HYDROLOGIC INVESTIGATION OF THE RAW WATER SOURCE FOR MARCO ISLAND UTILITIES, COLLIER COUNTY, FLORIDA

PREPARED FOR

DELTONA CORPORATION
MIAMI, FLORIDA

SEPTEMBER, 1980

MISSIMER AND ASSOCIATES, INC.

CONSULTING HYDROLOGISTS, GEOLOGISTS
AND ENVIRONMENTAL SCIENTISTS

CAPE CORAL, FLORIDA

HYDROLOGIC INVESTIGATION OF THE RAW WATER SOURCE FOR MARCO ISLAND UTILITIES, COLLIER COUNTY, FLORIDA

prepared for

DELTONA CORPORATION
Miami, Florida

September, 1980

MISSIMER AND ASSOCIATES, INC.
CONSULTING HYDROLOGISTS, GEOLOGISTS, AND ENVIRONMENTAL SCIENTISTS

CAPE CORAL, FLORIDA

MISSIMER AND ASSOCIATES, INC.
Consulting Hydrologists · Geologists · Environmental Scientists
1031 CAPE CORAL PARKWAY
CAPE CORAL, FLORIDA 33904
PHONE (813) 542-6106

THOMAS M. MISSIMER
RICHARD L. HOLZINGER
LARRY K. HOLLAND
LLOYD E. HORVATH
THOMAS H. O'DONNELL

September 16, 1980

Mr. Rafael Terrero
Chief Utilities Engineer
Deltona Corporation
3250 S.W. 3rd Avenue
Miami, FL 33132

Dear Ralph:

Missimer and Associates, Inc. is pleased to submit this final report entitled "Hydrologic Investigation of the Raw Water Source for Marco Island Utilities". The report is the product of a six month investigation to quantify the safe yield of fresh water from your entire property at the present utilities withdrawal site and also from the proposed auxiliary wellfield site.

The information contained in this report should enable Marco Island Utilities, Inc. to develop a shallow aquifer withdrawal system which is compatible with the local hydrogeology. We will be pleased to discuss our findings with you at your convenience.

Very truly yours,

MISSIMER AND ASSOCIATES, INC.

Lloyd E. Horvath, P.E.
Senior Hydrologist

LEH:sm

Enclosure

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF FIGURES

LIST OF TABLES

I. CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions

The hydrologic system at the site of the future withdrawal for Marco Island Utilities was investigated in order to determine the maximum safe yield of fresh water from the property.

The information compiled and analyses performed as part of this investigation lead to the following conclusions:

1) Two aquifers containing fresh water underlie the site investigated. These aquifers are the shallow water-table aquifer and Tamiami Aquifer System-Zone I.

2) The property presently planned for future water supply development is capable of safely yielding 14 MGD of fresh water without increasing the dissolved chloride content of the pumped waters beyond potable standards.

3) The construction of the salinity barrier on Henderson Canal will greatly benefit the hydrologic system in the investigation area by both increasing recharge to the area, and by preventing tidal

waters from migrating upstream and infiltrating the shallow aquifer.

4) After construction of the Henderson Canal control structure, withdrawals from the Marco Island Lake System could be safely increased to 8 MGD.

5) The amount of water which can be produced at the investigation site will be limited in the future by the amount of water used in neighboring areas and in areas up gradient from the withdrawal site. Large withdrawals within the area of influence of the proposed Marco Island Utilities, Inc. withdrawal must be discouraged.

6) The water-table aquifer at the investigation site has a transmissivity of about 70,000 gpd/ft, and Zone I at the Tamiami Aquifer System has a transmissivity of approximately 860,000 gpd/ft. The two aquifers are not separated to a high degree. The leakance value of the semi-confing bed is approximately 0.15 gpd/ft^3.

7) The investigation conducted approximately 6 miles west of the existing utilities site in Section 35 showed that the property selected as a location for an auxiliary wellfield is capable of safely producing

5 MGD of freshwater. This is based on a conservative estimate of the aquifer characteristics of the area.

2. Recommendations

1) At the maximum sustained production rate (14 MGD), approximately 4 MGD should be withdrawn from the lake system, and the remaining 10 MGD should be withdrawn from the shallow aquifer in Sections 26 and 35 in Township 50 South, Range 26 East.

2) The direct groundwater withdrawals should be made from either an infiltration gallery system or from low rate production wells producing from an approximate 15 foot depth.

3) Both the shallow well system, and the infiltration gallery system are compatible with the local hydrology of the area. Detailed economic analysis should be done to select the desired alternative.

4) Prior to finalization of plans for the withdrawal system, numerous test holes should be drilled on the property to confirm the assumption of uniform water quality.

5) Since the geology of the shallow zone (upper 20 feet of aquifer) is relatively inconsistent, testing should be done to determine its hydraulic variability. This information is essential to the design of the shallow withdrawal system.

6) Competition for the limited amount of available water is likely to occur. A consumptive use permit for at least enough water to meet the 10-year demand should be applied for in the near future.

II. INTRODUCTION

1. Authorization, Purpose, and Scope of Work

Missimer and Associates, Inc. was authorized in January, 1980, by Marco Island Utilities, Inc. to conduct a hydrologic investigation of the approximate 1600 acres of land which is proposed for future development of Marco Island's raw water source. The location of the investigation area is shown in Figure 2-1.

The purpose of the investigation was to determine the maximum safe yield of fresh water from the existing withdrawal facilities and from 2.5 additional sections of land northeast of the present withdrawal locations. The work scope included: 1) review of pertinent existing information, 2) a detailed well inventory, 3) drilling of 4 test wells and 1 test production well, 4) conducting an aquifer test, 5) analysis and interpretation of data, 6) the determination of maximum amount of water available and the impacts of the withdrawal, 7) preparation of a final report including conclusions, recommendations, data obtained and interpretations. The recommendations for developing the water source and the impact analysis were to be key aspects of the study.

In addition to the above study, a parcel of land approximately 6 miles east of the existing utility site was investigated to determine its potential to serve as an auxiliary wellfield.

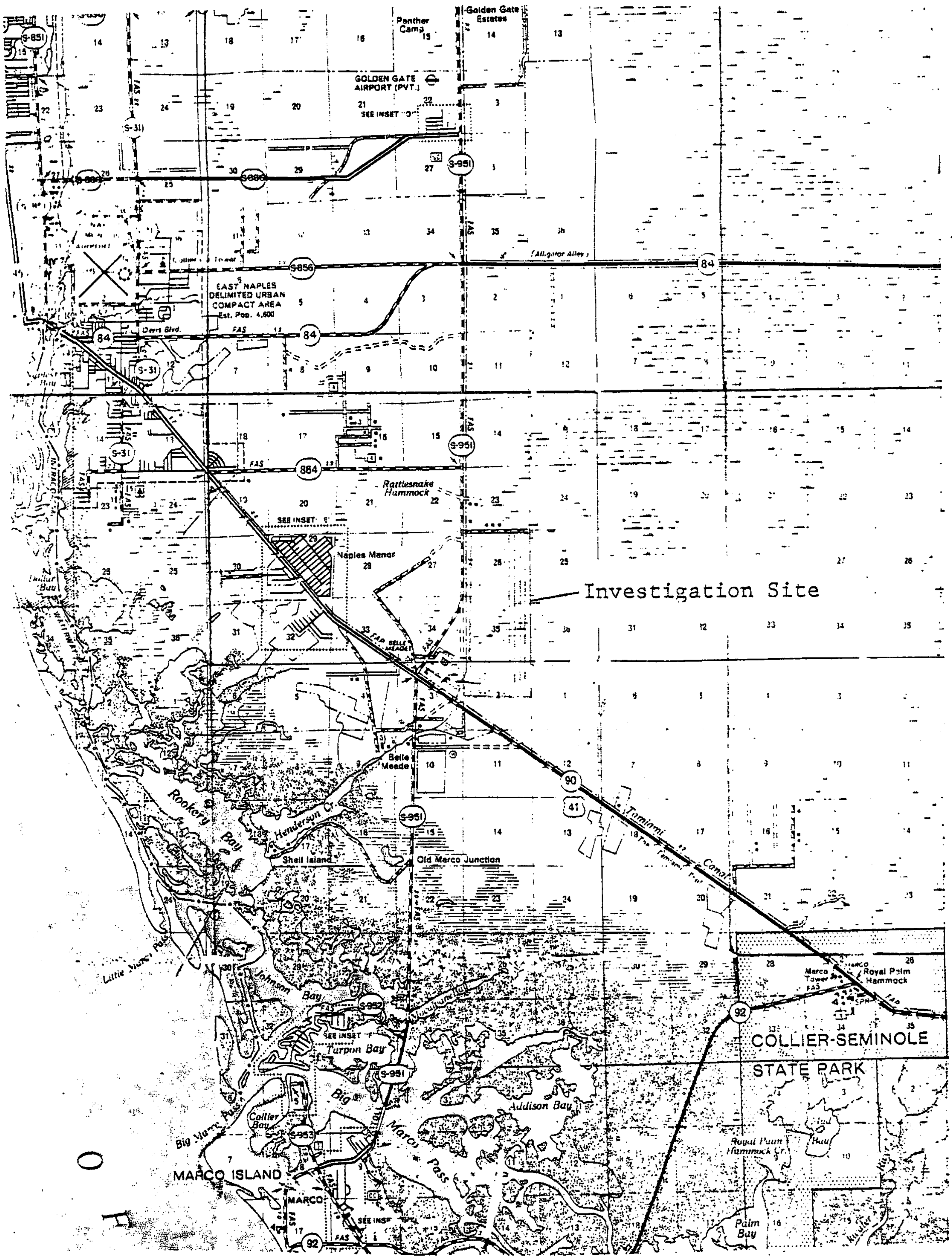


FIGURE 2-1. LOCATION OF INVESTIGATION SITE

2. Acknowledgments

We wish to thank Mr. Arsenio Milian and Mr. Ralph Terrero for providing information and for their co-ordination of efforts associated with this investigation; Mr. Patrick Gleason and Mr. Paul Jacobs of South Florida Water Management District for their information and help; Mr. Cliff Barksdale of Collier County Public Works Department for the information which he made available; and Mr. Bob Buckmiller and Mr. Henry LaRose of the U.S.G.S. for the time and information which they provided.

III. INVESTIGATION OF EXISTING UTILITIES SITE AND CONTIGUOUS ACREAGE

1. Introduction

The area investigated lies east of County Road 951 in Collier County and extends north from U.S. 41, a distance of approximately 2.5 miles. The property controlled by Marco Island Utilities at this location includes parts of Sections 2 and 3 in Township 51 South, Range 26 East and most of Sections 26 and 35 in Township 50 South, Range 26 East.

Within the investigation area, Marco Island Utilities, Inc. presently withdraws water from an abandoned rock pit with a surface area of 19 acres. This pit is connected to another large pit of approximately 27 acres, and the lakes behave as one large surface water body. Good records of water levels, pumpage and raw water quality have been maintained, and these records have served as input to this investigation. Other existing information used in conducting this investigation include; ground-water level and quality records, and Henderson Creek flow records as maintained by the USGS; and testing information collected by the utilities department under the supervision of Art Finney.

2. Test Drilling

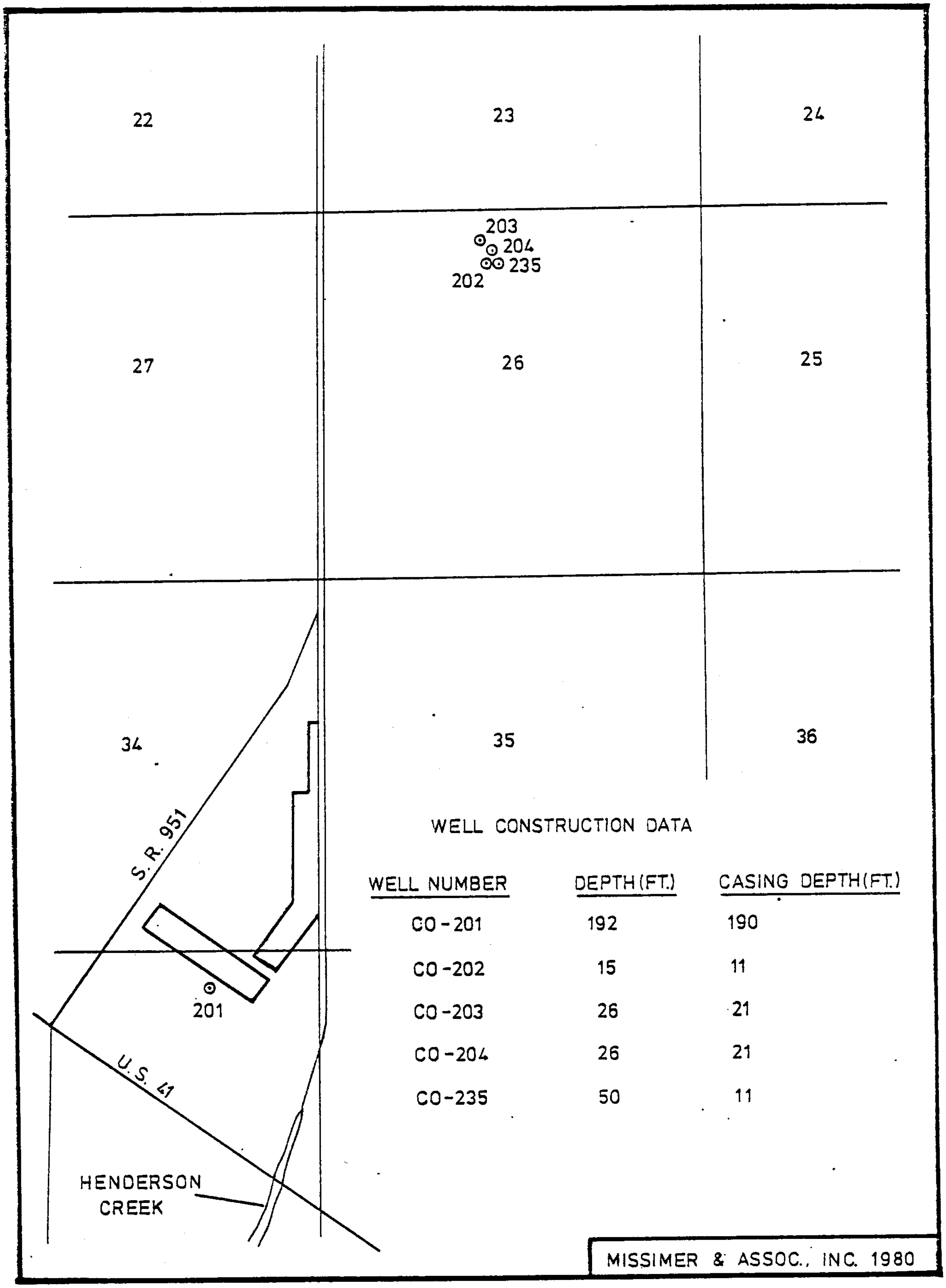
A test drilling program was conducted within the investigation area. The program included the construction of one deep test hole to determine a dissolved chloride profile, and the construction of three shallow test wells. The deep test hole was drilled on the south side of the lake which presently serves as Marco Island's water source.

The shallow test wells were drilled approximately 2.5 miles north of U.S. 41 in the north part of Section 26. An 8-inch production well was also drilled at this location for the purpose of conducting a high pumping rate aquifer test. Figure 3-1 shows the locations and the construction data on the test wells.

Well CO-201 was constructed by the cable tool method in order to obtain a chloride profile within the Tamiami Zone I aquifer. Construction by driving and jetting allowed a pumped sample to be obtained at approximate 21-foot intervals. At certain locations it was not possible to obtain a pumped sample due to a caving formation. The water quality and depth data from this well are given in appendix Table A-1.

3. Well Inventory

A well inventory was conducted on lands within and around the investigation site. Forty existing wells were



WELL CONSTRUCTION DATA

WELL NUMBER	DEPTH (FT.)	CASING DEPTH (FT.)
CO-201	192	190
CO-202	15	11
CO-203	26	21
CO-204	26	21
CO-235	50	11

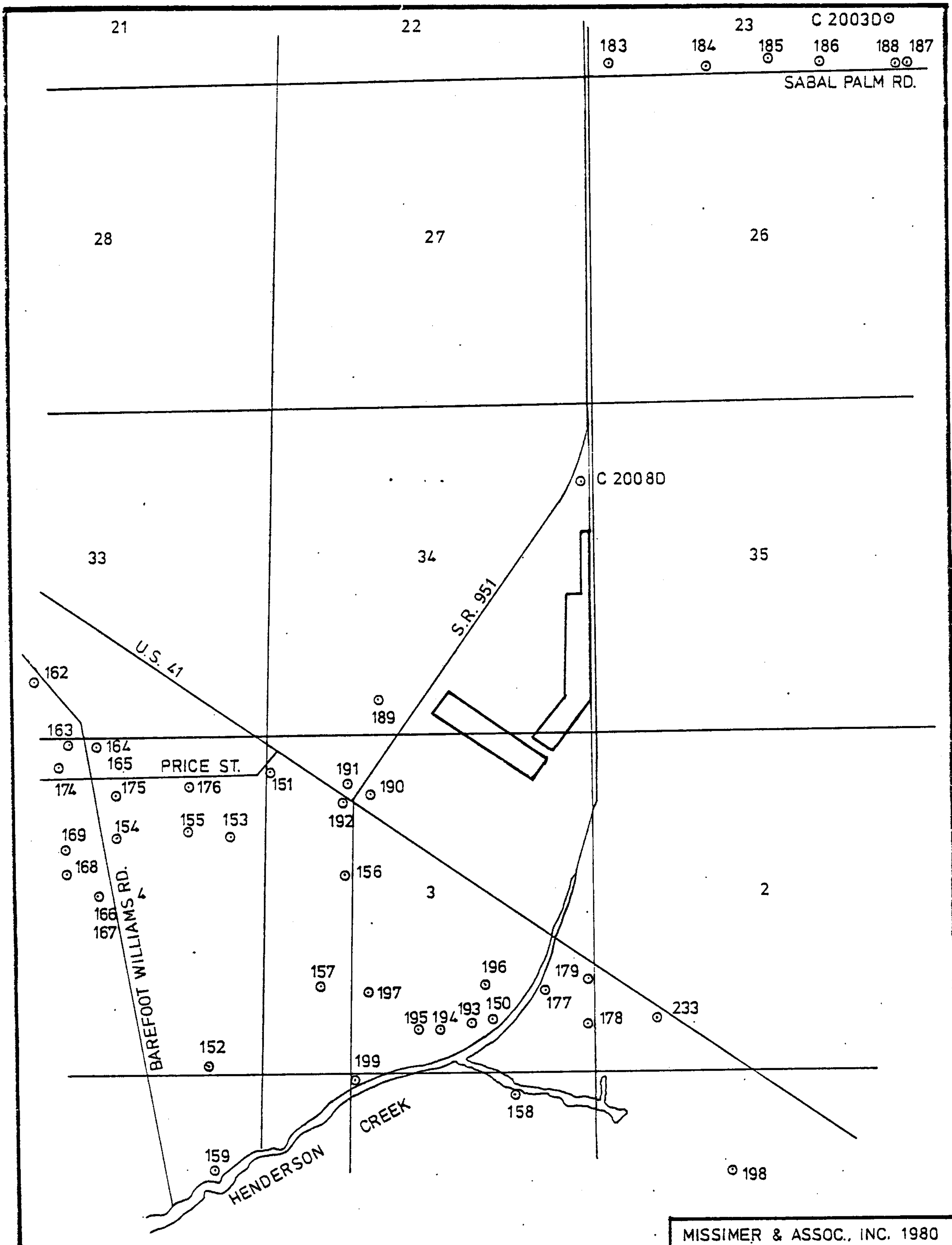
FIGURE 3-1. LOCATION OF NEW TEST WELLS AND WELL CONSTRUCTION DATA.

located mostly to the south of the investigation area. These wells were logged wherever possible to determine depth and water quality. The locations of these wells are shown on Figure 3-2, and the water quality characteristics of each well are given in Table 3-1.

4. Aquifer Test

An aquifer test was performed on the Tamiami Aquifer-Zone I. Test production well CO-235 was pumped continuously at a rate of 900 gpm for a period of 48 hours. Pump discharge was monitored using an orifice plate at the end of an approximate 350-foot discharge line. Drawdowns of the potentiometric surface were monitored in the test production well and in 3 monitor wells. Two of the wells monitored drawdowns in the Tamiami Zone I aquifer, and one well monitored drawdowns in the shallow water-table aquifer. A schematic diagram of the aquifer test set up is given in Figure 3-3. Both of the Tamiami Aquifer monitor wells were equipped with Stevens Type-F water level recorders. The depth to water in the water-table well was measured with a tape.

Pumping was terminated after 48 hours, and recovery of the potentiometric surface was monitored. The recovery data were used to check and verify the drawdown data.



MISSIMER & ASSOC., INC. 1980

FIGURE 3-2. MAP SHOWING THE LOCATION OF WELLS INVENTORIED DURING THE INVESTIGATION.

TABLE 3-1. CONSTRUCTION DETAILS AND WATER QUALITY OF INVENTORIED WELLS.

WELL NO.	DEPTH (FEET)	DIAMETER (INCHES)	DISSOLVED CHLORIDES (mg/l)	CONDUCTIVITY	USE
CO-150	-	-	170	-	Irr.
CO-193	40-47	-	260	1250	Irr.
CO-194	40	2"	240	1180	Irr.
CO-195	40	2"	300	1430	Irr.
CO-196	34	4"	260	1150	Irr.
CO-197	30-40	2"	280	1260	Irr.
CO-198	-	4"	140	820	Isle Capri,P.S.
CO-199	-	-	680	2500	Irr.
CO-158	±20	2"	170	-	Irr.
CO-159	-	2"	2680	-	Not used
CO-162	-	8"	170	-	Irr. farm
CO-163	44	4"	220	-	Dom.
CO-164	-	1¼"	150	910	Dom.
CO-165	-	2"	230	-	Dom.
CO-166	21	2"	220	1250	Irr.
CO-167	50	2"	230	1250	Dom.
CO-168	-	-	250	1290	Dom.
CO-169	-	2"	200	1210	Dom.
CO-174	-	-	220	-	Dom.
CO-175	-	2"	120	-	Dom.
CO-176	30	2"	120	-	Dom., Irr.
CO-177	-	-	220	-	Irr.
CO-178	-	-	300	-	Irr.
CO-179	-	-	20	-	Irr.
CO-183	44	2"	200	-	Dom., Irr.
CO-184	33	2"	180	-	Irr.
CO-185	45	2"	380	-	Irr.
CO-186	42	-	280	-	Dom., Irr.
CO-187	-	-	420	-	Dom.
CO-188	-	2"	260	-	Irr., Ind.
CO-189	-	4"	80	-	Dom., Stock
CO-190	-	-	12	-	Irr., Ind.
CO-191	-	-	45	-	Irr.
CO-192	-	-	40	-	Irr.
CO-233	32	2"	120	-	Not used
CO-203	18	2"	80	-	Not used
CO-204	18	2"	80	-	Not used
CO-235	50	8"	200	-	Test prod.
CO-198	-	8"	140	820	P.S.
CO-199	-	2"	680	2500	Irr.

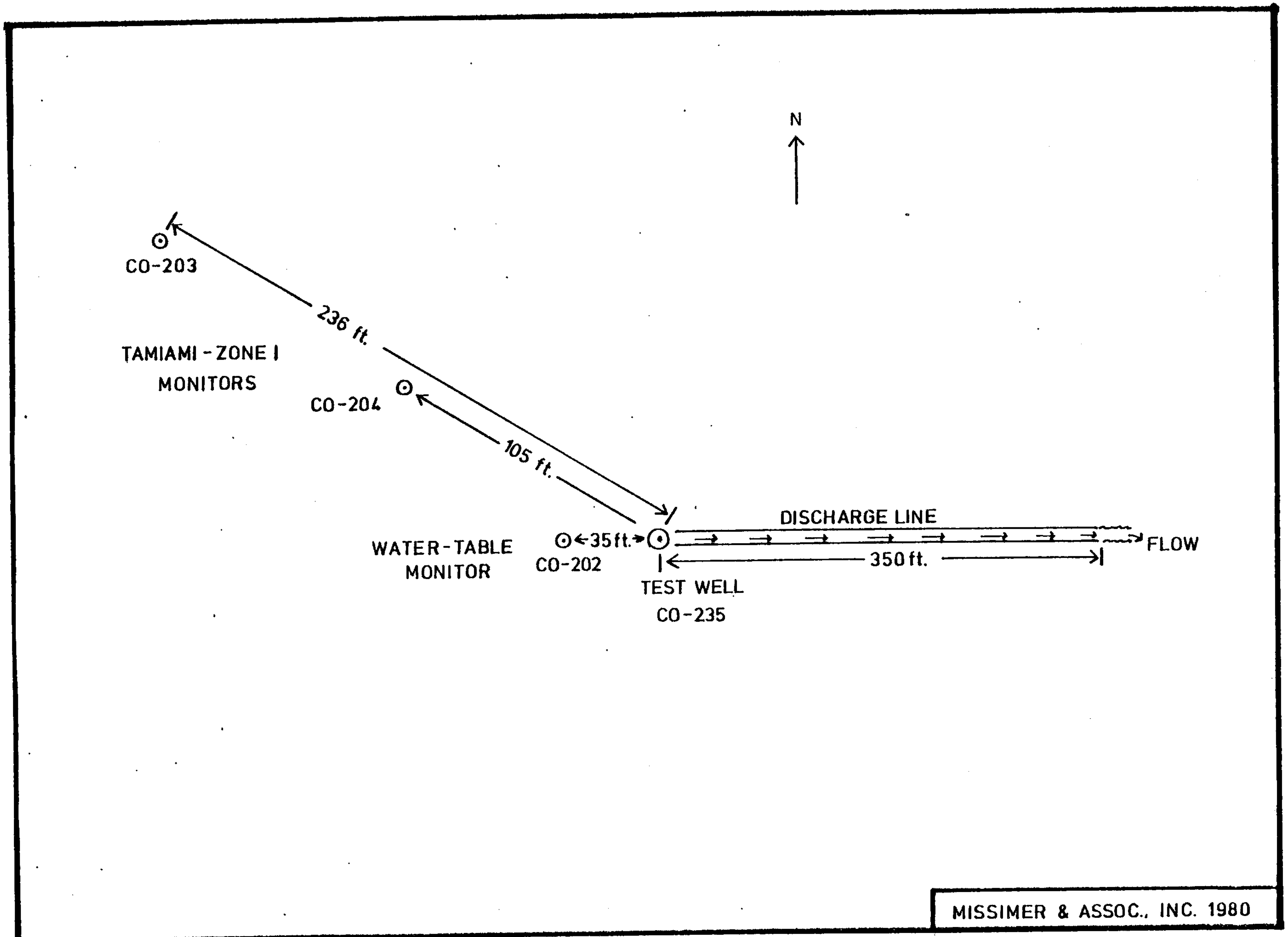


FIGURE 3-3. SCHEMATIC DIAGRAM SHOWING THE AQUIFER TEST SET-UP.

IV. HYDROGEOLOGY OF THE INVESTIGATION AREA

1. Geology

The geology in and around the investigation area was studied by analyzing data from 3 wells on the site and 3 other wells located to the north and south of the site. The stratigraphic terminology utilized herein conforms to that proposed by Missimer and Associates (1978a) and Peck, Slater, Missimer, Wise, and O'Donnell (1979). A geologist's log for each well is given in the appendix (Tables A-1 to A-6).

In the upper 190 feet of sediments underlying the site, five stratigraphic units were penetrated. These units are: the Pamlico Sand, the Fort Thompson Formation, the Caloosahatchee Marl, the Ochopee Limestone Member and the Buckingham Limestone Member of the Tamiami Formation. The stratigraphic position of each unit is shown in a north-south cross section (see Figure 4-1).

Pamlico Sand

Between 1 and 6 feet of sand covers the area in and near the Marco Island Wellfield. This sand consists of subangular, medium to fine, quartz grains. The Pamlico Sand is late Pleistocene in age and regionally occurs up to the 25-foot contour. The sand is usually white to light

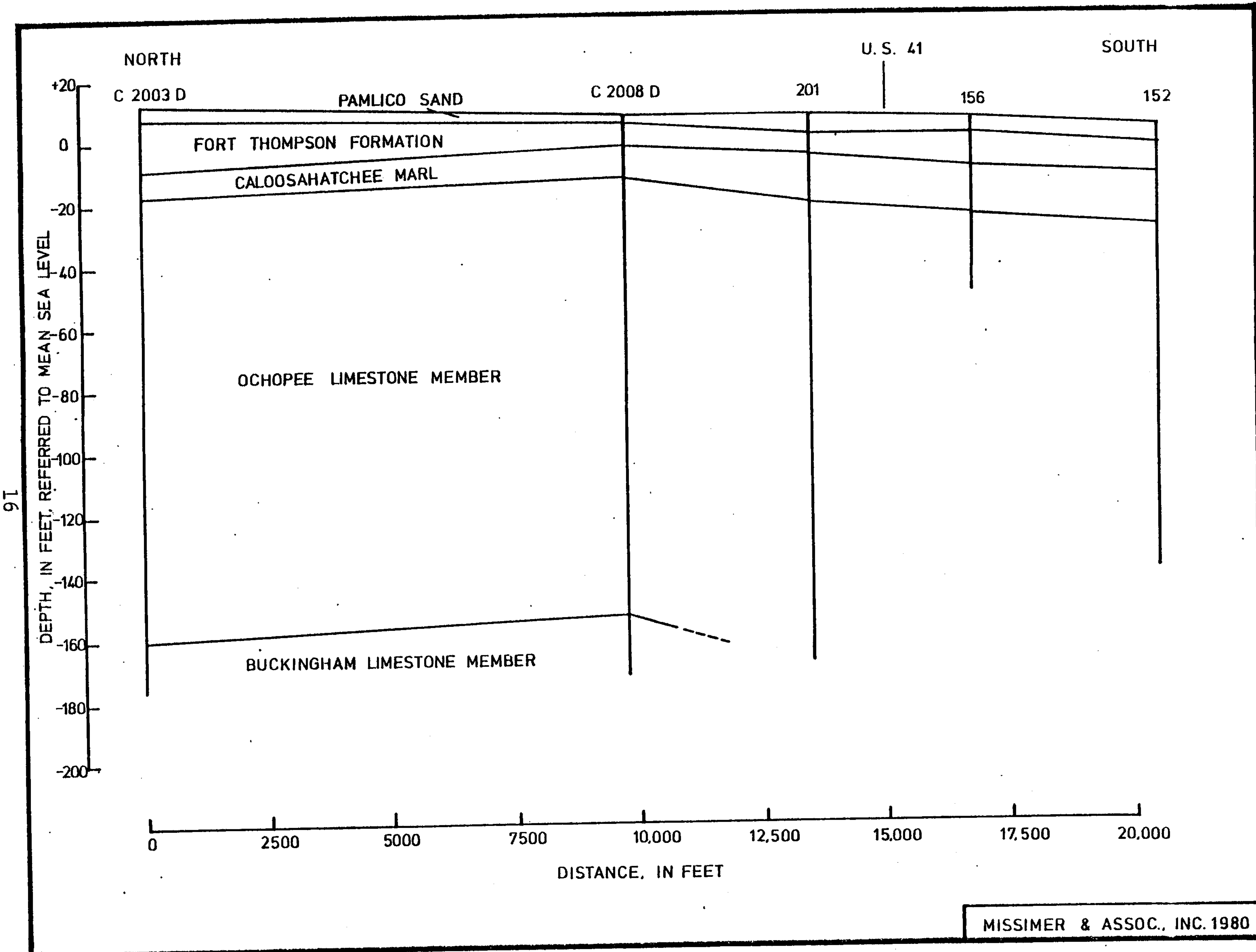


FIGURE 4-1. GEOLOGIC SECTION NORTH TO SOUTH ACROSS THE INVESTIGATION SITE.

tan in color, but sometimes contains dark brown organic-rich material. Some clay occurs within the sand at the study-site, but the clay-content is limited to only a few percent within the soil zone. The Pamlico Sand has overall medium permeability in the area studied.

Fort Thompson Formation

A white to light tan limestone unit lies unconformably beneath the Pamlico Sand. The unit is herein termed the Fort Thompson Formation, but the lithologies studied are not typical of those described by DuBar (1958) in the type localities to the north. This limestone unit is very hard and contain a large number of solution cavities which are decorated with sparry calcite. It ranges from 10 to 20 feet in thickness and has very high permeability.

Caloosahatchee Marl

The Plio-Pleistocene Caloosahatchee Marl underlies the Fort Thompson Formation. It is an interbedded sequence of unconsolidated lime muds and limestones. The lime mud strata vary in thickness from 1 to 9 feet. Caloosahatchee sediments thicken from 10 to 20 feet across the site from north to south. The more pelatic strata are present in the northern area. Since the formation is an interbedded sequence, it has medium horizontal permeability and probably low vertical permeability.

Tamiami Formation

Mio-Pliocene sediments of the Tamiami Formation lie unconformably beneath the Caloosahatchee Marl. Only two of the eight described members of the formation, the Ochopee Limestone and the Buckingham Limestone, were penetrated at the site. The Ochopee Limestone Member is more than 120 feet thick beneath the investigation site. This member consists of several different lithologies with light gray to tan limestone forming the upper 80 feet of unit and light to dark gray sandy limestone and sandstone forming the lower 40 feet. The upper part of the member has high permeability and permeability appears to decrease with depth. The Buckingham Limestone Member lies conformably beneath the Ochopee Limestone. It is a sandy lime mud or a limey quartz sand. Only the uppermost part of the unit was penetrated in the test holes. The Buckingham Member has an overall low permeability.

2. Aquifer and Confining Bed Description

Water-Table Aquifer

Unconfined sediments of the Pamlico Sand, the Fort Thompson Formation, and the upper part of the Caloosahatchee Marl form the water-table aquifer (see Figure 4-2). The aquifer is not homogeneous and probably contains areas with extremely high permeabilities, as in the case of the solution

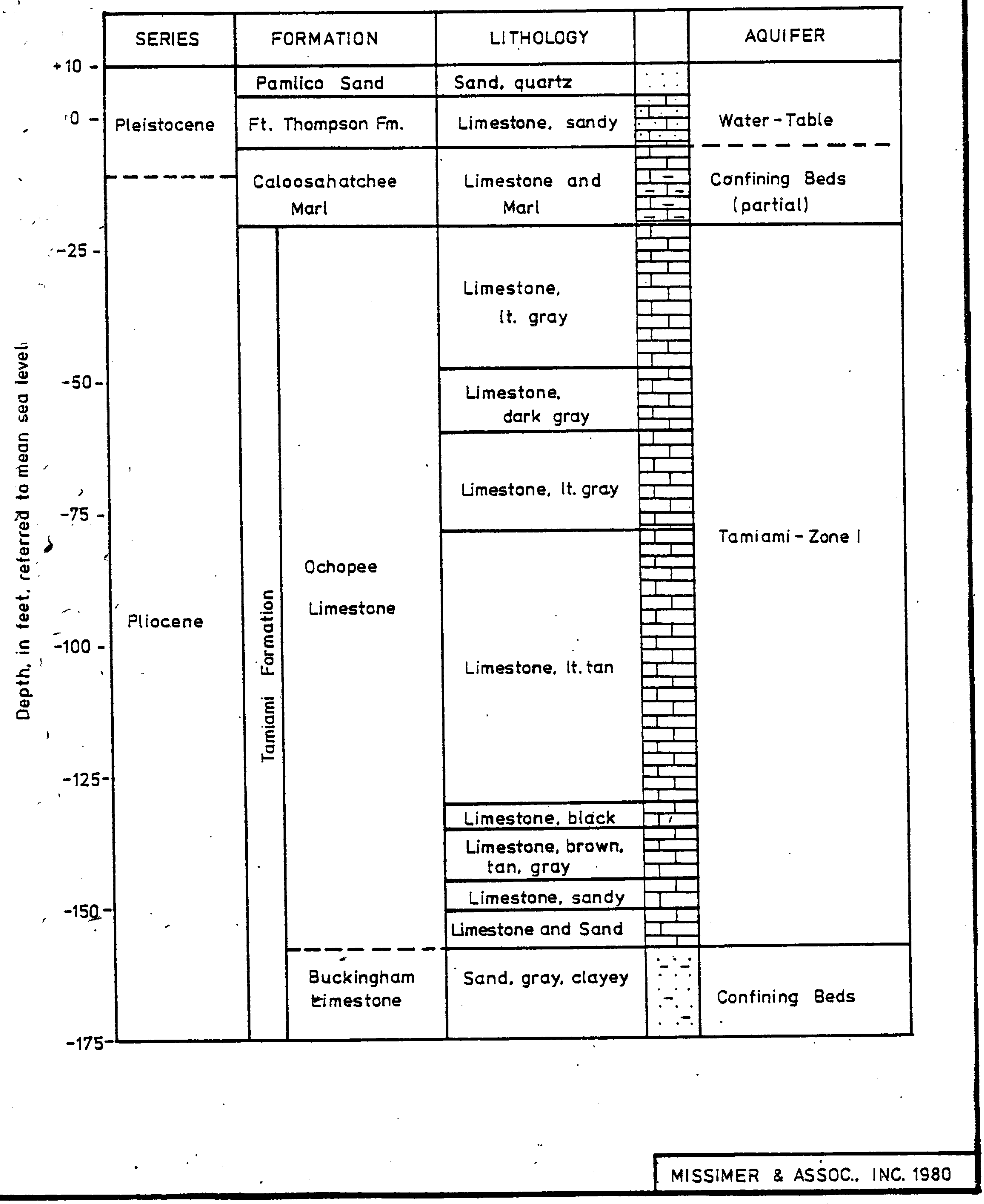


FIGURE 4-2. LOG OF WELL CO-201 SHOWING GEOLOGY AND AQUIFER LOCATIONS.

cavities within the Fort Thompson limestone, and other areas of only medium permeability. Some fine-grain material within the soil zone at the top of the Pamlico Sand may cause the aquifer to behave with a significant amount of delayed yield.

Confining Beds

Clayey sediments within the Caloosahatchee Marl confine the water-table aquifer from the underlying Tamiami Aquifer System-Zone I. The degree of confinement will vary considerably due to large variation in the effective thickness of confining sediments. In some areas, only a foot or less of lime mud or clay occurs within the Caloosahatchee Marl, while in the north part of the area in well C2003D about 9 feet of lime mud occurs in the sequence. Therefore, the confining beds will cause the underlying aquifer to react as either a semi-confined or semi-unconfined aquifer depending on the geology in the immediate vicinity of any given well location.

Tamiami Aquifer System-Zone I

Tamiami Aquifer System-Zone I occurs in the lower permeable beds of the Caloosahatchee Marl and in the Ochopee Limestone. It is the primary source of water-supply in all of western Collier County. There has been considerable confusion in the past concerning the definition and regional extent of this aquifer. It has been termed the shallow cavities within the Fort Thompson limestone, and other areas of only medium permeability. Some fine-grain material within the soil zone at the top of the Pamlico Sand may cause the aquifer to behave with a significant amount of delayed yield.

Confining Beds

Clayey sediments within the Caloosahatchee Marl confine the water-table aquifer from the underlying Tamiami Aquifer System-Zone I. The degree of confinement will vary considerably due to large variation in the effective thickness of confining sediments. In some areas, only a foot or less of lime mud or clay occurs within the Caloosahatchee Marl, while in the north part of the area in well C2003D about 9 feet of lime mud occurs in the sequence. Therefore, the confining beds will cause the underlying aquifer to react as either a semi-confined or semi-unconfined aquifer depending on the geology in the immediate vicinity of any given well location.

Tamiami Aquifer System-Zone I

Tamiami Aquifer System-Zone I occurs in the lower permeable beds of the Caloosahatchee Marl and in the Ochopee Limestone. It is the primary source of water-supply in all of western Collier County. There has been considerable confusion in the past concerning the definition and regional extent of this aquifer. It has been termed the shallow aquifer and has been assumed to be unconfined (Sherwood and Klein, 1961; McCoy, 1972; Klein, 1972). The aquifer has also been referred to as the Coastal Ridge Aquifer with the implication that it is limited in lateral extent to the Naples ridge area. It is now known that the Tamiami Aquifer System-Zone I is a large regional aquifer extending from Lee County south through Collier and Dade Counties.

At the investigation site, Tamiami-Zone I is more than 120 feet thick and has a high permeability. It behaves as either a semi-unconfined or semi-confined aquifer depending on the specific site geology of the confining beds within the Caloosahatchee Marl, and the rate and duration of pumping. The base of the aquifer is formed by marls and clays with low permeability. Upward movement of water into Zone I through the lower confining beds is unlikely because of the thickness and low permeability of these beds.

Lower Confining Beds

Tamiami Aquifer System-Zone I is confined from Tamiami Zone II and other aquifers by low permeability clays and marls within the Buckingham Limestone and Cape Coral clay members of the Tamiami Formation. Although the confining bed sequence was not fully penetrated at the wellfield site, test drilling at a location about 5 miles to the northwest, at The Glades development has shown that the confining strata are more than 50 feet thick (see Missimer and Associates, 1978b). Therefore, Zone I and lower aquifers are connected to a very minor, insignificant degree.

3. Water Quality

Water-table Aquifer

Limited data are available on the water quality of the water-table aquifer. The dissolved chloride concentration in a 15-foot deep well at the site of the aquifer test was 60 mg/l. The chloride concentration at a depth of 20-22 feet in a well beside the raw water source lake was 90 mg/l. At this depth it is likely that the water is a combination of that from the semi-confining unit and from Tamiami Aquifer-Zone I. The shallow USGS monitor well in the water-table aquifer located approximately 1 mile north of the investigation site produces water with a chloride concentration ranging from 10 to 30 mgl. Concentrations of iron and color are generally high in the shallow aquifer. Results of water analysis on the shallow well at the aquifer test site are given in Appendix Table A-8.

Tamiami Aquifer-Zone I

The water quality with respect to chloride concentration in the Tamiami Zone I aquifer was evaluated in considerable detail in several areas within and around the investigation site. Generally, the upper-most part of this aquifer contains water with chloride concentrations ranging from 80 to 200 mg/l (see Table 3-1). However, wells slightly to the northwest of the investigation site showed chloride concentration of 380 and 405 mg/l at depths of approximately 40 feet.

A well was drilled at the utility's raw water source lake in order to determine the salinity profile within the Tamiami Zone I aquifer (see Appendix Table A-1). Water quality with respect to dissolved chlorides ranges in concentration from 90 mg/l at a depth of 20 feet to 680 mg/l dissolved chloride at a depth of 137 feet. After this depth it was not possible to withdraw a sample until the 190 foot depth. The indicated chloride concentration at 190 feet was 620 mg/l but it is suspected that the formation water was contaminated by water used in the drilling and jetting process.

Figure 4-3 shows the variation of chloride concentration with depth across the investigation area as determined from several wells drilled prior to, or as part of this investigation. The position of the fresh-saline water interface is not consistent with that which is predicted by the generally accepted Ghyben-Herzberg theory. This is likely due to previous heavy pumping during the old rock mining operation, which is estimated to have been in excess of 20 mgd, and which maintained water level elevations below sea level for a considerable length of time. This pumpage combined with dry season low or zero flow conditions in Henderson Canal allowed saline water to advance up the

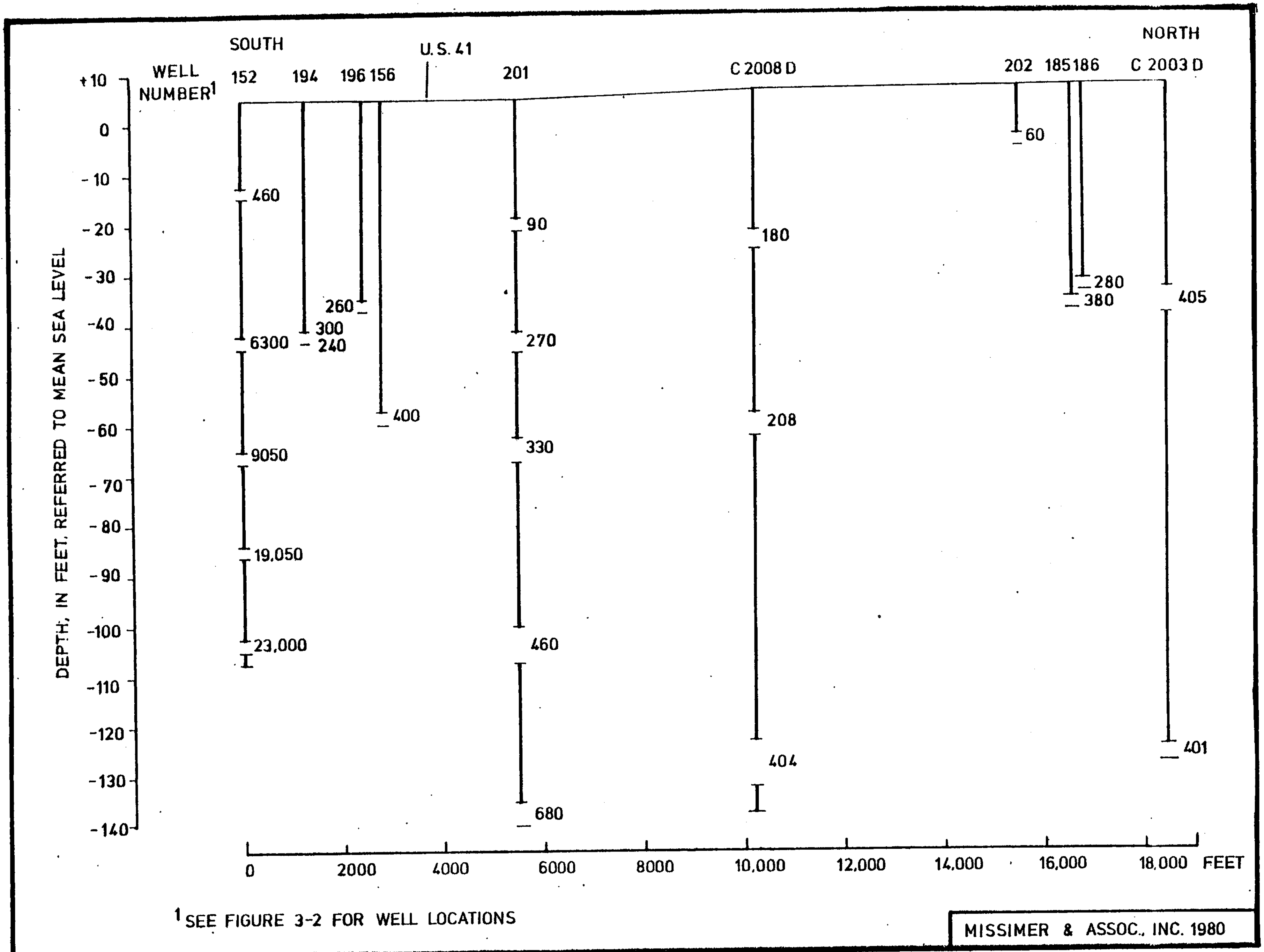


FIGURE 4-3. SOUTH TO NORTH PROFILE OF INVESTIGATION AREA SHOWING VARIATION OF DISSOLVED CHLORIDE CONCENTRATION WITH DEPTH.

canal and contaminate the groundwater in the areas near the canal. The variation in groundwater quality around the site may also be the result of selective flushing of remnant seawater from the aquifer.

Concentrations of total dissolved solids have been found to be in excess of 500 mg/l within the upper portions of the Tamiami Zone I Aquifer. It is not uncommon for raw water from the lake source to have TDS values ranging from 600-800 mg/l. As shown in Table A-6, a large part of the dissolved ions and minerals constituting the total dissolved solids are dissolved calciums, magnesium, bicarbonate, and iron, which are removed to a degree by conventional water treatment processes. Such dissolved constituents as chlorides, fluorides, and sodium are not removed by conventional treatment processes and therefore remain in the product water. The concentrations of these ions in the aquifer are acceptable.

4. Henderson Canal

Henderson Canal is the most significant hydrologic feature of the investigation area. Its affect on the inflow and discharge from the investigation area has much to do with the groundwater situation within the study area.

The size of the watershed contributing to its flow above the investigation area is estimated to be about 10 square miles. The average discharge from the canal measured at the USGS gaging station 0.3 mile north of the investigation area has averaged about 22 cfs (14 mgd). The most important aspect of the Henderson Canal flow records however is the dry season discharge which has averaged about 6 cfs (4 mgd) for the months of January thru May.

Canal discharge during the dry season is derived primarily from groundwater drainage of the surrounding land. Henderson Canal is responsible for lowering the groundwater levels throughout its drainage basin by providing a conduit for rapidly transporting to the bay water which would otherwise recharge the shallow aquifer system and maintain higher water levels down gradient. This action works to the detriment of the hydrologic system from a groundwater management point of view because reduced water levels particularly at the down-stream end of the basin allow saline water in deeper portions of the aquifer to rise. The canal can however, work to the advantage of water users along the canal's downstream section.

Presently Henderson Canal serves as a discharge point from the aquifer year round. With the construction of the salinity barrier on Henderson Creek at U.S. 41, the water that is drained from the upper part of the basin will be recharged at the part of the basin just behind the control structure. This will occur because the control structure will elevate the water level above that typically present in the groundwaters at the Marco Island Utilities site and water will then flow from the canal into the shallow aquifer system.

As long as groundwater levels are properly managed in the area around Marco Island Utilities' property, the new structure will effectively allow the utility company to benefit from the canals dewatering of upland areas.

One effect of constructing the salinity control structure on Henderson Canal will be to reduce the rate of decline of regional water levels in the dry season. This will tend to smooth the annual hydrograph and should increase the dry season flow somewhat. The additional water will be available to recharge the aquifer in the Marco Island Utilities area.

In addition to slowing drainage of the adjacent areas, the new salinity control structure will prevent migration of saline water up the canal. Historically, the migration of tidal water upstream has caused increases in the salinity of shallow groundwaters on the north side of U.S. 41. Since this source of contamination will be eliminated, it is expected that the quality of the water in areas adjacent to the canal will improve as the residual salinity is flushed from the system.

5. Aquifer Characteristics

The aquifer system beneath the investigation site is geologically and hydraulically complex. Accurate determinations of the hydraulic properties of the water withdrawal zones are required in order to predict aquifer responses to long term pumping. Determination of the hydraulic properties of the two aquifers requires the following information: 1) detailed geologic data, 2) aquifer test data, and 3) water level data. The geologic information and aquifer delineation has been presented earlier in this section of the report.

There are four general types of aquifers that can occur in nature: 1) unconfined or water-table, 2) semi-unconfined, 3) semi-confined, and 4) confined (Kruseman and DeRidder, 1970). A schematic illustration of the geologic setting characteristic of each is shown in Figure 4-4. For simplicity, only two kinds of deposits are shown, permeable and impermeable. The latter is present on the bottom of each diagram.

The setting of the unconfined or confined aquifer is relatively straightforward. The former is characterized by a partially water-filled permeable bed whose upper surface, the water-table, is under atmospheric pressure. The latter is characterized by a completely filled permeable bed that is overlain by impermeable material.

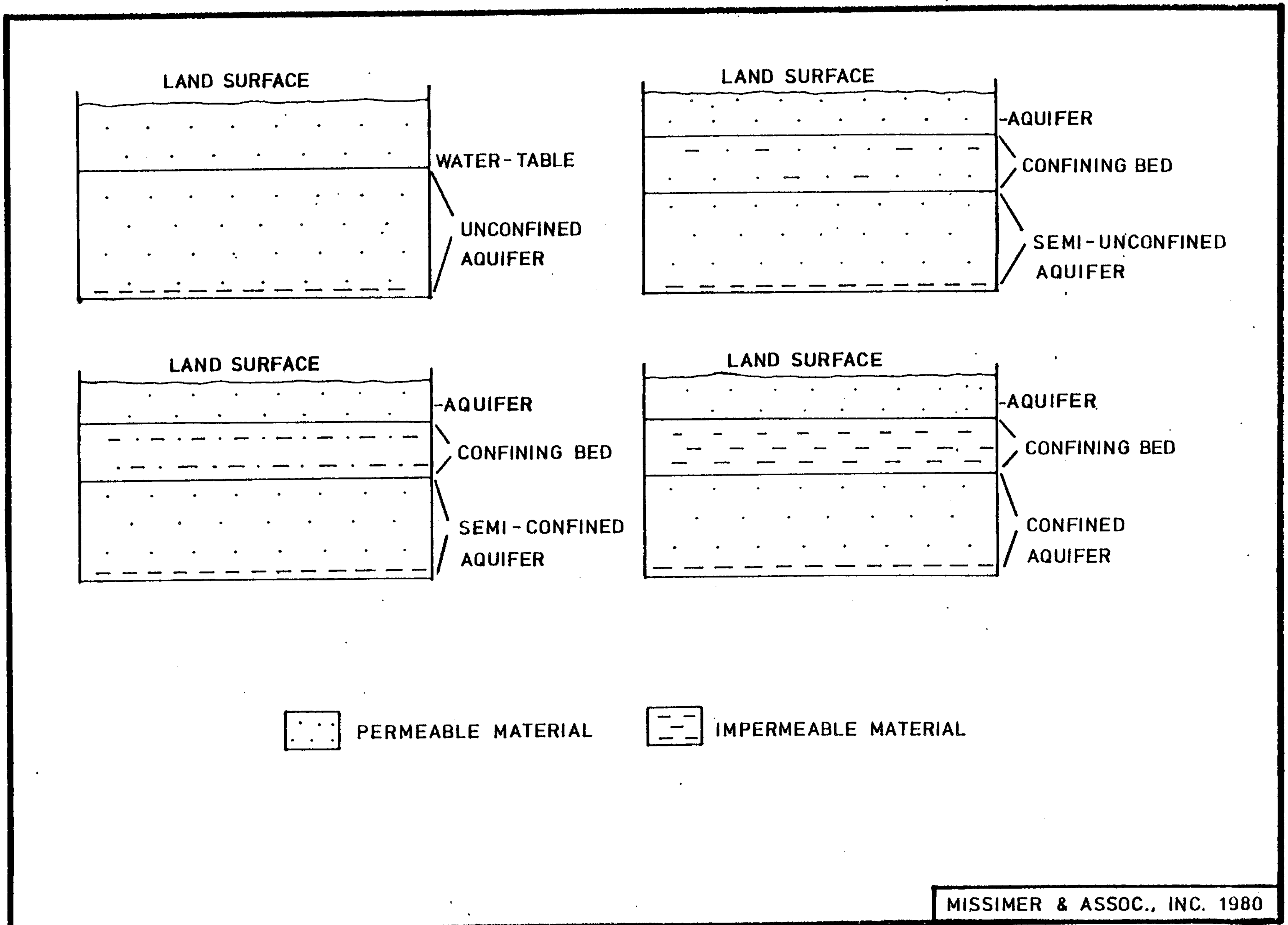


FIGURE 4-4. EXAMPLE GEOLOGIC SETTINGS OF AQUIFER TYPES.

Both the semi-unconfined and semi-confined aquifers occur when permeable beds are directly overlain by a unit that has a finite but small permeability. The difference between the two is related to the ease and rate of inter-aquifer water movement through the confining bed. These factors can most readily be visualized when the partially confined aquifer is being pumped. In the semi-unconfined case, water-levels decline in the overlying aquifer relatively fast and will eventually equal those in the pumped zone. In the semi-confined case, water-level declines in the overlying aquifer can sometimes be detected after a long period of pumping, but are smaller than those in the pumped zone.

Time-drawdown data collected from pumped and observation wells are used to determine important hydraulic properties of an aquifer. Three of these properties, defined below, are used in determining aquifer yield and hydrologic impacts:

a) Transmissivity (T) - Equivalent to permeability times the aquifer thickness. It is a measure of the ability to transmit water in units of gallons per day.

b) Storage Coefficient (S) - The volume of water released from storage within an aquifer that occurs beneath one square of its surface as a

5 CYCLES X 10 DIVISIONS PER INCH

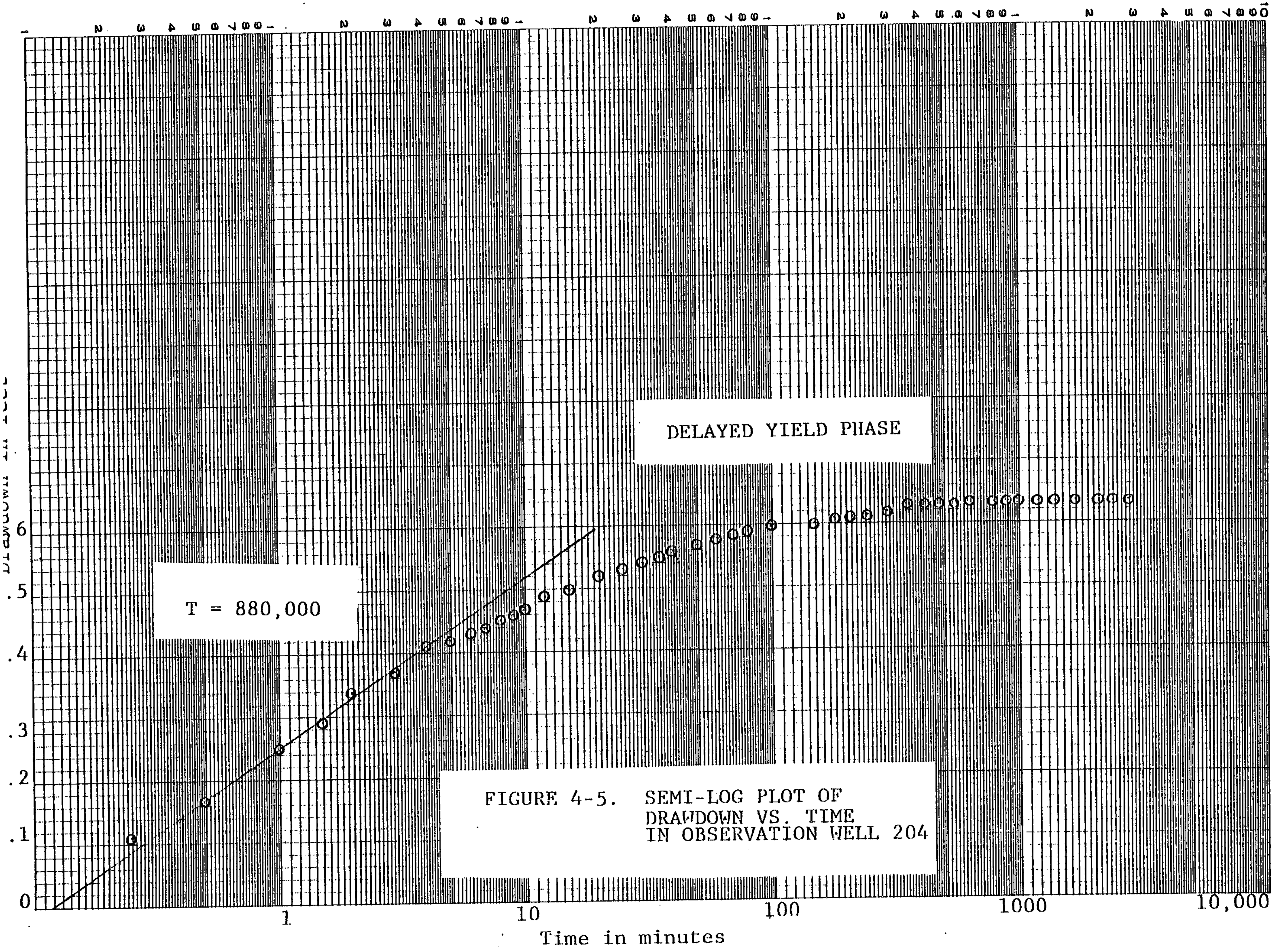


FIGURE 4-5. SEMI-LOG PLOT OF DRAWDOWN VS. TIME IN OBSERVATION WELL 204

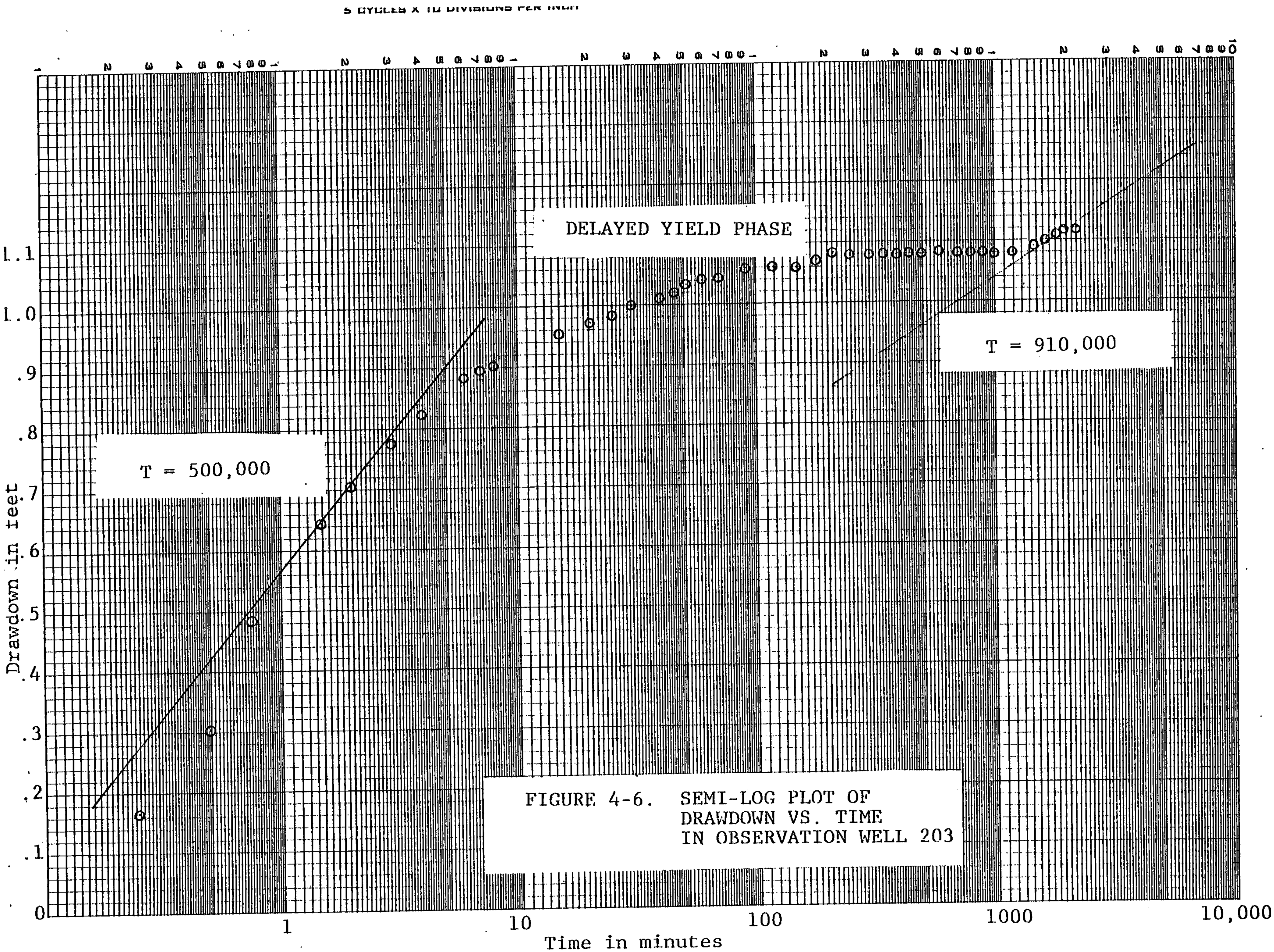


FIGURE 4-6. SEMI-LOG PLOT OF DRAWDOWN VS. TIME IN OBSERVATION WELL 203

result of a one foot change in head. The units are dimensionless.

c) Leakage Coefficient (k'/b') - The effective vertical permeability of a confining bed divided by its thickness. Reported in units of gallons per day per cubic foot.

Tamiami Zone I Aquifer

The aquifer of primary concern to this investigation is the Tamiami Zone I aquifer. It is responsible for storing and transporting the very major portion of the fresh groundwater in southwest Collier County.

An aquifer test was performed on the Zone I aquifer with continuous pumping at 900 gpm for a period of 48 hours. A detailed description of the test is given in Section 3. The drawdown in the test-production well stabilized at approximately 12 feet after one hour of pumping which yields a specific capacity of 75 gpm per foot of drawdown. Continuous records of drawdown in the observation wells were maintained throughout the pumping and recovery period.

A preliminary data analysis was made of Zone I 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. For a semi-unconfined or water-table aquifer, the late drawdown data, after recharge effects or delayed yield has ceased to affect water level declines, can be used to calculate accurate aquifer coefficients. The pumping test at the proposed wellfield site did not continue sufficiently long to make this computation.

Primary evaluation of the aquifer test data was accomplished using the method developed by Boulton (1963). This method was derived to account for the phenomenon known as "delayed yield" where water level drawdowns in the production zone cease as water drains from the upper strata at a rate sufficient to recharge the lower zone. This occurance continues until the upper strata is no longer able to recharge the production zone at a sufficient rate, and water levels again begin to decline in the production zone, this time the decline occurs simultaneously with the declines in the upper zone water level. At this point it is considered that the system is behaving as an unconfined aquifer.

During the Tamiami Zone I aquifer test, conditions did not proceed beyond the "delayed yield" phase although some small departure from the equilibrium condition began to occur late in the test at well CO-204. In this case the analysis could be done equally well using the method of Hantush-Jacob (1955) as adapted to a method published by Cooper (1963). Both the Hantush-Jacob method and the Boulton method are identical for the early part of the test.

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:

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

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

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

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

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

$v = {}^r/2 \; (k'/b' \; T)^{1/2}$ 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 early storage coefficient. It was not possible to determine the late storage coefficient because drawdowns did not proceed significantly beyond the delayed yield phase. The aquifer coefficients yielded

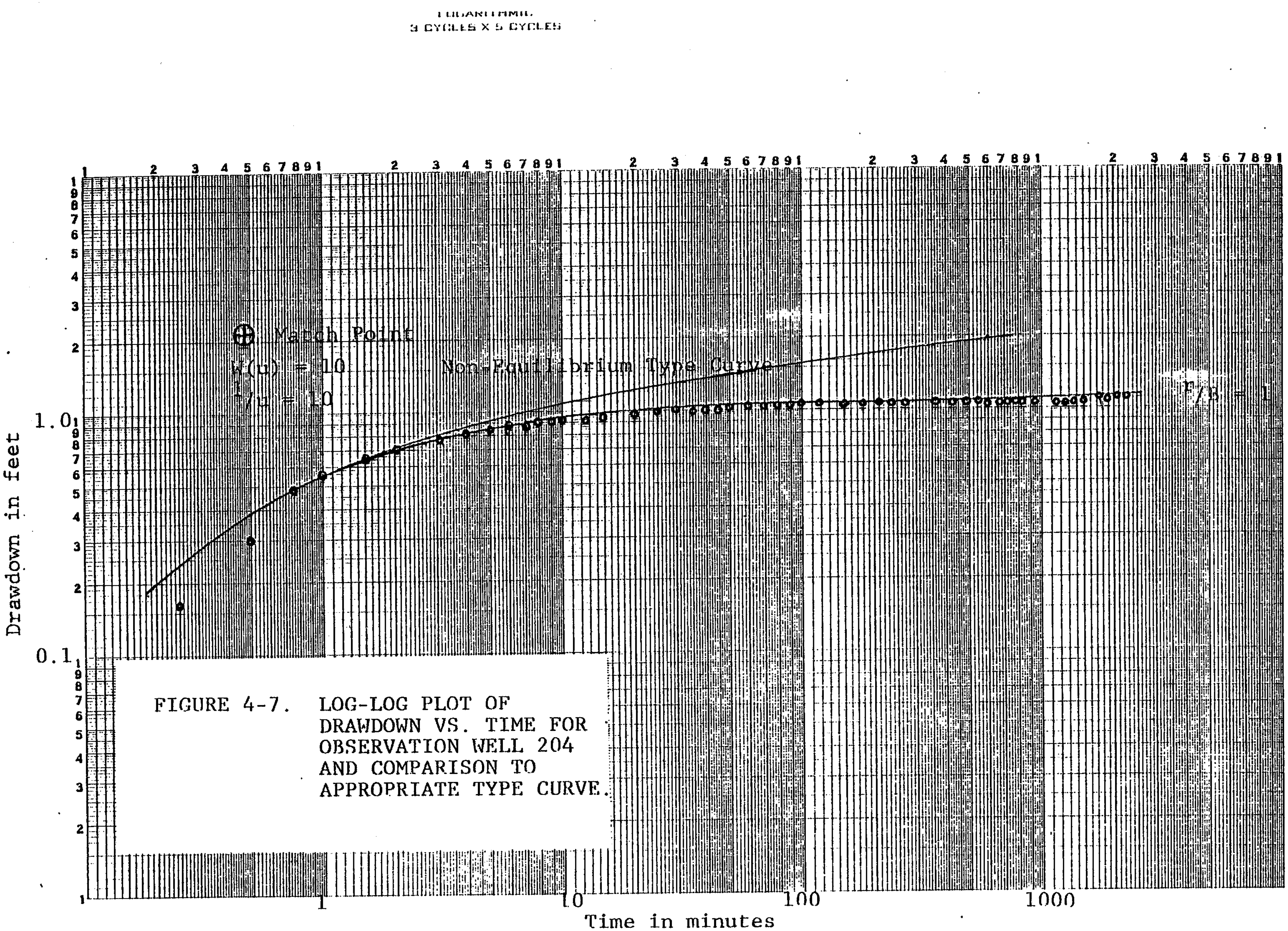


FIGURE 4-7. LOG-LOG PLOT OF DRAWDOWN VS. TIME FOR OBSERVATION WELL 204 AND COMPARISON TO APPROPRIATE TYPE CURVE.

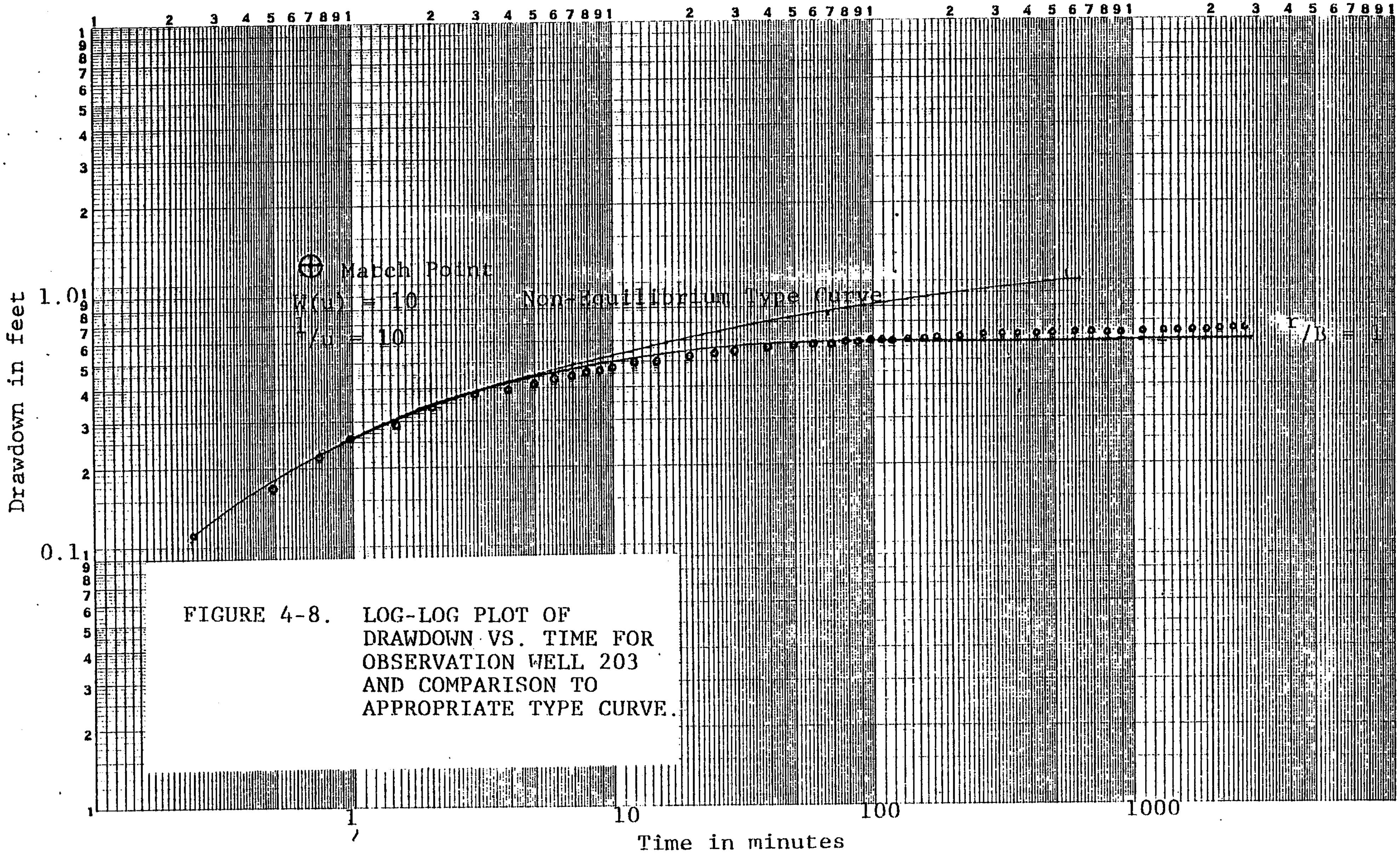


FIGURE 4-8. LOG-LOG PLOT OF DRAWDOWN VS. TIME FOR OBSERVATION WELL 203 AND COMPARISON TO APPROPRIATE TYPE CURVE.

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

Transmissivity = 860,000 gpd/ft

Leakance $^{k'}/_{b'}$ = .15 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. Also, this well is less likely to experience the effect of partial penetration.

Because the value of leakance is very high and the water-table declined steadily during the aquifer test, it is expected that for long term pumpage (10 days or more) the system can be expected to behave as a water-table aquifer. 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.

Water-table Aquifer

Test drilling showed that the amount of confinement between the water-table and the Tamiami Zone I aquifer

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

Analysis Method	Transmissivity gpd/ft	Leakance k'/b' gpd/ft^3	Storage Coefficient [1]
Hantush Jacob well 203	860,000	.15	4×10^{-4}
Hantush Jacob well 204	480,000	.41	7×10^{-4}
Jacob (log-time) well 203	880,000	---	4×10^{-4}
Jacob (log-time) well 204	500,000	---	2×10^{-4}
Jacob (log-distance)	475,000 - 560,000	---	5×10^{-4} to 9×10^{-4}
Recovery well 203	880,000	---	8×10^{-4}
Recovery well 204	460,000	---	------

[1] Values calculated from early test data before leakage or delayed yield

was minimal, and for this reason, little testing was done on the shallow zone. A short pumping test was conducted however, in order to determine the transmissivity of the shallow zone. In this test a 15-foot deep well was pumped at 50 gpm for 120 minutes while the drawdown in an observation well 35 feet away was measured. The data was analyzed yielding a transmissivity of 71,000 gpd/ft. It was not possible to determine the storage coefficient from this test but a conservative estimate of its value would be about 0.1.

V. WATER AVAILABILITY AND IMPACTS

1. Introduction

It was the intent of this investigation to determine the maximum safe yield of the approximately 1600 acres of land to be used in development of a water withdrawal scheme. In order to accomplish the objective in a conservative manner, practical worst case conditions have been selected which serve as the limiting framework for making quantitative assessments. The following criteria were used in this assessment.

a) Drawdowns in the Tamiami Zone I aquifer will be used as the primary indication of potential problems regarding saltwater intrustion.

b) The potentiometric surface of the Tamiami Zone I aquifer will not be lowered below sea level. Rather, it should average at least 0.5 feet above sea level during a typical dry season.

c) Allowable drawdown in the Tamiami Zone I aquifer in the southern end of the property is 2.5 feet (in Section 3), and in the northern part of the property (Section 26) the allowable drawdown is

4.0 feet.

d) Drawdowns will be calculated using water-table conditions, with 5 months of continuous pumpage without recharge by rainfall.

e) Aquifer coefficients used to make the dry season drawdown analysis will be: Transmissivity = 860,000 gpd/ft - Storage Coefficient = 0.1.

f) The amount of recharge during the dry season by Henderson Canal will average 3 mgd.

2. Groundwater Withdrawals and Drawdowns

The presence of water which is of an undesirable salinity at depths of approximately 40 feet necessitates the construction of a withdrawal system which uses only the upper part of the aquifer system. For this reason the system selected will withdraw water only from a depth of about 15 feet below land surface.

The hydrogeology of the aquifer system is such that this system, will withdraw from the shallow aquifer which overlies the Tamiami Zone I aquifer. The transmissivity of this zone is about 70,000 gpd/ft^2 and the leakance between the shallow zone and the Tamiami Zone I aquifer is about .15

gpd/ft^3.

Computation of drawdowns due to pumpage of the shallow aquifer coupled with the drawdowns which will occur in the potentiometric surface of the Tamiami Zone I aquifer show that the water levels of the two aquifers will decline by the same amount beyond a rather short distance from the withdrawal point. This is due to the high leakage rate of the semi-confining zone.

This implies that for long term dry season pumpage conditions, the withdrawal system may be looked at as that of one aquifer having the transmissivity of Tamiami Aquifer Zone I (860,000 gpd/ft) and a water table storage coefficient (assumed 0.1). Using these aquifer coefficients the drawdowns in the Tamiami Zone aquifer were assessed for numerous pumping rates and well positions.

The drawdown in the Tamiami Zone I aquifer due to a pumpage of 14 mgd during the dry season is shown in Figure 5-1. The drawdowns shown are for 150 days of continuous pumpage without rainfall.

In this model, the withdrawal amount from the Marco Island Lake System is 4 mgd, and 10 mgd is withdrawn from shallow wells located in Sections 35 and 26. This figure also represents, the conditions which would be present if the 10 mgd withdrawal was from an infiltration gallery system arranged along the lines of the shallow wells. The model is based on a recharge rate of 3 mgd along Henderson

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	1.90	1.98	2.07	2.16	2.25	2.35	[illegible]	2.54	2.62	2.68	2.71	2.72	2.70	2.67	2.62	2.56	2.48	2.40	2.3
2	1.96	2.05	2.14	2.24	2.35	2.46	2.58	2.70	2.81	2.88	2.92	2.92	2.90	2.85	2.79	2.72	2.63	2.53	2.4
3	2.01	2.11	2.21	2.31	2.43	2.57	2.72	2.88	3.04	3.13	3.17	3.16	3.11	3.05	2.98	2.91	2.79	2.66	2.5
4	2.06	2.16	2.27	2.38	2.51	2.65	2.83	3.07	3.34	3.44	3.46	3.43	3.34	3.24	3.18	3.15	2.96	2.79	2.6
5	2.11	2.21	2.32	2.44	2.57	2.72	2.89	3.19	3.57	3.73	3.76	3.72	3.56	3.40	3.34	3.30	3.10	2.91	2.7
6	2.14	2.25	2.36	2.48	2.62	2.77	2.95	3.25	3.57	3.67	3.69	3.65	3.57	3.48	3.44	3.41	3.20	3.00	2.8
7	2.18	2.28	2.40	2.52	2.66	2.81	3.01	3.27	3.54	3.60	3.61	3.59	3.55	3.52	3.50	3.48	3.28	3.07	2.8
8	2.20	2.31	2.42	2.55	2.68	2.82	2.98	3.26	3.52	3.56	3.56	3.55	3.54	3.53	3.53	3.53	3.33	3.12	2.9
9	2.22	2.33	2.44	2.56	2.69	2.83	2.99	3.25	3.50	3.53	3.53	3.53	3.53	3.53	3.55	3.55	3.36	3.15	2.9
10	2.24	2.34	2.45	2.57	2.70	2.84	3.01	3.24	3.48	3.50	3.50	3.50	3.51	3.52	3.55	3.56	3.37	3.16	2.9
11	2.25	2.35	2.46	2.57	2.69	2.82	2.96	3.21	3.45	3.47	3.47	3.47	3.49	3.51	3.54	3.56	3.37	3.17	2.9
12	2.26	2.36	2.47	2.57	2.68	2.80	2.93	3.18	3.42	3.44	3.44	3.44	3.46	3.48	3.52	3.54	3.35	3.16	2.9
13	2.27	2.37	2.47	2.57	2.67	2.78	2.91	3.15	3.38	3.40	3.40	3.41	3.42	3.45	3.49	3.51	3.33	3.13	2.9
14	2.28	2.37	2.47	2.57	2.66	2.76	2.88	3.12	3.35	3.37	3.36	3.36	3.38	3.40	3.44	3.47	3.29	3.10	2.9
15	2.28	2.38	2.47	2.56	2.66	2.75	2.86	3.09	3.31	3.32	3.31	3.31	3.32	3.35	3.39	3.41	3.24	3.05	2.88
16	2.29	2.38	2.47	2.56	2.65	2.73	2.83	3.06	3.27	3.27	3.25	3.25	3.26	3.28	3.32	3.34	3.17	2.99	2.82
17	2.30	2.39	2.48	2.57	2.65	2.72	2.81	3.02	3.22	3.21	3.19	3.18	3.18	3.20	3.23	3.26	3.09	2.92	2.76
18	2.31	2.40	2.49	2.58	2.65	[illegible]	2.79	2.98	3.16	3.14	3.11	3.09	3.09	3.10	3.12	3.15	2.99	2.83	2.68
19	2.32	2.41	2.51	2.60	2.67	2.73	2.78	2.93	3.08	3.05	3.02	3.00	2.99	2.99	3.00	3.01	2.87	2.72	2.59
20	2.33	2.43	2.53	2.63	2.71	2.78	2.80	2.88	2.94	2.95	2.93	2.90	2.88	2.86	2.84	2.80	2.71	2.61	2.50
21	2.35	2.46	2.56	[illegible]	2.78	2.88	2.88	2.87	2.87	2.86	2.83	2.81	2.78	2.74	2.71	2.65	2.58	2.49	2.40
22	2.36	2.48	2.60	2.72	2.84	2.98	2.96	2.87	2.82	2.78	2.75	2.71	2.67	2.63	2.59	2.53	2.47	2.39	2.31
23	2.38	2.51	2.64	2.76	2.89	3.03	2.98	2.85	2.77	2.71	2.66	2.62	2.57	2.53	2.48	2.42	2.36	2.29	2.22
24	2.38	2.54	2.70	2.82	2.92	3.03	2.94	2.80	2.70	2.63	2.58	2.53	2.48	2.43	2.38	2.32	2.27	2.20	2.14
25	2.38	2.57	2.80	2.89	2.94	3.00	2.84	2.70	2.62	2.55	2.49	2.43	2.38	2.33	2.28	2.23	2.18	2.12	2.06
26	[illegible]	2.53	2.79	2.92	2.94	2.88	2.68	2.58	2.51	2.45	2.39	2.34	2.29	2.24	2.19	2.14	2.09	2.04	1.98
[illegible]	2.26	2.41	2.58	2.72	2.82	2.71	2.53	2.46	2.40	2.35	2.30	2.25	2.20	2.15	2.11	2.06	2.01	1.96	1.91
28	[illegible]	2.28	2.39	2.50	2.57	2.52	2.38	2.33	2.29	2.24	2.20	2.15	2.11	2.07	2.02	1.98	1.93	1.88	1.84
29	2.05	[illegible]	2.23	2.30	2.34	2.32	2.27	2.22	2.18	2.14	2.10	2.06	2.02	1.98	1.94	1.90	1.86	1.81	1.77
30	1.95	2.02	[illegible]	2.14	2.16	2.16	2.14	2.11	2.08	2.04	2.01	1.97	1.94	1.90	1.86	[illegible]	1.78	1.74	1.70
31	1.85	1.91	1.96	[illegible]	2.02	2.03	2.02	2.00	1.97	1.95	1.92	1.89	1.85	1.82	1.79	1.75	1.71	1.67	1.64

FIGURE 5-1. WATER LEVEL DRAWDOWNS FOR A WITHDRAWAL OF 14 MGD FROM THE LAKE AND SHALLOW AQUIFER SYSTEM DURING THE DRY SEASON.

Canal. The 14 MGD withdrawal rate is what should be considered the maximum safe pumping rate from the investigation area during the dry season based upon established limiting criteria.

Until groundwater withdrawals begin from Sections 35 and 26, additional withdrawals can be made from the lake system. After the construction of the Henderson Canal structure, a withdrawal from the lakes of up to 8 MGD can be made without creating drawdowns below sea level. The drawdowns which accompany such a withdrawal are shown in Figure 5-2 for a 150-day dry season condition. This figure also includes 3 MGD of recharge along Henderson Canal. The 8 MGD withdrawal rate should be considered the maximum safe yield of the lake system operating alone.

3. Saline Water Concerns

The rather close proximity of the proposed withdrawals to saline water indicates that special consideration needs to be given to potential for advancement of the salt water front.

The position of the fresh-saline water interface was described in Section 4. Construction of the salinity control structure on Henderson Creek should change the position of the fresh-salt water interface considerably. This structure will raise the natural elevation of the potentiometric surface within the investigation area causing the salt water grid spacing = 480 ft

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	0.86	0.85	0.84	0.82	0.79	0.74	0.69	0.73	0.75	0.77	0.78	0.78	0.77	0.76	0.75	0.74	0.72	0.70	0.68
2	0.92	0.91	0.90	0.87	0.83	0.78	0.72	0.76	0.79	0.81	0.82	0.82	0.81	0.80	0.79	0.77	0.75	0.73	0.71
3	0.98	0.98	0.96	0.93	0.89	0.83	0.77	0.81	0.85	0.87	0.87	0.87	0.86	0.85	0.83	0.81	0.79	0.77	0.74
4	1.05	1.05	1.04	1.01	0.97	0.91	0.85	0.88	0.92	0.93	0.94	0.93	0.92	0.90	0.88	0.85	0.83	0.80	0.77
5	1.14	1.14	1.13	1.11	1.07	1.01	0.94	0.97	1.00	1.01	1.01	1.00	0.98	0.95	0.93	0.90	0.87	0.83	0.80
6	1.23	1.24	1.24	1.23	1.19	1.13	1.06	1.09	1.11	1.11	1.09	1.07	1.04	1.01	0.98	0.94	0.91	0.87	0.83
7	1.33	1.36	1.37	1.36	1.34	1.28	1.21	1.22	1.23	1.22	1.19	1.15	1.12	[illegible]	1.03	0.99	0.95	0.90	0.87
8	1.45	1.49	1.52	1.53	1.51	1.46	1.38	1.38	1.37	1.34	1.29	1.24	1.19	1.14	1.08	1.03	0.99	0.94	0.90
9	1.57	1.63	1.68	1.71	[illegible]	1.69	1.60	1.58	1.54	1.47	1.40	1.33	1.26	1.20	1.14	1.08	1.02	0.97	0.92
10	1.70	1.78	1.86	1.93	1.98	1.98	1.89	1.81	1.72	1.62	1.52	1.42	1.34	1.26	1.19	1.12	1.06	1.00	0.95
11	1.83	1.94	2.06	[illegible]	2.28	2.39	2.29	2.08	1.91	1.76	1.62	1.51	1.40	1.31	1.23	1.16	1.09	1.03	0.97
12	1.96	2.11	2.26	2.40	2.57	2.79	2.67	2.32	2.07	1.88	1.72	1.58	1.46	1.36	1.27	1.19	1.12	1.05	0.99
13	2.09	2.27	2.46	2.63	2.82	3.04	2.89	2.49	2.20	1.97	1.78	1.63	1.50	1.39	1.30	1.21	1.14	1.07	1.01
14	2.20	2.44	2.68	2.86	3.01	3.19	2.99	2.56	2.25	2.01	1.82	1.66	1.53	1.42	1.32	1.23	1.15	1.08	1.02
15	2.27	2.59	3.00	3.12	3.18	3.28	2.93	2.54	2.25	2.02	1.83	1.67	1.54	1.42	1.32	1.24	1.16	1.09	1.02
16	[illegible]	2.60	3.08	3.28	3.28	3.14	2.73	2.43	2.19	1.98	1.81	1.66	1.53	1.42	1.32	1.24	1.16	1.09	1.02
17	2.20	2.45	2.72	2.96	3.12	2.89	2.51	2.28	2.08	1.91	1.76	1.63	1.51	1.40	1.31	1.23	1.15	1.08	1.02
18	2.08	2.26	2.44	2.59	2.70	2.57	2.28	2.11	1.96	1.82	1.70	1.58	1.47	1.38	1.29	1.21	1.14	1.07	1.01
19	1.94	2.07	2.19	2.27	2.28	2.18	2.04	1.94	1.84	1.73	1.62	1.52	1.43	1.34	1.26	1.19	1.12	1.06	1.00
20	1.81	1.90	1.97	2.00	1.99	1.90	1.83	1.78	1.71	1.63	1.54	1.46	1.38	1.30	1.23	1.16	1.10	1.04	0.98
21	1.68	1.74	1.79	1.80	1.77	1.69	1.68	1.65	1.59	1.53	1.46	1.39	1.32	1.26	1.19	1.13	1.07	1.02	0.97
22	1.56	1.61	1.64	1.64	1.61	1.55	1.55	1.53	1.49	1.44	1.39	1.33	1.27	1.21	1.15	1.10	1.04	0.99	0.94

FIGURE 5-2. WATER LEVEL DRAWDOWNS FOR A WITHDRAWL OF 8 MGD FROM THE LAKE SYSTEM DURING THE DRY SEASON.

interface to receed. The expected rise in the potentiometric surface will decrease with distance from the canal but it is expected that an area at least 1 mile on either side of the canal will be appreciably affected. Based on the existing aquifer coefficients and a semi-unconfined aquifer system, it is estimated that for a 2 foot rise in average water level in the canal, the potentiometric surface will rise about an average 1 foot within a 2000 foot distance, and should rise more than .2 foot at a distance one mile from the canal.

The design of the proposed salinity control structure specifies a wier elevation of +5 feet M.S.L. It will not likely be possible to maintain this elevation in the water surface during the late part of the dry season due to the high transmissivity of the aquifer in the region, and the eventual pumping of a large amount of groundwater from lands behind the structure. However, during the wet season and during storm events the structure will cause more water to be stored within the shallow zones, and will prevent rapid drainage of this water to the bay system. Based on increased storage volumes and expected drainage rates the Henderson Canal water level elevation behind the control structure should average at least a 2 foot increase.

As Marco Island Utilities increases its withdrawals from the surrounding shallow aquifer, the flow in Henderson Creek will be reduced. This will be due to interception of much of the stream flow by the withdrawal of water from the property along approximately 2 miles of the canal.

Movement of the saline water interface will take place in response to changes in the potentiometric surface of the Tamiami Zone 1 Aquifer. The proposed scheme for the withdrawal of 14 mgd was designed to minimize potentiometric surface drawdowns and prevent saline water contamination.

Due to the nature of the aquifer system and climatic cycles, drawdowns will vary seasonally. In the wet season the Tamiami Zone I Aquifer will not experience significant drawdowns because recharge to the water table by both rainfall and canal recharge will occur faster than the loss of water by pumping. Wet season drawdowns in this aquifer will not exceed about 1 foot. In the dry season, when recharge by rainfall is low, the aquifer system will behave as an unconfined aquifer with drawdowns in the Tamiami Zone I Aquifer of 2 to 4 feet uniformly across the property.

The fresh-saline water interface will tend to move up in response to this lowering of water levels. However, in order to contaminate the proposed shallow withdrawal system, saline water must migrate a distance of at least 25 feet vertically. This implies that a water volume equivalent to that stored in 25 feet of aquifer below the withdrawal points must be removed and replaced in order for saline water to reach the infiltration galleries or shallow wells.

The amount of water stored in 25 feet of aquifer below the 1.5 foot cone of depression is sufficient to last over 500 days at a pumping rate of 14 mgd. The expected maximum amount of time which conditions for upward migration would exist is about 200 days. After this time, upward migration of saline water would cease as the wet season's high water levels flush the aquifer and force saline water back deeper into the formation. This phenomena of the fresh-salt water interface ascending in the dry season and receeding in the wet season is typical of the coastal aquifers and has been observed in numerous production and monitor wells.

A shallow well or infiltration gallery system at the investigation site which withdraws water from a depth of approximately 15 feet should not experience significant degradation in water quality by vertical migration of saline water.

Horizontal migration of saline water can occur only for water within reach of the cone of depression. Figure 5-3 shows a flow net for the withdrawal of 14 mgd during the dry season. Test wells have shown that shallow water (to 30 foot depths) within the boundary which encompasses flow toward the Marco Island Utility withdrawal system is acceptable with respect to chloride concentration.

For the proposed withdrawal system pumping 14 mgd from the Marco Island Utilities site, the salinity of the pumped water will likely increase somewhat in the dry season and decrease in the wet season. The chloride concentration of

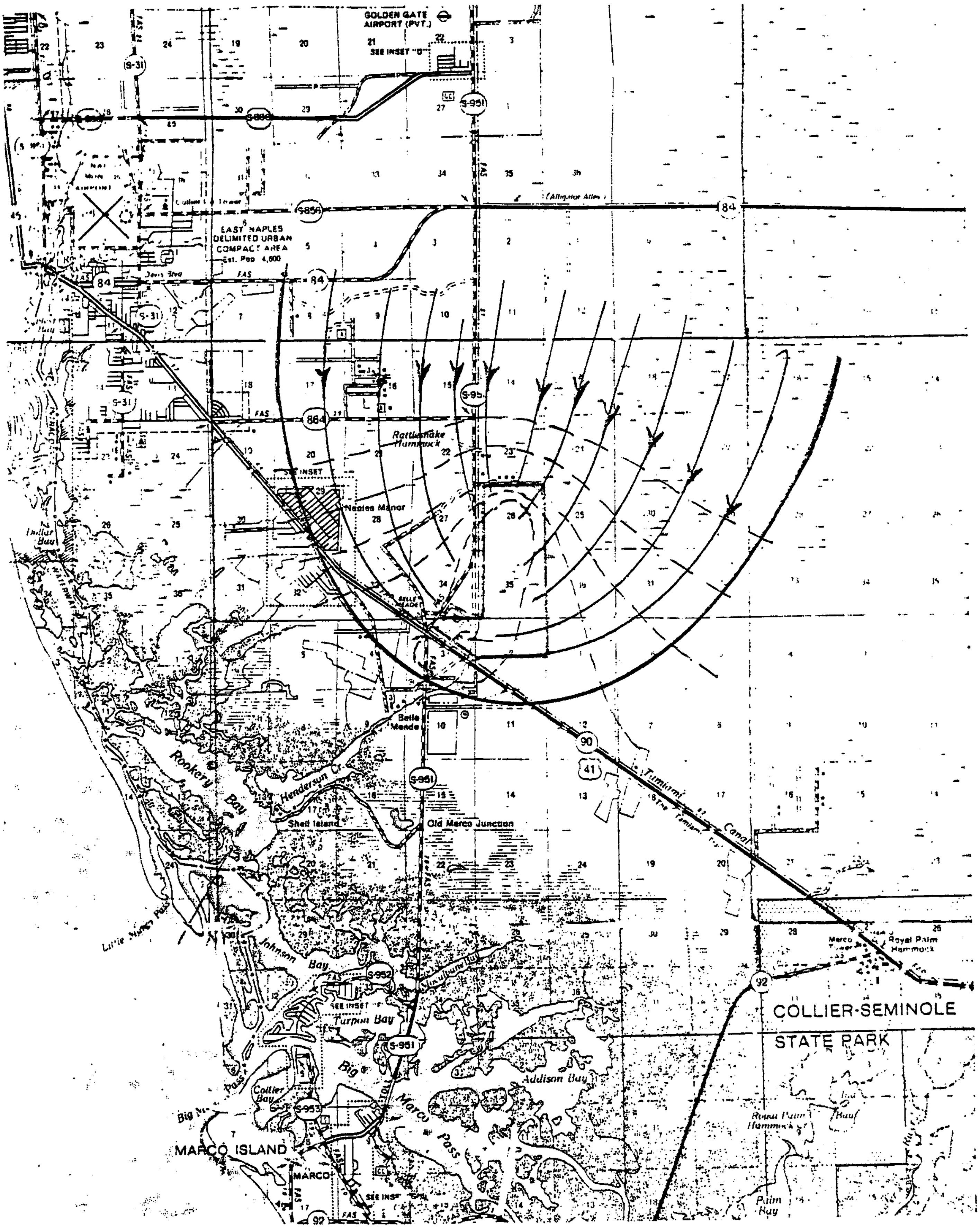


FIGURE 5-3. MAP SHOWING GENERALIZED FLOWNET FOR RECHARGE OF TAMIAMI AQUIFER ZONE I WHILE PUMPING 14 MGD FROM INVESTIGATION SITE.

the waters withdrawn from this system can however, be expected to remain below 250 mg/l indefinitely. This conclusion is based on the data from the test wells drilled on the property. Prior to finalizing plans for construction of the withdrawal system, a number of shallow test wells should be drilled in and around the property to confirm the assumption of uniform water quality.

Management of the groundwater withdrawals both in and around the investigation site is essential to maintaining water quality. The amount of water available to Marco Island Utilities will be limited by the amount of water use within the recharge area which contributes to the withdrawals. Serious efforts must be made to restrict water use within the contributing flow region shown on Figure 5-3.

VI. WATER WITHDRAWAL SYSTEM

1. Introduction

At present, average withdrawals from the south lake in the Marco Island water system are approximately 5 mgd. The surface area of this lake is approximately 19 acres, however 2-18 inch diameter pipes have been installed between the north and south lakes which make the lakes behave essentially as one lake of approximately 46 acres. Considering the amount of land available over which the necessary withdrawals may be distributed, and the effect which these withdrawals will have on the lake source, it is recommended that the lake withdrawal be limited to 4 mgd on an average daily basis. The remaining 10 mgd can be developed from the two sections of land located northeast of the lakes.

The large amount of land available for use in developing the withdrawal system for a 10 mgd raw water source provides a valuable opportunity to construct a system which is compatible with the hydrogeology of the area. The objectives of such a system are:

1) To distribute the withdrawals over as large an area as possible, thereby minimizing regional drawdowns of the potentiometric surface.

2) To minimize the amount of water withdrawn from any single point in order to minimize localized drawdowns.

3) To withdraw only water with the lowest salinity, such as that present in the upper approximately 30 feet of the aquifer.

Two options are available for accomplishing these objectives. One option involves the installation of rows of shallow wells, each pumping only a small volume. The second option is the installation of an infiltration gallery system.

2.. Shallow Well System

The geologic characteristics of the investigation site, where a very high permeability zone is located between the 10 and 20 foot depth makes the site ideally suited for a shallow well system. The proposed production zone is that which lies immediately below the surface rock. The most permeable section of this zone is only 3 to 8 feet in thickness and is solution riddled. Due to geologic and regulatory considerations, for construction of each well, a hole should be augered or drilled thru the surface rock. A 6-inch diameter casing should be installed with approximately 5 feet of screen at the base to a total depth of approximately 15 feet.

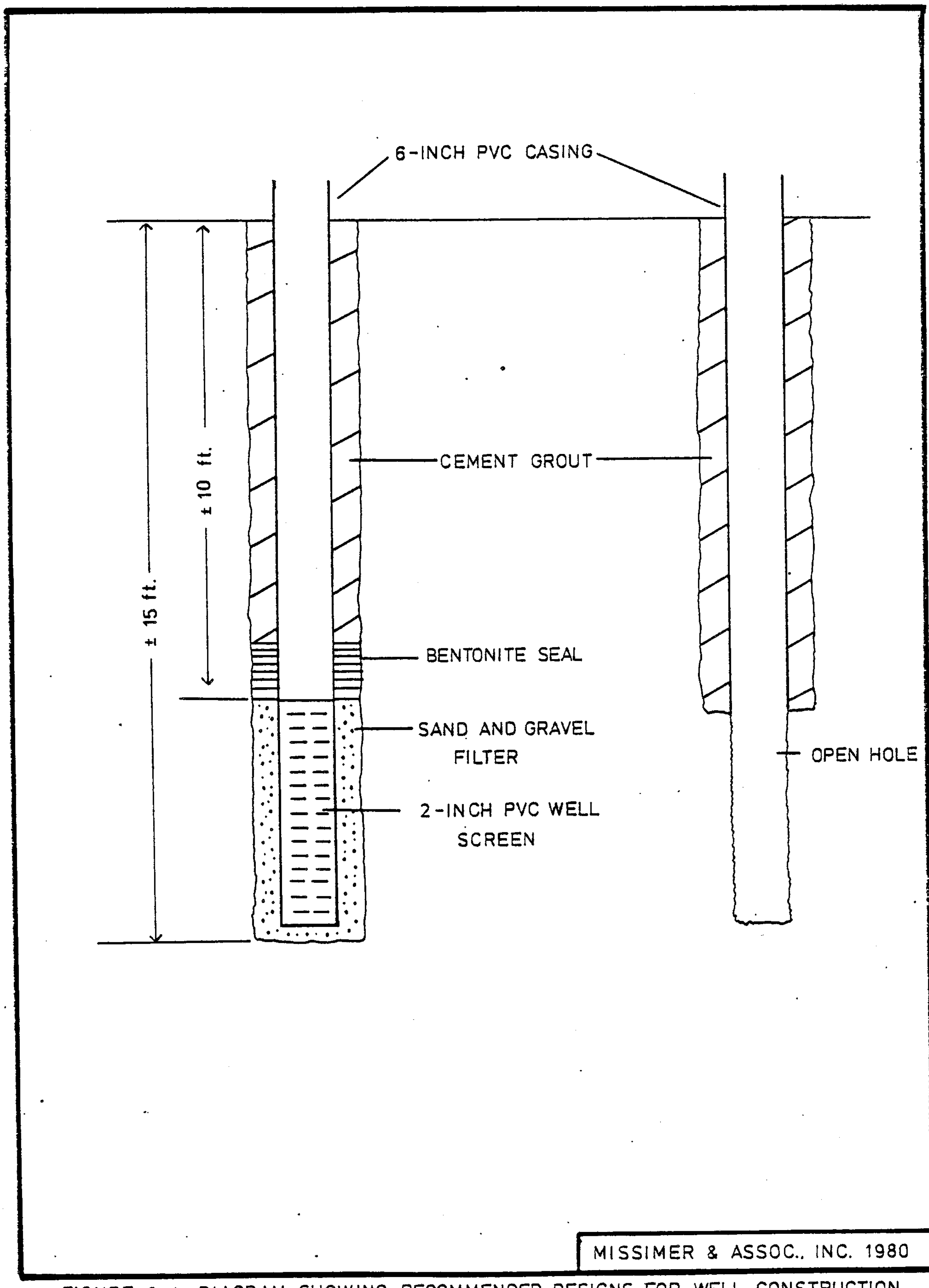


FIGURE 6-1. DIAGRAM SHOWING RECOMMENDED DESIGNS FOR WELL CONSTRUCTION.

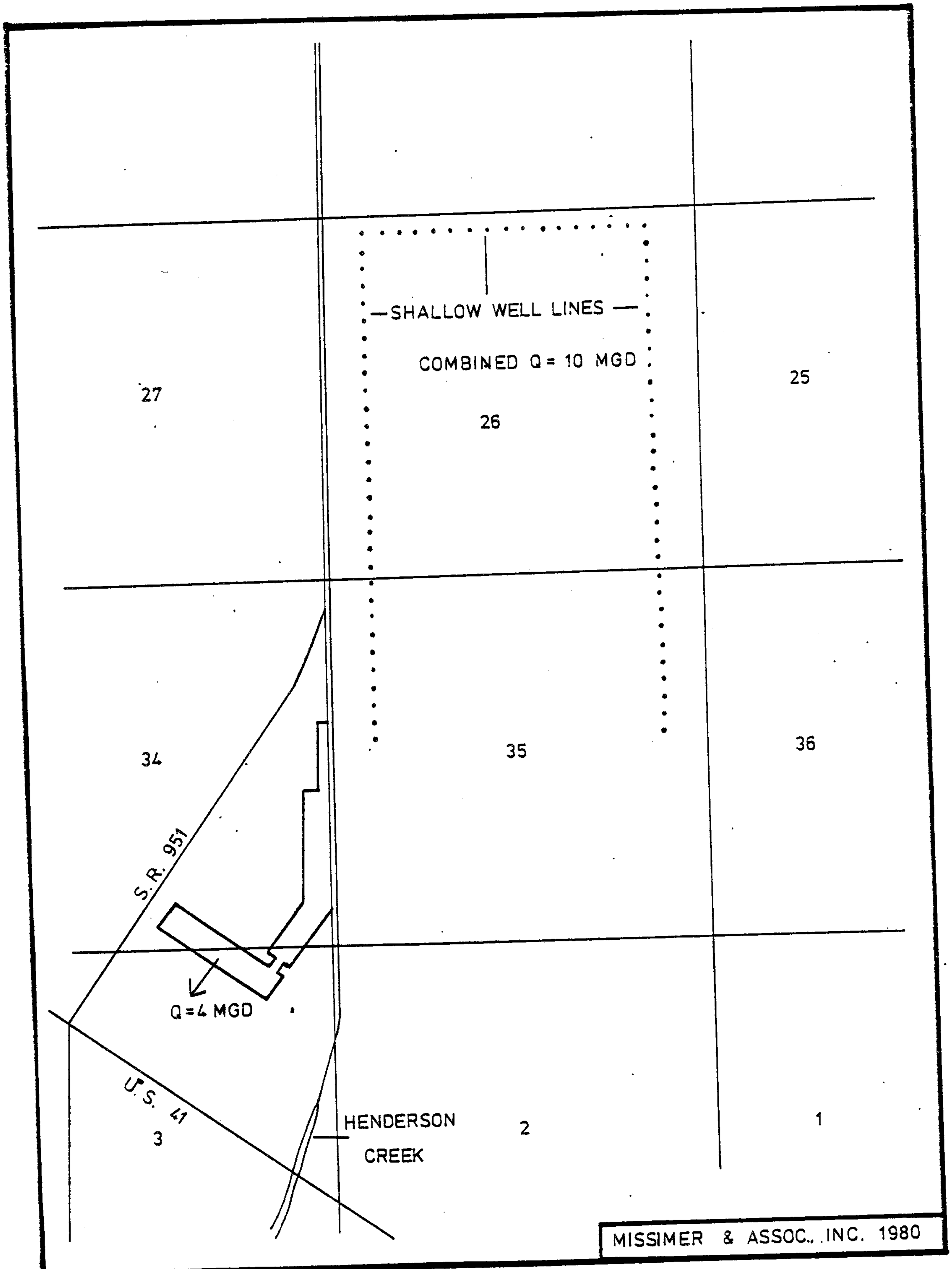


FIGURE 6-2. DIAGRAM SHOWING ARRANGEMENT OF SHALLOW AQUIFER WITHDRAWAL SYSTEM FOR 14 MGD.

Following the screen and casing installation, a gravel pack should be installed, surrounding the well screen, a bentonite cap placed on top of the gravel pack, and cement grout tremmied to the land surface.

It may be possible to eliminate the screen and gravel placement operation if further test drilling shows that a sand free open hole can be maintained in the desired production zone. A diagram showing well construction details of the two types of wells is shown in Figure 6-1. Each well installed in this zone would be designed to produce approximately 80 to 100 gpm.

Wells would be spaced on approximate 200 foot centers arranged in two North-South lines and one East-West line as shown in Figure 6-2. This arrangement will take advantage of as much recharge as possible from Henderson Creek, and also will distribute withdrawals around the property perimeter to maximize the interception of regional flow.

3. Infiltration Galleries

An infiltration gallery is a horizontal permeable conduit for collecting groundwater. Water may be collected by either gravity flow or by pumping.

At the proposed site, infiltration pipes should be installed at a depth approximately 15 feet below land surface. The total length of infiltration pipe necessary would be variable depending on the gallery arrangement and the desired limitations on water level drawdowns. The recommended arrangement is along the lines of the shallow well system, and is designed to maximize the amount of recharge from Henderson Creek while also taking advantage of the regional groundwater flow direction. Due to the lack of ground surface slope and the desire to limit drawdowns in the water table, it will not be possible to develop a gravity flow system with long conduit lengths. In order to accomplish the desired objective of minimizing localized drawdown, a number of withdrawal points should be established along each infiltration pipe line. Water can then be withdrawn by pumping either from gravity fed collection sumps or directly from the infiltration pipe. The distance between the withdrawal points should be no longer than approximately 800 feet for 8-inch diameter infiltration line, otherwise the lowering of the water level near the withdrawal site will be higher than desirable. If large diameter infiltration pipes are used, the distance between withdrawal points may be increased.

The construction of such an infiltration system would involve digging a trench approximately 15 feet deep, and of a width 8 to 12 inches greater than the diameter of the infiltration pipe. A graded sand and gravel filter should be placed at the base of the trench, and subsequently placed around the infiltration pipe such that 4 to 6 inch envelope of filter material surrounds the pipe. A sand backfill should then be placed on top of the filter material. It may be required that a bentonite cap or other seal be placed above the gravel envelope in order to minimize the chances of contamination from surface sources. Figure 6-3 shows details of a properly constructed infiltration pipe.

4. Alternative Selection

The objective of designing a withdrawal system which is compatible with the hydrogeologic characteristics of the area can be met equally well by both of the proposed alternatives. However, there are advantages and disadvantages of each method.

The construction and operation of an infiltration gallery system has a number of disadvantages. The most obvious of these is the fact that the infiltration pipes must be installed beneath the very hard surface rock, and removal of this rock will be costly. Installation of the infiltration pipe and gravel envelope would be accomplished with better quality control if it is done in a dry trench, and dewatering a large trench may be difficult.

During operation of the infiltration gallery system, discharge and water level control points on the system are at the withdrawal pumps while most of the system is inaccessible. This makes control of distribution of the withdrawals, along the infiltration pipes difficult, and may

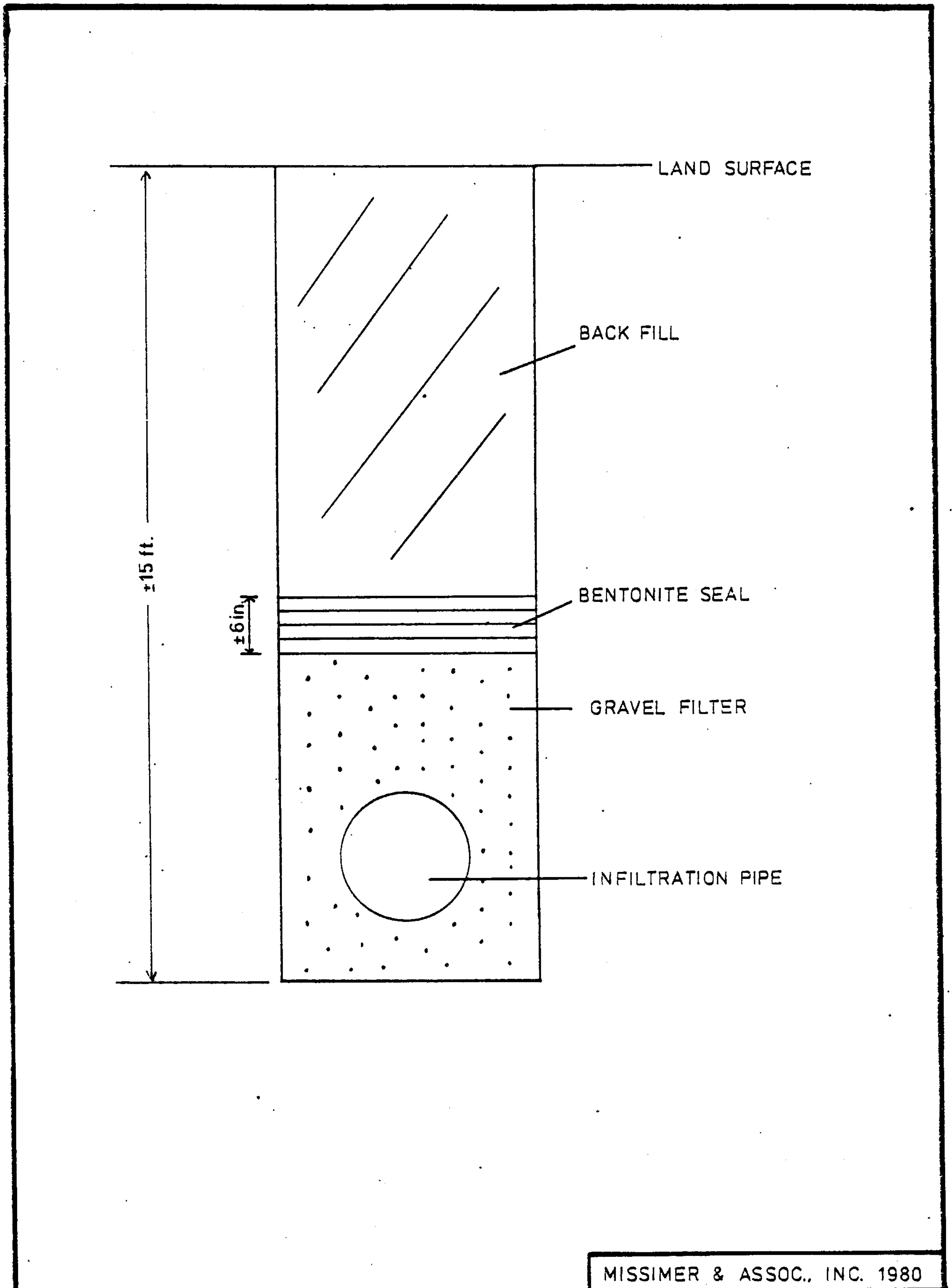


FIGURE 6-3. CROSS SECTION OF INFILTRATION TRENCH SHOWING PLACEMENT OF GRAVEL FILTER AND BENTONITE SEAL.

result in over pumpage from some areas while others would contribute little water. The problem can probably be overcome however, by experimentation during the design and construction phases and by careful operation of the system.

Another problem associated with the inaccessibility of the infiltration gallery system, is that of maintenance. The high iron concentrations present in the water-table aquifer increase the potential for plugging of screen openings by iron bacteria. Also incrustation by precipitation of carbonates may cause problems. In these cases, cleaning of the gallery screens would be difficult.

A shallow well withdrawal system using numerous low volume wells has none of the disadvantages of the infiltration gallery system. Wells can be drilled through the cap rock and sealed and grouted for protection from surface contamination at relatively low cost. Water level control and flow dispersion among groups of wells can be easily controlled by use of valves. In addition, well maintenance can be easily performed on a well by well basis if it should become necessary.

The primary disadvantage of the shallow well system is that a large number of pumps will be required.

Both of the alternatives will satisfy the objectives of the system design. The selection of the desired alternative should be based on a careful study of economics and management aspects of each system.

VII. AUXILIARY WELLFIELD FOR LONG RANGE WATER DEMANDS

In order to provide a factor of safety with regard to meeting future water demands, a piece of property was purchased for a potential long range water supply. The property lies in Section 35, Township 50S, Range 27E (see Figure 7-1). This 160 acre site was selected because it contains good quality water and it is within an area which is recharged by the Golden Gate Canal System.

1. Investigation of Section 35

A preliminary investigation of the feasibility of developing a raw water source was undertaken prior to the purchase of the property. The investigation included: drilling of two test wells; pumping for a short period of time to determine water quality characteristics; and computer modeling to estimate potential yield.

Test wells were drilled in Section 35 at the locations shown on Figure 7-2. The wells were 2 inches in diameter and were cased to a depth of 40 feet. Each of the wells were pumped for a period of approximately 1 hour. Well 263 produced water at a rate of 100 gpm, and well 264 was pumped at 20 gpm. Water quality samples were taken at the end of the pumping period.

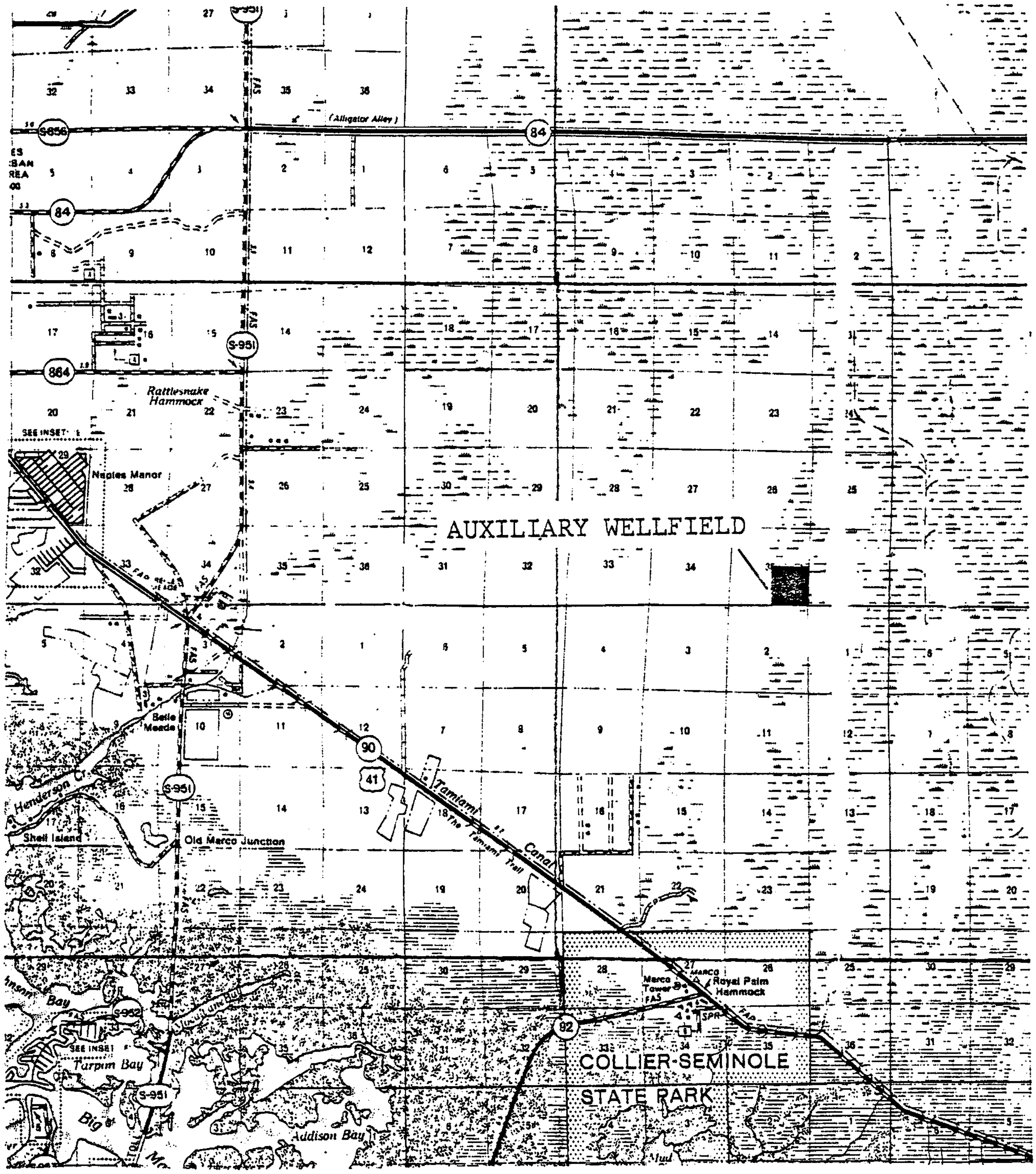


FIGURE 7-1. MAP SHOWING FUTURE LOCATION OF AUXILIARY WELLFIELD.

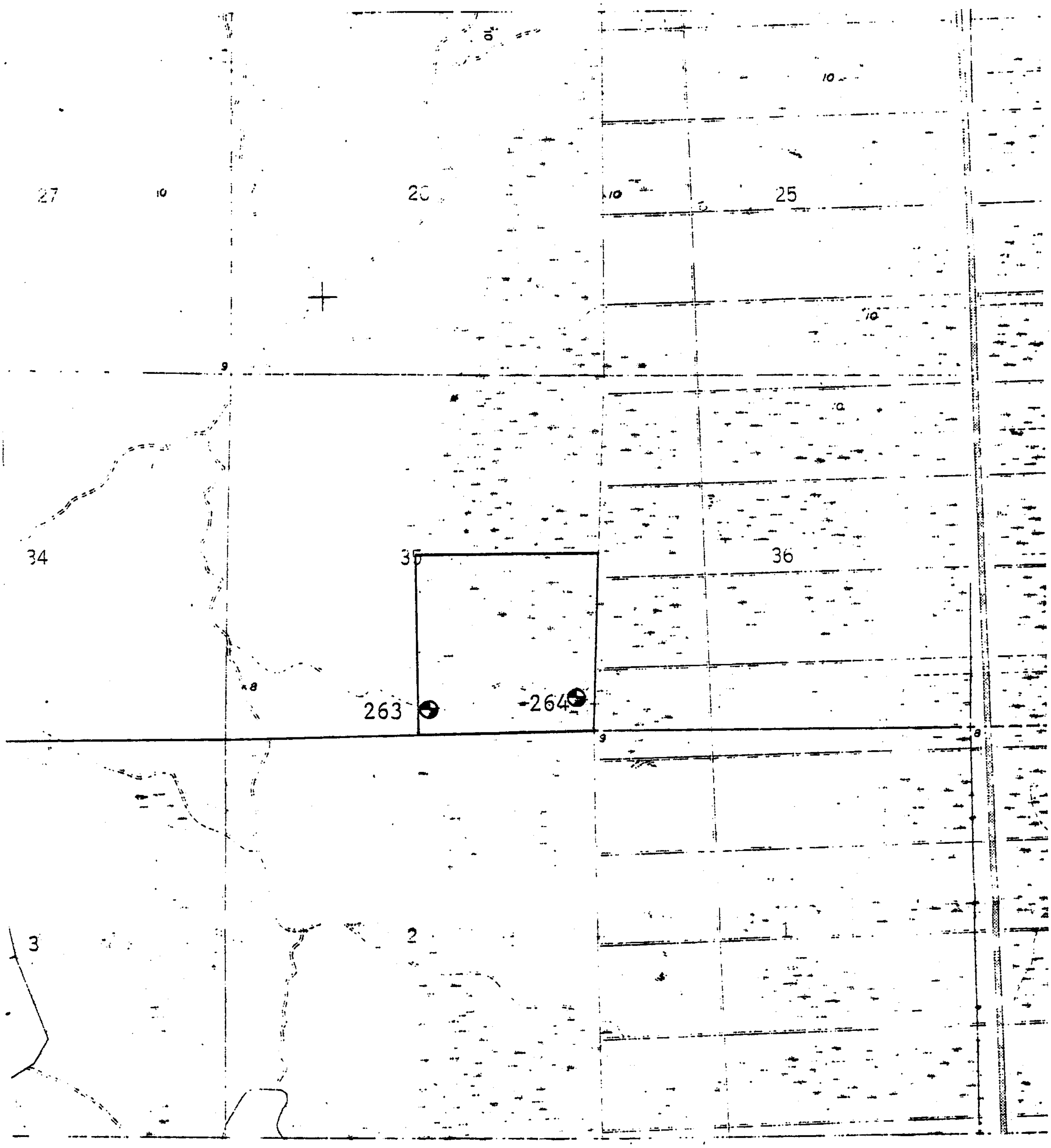


FIGURE 7-2. MAP SHOWING THE LOCATIONS OF TEST WELLS IN SECTION 35.

2. Discussion of Results

The geology of Section 35 is somewhat different than that of the existing utilities site. There is approximately 2 feet of sand and soil overlying the Ochopee limestone unit. The limestone unit encountered contained only a minimum amount of marl throughout the depth of the boreholes, and the aquifer system appears to be insignificantly confined. Geologist's logs for wells 263 and 264 are given in Table A-9 and A-10.

The results of the chemical analysis of the water samples is given in Table 7-1. The dissolved chloride concentrations in the two wells was 53 and 95 mg/l, which are relatively low with respect to public supply standards. Although there is some salinity present, the fact that this water was taken from a depth of 40 feet indicates that there is a sufficiently thick zone of fresh water which can be developed to supply potable water using conventional treatment methods. With the information obtained, it is expected that a wellfield can be developed to produce water from wells into the upper 20 feet of the aquifer system at the investigation site. It is recommended that a number of low yield (approximately 100 to 150 gpm) wells be used. Further investigation may show that higher yield wells can be safely developed.

TABLE 7-1. CHEMICAL ANALYSIS OF WATER FROM THE SECTION 35 TEST WELLS

Well No. 263

Total Dissolved Solids	484 mg/l
p-Alkalinity	0 mg/l
Total Alkalinity	348 mg/l
Chloride	53 mg/l
Sulfate	1.0 mg/l
Fluoride	.10 mg/l
pH	6.6
Color	68 PCU
Turbidity	6.1 NTU
Total Hardness	360 mg/l
Calcium Hardness	190 mg/l
Magnesium Hardness	170 mg/l
Calcium, atomic absorption	187 mg/l
Magnesium, atomic absorption	6.9 mg/l
Sodium, atomic absorption	62 mg/l
Iron, atomic absorption (filtered)	.11 mg/l
Manganese, atomic absorption	.04 mg/l
Copper, atomic absorption	.01 mg/l
Silica, atomic absorption	6.0 mg/l

Calculations:

Carbonate Alkalinity	0 mg/l
Bicarbonate Alkalinity	348 mg/l
Carbonates, as CO_3	0 mg/l
Bicarbonates, as HCO_3	190 mg/l
Hydroxides, as OH	0 mg/l
Carbon Dioxide, as CO_2 (free)	0 mg/l
Total CO_2 by calculation	306 mg/l
pH_s	7.02
Stability Index	7.44
Saturation Index	-0.42

Well No. 264

Chloride	95 mg/l

3. Site Production Capability

The production capability of the 160 acres in Section 35 was assessed using a computer model and assumed aquifer coefficients. The aquifer coefficients selected were chosen conservatively using information from several tests conducted on the Tamiami Zone I aquifer in Collier County. The conditions simulated are for 150 days of continuous pumpage with no rainfall. In this case the aquifer system is expected to behave as an unconfined aquifer. Modeling was done using a transmissivity of 350,000 gpd/ft and a storage coefficient of 0.1. The transmissivity value used is a conservative estimate. Recent studies have indicated that the transmissivity in the study area may range between 500,000 and 900,000 gpd/ft^2.

The limiting condition which was selected to determine the amount of water which could be safely withdrawn from the property was the drawdown within the wellfield boundaries. This drawdown was not allowed to exceed 5 feet for any pumping configuration. A number of pumping options were evaluated, and the one which yielded the best results is that shown in Figure 7-3. This figure depicts the drawdowns in the potentiometric surface due to pumping 5 MGD from 24 wells situated along the property boundaries, with each well pumping 145 gpm. It can be seen that the water table drawdown is approximately 5 feet uniformly across the property.

	1	2	3	4	5	6	7	8	9	10	11
1	1.83	1.99	2.15	2.29	2.40	2.47	2.47	2.42	2.32	2.18	2.02
2	1.98	2.19	2.39	2.59	2.76	2.85	2.86	2.78	2.63	2.44	2.23
3	2.14	2.39	2.66	2.94	3.19	3.34	3.35	3.23	3.00	2.72	2.44
4	2.27	2.58	2.93	3.34	3.75	3.98	4.01	3.81	3.43	3.01	2.64
					35						36
5	2.38	2.73	3.16	3.72	4.[illegible]4	4.[illegible]	4.[illegible]7	4.74	3.85	3.26	2.81
6	2.44	2.81	3.29	3.92	4.[illegible]1	4.83	4.83	5.[illegible]0	4.07	3.40	2.90
7	2.44	2.81	3.29	3.92	4.[illegible]1	4.83	4.83	5.[illegible]0	4.07	3.40	2.90
8	2.38	2.73	3.16	3.72	4.[illegible]4	4.[illegible]5	4.[illegible]7	4.[illegible]4	3.85	3.26	2.81
9	2.27	2.58	2.93	3.34	3.75	3.98	4.01	3.81	3.43	3.01	2.64
10	2.14	2.39	2.66	2.94	3.19	3.34	3.35	3.23	3.00	2.72	2.44
					2						1
11	1.98	2.19	2.39	2.59	2.76	2.85	2.86	2.78	2.63	2.44	2.23
12	1.83	1.99	2.15	2.29	2.40	2.47	2.47	2.42	2.32	2.18	2.02

○ Well location

FIGURE 7-3. DRAWDOWN IN WATERTABLE AT SECTION 35 FOR A WITHDRAWAL OF 5 MGD DURING THE DRY SEASON.

On this basis, the amount of 5 MGD is considered a very safe yield for the Section 35 property.

It is likely that the amount of water available from this piece of property is more than that presently estimated. If the thickness of the fresh water zone is substantial, more than 5 feet of drawdown can be tolerated, or if the transmissivity value is higher than that estimated, more water could be produced for the same limiting drawdown conditions. Similarily, a reduction in the amount of available water may be necessary if testing shows that the transmissivity is lower than the assumed value or that the area is more severely subject to vertical or lateral salt water migration. In all cases, a detailed investigation should be done before final plans are made to produce water from Section 35.

VIII REFERENCES

Boulton, N.S., 1954, Unsteady radial flow to a pumped well allowing for delayed yield from storage: International Assoc. Sci. Hydrology Pub. 37, pp. 472-477.

Boulton, N.S., 1963, Analysis of data from non-equilibrium pumping tests allowing for delayed yield from storage: Proc. Inst. Civ. Eng., V. 26, pp. 469-482.

Cooper, H.H., and Jacob, C.E., 1946, Generalized and graphical method for evaluation formation constants and summarizing wellfield history, Trans. Amer. Geophys. Union, V. 33.

Finney, A.R., 1963, Report of Availability of Potable Water for Marco Island, Collier County Florida: Report to Utilities Engineering Department.

Jacob, C.E., 1950, Flow of groundwater in Engineering Hydraulics (H. Rouse, ed.), John Wiley and Sons, New York.

Kruseman, G.P., and DeRidder, M.A., 1970, Analysis and evaluation of pumping test data, International Institution for Land Reclamation and Improvement, Bull. II, Wageningen, The Netherlands.

Missimer and Associates, Inc., 1978, Hydrology and geology of a proposed new wellfield site in south Lee County, Florida: Rept. to Lee County Commissioners.

Missimer, T.M., 1978, The Tamiami Formation - Hawthorn Formation contact in southwest Florida: Florida Scientist, V. 41, No. 1, 31-39 pp.

Theis, C.V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage; Trans. Amer. Geophys. Union, V. 16, pp. 519-524.

Walton, W.E., 1970, Groundwater Resource Evaluation, McGraw-Hill Publishers, New York

IX. APPENDIX

TABLE A-1. GEOLOGIST'S LOG OF WELL C-2003D

Depth(feet)	Description
0-5	Quartz, sand; medium size, clear, subrounded.
5-20	Limestone, very hard, white and gray micrite, minor shell inclusions, lost circulation at 14', no cuttings 14' to 20'.
20-29	Sandy marl, soft drilling, cuttings well suspended in drilling mud, sand is medium to fine quartz, marl white.
29-38	Limestone, small rounded shell fragments loosely cemented in micrite, few streaks of dense limestone, some quartz sand, lost circulation at 34', drilling soft.
38-44	Limestone, dense micrite, gray; some shell fragments, subrounded, drilling medium.
44-54	Limestone, loose micrite matrix holding subrounded small shell fragments, 20% hard limestone streaks, medium drilling, lost circulation at 49', trace of phosphorite.
54-79	Limestone, micrite matrix holding small shell fragments, subrounded, lesser amounts of dense limestone fragments, all gray to white, lost circulation at 79', drilling medium.
79-99	Limestone, subrounded shell fragments in micrite, some dense limestone streaks, some phosphorite content from 80' to 85', lost circulation at 98', medium drilling, increasing quartz content towards bottom, drilling soft from 95'.
99-138	Sandstone, quartz grains cemented loosely, some very small shell fragments, some dense limestone streaks, soft drilling, some phosphorite nodules.
138-142	Sandstone, less quartz than above, loose cementing, significant shell content, some phosphorite, drilling soft, hard streak at 138' - 139'.
142-171	Sandstone, poor cementation, mostly medium and fine quartz grains, shell content down to 5%, subrounded fragments, phosphorite present, hard limestone streaks 146' to 148', lost circulation 153' - 155', and 166' to 168'.

TABLE A-1. GEOLOGIST'S LOG OF WELL C-2003D

171-179	Calcareous clay and silt, 20% fine quartz grains, minor phosphate mineral.

TABLE A-2. GEOLOGIST'S LOG OF WELL C-2008D

Depth(feet)	Description
0-10	Limestone, sandy, brown to gray to white, fossiliferous, some iron staining, vuggy, shell imprints.
10-20	Limestone, marly, white to light gray, shell in micrite, vuggy, minor quartz sand, trace of phosphorite.
20-30	Limestone, white to light gray, sand and shell in micrite, vuggy, a little coral, a minute trace of phosphorite.
30-40	Same as above.
40-50	Same as above, with more coral and shell.
50-60	Limestone, abundant shell, white to light gray, minor quartz sand, some oolite present, minor coral, trace of phosphorite.
60-70	No sample.
70-80	Same as above with more coral and phosphorite.
80-90	Limey sandstone, light gray to light greenish gray, fine to medium grained quartz, some shell, trace of phosphorite.
90-100	Same as above.
100-110	Limey sandstone, white to light gray, some shell, trace of phosphorite, minor coral.
110-120	Limey sandstone, white to light gray, friable, some shell, trace of phosphorite.
120-133	Same as above with some coral.
133-138	Clay.
138-150	Sandy limestone, light brown, abundant shell, minor coral.
150-158	Same as above with brown and gray limestone, and some coarse, well rounded quartz grains.

TABLE A-2. GEOLOGIST'S LOG OF WELL C-2008D

158-160	Coarse quartz sand, rounded to subrounded, elongated, frosted, weak micrite matrix, trace of phosphorite.
160-170	Clay with fine to medium quartz sand, grayish green color, a few well rounded elongated coarse quartz sand grains.
170-180	Clay to fine sand, grayish green color, minor well rounded coarse quartz sand.

TABLE A-3. GEOLOGIST'S LOG OF WELL CO-201

Depth(feet)	Description
0-6	Sand, gray, fine to medium grained, subangular quartz, clayey and brownish at base, low to medium permeability.
6-12	Limestone, hard, sandy, medium to high permeability.
12-20	Limestone, soft, sandy, marly, medium permeability.
20-27	Limestone, light gray, soft, sandy, biomicrudite, abundant bivalves and barnacles, medium permeability.
27-34	Limestone, light gray, soft, sandy, fossils same as above with addition of bryozoans and echinoids, abundant moldic porosity, medium to high permeability.
34-36	Limestone, light gray to tan, medium hard, sandy, vugged, high permeability.
36-39	Limestone, light gray, similar to above but not as hard, high permeability.
39-49	Limestone, light gray, hard, biomicrudite, sandy, trace micro-phosphorite nodules, spar crystals lining vugs and nolds, high permeability.
49-54	Limestone, light gray, medium hard, similar to above in texture and composition, high permeability.
54-60	Limestone, dark gray, hard, sandy, crystalline (biosparrudite), interconnected spar lined vugs, trace micro-phosphorite nodules, very high permeability.
60-65	Limestone, light to dark gray, alternating hard and soft layers (crystalline and micritic), sandy, abundant bivalve shells and molds, high to very high permeability.
65-70	Limestone, light gray, hard, sandy, biomicrudite, more shells than above including bivalves and echinoids, bugs common, high permeability.

TABLE A-3. GEOLOGIST'S LOG OF WELL CO-201

70-84	Limestone, light gray to beige, alternating hard and medium hard layers, similar to above in texture and composition, high permeability.
84-91	Limestone, beige, medium sandy, shelly, micritic, with 30% quartz sand, trace microphosphorite, lots of bivalve shells, echinoids, bryozoans, gastropods, abundant primary porosity, high permeability.
91-102	Limestone, beige, medium to hard, similar to above, harder at 98 feet, high permeability.
102-107	Limestone, beige, harder than above, predominately bivalve shells with quartz sand in micrite matrix, medium to high permeability.
107-112	Limestone, beige, not as much shell as above, 40% quartz sand, 1% micro-phosphorite nodules, lime mud matrix, biomicrite, medium permeability.
112-118	Limestone, beige, similar to above with lots of bivalves and bryozoan shells, low to medium permeability.
118-123	Limestone, beige, biomicrite, similar to above with abundant foraminifera in quartz-rich matrix, low to medium permeability.
123-131	Limestone, beige, sandy, biomicrite, bryozoan-rich, lots of bivalves, trace microphosphorite nodules, medium permeability.
131-137	Limestone, beige, same as above, medium permeability.
137-141	Limestone, dark gray-black, very hard, phosphate crust, solution channeled with trace green clay, corals and bivalves most common shells, high secondary porosity and permeability.
141-145	Limestone, beige and brown, medium hard, microspar crystals, 5% quartz sand, moldic and vuggy porosity with spar lining, very high permeability.

TABLE A-4. GEOLOGIST'S LOG OF WELL 156

Depth(feet)	Description
5-10	Limestone, beige, very hard, vugged, biomicrite, some sparry lining 5-10%, medium to high permeability.
10-15	Limestone, beige-cream, very hard, less spar than above, biomicrite, vugged, calcareous algae plates, medium to high permeability.
15-20	Limestone, cream to beige, medium, more micritic than above, minor white clay, clamys, some secondary porosity (casts-micro-fossil), medium permeability.
20-30	Limestone and clay, white, marly, biomicritic, medium to soft, clamys, limestone and shell in a clayey matrix, medium to low permeability.
30-40	Limestone, cream to beige, silty, medium, vugged, quartz silt, algae plates, trace phosphorite sand coral, medium permeability.
40-50	Limestone, beige, hard, spar cement 5%, biomicritic corals, vugged, more shells than above, medium to high permeability.
50-55	Limestone, beige, same as above.
55-70	Limestone, beige to cream, medium-hard, vugged, secondary porosity, corals, some spar fillings, medium to high permeability.

TABLE A-5. GEOLOGIST'S LOG OF WELL CO-152

Depth(feet)	Description
0-3	Sand, gray, soft, fine to coarse, angular to sub-angular quartz sand, medium permeability.
3-6	Sand, brown, clayey, soft, fine to medium grained quartz, low permeability.
6-13	Limestone, dark gray, sandy, hard, dense, biosporite, with minor biomicrudite layer, 30% predominately fine grained quartz sand, Chione cancellata shell, low secondary porosity, medium permeability.
13-15	Limestone, medium hard, high permeability.
15-32	Limestone, soft, high permeability.
32-40	Limestone, light gray, hard, biosparrudite, abundant bivalve shells, 5% quartz sand, micrite filling primary porosity, spar lined secondary porosity, high permeability.
40-47	Limestone, white to light gray, sandy, medium hard, biomicrudite with abundant echinoid fragments, 10% quartz sand, high permeability.
47-55	Limestone, white to light gray, similar to above but more micritic, medium to high permeability.
55-62	Limestone, white to light gray, hard, sandy, biomicrudite, packstone, shells predominately echinoid fragments and bryozoans; 15% quartz sand, trace micro-phosphorite nodules, high secondary porosity and permeability.
62-72	Limestone, light gray, sandy, medium soft, biomicrudite, abundant bivalve shells, 30% predominately fine grained quartz sand, medium to high permeability.
72-80	Limestone, white to light gray, sandy, medium hard, similar to above but slightly more quartz sand, less shells, trace micro-phosphorite nodules, medium permeability.

TABLE A-5. GEOLOGIST'S LOG OF WELL CO-132

80-84	Limestone, beige, medium, sandy, abundant shells in calcarenite matrix of calcareous fragments, fine quartz sand and lime mud, 30-40% quartz, 1% micro-phosphorite nodules, medium permeability.
84-91	Limestone, beige, medium soft, sandy, similar to above but smaller shell fragments, abundant foramunefera and echinoid fragments, medium permeability.
91-95	Limestone, beige, medium soft, sandy, calcarenite, less shells and more echinoid fragments and foraminifera, medium permeability.
95-97	Sandstone, brown, hard, calcareous, shells common preserved as molds, trace micro-phosphorite nodules, high secondary porosity and permeability.
97-105	Limestone, beige, medium soft, sandy, shelly with abundant bivalves and echinoid, bryozoans and foraminifera, micritic calcarenite, medium permeability.
105-110	Limestone, beige, medium soft, quartz-rich calcarenite with less shells than above, 1% micro-phosphorite nodules, low to medium permeability.
110-118	Limestone, beige, medium hard, similar to above with more shell fragments, medium permeability.
118-125	Alternating sandstone and sand, gray, 1-3 foot thick layers, hard and soft; predominately fine grained, subangular to subrounded quartz sand, occasional shell fragments, lime mud cement in sandstone, trace micro-phosphorite nodules, medium to high permeability.
125-132	Sand, gray, soft, moderately sorted, very fine to medium grain quartz, subangular to rounded, trace micro-phosphorite nodules, medium to hard permeability.
132-141	Sand, gray, same as above with occasional thin hard sandstone layers, medium to high permeability.
141-	Limestone, very hard, dense, medium permeability.

TABLE A-6. TAMIAMI AQUIFER ZONE I (DEPTH 50 FEET)

ROUTINE WATER ANALYSIS REPORT

Orlando Laboratories, Inc.

P. O. Box 8008 • Orlando, Florida 32856 • 305/843-1661

Report to: Missimer & Associates

Date: 26 March 80

Report Number: 19852 (1401)

Appearance: Yellow

Sampled by: Client

Identification: Marco Island Utilities Test 48 hours

METHODS

This water was analyzed according to "Standard Methods for the Examination of Water and Wastewater," Latest Edition, APHA, AWWA and WPCF.

RESULTS

Determination	Data Significance	mg/l	Determination	Data Significance	mg/l
Total Dissolved Solids	x.	905	Total Hardness, as $CaCO_3$	x.	479
Phenolphthalein Alkalinity, as $CaCO_3$	x.	0	Calcium Hardness, as $CaCO_3$	x.	408
Total Alkalinity, as $CaCO_3$	x.	336	Magnesium Hardness, as $CaCO_3$	x.	71
Carbonate Alkalinity, as $CaCO_3$	x.	0	Calcium, as Ca	x.	163
Bicarbonate Alkalinity, as $CaCO_3$	x.	336	Magnesium, as Mg	.x	17
Carbonates, as CO_3	x.	0	Sodium, as Na	x.	125
Bicarbonates, as HCO_3	x.	410	Iron, as Fe	.x	0.43
Hydroxides, as OH	x.	0	Manganese, as Mn	.x	<0.05
Carbon Dioxide, as CO_2	x.	109	Copper, as Cu	.x	<0.1
Chloride, as Cl	x.	205	Silica, as SiO_2		10
Sulfate, as SO_4	x.	80	Sulfide, S (field fixed)		0.20
Fluoride, as F	.x	0.07			
pH (Laboratory)	.x	6.8			
pHs	.x	6.7			
Stability Index	.x	6.6			
Saturation Index	.x	0.1			
Color, PCU	x.	25			
Odor Threshold	x.	0			
Turbidity, NTU	x.	0.91			

Signed: Susan J. Smallwood
Chemist

INTERNATIONAL ANALYSIS OF WATER, WASTEWATER, COAL, OIL & GAS • RADIATION MONITORING

T-10

TABLE A-7. VARIATION IN DISSOLVED CHLORIDE CONCENTRATION WITH DEPTH IN WELL 201

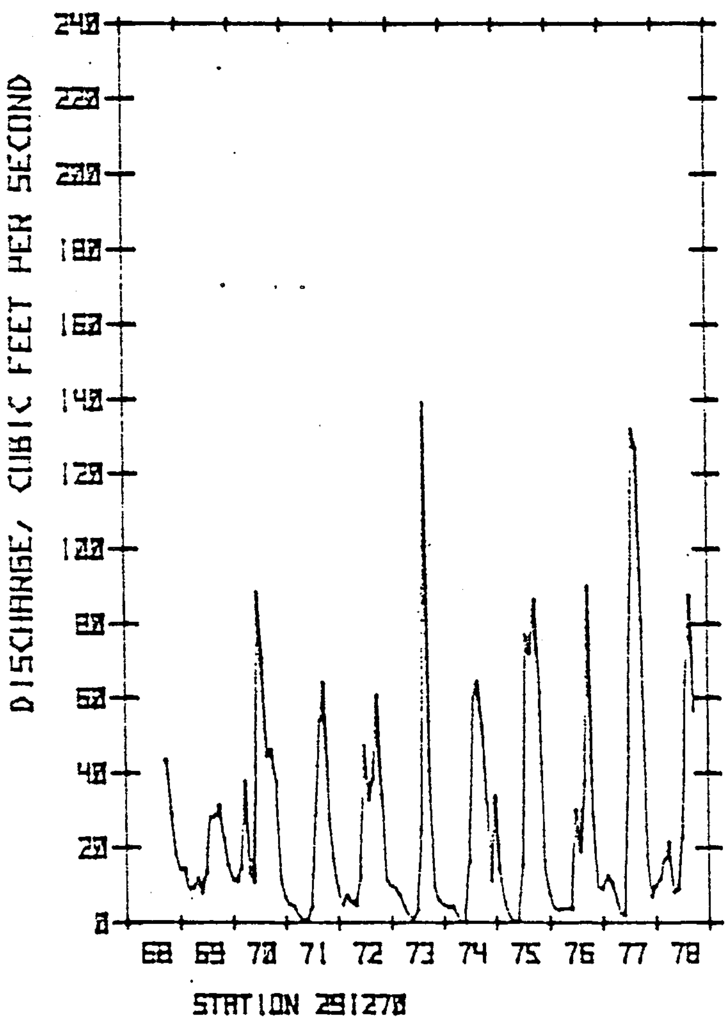
Depth(feet)	Dissolved Chloride(mg/l)
20	90
42-49	270
63-70	330
84-91	380
102-112	460
137-139	680
190-192	620

TABLE A-8. WATER QUALITY CHARACTERISTICS OF WATER-TABLE AQUIFER

Well Depth = 12 feet

Dissolved Chloride	60 mg/l
TDS	440 mg/l
Dissolved Iron	.08 mg/l
Dissolved Magnesium	56 mg/l

FIGURE A-1. HENDERSON CREEK FLOW RECORD - FROM USGS



MISSIMER AND ASSOCIATES, INC.

GEOPHYSICAL LOG

WELL NUMBER: 90-201

DATE LOGGED: 3/6/90

PROJECT: Marco Island Water Supply

NUMBER: 90-7

LOGS, SCALES, AND CONSTANTS

		HORIZONTAL	VERTICAL	SPEED
SPONTANEOUS POTENTIAL	☐			
RESISTIVITY	☐			
GAMMA RAY	☒	1"=400 c.p.s.	1"=20'	12'/min.
CALIPER	☐			
TEMPERATURE	☐			
FLOW VELOCITY	☐			

INSTRUMENT ______

LOCATION: COUNTY: Collier, ___1/4 ___1/4 ___1/4, SECTION: 3, TOWNSHIP: 51, RANGE: 26

ELEVATION (LSD) ______ FEET (MSL)

FIRST READING	AT 46'
LAST READING	AT 4'
FEET LOGGED	42'
BOTTOM - DRILLER	
CASING - LOG	
CASING - DRILLER	
HOLE DIAMETER	
CASING DIAMETER	

LOGGED BY: D. Hire

ASSISTED BY: ______

REMARKS AND INTERPRETIVE COMMENTS OR NOTES: T.C. = 3

PROBE WOULD NOT PASS 46 FOOT DEPTH

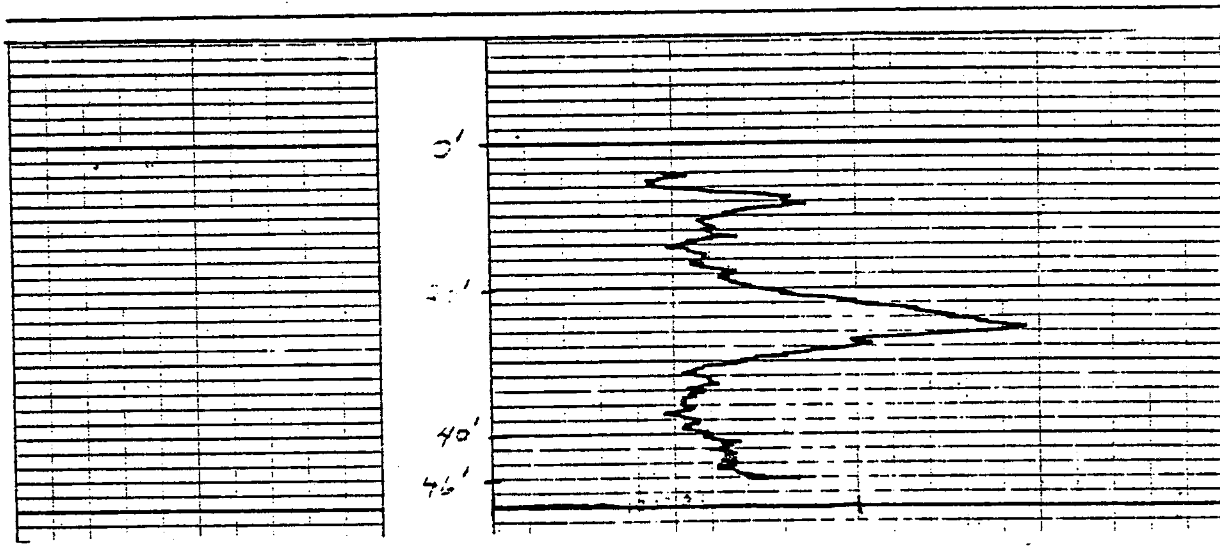


FIGURE A-2. GAMA-RAY LOG OF WELL 201.

TABLE A-9. GEOLOGIST'S LOG OF WELL CO-263

Depth(feet)	Description
0-1	Sand, brown, soft.
1-3	Limestone, tan, slightly sandy, hard, fossiliferous, biosparrudite, moldic and vuggy porosity, high permeability.
3-10	Limestone, light gray, soft-medium, lots of shells, marly slightly sandy biomicrudite large oyster shells, medium permeability.
10-15	Limestone, tan and light gray, medium hard, lots of bivavles and barnacles, slightly sandy, high permeability.
15-19	Limestone, light gray, marly, soft large shells, similar to sample (3-10'), medium permeability.
19-29	Limestone, light gray, similar to above but more quartz sand - 10%, harder at 27', trace micro-phosphorite, medium to high permeability.
29-34	Limestone, light gray, granular, calcarenite, sandy (quartz) 10%, 1% phosphorite intergranular porosity large shells, high permeability.
34-40	Limestone, light gray, coarser grained than above, larger pores, high permeability.

TABLE A-10. GEOLOGIST'S LOG OF WELL CO-264

Depth(feet)	Description
0-5	Limestone, tan, slightly sandy, hard, fossiliferous, high permeability.
5-10	Limestone, light gray, marly, less quartz sand than above. Biomicrudite with large gray pectens, bryozoans and various fossil molds, medium permeability.
10-20	Limestone, light gray, medium, similar to above but shells more abundant, medium to high permeability.
20-30	Limestone, light gray, medium to hard, lots of molds, biomicrudite with minor hard biosparrudite beds, more quartz sand than above, granular texture, high permeability.
30-35	Limestone, light gray, soft to medium, more quartz than above ($\sim$10%), trace microphosphorite nodules, spar lined molds, high permeability.
35-40	Limestone, light gray, harder than above, coarser grained, granular biomicrudite with minor biosparrudite beds, high permeability.