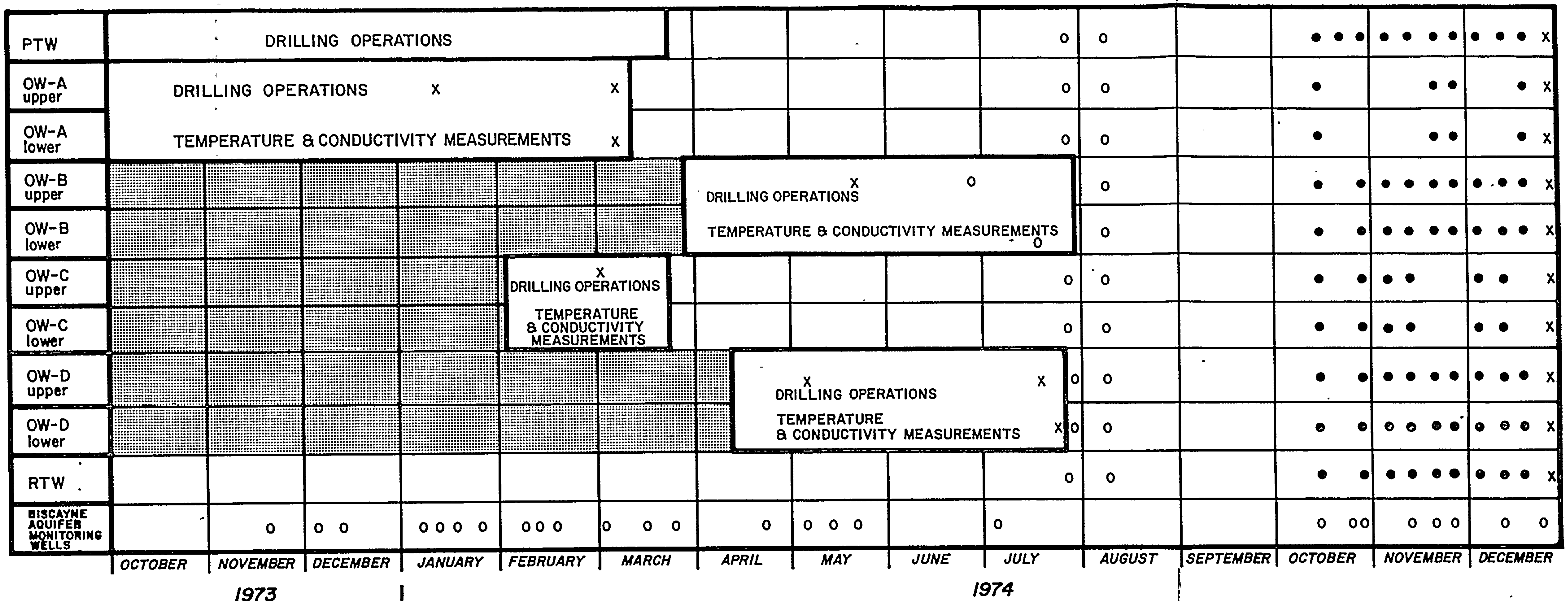
A principal objective of the Production Test Well program was to evaluate the chemical composition of the waters from various depths within the principal artesian water-bearing zone of the Floridan aquifer. This baseline data could then be compared with later data in order to assess changes caused by pumping and also to provide information with which to evaluate and predict future changes possibly resulting from pumping.

9.3.1 Method of Investigation

The present study was preceded by the Research Test Well investigation of the Floridan aquifer initiated in April, 1972 at Turkey Point. Hydrochemical data collected during the Research Test Well Program together with data from other studies in the Dade County area (Meyer, 1971) provided guidelines for the present investigation.

A synopsis of the water sampling program is presented in Figure 9-1. Conductivity and temperature data were initially obtained from the discharge waters at the well head. These data were collected as drilling progressed in Observation Wells A, B, C, and D and are presented in Appendix C-2. The field instrumentation consisted of the Beckman Salinometer, the Hydrolab TC-2 Conductivity-Temperature Meter, and the Beckman RC-19 Conductivity Bridge. The conductivity instruments were calibrated with standard solutions.

During and after the drilling of each observation well and toward the end of the 90-day test, water samples were collected for a "complete" analysis. A list of parameters evaluated during the complete chemical analysis is given in Table 9-1. Another type of analysis, the abbreviated or



x- COMPLETE ANALYSIS (TABLE 9-1)
●- MODIFIED ANALYSIS (TABLE 9-1)
o- PARTIAL ANALYSIS (Normally a combination of conductivity and temperature)

DEPTH INTERVALS OF MONITORING ZONES GIVEN IN TABLE 8-1
TEMPERATURE & CONDUCTIVITY DATA DURING DRILLING OPERATIONS IN APPENDIX (C-2)

DAMES & MOORE

SCHEDULE OF WATER SAMPLING & ANALYSIS

6-22-75 *FIGURE 9-1*

Table 9-1

WATER ANALYSES—COMPLETE AND MODIFIED*

	mg/l as indicated	mg/l as CaCO3	Actual Value
*Calcium (Ca^{++})	X	X	
*Magnesium (Mg^{++})	X	X	
*Sodium (Na^{+})	X	X	
*Potassium (K^{+})	X	X	
*Total Cations		X	
Bicarbonate (HCO_3^-)	X	X	
Carbonate ($CO_3^=$)	X	X	
Hydroxide (OH^-)	X	X	
*Sulfate ($SO_4^=$)	X	X	
*Chloride (Cl^-)	X	X	
Nitrate (NO_3^-)	X	X	
Fluoride (F^-)	X	X	
*Total Anions		X	
*Total Hardness		X	
*Methyl Orange Alkalinity		X	
Total Surfactants, (Methylene Blue)	X		
Carbon Dioxide, Free (as CO_2)	X		
Silica (as SiO_2)	X		
*Total Dissolved Solids (Actual)	X		
Total Dissolved Solids (Calc)	X		
*Turbidity (JTU)			X
*Color (APHA)			X
*pH			X
*Hydrogen Sulfide (as H_2S)	X		
Methane (as CH_4)	X		
Total Iron (as Fe)	X		
Total Manganese (as Mn)	X		
Total Phosphate (as PO_4)	X		
*Conductance (micromhos/cm 25°C)			X
Total Suspended Solids	X		
Total Lead (as Pb)	X		
Total Copper (as Cu)	X		
Total Arsenic (as As)	X		
Total Selenium (as Se)	X		
Total Chromium (as Cr)	X		

* Modified Analysis

"modified" analysis, was used throughout the 90-day test to monitor possible changes in selected chemical constituents resulting from the long-term pumping. Parameters for the modified analysis are indicated by an asterisk in Table 9-1. In addition, "partial" analyses, which normally consisted of conductivity, and temperature measurements were made throughout the study.

The complete, modified, and partial chemical analyses were made by several laboratories during the test program. These included: the Dames & Moore Environmental Laboratories in Cincinnati, Ohio; the Florida Power & Light Laboratories at the Power Resources Laboratory in Coral Gables and the Turkey Point Laboratory at the Turkey Point generating station; and, Wingerter Laboratories in Miami, Florida. Additional information concerning methods of analysis is presented in Appendix C-3. In order to cross-check laboratory results, field analysis of split samples were made for conductivity, chloride, temperature, salinity and hydrogen sulfide.

In order to monitor the effects of the discharge from the Production Test Well on the Biscayne aquifer, two shallow wells were drilled approximately 700 feet to the east and west of PTW. Partial analyses were made for each well from samples taken at regular intervals throughout the test program.

9.3.2 Analysis of Data

The hydrochemical data collected during this investigation were used to: 1) determine a baseline chemical composition of Floridan waters prior to pumping; 2) observe potential changes with time as a result of long-term pumping; and, 3) based on all sampling and analyses data, determine a representative chemical concentration for the water at various depths in the Floridan aquifer.

Baseline water chemistry for the Floridan aquifer prior to the long-term test was determined by comparing water analyses from early in the investigation (March 1, 1975) to analyses of samples taken just before the long-term test (October 15, 1974). The close agreement between these two analyses (see Table 9-2) indicated that hydrochemical conditions had remained fairly stable over this 8-month period. Therefore, samples collected and analyzed for each well and zone on October 15, 1974 were used as baseline data with which to compare data collected during the pumping test.

A summary of the data collected for the Production Test Well and Observation Well A (upper and lower zones) during the long-term test is presented in Tables 9-3, 9-4, and 9-5. The results of analysis for samples collected on October 15 and December 30 are presented in addition to data showing the observed range in the various parameters during the period October 16-December 30, 1974.

The values for most constituents appear to remain fairly stable or even decrease during the test especially in

Table 9-2

OBSERVATION WELL A
UPPER MONITORING ZONE (-1113 to -1345 MSL)
COMPARISON OF WATER ANALYSES
MARCH 1, 1974 AND OCTOBER 15, 1974

	Dames & Moore Laboratories Cincinnati, Ohio March 1, 1974	Florida Power & Light Power Resources Testing Lab October 15, 1974
pH	7.5	7.56
Specific Conductance (umhos/cm)	8300	8250
Dissolved Solids (mg/l)	5331	5446
Hardness (ppm, $CaCO_3$)	1004	1000
Calcium (mg/l)	140	140
Magnesium (mg/l)	155	156
Sodium (mg/l)	1400	1560
Potassium (mg/l)	95	73
Chloride (mg/l)	2517	2600
Sulfate (mg/l)	650	610
Hydrogen Sulfide (mg/l)	1.6	1.0
Color (Chloroplatinate Units)	10	2
Turbidity (FTU)	1.0	0.6

Table 9-3

PRODUCTION TEST WELL
UPPER MONITORING ZONE (-1116 to -1396 MSL)
VARIATION IN HYDROCHEMICAL COMPOSITION
OCTOBER 15, 1974 - DECEMBER 30, 1974

Constituent	October 15, 1974	December 30, 1974	Range During Test (Oct. 16-Dec. 30) Min	Max
pH	7.59	7.59	7.48	7.86
Specific Conductance (umhos/cm)	8710	9290	8900	9630
Total Dissolved Solids	6142	6100	5916	6180
Alkalinity ($CaCO_3$)	164	200	162	200
Hardness	1145	1156	1116	1175
Calcium	148	149	134	196
Magnesium	188	190	155	191
Sodium	1650	1800	1650	2100
Potassium	86	60	63	120
Chloride	3000	3000	2900	3300
Sulfate	640	630	622	886
H_2S	1.5	3.06	1.0	3.50
Color (Chloroplatinate Units)	<2	14	2	2
Turbidity (FTU)	0.6	1.9	0.3	1.2

Unless otherwise noted, concentrations given in milligrams per liter (mg/l).

Table 9-4

OBSERVATION WELL A
UPPER MONITORING ZONE (-1113 to -1345 MSL)
VARIATION IN HYDROCHEMICAL COMPOSITION
OCTOBER 15, 1974 - DECEMBER 30, 1974

Constituent	October 15, 1974	December 30, 1974	Range During Test (Oct. 16-Dec. 30) Min	Max
pH	7.56	7.88	7.51	7.88
Specific Conductance (umhos/cm)	8250	7400	6900	7520
Total Dissolved Solids	5446	4500	4500	4775
Alkalinity ($CaCO_3$)	182	217	191	217
Hardness	1000	940	900	1050
Calcium	143	123	116	123
Magnesium	156	154	145	181
Sodium	1560	1380	1150	1380
Potassium	73	50	50	65
Chloride	2600	2190	1940	2275
Sulfate	610	555	555	630
H_2S	1.0	2.4	1.2	3.3
Color (Chloroplatinate Units)	<2	10	10	70
Turbidity (FTU)	0.6	1.5	1.5	4.8

Unless otherwise noted, concentrations given in milligrams per liter (mg/l).

Table 9-5

OBSERVATION WELL A
LOWER MONITORING ZONE (-1532 to -1915 MSL)
VARIATION IN HYDROCHEMICAL COMPOSITION
OCTOBER 15, 1974 - DECEMBER 30, 1974

Constituent	October 15, 1974	December 30, 1974	Range During Test (Oct. 16-Dec. 30) Min	Max
pH	7.34	7.82	7.22	7.82
Specific Conductance (umhos/cm)	22,200	23,000	20,750	23,600
Total Dissolved Solids	16,181	16,100	15,650	16,170
Alkalinity ($CaCO_3$)	172	200	176	200
Hardness	2815	3200	2775	3200
Calcium	341	338	333	375
Magnesium	478	572	447	572
Sodium	5000	5000	4800	5000
Potassium	202	150	150	215
Chloride	8500	8200	7870	8500
Sulfate	1003	1590	1590	1776
H_2S	1.8	6.0	3.0	6.0
Color (Chloroplatinate Units)	<2	28	<2	80
Turbidity (FTU)	0.4	3.5	0.4	18.5

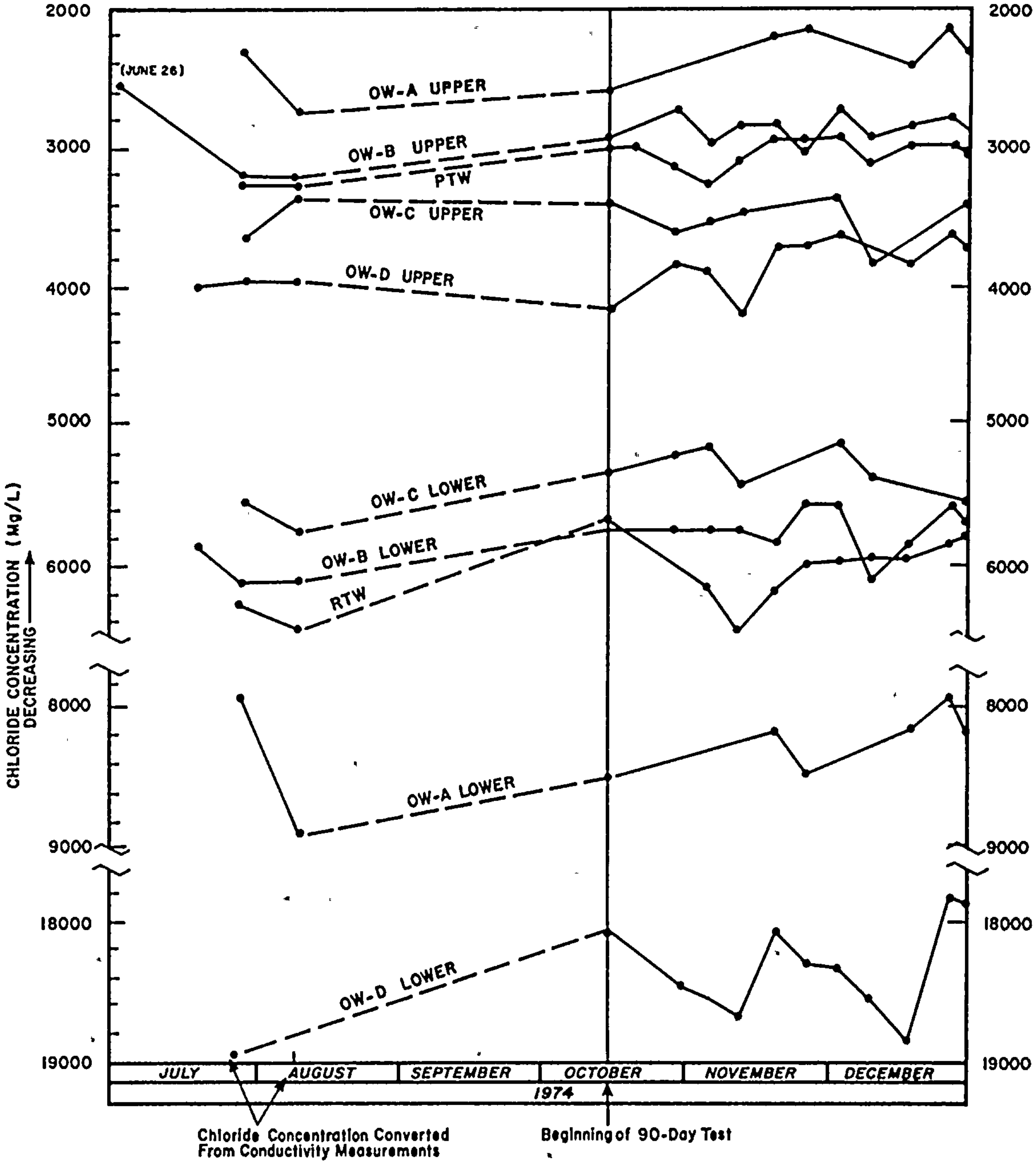
Unless otherwise noted, concentrations given in milligrams per liter (mg/l).

the upper zone of Observation Well A. A graph of chloride concentration for each of the wells versus time beginning in July, 1974 (Figure 9-2) indicates that conditions during the long-term test had very little influence on the chloride concentration and if anything, the chlorides show a slight decrease in most zones during the test.

Noticeable changes during the course of the pump test were observed, however, in the values of color, turbidity, and hydrogen sulfide for both zones monitored in OW-A. The difference in the values for H_2S is thought to be the result of the different methods of analysis. The higher value was obtained in the field with a Hach hydrogen sulfide test kit. Due to the problem of chemically fixing a gas such as H_2S, field analysis is believed to be more accurate.

The higher turbidity measured during the pumping may be caused by the increased flow and the resulting transport of sediment from solution openings. Color within the Floridan water varied significantly possibly for the same reasons as turbidity where the concentration of color-adding elements such as iron, which were not measured in the modified analysis, may have increased.

The third phase of the hydrochemical investigation was to take all the data and develop a composite or representative chemical composition for each of the monitored zones in the Floridan aquifer. This was done for the upper, lower, and deep zones in the Production Test Well area, the upper and lower zones at Observation Well D, and the inter-



DEPTH INTERVALS FOR VARIOUS ZONES ARE GIVEN IN TABLE 8-I

WELL LOCATIONS SHOWN ON FIGURE 5-I

DAMES & MOORE

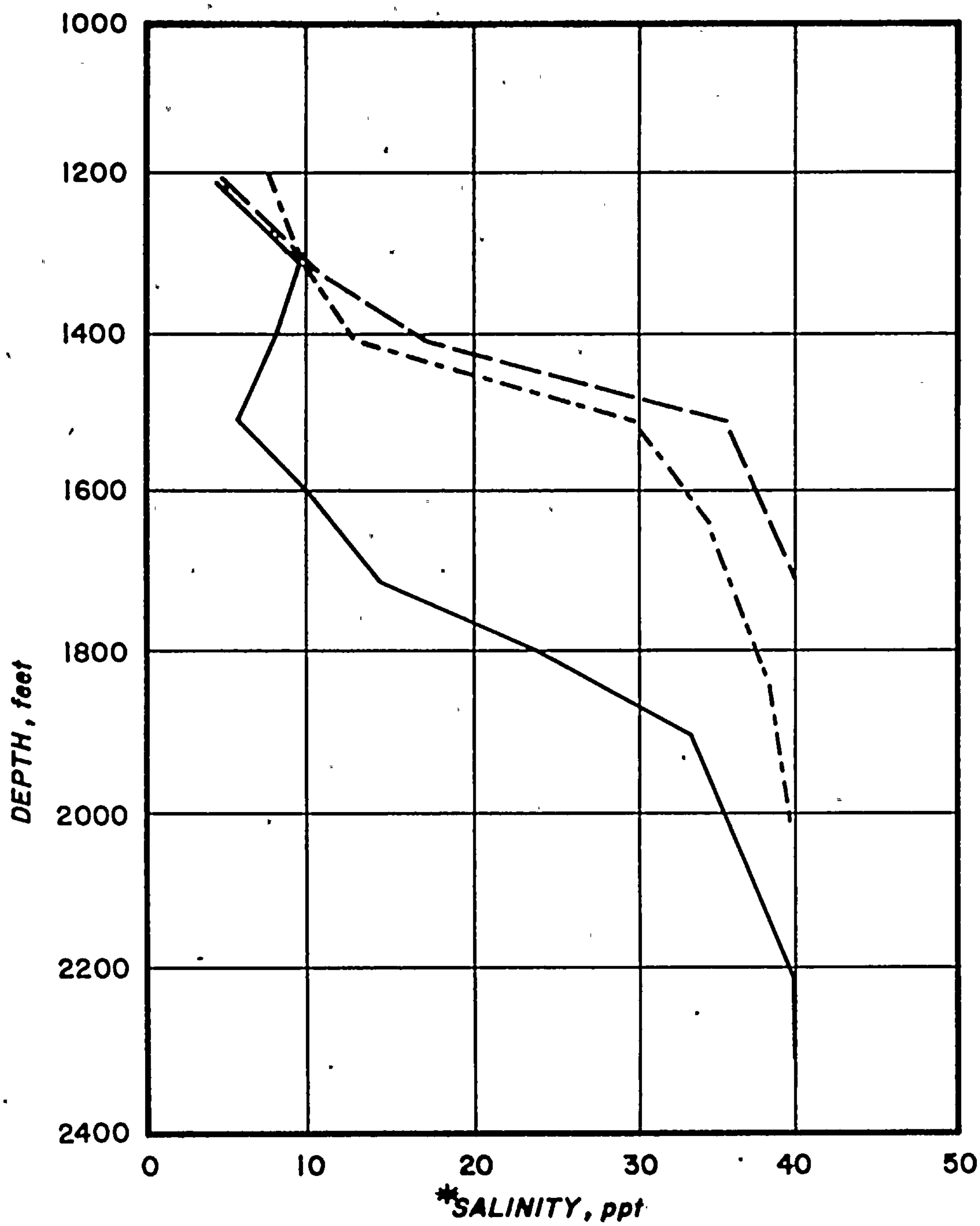
VARIATIONS IN CHLORIDE CONCENTRATION OF THE FLORIDAN AQUIFER WITH TIME IN THE AREAS OF TURKEY POINT AND KEY LARGO

6-22-75 FIGURE 9-2

val from 990-1990 feet deep in the Research Test Well (Tables 9-6 through 9-11 at end of section).

For these tables, values for individual constituents determined from each of the samples were summed and a mean was obtained. In addition, the minimum and maximum values for each constituent and the number of samples used in calculating the mean are shown for the upper and lower monitoring zones in the Production Test Well area. Because of the relatively large number of analyses and the length of time over which samples were collected, the minimum and maximum values should represent a reliable range of values for each constituent in each of the monitoring zones. Total cations and anions for the different monitoring zones will not balance, however, because of the averaging technique utilized for determining a representative concentration.

Hydrochemical data obtained from the complete, modified, and partial analyses together with field conductivity values and geophysical resistivity logs were used to plot salinity profiles for Observation Well A, Research Test Well and Observation Well D (Figure 9-3). Data from the profiles were then used to construct an idealized salinity cross-section from the Production Test Well area to Observation Well D (Figure 9-4). Salinity in parts per thousand is used in studies of seawater composition (Hem, 1970, p. 79) and is presented in these Figures to show a relationship between the chemical composition of Floridan waters and seawater.



PRODUCTION TEST WELL AREA

RESEARCH TEST WELL

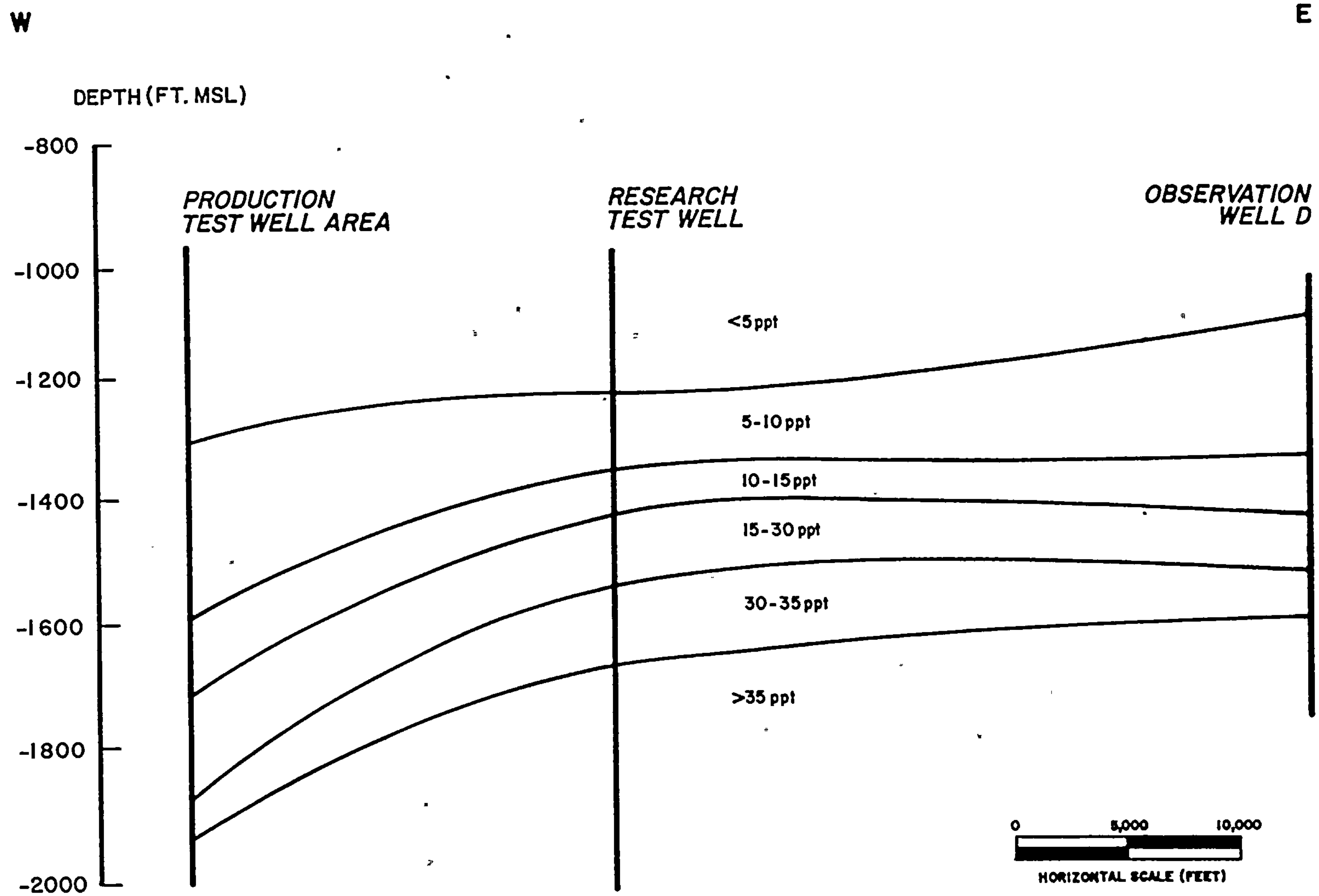
OBSERVATION WELL D

*SALINITY (ppt) = $\frac{\text{GRAMS of TOTAL DISSOLVED SOLIDS}}{\text{1000 GRAMS of } H_2O}$

DAMES & MOORE

SALINITY PROFILES

JULY 1975 FIGURE 9-3



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IDEALIZED SALINITY CROSS SECTION FROM PRODUCTION TEST WELL AREA TO OBSERVATION WELL D

6-9-75 FIGURE 9-4

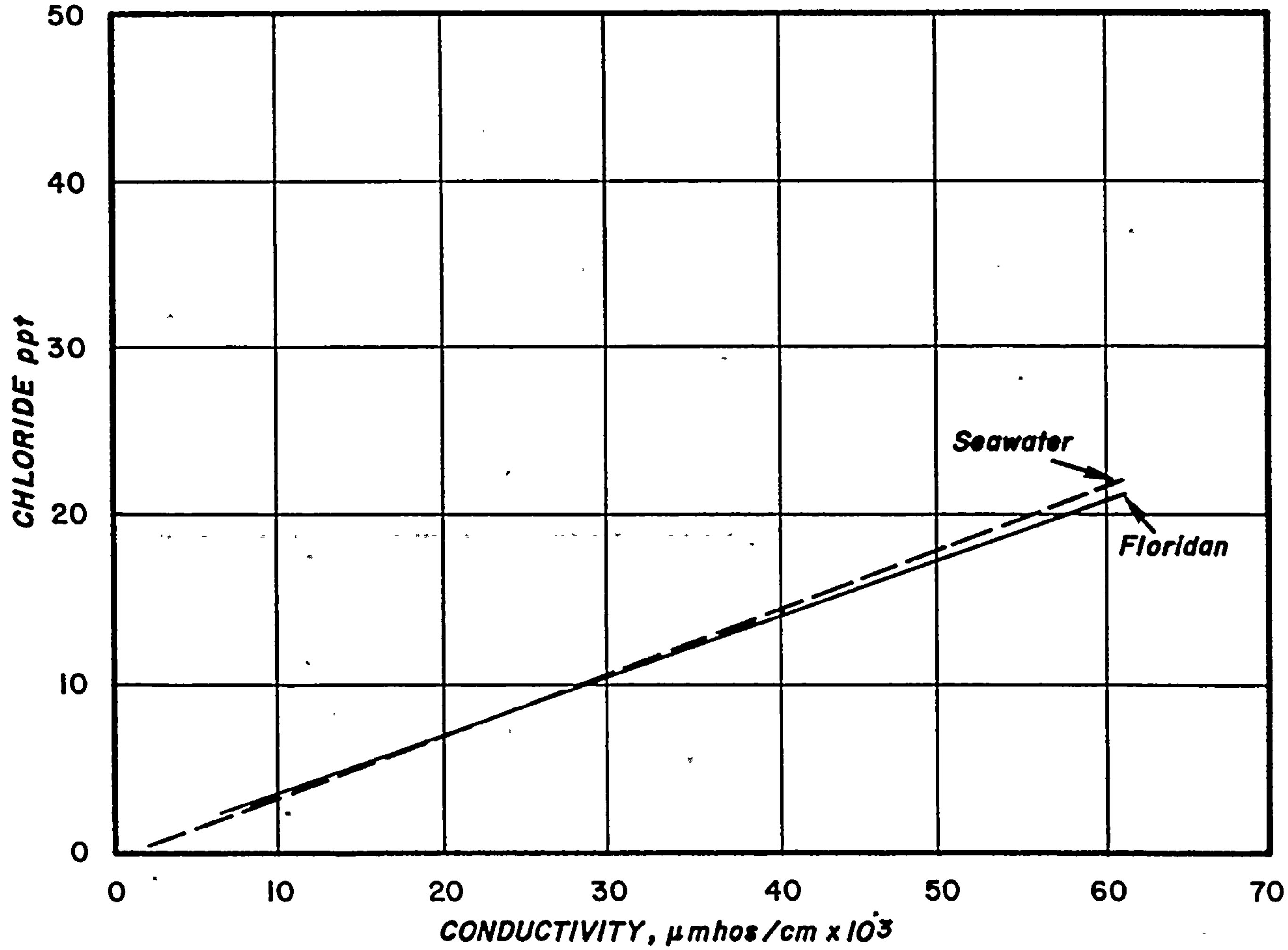
To construct these figures, conductivities were determined versus depth in the aquifer. Chloride values were assigned to each conductivity measurement by utlization of the conductivity-chloride relationship shown in Figure 9-5. This relationship was developed by performing a regression analysis of conductivity-chloride data. Salinity profiles were then developed from the following relationship:

Salinity = chloride x 1.805

The profiles and the cross-section indicate that the Production Test Well area is the least saline of the three monitored sites. The salinity of the deep zone designated as >35 ppt on Figure 9-4 is taken to be essentially seawater. This zone or layer corresponds to the deep monitoring zone in the Production Test Well area and the lower monitoring zone at Observation Well D. Salinities decrease upward to less than 5 ppt in the upper zones of the Floridan in each of the monitoring areas.

9.4 BISCAYNE AQUIFER, TURKEY POINT AREA

In order to determine any effects on the Biscayne aquifer due to the surface discharge from the Floridan aquifer, two 70-foot deep monitoring wells were drilled approximately 700 feet east and west respectively of the Production Test Well. From November 20, 1973 to December 23, 1974, conductivity and temperature profiles were run on these wells consisting of measurements at 5-foot intervals.



DAMES & MOORE

FLORIDAN AQUIFER VERSUS SEAWATER CONDUCTIVITY-CHLORIDE RELATIONSHIP

JULY 1975

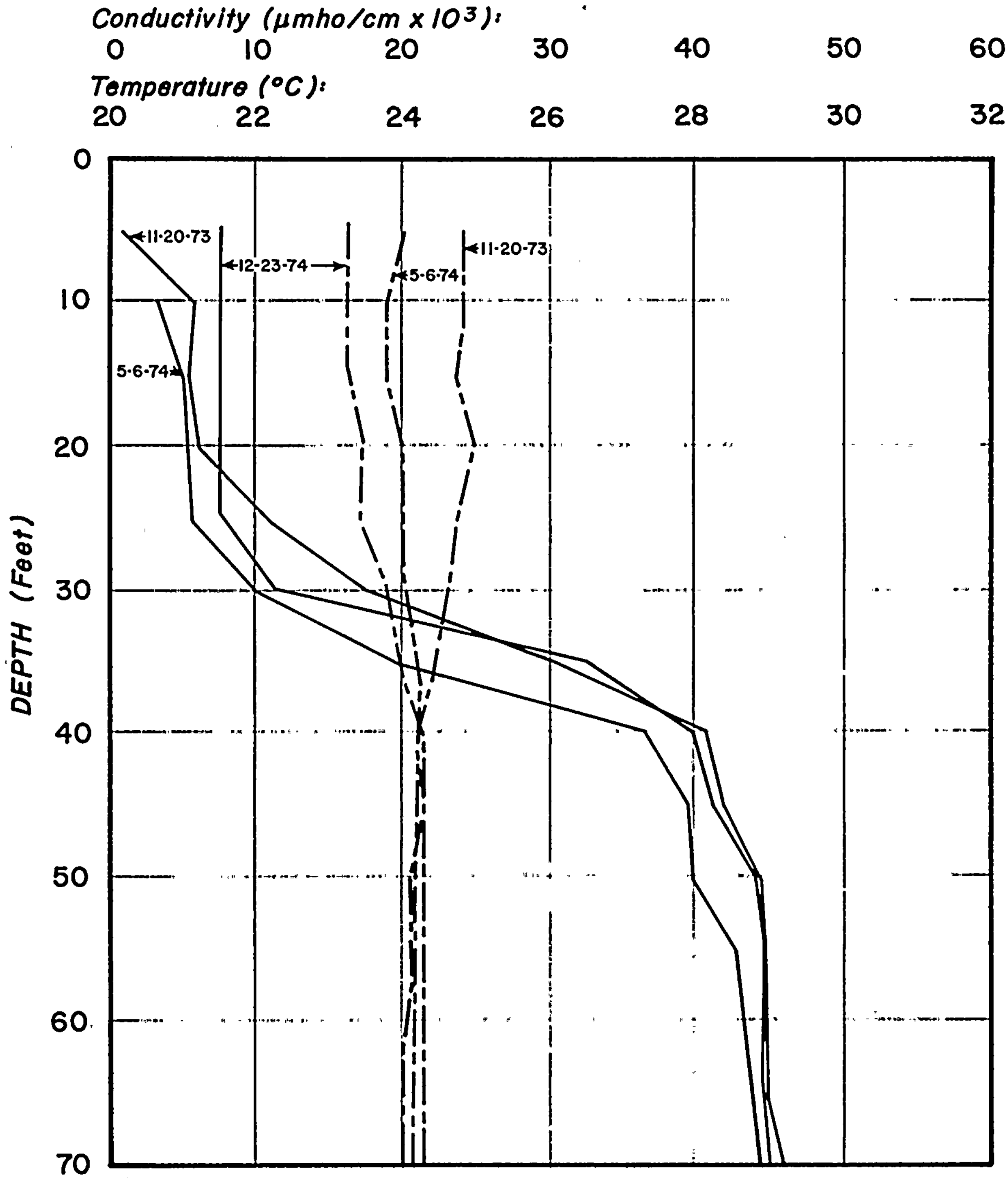
FIGURE 9-5

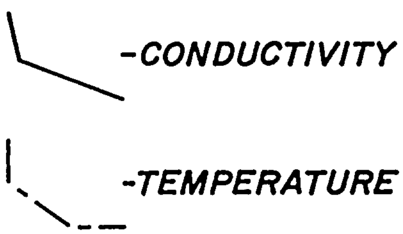
Conductivity and temperature profiles are divided into 3 time periods. These are: 1) prior to completion of the deep Floridan wells, 2) subsequent to the completion of the Floridan wells, and 3) during the 90-day pumping tests.

Conductivity-temperature profiles taken on 11/20/73 of the Biscayne monitoring wells are shown on Figures 9-6 and 9-7. The profiles reflect seasonal trends. Temperatures ranged between 24^{o}-25^{o} Centigrade at the 70-foot depth in both wells. Conductivities increased from 5 feet to 10 feet with a value of 6000 µmhos at 10 feet. From 10 feet conductivities are relatively constant down to 20 feet. Between 20 and 40 feet conductivities increase significantly to approximately 40,000 µmho/cm. From 40 feet to the base of the wells at 70 feet, conductivities remain nearly constant.

Conductivity and temperature profiles taken on 5/6/74 for the monitoring wells (Figures 9-6 and 9-7) show some effects of the 3 months of mixing Floridan waters in the Biscayne aquifer. Temperatures are cooler for the entire 70 foot profile by approximately one-half a degree Centigrade. Conductivities for this period show no apparent change in either well.

The December 23, 1974 (during the 90-day pumping test) conductivity and temperature profiles show significant changes in both temperature and conductivities. These profiles are also shown on Figures 9-6 and 9-7. In both wells temperature in the upper 30 feet are near $23.5^{o}C$.

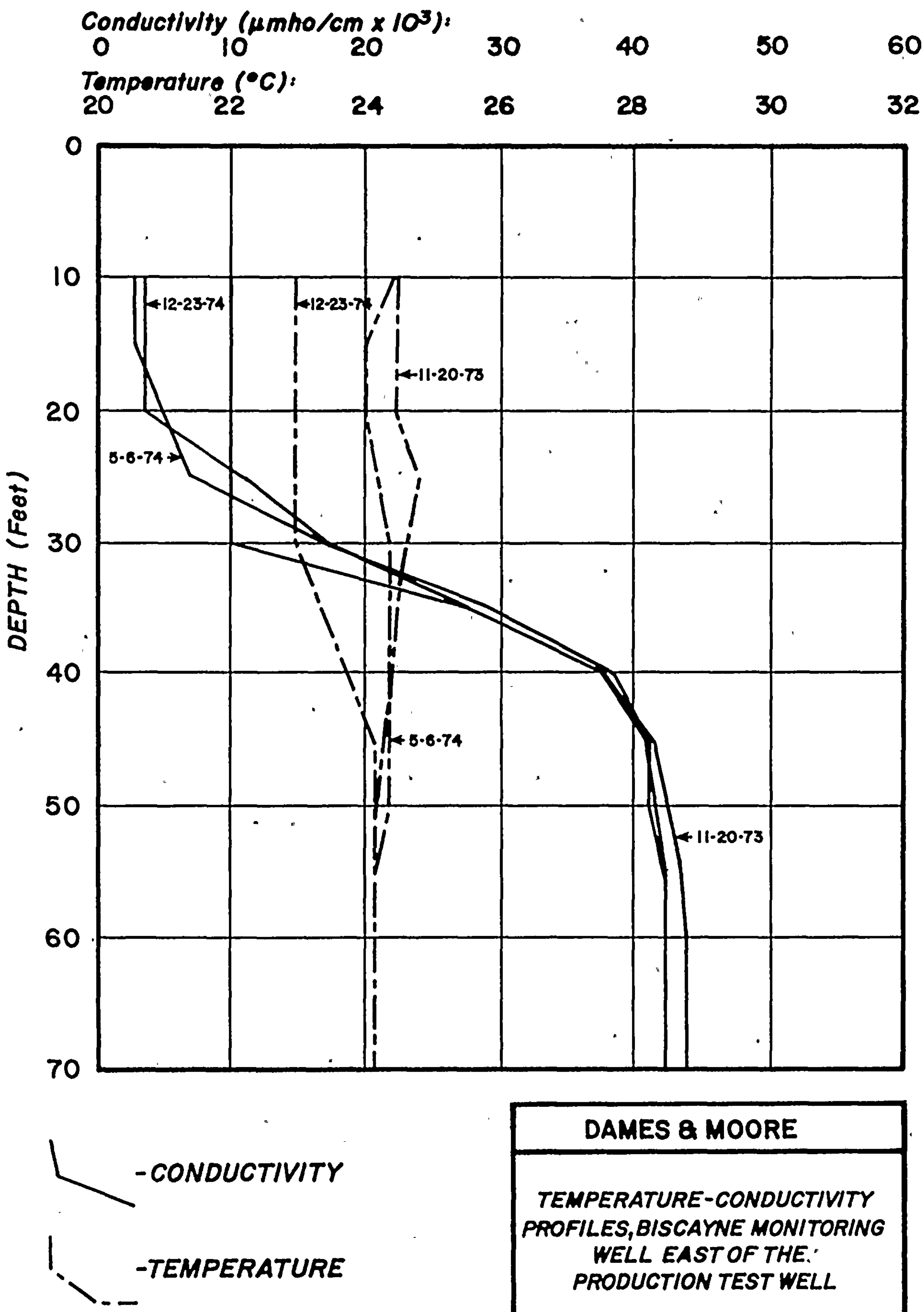




DAMES & MOORE

TEMPERATURE-CONDUCTIVITY PROFILES, BISCAYNE MONITORING WELL WEST OF THE PRODUCTION TEST WELL

JULY 1975 FIGURE 9-6



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TEMPERATURE-CONDUCTIVITY PROFILES, BISCAYNE MONITORING WELL EAST OF THE PRODUCTION TEST WELL

JULY 1975 FIGURE 9-7

which is less than the November 20, 1973 temperatures. Conductivities in the upper 30 feet have increased to 8-10,000 µmho/cm. This conductivity increase is especially pronounced in the upper 30 feet.

The profiles examined show that the natural artesian flow of the Production Test Well influences temperatures and conductivities in the upper 30 feet of each well. The 90-day pumping test of the Production Test Well at 5,000 gpm lowered temperatures approximately one degree from previously observed temperatures. Conductivities during pumping tests have increased in the upper 30 feet. Both conductivity and temperature changes observed are attributed to the mixing of cooler more saline Floridan water in the Biscayne aquifer.

Table 9-6

PRODUCTION TEST WELL AREA
UPPER MONITORING ZONE (-1113 to -1345 MSL)
REPRESENTATIVE HYDROCHEMICAL COMPOSITION

Constituent	Number Samples	Range Min	Range Max	Mean
Calcium	48	116	196	149
Magnesium	48	120	252	177
Sodium	48	1150	2100	1714
Potassium	49	50	120	77
Bicarbonate (HCO_3)	45	162	268	196
Carbonate	0	0	0	0
Hydroxide	0	0	0	0
Sulfate	49	575	770	661
Chloride	48	2190	3850	2909
Nitrate (as N)	10	<0.001	0.03	<0.01
Fluoride	8	0.28	3.6	1.6
Total Hardness as $CaCO_3$	47	900	1750	1136
Methyl Orange Alk	5	165	220	193
MBAS	3	0.001	0.014	0.007
CO_2 free, by calculation	4	4	5	5
Silica	8	6	18	12
TDS Actual	53	4500	7016	5451
TSS	11	0.1	<10	<1.0
Turbidity (FTU)	32	0.3	5.2	1.1
Color (Chloroplatinate units)	32	<2	70	16
pH (units)	49	7.3	7.9	7.7

Table 9-6 (Cont.)

PRODUCTION TEST WELL AREA
UPPER MONITORING ZONE (-1113 to -1345 MSL)
REPRESENTATIVE HYDROCHEMICAL COMPOSITION

Constituent	Number Samples	Range Min	Range Max	Mean
Conductance (μmhos/cm)	50	6800	10850	9066
H_2S as H_2S	38	1.0	3.5	2.4
Total Phosphate (PO_4)	9	0.10	0.14	0.11
Total Iron	11	0.07	0.67	0.28
Manganese	10	<0.002	<0.10	<0.07
Lead	10	<0.002	<0.10	<0.07
Copper	10	<0.004	<0.03	<0.02
Arsenic	7	Nil	<0.8	<0.2
Selenium	5	<0.003	<0.5	<0.2
Chromium	10	<0.002	<0.02	<0.0147
Mercury	11	<0.001	<0.0013	<0.0003
Zinc	10	<0.002	<0.02	<0.010
Silver	5	<0.001	<0.01	<0.005
Cadmium	5	<0.001	<0.003	<0.002
Aluminum	10	<0.05	<0.5	<0.02
Nickel	10	<0.001	0.06	<0.031
Molybdenum	9	Nil	<0.1	<0.1
Strontium	4	5.8	9.0	6.8

All values are expressed in milligrams/liter unless otherwise notated.

Table 9-7

PRODUCTION TEST WELL AREA
LOWER MONITORING ZONE (-1496 to -1696 MSL)
REPRESENTATIVE HYDROCHEMICAL COMPOSITION

Constituent	Number Samples	Range Min	Range Max	Mean
Calcium	29	215	355	267
Magnesium	30	285	572	377
Sodium	30	2600	5000	3638
Potassium	27	104	215	148
Bicarbonate (HCO_3)	4	109	244	204
Carbonate	0	0	0	0
Hydroxide	0	0	0	0
Sulfate	29	1040	1776	1313
Chloride	32	4713	8500	6359
Nitrate (as N)	8	<0.001	0.10	<0.02
Fluoride	7	1.26	2.80	1.72
Total Hardness as $CaCO_3$	26	1580	3200	2134
Methyl Orange Alk	3	166	221	196
MBAS	4	0.001	0.01	0.01
CO_2 free, by calculation	5	4.0	7.4	5.3
Silica	8	9	20	14.9
TDS Actual	31	10365	16632	12724
TSS	9	0.9	75	16.3
Turbidity (FTU)	26	0.3	18.5	1.1
Color (Chloroplatinate units)	29	2	80	10.4
pH (units)	28	7.2	7.8	7.5

Table 9-7 (Cont.)

PRODUCTION TEST WELL AREA
LOWER MONITORING ZONE (-1496 to -1696 MSL)
REPRESENTATIVE HYDROCHEMICAL COMPOSITION

Constituent	Number Samples	Range Min	Range Max	Mean
Conductance (umhos/cm)	29	15500	23600	18091
H_2S as H_2S	29	1.8	6.0	4.3
Total Phosphate (PO_4)	8	0.012	0.43	<0.13
Total Iron	8	0.012	2.86	0.50
Manganese	9	<0.002	<0.10	<0.06
Lead	9	<0.002	<0.1	<0.059
Copper	8	0.0005	0.12	0.0273
Arsenic	6	0.001	0.8	0.269
Selenium	5	0.003	0.50	<0.22
Chromium	9	0.002	<0.05	<0.02
Mercury	9	0.0001	0.002	<0.0004
Zinc	9	<0.002	<0.05	<0.02
Silver	7	Nil	<0.01	<0.005
Cadmium	7	0.001	0.005	0.002
Aluminum	9	<0.05	<0.1	<0.02
Nickel	9	0.001	0.08	0.05
Molybdenum	7	<0.01	<0.10	<0.09
Strontium	3	5.8	13.3	16.2

All values are expressed in milligrams/liter unless otherwise notated.

Table 9-8

PRODUCTION TEST WELL AREA
DEEP MONITORING ZONE* (-2095 to -2301 MSL)
REPRESENTATIVE HYDROCHEMICAL COMPOSITION

Constituent	Results of Analysis
Calcium	785
Magnesium	1350
Sodium	11200
Potassium	380
Bicarbonate (HCO_3)	156
Carbonate	0
Hydroxide	0
Sulfate	2950
Chloride	21000
Nitrate (as N)	<0.001
Fluoride	1.12
Total Hardness as $CaCO_3$	7210
Methyl Orange Alk	177
MBAS	0.012
CO_2 free, by calculation	<5
Silica	6.6
TDS, Actual	40350
TDS, Calculation	37710
Color (Chloroplatinate units)	15
pH (units)	7.0
Conductance (μmhos/cm)	60000
H_2S as H_2S	<0.1
Total Phosphate (PO_4)	0.019

Table 9-8 (Cont.)

PRODUCTION TEST WELL AREA
DEEP MONITORING ZONE* (-2095 to -2301 MSL)
REPRESENTATIVE HYDROCHEMICAL COMPOSITION

Constituent	Results of Analysis
Total Iron	7.4
Manganese	<0.002
Lead	<0.002
Copper	<0.006
Arsenic	<0.8
Selenium	<0.5
Chromium	<0.002
Mercury	<0.004
Zinc	<0.002
Silver	<0.001
Cadmium	<0.001
Aluminum	<0.5
Nickel	<0.002

All values are expressed in milligrams/liter unless otherwise notated.

* Analysis based on one sample.

Table 9-9

OBSERVATION WELL D - KEY LARGO
UPPER MONITORING ZONE (-1042 to -1379 MSL)
REPRESENTATIVE HYDROCHEMICAL COMPOSITION

Constituent	Results of Analysis
Calcium	168
Magnesium	226
Sodium	2287
Potassium	97
Bicarbonate (HCO_3)	231
Carbonate	0
Hydroxide	0
Sulfate	769
Chloride	3758
Nitrate (as N)	0.01
Fluoride	1.20
Total Hardness as $CaCO_3$	1346
Methyl Orange Alk	190
MBAS	0.040
Carbon Dioxide as CO_2	9.0
Silica	13
TDS Actual	7269
TSS	1.0
Turbidity (FTU)	4.2
Color (Chloroplatinate units)	28
pH (units)	7.8
Conductance (μmhos/cm)	11,255

Table 9-9 (Cont.)

OBSERVATION WELL D - KEY LARGO
UPPER MONITORING ZONE (-1042 to -1379 MSL)
REPRESENTATIVE HYDROCHEMICAL COMPOSITION

Constituent	Results of Analysis
H_2S as H_2S	2.9
Total Phosphate (PO_4)	0.1
Total Iron	0.65
Manganese	<0.1
Lead	<0.1
Copper	0.04
Arsenic	<0.002
Selenium	0.01
Chromium	<0.02
Mercury	<0.002
Zinc	<0.02
Silver	<0.01
Cadmium	<0.0005
Aluminum	<0.1
Nickel	0.14
Molybdenum	<0.1
Strontium	7.4

All values are expressed in milligrams/liter unless otherwise notated.

Table 9-10

OBSERVATION WELL D - KEY LARGO
LOWER MONITORING ZONE (-1436 to -1714 MSL)
REPRESENTATIVE HYDROCHEMICAL COMPOSITION

Constituent	Results of Analysis
Calcium	605
Magnesium	1072
Sodium	10510
Potassium	385
Bicarbonate (HCO_3)	550
Carbonate	0
Hydroxide	0
Sulfate	2559
Chloride	18359
Nitrate (as N)	0.015
Fluoride	1.41
Total Hardness as $CaCO_3$	5921
Methyl Orange Alk	450
MBAS	0.010
Carbon Dioxide, as CO_2	16.6
Silica	9
TDS Actual	34863
TSS	0.4
Turbidity (FTU)	9.2
Color (Chloroplatinate units)	77
pH (units)	7.3
Conductance (μmhos/cm)	44,834

Table 9-10 (Cont.)

OBSERVATION WELL D - KEY LARGO
LOWER MONITORING ZONE (-1436 to -1714 MSL)
REPRESENTATIVE HYDROCHEMICAL COMPOSITION

Constituent	Results of Analysis
H_2S as H_2S	2.8
Total Phosphate (PO_4)	0.1
Total Iron	1.42
Manganese	<0.1
Lead	<0.1
Copper	0.06
Arsenic	0.001
Selenium	<0.01
Chromium	0.05
Mercury	<0.0002
Zinc	<0.02
Silver	<0.01
Cadmium	0.004
Aluminum	0.25
Nickel	0.22
Molybdenum	<0.1
Strontium	15.8

All values are expressed in milligrams/liter unless otherwise notated.

Table 9-11

RESEARCH TEST WELL
COMPOSITE MONITORING ZONE (-990 to -1990 MSL)
REPRESENTATIVE HYDROCHEMICAL COMPOSITION

Constituent	Results of Analysis
Calcium	245
Magnesium	362
Sodium	3467
Potassium	144
Bicarbonate (HCO_3)	185
Carbonate	0
Hydroxide	0
Sulfate	1080
Chloride	6059
Nitrate (as N)	0.01
Fluoride	1.1
Total Hardness as $CaCO_3$	2097
Methyl Orange Alk	179
MBAS	0.012
CO_2 free, by calculation	<4
Silica	11
TDS Actual	11,583
TSS	0.8
Turbidity (FTU)	1.7
Color (Chloroplatinate units)	7
pH (units)	7.5
Conductance (µmhos/cm)	16,925
H_2S as H_2S	3.3

Table 9-11 (Cont.)

RESEARCH TEST WELL
COMPOSITE MONITORING ZONE (-990 to -1990 MSL)
REPRESENTATIVE HYDROCHEMICAL COMPOSITION

Constituent	Results of Analysis
Total Phosphate (PO_4)	0.1
Total Iron	0.18
Manganese	<0.1
Lead	<0.1
Copper	<0.0005
Arsenic	<0.005
Selenium	<0.003
Chromium	<0.02
Mercury	<0.0002
Zinc	<0.005
Silver	<0.002
Cadmium	<0.001
Aluminum	0.2
Nickel	<0.001
Molybdenum	<0.1
Strontium	9.4

All values are expressed in milligrams/liter unless otherwise notated.

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Appendix A-1

LITHOLOGIC LOG OF PRODUCTION TEST WELL

Owner:	Florida Power & Light Company
Location:	T58S, R39E, SW ¼ of Section 26
County:	Dade
Elevation:	4.23' above mean sea level
Driller:	Alsay Pippin Corporation, Lake Worth, Florida
Started:	9/30/73
Completed:	3/12/74
Depth:	1400'
Casing:	36" to 237'; 24" to 872'; 20" from 805'-1126'

DEPTH

0-3 Rock fill

Recent:

3-7 Marl soil

Pleistocene Series:

Miami Limestone:

7-10	Limestone:	brown to buff, poorly consolidated, sparsely fossiliferous, some surface weathering
10-25	Limestone:	brown, poorly consolidated, friable, local solution and secondary crystallization

Fort Thompson Formation:

25-33	Limestone:	white, indurated, sparsely fossiliferous, local solution and secondary crystallization
33-60	Limestone:	white, indurated to poorly consolidated, sparsely fossiliferous, locally crystalline
60-72	Limestone:	white, poorly consolidated, friable, sparsely fossiliferous, locally crystalline
72-90	Limestone:	white to brown, poorly consolidated, fossiliferous

Miocene Series:

Tamiami Formation:

90-100	Sand:	light tan, unconsolidated, fine grained, quartz sand

LITHOLOGIC LOG OF PRODUCTION TEST WELL (Continued)

Hawthorn Formation:

100-183	Sand:	olive green, very fine grained quartz, slightly silty, sparsely fossiliferous
183-276	Clay:	dark olive green, calcareous, slightly sandy and phosphatic, sparsely fossiliferous
276-446	Clay:	dark olive green calcareous, silty (decreasing with depth), slightly phosphatic from 440'-460' sparsely fossiliferous, inter-bedded with thin beds of limestone: dark olive green, argillaceous, sparsely fossiliferous

Tampa Stage, St. Marks Formation:

446-570	Limestone:	buff, poorly consolidated to well consolidated, locally argillaceous, sandy, sparsely fossiliferous
570-660	Limestone:	buff to occasionally gray, poorly consolidated to well consolidated, silty, sparsely fossiliferous
660-670	Limestone:	buff to gray, poorly consolidated to well consolidated, sandy, argillaceous, sparsely fossiliferous
670-745	Limestone:	tan to buff, poorly consolidated to well consolidated, silty, sparsely fossiliferous
745-850	Limestone:	tan to buff, poorly consolidated to well consolidated, locally sandy and argillaceous
850-920	Limestone:	gray to buff, poorly consolidated to well consolidated, locally crystalline, sparsely fossiliferous
920-940	Limestone:	gray to buff, poorly consolidated to well consolidated, slightly silty, sandy, phosphatic, locally crystalline, sparsely fossiliferous
940-950	Limestone:	white to buff, poorly consolidated, argillaceous, sparsely fossiliferous
950-960	Limestone:	white to buff, poorly consolidated, very argillaceous, sparsely fossiliferous
960-980	Claystone/ Siltstone:	white to pale green, calcareous with some limestone: white to pale green, poorly consolidated, very argillaceous
980-990	Limestone:	white to buff, poorly consolidated, very argillaceous

990-1098	Claystone/ Siltstone:	white to pale green, calcareous with some limestone: white to pale green, very argillaceous

Oligocene Series:

Suwannee Limestone:

1098-1120	Limestone:	white to buff, consolidated, silty
1120-1140	Limestone:	white to gray, indurated, sparsely fossiliferous
1140-1255	Limestone:	white to light brown, poorly consolidated to well consolidated, granular to dense, sandy, local solution and secondary crystallization, fossiliferous, large foraminifera common

Eocene Series:

Avon Park Limestone:

1255-1310	Limestone:	white to light brown, poorly consolidated to well consolidated, granular to dense, fossiliferous
1310-1330	Limestone:	white to light brown, poorly consolidated to well consolidated, granular to dense, fossiliferous coral abundant and clay: pale grayish green, calcareous, sandy
1330-1340	Limestone:	white to light brown, poorly consolidated, granular, occasionally dense and well consolidated, abundantly fossiliferous
1340-1400	Limestone:	white to light brown, well consolidated, dense, occasionally poorly consolidated and granular, moderately fossiliferous

Appendix A-2

LITHOLOGIC LOG OF OBSERVATION WELL A

Owner:	Florida Power & Light Company
Location:	T58S, R39E, SW ¼ of Section 26
County:	Dade
Elevation:	3.13' above mean sea level
Driller:	Alsay Pippin Corporation, Lake Worth, Florida
Started:	10/3/73
Completed:	3/11/74
Depth:	2300'
Casing:	24" to 239'; 14" to 1116'; 8" to 1535'; 5" to 2098'

DEPTH

0-4 Rock fill

Recent:

4-5.5 Marl soil

Pleistocene Series:

Miami Limestone:

5.5-15	Limestone:	white to gray, brittle
15-23	Clay:	brown, sandy and limestone: white to gray, brittle

Fort Thompson Formation:

23-60	Limestone:	brown to gray to white, brittle, sparsely fossiliferous
60-85	Limestone:	buff, poorly consolidated to consolidated, sparsely fossiliferous

Miocene Series:

Tamiami Formation:

85-95	Sand:	light tan, unconsolidated, fine grained quartz sand

Hawthorn Formation:

95-150	Sand:	olive green, very fine grain quartz, sparsely phosphatic, sparsely fossiliferous, some thin cemented zones
150-160	Clay:	olive green, calcareous, silty, sparsely fossiliferous
160-183	Sand:	olive green, calcareous, gravelly, argillaceous, abundantly fossiliferous
183-250	Clay:	dark olive green, calcareous, sandy,

LITHOLOGIC LOG OF OBSERVATION WELL A (Continued)

		silty, sparsely fossiliferous
250-330	Clay:	olive green, calcareous, sandy, silty, sparsely fossiliferous, and limestone: tan to gray, moderately well consolidated
330-446	Clay:	olive green, calcareous, sandy, silty, sparsely fossiliferous

Tampa Stage, St. Marks Formation:

446-470	Limestone:	white, brittle, sparsely fossiliferous, also abundant black material possibly a weathering product
470-500	Limestone:	white to gray, brittle, sparsely fossiliferous
500-530	Limestone:	cream to buff, poorly consolidated to moderately well consolidated, slightly phosphatic at 520'
530-720	Limestone:	white to buff, poorly consolidated to moderately well consolidated, sparsely fossiliferous, occasional fragments of gray limestone
720-760	Limestone:	tan to buff, poorly consolidated to well consolidated, slightly sandy, sparsely fossiliferous
760-790	Claystone/ Siltstone:	olive green, calcareous, sandy, and limestone: tan to gray, consolidated
790-810	Limestone:	light olive green, poorly consolidated to moderately well consolidated, argillaceous
810-920	Limestone:	white to tan, poorly consolidated to moderately well consolidated, sparsely fossiliferous
920-970	Limestone:	tan to gray, poorly consolidated to moderately well consolidated, sparsely fossiliferous
970-990	Limestone:	cream to buff, poorly consolidated to moderately well consolidated, sparsely fossiliferous
990-1056	Claystone/ Siltstone:	pale green to gray, calcareous, sandy, limestone occurs locally
1056-1060	Limestone:	tan to gray, poorly consolidated, argillaceous, sparsely fossiliferous
1060-1098	Claystone/ Siltstone:	pale green, calcareous, silty, limestone occurs locally

Oligocene Series:

Suwannee Limestone:

1098-1115	Limestone:	white, poorly consolidated to well consolidated, also abundant dark material, possibly weathering product

1115-1130	Limestone:	tan, consolidated, sparsely fossiliferous
1130-1180	Limestone:	tan to light gray, poorly consolidated, brittle, locally crystalline
1180-1190	Limestone:	white to light brown, coquinoidal, poorly consolidated, occasional fragments of limestone: tan to light brown, consolidated, dense
1190-1236	Limestone:	tan to light brown, consolidated, brittle, dense, crystalline, locally porous, sparsely fossiliferous
1236-1255	Limestone:	brown to gray, granular, poorly consolidated to consolidated, sandy, sparsely fossiliferous

<u>Eocene Series:</u>

<u>Avon Park Limestone:</u>

1255-1280	Limestone:	white to light brown, coquinoidal, moderately well consolidated, coral abundant, occasional fragments of limestone: light gray, consolidated, dense
1280-1340	Limestone:	light brown, consolidated, dense, porous, vuggy, sparsely fossiliferous
1340-1380	Limestone:	tan, granular, poorly consolidated, porous, occasional fragments of limestone: gray, consolidated, dense
1380-1395	Limestone:	tan, well consolidated to moderately well consolidated, dense to granular and porous, sparsely fossiliferous
1395-1410	Limestone:	tan to gray, well consolidated to moderately well consolidated, dense to granular and porous, sparsely fossiliferous, trace of black argillaceous material
1410-1490	Limestone:	tan to gray to cream, moderately well consolidated, moderately dense, vuggy, sparsely fossiliferous
1490-1493	Clay:	light gray to dary gray, silty
1493-1530	Limestone:	tan to gray, consolidated, moderately dense, vuggy, abundantly fossiliferous
1530-1540	Limestone:	cream to buff, poorly consolidated, granular, sparsely fossiliferous
1540-1550	Limestone:	tan to buff, poorly consolidated to consolidated, slightly sandy, cherty, sparsely fossiliferous, whole small echinoids present
1550-1630	Limestone:	tan to buff, poorly consolidated, friable, porous, abundantly fossiliferous, microfossils and echinoids common

LITHOLOGIC LOG OF OBSERVATION WELL A (Continued)

1630-1642	Limestone:	light gray, poorly consolidated, porous, vuggy, moderately fossiliferous
1642-1660	Limestone:	tan to light brown, poorly consolidated, sandy, fossiliferous, and limestone: gray, poorly consolidated, dense, sparsely fossiliferous
1660-1690	Limestone:	tan, moderately well consolidated, brittle, porous, fossiliferous, and limestone: gray, consolidated, dense, sparsely fossiliferous
1690-1720	Limestone:	tan, poorly consolidated, granular, friable, crystalline calcite present, abundantly fossiliferous
1720-1730	Limestone:	tan, moderately well consolidated, moderately dense, sandy, sparsely fossiliferous
1730-1760	Limestone:	tan to gray, moderately well consolidated, moderately dense, argillaceous

Lake City Limestone:

1760-1810	Limestone:	tan, moderately well consolidated, granular, porous, occasionally dense, abundantly fossiliferous
1810-1820	Limestone:	gray, consolidated, dense
1820-1890	Limestone:	tan to buff, poorly consolidated, porous and vuggy, sparsely fossiliferous
1890-1910	Limestone:	buff to light brown, poorly consolidated to moderately well consolidated, oolitic and limestone: brown, consolidated, dense, oolitic
1910-1920	Limestone:	buff, poorly consolidated, sandy, sparsely fossiliferous
1920-1930	Limestone:	tan to black, moderately well consolidated, sparsely fossiliferous and limestone: light gray, consolidated, dense and limestone: tan, unconsolidated, sandy
1930-1940	Limestone:	tan, poorly consolidated, fossiliferous
1940-2020	Limestone:	tan, poorly consolidated, granular, friable, fossiliferous and limestone: light gray, consolidated, dense, sparsely fossiliferous
2020-2030	Limestone:	buff, poorly consolidated, porous, vuggy
2030-2040	Limestone:	light gray, consolidated, porous, vuggy
2040-2110	Limestone:	tan to buff, poorly consolidated, porous, sparsely fossiliferous and limestone: dary brown, consolidated, dense
2110-2120	Limestone:	buff to white, poorly consolidated, granular, friable, porous, slightly

		sandy, sparsely fossiliferous
2120-2170	Limestone:	buff to white, poorly consolidated, granular, friable, porous, fossiliferous, locally crystalline, consolidated, dense
2170-2200	Limestone:	grayish brown to dark yellowish brown, crystalline, dense
2200-2220	Limestone:	buff, moderately well consolidated, granular, somewhat friable, fossiliferous, locally consolidated, dense
2220-2230	Claystone/ Siltstone	laminated, black to medium gray grading to very light gray, calcareous, slightly sandy
2230-2300	Limestone:	buff, moderately well consolidated to poorly consolidated, granular, friable, fossiliferous, locally dense

Appendix A-3

LITHOLOGIC LOG OF OBSERVATION WELL B

Owner:	Florida Power & Light Company
Location:	T58S, R39E, SW ¼ of Section 26
County:	Dade
Elevation:	4.41' above mean sea level
Driller:	Alsay Pippin Corporation, Lake Worth, Florida
Started:	3/29/74
Completed:	7/2/74
Depth:	1700 feet
Casing:	14" to 248'; 8" to 1098'; 5" to 1498'

DEPTH

0-3.5	Rock fill	

Recent:

3.5-7.5	Marl soil	

Pleistocene Series:

Miami Limestone:

7.5-30	Limestone:	cream, consolidated, brittle, sandy, fossiliferous, crystalline calcite present

Fort Thompson Formation:

30-60	Limestone:	cream to light brown, moderately well consolidated, sandy, sparsely fossiliferous, crystalline calcite present
60-85	Limestone:	light gray, poorly consolidated to consolidated, sandy

Miocene Series:

Tamiami Formation:

85-100	Sand:	light tan, unconsolidated, fine grain quartz, sparsely fossiliferous

LITHOLOGIC LOG OF OBSERVATION WELL B (Continued)

Hawthorn Formation:

100-181.5	Sand:	olive green, very fine grain quartz, silty, sparsely fossiliferous, some cemented zones
181.5-182	Clay:	light gray, calcareous, sandy, fossiliferous
182-260	Lost circulation, no recovery	
260-300	Sand:	dark olive green, fine grained, argillaceous
300-390	Sand:	dark olive green, fine grained, very argillaceous, slightly phosphatic.
390-449	Clay:	dark olive green, calcareous, slightly phosphatic, sparsely fossiliferous, trace limestone fragments

Tampa Stage, St. Marks Formation:

449-560	Limestone:	light gray to buff, consolidated, sandy, fossiliferous
560-640	Limestone:	light gray, granular, poorly consolidated to moderately well consolidated, dense, locally porous, sandy, argillaceous, abundantly fossiliferous
640-650	Claystone/Siltstone:	olive green, calcareous, sandy, fossiliferous, with light gray argillaceous limestone
650-710	Limestone:	light gray to buff, granular, poorly consolidated to moderately well consolidated, generally friable, porous, vuggy, slightly sandy and phosphatic, abundantly fossiliferous
710-750	Claystone/Siltstone:	light yellowish gray, calcareous, silty, fossiliferous, locally limestone
750-790	Claystone/Siltstone:	light greenish gray, calcareous, silty, fossiliferous, locally limestone
790-820	Claystone/Siltstone:	olive green, calcareous, silty, slightly phosphatic, fossiliferous, locally limestone
820-850	Limestone:	light gray, poorly consolidated, dense and clay: as above
850-870	Limestone:	light gray to white, consolidated, sparsely fossiliferous
870-880	Sand:	light gray, very fine grained, phosphatic and limestone: light gray to white, consolidated, sparsely fossiliferous
880-900	Limestone:	light gray to white, consolidated, sandy
900-950	Claystone/Siltstone:	light greenish gray, calcareous, slightly sandy, sparsely fossiliferous, with some limestone fragments present

LITHOLOGIC LOG OF OBSERVATION WELL B (Continued)

950-990	Limestone:	tan to buff, moderately well consolidated, vuggy, argillaceous, fossiliferous, and sandstone: dark olive green, fine grained, calcareous
990-1098	Claystone/ Siltstone:	grayish green, calcareous, sandy and limestone: white to buff, consolidated, dense, fossiliferous

Oligocene Series:

Suwannee Limestone:

1098-1130	Limestone:	white to tan, moderately well consolidated, moderately dense, crystalline calcite present, sparsely fossiliferous
1130-1170	Limestone:	white to tan, granular, poorly consolidated, friable, fossiliferous
1170-1180	Limestone:	white to light brown, consolidated, dense, locally porous and vuggy, sparsely fossiliferous
1180-1210	Limestone:	light brown, consolidated, dense, somewhat vuggy, fossiliferous
1210-1246	Limestone:	medium gray, consolidated, dense dolomitic, slightly gypsiferous, sparsely fossiliferous

Eocene Series:

Avon Park Limestone:

1246-1250	Limestone:	tan, poorly consolidated, very porous, fossiliferous, coral abundant
1250-1260	Limestone:	tan, consolidated, dense, somewhat vuggy, fossiliferous, larger foraminifera casts common
1260-1280	Limestone:	light gray, granular, poorly consolidated to consolidated, sandy, abundantly fossiliferous
1280-1300	Limestone:	tan, consolidated, somewhat vuggy, abundantly fossiliferous
1300-1390	Limestone:	tan to light brown, coquinoidal, poorly consolidated, friable, crystalline calcite present, locally consolidated and dense
1390-1410	Limestone:	buff, granular, poorly consolidated, porous, locally dense, abundantly fossiliferous
1410-1590	Limestone:	saccharoidal, poorly consolidated, locally dense, crystalline calcite present, abundantly fossiliferous
1590-1610	Limestone:	medium gray to light gray, consolidated, dense

LITHOLOGIC LOG OF OBSERVATION WELL B (Continued)

1610-1700	Limestone:	buff, granular, poorly consolidated, porous, locally dense, abundantly fossiliferous

Appendix A-4

LITHOLOGIC LOG OF OBSERVATION WELL C

Owner:	Florida Power & Light Company
Location:	T58S, R39E, SW ¼ of Section 26
County:	Dade
Elevation:	3.30' above mean sea level
Driller:	Alsay Pippin Corporation, Lake Worth, Florida
Started:	February 1, 1974
Completed:	March 21, 1974
Depth:	1700'
Casing:	14" to 242'; 8" to 1122'; 5" to 1535'

DEPTH

0-5 Rock fill

Recent:

5.7 Marl soil

Pleistocene Series:

Miami Limestone:

7-32	Limestone:	white to buff, consolidated, moderately dense, cherty, fossiliferous, larger foraminifera common

Fort Thompson Formation:

32-50	Limestone:	white, consolidated, vuggy, locally crystalline
50-70	Limestone:	buff to tan, consolidated, vuggy, sparsely fossiliferous
70-80	Limestone:	buff to white, poorly consolidated to consolidated, abundantly fossiliferous, coral abundant
80-85	Limestone:	buff to gray, poorly consolidated, abundantly fossiliferous

Miocene Series:

Tamiami Formation:

85-100	Sand:	light tan, unconsolidated, fine grain quartz, sparsely fossiliferous

LITHOLOGIC LOG OF OBSERVATION WELL C (Continued)

Hawthorn Formation:

100-180	Sand:	olive green, very fine quartz sand, slightly silty, sparsely fossiliferous, phosphatic, some cemented zones
180-444	Clay:	dark olive green to greenish gray, calcareous, sandy, slightly phosphatic, fossiliferous (decreasing with depth), sand content decreasing to 350', increasing and becoming coarse grained from 350' to 380'

Tampa Stage, St. Marks Formation:

444-470	Limestone:	buff to very light brown, granular, poorly consolidated, argillaceous, slightly gypsiferous, sparsely fossiliferous
470-480	Limestone:	white to buff, consolidated, sparsely fossiliferous, and limestone: olive green, poorly consolidated, argillaceous
480-510	Limestone:	white to black, poorly consolidated fossiliferous
510-550	Limestone:	cream to buff, poorly consolidated, slightly phosphatic, sparsely fossiliferous
550-740	Limestone:	buff, poorly consolidated, dense fissile, occasionally black to gray, sparsely fossiliferous
740-770	Limestone:	buff to cream, poorly consolidated, slightly sandy and clay: light gray, silty, sandy
770-810	Claystone/Siltstone:	light green, calcareous, silty, sandy and limestone: buff to cream, sandy
810-840	Limestone:	buff to white, poorly consolidated to moderately well consolidated, fossiliferous
840-850	Limestone:	very light gray to buff, poorly consolidated to moderately well consolidated, moderately dense, sparsely fossiliferous
850-860	Limestone:	white to buff, consolidated, dense, sparsely fossiliferous
860-960	Limestone:	very light gray to buff, poorly consolidated to moderately well consolidated, moderately dense, locally porous, sandy, sparsely fossiliferous and clay: pale green, calcareous, sandy, silty
960-1098	Claystone/ Siltstone:	pale green, calcareous, sandy, silty and limestone: very light gray to buff,

LITHOLOGIC LOG OF OBSERVATION WELL C (Continued)

	moderately dense, fossiliferous, porous, sandy

Oligocene Series:

Suwannee Limestone:

1098-1240 Limestone:	buff, poorly consolidated to moderately well consolidated, porous, sandy, crystalline calcite present, fossiliferous to abundantly fossiliferous
1240-1246 Limestone:	buff, granular, poorly consolidated to moderately well consolidated, sandy, sparsely fossiliferous

Eocene Series:

Avon Park Limestone:

1246-1280 Sand:	buff, fine to coarse grained, slightly phosphatic, and limestone: buff, granular, poorly consolidated, fossiliferous
1280-1350 Limestone:	buff, granular, poorly consolidated, vuggy, sandy, locally dense, fossiliferous
1350-1380 Limestone:	buff, coquinoidal, poorly consolidated, vuggy, crystalline calcite present, locally dense and sparsely fossiliferous
1380-1550 Limestone:	white to buff, sacchaoidal, poorly consolidated, porous, crystalline calcite present, locally coquinoidal, fossiliferous to abundantly fossiliferous
1550-1700 Limestone:	buff to white, granular, poorly consolidated to occasionally consolidated, abundantly fossiliferous

Appendix A-5

LITHOLOGIC LOG OF OBSERVATION WELL D

Owner:	Florida Power & Light Company
Location:	T54S, R40E, NW ¼ of Section 35
County:	Monroe
Elevation:	11.7' above mean sea level
Driller:	Alsay Pippin Corporation, Lake Worth, Florida
Started:	4/12/74
Completed:	7/25/74
Depth:	1727'
Casing:	14" to 241'; 8" to 760'; 7" from 704' to 1050'; 5" to 1450'

DEPTH

Pleistocene Series:

Key Largo Limestone:

0-10	Limestone:	cream to reddish brown, consolidated, vuggy, crystalline calcite present, sparsely fossiliferous
10-50	Limestone:	cream to light gray, consolidated, dense, sandy, sparsely fossiliferous

Fort Thompson Formation:

50-60	Limestone:	light gray, consolidated, cherty
60-70	Limestone:	white, consolidated, dense
70-80	Limestone:	white to brown, consolidated dense, slightly sandy
80-130	Limestone:	cream, consolidated, dense, vuggy, fossiliferous

Miocene Series:

Tamiami Formation:

130-175	Sand/ Limestone:	light tan, unconsolidated, fine grain quartz, with grey to white cemented sand and sandy limestone

Hawthorn Formation:

175-188	Sand:	olive green, very fine quartz, silty, sparsely phosphatic, some clayey and cemented zones

LITHOLOGIC LOG OF OBSERVATION WELL D (Continued)

188-220	Clay:	dark olive green, calcareous, sandy, silty, fossiliferous
220-250	Sand:	dark olive green, fine-grained, calcareous, argillaceous, fossiliferous
250-320	Clay:	dark olive green, calcareous, sandy, with limestone fragments present
320-437	Clay:	dark olive green, calcareous, sandy, silty and limestone: buff, consolidated, abundantly fossiliferous

Tampa Stage, St. Marks Formation:

437-450	Limestone:	very light greenish gray, granular, poorly consolidated, porous, sandy, fossiliferous, evidence of surface weathering present
450-470	Claystone/Siltstone:	very light greenish gray, calcareous, sandy, fossiliferous and limestone: buff, sandy
470-550	Limestone:	very light greenish gray, poorly consolidated, sandy, fossiliferous
550-640	Claystone/Siltstone:	light greenish gray, calcareous, sandy, sparsely fossiliferous
640-680	Claystone/Siltstone:	light greenish gray, calcareous, sandy, sparsely fossiliferous and limestone: tan, sandy
680-730	Limestone:	medium gray, consolidated, moderately porous, sandy, argillaceous
730-790	Limestone:	very light greenish gray, granular, poorly consolidated, porous, sandy, argillaceous, sparsely fossiliferous
790-850	Claystone/Siltstone:	very light greenish gray, calcareous, sandy, slightly phosphatic, sparsely fossiliferous
850-986	Claystone/Siltstone:	very light greenish gray, with stringers of sand: very light greenish gray, fine grained, phosphatic, argillaceous

Oligocene Series:

Suwannee Limestone:

986-1060	Limestone:	white to tan, granular to dense, poorly consolidated and friable to consolidated, porous, abundantly fossiliferous
1060-1100	Limestone:	very light brown, granular, poorly consolidated to moderately well consolidated, porous, abundantly fossiliferous, coral abundant, occasional fragments of limestone: consolidated, dense, sandy

1100-1150	Limestone:	buff, moderately well consolidated, porous, fossiliferous and limestone: light brown, granular, poorly consolidated, abundantly fossiliferous and limestone: medium gray, consolidated, dense, sparsely fossiliferous

Eocene Series:

Avon Park Limestone:

1150-1220	Limestone:	buff, granular, moderately well consolidated, porous, abundantly fossiliferous
1220-1310	Limestone:	buff to white, granular, moderately well consolidated, porous, abundantly fossiliferous
1310-1420	Limestone:	buff to white, granular, moderately well consolidated and limestone: light brown, consolidated, porous
1420-1727	Limestone:	buff, coquinoidal, poorly consolidated to moderately well consolidated and limestone: light brown, consolidated, dense

Appendix A-6

LITHOLOGIC LOG OF BORING GB-1

Owner:	Florida Power & Light Company
Location:	Palm Drive, 3000 ft. south on S. W. 117 Avenue
County:	Dade
Elevation:	2.76' above mean sea level
Driller:	Delta Drilling, Lakeland, Florida
Started:	January 17, 1975
Completed:	March 20, 1975
Depth:	1225'
Casing:	10" to 187'; 6" PVC to 1010'

<u>DEPTH</u>

0-2.5 Rock fill

2.5-5.5 Marl soil

<u>Pleistocene Series:</u>

<u>Miami Limestone:</u>

5.5-18.6	Limestone:	light brown to greyish white, fine to coarse grain, poor to well cemented, trace of fossils, vuggy

<u>Fort Thompson Formation:</u>

18.6-56	Limestone:	white to light brown, fine grain, moderately well cemented, fossiliferous in zones, scattered vugs
56-62	Sandstone:	grey white, very fine grain, moderately vuggy
62-92	Limestone:	light brown, fine grain, well cemented, abundantly fossiliferous, slightly vuggy

<u>Miocene Series:</u>

<u>Tamiami Formation:</u>

92-114	Sand:	grey to tan, very fine grain

<u>Hawthorn Formation:</u>

114-124	Sand:	olive green, fine grain, contains scattered zones of cemented sand fragments
124-135.5	Sand:	silty, olive green, fine grain

135.5-159.5	Sand:	clayey, olive green, fine grain
159.5-162.5	Silt:	clayey, greenish grey, calcareous
162.5-187	Sand:	olive green, fine to medium grain, occasional cemented sand fragments
187-204	Sand:	light grey, fine grain
204-215	Sand:	silty, light grey to dark greyish green, fine grain
215-298	Sand:	grey, fine to medium grain
298-366	Sand:	silty grey, fine grain
366-405	Sand:	grey, fine to medium grain, occasional think beds of dark olive green clay

Tampa Stage, St. Marks Formation:

405-450	Limestone:	light olive grey to grey, fine to medium grain, poor to moderately cemented, abundantly fossiliferous, moderately vuggy
450-452	Clay:	sandy, light olive grey, abundantly fossiliferous
452-500	Limestone:	argillaceous, light olive grey, medium grain, moderately well cemented, abundantly fossiliferous, moderately vuggy
500-540	Limestone:	light brown to pale green, fine to medium grain, abundantly fossiliferous, moderately vuggy
540-580	Limestone:	argillaceous, light olive grey, poor to moderately well cemented, abundantly fossiliferous
580-620	Limestone:	pale green to light brown, fine grain, poor to moderately well cemented, fossiliferous in zone, moderately vuggy
620-660	Limestone:	argillaceous, light olive grey, poor to moderately well cemented, abundantly fossiliferous
660-690	Limestone:	moderately argillaceous, pale olive green to light brown, five to medium grain, poorly to moderately well cemented, fossiliferous in zones, trace of vugs
690-701	Limestone:	light brown to pale olive green, very fine to fine grain, well cemented, abundantly fossiliferous, trace of vugs

LITHOLOGIC LOG OF BORING GB-1 (Continued)

701-836	Limestone:	moderately argillaceous, light grey to pale olive green, very fine to coarse grain, poor to well cemented, moderately fossiliferous, moderately vuggy
836-866	Limestone:	argillaceous, light olive green, fine to coarse grain, moderately cemented, trace of fossils
866-886	Limestone:	very argillaceous, light olive green, fine to medium grain, moderately cemented, moderately fossiliferous, slightly vuggy
886-926	Claystone:	light olive green, poor to moderately indurated
926-929.5	Limestone:	argillaceous, light olive grey, fine to medium grain, poorly cemented, slightly fossiliferous
929.5-950.5	Claystone:	silty, olive grey, moderately cemented, calcareous
950.5-970	Limestone:	light olive green, medium grain poor to moderately well cemented, fossiliferous
970-981	Claystone:	silty, olive green, calcareous

Oligocene Series:

Suwannee Limestone:

981-1225'	Limestone:	light grey, medium grain, well cemented, fossiliferous, abundantly vuggy

NOTE: GB-1 was rock cored from 0-1009.5' and roller cone drilled to 1225' into the Suwannee Limestone. As a result of comments from a member of the Government Advisory Board, this test boring was converted to an observation well to provide an additional point of reference for long term monitoring.

Appendix A-7

LITHOLOGIC LOG OF BORING GB-2 AND GB-2A

Owner:	Florida Power & Light Company
Location:	T58S, R39E, SW ¼ of Section 25
County:	Dade
Elevation:	GB2 3.55' above mean sea level GB-2A 2.67' above mean sea level
Driller:	Graham's Drilling Co., Bon Weir, Texas
Started:	January 15, 1975
Completed:	March 14, 1975
Depth:	GB-2 505' GB-2A 1047.5'
Casing:	GB-2 3" PVC to 505' GB-2A 3" PVC to 1047.5'

DEPTH

0-8 Rock fill

Pleistocene Series:

Miami Limestone:

8-26.5	Limestone:	white to greyish white, fine to medium grain, well cemented, abundantly vuggy

Key Largo Limestone:

26.5-34	Coralline Limestone:	white to tan coral and greyish white limestone fine to medium grain, well cemented, moderately vuggy

Fort Thompson Formation:

34-78	Limestone:	sandy greyish white, fine to medium grain, moderately well cemented, abundantly vuggy, fossiliferous in zones
78-98	Limestone:	moderately sandy, greyish white, well cemented, moderately vuggy, abundantly fossiliferous

Miocene Series:

Tamiami Formation:

98-112	Sand:	white to light grey, fine grain. Contains gravel size cemented quartz sand

LITHOLOGIC LOG OF BORING GB-2 AND GB-2A (Continued)

Hawthorn Formation:

112-156	Sand:	silty, glayey, dark olive green, very fine to fine grain. Contains scattered zones of cemented sand fragments
156-164	Clay:	sandy, dark olive green, slightly fossiliferous
164-222.5	Sand:	silty, clayey, fine grain, trace of fossils
222.5-237.5	Clay:	sandy, dark olive green
237.5-262.5	Sand:	silty, clayey, dark olive green, very fine grain. Contains scattered zones of cemented sand fragments
262.5-305	Clay:	sandy, dark olive green
305-389.5	Sand:	clayey, dark olive green, fine grain
389.5-423.5	Sand:	silty, clayey, dark olive green, fine grain. Contains lenses of poorly cemented sand
423.5-428	Clay:	silty, sandy, grey, trace of fossils. Contains limestone fragments, well cemented

Tampa Stage, St. Marks Formation:

428-455	Limestone:	moderately silty, grey, fine grain, moderately to well cemented, moderately fossiliferous
455-505	Limestone:	grey, fine to medium grain, poor to moderately cemented, abundantly fossiliferous, moderately vuggy

NOTE: Boring GB-2 terminated at 505'.

505-609	Limestone:	moderately argillaceous, light grey, moderately to well cemented, abundantly fossiliferous, slightly vuggy
609-681	Limestone:	light olive green to light brown, fine to coarse grain, poor to moderately cemented, moderately fossiliferous, moderately vuggy
681-687.5	Siltstone:	olive green, indurated, poor to well cemented, calcareous
687.5-696	Limestone:	silty, olive green, fine grain, fossiliferous
696-706.5	Siltstone:	cream white, indurated, poor to well cemented, abundantly vuggy, calcareous

LITHOLOGIC LOG OF BORING GB-2 AND GB-2A (Continued)

706.5-716.5	Siltstone & Claystone:	mottled greenish grey and dark green, indurated, well cemented, calcareous
716.5-730	Claystone:	silty, greenish grey, indurated, poor to well cemented, fossiliferous in zones, moderately vuggy, calcareous
730-734	Limestone:	very argillaceous, greenish grey, fine grain, well cemented, fossiliferous
734-746	Claystone:	greenish grey, indurated, well cemented, slightly fossiliferous
746-756.5	Limestone:	very silty, light brown, fine grain, well cemented, abundantly fossiliferous, abundantly vuggy
756.5-787	Limestone:	silty, grey, fine to medium grain, well cemented, slightly vuggy, moderately fossiliferous
787-815	Limestone:	silty to sandy, mottled white and bluish white, poor to moderately cemented, moderately fossiliferous, moderately vuggy, chalky,
815-830	Limestone:	very silty, whitish green, fine to coarse grain, moderately well cemented
830-846	Siltstone:	light green, indurated, well cemented, moderately fossiliferous, calcareous
846-862	Limestone:	very silty, white to light green, fine to coarse grain, moderately
862-871	Limestone:	silty, light green, fine to coarse grain, well cemented, moderately fossiliferous, slightly vuggy
871-901	Siltstone:	greyish green, indurated, well cemented, slightly fossiliferous, calcareous
901-909	Limestone:	silty, light green to grey, fine to coarse grain, well cemented, moderately fossiliferous, moderately vuggy
909-913	Siltstone & Claystone:	greenish grey, indurated, well cemented, calcareous
913-931	Limestone:	argillaceous, fine to medium grain, well cemented, very fossiliferous
931-954	Claystone:	light green, indurated, well cemented, slightly fossiliferous, calcareous
954-965	Limestone:	grey, fine to medium grain, moderately to well cemented

LITHOLOGIC LOG OF BORING GB-2 AND GB-2A (Continued)

965-987	Siltstone & Claystone:	mottled olive green and light green, indurated, well cemented, calcareous
987-996.5	Siltstone:	greyish green, indurated, well cemented, slightly fossiliferous, calcareous
996.5-1032	Siltstone & Claystone:	mottled olive green and light green, indurated, well cemented, calcareous

<u>Oligocene Series:</u>

<u>Suwannee Limestone:</u>

1032-1047.5	Limestone:	light brown, fine to medium grain, well cemented, slightly fossiliferous, slightly vuggy

Appendix A-8

REVISED LITHOLOGIC LOG OF RESEARCH TEST WELL

Owner:	Florida Power & Light Company
Location:	Turkey Point; South end of Card Sound Canal
County:	Dade
Elevation:	9.7' above mean sea level
Driller:	Alsay Drilling Company, Lake Worth, Florida
Started:	April 5, 1972
Completed:	September 15, 1972
Depth:	2000'
Casing:	24" to 156.5'; 16" to 572'; 9-3/4" to 995'
Remarks:	Geologist: J. W. Furlow, Dames & Moore, Atlanta

Note: This well cored from 13.5 feet to 150 feet; wash samples taken from depth of 90 feet to total depth.

DEPTH

0-5	Rock fill	no recovery

Recent:

5-10	Swamp peat	no recovery

Pleistocene Series:

Miami Oolite:

10-20	Limestone:	white to cream, chalky, soft, core recovery: none

Fort Thompson Formation:

20-33	Limestone:	white to cream, chalky, soft, core recovery: none
33-37	Cavern:	no recovery
37-42.5	Limestone:	white to gray, locally very cherty, core recovery: approximately 6 inches
42.5-47	Marl:	gray, soft, core recovery: none
47-52		no recovery
52-57	Sandstone:	white, well consolidated, but highly leached and cavernous, core recovery: 1 foot
57-62	Sandstone:	white, fine-grained, calcareous, highly leached and cavernous, core recovery: 6 inches

REVISED LITHOLOGIC LOG OF RESEARCH TEST WELL (Continued)

62-66	Limestone:	white, very sandy (fine to medium-grained), fossiliferous cavernous, core recovery: 1 foot
66-69		no recovery
69-70.5	Sandstone:	white, fine to medium-grained, well consolidated, cavernous, core recovery: 1.5 feet
70.5-73.5	Limestone:	white, fossiliferous, cavernous, soft to hard and dense, core recovery: 2.5 feet
73.5-77	Limestone:	white, sandy, fossiliferous, cavernous, moderately soft to hard and dense, core recovery: 4 inches
77-82	Limestone:	white, dense, fossiliferous, moderately cavernous, becomes softer in lower portion, core recovery: 1 foot
82-86	Limestone:	white to gray, soft to hard, fossiliferous, cavernous, core recovery: 2 feet
86-89	Limestone:	white, slightly sandy, hard and dense, very fossiliferous, slightly to moderately cavernous, core recovery: 1 foot
89-94	Limestone:	white, slightly sandy, moderately hard and dense, very fossiliferous, slightly cavernous, core recovery: none
94-97	Limestone:	white, moderately hard to soft, very fossiliferous, slightly cavernous, core recovery: 1 foot
97-104	Limestone:	white, hard, fossiliferous, very cavernous, core recovery: 2 feet
104-108	Limestone:	white, chalky to hard, fossiliferous, cavernous, highly leached, core recovery: 2 feet
108-111	Limestone:	white, hard, highly fossiliferous, highly cavernous, highly leached, core recovery: 6 inches
111-120	Limestone:	white, soft, core recovery: none

<u>Miocene Series:</u>

<u>Tamiami Formation:</u>

120-125	Sand:	light tan, fine grain quartz sand, unconsolidated
125-132	Cavern:	no recovery
132-135	Sand:	tan to gray, very fine-grain, unconsolidated, some fossil fragments, core recovery: 3 inches

REVISED LITHOLOGIC LOG OF RESEARCH TEST WELL (Continued)

Hawthorn Formation:

135-150	Sand:	olive green, very fine quartz sand, sparsely fossiliferous, phosphatic

Note: End of coring. Wash samples were taken in addition to cores from 90 to 150 feet and wash samples only were taken from 150 feet on.

150-165	Sand:	olive green to gray, very fine-grained, with abundant shell fragments
165-185	Clay:	olive green, very sandy (very fine-grained), with abundant shell fragments
185-200	Clay:	olive green, sandy, with abundant shell fragments
200-230	Clay:	olive green, silty to sandy (very fine-grained), slightly fossiliferous, phosphatic
230-270	Sand:	olive green to tan, very fine-grained, very argillaceous, phosphatic
270-330	Sand:	olive green to tan, silty to fine-grained, very argillaceous, phosphatic
330-390	Clay:	olive green, silty to sandy (very fine-grained), phosphatic
390-410	Sand:	olive green, very fine to fine-grained, very argillaceous, slightly phosphatic
410-428	Clay:	olive green to light gray, very silty, phosphatic, some shell fragments

Tampa Stage, St. Marks Formation:

428-460	Limestone:	cream to tan, some interbedded clay in upper 10 feet, fossiliferous, with abundant shell fragments
460-470	Claystone/ siltstone:	pale to olive green, with minor amount of shell fragments
470-550	Claystone/ siltstone:	cream to tan, with abundant shell fragments and chips of silty to sandy limestone which appear to be mostly shell filling material
550-560	Claystone/ siltstone:	cream to olive green, silty, with abundant shell fragments and shell filling material as above

REVISED LITHOLOGIC LOG OF RESEARCH TEST WELL (Continued)

560-630	Claystone/ siltstone:	cream to pale green, silty to sandy (very fine-grained), with shell fragments, microfossils, and abundant tan, calcareous siltstone which is mostly shell-filling material
630-680	Limestone:	cream to tan, soft, with shell fragments and abundant shell filling material of tan, calcareous siltstone
680-700	Limestone:	cream to tan, hard, with silty, clay, shell fragments, and abundant calcareous siltstone
700-770	Claystone/ siltstone:	tan to pale green to dark olive green, with abundant shell fragments, pale green calcareous siltstone, and very fine-grained pale green sandstone
770-820	Limestone:	flat-white, soft, silty to sandy (very fine-grained), with abundant shell fragments and light gray to white clay
820-900	Limestone:	flat-white, soft to moderately hard, silty to sandy, with shell fragments, abundant pale green clay and fine-grained sand
900-960	Claystone/ siltstone:	tan to pale green, silty to sandy (very fine-grained), with shell fragments and silty limestone, some fine-grained sandstone
960-970	Limestone:	cream to tan, soft, with moderate amounts of pale green clay and fine-grained sand
970-995	Claystone/ siltstone:	pale green, silty to sandy (very fine-grained), with minor amounts of tan, silty limestone

<u>Oligocene Series:</u>

<u>Suwannee Limestone:</u>

995-1050	Limestone:	tan to cream, hard, silty to sandy (very fine-grained), with shell fragments and some pale green clay
1050-1100	Limestone:	white to gray, moderately hard, slightly cavernous, moderately to abundantly fossiliferous, fossils are well preserved
1100-1110	Coquina:	microfossils and macrofossils in great abundance, to the exclusion of other rock types, fossils are well

	preserved, some even exhibit vitreous luster; small pebbles of poorly cemented fossils are present in moderate amounts, but major portion of sample consists of clean, loose fossils
1110-1120 Limestone:	gray to dary gray, hard, dense, fossiliferous, sandy (fine-grained), slightly cavernous, with microscopic calcite crystals lining the walls of the cavities
1120-1150 Limestone:	tan to gray, hard, moderately dense to dense, slightly leached, sparsely fossiliferous, mostly megafossils

Eocene Series:

Avon Park Limestone:

1150-1190 Limestone:	cream to tan, granular, soft and friable, with abundant small calcite crystals; abundantly fossiliferous, mostly poorly cemented microfossils; preservation is fair to good
1190-1280 Limestone:	white to cream, soft to moderately hard, porous, locally contains argillaceous and cherty seams; fossiliferous, with abundant microfossils and sparse to abundant small echinoids 5-20 mm in diameter; excellent preservation
1280-1470 Limestone:	cream to tan to gray, soft to moderately hard; highly fossiliferous, with abundant microfossils and abundant to frequent small echinoids 5-20 mm in diameter; fossil preservation excellent
1470-1580 Limestone:	cream to tan to gray, soft, slightly leached; fossiliferous, with frequent to sparse small echinoids and shell fragments, and abundant microfossils; preservation excellent
1580-1590 Limestone:	cream to tan to dark gray, moderately hard to hard, slightly leached; fossiliferous, with sparse shell fragments and frequent microfossils
1590-1610 Siltstone:	tan, soft, calcareous; frequent well-preserved microfossils
1610-1620 Limestone:	cream to tan to dark gray, soft to hard, slightly leached; fossiliferous, with sparse shell fragments and abundant microfossils

REVISED LITHOLOGIC LOG OF RESEARCH TEST WELL (Continued)

1620-1660 Limestone:	cream to tan, soft to moderately hard, slightly leached; fossiliferous, with sparse small echinoids and abundant well-preserved microfossils
1660-1770 Limestone:	tan to gray, soft, with intermittent hard seams, granular and friable, poorly consolidated; fossiliferous, with sparse to rare small echinoids and abundant well-preserved microfossils

<u>Lake City Limestone:</u>

1770-1900 Limestone:	tan to gray, soft, granular and friable, poorly consolidated; abundant well-preserved microfossils
1900-1930 Limestone:	tan to gray, soft to moderately hard, fine-grained; fossiliferous, with abundant microfossils
1930-1970 Limestone:	tan to gray, soft, silty, granular and friable; fossiliferous, with numerous mocrofossils
1970-2000 Limestone:	tan to cream, soft to moderately hard, slightly granular; fossiliferous, with frequent shell and small echinoid fragments, and abundant microfossils

T.D. 2000 feet

APPENDIX B-1

WELLS USED FOR HYDROGEOLOGIC CROSS SECTION*

Number		Reference	Well Identification Used In Referenced Report
1		Stewart, 1966	#815-152-2
2		Stewart, 1966	#815-155-1
3		Stewart, 1966	#807-154-4
4		Stewart, 1966	#805-154-8
5		Stewart, 1966	#803-153-3
6		Stewart, 1966	#800-153-3
7		Stewart, 1966	#757-152-1
8		Stewart, 1966	#754-151-4
9		Stewart, 1966	#752-150-1
10		Stringfield, 1966	#16
11		Stewart, 1966	#749-149-1
12		Stewart, 1966	#747-148-1
13		Stewart, 1966	#742-150-2
14		Bishop, 1956	#401
15		Stringfield, 1966	#17
16		Bishop, 1956	#403
17		Bishop, 1956	#408
18		Bishop, 1956	#22
19		Bishop, 1956	#211
20		Bishop, 1956	#358
21		Stringfield, 1966	#21
22		Klein and others, 1964	#266
23		Klein and others, 1964	#207
24		Klein and others, 1964	#277
25		Klein and others, 1964	#4
26		Klein and others, 1964	#194
27		Klein and others, 1964	#281
28		Klein and others, 1964	#282
	and	Chen, 1965	#2631
29		Stringfield, 1966	#19
30		Deju and Miller	#6
31		Deju and Miller	#5
32		Chen, 1965	#935
33		Stringfield, 1966	#20
34		Puri and Winston, 1974	#35
35		Grossman Hammock	
36		Royal Palm Well	
37		Observation Well A	
38		Research Test Well	
39		Observation Well D	

Offshore data from Uchupi, 1968 and U.S.G.S. Topographic Maps

* Location of wells shown on Figures 8-1 and 8-2.

APPENDIX B-2
DEEP WATER SUPPLY AND DISPOSAL WELLS IN DADE COUNTY AND KEY LARGO, FLORIDA*

No.	Location	Owner	Use	Total Depth	Source of Data
1.	553725	M. L. Grossman	Recreation area	1248	U.S. Geological Survey
2.	554206	E. H. Underwood	Irrigation	957	" " "
3.	543944	Gen. Water Works	Industrial (injection)	3200	" " "
4.	544032	Gen. Water Works	Industrial (injection)	2950	" " "
5.	544035	Gay	Med.	1065	" " "
6.	544003	U.S.G.S.	Domestic	817	" " "
7.	534214	La Gorce CC	Irrigation	950	" " "
8.	583714	U.S.G.S. (Royal Palm)	Unused	1333	" " "
9.	534215	La Gorce CC	Irrigation	1000	Black, Crow and Eidsness, 19
10.	534234	Miami Beach			" " "
11.	524234	Indian Creek CC	Irrigation	950	Florida Geological Survey
12.	524234	Indian Creek CC	Irrigation	945	" " "
13.	534136	Gas plant	Industrial	1157	" " "
14.	544004	Church	Irrigation	817	" " "
15.	544110	City of Miami	Public supply	960	" " "
16.	583926	Fla. Power & Light	Test well	1400	Florida Power & Light
17.	583926	Fla. Power & Light	Test well	2300	" " "
18.	583926	Fla. Power & Light	Test well	1700	" " "

APPENDIX B-2 (Continued)
DEEP WATER SUPPLY AND DISPOSAL WELLS IN DADE COUNTY AND KEY LARGO, FLORIDA*

No.	Location	Owner	Use	Total Depth	Source of Data
19.	583926	Fla. Power & Light	Test well	1700	Florida Power & Light
20.	584028	Fla. Power & Light	Test well	2000	" " "
21.	594035	Fla. Power & Light	Test well	1727	" " "
22.	594107	Ocean Reef Club	Irrigation	1074	U.S. Geological Survey
23.	534012	Hialeah Treatment Plant	Test well	1200	" " "
24.	573925	Fla. Power & Light	Test well	1225	Florida Power & Light
25.	Penne-kamp State Park, Key Largo	U.S.G.S.	Recreation	1330	Meyer, 1971
26.	Key Largo	Private	Unused	Approx. 1000	U.S. Geological Survey

* Location of wells shown on Figure 8-4.

APPENDIX B-3

First Pump Test Data (2/14/74)

Name of Well: Observation Well A

Well Owner: Florida Power & Light Company
P.O. Box 013100
Miami, Florida 33101

Well Location: Longitude 80° 24' 23" W
Latitude 25° 21' N
T58S, R39E, Sec. 26, SW¼
Dade County, Florida
100 feet SE of Production Test Well

Nature of Test: Vertical Hydraulic Conductivity Test on limestone formation just below upper Floridan Aquifer

Pumping Zone: Between 1535 feet to 1900 feet below well pad

Monitoring Zone: Between 1120 feet to 1350 feet below well pad

Well Pad Elevation: 3.13 feet above MSL

Remarks: Artesian pressure of monitoring zone before testing was 16.4 psi. Pump rate was measured by an orifice weir.

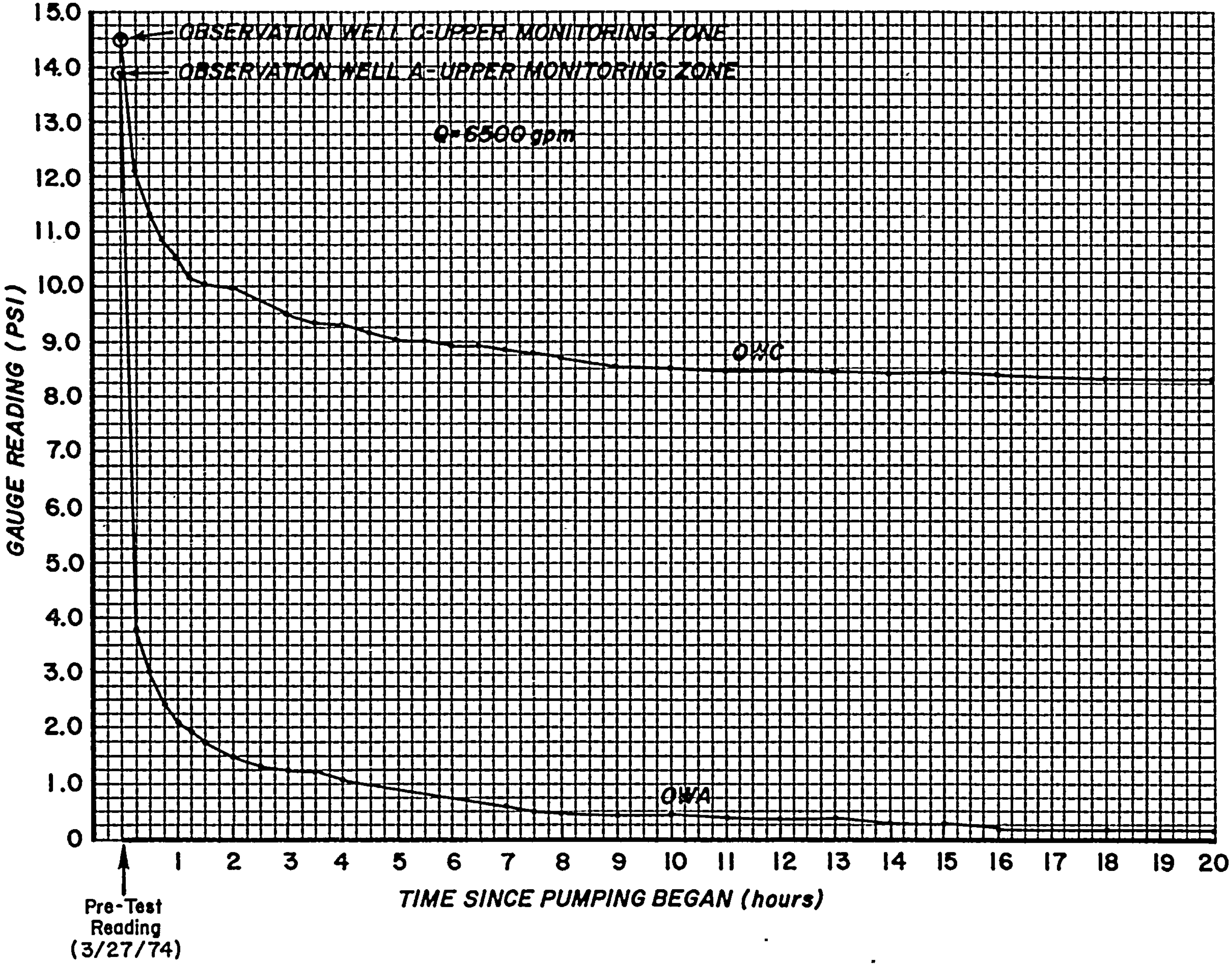
Time (Hrs)	Discharge gpm	Upper Floridan psi	Salinity ppt	Conductivity Millimho/cm	Temp. °C
0	870	16.40	17.30	27.50	25.2
.5	880	16.40	17.00	27.30	25.2
1.0	890	16.40	16.80	27.00	25.3
1.5	870	16.40	16.60	26.60	25.6
2.0	875	16.40	16.30	26.40	26.0
2.5	870	16.40	16.20	26.40	26.1
3.0	865	16.40	16.20	26.40	26.2
3.5	870	16.40	16.20	26.30	26.1
4.0	865	16.40	16.20	26.40	26.2

APPENDIX B-4

Second Pump Test Data (3/27/74)

Pumping well/rate:	Production Test Well/6500 gpm
Observation wells:	OWA, OWC
Well Owner:	Florida Power & Light Company
Well Locations:	
Production Test Well	- longitude 80° 24' 23" W latitude 25° 21' N T58S, R39E, Sec. 26, SW ¼ Dade County, Florida
Observation Well A	- 100 feet SE of PTW
Observation Well C	- 500 feet NW of PTW
Pumping Zone:	1120 feet to 1350 feet below well pad (+ 4.23 ft. MSL)
Monitoring Zone:	Elevation of monitoring zones for each well given in Table 8-1.
Remarks:	Pumping test to evaluate the hydrologic parameters of the main producing zone of the Floridan Aquifer at the Turkey Point area and to provide information helpful in locating Observation Well B.

APPENDIX B-4 (cont.)



PRESSURE DECLINE vs. TIME - SECOND PUMPING TEST

APPENDIX B-5

Third Pump Test Data (7/30/74 - 8/7/74)

Pumping well/rate: Production Test Well/5000 gpm

Observation wells: OWA, OWB, and OWC, RTW, Royal Palm

Well Owner: Florida Power & Light Company

Well Locations:

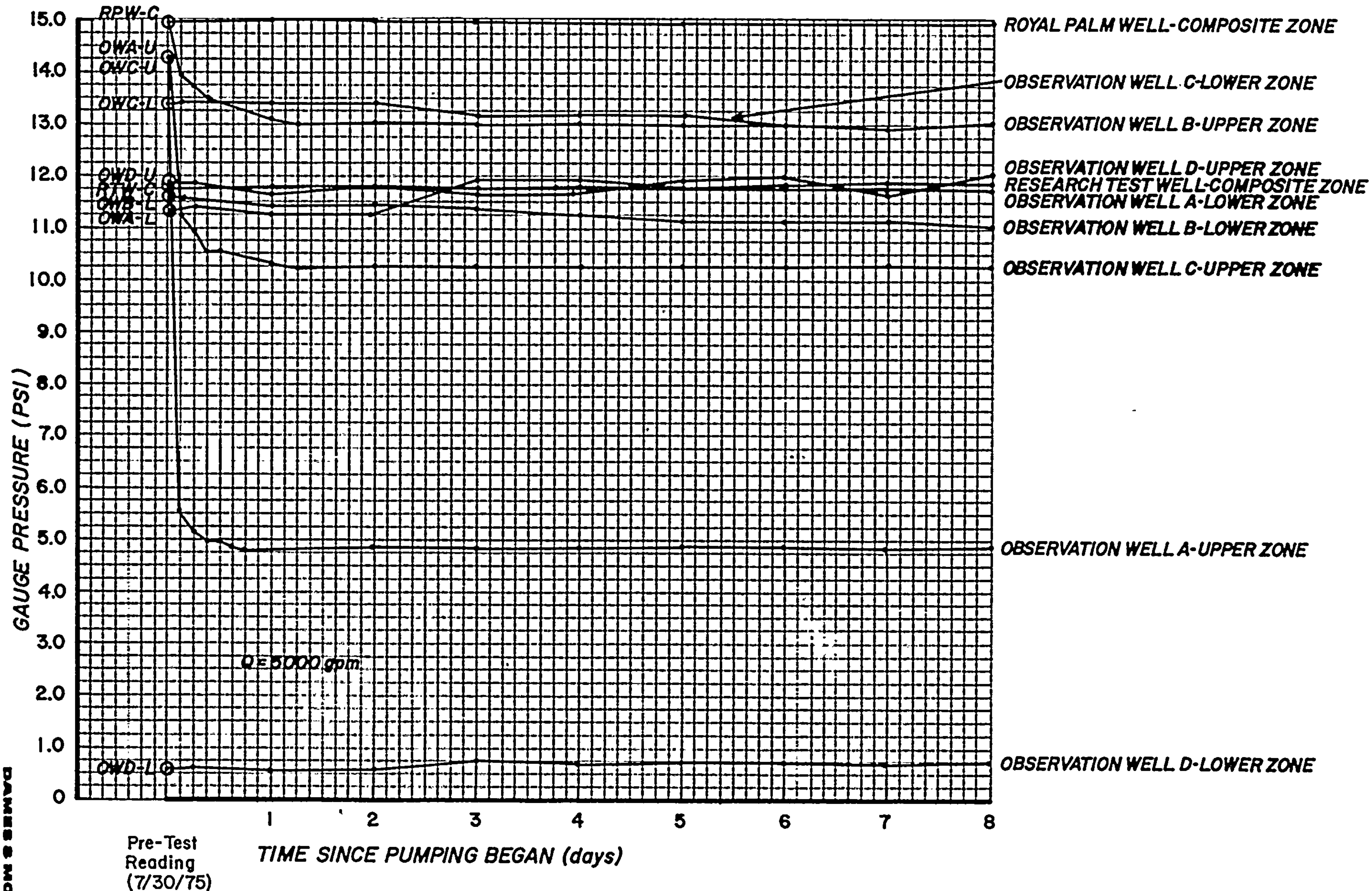
Production Test Well	- longitude 80° 24' 23" W latitude 25° 21' N T58S, R39E, Sec. 26, SW ¼ Dade County, Florida
Observation Well A	- 100 feet SE of PTW
Observation Well B	- 2000 feet SE of PTW
Observation Well C	- 500 feet NW of PTW
Observation Well D	- 44800 feet SE of PTW (Key Largo)
Research Test Well	- 22600 feet E of PTW
Royal Palm Well	- 63200 feet N 77° W of PTW

Pumping Zone: 1120 feet to 1350 feet below well pad (+ 4.23 ft. MSL)

Monitoring Zone: Elevation of monitoring zones for each well given in Table 8-1.

Remarks: Pumping test to evaluate the hydrologic parameters of the main producing zone of the Floridan Aquifer at the Turkey Point area.

APPENDIX B-5 (cont.)



DAMES & MOORE

PRESSURE DECLINE vs. TIME – THIRD PUMPING TEST

APPENDIX B-6

Fourth Pump Test Data (10/16/74 - 1/14/75) and Recovery Test Data (1/14/75 - 1/28/75)

Pumping well/rate: Production Test Well/5000 gpm

Observation wells: OWA, OWB, OWC, OWD, RTW, Royal Palm

Well Owner: Florida Power & Light Company

Well Locations:

Production Test Well - longitude 80° 24' 23" W
latitude 25° 21' N
T58S, R39E, Sec. 26, SW ¼
Dade County, Florida

Observation Well A* - 100 feet SE of PTW

Observation Well B* - 2000 feet SE of PTW

Observation Well C* - 500 feet NW of PTW

Observation Well D - 44800 feet SE of PTW on Key Largo

Research Test Well - 22600 feet E of PTW

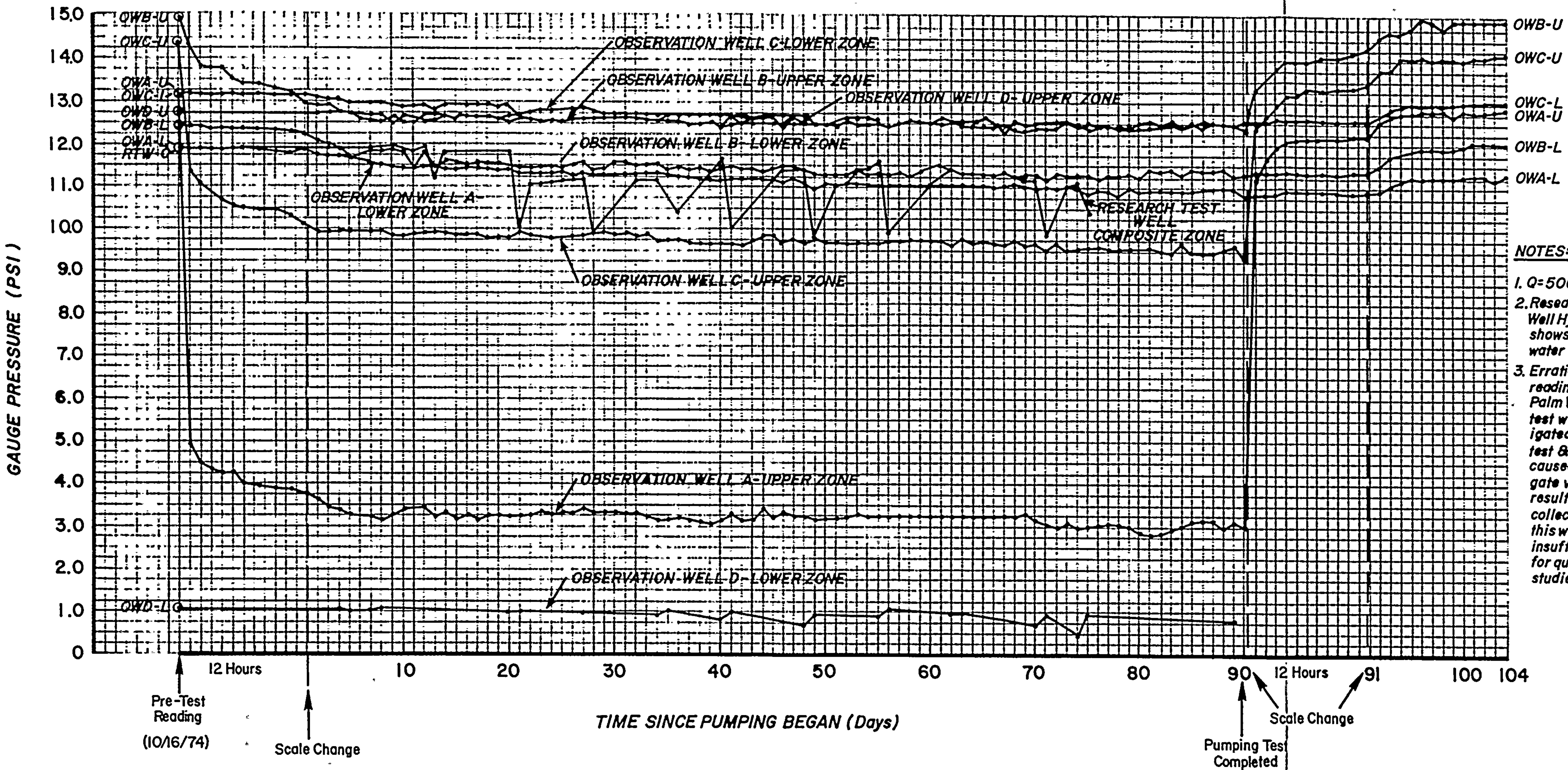
Royal Palm Well - 63200 feet N 75° W of PTW

Pumping Zone: 1120 feet to 1350 feet below well pad

Monitoring Zones: Elevations of monitoring zones for each well given in Table 8-1.

Remarks: Long-term pumping and recovery tests to evaluate aquifer parameters and changes in chemical composition of water in the Floridan aquifer at the Turkey Point area.

* Observed during recovery test.



NOTES:

1. Q=5000 gpm
2. Research Test Well Hydrograph shows effects of water sampling.
3. Erratic gauge readings for Royal Palm Well during test were investigated during test & believed caused by a leaky gate valve. As a result, data collected from this well were of insufficient quality for quantitative studies.

PRESSURE DECLINE and RECOVERY vs.
TIME — LONG-TERM PUMPING and RECOVERY TESTS

APPENDIX B-7

INTERNAL ADVISORY GROUP

The Internal Advisory Group was established to provide a means of independent internal review for technical specification and project review. The ground-water professionals involved were:

William M. Greenslade, Dames & Moore (chairman)

William E. Mead, Dames & Moore

R. Brian Ellwood, Dames & Moore

C. Ross Sproul, Black, Crow and Eidsness, Inc.

Other senior professionals attending meetings and/or providing significant advisory input were:

W. E. Clark, Black, Crow and Eidsness, Inc., hydrologist

Henry A. Baski, Dames & Moore, hydrologist

Patrick A. Domenico, University of Illinois, hydrologist

Dean O. Gregg, Dames & Moore, hydrologist

Charles P. Gupton, Dames & Moore, civil engineer

Porter-C. Knowles, Dames & Moore, hydrologist

Richard F. Langill, Dames & Moore, geologist

J. Russell Mount, Dames & Moore, hydrologist

Benjamin S. Persons, Dames & Moore, civil engineer

Meetings and/or discussions with the above-mentioned professionals were conducted throughout the project.

Recognition should also be given to the following Dames & Moore personnel for significant contributions to this project and report:

Peter J. Barth

Gregory R. Fisher

James W. Furlow

W. Douglas Hall

Walter W. Loo

Michael A. Luckett

Tommy R. Partridge

APPENDIX B-8

GOVERNMENT ADVISORY GROUP

The participation of the following agencies and individuals throughout this study in the Government Advisory Group is gratefully acknowledged. (Over the study period, names of some agencies have changed through reorganization.)

1. Mr. Peter P. Baljet, Executive Director
   Florida Department of Pollution Control

2. Mr. Paul Beam
   Florida Department of Natural Resources
   Division of Interior Resources

3. Mr. Thomas Buchanan
   U. S. Geological Survey, Miami, Florida

4. Mr. Walter Dinn
   Miami-Dade Water and Sewer Authority

5. Mr. Jim Hartwell
   University of Miami, Center for Urban Studies

6. Mr. C. W. Hendry, Jr., Chief
   Florida Bureau of Geology

7. Mr. Howard Klein
   U. S. Geological Survey, Miami, Florida

8. Mr. Abe Kreitman
   Central & Southern Florida Flood Control District

9. Mr. Fred W. Meyer
   U. S. Geological Survey, Miami, Florida

10. Mr. Colin Morrissey, Director
    Pollution Control, Metropolitan Dade County

11. Mr. F. D. R. Parks, Water Control Engineer
    Public Works Department, Metropolitan Dade County

12. Mr. Charles W. Sever
    United States Environmental Protection Agency

13. Mr. Hans Schmitz
    Pollution Control, Metropolitan Dade County

14. Mr. Garrett Sloan, Director
    Miami-Dade Water and Sewer Authority

APPENDIX B-8 (Continued)

GOVERNMENT ADVISORY GROUP

15. Mr. Harry M. Stern
    Public Works Department, Metropolitan Dade County

16. Mr. William V. Storch, Director
    Resources Planning Department
    Central & Southern Florida Flood Control District

17. Mr. Warren Strahm, Regional Administrator
    Florida Department of Pollution Control

18. Dr. R. O. Vernon, Director
    Florida Department of Natural Resources
    Division of Interior Resources

19. Mr. John White, Regional Deputy Administrator
    United States Environmental Protection Agency

20. Mr. Gerry Winter
    Central & Southern Florida Flood Control District

21. Mr. Jack Woodard
    Florida Department of Natural Resources
    Division of Interior Resources

APPENDIX C-1

AVERAGE CHEMICAL COMPOSITION OF SEA WATER *

Major Constituents (>1 mg/l)	Concentration (mg/l)
Chloride	19,000
Sodium	10,500
Sulfate	2,700
Magnesium	1,350
Calcium	400
Potassium	380
Bicarbonate	142
Bromide	65
Strontium	8
Silica	6.4
Boron	4.6
Fluoride	1.3

* After Hem, 1970, p.11.

NOTE: Although not presented in this report, lab verification using samples of "Standard" sea water were made during the investigation.

APPENDIX C-2

OWA Water Quality Profile During Drilling

Depth (ft.)	Temp. (^{o}C)	Conductivity (µmho/cm)	Depth (ft.)	Temp. (^{o}C)	Conductivity (µmho/cm)
1197	27.5	6180	1740	27.18	18900
1210	26.4	7500	1750	27.55	18800
1220	26.8	7500	1760	28.78	18600
1230	27.1	7500	1770	27.09	20200
1240	26.65	7000	1780	27.35	19500
1250	26.44	7500	1790	27.98	19500
1260	25.42	8200	1800	27.05	19600
1270	25.83	8000	1810	27.25	19500
1280	25.92	8100	1820	27.36	19600
1290	27.6	8200	1830	26.92	19600
1300	26.6	8500	1840	26.2	19750
1310	26.6	8500	1850	25.38	20200
1320	25.65	8750	1860	25.76	20200
1330	25.62	9250	1870	26.8	19800
1340	25.77	9100	1890	25.8	21250
1350	25.52	9100	1910	25.88	19750
1360	25.6	10200	1920	25.66	19700
1370	26.3	10400	1930	25.62	19600
1380	26.75	10200	1940	25.28	19700
1390	25.95	10200	1950	26.0	19600
1400	25.88	10600	1960	25.55	19700
1410	25.76	10700	1970	24.48	20200
1420	25.82	10750	1980	25.6	20200
1425	25.71	10600	1990	25.84	20500
1430	25.98	10500	2020	27.72	20500
1440	25.93	10200	2030	27.78	20500
1450	26.69	10400	2040	27.85	20500
1460	27.13	10600	2050	28.0	20600
1470	26.64	10200	2060	27.22	20300
1480	26.61	9800	2070	26.2	20700
1490	27.15	10400	2080	25.68	20500
1500	26.78	9900	2090	26.35	21100
1510	26.55	10600			
1520	26.86	10600			
1530	26.05	10650			
1600	27.27	14500			
1650	26.82	16100			
1660	25.53	16600			
1670	25.92	16100			
1680	25.95	16300			
1690	26.15	15200			
1700	26.27	16100			
1710	27.69	16600			
1720	27.08	16100			
1730	28.22	18600			

APPENDIX C-2 (Continued)

OWB Water Quality Profile During Drilling

Depth (ft.)	Temp. (°C)	Conductivity (µmho/cm)	Depth (ft.)	Temp. (°C)	Conductivity (µmho/cm)
1180	26.5	8000	1360	26.0	9400
1190	26.0	7900	1370	26.0	9550
1200	26.5	8000	1380	26.0	9700
1210	26.5	8000	1390	26.0	9800
1220	26.5	8000	1400	26.0	9900
1230	26.0	8100	1410	26.0	10000
1240	26.0	8300	1420	26.5	10500
1250	26.0	8300	1430	26.5	10500
1260	26.0	8400	1440	26.5	11000
1270	26.0	8450	1450	26.5	11000
1280	26.0	8500	1460	26.0	11000
1290	26.0	8600	1470	26.0	11000
1300	26.0	8650	1480	26.0	11000
1310	27.0	8800	1490	26.0	11000
1320	26.5	8850	1500	26.0	11000
1330	27.0	9000	1640	26.0	15550
1340	26.5	9100	1670	25.5	16000
1350	26.0	9300	1700	26.0	18000

OWC Water Quality Profile During Drilling

Depth (ft.)	Temp. (°C)	Conductivity (µmho/cm)	Depth (ft.)	Temp. (°C)	Conductivity (µmho/cm)
1198	26.6	4700	1470	25.1	9900
1212	26.0	7400	1480	25.1	9900
1220	26.0	7320	1490	25.3	10090
1240	26.5	7020	1500	25.8	9990
1260	26.5	7300	1510	25.6	10060
1280	26.0	8000	1520	25.9	10100
1300	26.4	7800	1530	26.	10000
1312	26.0	8050	1548	25.	13000
1320	25.4	8400	1560	25.	13000
1338	27.0	8300	1600	26.5	12500
1350	27.0	9010	1610	27.0	11000
1360	26.0	9600	1620	27.0	11500
1370	26.5	9440	1630	26.5	11000
1380	26.5	9500	1640	27.5	11500
1390	26.5	9500	1650	26.5	11000
1400	25.6	9600	1660	27.0	12000
1410	25.4	9780	1670	27.0	12000
1420	26.0	9500	1680	27.0	12000
1430	26.4	9540	1690	27.0	12000
1440	26.4	9600	1700	27.5	14000
1460	25.0	10050			

APPENDIX C-2 (Continued)

OWD Water Quality Profile During Drilling

Depth (ft.)	Temp. (°C)	Conductivity (µmho/cm)	Depth (ft.)	Temp. (°C)	Conductivity (µmho/cm)
1210	28.0	11,500	1430	27.5	11,500
1220	28.0	11,500	1440	27.5	11,500
1230	27.0	11,500	1450	27.5	11,500
1240	27.0	11,500	1510	28.0	39,000
1250	27.0	11,500	1540	28.0	39,000
1260	27.0	11,500	1550	28.0	39,000
1270	27.0	11,500	1560	28.0	41,200
1280	27.0	11,500	1570	28.0	45,000
1290	27.0	11,500	1580	28.0	45,000
1300	26.5	10,000	1590	29.0	44,200
1310	27.0	10,000	1600	29.0	44,200
1320	27.0	11,500	1610	29.0	44,200
1330	27.0	11,500	1620	29.0	42,200
1340	27.0	11,500	1630	29.0	42,200
1350	27.0	11,500	1640	28.0	43,500
1360	27.0	11,500	1650	28.0	44,500
1370	27.0	11,500	1660	28.0	46,500
1380	27.0	11,500	1670	28.0	46,500
1390	27.0	11,500	1680	28.0	46,500
1400	27.0	11,500	1690	28.0	46,500
1410	27.0	11,500	1700	28.0	48,300
1420	28.0	11,500			

APPENDIX C-3

ANALYTICAL METHODS, WINGERTER LABORATORIES

1. Using Standard Methods, 13th Edition, Colorimetric procedures, Bausch and Lomb Spectronic 20:
   Calcium, Magnesium, Alkalinity, Bicarbonates, Carbonates, Hydroxides, Sulfate, Chloride, Fluoride, Hardness, Carbon Dioxide, Silica, Solids, Color, pH, Sp. Conductance, H_2S, Iron, Manganese, Arsenic, Chromium, Zinc, Cadmium, Aluminum, Phosphates, and Copper.

2. Using Hach Chemical Company Methods, based on Analytical Chemical Methods/and Snell and Snell Colorimetric Methods of Analysis, Volume II A:
   Detergent, Lead, Silver and Nickel.

3. Using Atomic Absorption Spectrophotometers:
   Sodium, Potassium, Molybdenium and Strontium.

ANALYTICAL METHODS, FLORIDA POWER & LIGHT LABORATORIES

ANALYSIS	TURKEY POINT LAB	POWER RESOURCES TESTING LAB
pH	Electrode	Electrode
Conductivity	"Beckman"Cond. Meter	"L&N" Conductivity Meter
Dissolved Solids	Samples evaporated in ceramic dishes @105°C	Samples evaporated in ceramic dishes @ 105°C
Alkalinity	Titration with 0.02N H_2SO_4	Titration with 0.02N H_2SO_4
Hardness	Titration with EDTA	Titration with EDTA
Calcium	Titration with EDTA	Titration with EDTA
Magnesium	Math. Difference	Atomic Absorption Spectrometer or Difference
Sodium	-	"Thomas" Specific Ion Electrode
Potassium	-	Atomic Absorption Spectrometer
Chloride	Titration with $AgNO_3$	Titration with $AgNO_3$
Sulfate	-	Gravametric Method or Turbidometric Method
Hydrogen Sulfied	Spec. 20, Hach	Spec. 20
Color	-	D.U. at 450 m
Turbidity	"Hach 2100"	"Hach 2100"
Silica	-	Ammonium molybdate
Iron	-	Atomic Absorption Spectrometer
Manganese	-	"
Copper	-	"
Zinc	-	"
Nickel	-	"
Lead	-	"

ANALYTICAL METHODS, FLORIDA POWER & LIGHT LABORATORIES

CONTINUED

ANALYSIS	TURKEY POINT LAB	POWER RESOURCES TESTING LAB
Aluminum	-	Atomic Absorption Spectrometer
Molybdenum	-	"
Chromium	-	"
Mercury	-	"

DAMES & MOORE

ANALYTICAL METHODS

DAMES & MOORE ENVIRONMENTAL LABORATORIES
CINCINNATI, OHIO

Parameter and units	Method	References: Standard methods	ASTM	EPA methods
General analytical methods:				
1. Alkalinity as $CaCO_3$ mg $CaCO_3$/liter.	Titration: electrometric, manual or automated method-methyl orange	p.370	p.143	p.6. p.8.
2. B.O.D. five day mg/liter	Modified wrinkler or probe method	p.489		
3. Chemical oxygen demand (C.O.D.) mg/liter	Dichromate reflux	p.495	p.219	p.17.
4. Total solids mg/liter	Gravimetric 103-105° C	p.535		p.280.
5. Total dissolved (filterable) solids mg/liter.	Glass fiber filtration 180° C			p.275.
6. Total suspended (non-filterable) solids mg/liter.	Glass fiber filtration 103-105° C	p.537		p.278.
7. Total volatile solids mg/liter.	Gravimetric 550° C	p.536		p.282.
8. Ammonia (as N) mg/liter.	Distillation-nesslerization or titration---automated phenolate.			p.131.
9. Kjeldahlnitrogen (as N) mg/liter.	Digestion + distillation-nexxlerization or titration utomated digestion phenolate.	p.409		p.149. p.157.
10. Nitrate (as N) mg/liter.	Cadmium reduction; brucine sulfate; automated cadmium or hydrazine reduction.	p.458 p.461	p.124	p.170. p.175. p.185.
11. Total phosphorus (as P) mg/liter.	Persulfate digestion and single reagent (ascorbic acid), or manual digestion, and automated single reagent or stanous chloride.	p.526	p.42	p.235. p.259.
12. Acidity mg $CaCO_3$/liter.	Electrometric end point or phenolphthalein end point.		p.148	
13. Total organic carbon (TOC) mg/liter.			p.702	p.221.
14. Hardness - total mg $CaCO_3$/liter.	EDTA titration: automated colorimetric atomic absorption.	p.179	p.170	p.76. p.78.

ANALYTICAL METHODS (cont.)

DAMES & MOORE ENVIRONMENTAL LABORATORIES
CINCINNATI, OHIO

Parameter and units	Method	References: Standard methods	References: ASTM	References: EPA methods
15. Nitrite (as N) mg/liter	Manual or automated colorimetric diazotization			p.185.

Analytical methods for trace metals:

Parameter and units	Method	Standard methods	ASTM	EPA methods
16. Aluminum - total mg/liter.	Atomic absorption	p.210		p.98.
17. Antimony - total mg/liter.	Atomic absorption			
18. Arsenic - total mg/liter.	Digestion plus silver diethyldithiocarbamate atomic absorption.	p.65 p.62		p.13.
19. Barium - total mg/liter.	Atomic absorption	p.210		
20. Beryllium - total mg/liter	Aluminon; atomic absorption	p.67 p.210		
21. Boron - total mg/liter	Curcumin	p.69		
22. Cadmium - total mg/liter.	Atomic absorption; colorimetric	p.210 p.422	p.692	p.101.
23. Calcium - total mg/liter	EDTA titration; atomic absorption	p.84	p.692	p.102.
24. Chromium Vl mg/liter	Extractions and atomic absorption; colorimetric.	p.429		p.94.
25. Chromium - total mg/liter	Atomic absorption; colorimetric	p.210 p.426	p.692 p.403	p.104.
26. Cobalt - total mg/liter	Atomic absorption		p.692	
27. Copper - total mg/liter	Atomic absorption; colorimetric	p.210 p.130	p.692 p.110	p.106.
28. Iron - total mg/liter	---do	p.210 p.433	p.692 p.152	p.108.
29. Lead - total mg/liter	---do	p.210 p.436	p.692	p.110.
30. Magnesium - total mg/liter.	Atomic absorption; gravimetric	p.210 p.416 p.201	p.692	p.112.

ANALYTICAL METHODS (cont.)

DAMES & MOORE ENVIRONMENTAL LABORATORIES
CINCINNATI, OHIO

Parameter and units	Method	References: Standard methods	ASTM	EPA methods
31. Manganese - total mg/liter.	Atomic absorption	p.210	p.692	p.114.
32. Mercury - total mg/liter	Flameless atomic absorption			
33. Molybdenium - total mg/liter.	Atomic absorption			
34. Nickel - total mg/liter	Atomic absorption; colorimetric	p.413	p.692	
35. Potassium - total mg/liter.	Atomic absorption; colorimetric; flame photometric	p.283 p.285	p.326	p.115.
36. Selenium - total mg/liter	Atomic absorption			
37. Silver - total	Atomic absorption	p.210		
38. Sodium - total mg/liter	Flamephotometric; atomic absorption	p.317	p.326	p.118.
39. Thallium - total mg/liter	Atomic absorption			
40. Tin - total mg/liter	---do			
41. Titanium - total mg/liter	---do			
42. Vanadium - total mg/liter	Atomic absorption; colorimetric	p.157		
43. Zinc - total mg/liter	Atomic absorption; colorimetric	p.210	p.692	p.120.

Analytical methods for nutrients, anions, and organics:

Parameter and units	Method	Standard methods	ASTM	EPA methods
44. Organic nitrogen (as N) mg/liter.	Kjeldahlnitorgen minus ammonia nitorgen	p.463		p.149.
45. Ortho-phosphate (as P) mg/liter.	Direct single reagent; automated single reagent or stannous chloride.	p.532	p.42	p.235. p.246. p.259.
46. Sulfate (as SO_4) mg/liter	Gravimetric; turbidimetric; automated colorimetric - barium chloranilate.	p.331 p.331	p.51 p.52	p.286. p.288.
47. Sulfide (as S) mg/liter.	Titrimetric - iodine	p.651		p.294.
48. Sulfite (as SO_3) mg/liter	Titrimetric - iodide - iodate	p.337	p.261	
49. Bromide mg/liter	---do		p.216	
50. Chloride mg/liter	Silver nitrate; mercuric nitrate; automated colorimetric-ferricyanide.	p.96 p.97	p.23 p.21	p.29. p.31.

ANALYTICAL METHODS (cont.)

DAMES & MOORE ENVIRONMENTAL LABORATORIES
CINCINNATI, OHIO

Parameter and units	Method	References		
		Standard methods	ASTM	EPA methods
51. Cyanide - total mg/liter	Distillation - silver nitrate titration or pyridine pyrazolone colorimetric.	p.397	p.556	p.41.
52. Fluoride mg/liter	Distillation - SPADNS	p.171 p.174	p.191	p.61.
53. Chlorine - total residual mg/liter.	Colorimetric; amperometric titration	p.382	p.223	
54. Oil and grease mg/liter	Liquid-liquid extraction with trichloro-trifluoroethane.	p.254		
55. Phenols mg/liter.	Colorimetric; 4 A A P	p.502	p.415	p.232.
56. Surfactants mg/liter	Methylene blue colorimetric	p.339	p.619	p.131.
57. Algieldes mg/liter	Gas chromatography			
58. Benzadien mg/liter	Diazotization - colorimetric			
59. Chlorinated organic compounds (except pesticides) mg/liter.	Gas chromatography			
60. Pesticides mg/liter.	Gas chromatography			

Analytical methods for physical and biological parameters:

Parameter and units	Method	Standard methods	ASTM	EPA methods
61. Color platinum - cobalt units or dominant wave-length, hue, luminance, purity.	Colorimetric; spectrophotometric	p.160 p.302		p.36.
62. Specific conductance mho/cm at 25° C.	Wheatstone bridge	p.328	p.103	p.284.
63. Turbidity jackson units.	Turbidimeter	p.350	p.407	p.308.