HYDROGEOLOGY OF THE LELY RESORT COMMUNITY SITE COLLIER COUNTY, FLORIDA

Prepared for

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I. CONCLUSIONS OF THE INVESTIGATION

A hydrologic investigation was conducted in and around the Lely Resort Community development site. The purpose of the investigation was to evaluate the water resources of the approximate 2,600 acre parcel to determine the availability of water for irrigation use. The information collected and the analyses performed lead to the following conclusions:

1) Approximately 5.63 **million gallons of water per day** will be needed at final buildout for irrigation of landscaping and golf course turf at the Lely Resort Community.
2) The irrigation requirement will be met using approximately 2.1 **million** gallons per day of sewage effluent; 2.1 **million** gallons per day of **groundwater**, and 1.4 **million** gallons per day of **surface** water.
3) The groundwater withdrawals should be made from the **Tamiami Aquifer**, with well construction phased to correspond to the development demands.
4) Pumping of 2.1 million gallons of groundwater per day will have no significant impact on the aquifer system, surface environment or any existing water user. The proposed use is only slightly higher than current permitted use of 1.9 MGD

for agricultural irrigation on the site.

5) The Tamiami Aquifer on the site was tested and found to have a transmissivity of 504,000 gpd/ft and a leakance of .077 gpd/ft^3. The water-table aquifer was tested and found to have a transmissivity of about 48,000 gpd/ft.

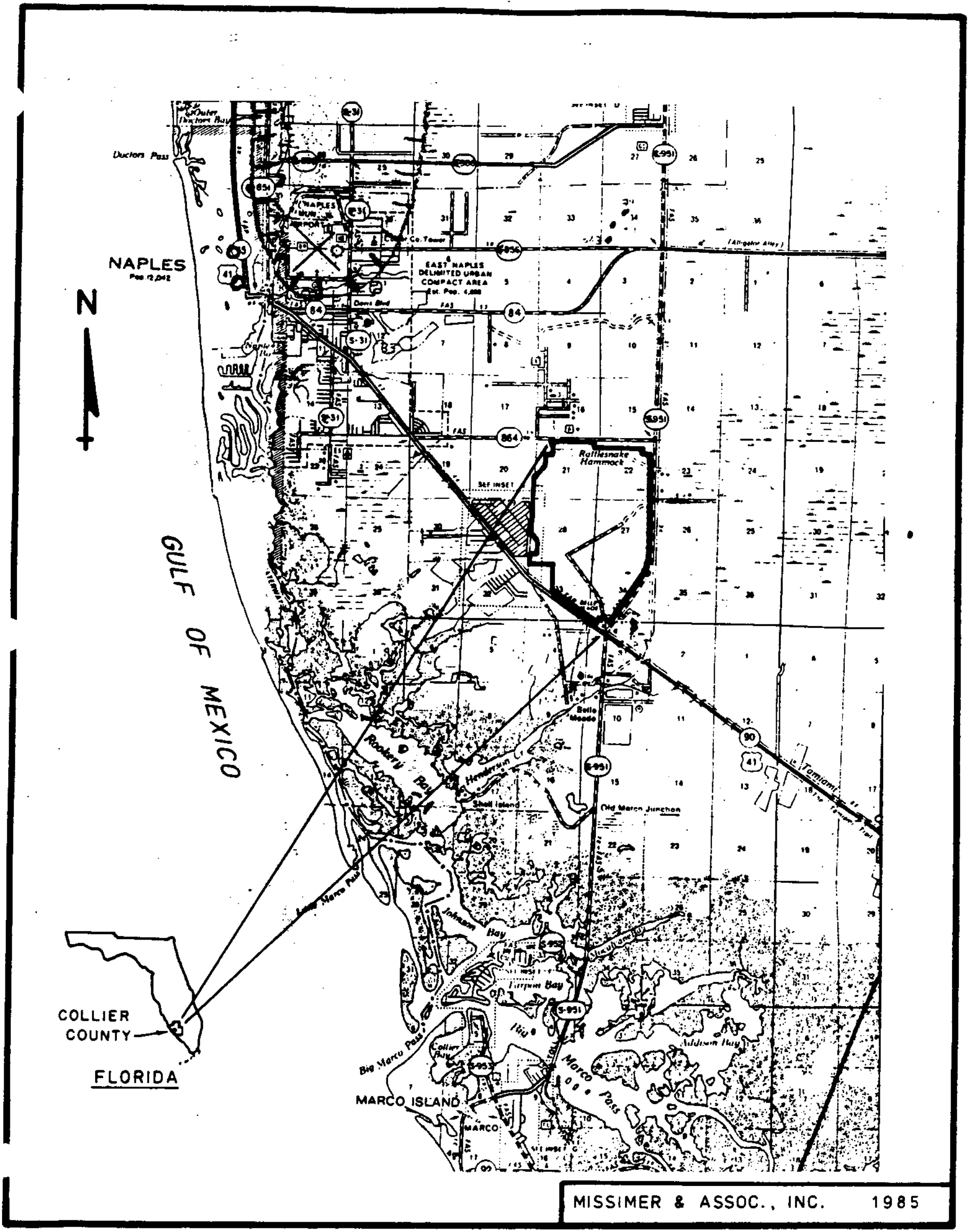

FIGURE 2-1. MAP SHOWING LOCATION OF LELY ESTATES DEVELOPEMENT

II. INTRODUCTION

1. Authorization

Missimer and Associates, Inc. was authorized by Wilson, Miller, Barton, Soll & Peek to investigate the groundwater system of the Lely Estates property. This includes parts of Sections 21, 23, 27, 28, 33 and 34 of Township 50 South, Range 26 East, in southwest Collier County, totaling 2,628 acres.

The purpose of the investigation was to evaluate the groundwater resources in order to assess whether a safe sustained yield of fresh water for irrigation use is available. The general location of the study area is shown in Figure 2-1.

2. Scope of Work

The scope of work included: 1) a compilation and review of all existing geologic and hydrologic information on the area, 2) a well inventory of the surrounding area, 3) a test drilling and observation well construction program to detail the geology and define the aquifer system, 4) the collection of geologic, geophysical, and hydrologic data from all test holes, 5) the performance and analysis of aquifer tests, and 6) the production of a report with recommendations concerning the availability of water.

III. HYDROLOGIC INVESTIGATION OF THE SITE

1. Well Inventory

A well inventory was conducted of the existing wells both on and in the vicinity of the project site in order to assess water quality and water use. The locations of the wells are shown in Figure 3-1. The well construction information and the water quality characteristics are given in Table 3-1.

Prior to the drilling of test wells, 12 existing wells were located on the site. These wells have been used for agricultural purposes producing from both the water-table aquifer and the Tamiami Aquifer.

2. Test Drilling and Observation Well Construction

In order to determine the hydrogeologic characteristics of the site, six pairs of test wells were constructed. The locations of the well pairs are shown in Figure 3-2. The construction and water quality information on each well is given in Table 3-2. The well pairs consisted of one water-table aquifer well and one Tamiami Aquifer well. Geologic samples were collected from each well.

Well CO-820 was constructed to obtain a profile of the salinity in the aquifer beneath the site. The well was

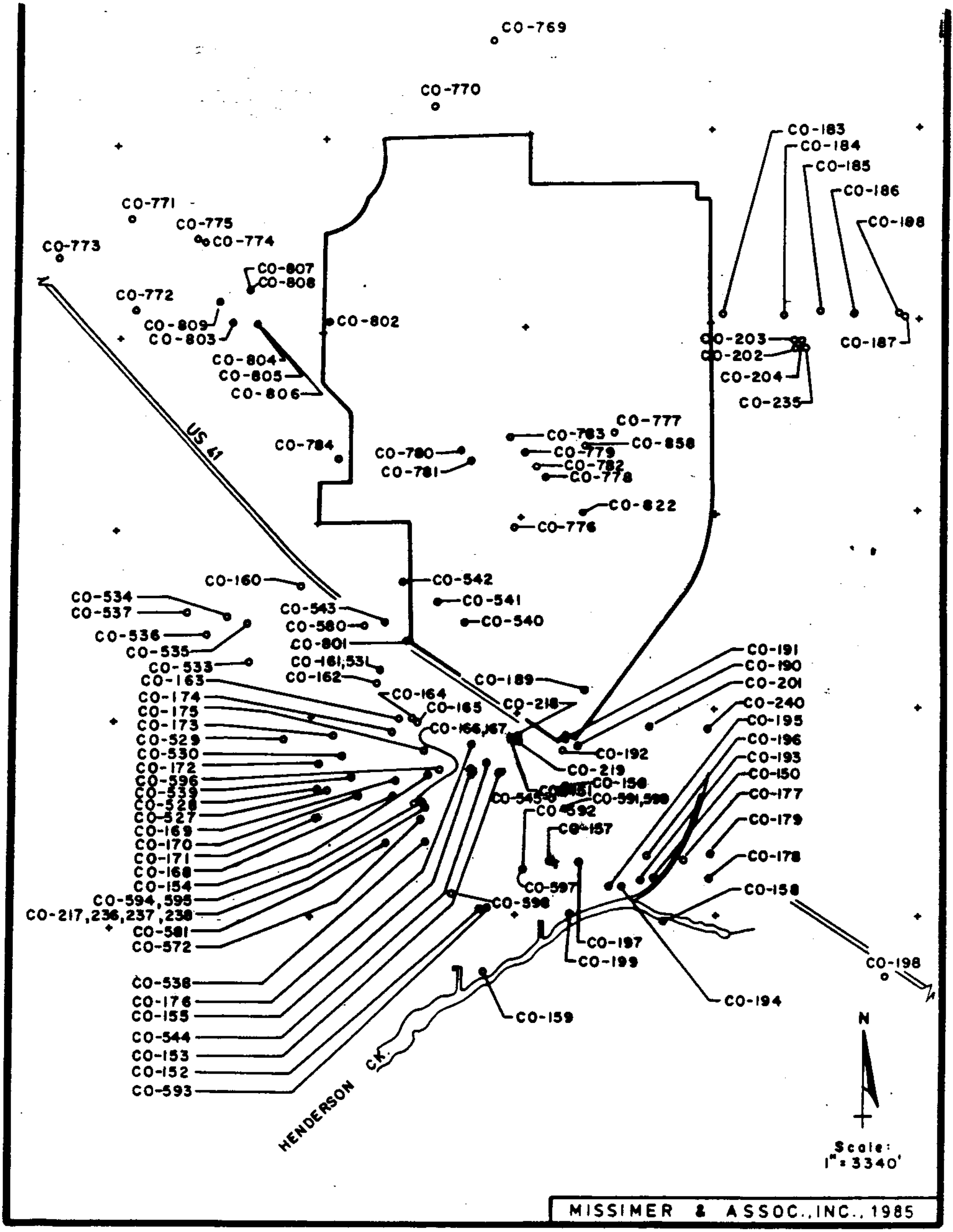

FIGURE 3-1. MAP SHOWING LOCATION OF INVENTORIED WELLS.

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TABLE 3-1. INVENTORIED WELLS

Well No.	Diameter (inches)	Casing Depth (feet)	Total Depth (feet)	Cl$^-$ (mg/l)	Use
CO-150	--	--	--	170	Domestic, Irrigation
CO-151	2	98	103	720	Observation, destroyed
CO-152	2	140	141	Profile	Observation
CO-153	2	61	66	400	Observation, destroyed
CO-154	2	60	65	420	Observation, destroyed
CO-155	2	57	62	680	Observation, destroyed
CO-156	2	58	63	440	Observation, destroyed
CO-157	2	60	65	2600	Observation, destroyed
CO-158	2	20	--	170	Domestic, Irrigation
CO-159	2	--	--	200	Domestic, Irrigation
CO-160	4	--	--	60	Public Supply
CO-161	2	--	--	--	Observation
CO-162	8	--	--	169	Agricultural, Irrigation
CO-163	4	38	44	220	Domestic
CO-164	1¼	--	--	150	Domestic
CO-165	2	--	--	230	Domestic
CO-166	2	--	21	220	Domestic, Irrigation
CO-167	2	--	50	230	Domestic, Irrigation
CO-168	2	--	--	250	Domestic
CO-169	2	--	--	200	Domestic
CO-170	--	--	40	300	Domestic, Irrigation
CO-171	2	--	--	420	Domestic, Irrigation
CO-172	--	--	--	290	Domestic, Irrigation
CO-173	2	--	--	250	Domestic, Irrigation
CO-174	--	--	--	220	Domestic
CO-175	2	--	--	120	Domestic
CO-176	2	--	30	120	Domestic, Irrigation
CO-177	--	--	--	220	Domestic, Irrigation
CO-178	--	--	--	300	Domestic, Irrigation
CO-179	2	--	--	20	Domestic, Irrigation
CO-183	2	--	44	200	Domestic, Irrigation
CO-184	2	--	33	180	Domestic, Irrigation
CO-185	2	--	45	380	Domestic, Irrigation
CO-186	--	--	42	280	Domestic, Irrigation
CO-187	--	--	--	420	Domestic
CO-188	2	--	--	260	Domestic, Irrigation
CO-189	4	--	--	80	Domestic, Stock
CO-190	--	--	--	12	Industrial, Irrigation
CO-191	--	--	--	45	Industrial, Irrigation
CO-192	--	--	--	40	Industrial, Irrigation
CO-193	--	--	47	260	Domestic, Irrigation
CO-194	2	--	40	240	Domestic, Irrigation
CO-195	2	--	40	300	Domestic, Irrigation
CO-196	4	--	34	260	Domestic, Irrigation
CO-197	2	--	40	280	Domestic, Irrigation
CO-198	4	--	--	140	Public Supply

TABLE 3-1. INVENTORIED WELLS - Continued:

Well No.	Diameter (inches)	Casing Depth (feet)	Total Depth (feet)	Cl^- (mg/l)	Use
CO-199	--	--	--	680	Domestic, Irrigation
CO-201	2	186	195	Profile	Observation
CO-202	2	12	15		Test Observation
CO-203	2	18	25	80	Test Observation
CO-204	2	18	25	80	Test Observation
CO-217	8	30	45	380	Ag. Irr., destroyed
CO-218	2	40	45	--	Observation
CO-219	2	10	15	--	Observation, destroyed
CO-235	8	10	50	200	Test
CO-236	2	40	45	--	Observation, destroyed
CO-237	2	40	45	320	Observation
CO-238	2	10	15	80	Observation
CO-240	2	40	42	--	--
CO-527	--	--	18	320	Domestic, Irrigation
CO-528	2	--	32	370	Domestic, Irrigation
CO-529	--	--	--	260	Domestic, Irrigation
CO-530	2	30	--	550	Stock Dom., Irrigation
CO-531	4	--	80	150	Domestic, Irrigation
CO-533	8	--	--	510	Agricultural, Irrigation
CO-534	8	--	--	240	Agricultural, Irrigation
CO-535	8	--	--	200	Agricultural, Irrigation
CO-536	8	--	--	500	Agricultural, Irrigation
CO-537	8	--	--	470	Agricultural, Irrigation
CO-538	6	--	47	660	Agricultural, Irrigation
CO-539	6	--	--	280	Agricultural, Irrigation
CO-540	8	--	--	130	Agricultural, Irrigation
CO-541	8	--	63	94	Agricultural, Irrigation
CO-542	8	--	--	100	Agricultural, Irrigation
CO-543	8	--	73	120	Agricultural, Irrigation
CO-544	8	30	45	240	Golf Course Irrigation
CO-545	8	26	45	240	Golf Course Irrigation
CO-572	2	150	160	Profile	Observation
CO-580	2	160	161	Profile	Observation
CO-581	2	40	50	1380	Observation
CO-591	2	6.5	11.5	--	Observation
CO-592	2	7.5	12.5	--	Observation
CO-593	2	7	12	--	Observation
CO-594	2	4	9	--	Observation
CO-595	2	11.5	16.5	--	Observation
CO-596	2	6	11	--	Observation
CO-597	2	38	40	230	Observation
CO-598	2	35	40	920	Observation
CO-599	2	43	45	180	Observation
CO-769	1½	--	15	40	Domestic, Irrigation
CO-770	2	--	40	170	Domestic, Irrigation
CO-771	--	--	--	80	Domestic, Irrigation

TABLE 3-1. INVENTORIED WELLS - Continued:

Well No.	Diameter (inches)	Casing Depth (feet)	Total Depth (feet)	Cl^- (mg/l)	Use
CO-772	--	--	40	120	Domestic, Irrigation
CO-773	--	--	70?	50	Domestic, Irrigation
CO-774	8-10	--	--	150	Golf Course Irrigation
CO-775	2	--	--	160	Irrigation
CO-776	8	12	52	200	Agricultural, Irrigation
CO-777	8	11	16	130	Stock
CO-778	8	--	--	--	Agricultural, Irrigation
CO-779	14?	--	24	30	Agricultural, Irrigation
CO-780	8	--	--	--	Agricultural, Irrigation
CO-781	8	--	47	190	Agricultural, Irrigation
CO-782	8	--	14	--	Agricultural, Irrigation
CO-783	8	--	11	110	Agricultural, Irrigation
CO-784	6	--	--	50	Agricultural, Irrigation
CO-785	--	--	--	22	Industrial, Irrigation
CO-801	8	--	>100	500	Agricultural, Irrigation
CO-802	6	--	61	90	Unused
CO-803	--	--	--	130	Industrial
CO-804	2	29	45	100	Observation
CO-805	2	36	45	100	Observation
CO-806	2	10	15	90	Observation
CO-807	2	30	45	110	Observation
CO-808	2	10	15	60	Observation
CO-809	2	10	15	80	Observation
CO-822	8	--	--	--	Agricultural, Irrigation

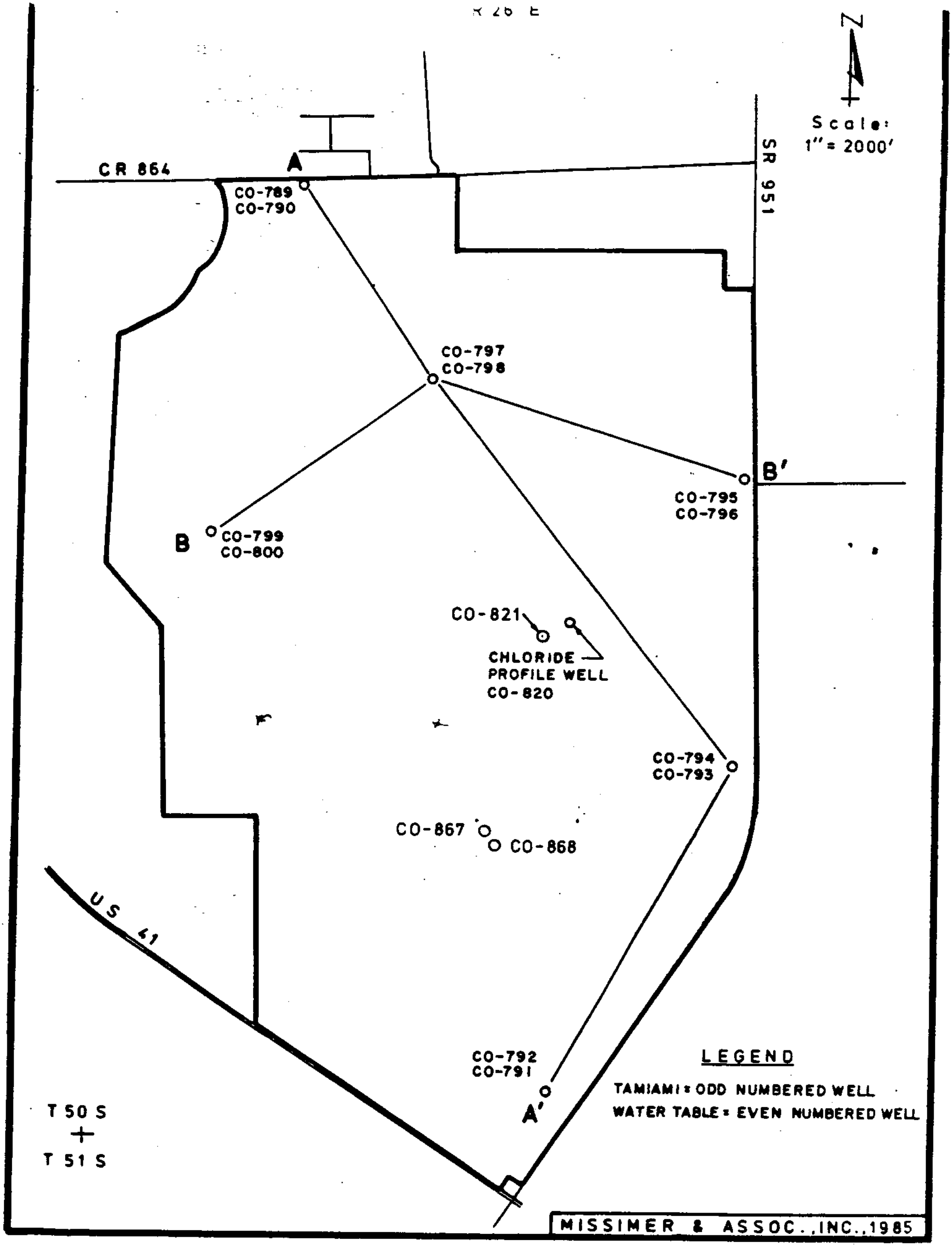

FIGURE 3-2. MAP SHOWING TEST WELLS ON SITE AND LOCATION OF CROSS SECTIONS.

TABLE 3-2. CONSTRUCTION DETAILS OF TEST WELLS ON THE SITE

Well No.	Casing Diameter (inches)	Casing Depth (feet)	Screened Interval (feet)	Total Depth (feet)	Cl$^-$ (mg/l)	Conductivity (umhos/cm)
CO-789	2	45	45-50	60	140	920
CO-790	2	10	10-15	15	46	650
CO-791	2	45	45-50	60	80	650
CO-792	2	10	10-15	15	18	500
CO-793	2	45	45-50	60	150	1000
CO-794	2	10	10-15	15	20	650
CO-795	2	45	45-50	60	160	1150
CO-796	2	10	10-15	15	22	620
CO-797	2	45	45-50	60	120	880
CO-798	2	10	10-15	15	62	750
CO-799	2	45	45-50	60	100	870
CO-800	2	10	10-15	15	34	650
CO-820	2	168	Open Hole 168-176	176	Chloride Profile	
CO-821	2	11	Open Hole 11-16	16	40	850

constructed by driving a 2-inch steel well casing and jetting out the cuttings in 21-foot intervals. The well was pumped after each length of casing was cleared. A water sample was taken after approximately 15 minutes pumping and analyzed for dissolved chloride concentrations. In addition to the above wells, three wells were constructed as monitor wells for conducting pumping tests. These wells are CO-821, CO-867 and CO-868. The water levels were measured in all wells at several occasions and a water sample was collected and analyzed for dissolved chloride and conductivity.

3. Aquifer Testing

A test of the Tamiami Aquifer was conducted by pumping an existing 8-inch irrigation well, CO-776, at a rate of 440 gallons per minute for a period of 48 hours. Water levels were continuously monitored in three wells using Stevens Type-F water level recorders. The observation wells used are identified by numbers CO-867, CO-868, and CO-822 located at distances of 104 feet, 256 feet and 1,600 feet respectively from the production well. A diagram of the aquifer test set-up is shown in Figure 3-3. While pumping at 440 gallons per minute, the drawdown in the production well stabilized at 3.7 feet. The drawdown data from the observation wells were analyzed to determine the aquifer's hydraulic coefficients.

Water samples were collected at several times during

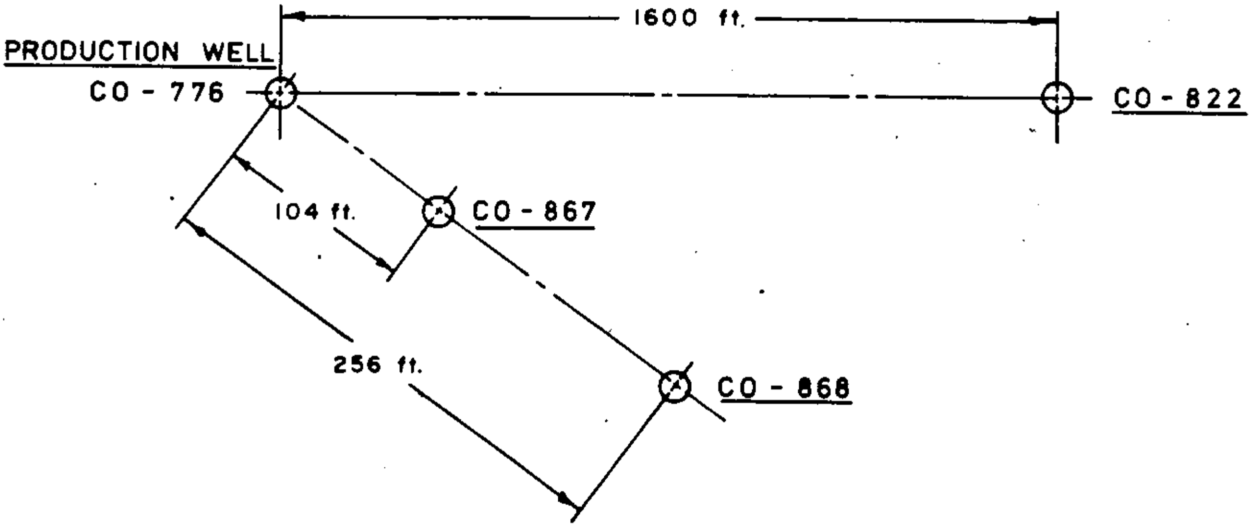

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FIGURE 3-3. DIAGRAM SHOWING AQUIFER TEST SETUP

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the test and analyzed to determine dissolved chloride concentrations and conductivity.

Additionally an aquifer test was conducted on the water-table aquifer. Well CO-777 was pumped at a rate of 42 gallons per minute for a period of 150 minutes. The drawdown was continuously monitored in Well CO-831, which was located 40 feet from the production well. This data was analyzed to obtain an estimate of the transmissivity of the shallow water table.

IV. GEOLOGY AND HYDROLOGY OF THE SITE

1. Geology

The geologic sequence beneath the project site was revealed by constructing six (6) pairs of test wells (see Figure 3-2 and Table 3-2). At each location one water-table and one Tamiami Aquifer well were constructed. Gamma ray, and where possible, electric logs were run on the deeper test holes. Water level, water quality, and geologic data were collected at each of the wells. A chloride profile test well was also constructed in order to delineate the freshwater/saltwater interface. A geologic column of this 176 foot deep test well is given in Figure 4-1. Geologic cross sections N-S and E-W across the site are given in Figures 4-2 and 4-3. Geologic logs are given in Tables A-1 through A-7.

Six stratigraphic units were penetrated beneath the site. These units are the Pamlico Sand, lithologic unit A, lithologic unit B, the Ochopee Limestone, the Lehigh Acres Sandstone, and the Green Meadows Clay.

The Pamlico Sand was fully penetrated in each of the test wells. At all well locations with the exception of well pair CO-789 and CO-790, the Pamlico consisted of 4 to 5 feet of light gray and brown, fine to medium grained quartz sand and minor shell underlain by a crustal sandy limestone.

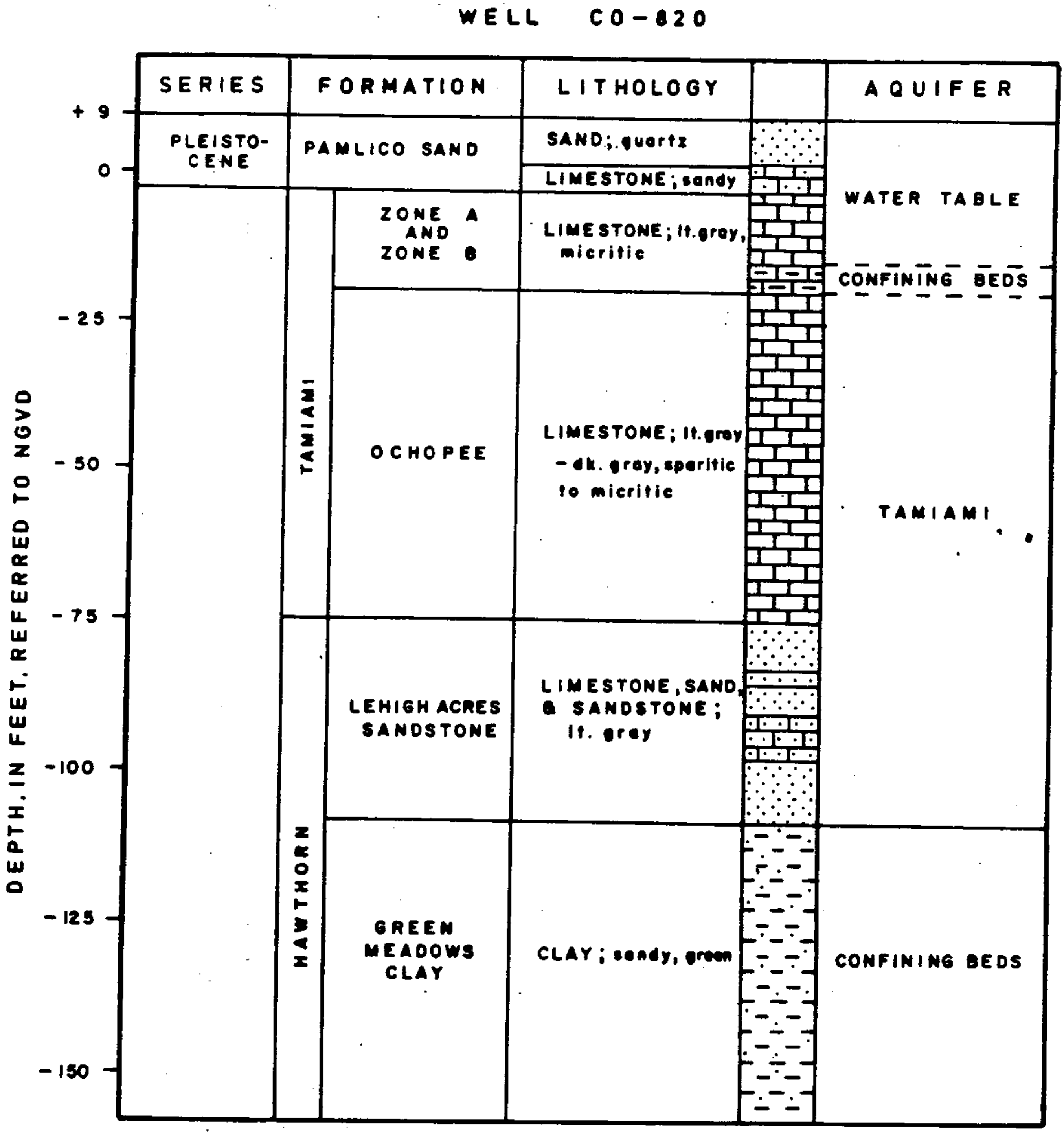

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FIGURE 4-1. GEOLOGIC COLUMN OF TEST WELL CO-820.

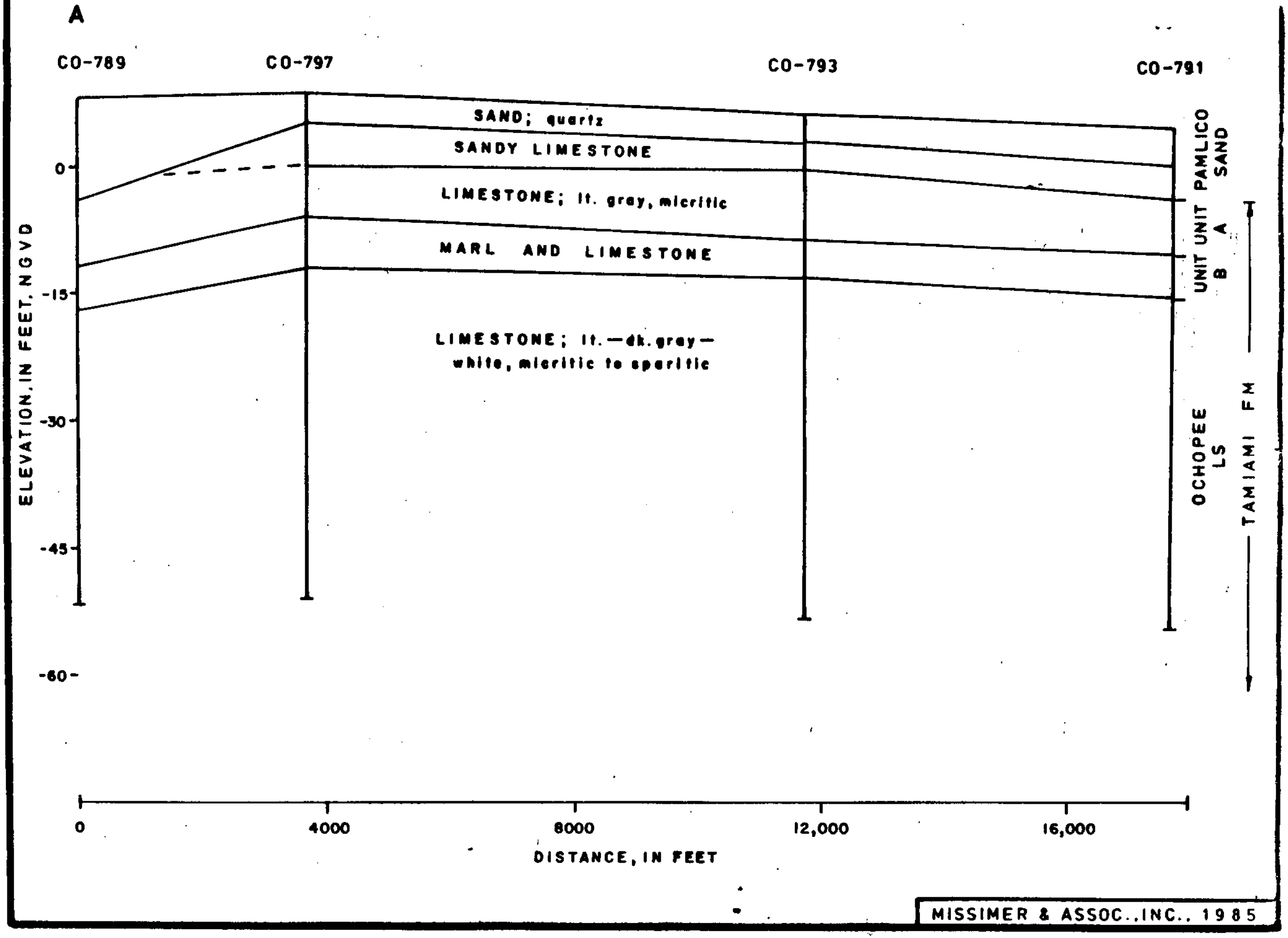

FIGURE 4-2 GEOLOGIC X-SECTIONS NORTH — SOUTH ACROSS THE SITE.

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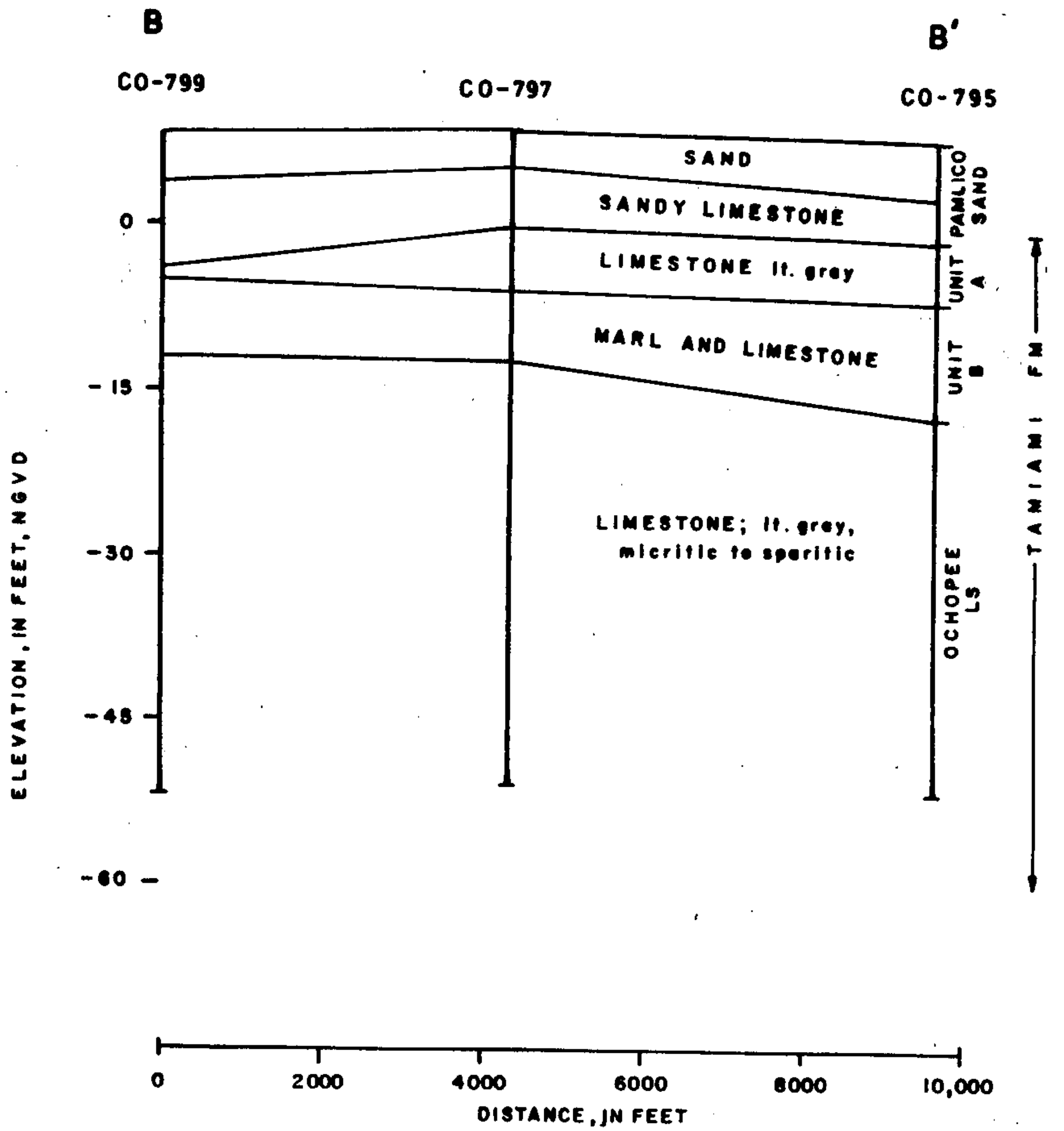

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FIGURE 4-3. GEOLOGIC X-SECTION EAST - WEST ACROSS THE SITE.

This dense, sandy limestone is tan-rust in color and ranges from 3 to 8 feet in thickness. It contains up to 40% medium grained quartz sand and shell cemented in a micritic matrix. In well pair CO-789 and CO-790, this crustal limestone was not present. The unconsolidated quartz sand persisted to a depth of 12 feet with a shell and clay lense at its base. It is probable that this crustal limestone does not occur uniformly over the project site.

Lithologyc Unit A, or Pinecrest Limestone equivalent, lies unconformably beneath the Pamlico Sand. This uppermost member of the Tamiami Formation is a light gray, medium hard, biomicritic limestone beginning at a depth between 7-12 feet below land surface. It is thinnest (2') in well pair CO-799 and CO-800, but is at least 7 feet thick at all other well locations. The limestone unit is highly fossiliferous with good secondary moldic and vuggy porosity common.

Underlying lithologic unit A is lithologic unit B, or the Bonita Springs Marl equivalent. This marly unit is between 5 and 10 feet thick and contains variable amounts of limestone, clay and shell. In all well pairs the unit consists of a soft, marly limestone containing traces of white, sandy clay and silt. These beds are 5 to 10 feet thick occurring generally between 15 and 25 feet below land surface. In well pairs CO-789 and CO-790, CO-795 and CO-796, the amount of clay within this unit increased. A thin lense (5' thick) of green-gray, sandy clay appeared at a depth between 20 and 25 feet below land surface at both locations with the degree of confinement somewhat greater in well pair CO-789 and CO-790.

Beneath lithologic unit B lies the Ochopee Limestone Member of the Tamiami Formation. This unit is laterally extensive and well defined in Collier County. The full thickness of the unit was penetrated only in the deeper chloride profile well, where it was found to be approximately 65 feet thick. The Ochopee Limestone contains several lithologies. The upper 10 to 15 feet of the unit is a medium hard, light gray biomicritic limestone with occasional moldic and vuggy porosity. Beneath this lithofacies is a harder light to dark gray biosparitic to biomicritic limestone with abundant moldic and vuggy porosity. This unit is 15 to 20 feet thick and occurs to a depth of 60 feet below land surface. In well pairs CO-789 and CO-790, CO-793 and CO-794, CO-799 and CO-800, a whiter biosparitic limestone occurs at varying depths between 30 and 60 feet. This whiter limestone is probably not continuous across the site. At a depth of approximately 85 feet below land surface the amount of quartz sand increases to over 20% within the Ochopee. It is here that the gradational contact is placed between the Ochopee and Lehigh Acres Sandstone.

The Lehigh Acres Sandstone Member of the Tamiami Formation lies below the Ochopee Limestone. It is a poorly consolidated sandstone, limestone and sand unit appearing at between 85 and 118 feet below land surface at the site.

This unit is thinner than expected based on other geologic data in the area.

Below the Lehigh Acres Sandstone lies the Green Meadows Clay. This unit contains variable amounts of quartz sand in a green clayey matrix ranging from 10% to over 50% clay. This lithology persists to a depth of 176 feet, the base of well CO-870, with a minor marly limestone unit occurring between 138 and 144 feet. The full thickness of the Green Meadows Clay was not penetrated at the site.

2. Aquifer Descriptions

Water-Table Aquifer

The water-table aquifer occurs within the Pamlico Sand and lithologic unit A of the Tamiami Formation. The aquifer consists of fine grained quartz sand of medium permeability, underlain by a low permeability dense sandy limestone and a medium permeability micritic limestone. Overall, the aquifer consists of 15 feet of sediments of mostly medium permeability. Existing at the base of the aquifer are the confining beds of lithologic unit B. These confining beds, consisting of marly limestone with interbedded clays, provide only a small degree of confinement and may not fully separate the water-table from the underlying Tamiami Aquifer. The beds will be somewhat more confining at the far northern and eastern parts of the property where the clay unit is thickest.

Tamiami Aquifer

The Tamiami Aquifer underlies the water-table aquifer and occurs within the Ochopee Limestone and Lehigh Acres Sandstone. The Ochopee Limestone contains limestones of medium permeability in its upper 10 to 15 feet with limestones of higher permeability below. As the amount of quartz sand increases (at approximately 70 feet below land surface) in the Ochopee, permeabilities are generally low to medium in the Lehigh Acres Sandstone, which consists of mostly unconsolidated quartz sand at the site. The entire thickness of the Tamiami Aquifer was found to be approximately 100 feet.

Beneath the Lehigh Acres are the low permeability sandy clays of the Green Meadows Clay. These were found to be over 50 feet thick in the chloride profile well and should provide a good degree of confinement from the Hawthorn Aquifer below. The full thickness of the Green Meadows Clay was not penetrated on the site.

3. Aquifer Hydraulic Properties

There are four types of aquifers defined by Kruseman and DeRidder (1970) in terms of their degree of confinement. The four types are: 1) unconfined, 2) semi-unconfined, 3) semi-confined, and 4) confined aquifers (Figure Of the two aquifers penetrated during this investigation, the water-table aquifer is semi-unconfined, and the Tamiami Aquifer is semi-confined.

Semi-Unconfined Aquifers:

Although open to atmospheric pressure and recharged directly by rainfall, a semi-unconfined aquifer is stratified to a certain extent. This stratification creates an impediment to the vertical flow of water from land surface to the aquifer base. Its simplest form is that of a permeable hydrologic unit which is bounded below by an impervious layer and above by a layer which has a hydraulic conductivity notably lower than that of the prime aquifer material, but not so low that it effectively blocks the vertical flow of water.

When a semi-unconfined aquifer is pumped, the water table in the covering layer also drops, though initially less than the piezometric head in the underlying pumped aquifer. As water slowly drains from the overlying strata, an equilibrium is created between these two components of flow within the aquifer, causing the rate of water level drawdown to decrease and stabilize. This phenomenon is known as delayed yield. When the rate of drainage of the less permeable zone becomes less than the rate a well is being pumped the water table begins to decline as it did intially. In order to assess the effects of pumping a semi-unconfined aquifer, it is necessary to determine the hydraulic coefficients of transmissivity, and a late storage coefficient (or specific yield).

Semi-Confined Aquifers:

Semi-confined aquifers occur where continuous beds of low permeability bound the aquifer above and/or below it and confine it from the atmosphere and other aquifers. Although the aquifer appears confined, water can still move vertically through the confining beds. When a semi-confined aquifer is pumped, water is withdrawn not only from the aquifer, but also from and through the adjacent confining beds. Since pumping reduces the pressure in the aquifer, groundwater in the confining beds moves vertically into the aquifer. In long term pumping of a semi-confined aquifer, an equilibrium between the rate of withdrawal and the recharge rate through the confining beds will occur. In order to properly assess the effects of pumping a semi-confined aquifer, it is necessary to determine three hydraulic coefficients from aquifer test data. These coefficients are:

Transmissivity (T) - The ability of an aquifer to transmit water, reported in gallons/day/foot (gpd/ft)

Storage Coefficient (S) - The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head, reported as a dimensionless number.

Leakance (k'/b') - The effective permeability of a confining bed divided by the thickness of the confining bed, reported in gallons/day/cubic foot (gpd/ft^3)

Water-Table Aquifer

A pumping test was conducted on the water-table aquifer near the central part of the property. Well number CO-777 16' total depth was pumped at a rate of 42 gallons per minute for 150 minutes. Water levels were monitored in well CO-821, which was located 40 feet from the production well. Time and drawdown data from this test are shown in Figure 4-4, along with a match to the early segment of the appropriate Boulton type curve. The transmissivity value computed by this analysis technique is 48,000 gpd/ft. Due to the rather short duration of the test, it was not possible to determine a specific yield value.

A pumping test was also conducted in a previous investigation just west of S-951 in Section 26 for Marco Island Utilities (Missimer and Associates, Inc., 1980). The results of this test showed the water table to have a transmissivity of 71,000 gpd/ft. This test also was not of sufficient duration to determine a specific yield value.

Tamiami Aquifer

An aquifer test was performed on the Tamiami Aquifer with continuous pumping at 440 gpm for a period of 72 hours. A detailed description of the test is given in Section 3. The drawdown in the test-production well stabilized at approximately 3.7 feet after one hour of pumping which yields a specific capacity of 119 gpm per foot of drawdown. Continuous records of drawdown in the observation wells were

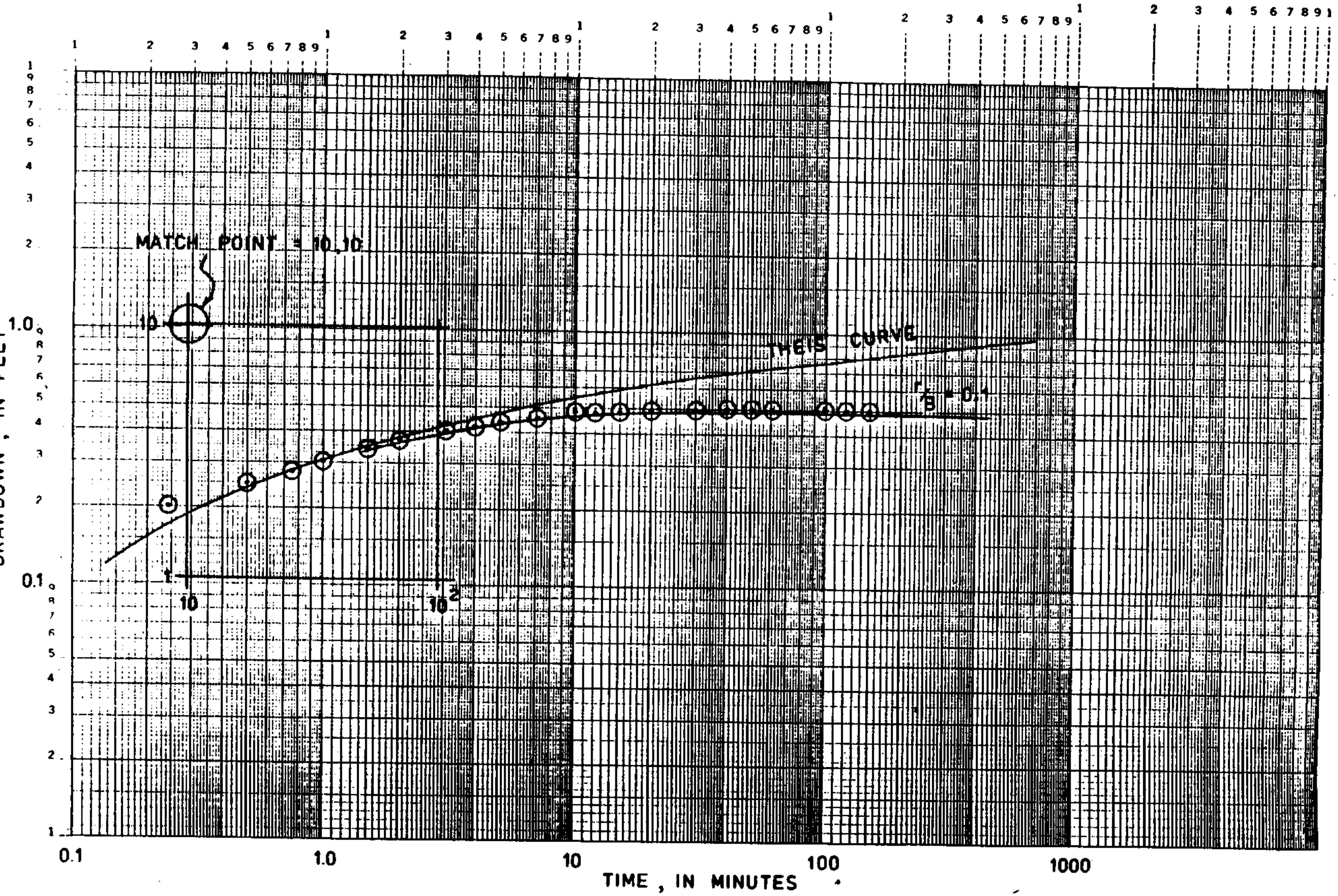

FIGURE 4-4. TIME VS. DRAWDOWN PLOT FOR WATER TABLE MONITOR WELL CO-821. Q = 42 gpm, r = 40 feet

maintained throughout the pumping and recovery period.

A preliminary data analysis was made of the Tamiami Aquifer using the Jacob straight line method (Cooper and Jacob, 1946; Jacob, 1950) for both the pumping and recovery data. A semi-log plot of drawdown versus time from the two observation wells is given in Figures 4-5 and 4-6 .

In leaky or semi-confined aquifers the Jacob method yields accurate values for transmissivity and storage coefficient only if the early data from the pumping test are used to construct the straight line. After leakage or delayed yield begins to recharge the production zone, drawdowns are not only due to the hydraulic properties of the production zone, but also include effects of vertical flow from zones above and/or below, and therefore this data cannot be used in the straight line analysis method.

Primary evaluation of the aquifer test data was done using the method of Hantush-Jacob (1955) as adapted to a method published by Cooper (1963).

The drawdown data were plotted on log-log paper and the resultant curve was matched to the appropriate Boulton function type-curve. The match point was substituted into the following equations:

$$T = \frac{Q\ W\ (u, {}^{r}/B)}{4\pi s}$$

$$S = \frac{4\ T\ u\ t}{r^2}$$

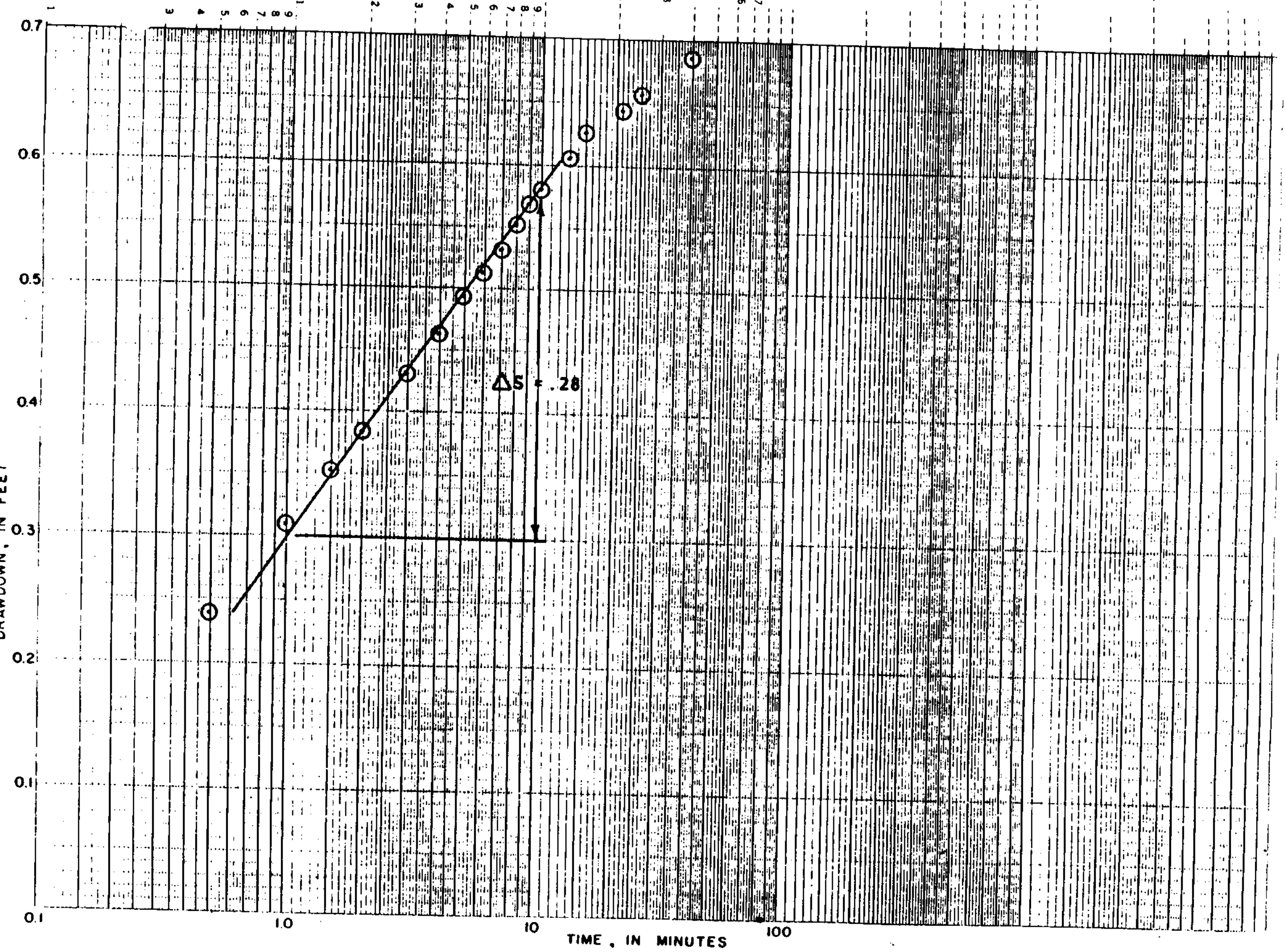

FIGURE 4-5. STRAIGHT LINE ANALYSIS OF THE INITIAL TEST DATA FROM WELL CO-867. Q = 440 gpm, r = 104 feet

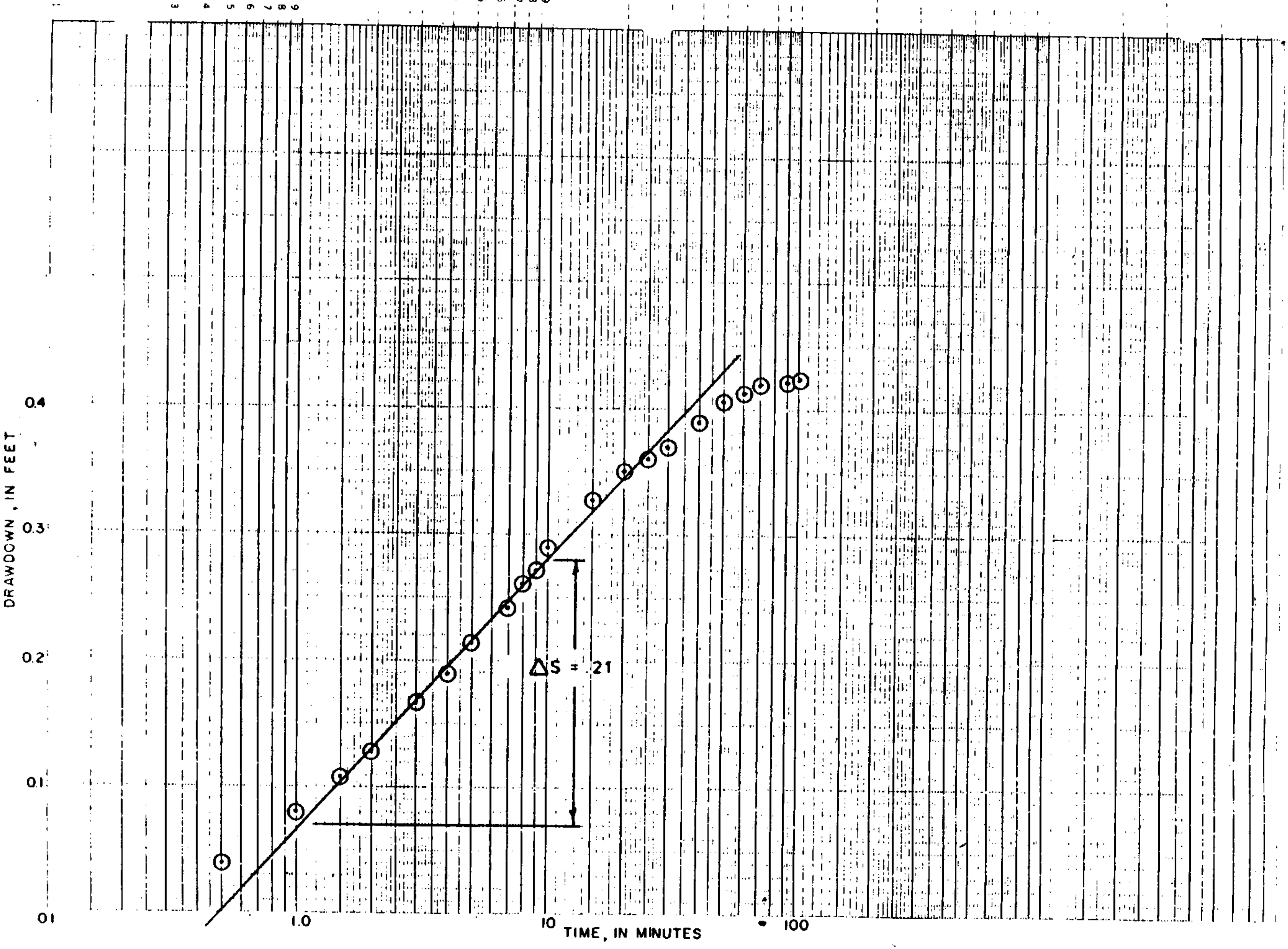

FIGURE 4-6. STRAIGHT LINE ANALYSIS OF THE INITIAL TEST DATA FROM MONITOR WELL CO-868.
Q = 440 gpm, r = 256 feet

$$k'/b' = \frac{T\ (r/B)^2}{r^2} = \frac{S\left(\frac{v2}{u}\right)}{t}$$

where,

T = transmissivity

Q = well discharge

W = $(u, {}^{r}/B)$ = well function for leaky aquifers without water released from storage in the aquifer (for time drawdown)

s = drawdown (from match point)

S = storage coefficient

t = time (from match point)

r = distance from pumped well to observation well

k' = permeability of confining layer

b' = thickness of confining layer

B = $(T/k'b'/)^{\frac{1}{2}}$ obtained from family of ${}^{r}/B$ type curves

v = ${}^{r}/2\ (k'/b'\ T)^{\frac{1}{2}}$ obtained from family of $v^2/_u$ type curves

The data plots of time versus drawdown for the two observation wells are shown in Figures 4-7 and 4-8. The plots were matched to the appropriate type curve and good matches were obtained showing that the aquifer has no unusual boundary conditions.

The data from this test allowed determination of the transmissivity, leakance and storage coefficient. The aquifer coefficients yielded by various analyses are given in Table 4-1. These coefficients vary somewhat depending on the particular well or analysis method used. The set of

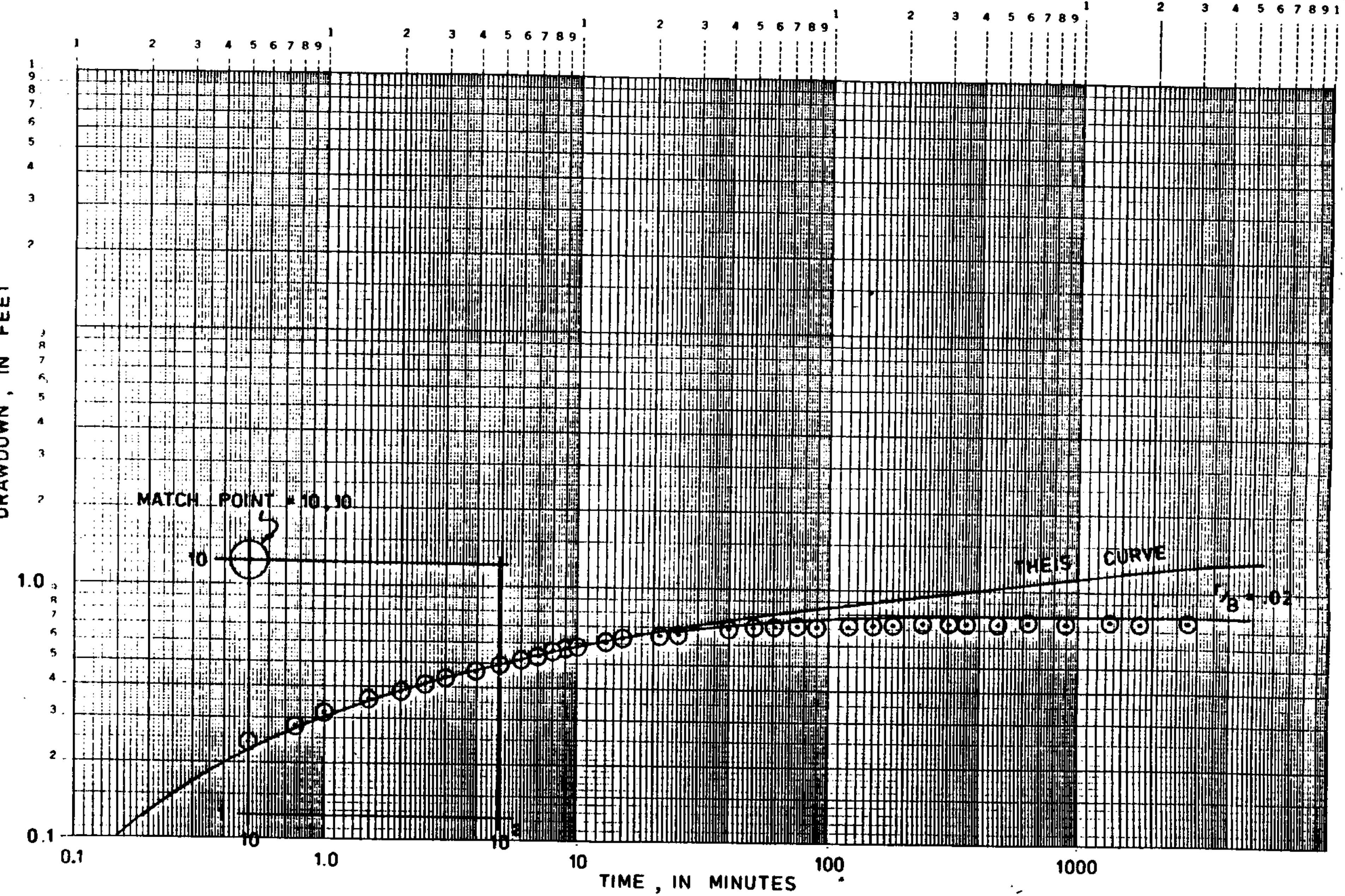

FIGURE 4-7. TIME VS. DRAWDOWN PLOT FOR MONITOR WELL CO-867.

Q = 440 gpm, r = 104 feet

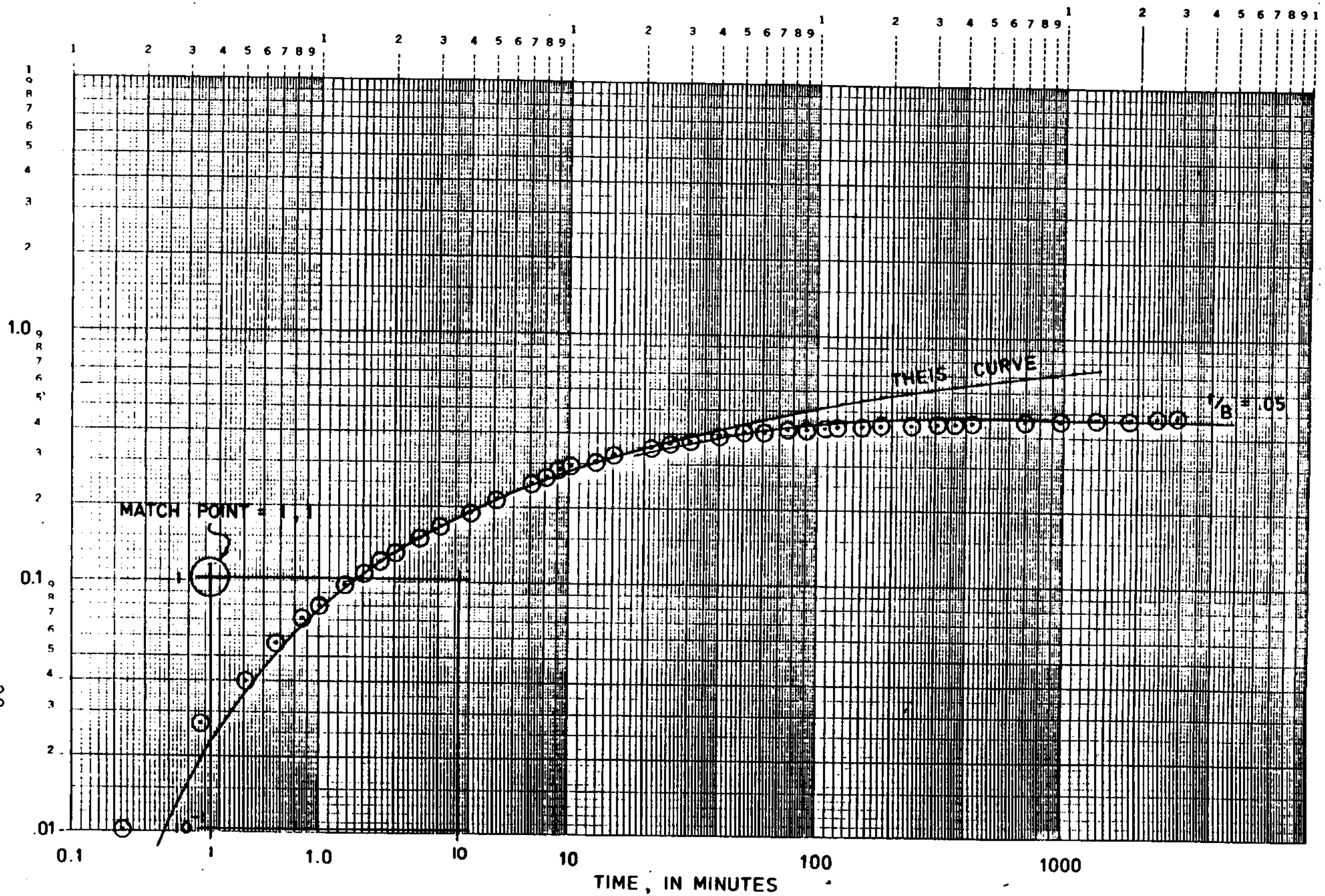

FIGURE 4-8. TIME VS. DRAWDOWN PLOT FOR MONITOR WELL CO-868. Q = 440 gpm, r = 256 feet

TABLE 4-1. AQUIFER COEFFICIENTS FOR TAMIAMI AQUIFER BY VARIOUS ANALYSIS METHODS

Analysis Method	Transmissivity gpd/ft	Leakance k'/b' gpd/ft3	Storage Coefficient
Hantush Jacob Well CO-867	420,000	.056	6.6×10^{-4}
Hantush-Jacob Well CO-868	504,000	.077	1.0×10^{-2}
Jacob (semi-log) Well CO-867	415,000	---	7.2×10^{-4}
Jacob (semi-log) Well CO-868	553,000	---	7.9×10^{-3}

coefficients which best represent the aquifer in the study area are:

Transmissivity = 504,000 gpd/ft

Leakance $k'/_{b'}$ = .077 gpd/ft^3

These coefficients were chosen because it is felt that the distant observation well gives a more representative picture of the regional characteristics.

The semi-confining beds below the Tamiami Aquifer at the Lely site are relatively leaky and it can therefore be expected that during the dry season, the water table will decline somewhat from long term pumpage. This situation will occur during the dry season but it is not likely to occur in the wet season as rainfall will recharge the shallow zone faster than it can drain. Modeling of the aquifer behavior during the dry season will be done using a storage coefficient of 0.1, which is conservative for such a system.

4. Water Levels

Water-Table Aquifer

The position of the water table fluctuates as a response to recharge and discharge, which are controlled by climatic conditions (rainfall), drainage (surface gradient), and aquifer pumpages. Flow of water, under natural conditions, will follow the natural slope of the land surface.

The mid-dry season position of the water table on the site is given in Figure 4-9. These elevations correspond to a water table depth which ranges between approximately 2 and 5 feet below land surface. Wet season water levels will be higher with water levels above land surface in lower areas while being about 2 feet below land surface in the higher elevation areas.

The hydraulic gradient N-S across the site appears to follow the land surface gradient. These contours do not appear to be affected by unnatural drainage or pumpages. The agricultural irrigation ditches on the property and Henderson Creek Canal have a small affect on the groundwater flow direction, but only in areas adjacent to these water bodies. The effect of Henderson Creek Canal as it relates to drainage and subsurface flow direction will be more significant in extended dry periods when its influence may be detected one-half mile or more from the canal location. The groundwater flow direction on the site is toward the south/southwest (see map), generally following the natural slope of land surface.

Tamiami Aquifer

The mid-dry season position of potentiometric surface for the Tamiami Aquifer is given in Figure 4-10. Little difference is shown in the relative altitudes of the water table and Tamiami at each of the well sites. The potentiometric

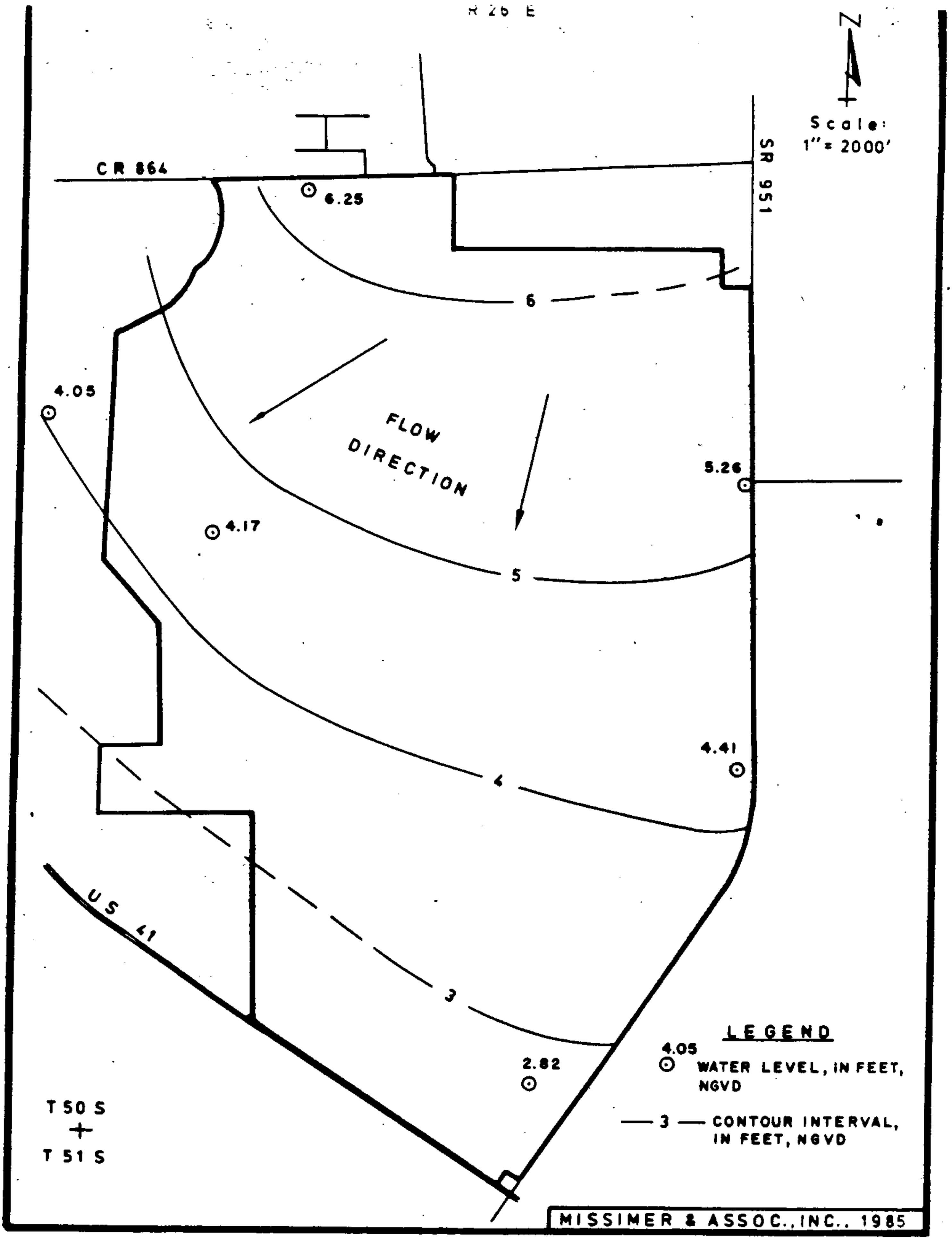

FIGURE 4-9. MAP SHOWING THE POTENTIOMETRIC SURFACE FOR THE WATER TABLE AQUIFER DURING THE DRY SEASON.

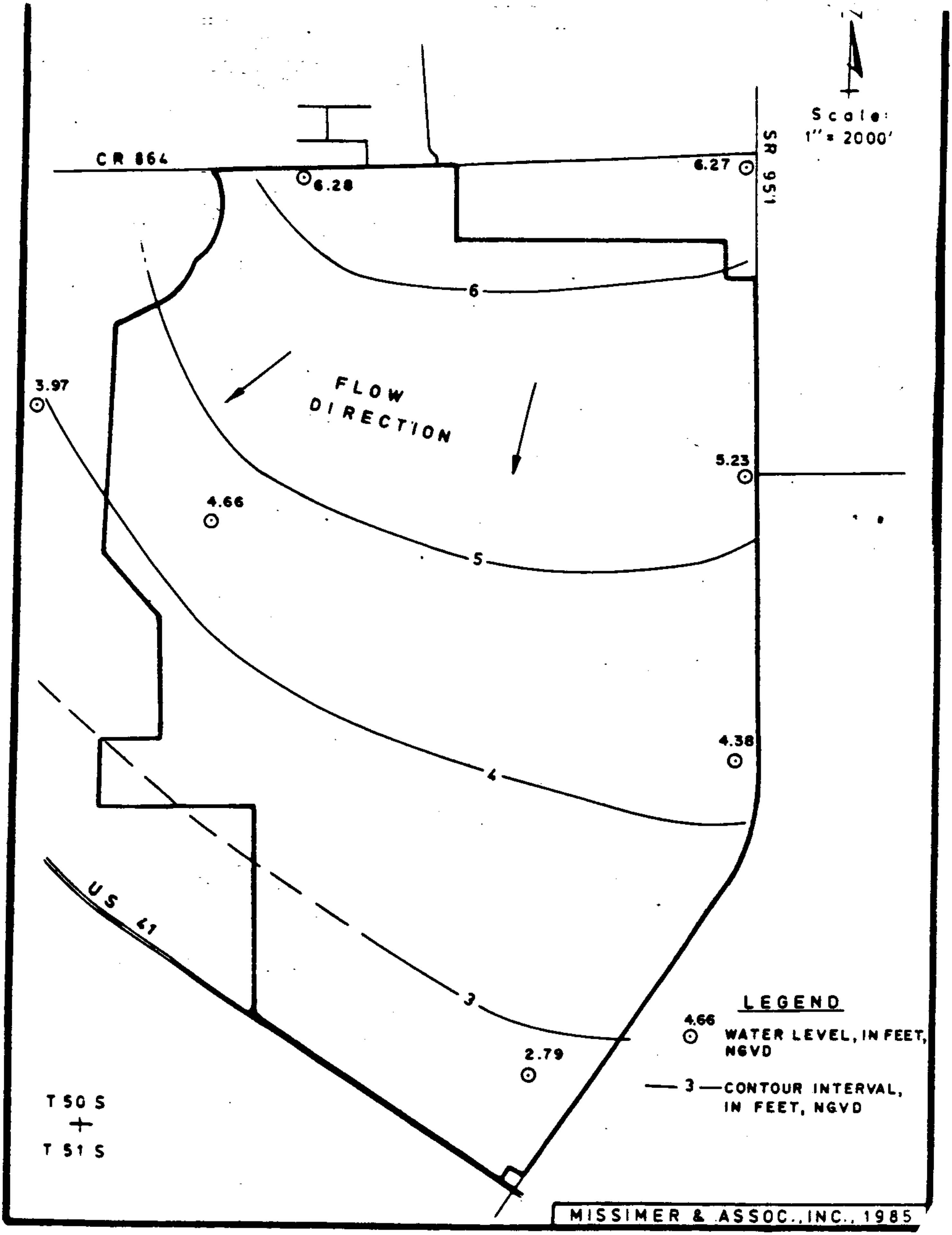

FIGURE 4-10. MAP SHOWING THE POTENTIOMETRIC SURFACE FOR THE TAMIAMI AQUIFER DURING THE DRY SEASON.

surface of the Tamiami is slightly below the water table but not by more than 0.3 foot. These aquifers appear to be hydraulically connected to one another. The water-table aquifer will recharge the Tamiami Aquifer through downward drainage or leakage through the thin confining beds.

During the wet season, the water table is expected to be about one foot (depending on location) higher than the Tamiami potentiometric surface because increased rainfall recharge to the water table will exceed the rate at which it can leak into the Tamiami.

Lateral flow through the aquifer also recharges the shallow aquifers. Groundwater flow direction on the site is toward the south/southwest as evidenced by the slope of the water level contours. The exception to this flow direction will occur only in areas adjacent to Henderson Creek Canal and the agricultural irrigation ditches.

V. IRRIGATON WATER DEMANDS AND SOURCES

1. Irrigation Water Demands

The irrigation demand for the development is made up of three parts. These are golf course demands, non-residential demands, and residential demands. The computation of irrigation water demands is based on a water application rate of 0.22 inches per day on all irrigated land. This amounts to an annual average of 5,973 gpd per acre irrigated. Table 5-1 provides the breakdown for total non-potable water use, based on irrigated acreage. The amount of irrigated land in each category other than golf course is based on the percentage of impervious area shown in the table. The total irrigation demand will be approximately 5.63 million gallons per day.

The irrigation demand by phases is shown in Table 5-2. The first 18-hole golf course is to be constructed in Phase I. An additional golf course will be constructed in each of Phases III and IV.

2. Irrigation Water Sources

Irrigation water needs are proposed to be met using three sources. These include: sewage effluent for golf course irrigation and surface water augmented by groundwater for landscape irrigation. The water for landscape irrigation will

TABLE 5-1. LELY A RESORT COMMUNITY: ESTIMATED IRRIGATION WATER USE BY LAND USE

Land Use	Total Acreage	Percent Irrigated	Acreage Irrigated
Residential			
Single Family	400	70%	280
Patio Homes/Villas	165	50%	83
Low Density Townhome	285	40%	114
Moderate Density Townhome	150	20%	30
Garden Condominium	240	30%	72
Midrise Condominium	88	30%	26
Non-Residential			
Golf Course (3)	470	58%	270
Commercial	114	15%	17
College	50	30%	15
Cultural & Resort Center	100	30%	30
Park	12	50%	6
		Total Irrigated	943

Total Demand @ 5,973 gpd/acre = 5.63 MGD

TABLE 5-2. LELY A RESORT COMMUNITY: ESTIMATED IRRIGATION DEMAND BY PHASE

Year	Phase	Use	Irrigated Acreage	Demand	Cumulative Demand GPD
1990	I	Residential	42	251,000	
		Golf Course	90	538,000	
		Resort	7	42,000	
		Cultural Center	10	59,000	
		Commercial	1 150 ac.	5,000	895,000
1995	II	Residential	74	442,000	
		Cultural Center	13	77,000	
		College	5	30,000	
		Park	6	36,000	
		Commercial	~~2~~ 100	12,000	1,492,000
2000	III	Residential	74	442,000	
		Golf Course	90	538,000	
		College	5	30,000	
		Commercial	2	12,000	2,514,000
2005	IV	Residential	74	442,000	
		Commercial	2	12,000	2,968,000
2010	V	Residential	74	442,000	
		Golf Course	90	538,000	
		College	5	30,000	
		Commercial	2	12,000	3,990,000
2015	VI	Residential	78	466,000	
		Commercial	3	18,000	4,474,000
2020	VII	Residential	95	567,000	
		Commercial	3	18,000	5,059,000
2025	VIII	Residential	93	555,000	
		Commercial	3	18,000	5,632,000

be pumped from the lake system into a secondary non-potable pipeline for distribution throughout the development. It is expected that the lakes will be an adequate source of water for approximately 5 months of the year. For the remaining months, groundwater will be pumped into the lakes for storage and distribution. On an annual basis, surface water is expected to make up about 40 percent of the total landscape irrigation demand. This amounts to 1.4 MGD. Groundwater will make up the remaining 60 percent or 2.1 MGD.

All demands for golf course irrigation will ulitmately be met by use of renovated wastewater. The golf course demand during the early phases will be met using effluent from the existing sewage treatment facilities on the adjacent Lely project. Currently, most of the effluent from the existing treatment plant is used to irrigate a golf course at the adjacent project. However, since the project is in a growth phase, it is expected that about 300,000 gpd of effluent may be available for spraying on the golf course proposed for Phase I. During Phases VII and VIII there will be an excess of sewage effluent beyond the amount needed for golf course irrigation. This water will then be used to irrigate the landscaped areas of the park, the cultural center, and certain other common areas.

Table 5-3 is a breakdown of the approximate irrigation water sources at the end of each phase.

TABLE 5-3. LELY A RESORT COMMUNITY: IRRIGATION WATER DEMANDS AND SOURCES BY PHASE (Average Daily Use on Annual Basis)

Year	Phase	Renovated[1] Wastewater (gpd)	Surface Water (gpd)	Groundwater (gpd)	Total (gpd)
1990	I	300,000	143,000	452,000	895,000
1995	II	538,000	382,000	572,000	1,492,000
2000	III	1,076,000	575,000	863,000	2,514,000
2005	IV	1,076,000	757,000	1,135,000	2,968,000
2010	V	1,614,000	950,000	1,426,000	3,990,000
2015	VI	1,614,000	1,144,000	1,716,000	4,474,000
2020	VII	2,130,000	1,172,000	1,757,000	5,059,000
2025	VIII	2,130,000	1,401,000	2,101,000	5,632,000

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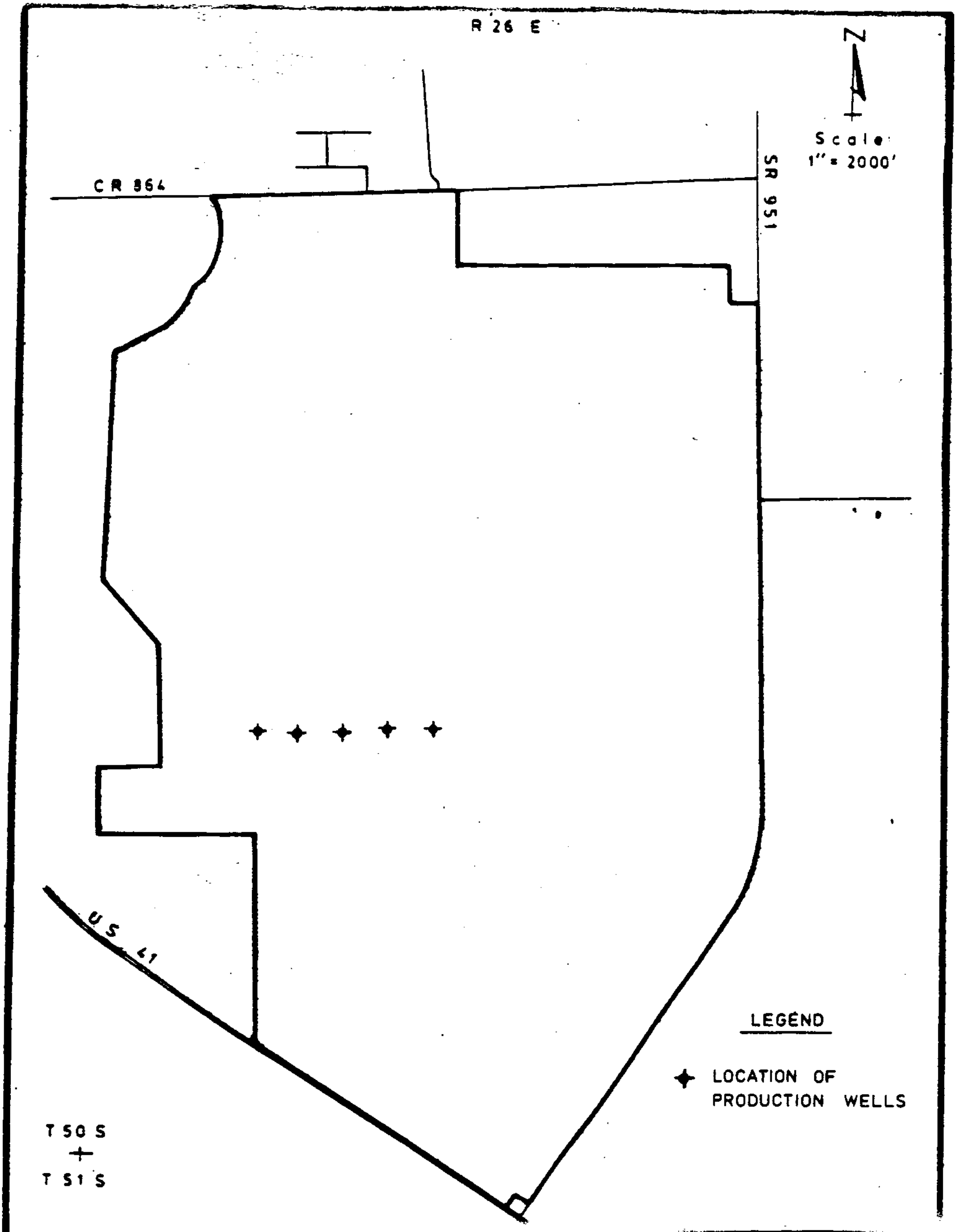
[1] Wastewater flows in Phase I and II include both the on-site development and the neighboring Lely Project.

3. Groundwater Withdrawals

Water for irrigation of landscaping around homes, condominiums, and green areas other than the golf course will be pumped from storage in the lake system, which will be augmented by wells tapping the Tamiami Aquifer System-Zone I. Five wells are proposed to be installed at the locations shown on Figure 5-1. The wells will be approximately 40 feet deep. They will be cased to approximately the 25-foot depth with 10-inch casing and they will have a capacity of approximately 500 gallons per minute each. The average yield from the well-field will be 2.5 MGD at full development.

Initially, one well is proposed to meet the groundwater demands of Phase I. Total Phase I demand includes one golf course (90 irrigated acres) and 61 acres of landscaping, requiring 895,000 gallons per day on an average annual basis. Remaining wells will be installed as needed at approximately 5-year intervals.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T 51 S

VI. IMPACT ANALYSIS

1. Aquifer Drawdowns

The planned use of 2.5 mgd of water from the Tamiami Aquifer was assessed for both wet season and dry season conditions. Wet season drawdowns were modeled for a semi-confined aquifer system. This situation would apply to conditions where rainfall is frequent enough to prevent water level decline in the shallow water table aquifer. The drawdown in the Tamiami Aquifer for this condition is shown in Figure 6-1. Except in the immediate vicinity of the wells, the drawdown in the potentiometric surface of the Tamiami Aquifer is less than 1 foot.

For dry season conditions, the Tamiami Aquifer was modeled as though it behaved as an unconfined aquifer. It was assumed to have a specific yield value of 0.1 which is considered a conservative estimate. The drawdown amounts for 100 days of pumpage without rainfall recharge are shown in Figure 6-2. Water level declines in the area of the wellfield are shown to range between 1 and 2 feet.

2. Saline Water Migration

Drawdowns caused by pumping the proposed wells at a total of 2.5 mgd are quite minor. Except in the immediate vicinity of the wells, the potentiometric surface of the

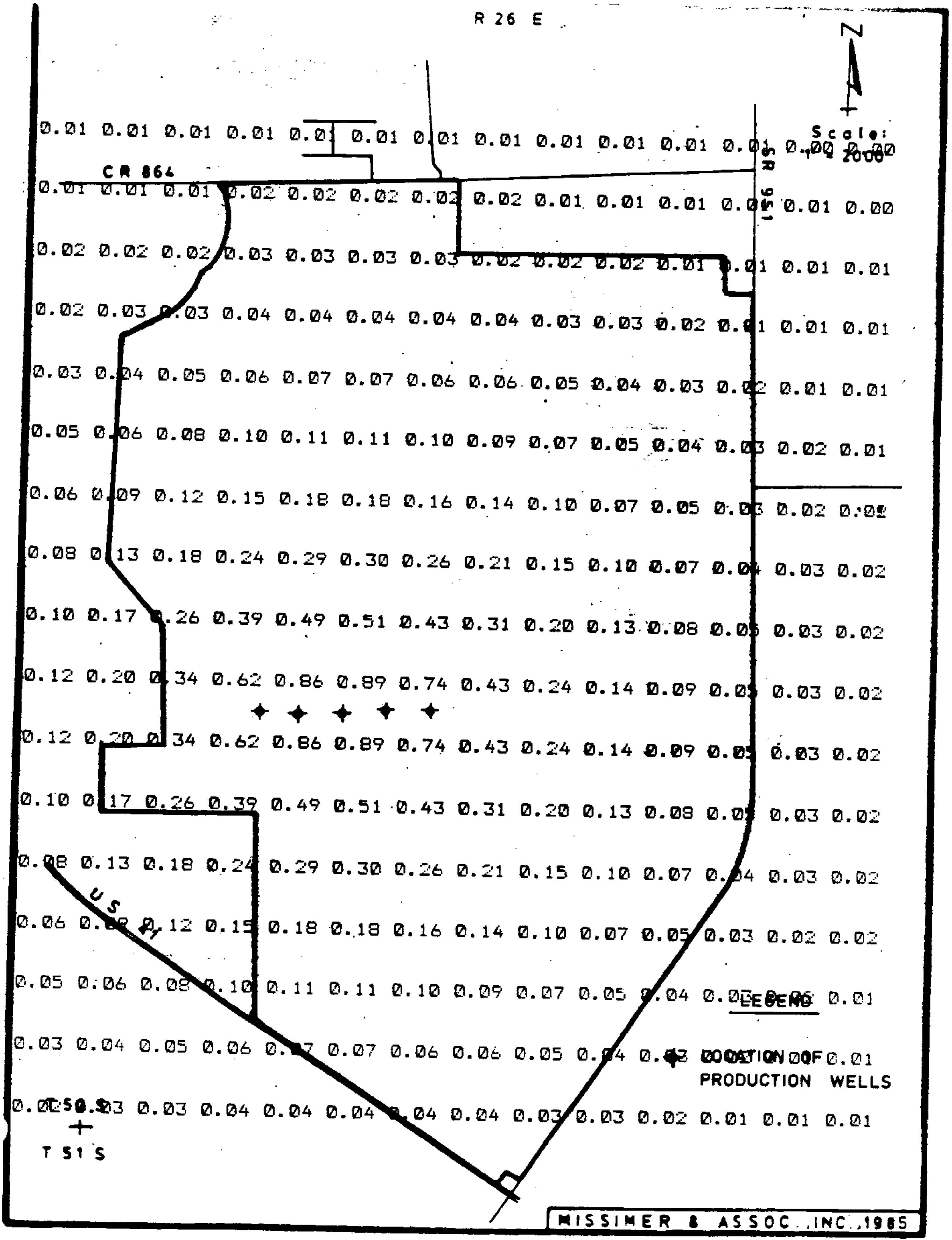

FIGURE 6-1. MAP SHOWING THE DRAWDOWN IN THE TAMIAMI AQUIFER FOR A

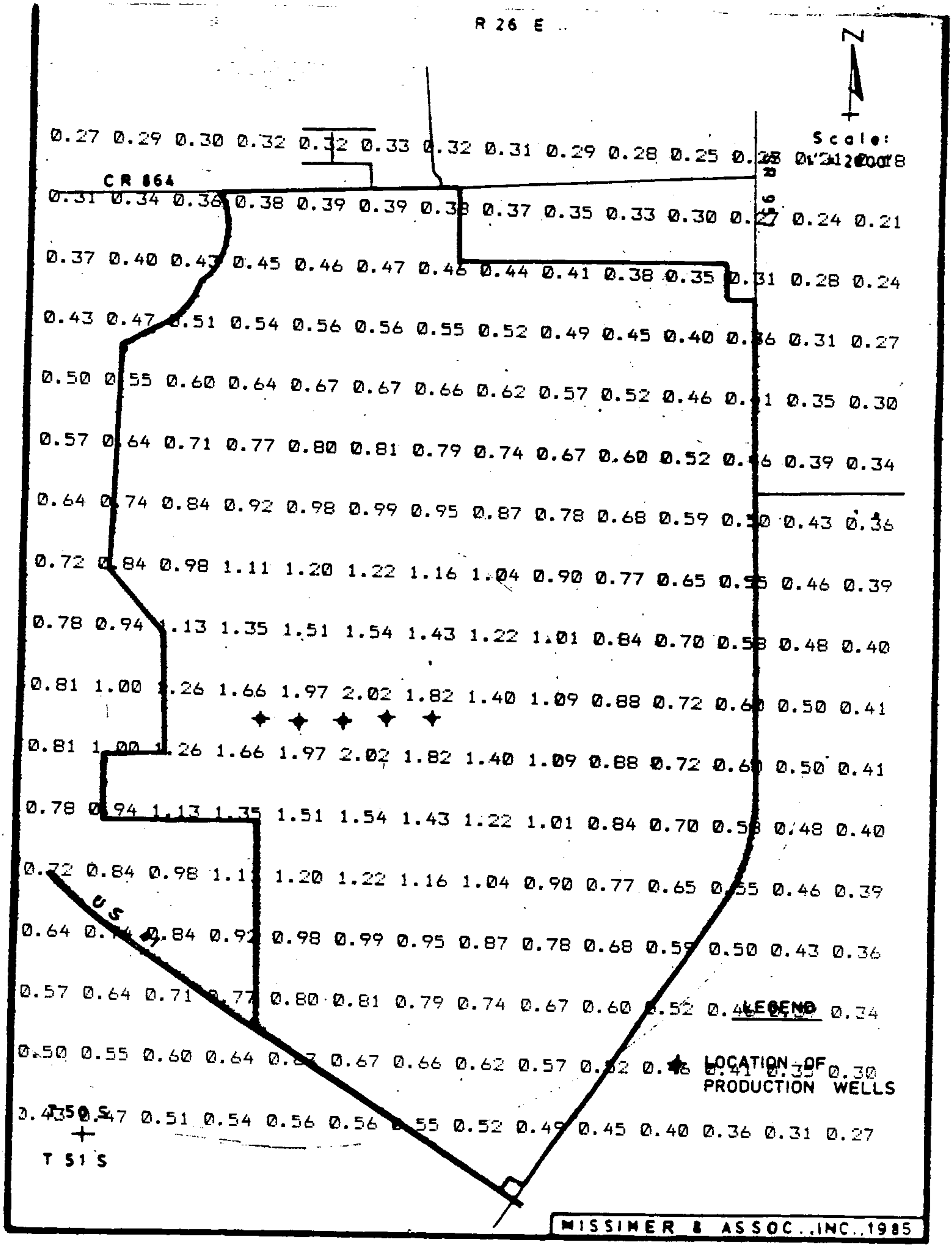

FIGURE 6-2. DRAWDOWN IN THE TAMIAMI AQUIFER FOR PUMPAGE OF 2.5 M.G.D.

Tamami Aquifer will not be lowered below sea level. Also, the slope of the groundwater table toward the southwest will not be changed significantly and therefore lateral migration of saline water should not be expected.

At the individual well sites, some upward movement of the salt water interface is expected. However, this movement is expected to occur mostly during the dry season. During the wet season when Tamiami Aquifer water levels are high and when wells are not being used, it is expected that the salt water interface will recede. This condition has likely occurred on the site during the past agricultural operations. No water quality problems or significant salt water intrusion has been noticed to date.

VII. APPENDIX

TABLE A-1. WATER QUALITY DATA FROM CHLORIDE PROFILE WELL

Depth (feet)	Cl^- (mg/l)	Conductivity (umhos/cm)
21	80	1240
42	120	1350
63	400	2000
84	440	2110
105	450	2160

TABLE A-2. GEOLOGIST'S LOG OF WELL CO-820

Depth(feet)	Lithology
0-7	Sand, light gray-brown, fine to medium grained, subangular, very well sorted, clayey at base, shell increasing with depth.
7-8	Clay, white-light gray, calcareous, interbedded with shell.
8-12	Limestone, light gray-tan, hard, biomicrudite, crystalline, little secondary porosity, minor shell.
12-16	Limestone, light gray, hard, fossiliferous, biomicrudite, loss of circulation, very good secondary porosity.
16-45	Limestone, light gray, biomicritic-biosparitic, spar crystals as veinlets and vug fillings, good secondary porosity, large shell fragments abundant, quartz sand minor to common.
45-57	Limestone, light-dark gray, biomicritic-biosparitic, similar to above but with increasing amount of spar cement and shell fragments.
57-68	Limestone, light gray to white, biosparitic-biomicritic, not as well indurated, medium quartz sand is more abundant (5%), minor small scale vugs and molds.
68-84	Limestone, light gray to dark gray, biomicritic, sandy, fine to medium quartz sand (10-20%), subangular to subrounded, softer than above, large bivalve shell fragments common.
84-95	Limestone, light to dark gray, sandy, similar in texture to above but with increasing amounts (20-30%) quartz sand, bivalve shell fragments common.
95-105	Limestone, light gray, sandy, quartz sand continues to increase to nearly 50% of sample, echinoids are predominant over bivalves.
105-118	Sandstone and sand, light gray, calcareous, not well indurated, fine to medium grained, subangular, very well sorted, shell is common.

TABLE A-2. GEOLOGIST'S LOG OF WELL CO-820 - Continued:

Depth(feet)	Lithology
118-123	Sand, quartz, clayey, light green to gray, calcareous, green clay (~5%) mixed with over 50% quartz sand, shell common.
123-128	Sand, quartz, clayey, green, clay percentage increasing to 20%, stiffer textured, medium to coarse grained quartz sand is predominant, shell common as above.
128-131	Limestone, light gray-beige, biomicritic, echinoids and other shell fragments common, quartz is minor, little secondary porosity.
131-138	Sand, quartz, clayey, light gray-green, medium grained, subangular, very well sorted, green calcareous clay 5-10%, minor shell.
138-144	Limestone, marly, light gray-green, abundant shell fragments (30%), biomicritic limestone (50%), fine quartz (10%) and green clay (5-10%) form this weakly consolidated marly limestone.
144-168	Clay, calcareous, sandy, light gray, fine quartz sand (20-30%) and minor shell fragments in a clay matrix.

TABLE A-3. GEOLOGIST'S LOG OF WELL CO-797

Depth(feet)	Lithology
0-4	Sand, light gray to brown, fine to medium, minor organics.
4-9	Limestone, light gray to rust, very hard cap rock, sandy biomicrudite, little secondary porosity.
9-15	Limestone, light gray, medium, biomicritic, shell fragments common, minor (5%) quartz sand.
15-27	Limestone, light gray, softer than above, marly, traces of white clay at 15'-20', numerous shell fragments in a mud/micritic matrix.
27-45	Limestone, light to dary gray, medium to hard, biosparitic - biomicritic, bryozoans, gastropods, and bivalves predominant, occasional molds and vugs in micritic limestone, vugs more common in darker gray biosparite, phosphorite common in sparite.
45-60	Limestone, light to dary gray, biosparitic, good moldic and vuggy porosity, abundant large shell fragments, micritic filling primary porosity, minor phosphorite and quartz sand.

TABLE A-4. GEOLOGIST'S LOG OF WELL CO-799

Depth(feet)	Lithology
0-4	Sand, quartz, light gray to brown, fine to medium grained, minor organics.
4-12	Limestone, light gray to rust, very hard, sandy biomicrudite, dense, bivalves are most abundant as fragments, little secondary porosity.
12-20	Limestone, light gray, marly, medium to soft, traces of white clay, biomicrudite, large shell fragments in marly matrix.
20-45	Limestone, light gray, medium to hard, biosparrudite, frequent small molds and vugs, common large shell fragments.
45-60	Limestone, light gray to white, biosparitic-biomicritic, quartz is common with micritic grains, good secondary porosity.

TABLE A-5. GEOLOGIST'S LOG OF WELL CO-789

Depth(feet)	Lithology
0-10	Sand, quartz, light gray-brown, soft, fine to medium grained, minor organics, shell present last few feet.
10-12	Shell, *Chione cancellata* lense, minor quartz sand.
12-17	Limestone, light gray, medium to hard, sandy biomicrudite, occasional vuggy and moldic porosity, gastropods and bivalves most common, traces of white clay (10'-14').
17-27	Limestone, light gray, medium to soft, marly, sandy biomicrite, light gray to green sandy clay interbedded at approximate 20'-25' depth, shell more abundant than above in micritic matrix.
27-35	Limestone, light gray, medium, biomicrudite, large (1-10 mm) shell fragments of echinoids, bryozoans and bivalves (pectens) in fine micritic matrix, occasional small (microscopic) molds and vugs.
35-45	Limestone, light gray to gray, hard, biomicrudite, very good secondary porosity with abundant molds and vugs, large shell fragments include mostly gastropods and pectens, minor fine sand sized quartz and phosphorite.
45-55	Limestone, light gray to gray, hard, biomicritic, limestone intraclasts, minor quartz and abundant shell in a biomicritic matrix, microspar common, occasional to frequent molds and vugs.
55-60	Limestone, light gray to white, harder than above, biosparrudite, frequent small molds and vugs, intraclastic as above in a sparitic matrix.

TABLE A-6. GEOLOGIST'S LOG OF WELL CO-791

Depth(feet)	Lithology
0-4	Sand, quartz, light gray-brown, soft, fine grained, organic rich.
4-8	Limestone, light gray to rust, very hard, sandy biomicrudite, dense, little secondary porosity.
8-25	Limestone, light gray, medium, biomicrudite, large shell fragments of mostly pectens, minor quartz sand, common small scale shell molds and vugs, traces of white clay interbedded.
25-45	Limestone, light gray to white, hard, biosparrudite, frequent small molds and vugs, common shell fragments as pectens, bryozoans, gastropods.
45-60	Limestone, light gray to gray, hard, very good secondary porosity, biosparitic, large shell fragments also abundant, trace of phosphorite.

TABLE A-7. GEOLOGIST'S LOG OF WELL CO-793

Depth(feet)	Lithology
0-4	Sand, quartz, light gray to brown, fine to medium grained, minor organics.
4-7	Limestone, light gray to rust, very hard surface rock, sandy biomicrudite, little secondary porosity.
7-20	Limestone, light gray, medium, biomicrudite, large shell fragments common, common small scale molds and vugs, traces of white clay from 15'-20', marly.
20-30	Limestone, light gray, medium to hard, large shell fragments in micritic matrix, fairly good secondary porosity with occasional molds and vugs.
30-60	Limestone, light gray to white, hard, biosparrudite, occasional molds and vugs, abundant large shell fragments, minor quartz sand.

TABLE A-8. GEOLOGIST'S LOG OF WELL CO-795

Depth(feet)	Lithology
0-5	Sand, light gray to brown, fine to medium grained, minor organics.
5-9	Limestone, light gray to rust, very hard, sandy biomicrudite, dense, little secondary porosity.
9-15	Limestone, light gray, medium to soft, biomicritic, quartz and small shell fragments in a micritic matrix, traces of light gray-green sandy clay beneath surface rock, occasional molds and vugs.
15-25	Limestone, light gray, softer than above, marly, shell fragments and light gray-green and white clay interbedded with micritic limestone.
25-40	Limestone, light gray, medium to hard, large shell fragments of echinoids, bryozoans and pectens in fine micritic matrix, occasional small molds and vugs.
40-60	Limestone, light to dark gray, hard, biosparitic to biomicritic, interbedded with dense, gray calcareous sandstone (40-45'), very good secondary porosity overall from 45-60', large shell fragments abundant.