HYDROLOGIC INVESTIGATION OF THE HAWTHORN AND SUWANNEE AQUIFER SYSTEMS IN THE CENTRAL AREA SANIBEL, FLORIDA

PREPARED FOR

THE ISLAND WATER ASSOCIATION, INC.
P. O. BOX 56
SANIBEL, FLORIDA 33957

FEBRUARY, 1979

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

March 8, 1979

Mr. Ian Watson,
Assistant General Manager
The Island Water Association, Inc.
Post Office Box 56
Sanibel, Florida 33957

RE: Final report entitled: "Hydrologic Investigation of the Hawthorn and Suwannee Aquifer Systems in the Central area, Sanibel, Florida".

Dear Mr. Watson:

Missimer and Associates, Inc. is pleased to submit this final report entitled, "Hydrologic Investigation of the Hawthorn and Suwannee Aquifer Systems in the Central Area, Sanibel, Florida". This document is the result of an investigation of the suitability of utilizing the lowermost part of the Hawthorn Aquifer System and the uppermost part of the Suwannee Aquifer System for a long-term water source for the new reverse osmosis treatment plant.

The investigators for Missimer and Associates, Inc. are:

Project Chief: Larry K. Holland, Hydrogeologist
Thomas M. Missimer, P.G., Hydrologist
Lloyd E. Horvath, P.E., Hydrologist
Marycarol E. Testi, Hydrologist
David B. Hire, Hydrologic Technician

This project was conducted under the supervision of Mr. Ralph Zeiss, General Manager, Mr. Ian Watson, Assistant General Manager (Technical), and the members of the Island Water Association Board of Directors listed below:

Mr. Joe Winterrowd
Mr. John Cook
Mr. Jack Ronk
Mr. Arthur Wycoff
Mr. Jim Robson

We believe that the information given in this report will allow the Island Water Association to develop a long-term reliable source of raw water from the lowest part of the Hawthorn Aquifer System (Zone IV), which was previously believed to be part of the Suwannee Aquifer. We will be pleased to discuss our findings with you at your earliest convenience.

Very truly yours,

MISSIMER AND ASSOCIATES, INC.

Larry K. Holland
Project Manager

Thomas M. Missimer
President

LKH,TMM/tgs

TABLE OF CONTENTS

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TABLE OF CONTENTS (CON'T.)

(Con't.)

TABLE OF CONTENTS (CON'T.)

LIST OF FIGURES

LIST OF TABLES

I. CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions

A site at the new water plant on Sanibel was selected for investigation of the Hawthorn and Suwannee Aquifer Systems. A full hydrologic investigation was completed at the site. The investigation included test drilling for geologic data, observation and test-production well construction, a 72-hour aquifer test, packer-stem tests, and a water quality test program. The data collected during the testing program were combined with data collected from the northwest Sanibel investigation to conclude the following:

1) The aquifer coefficients for the combination of Hawthorn Aquifer System - Zone IV and Suwannee Aquifer System - Zone I are:

   Transmissivity = 74,000 gpd/ft
   Storage Coefficient = 2×10^{-4}
   Leakance = 3.0×10^{-3} gpd/ft^3

2) The estimated aquifer coefficients for Hawthorn Aquifer System - Zone IV are:

   Transmissivity = 50,000
   Leakance = 1×10^{-4} gpd/ft^3

3) Water yielded from Hawthorn Aquifer System - Zone III at the site has an average dissolved chloride concentration of about 1500 mg/l; Hawthorn Aquifer System - Zone IV has an average concentration of about 1400 mg/l; and Suwannee Aquifer System - Zone I has an average concentration of 2000 mg/l.

4) The combined recharge rate for Hawthorn Aquifer Aquifer System - Zones III and IV and Suwannee Aquifer

System - Zone I is about 1.6 MGD for all of Sanibel and part of Captiva Island.

5) If 1.44 MGD is equally pumped from two production wells, tapping Hawthorn Aquifer System - Zone IV, spaced at 1000 feet apart, about 40 percent of the pumpage will come from lateral recharge and the remaining 60 percent of the water will leak from the bordering zones.

6) If 1.44 MGD is pumped from two wells tapping Hawthorn Aquifer System - Zone IV, then the quality of water will decline to a certain predictable degree. After 10 years of pumping Zone IV, the dissolved chloride concentration in the overlying Zone III will rise from 1500 to 2200 mg/l; the concentration in Zone IV will increase from 1400 to 2200 mg/l; and in Suwannee - Zone I the concentration will increase from 2000 to 2500 mg/l. At some future time the dissolved chloride concentration and total dissolved solid concentration will completely stabilize at a value slightly higher and remain constant with the 1.44 MGD pumping rate.

7) It presently appears that water quality declines regularly in Hawthorn Aquifer System - Zones III and IV moving from northwest to southeast across Sanibel.

8) The pumping of Hawthorn Aquifer System - Zone IV will have the smallest impact on the hydrologic system compared to pumping other zones.

9) No other water users will be significantly affected by pumping Hawthorn Aquifer System - Zone IV.

2. Recommendations

The following specific recommendations are made to the Island Water Association:

1) All raw water required by the Island Water Association should be withdrawn exclusively from Hawthorn Aquifer System - Zone IV, which was previously believed to be part of the Suwannee Aquifer.

2) Raw water pumped from Hawthorn - Zone IV at the new water plant site should be withdrawn from two production wells to be spaced between 300 and 1000 feet apart. Each well should be pumped at a rate of 1.44 MGD.

3) Additional water in excess of 1.44 MGD should be withdrawn from "cluster" sites, which should contain two or three wells each and the "clusters" should be spaced about 2 to 3 miles apart.

4) During construction of the second production well at the new water plant, the initial exploratory hole should be drilled to a depth of about 950 feet to test the quality of water in the lower part of the Suwannee Aquifer System.

5) Two additional 4-inch diameter observation wells should be constructed near the center of pumpage at the water plant. One well should monitor Hawthorn - Zone III and the other should monitor Suwannee - Zone I. The existing observation well should be modified to exclusively monitor Hawthorn - Zone IV.

6) No new production wells should be drilled east of Tarpon Bay Road.

7) At least one additional production well should be drilled with the reverse air method, after which, the technology and knowledge are now available to drill production wells with the hydraulic rotary-mud method. This will save the Island Water Association about 50 percent on each new well constructed.

8) All existing production wells should be thoroughly investigated with geophysical methods and a down-hole camera to examine casing conditions. Certain wells should be plugged and others may be deepened and lined with ABS casing. This program must be undertaken in order to preserve water quality.

9) Over a period of time, production of water from Hawthorn Aquifer System - Zone III should be totally phased out with the exception of possible development of new production in the northwestern part of Sanibel.

II. INTRODUCTION

1. Authorization

Missimer and Associates, Inc., was authorized on June 23, 1978, by the Island Water Association, Inc. of Sanibel, Florida to investigate the possibility of utilizing the Suwannee Aquifer System as a source of raw water for a new reverse osmosis treatment plant. A hydrologic investigation was to be conducted at a site located several hundred feet north of Sanibel-Captiva Road and east of Rabbit Road (see Figure 2-1). This investigation was to include: 1) an analysis of existing hydrologic and geologic information; 2) a test drilling and water quality sampling program; 3) a test-production and observation well construction program; 4) a 72-hour aquifer test and analysis; 5) specific recommendations on potential maximum yield of the units studied; and 6) a final report with impact assessments of present and future pumping on the Suwannee Aquifer System.

2. Purpose and Scope

The purpose of the investigation is to test and assess the Suwannee Aquifer System in central Sanibel Island. The scope of the project includes the authorized tasks as previously outlined.

3. Acknowledgments

We sincerely thank the following persons for their cooperation during the course of the investigation: Mr. Ralph Zeiss, Mr. Ian Watson, and Mr. Dick Derowitsch of the Island Water Association, Inc.; Mr. Durward H. Boggess of the U.S. Geological Survey; and Mr. William Nungester, City Manager, City of Sanibel.

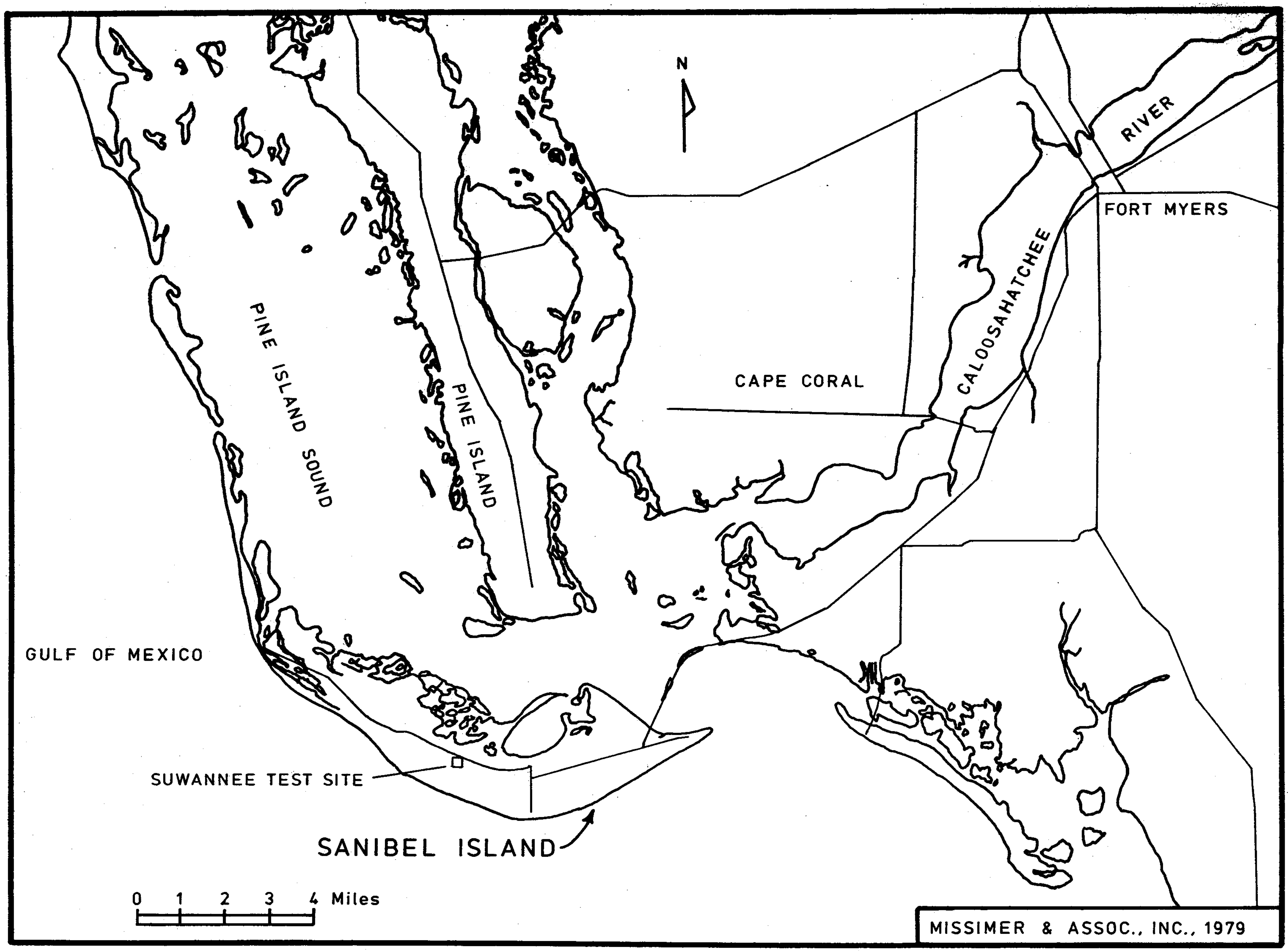

FIGURE 2-1. MAP SHOWING THE LOCATION OF SANIBEL ISLAND.

III. INVESTIGATION OF THE SUWANNEE AQUIFER SYSTEM AT THE NEW WATER PLANT SITE

1. Introduction

Investigation of the deep aquifers underlying Sanibel have been limited mostly to study of the Hawthorn Aquifer System and some of the shallow aquifers (Boggess, 1974a, 1974b; Missimer, 1976; Geraghty & Miller, Inc., 1978; Missimer and Associates, Inc., 1976). Aquifer tests have been performed on what is defined as Zone III of the Hawthorn Aquifer System (Geraghty & Miller, Inc., 1978; Missimer and Associates, Inc., 1978). The Suwannee Aquifer System has not been tested in any detail, but a few wells have penetrated the uppermost part of the system.

A site was chosen for exploration of the Suwannee Aquifer System at a location adjacent to the new reverse osmosis water treatment plant (Figure 3-1). This site was selected in order to minimize costs of raw water lines.

2. Test Drilling and Well Construction

A test drilling program was initiated and completed utilizing a stepped procedure so as to collect a large quantity of high quality data in an orderly and efficient manner.

A test-production well was constructed into the combination of Hawthorn Aquifer System and Zone I of the Suwannee Aquifer System. The upper part of the well was drilled by the hydraulic rotary-mud method. A 36-inch diameter borehole was drilled to slightly more than 40 feet below land surface. A 40-foot section of 30-inch diameter steel casing was installed in the hole and the annulus was grouted with neat cement. An 8-inch diameter pilot hole was drilled by the hydraulic rotary-mud method to a depth of 420 feet. Drill cuttings were collected during this operation and a set of geophysical logs was obtained. The pilot

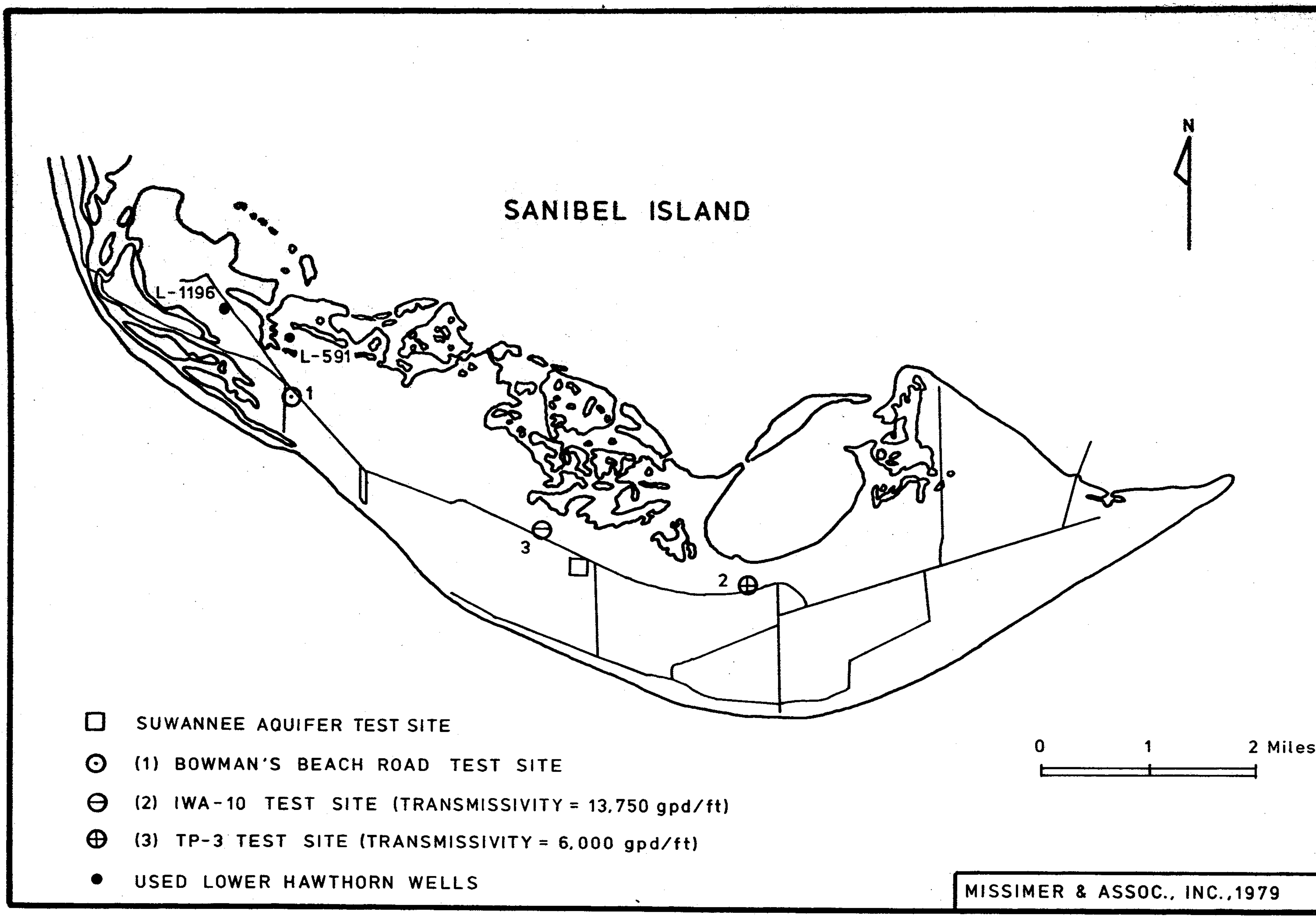

FIGURE 3-1. MAP SHOWING LOCATION OF SUWANNEE TEST SITE AND LOCATIONS OF PREVIOUS AQUIFER TEST SITES.

hole was then enlarged to a diameter of 30 inches to a depth of 400 feet. A 30-inch diameter steel casing was installed in the borehole to 391 feet below surface. The casing was centered by utilizing stabilizers spaced at a 40-foot interval. The annular space was pressure grouted with neat cement. An 8-inch pilot hole was started by use of the hydraulic rotary-mud method in order to clear the borehole of large-size debris. The mud drilling terminated about 420 feet below surface and drilling commenced using the reverse air method. The deep pilot hole was drilled with air to a final depth of 776 feet below surface. Drill cuttings and water samples were collected during this period and a set of geophysical logs was made.

Upon completion of the test hole, a series of packer-stem tests were made in order to isolate the water quality characteristics of each water-bearing zone. The packer interval was about 18-feet with 5 individual rubber packers attached at each end (see Figure 3-2). The testing was done on the way down the borehole. The duration of each packer setting was determined by the length of time required for the water quality to stabilize. This time interval varied from 20 to 40 minutes. The geologic and water quality data were utilized to determine the final well construction details.

The pilot hole was then enlarged to 18 inches in diameter to a depth of 671 feet below surface. A 660-foot string of 12-inch diameter PVC casing (Schedule 80) was installed in the borehole. The annular space was pressure grouted with neat cement part way up the casing. The remaining part of the annulus was grouted with neat cement by the tremie method. This cementing procedure was used in order to prevent casing failure due to the high temperatures created by the cement heat of hydration. The lower part of the borehole from 660 to 776 feet was enlarged to 12 inches by the reverse air method. The completed well taps both Hawthorn Aquifer System - Zone IV and Suwannee Aquifer System - Zone I. A diagram showing the well construction details

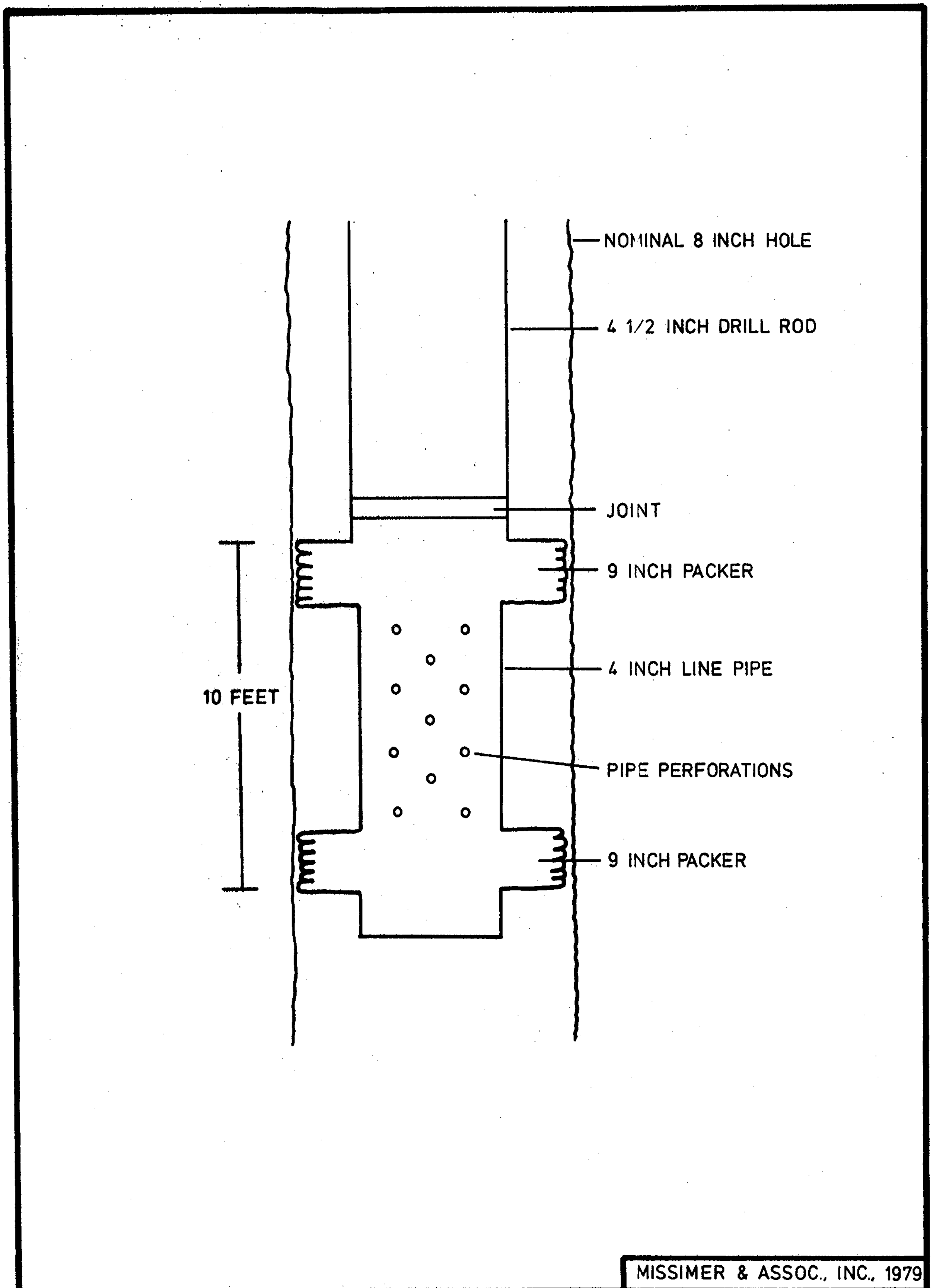

FIGURE 3-2. SCHEMATIC DIAGRAM OF TYPICAL PACKER STEM TEST APPARATUS SET-UP.

is given in Figure 3-3.

One observation well was drilled into the upper part of the Suwannee Aquifer System. This well was drilled using only the hydraulic rotary-mud method. The observation well was drilled to the same general specifications as the test-production well. An 8-inch hole was drilled to a depth of about 680 feet. A 660-foot string of 4-inch diameter PVC casing was installed in the borehole. The casing was centered by use of stabilizers. The annular space was pressure grouted with neat cement. A 4-inch diameter borehole was drilled below the casing to a depth of 768 feet. A diagram of the observation well is given in Figure 3-4.

3. Aquifer Test

An aquifer test was performed on Zone IV of the Hawthorn Aquifer System and Zone I of the Suwannee Aquifer System. Test-production well L-M-987 was pumped continuously at a rate of about 900 gpm for a period of 72 hours. Well L-M-987 was equipped with an extended shaft turbine pump powered by a diesel engine. The pump bowls were set at approximately 90 feet below land surface. Pump discharge was monitored using a standard 6-inch diameter orifice plate equipped with a clear plastic, vertical piezometer tube. Water free-fell from the end of the orifice plate into the discharge line.

The rate for the aquifer test was established during a step-drawdown test conducted several days prior to initiation of the final test. Each step lasted about 90 minutes. The step discharge rates were: 300 gpm; 600 gpm; 900 gpm; and approximately 1100 gpm. Suction was broken during the last step and the test was terminated. Drawdowns in the test-production well indicated that the best discharge rate for the test should be 900 gpm.

Water discharged during the test was pumped from a collection pit into a line, which conveyed it about 500 feet into the primary

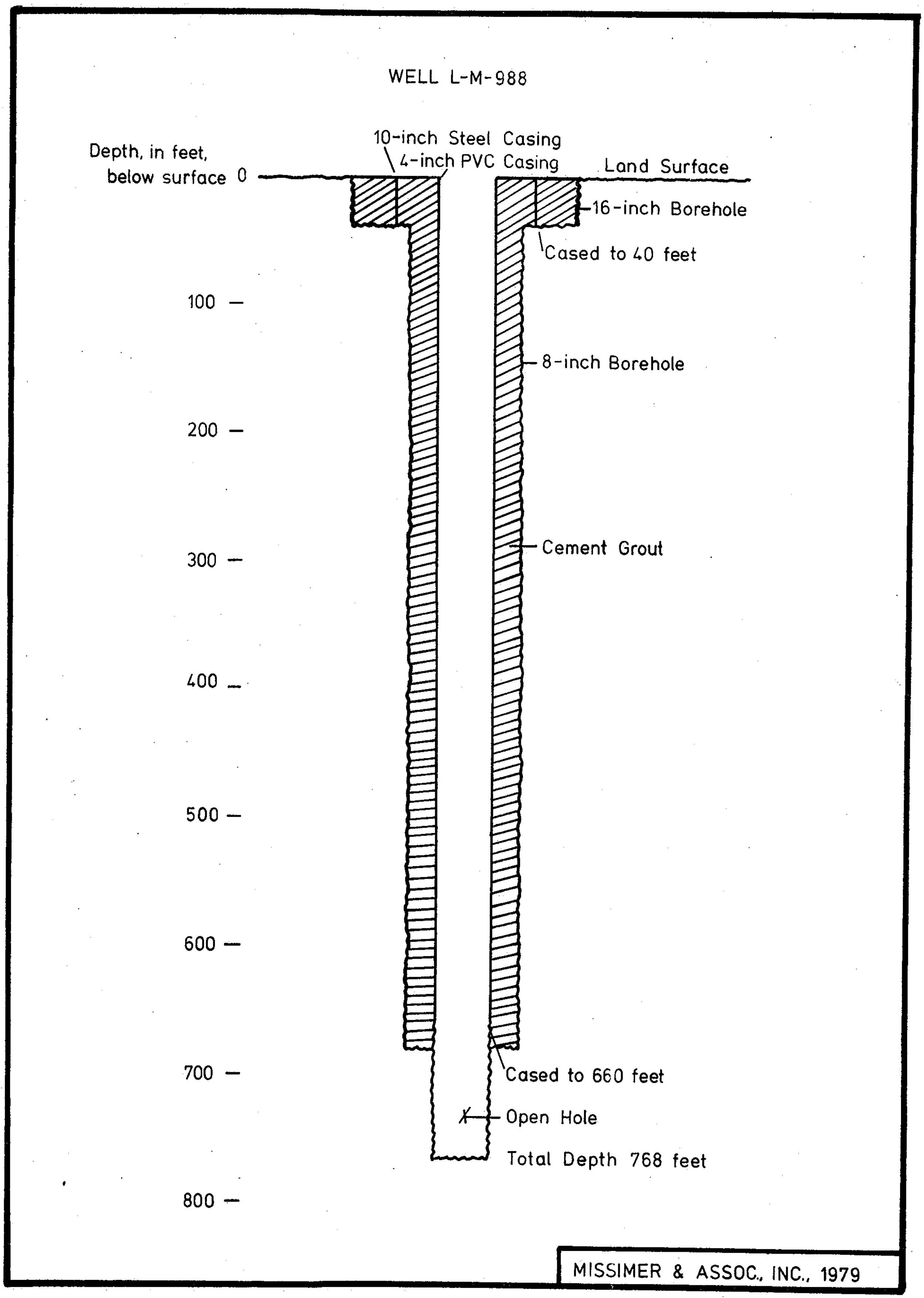

FIGURE 3-4. DIAGRAM SHOWING THE CONSTRUCTION DETAILS OF OBSERVATION WELL L-M-988.

brine line. The brine line conveyed the water into the Gulf of Mexico from an outfall pipe. This method prevented the saline water discharged from entering the interior wetlands of Sanibel.

Drawdown in the test-production well was monitored using a combination pressure gage-airline set-up. The production pump discharge appeared to vary only slightly during the test.

Drawdown of the potentiometric surface in the stressed aquifer in the area away from the pumped well was measured in an observation well (L-M-988). This well was equipped with a Stevens Type-F water level recorder, which was manually checked. Because of the relatively high head of the Suwannee potentiometric surface (up to 26 feet above land surface), the water level recorder was mounted on approximately 30 feet of 4-inch PVC riser pipe support by 25 feet of scaffolding.

Extraneous water level fluctuations caused by barometric pressure changes, ocean tide fluctuations, and nearby pumping were monitored. A tide gage was continuously monitored for a week before the aquifer test, during the test, and for several days after the test. A recording barometer was placed at the site and operated for three days before the test to three days following it. Pumping of all Island Water Association wells was terminated during the test.

Water levels in Hawthorn Aquifer System - Zone III were monitored in 2 wells, L-2085(3) and MW#1, which are located about 900 and 1000 feet respectively from the test site. These wells are shown in Figure 3-1.

Upon termination of pumping, recovery of the potentiometric surface was monitored in both the test-production well and the observation well. The recovery data were used to verify the drawdown data.

A schematic diagram of the aquifer test set-up is shown in Figure 3-5.

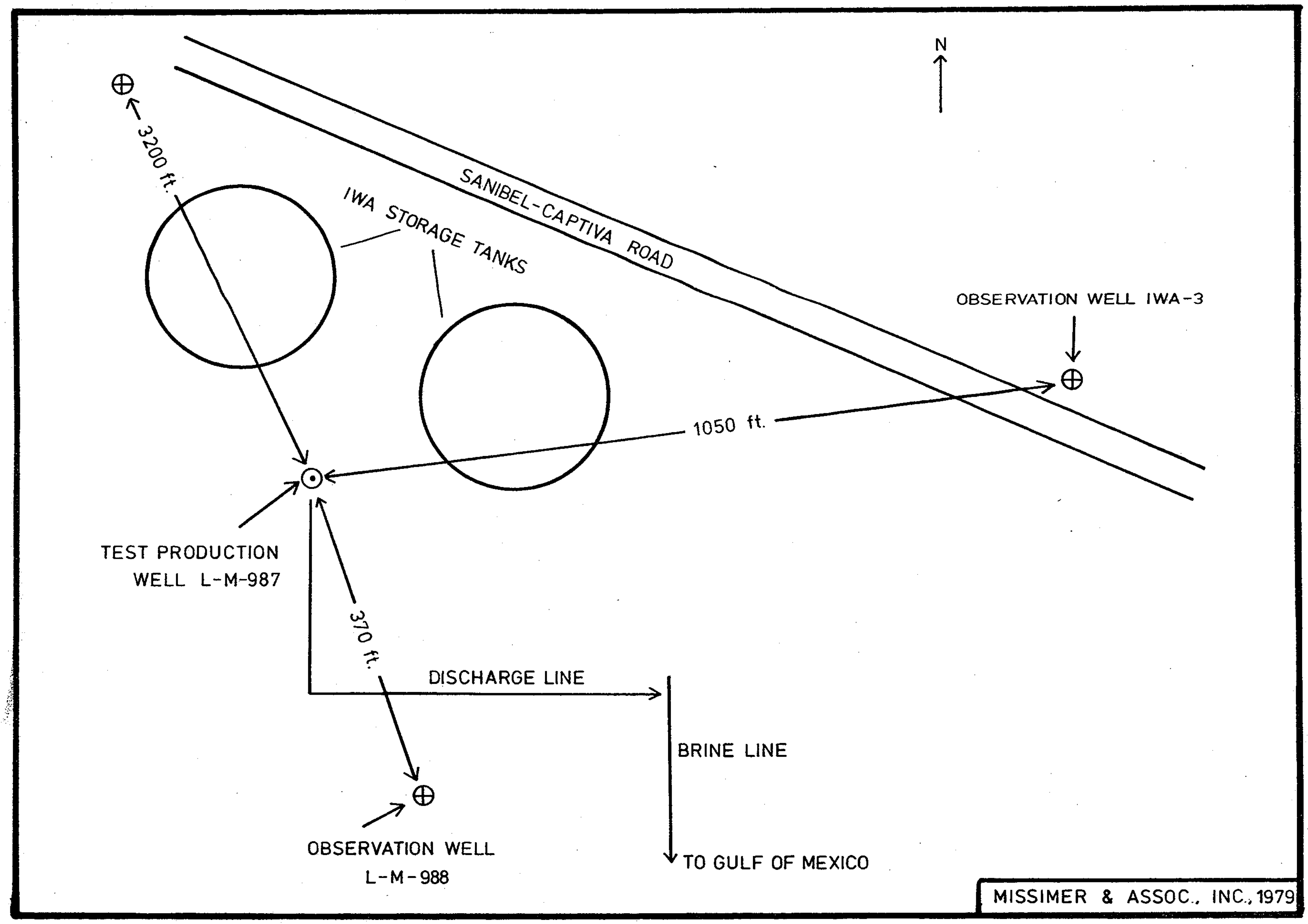

FIGURE 3-5. SCHEMATIC DIAGRAM SHOWING THE AQUIFER TEST SET-UP.

4. Well Inventory and Water Use Assessment

There are no known Suwannee Aquifer System production wells located within two miles of the test site. Therefore, a well inventory and water use assessment was not necessary.

IV. HYDROLOGY AND GEOLOGY AT THE TEST SITE

1. Geology

The sedimentary stratigraphic sequence beneath Sanibel Island ranges from Holocene to Cretaceous or perhaps Jurassic in age and is probably over 18,000 feet thick. Nearly all of this sequence was deposited in a shallow marine or brackish environment. Only the upper 776 feet of this sequence was penetrated in the test drilling program. A complete geologic log of the test well L-M-987 is presented for reference in Figure 4-1 and a detailed description of the sediments is given in Table A-1.

Holocene

Sediments occurring from land surface to a depth of 26 feet below it are Holocene in age. This sequence contains three minor stratigraphic units which are: 1) tan to light gray, quartz sand and shell; 2) fine, gray, quartz sand; and 3) carbonate clay, quartz sand, and shell. The Holocene sequence is less than 15,000 years old and has been described in considerable detail by Missimer (1973).

Tamiami Formation

Tamiami Formation sediments appear to lie unconformably beneath the Holocene sequence. There is some question concerning whether the uppermost 10 to 15 feet of the limestone unit is truly Tamiami in age or Fort Thompson in age. However, most of the upper limestone sequence appears to be part of the Tamiami Formation and most or all of the Fort Thompson Formation and Caloosahatchee Marl have been removed by erosion.

The uppermost member of the Tamiami Formation encountered is the Ochopee limestone (note: terminology used in this report is defined in Missimer and Associates, Inc., 1978a). This

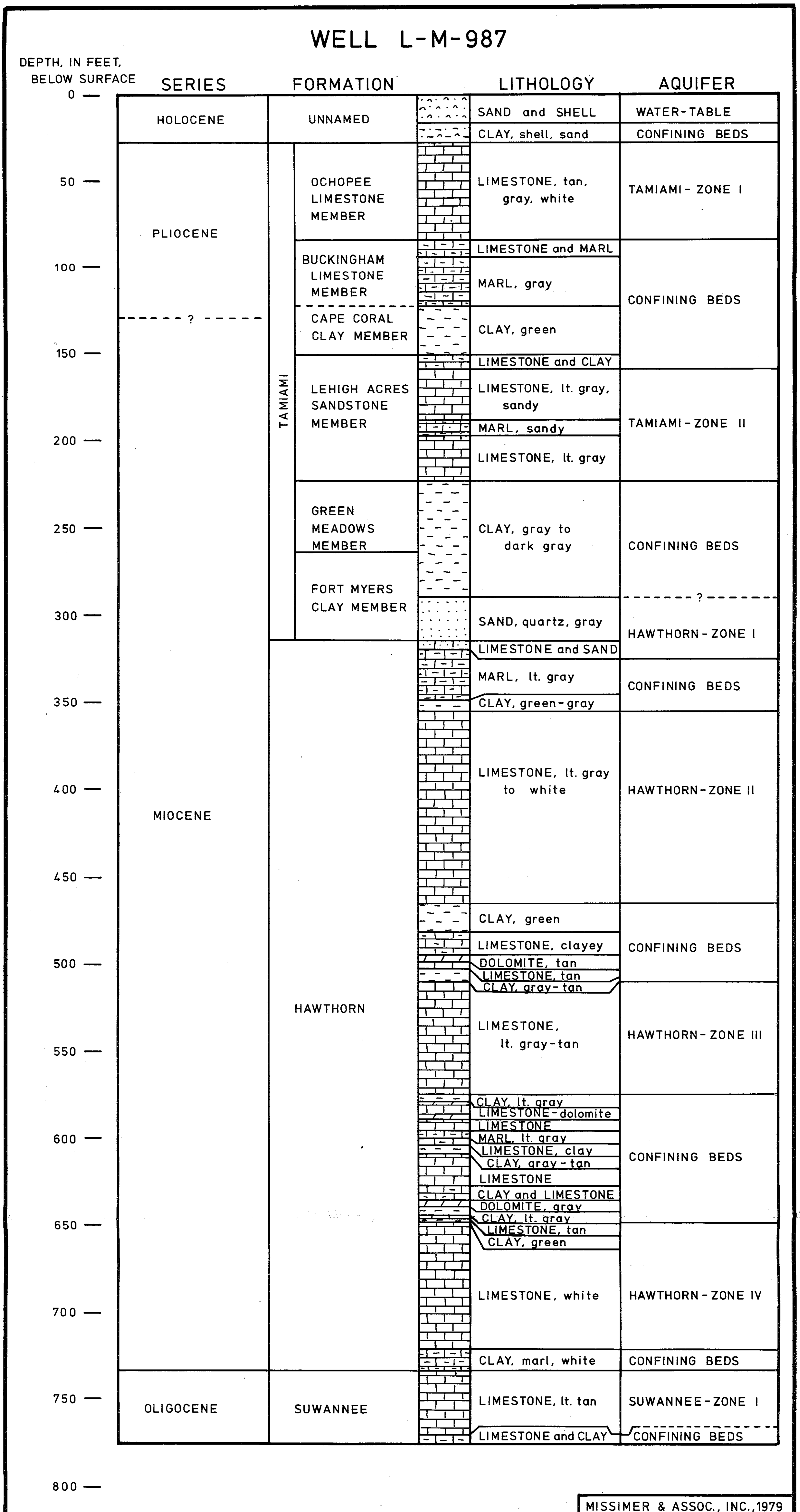

FIGURE 4-1. LOG OF TEST WELL L-M-987 SHOWING GEOLOGY AND LOCATION OF WATER-BEARING ZONES.

limestone is about 60 feet thick and is predominantly a hard white to gray limestone with some quartz sand and interbedded clay. It contains variable-sized solution cavities from microscopic vugs to pockets 1 to 2 feet in height. The unit is quite permeable and is water-bearing.

A sequence of gray marl lies below the Ochopee limestone. This unit appears to be the Buckingham limestone member. It is about 50 feet thick and contains a large number of lithologies created by mixtures, in various proportions, of lime mud, quartz sand and silt, rock fragments, and phosphorite nodules. This "marl" unit has low permeability and is not considered to be water-bearing.

The Cape Coral clay lies beneath the Buckingham limestone. The contact between the units is a gradual transition. Lime mud and quartz sand are the two primary components of the Cape Coral clay. There is considerable variation in the proportion of these components with the lime mud matrix ranging from 90% to as low as 25%. Some quartz silt, phosphorite, and shell fragments also occur within the units. The sequence is about 27 feet thick and has an overall low permeability. The Pliocene-Miocene time boundary lies within the unit probably near its top.

The Lehigh Acres sandstone member lies beneath the Cape Coral clay. It is mostly a tan to light gray limestone, but also contains some sandy marl. The unit is 75 feet thick and has low to medium permeability. It is a water-bearing unit.

In most of western Lee County, several of the lower members of the Tamiami Formation are absent. However, at this location some of the Green Meadow clay member lies under the Lehigh Acres sandstone. This unit is a gray to gray-green lime mud with some quartz sand. It is about 40 feet thick and has low permeability.

The basal member of the Tamiami Formation, the Fort Myers clay, underlies the Green Meadows clay. This unit is both a dark gray lime mud with quartz sand and phosphorite and a quartz sand with little mud. It is about 50 feet thick. The course clastic deposits which occur at the base of the Tamiami Formation are the result of past subaerial erosion of the Hawthorn Formation to the immediate east of Sanibel and subsequent transport into the marine environment (see Missimer, 1978). The upper part of the unit has a very low permeability, but the sandy lower part is probably water-bearing.

Hawthorn Formation

The Hawthorn Formation is a regional stratigraphic unit of middle Miocene age. It occurs regionally over all of southern Florida.

The full thickness of the Hawthorn Formation from the base of the Tamiami Formation to the top of the Suwannee Limestone was penetrated at the test site. The top of the Hawthorn was encountered at 314 feet below surface and the base at 734 feet below surface for a total thickness of 420 feet (see Figure 4-1).

The Hawthorn Formation is a sequence of shallow marine phosphatic limestones with some mixed terrestrial and marine clastics. There are certain specific stratigraphic characteristics of the Hawthorn Formation beneath Sanibel that have been made apparent from this investigation and a preceeding study (Missimer and Associates, Inc., 1978b). The top of the Hawthorn sequence always contains a thick section of clastic sediment, which consists of lime mud, quartz sand and silt, and shell, all in variable proportions. This sequence is in most part not water-bearing. Below the upper clastic sequence, a series of thick limestone units occur, which is separated by thinly-bedded, mixed carbonate-clastic strata. There are three thick limestone units (see Figure 4-1). The separation between the upper limestone and the middle limestone consists of four relatively thin beds of differing lithologies from green clay to dolomite. The separation between the middle and lower limestone is twelve different lithologies in a sequence only about 75 feet thick. Most of the lithic units are between 2 and 10 feet thick. The large variation in lithology with depth at the separations between major limestone units is apparently a characteristic which can be utilized for correlation on Sanibel in conjunction with geophysical logs. Implications with regard to island-wide correlation of geologic units and aquifers is discussed in more detail in Chapter VI.

All of the clays which occur in the Hawthorn sequence are relatively dense and contain a high percentage of lime mud with some clay minerals. These "clay" units have inferred low permeabilities and form confining beds between water-bearing strata. The basal "clay" unit is truly a compressed, dense, lime mud and forms a lithic discontinuity, which is believed to be the contact between the Hawthorn Formation and the Suwannee Limestone.

All limestone lithologies given in the appendix tables are described in terms of carbonate rock classifications, published by Folk (1968) and Dunham (1962). Most of the limestones in the Hawthorn Formation are micrites or biomicrites, which contain variable percentages of phosphorite and quartz sand. There are beds of massive dolomite which appear to be of secondary origin.

Many investigators have separated the phosphatic sediments of south Florida into two formations: the Hawthorn Formation and the Tampa Limestone. It is not possible to distinguish these formations beneath Sanibel. If there really is any Tampa Limestone present in the sequence, it would be the unit between the lower variable lithology sequence and the top of the Suwannee Limestone. It is quite probable that the Tampa Limestone is not a mapable stratigraphic unit in south Florida.

Suwannee Limestone

The Suwannee Limestone is an Oligocene-age formation, which occurs regionally beneath most of the Florida peninsula. In many areas of south Florida, the Suwannee Limestone contains several carbonate rock lithologies, which are all similar in that they contain few non-carbonate impurities.

Only the uppermost part of the Suwannee Limestone was penetrated at the test site. Drilling was terminated about 40 feet into the unit. The lithology ranged from a wackestone to a mudstone, which are both limestones. All of the Suwannee strata appeared to have medium permeability except the lower 5 feet, which contained some lime mud.

2. Aquifer and Confining Bed Descriptions

The water-table aquifer occurs in the upper 16 feet of Holocene sands and shell at the site. It has a high permeability, but it is a relatively thin aquifer. The water-table aquifer on Sanibel Island has been described in detail by Boggess (1973) and Missimer (1976). More detailed information is available in these publications.

Upper confining beds

A mixture of lime mud, quartz sand, shell, and some organic deposits forms a confining bed, which separates the water-table aquifer from the underlying Tamiami Aquifer System - Zone I. These beds are about 10 feet thick and are somewhat leaky. Again, detailed descriptions of these beds are given in Boggess (1973) and Missimer (1976).

Tamiami Aquifer System - Zone I

Tamiami Aquifer System - Zone I occurs within the Ochopee limestone member and the upper part of the Buckingham limestone member of the Tamiami Formation. The aquifer is about 80 feet thick at the test site. The upper part of the aquifer is very permeable, but permeability appears to decrease at the aquifer base. This aquifer has been previously termed the Shallow Artesian Aquifer by Boggess (1973) and Missimer (1976). Since the aquifer can be traced regionally throughout all of south, eastern, and coastal Lee County, it is considered part of the Tamiami Aquifer System. This aquifer is recharged on Sanibel by vertical leakage through the overlying confining beds.

Confining beds (middle Tamiami)

The Buckingham limestone and Cape Coral clay members of the Tamiami Formation form the beds which confine Zone I from the underlying Tamiami Aquifer System - Zone II. These beds are about 50 feet thick at the site. The rate of leakage across the beds is probably low.

Tamiami Aquifer System - Zone II

Tamiami Aquifer System - Zone II lies exclusively within the Lehigh Acres sandstone member of the Tamiami Formation. It is about 73 feet thick at the site. Zone II contains permeable limestone beds and beds of marl with low permeability. The aquifer, if considered as a single hydrologic unit, has good potential yield at this location. In most of western Lee County, the aquifer is poorly developed with low yield characteristics (see Missimer and Associates, Inc., 1978b). Zone II is recharged only by water moving vertically into it from either above, below, or both directions.

Confining beds (lower Tamiami)

Clays and sandy clays occurring in the Green Meadows clay and Fort Myers clay members of the Tamiami Formation confine the Tamiami Aquifer System from the underlying Hawthorn Aquifer System. These clays are about 66 feet thick and form a rather tight confining bed which allows only a very low rate of vertical leakage. The lowest part of the Fort Myers clay is actually a quartz sand that is hydraulically connected to and is probably part of Hawthorn Aquifer System - Zone I.

Hawthorn Aquifer System - Zone I

The water-bearing units within the Hawthorn Formation have been previously defined as the Upper Hawthorn Aquifer and the Lower Hawthorn Aquifer (Sproul and others, 1972). Because of the greater number of confining beds found within the Hawthorn sequence on Sanibel, the Hawthorn Aquifer System is broken down into four water-bearing zones. Each zone has characteristic properties which to a certain degree are unique depending upon the degree of separation (confinement) of each zone from the others.

Hawthorn Aquifer System - Zone I is the equivalent to what was previously termed the Upper Hawthorn Aquifer. Zone I is between 6 and 30 feet thick. The exact aquifer thickness cannot be determined because it is not known how much of the sand in the lower portion of the Tamiami Formation is hydraulically connected or part of the aquifer. Hawthorn - Zone I probably would yield a rather small quantity of water.

Confining beds between Hawthorn - Zones I and II

A series of marls, gray lime muds, and gray-green, sandy clays forms the confining beds separating Hawthorn Aquifer System - Zones I and II. The cumulative thickness of these beds is 35 feet. The vertical permeability is estimated to be low, but the degree of confinement provided by these beds at this location is less than in other areas on Sanibel (see Missimer and Associates, Inc., 1978b). The leakage gradient is directed upward and therefore, some water leaks from Zone II into Zone I. Because these confining beds contain lithologies other than clay or lime mud, they do store some water that would be yielded if either Zone I or Zone II were pumped at a high volume.

Hawthorn Aquifer System - Zone II

This aquifer is the uppermost really significant water-bearing unit in the Hawthorn Aquifer System beneath Sanibel Island. Zone II is about 111 feet thick and is mostly a light gray to white, phosphatic limestone. The limestone has a medium to high permeability. A thin bed of green lime mud occurs in the sequence between 427 and 429 feet below surface. This bed probably provides a small degree of confinement to the lower part of the aquifer. Zone II has probably high yield characteristics, but water quality is poor.

Confining beds between Hawthorn - Zones II and III

A group of beds forms the separation between Hawthorn Aquifer System - Zones II and III. The full thickness of the confining beds is about 40 feet. About 12 feet of very hard dense limestone interbedded with green and white lime muds lies below the upper clay. Below the mixed limestone and clay, there is about 9 feet of dense tan dolomite with low permeability and some light tan, very permeable limestone. The bottom 11 feet of the sequence is a light gray-tan lime mud with very low permeability. This geologic sequence provides a very high degree of confinement and permits a very small quantity of water to leak between Zones II and III.

Hawthorn Aquifer System - Zone III

Zone III is a very complex aquifer with water-bearing strata interbedded with semi-confining, low permeability beds. Most of the water yielded from Zone III comes from the upper 64 feet of the aquifer, which is a light gray-tan, phosphatic, limestone. The lower 60 feet of the sequence, which may or may not be water-bearing, is an alternating series of permeable limestones and low permeability clays. The possible total aquifer thickness is about 125 feet, but only about 70 feet of the total is water-bearing. Because of the complexity of the geology, wells partially penetrating Zone III should show considerable variability in yield.

Confining beds between Hawthorn - Zones III and IV

Zone IV is confined from Zone III by 19 to 79 feet of lime muds, limestones, and dolomites. The lime mud or "clay" appears to be quite dense and has very low permeability. The limestone is mixed with lime mud and has medium to low permeability. The dolomite is massive and very "tight". This series of beds does provide a fairly high degree of confinement, but they are not as effective as the confining strata above Zone III. Therefore, the leakance value calculated from aquifer test analysis for Zone III must be interpreted with caution, because the leakage rate across the upper beds is less than that across the lower beds.

Hawthorn Aquifer System - Zone IV

Zone IV is perhaps the most uniform aquifer, in terms of lithology, that underlies Sanibel Island. It is a white to light gray limestone with only a trace of phosphorite. It is about 74 feet thick. Zone IV has the highest potential yield of any aquifer explored to date of the island. It is reasonably well-confined from the overlying Zone III and confined to a lessor degree from the underlying Suwannee Aquifer System.

Confining beds between Hawthorn - Zone IV and Suwannee - Zone I

There has been considerable question in the past concerning whether the lower part of the Hawthorn Aquifer System and the upper part of the Suwannee Aquifer System have a direct or indirect connection. At the test site, these aquifer systems are distinctly separated by a 12-foot thick bed of clay and marl. The confining bed is actually a compact lime mud with very low permeability. Upward leakage across the confining bed would be significant only if a large head difference were induced between Hawthorn - Zone IV and Suwannee - Zone I.

Suwannee Aquifer System - Zone I

Little is known about the nature of the Suwannee Aquifer System beneath Sanibel Island. The uppermost part of the Suwannee System has herein been designated as Zone I, although it is not known if any other confined water-bearing zones are present. Only 40 feet of the Suwannee Limestone was penetrated in the test well. The upper 35 feet of the formation is a tan to light brown limestone, which has medium permeability. The lowermost 5 feet of the unit contains some unlithified lime mud, which may cause these beds to partially confine the underlying strata. This clayey limestone has comparatively high vertical permeability, and it could cause an increase in the numerical value of the leakance coefficient as calculated from an aquifer test.

3. Aquifer Characteristics

The major water-bearing units underlying Sanibel Island are shown in Figure 4-1. At the test site, the aquifer characteristics were determined for a composite of Zone IV of the Hawthorn Aquifer System and Zone I of the Suwannee Aquifer System.

The Hawthorn and Suwannee Aquifer Systems beneath Sanibel are hydraulically quite complex. An accurate determination of the aquifer hydraulic properties of a proposed production zone is required to predict aquifer response to long-term pumping and the perennial yield. In order to determine the hydraulic properties of an aquifer, the following types of information are required: 1) detailed geologic data; 2) aquifer test data; and 3) water level data. The geologic information and detailed aquifer delineation have been previously presented in this section and the water level and potentiometric surface data are presented in a following portion of this section.

There are four basic aquifer types which occur in nature. These types, following the Dutch terminology (Kruseman and DeRidder, 1970) are: 1) unconfined; 2) semi-unconfined; 3) semi-confined (leaky); and 4) confined. The lower part of the Hawthorn Aquifer System on Sanibel Island is semi-confined (leaky). This type of aquifer occurs where continuous beds having low permeability fully confine the aquifer from the atmosphere and from the underlying aquifers. Although the aquifer is fully confined, water still moves vertically through the confining beds. When the aquifer is stressed, water is yielded from a horizontal direction until the potentiometric head is lowered to a point where vertical inflow of water occurs through the confining beds (downward and/or upward).

There are three (3) hydraulic coefficients determined in most aquifer tests:

1) Transmissivity (T) - The ability of an aquifer to transmit water, reported in gallons/day/foot or m^2/day.

2) 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. Dimensionless.

3) Leakage Coefficient (k'/b') - The effective vertical permeability of a confining bed divided by the thickness of the confining bed in gpd/ft^3.

<u>Combined Hawthorn Aquifer System - Zone IV and Suwannee Aquifer System - Zone I</u>

A detailed aquifer test was performed on a combination of Hawthorn - Zone IV and Suwannee - Zone I. Two zones were chosen for composite testing because a fairly substantial volume of water was required. It was assumed from previous test drilling on Sanibel that Hawthorn - Zone IV would not provide the necessary volume and that opening of a part of the Suwannee Aquifer System would be necessary. The test-production well was terminated in a clayey limestone, which is believed to provide some confinement from underlying Suwannee strata. The definitions of the zones in the Hawthorn and Suwannee Aquifer Systems are given in Chapter IV, Section 2.

Water was pumped from a test-production well and one other observation well was used to continuously monitor drawdown in the production zone. The observation well was equipped with a Stevens Type-F water level recorder. A large quantity of background water level data were collected before and after the test. A complete description of the aquifer test set-up and procedure is given in Chapter III.

Test-production well L-M-987 was pumped continuously for 72 hours between November 27, and November 30, 1978. An attempt was made the previous week to complete the test, but pump failure was experienced after 21 hours. Drawdown in the test-production well stabilized at 105 feet, which yields a specific capacity of 8.6 gpm/foot of drawdown. The drawdown data from the test-production well were not used for calculation of aquifer coefficients. However, the raw time and drawdown data from well L-M-987 are given in Table A-3.

Drawdown data were recorded continuously in observation well L-M-988, which was located 370 feet from the test-production well. After 4320 minutes of continuous pumping, a drawdown of 6.97 feet was recorded in well L-M-988. At the termination of the test, a steady state had not been reached. The steady state condition was reached after approximately 2 days of pumping, however, tidal fluctuations created some variation in water levels during the last day of pumping. A comparison of barometric pressure fluctuations, tidal fluctuations, and the water levels in well L-M-988 is given in Figure 4-2.

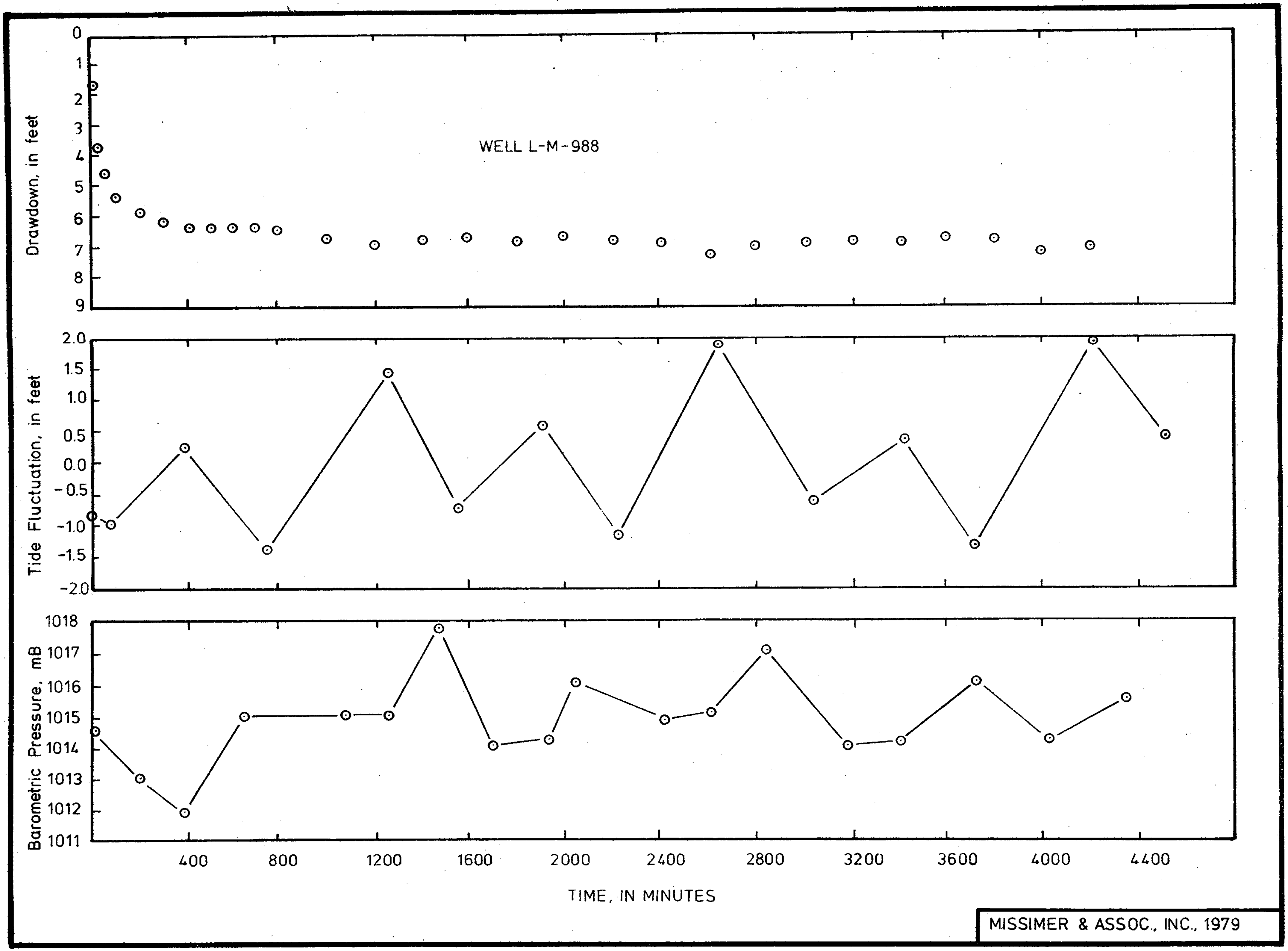

FIGURE 4-2. DIAGRAM SHOWING A COMPARISON OF WELL L-M-988 TO BAROMETRIC PRESSURE AND OCEAN TIDE FLUCTUATIONS.

Water levels in Hawthorn - Zone III were maintained during the test in wells L-2085 and MW#1. Water levels in the Zone III observation wells dropped about 0.8 foot in the first 8 hours of the test and never fluctuated even during the recovery period. It is assumed that the pumping of Zone IV has little or no direct effect on the head in Zone III. The observed drop in water levels is the probable result of the recovery of Zone III from pumping of the IWA Wellfield two days prior to beginning the aquifer test.

The influence of tidal effects on the production zones was determined from comparison of water level records collected from well L-M-988 and a tidal gage located along the north shore of Sanibel. Water levels in the production zone fluctuated rhythmically as much as 0.5 foot. The peaks and lows correlate well with high and low ocean tides with an approximate 30-minute time lag caused by the difference in location between the respective recording stations. The tidal efficiency of an aquifer (after Robinson and Bell, 1971) is given by the following equation:

$$TE = \frac{Sw}{S_t} \qquad (1)$$

where, Sw = the net change in water level in the well
S_t = the net corresponding change in tide level

The tidal efficiency of the production zone is not a unique number and varies with the magnitude and direction of the tides. The approximate mean tidal efficiency is 22%.

A preliminary analysis of drawdown data collected was made assuming that the aquifer was fully confined. The Jacob straight line method was used (Cooper and Jacob, 1946; Jacob, 1950). The Jacob method yields only approximate values for the transmissivity and storage coefficient, but it does give useful numbers to check the validity of other methods. A semi-log plot of drawdown versus time for well L-M-988 with a sample Jacob analysis is given in Figure 4-3. The analysis yielded the set of coefficients given in Table 4-1. These values are only slightly higher than aquifer coefficients determined by use of the leaky aquifer equations.

A primary analysis of the drawdown data from well L-M-988 was made using the method of Hantush and Jacob (1955) as modified by Walton (1960) for semi-confined aquifers. The drawdown data were plotted on a log plot versus time and the resultant curve was matched to the appropriate Walton function type-curve (see Figure 4-4). The match point was substituted into the following equation:

$$T = 114.6\ Q\ W(u, {}^{r}/_{B}) \qquad (2)$$

$$S = \frac{T\ u\ t}{1.87\ r^2} \qquad (3)$$

$$k'/b' = \frac{T\ (r/B)^2}{r^2} \qquad (4)$$

where,

T = transmissivity (gpd/ft)

Q = discharge (gpm)

$W(u, {}^{r}/_{B})$ = well function for leaky aquifers with fully penetrating wells without water released from storage in the aquifer

s = drawdown (ft)

S = storage coefficient

u = Walton curve function

t = time (days)

r = distance from pumped well to observation well (ft)

k' = permeability of confining layer (gpd/ft^2)

b' = thickness of confining layer (ft)

${}^{r}/_{B}$ = Walton curve function

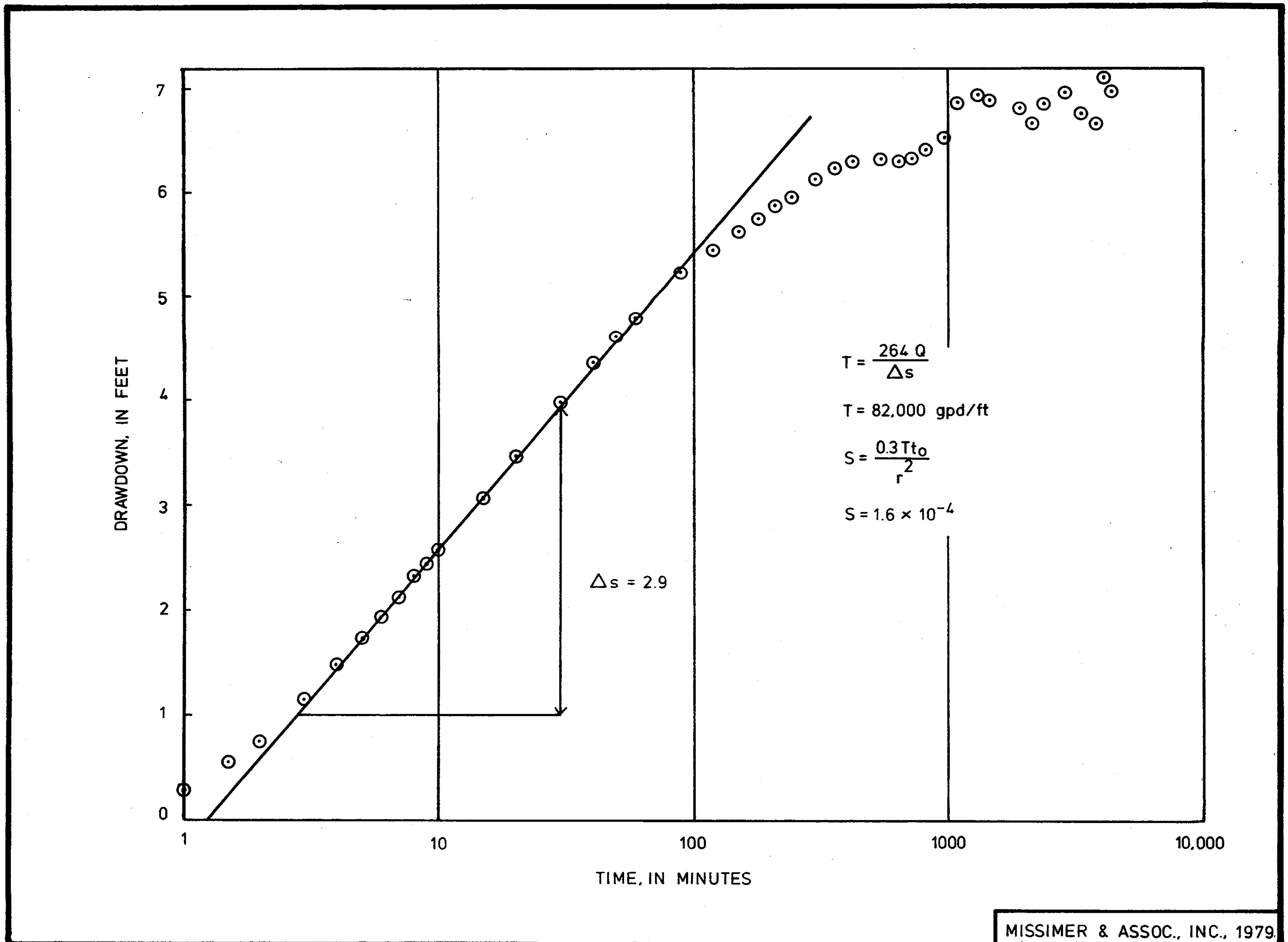

FIGURE 4-3. DIAGRAM SHOWING A SEMI-LOG PLOT OF DRAWDOWN IN WELL L-M 988 WITH TIME AND A SAMPLE JACOB ANALYSIS.

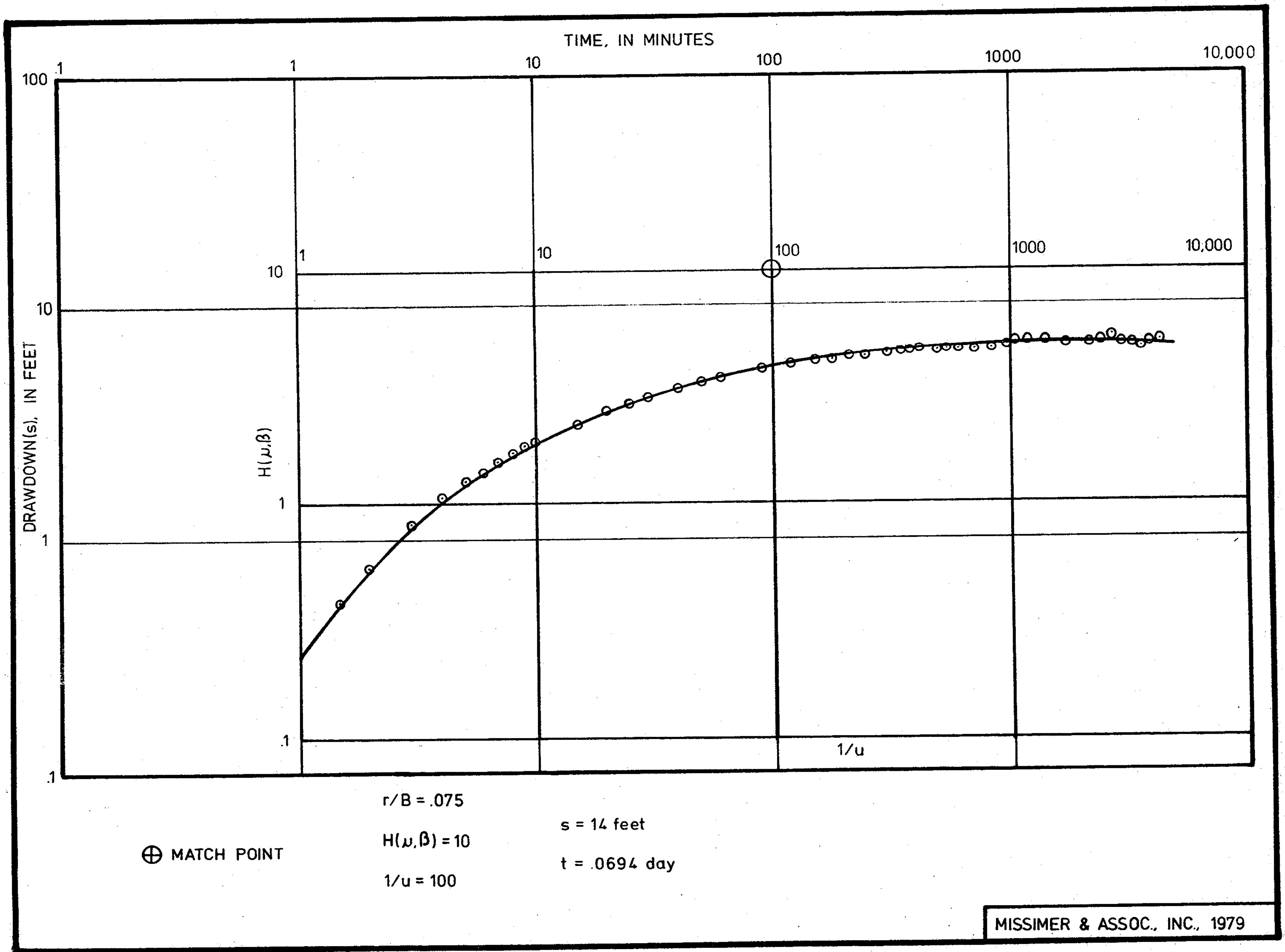

FIGURE 4-4. DIAGRAM SHOWING A LOG PLOT OF DRAWDOWN IN WELL L-M-988 WITH TIME AND THE HANTUSH-JACOB FUNCTION TYPE-CURVE MATCH.

TABLE 4-1. AQUIFER COEFFICIENTS CALCULATED FOR THE COMBINATION OF HAWTHORN AQUIFER SYSTEM - ZONE IV AND SUWANNEE AQUIFER SYSTEM - ZONE I USING DIFFERENT ANALYSIS METHODS

Analysis Method	T (gpd/ft)	S	k'/b' (gpd/ft^3)
1. Jacob (confined)	82,000	1.6×10^{-4}	-
2. Hantush-Jacob (semi-confined)	74,000	2×10^{-4}	3.0×10^{-3}

T = transmissivity

S = storage coefficient

k'/b' = leakance coefficient

The calculations are shown in Figure 4-4. Aquifer coefficients to be used for predictive purposes are as follows:

Transmissivity = 74,000 gpd/ft
Storage Coefficient = 2×10^{-4}
Leakance = 3.0×10^{-3} gpd/ft^3

All of these coefficients are composites for both Hawthorn Aquifer System - Zone IV and Suwannee Aquifer System - Zone I. The transmissivity values for the individual aquifers can be approximated based on thickness and lithologic character. It is evident from observations of the flow during drilling and a qualitative assessment of secondary porosity that Hawthorn - Zone IV is more permeable than Suwannee - Zone I. Using a thickness of 35 feet for Suwannee - Zone I, and a relative permeability difference of 30 percent between Zone IV and Suwannee - Zone I, the transmissivities of the two aquifers are calculated to be:

Hawthorn Aquifer System - Zone IV = 50,000 gpd/ft
Suwannee Aquifer System - Zone I = 24,000 gpd/ft

The transmissivity of Zone IV may be as high as 58,000 gpd/ft and Zone I may be as low as 16,000 gpd/ft.

It is not possible to assess the storage coefficients for each aquifer based on the available information.

The composite leakance value of 3.0×10^{-3} gpd/ft^3 is quite high and therefore, requires some explanation. Previous tests of Hawthorn Aquifer System - Zone III have yielded leakance values from 3.4 to 5.0×10^{-5} gpd/ft^3. Based on these test values, the confining bed between Hawthorn - Zones III and IV has a leakance value of under 1×10^{-4} gpd/ft^3. Therefore, the high leakance value calculated from this test is the probable result of a high leakance from the lower confining bed, which is a clayey limestone. There is no possible way to assess the real leakance for Hawthorn - Zone IV or Suwannee - Zone I as individual aquifers. It is possible that Suwannee - Zone I is actually a thicker zone than penetrated and the test well only partially penetrates it. However, the clayey nature of the lowermost beds penetrated does provide at least a minor degree of confinement.

4. Water Levels and Recharge

The subject of water levels and recharge in many of the various aquifers underlying Sanibel Island has been covered in detail by Boggess (1974a) and Missimer (1976). Certain aquifers such as Tamiami Aquifer System - Zone II, and Hawthorn Aquifer System - Zones I and II, have not been studied in detail and therefore, no water level data are available. Some better quality information is available from Hawthorn Aquifer System - Zone III as reported in Missimer and Associates, Inc. (1978b).

Hawthorn Aquifer System - Zone IV and Suwannee Aquifer System - Zone I

The potentiometric surface of Hawthorn Aquifer System - Zone IV responds to changes in the position of water levels in the water-table aquifer and other overlying aquifers as well as fluctuations caused by barometric pressure changes, and ocean tides. The static or perhaps mean water level at the test site, which is the combination of Hawthorn - Zone IV and Suwannee - Zone I, was approximately 29.3 feet above mean sea level. This potentiometric level is slightly higher than shown in the regional pattern described in Boggess (1974b).

Zone IV and Suwannee - Zone I are recharged by lateral flow through the aquifer from the mainland and by vertical leakage of water upward through the confining beds. Under natural conditions, lateral recharge is dominant and the aquifer is flushed with whatever water quality exists up-gradient. Under a stressed condition (pumping), induced vertical leakage becomes the dominant means of recharge. If the water quality in the confining beds or the adjacent aquifers is of poorer quality, then the water in the production zones will eventually take on the characteristics of the leaking water, to a certain degree.

Regional flow or recharge to Hawthorn - Zone IV and Suwannee - Zone I is defined as the quantity of desirable quality water that percolates laterally through the aquifer. The volume of water which recharges the aquifer beneath Sanibel and part of Captiva is calculated by multiplying the average width of the cross section of the aquifer normal to the ground-water flow direction, the aquifer transmissivity, and the hydraulic gradient, which is a modified Darcey calculation. An assessment of recharge to Hawthorn - Zone IV can be made by using a cross-sectional width of 9 miles, a transmissivity of 50,000 gpd/ft and the regional hydraulic gradient of 1.5 feet/mile. The regional flow or recharge rate for Hawthorn Aquifer System - Zone IV is approximately 700,000 gpd. The recharge rate of Suwannee Aquifer System - Zone I is assessed using a cross-sectional width of 9 miles, a transmissivity of 24,000 gpd/ft and a hydraulic gradient of 1.5 feet/mile. The recharge flow is approximately 300,000 gpd.

The combined recharge rate of the aquifers which yield relatively high quality water, Hawthorn Aquifer System - Zones III and IV and Suwannee Aquifer System - Zone I, is approximately 1,200,000 gpd. This value may be slightly higher since the hydraulic gradient estimation for the lower zones is probably low. If the hydraulic gradient in Hawthorn - Zone IV and Suwannee - Zone I is about 2 ft/mile, then the recharge rate for the combined three aquifers is about 1,600,000 gpd.

5. Water Quality

Previous studies have been made on the quality of water in both the shallow and deep aquifers beneath Sanibel Island. Water quality in the water-table aquifer ranges from fresh to very saline and is described in detail by Boggess (1974a) and Missimer (1976). Water in Tamiami Aquifer System - Zone I is very saline throughout Sanibel Island and its quality characteristics are also described in the above mentioned references.

The only occurrance of fresh water known on Sanibel was in the water-table aquifer until a recent exploratory program discovered small quantities possibly in Tamiami Aquifer System - Zone II and in Hawthorn Aquifer System - Zone I at the northwest test site (Missimer and Associates, Inc., 1978). These aquifers were not explored at the test site because of their minor nature.

In order to define the water quality characteristics of Zones II, III, and IV of the Hawthorn Aquifer System and Zone I of the Suwannee Aquifer System, the exploratory test hole was drilled with the reverse air method and packer stem tests were run. Water samples were collected frequently during test drilling. The dissolved chloride concentration and specific conductance of all the samples were measured.

The combined water quality data from both drilling and packer stem testing yielded a conclusive picture of water quality in the aquifers tested. A graph showing the dissolved chloride concentration with depth is given in Figure 4-5. The dissolved chloride concentrations shown were titrated in the field and rechecked in the laboratory. A complete list of data collected during the test program is given in the Appendix (Tables A-5 and A-6).

Hawthorn Aquifer System - Zone II

Water samples collected from Zone II during reverse air drilling showed dissolved chloride concentrations, which range from 10,700 to 12,200 milligrams per liter (mg/l). It is probable that water quality may be even worse in parts of this zone. No packer stem tests were made in Zone II, because use of this water would be impossible. The quality of water in Zone II at this test location is consistent with that observed at other locations on Sanibel (see Missimer, 1976; Missimer and Associates, Inc., 1978).

Hawthorn Aquifer System - Zone III

A major change in water quality occurs across the confining beds between Hawthorn - Zones II and III. The lower part of Zone II contains water with a dissolved chloride concentration of about 12,000 mg/l and water in the upper part of Zone III has a concentration of between 1420 and 1750 mg/l. This quality was confirmed with three packer stem tests. Reverse air water samples collected in the Zone III interval had concentrations of dissolved chlorides ranging from 11,000 mg/l down to 5,550 mg/l (see Figure 4-5). The reason water quality did not improve more drastically in the drilling fluid is that a great deal of mixing occurred going up the borehole. It is also believed that the transmissivity of Zone III is significantly lower than that of Zone II. Therefore, more water was pumped from Zone II compared to Zone III during test drilling and the water discharged at the well head was a mixture of water from the two aquifers.

Water in Zone III at the test site is not as good as that in the same zone at the northwest Sanibel site (see Missimer and Associates, Inc., 1978). Concentrations at the northwest site ranged from 310 to 880 mg/l as compared to this site from 1420 to 1750 mg/l. The character of the Hawthorn Aquifer System on western Sanibel is discussed in more detail in Chapter VI.

Hawthorn Aquifer System - Zone IV

Quality of water in Hawthorn - Zone IV is quite good as evidenced by the reverse air water samples and packer stem tests. Dissolved chloride concentrations in the reverse air water samples ranged from 1250 to 2200 mg/l and the packer stem test samples ranged from 1750 to 1820 mg/l. The two packer stem tests yielded very consistent results, but we believe that the water in the aquifer is slightly better than indicated. One of the water samples collected during drilling had a concentration of 1250 mg/l. It is believed that some water leaked upward

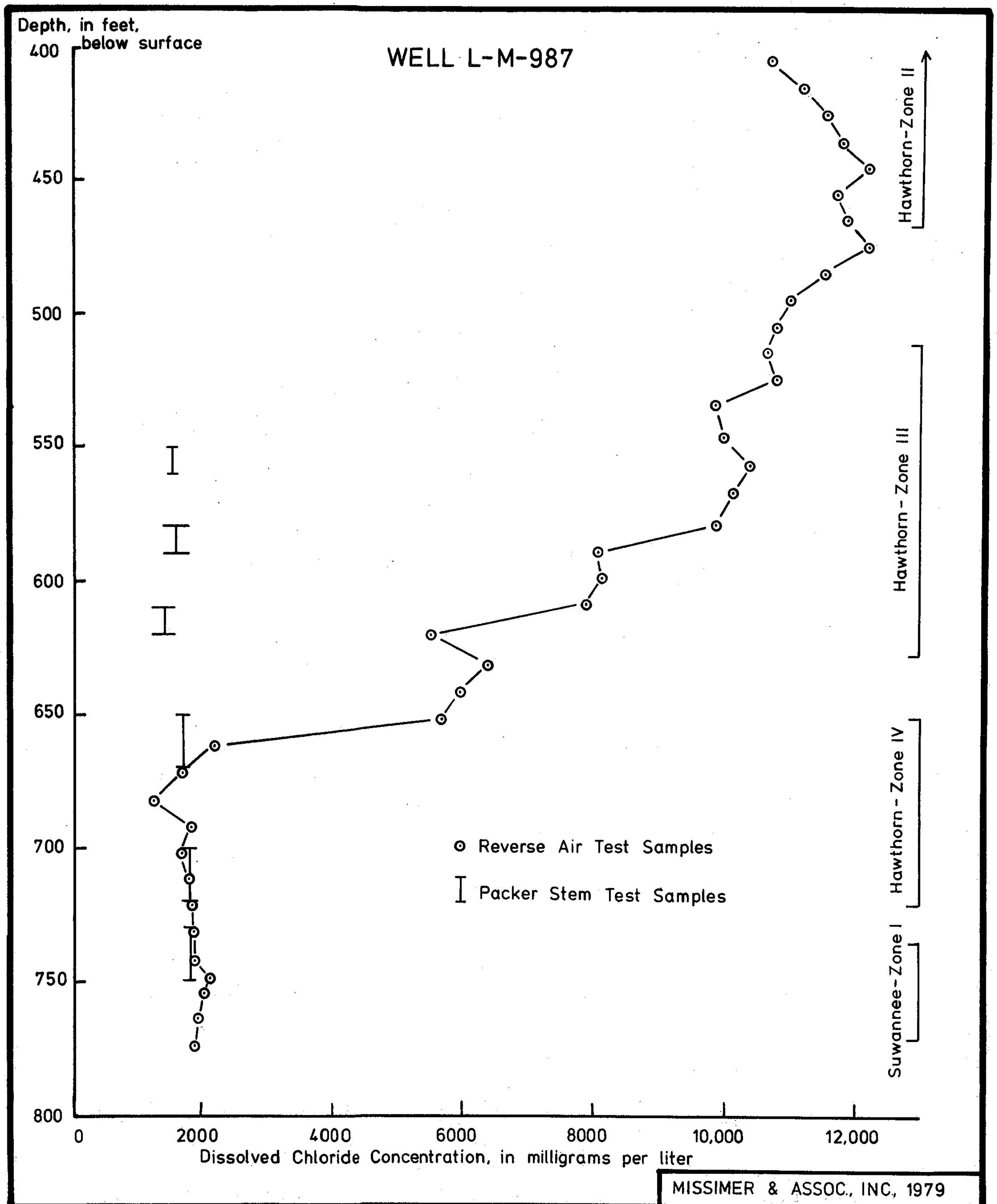

FIGURE 4-5. DIAGRAM SHOWING THE DISSOLVED CHLORIDE CONCENTRATION IN VARIOUS AQUIFERS BENEATH THE TEST SITE.

through the basal packer during the stem tests. The packer arrangement used does not absolutely seal the zone tested, but usually cuts leakage to a minimum. Some stratification of water quality within the aquifer is also possible. The mean water of water yielded from the aquifer lies between 1400 and 1500 mg/l.

Suwannee Aquifer System - Zone I

The quality of water in the Suwannee Aquifer System has been previously explored in a test hole drilled near the present Island Water Association water treatment plant (see Boggess, 1974a; and Missimer, 1976, p. 174). Dissolved chloride concentration measurements in well L-1533 ranged from about 2000 mg/l at 680 feet to about 6000 mg/l at 900 feet below surface in the Suwannee Aquifer System.

Water quality at the top of Suwannee - Zone I was accurately measured in a water sample collected during a packer stem test. The test interval was from 730 to 750 feet and the dissolved chloride concentration was 1840 mg/l. Water samples collected during reverse air drilling yielded a dissolved chloride concentration ranging from 1875 to 2150 mg/l. It is believed that the water is stratified with regard to quality. The more dense, higher salinity water lies at the base of the aquifer.

The production well is open to all of Hawthorn - Zone IV and the upper part of the Suwannee Aquifer System. During the aquifer test, well L-M-987 was pumped at a rate of 900 gpm and the quality of water discharged varied to a predictable degree. The water discharged from the well is in reality a mixture of water being yielded from two separate zones with different water qualities. The dissolved chloride concentrations of samples collected during the aquifer test are given in Table 4-2, and complete chemical analyses of samples collected at the beginning and end of the test are given in the Appendix (Tables A-7 and A-8). There is a marked improvement in water quality from the

TABLE 4-2. DISSOLVED CHLORIDE CONCENTRATIONS IN THE COMPOSITE OF HAWTHORN AQUIFER SYSTEM - ZONE IV AND SUWANNEE AQUIFER SYSTEM - ZONE I DURING THE AQUIFER TEST

Time(minutes)	Missimer and Associates, Inc.	Orlando Lab.
10	1580	1570
150	1400	
210	1400	
360	1400	
480	1400	
740	1400	
910	1400	
1080	1400	
1290	1400	
2220	1400	
2520	1400	
3660	1400	
4305	1400	1440 (1)

(1) See Table A-9

TABLE 4-3. SPECIFIC CONDUCTANCE OF WATER SAMPLES COLLECTED DURING THE AQUIFER TEST.

Time	Specific Conductance(μ mhos/cm)
10	5700
150	4990
210	4990
360	4980
480	4950
740	4980
910	4960
1080	5100
1290	4980
2220	4990
2520	4980
3660	4970
4305	4960

very beginning of the test until equilibrium was reached. In order to confirm this observation, the well was opened to flow at about 100 gpm on February 14, 1979. A sample collected after 2 minutes of flow yielded a dissolved chloride concentration of 1880 mg/l and a sample collected after 2 hours of flow yielded a concentration of 1760 mg/l. The initial improvement in water quality is explained by the temporary intrusion of poorer quality Suwannee Aquifer water under higher head into Hawthorn - Zone IV when the well head was closed. Since a higher percentage of the water yielded from the well comes from Zone IV, the water intruded into Zone IV is yielded at the beginning of flow from the well. The percentage of intruded water in Zone IV lessens with time and therefore, the overall quality of water at the well head improves until equilibrium is reached.

There is an apparent discrepancy between the laboratory data and the data collected in the field near the end of the aquifer test. We believe that water yielded from the combined Hawthorn - Zone IV and Suwannee - Zone I does vary more than indicated by the test results. The second laboratory analysis on the discharged water is apparently in error. No water quality changes were observed from the early to the late chemical analysis, but a definite reduction in the specific conductance and dissolved chloride concentration was measured in the field (Table 4-3). A reanalysis of the last sample showed a dissolved chloride concentration of 1400 mg/l (Table A-9).

6. Summary

There at least five water-bearing zones in Hawthorn Aquifer and Suwannee Aquifer Systems beneath Sanibel Island. Hawthorn - Zone I occurs between 290 and 314 feet below surface. It is a quartz sand with some sandy limestone and is probably equivalent to the Upper Hawthorn Aquifer on the mainland. Hawthorn - Zone II occurs between 355 and 466 feet below surface. It is the uppermost of three separate water-bearing zones collectively termed the Lower Hawthorn Aquifer. Zone II is a light gray limestone. It is separated from Zone I by 35 feet of low permeability clay. Hawthorn - Zone III lies between 510 and 574 feet below surface. It is a tan-gray limestone with medium permeability. Zone III is confined from Zone II by an alternating sequence of clays, limestones, and dolomites. Hawthorn - Zone IV occurs between 648 and 722 feet below surface. It is a white limestone with a trace of phosphorite. Zone IV is confined from Zone III by a 19-foot thick sequence of lime mud and tight limestone. Suwannee - Zone I lies between 734 and 769 feet below surface. It is confined from Hawthorn - Zone IV by 12 feet of clayey limestone. The absolute thickness of the Suwannee Aquifer System is not known and the effectiveness of the 5-foot clayey limestone at the base of Zone I is not known.

An aquifer test was performed on a composite of Hawthorn - Zone IV and Suwannee - Zone I. The following composite aquifer coefficients were determined from the test analysis: transmissivity = 74,000 gpd/ft, storage coefficient = 2×10^{-4}, and leakance = 3.0×10^{-3} gpd/ft^3. The transmissivities of the individual aquifers were estimated to be: Hawthorn - Zone IV = 50,000 gpd/ft and Suwannee - Zone I = 24,000 gpd/ft. The leakance of Hawthorn - Zone IV was estimated to be about 1×10^{-4} gpd/ft^3.

Water quality in Hawthorn - Zone I was not determined during the test program. Hawthorn - Zone II contains very saline water with dissolved chloride concentrations ranging from 10,700 to 12,200 mg/l. Hawthorn - Zone III contains much better water which is slightly saline and contains dissolved chloride concentrations ranging from 1420 to 1750 mg/l. Water quality in Hawthorn - Zone IV has some variation, but has an estimated mean dissolved chloride concentration of between 1400 and 1500 mg/l, which was the best quality observed at the test site. Suwannee Aquifer System - Zone I contains water with slightly poorer quality than the overlying aquifer. Water in the zone contains dissolved chloride concentrations ranging from 1875 to 2150 mg/l and the aquifer is density stratified.

V. AQUIFER YIELD AND WATER MANAGEMENT

1. Introduction

Three water-bearing zones which yield acceptable quality water have been located beneath the test site on Sanibel. These zones are Hawthorn Aquifer System - Zones III and IV and Suwannee Aquifer System - Zone I. A substantial volume of water can be pumped from these zones if the pumping rates are controlled and a viable water management program is utilized. It is therefore necessary to discuss some specific aquifer yield characteristics and required management practices.

2. Potential Yield

The potential yield of an aquifer system, such as that beneath Sanibel, must be defined in terms of volume alone. Therefore, because pumpage induces flow of water from zones above and below into a pumped zone, the quality and volume of water leaking from these zones is as significant or more significant than the volume of lateral recharge through the aquifer, and all recharge sources must be considered.

The volume of water moving through the useable aquifers from the mainland has been evaluated in Chapter IV, Section 4 to be a total of about 1.6 MGD. The percentage of the lateral recharge which is recoverable is variable depending on pattern of pumping and the area influenced by the pumping. The larger and steeper the cone of depression caused by pumping, the larger the area of regional flow intersected and the subsequent amount of lateral recharge captured.

A conceptual model of the capture of lateral flow through the aquifer system is given in Figure 5-1. This diagram was prepared for a pumping rate of 1.44 MGD (1000 gpm) from two wells spaced a distance of 1000 feet apart. The wells tap only Zone IV of the Hawthorn Aquifer System. The figure accounts

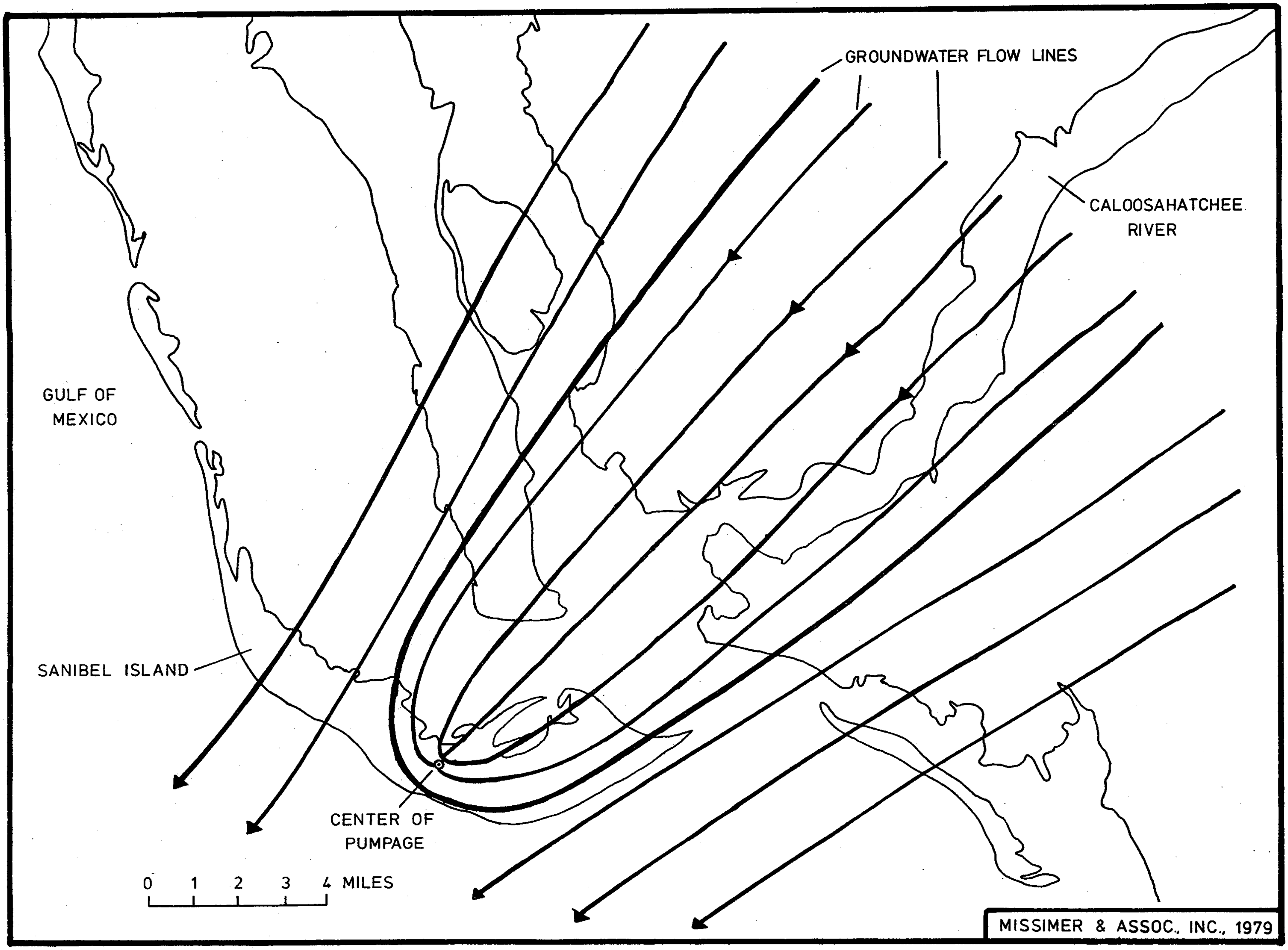

FIGURE 5-1. MAP SHOWING LATERAL RECHARGE CAPTURED WITHIN HAWTHORN AQUIFER SYSTEM - ZONE IV WHILE PUMPING THAT ZONE AT 1000 GPM.

for both the cone of depression created by pumping and the regional hydraulic gradient of Zone IV. The amount of lateral flow intercepted is about 0.6 MGD or about 40 percent of the total volume of water pumped from the wells. The remaining 60 percent of the pumpage is derived from vertical leakage originating in water-bearing zones above and below the pumped zone or in this case Hawthorn - Zone III and Suwannee - Zone I (see Figure 4-1).

The amount of lateral recharge intercepted can be increased by increasing the well spacing. However, because of the leaky nature of this aquifer system, it is not possible to derive the full volume of pumpage from strictly lateral recharge. It is therefore necessary to maximize the inflow of the best quality water into the production zone in order to maintain a high quality standard.

Hawthorn Aquifer System - Zone IV contains the best quality water of the useable zones and it is bordered above and below by other water-bearing zones which contain acceptable water quality. The hydraulic characteristics of Zone IV are also comparatively best for designation as the primary production zone. It is therefore most desirable to develop Zone IV as the production zone for all water-supply wells required by the Island Water Association. The quality of water in Zone IV will change to a certain degree with time but will still be useable.

3. Predicted Water Quality Changes

It is possible to quantitatively assess induced changes in water quality if the hydraulic and water quality characteristics of an aquifer system are well understood. Although not all of the necessary information is available on each water-bearing zone, estimates of each parameter can be made at an accuracy level adequate to assess long-term quality changes in the production zone.

The method used to assess the quality change is one of preparing a mass balance, which accounts for flow of dissolved chloride ions into and out of the production zone or other zone of concern. The dissolved chloride ion concentration was chosen for analysis because its concentration in each zone is well known.

Knowledge of the hydraulic characteristics of an aquifer allow determination of the amount of water flowing into a zone from above, below, and from lateral flow. The known water quality characteristics along with the hydraulic characteristics are used in the following basic equation:

$$I_t = I_o + I_i - I_r$$

where, I_t = dissolved chloride ion at a given time

I_o = original concentration of dissolved chloride ions

I_i = inflow of dissolved chloride ions from vertical leakage and horizontal flow

I_r = removed dissolved chloride ions by leakage or pumpage

In a multi-zoned aquifer system, the dissolved ion concentration with time must be calculated for each of the contributing zones, because water quality changes in each zone due to loss of water and its replacement with water of a different chemical quality. For example, if Zone IV is the production zone, then a certain volume of water enters it as leakage from both Hawthorn - Zones III and Suwannee - Zone I. In turn, water leaks from Hawthorn - Zone II into Zone III and from the lower part of the Suwannee into Zone I. It is a dynamic and very complex system.

The dissolved chloride mass balance method was used to calculate the anticipated water quality change which would take place in 10 years within Hawthorn - Zones III and IV and Suwannee - Zone I for a pumping rate of 1.44 MGD from two wells spaced 1000 feet apart. Only Zone IV is pumped. Predicted changes in the concentration of dissolved chlorides are:

1) For Hawthorn Aquifer System - Zone III
   Present: 1500 mg/l
   After 10 years: 2200 mg/l

2) For Hawthorn Aquifer System - Zone IV
   Present: 1400 mg/l
   After 10 years: 2200 mg/l

3) For Suwannee Aquifer System - Zone I
   Present: 2000 mg/l
   After 10 years: 2500 mg/l

It should be noted that these values are only estimates and their reliability is related to validity of existing information. In order to make more accurate predictions, the following information is required: a leakance value must be obtained for Hawthorn - Zone IV alone, the hydraulic and water quality characteristics must be obtained for various parts of the Suwannee Aquifer System, and the relative potentiometric heads of all the major zones should be known. This information should be collected before extensive development of Zone IV is initiated.

4. Water Management

This investigation has provided some rather conclusive evidence that the Island Water Association should develop Hawthorn Aquifer System - Zone IV as its primary source of raw water. There are numerous considerations to be made in order to properly develop and protect this source.

The quality of water in Zone IV will remain useable over a very long time period if it is the only zone pumped in the system. Continued pumping of Hawthorn Aquifer System - Zone III wells will lead to more rapid degradation of water quality in the overall system. Therefore, all Zone III wells should eventually be phased out of use, with the exception of those in the northwest area of Sanibel where continued pumping would not be harmful to the hydrologic system because of the exceptionally good quality water in that area.

Many of the older wells were constructed by the cable tool method utilizing steel casing. These wells should be logged and thoroughly investigated to be sure that they are not allowing interaquifer exchange of poor quality water. All unused or suspected wells should be immediately plugged with cement. Some of the old wells could be deepened into Zone IV and a liner could be installed and pressure grouted in place to seal off potentially harmful shallower zones.

If a few of the required new wells are constructed utilizing the reverse air drilling method in the lower borehole, sufficient information will be available to accurately locate the desired water-bearing zones using geophysical logs. This would allow for conventional direct circulation drilling of future wells at a savings of 50 percent on each well.

5. Monitoring Requirements

In order to successfully develop Hawthorn Aquifer System - Zone IV, some additional observation wells should be constructed near the production well at the new water plant. One of these wells should tap Hawthorn Aquifer System - Zone III in order to monitor potentiometric head and water quality changes. One well should be constructed into Suwannee Aquifer System - Zone I for the same general purpose. The pumping zone, Hawthorn -

Zone IV, should be monitored at the existing observation well site, L-M-988. A deep exploratory hole should be drilled into the lower part of the Suwannee Aquifer System in order to test the quality of water. The success of the Zone IV development program is greatly dependent on how the quality of water changes with depth in the Suwannee Aquifer System. Therefore, the lower part of this hole should be drilled with reverse air and should be packer stem tested. This deep testing could be accomplished during the drilling of the next production well on the site in order to reduce costs. An observation well should be finished in the lower part of the aquifer at a nearby location.

6. Summary

Hawthorn Aquifer System - Zone IV will potentially yield a substantial volume of useable water for the new reverse osmosis treatment plant. If 1.44 MGD of water is withdrawn from the aquifer through two wells spaced a distance of 1000 feet apart, about 0.6 MGD or 40 percent of the water will be intercepted recharge. The remaining 60 percent of the pumpage will come from vertical leakage.

A mass balance technique was used to predict the increase in dissolved chloride concentration within Hawthorn - Zones III and IV and Suwannee - Zone I due to the removal of 1.44 MGD of water. In 10 years of pumpage, the Zone III chloride concentration will increase from 1500 to 2200 mg/l; the Zone IV concentration will increase from 1400 to 2200 mg/l; and the Zone I concentration will increase from 2000 to 2500 mg/l.

All future withdrawals of water in central Sanibel should originate from Hawthorn - Zone IV only. Withdrawals from Hawthorn - Zone III should be phased out entirely. Old production wells should be thoroughly investigated to assure sound construction.

A few new observation wells should be constructed near the center of pumpage at the new water plant. One well should be constructed into each of the following zones: Hawthorn - Zone III; Suwannee - Zone I; and the lower part of the Suwannee Aquifer.

VI. IMPACT ASSESSMENTS

1. Impact on the Aquifer System

The impact of pumping Hawthorn Aquifer System - Zone IV and Suwannee Aquifer System - Zone I was assessed for two conditions. These were for the simultaneous pumping of both zones, and for pumping only Zone IV of the Hawthorn Aquifer.

A pumping rate of 1.44 MGD was selected for the assessment because this is the anticipated useage during the first phase of production by the new water plant. The pumpage is to be divided among two wells with pumping rates of 500 gpm each. Equilibrium determinations were made for two different production zone conditions because the hydraulic coefficients for Hawthorn Aquifer System - Zone IV are only estimated, while those of the composite Hawthorn - Zone IV and Suwannee - Zone I are actually calculated from a test.

The cone of depression for each of the conditions are shown in Figures 6-1 and 6-2. For the two zone pumping condition, the maximum drawdown in the production wells would be approximately 60 feet, which is based on the well efficiency experienced in the test production wells. This drawdown corresponds to a pumping lift of approximately 40 feet. The pumping lift for producing from only Hawthorn - Zone IV should be approximately 45 feet. The distance to the 1-foot drawdown contour is about 6.5 miles for pumping only Hawthorn - Zone IV, while it is only about 1.5 miles for the two zone pumping situation.

Spacing of the production wells is not a significant consideration regarding drawdowns. A minimum spacing of about 300 feet should be maintained however, for the 1000 gpm pumping rate. With regard to intercepting recharge, best results will be obtained by spacing pumping centers as far apart as possible, ideally 2 to 3 miles.

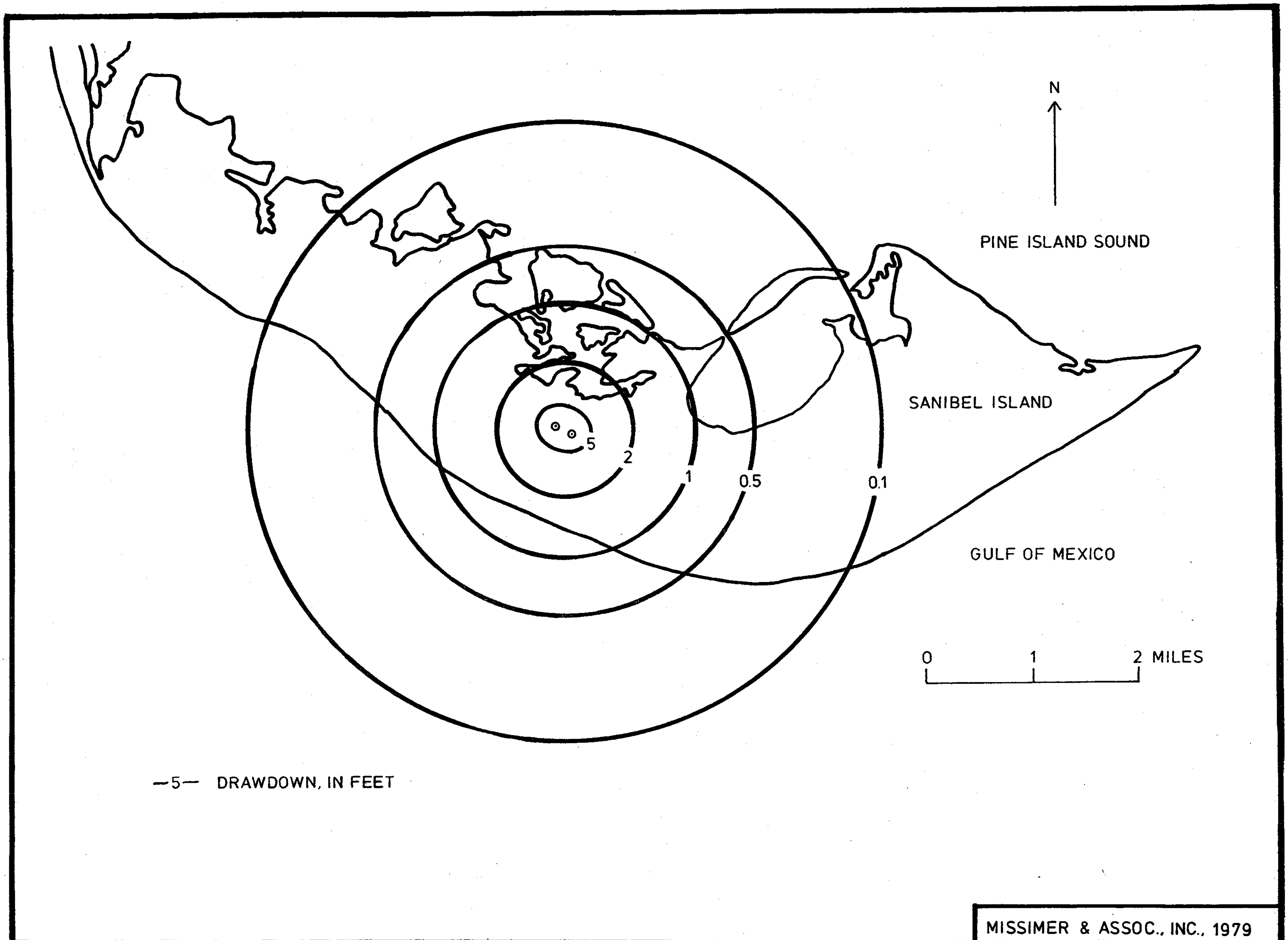

FIGURE 6-1. PREDICTED EQUILIBRIUM CONE OF DEPRESSION FOR A WITHDRAWL RATE OF 1.44 MGD FROM 2 WELLS IN COMBINED HAWTHORN AQUIFER SYSTEM-ZONE IV AND SUWANNEE AQUIFER SYSTEM-ZONE I.

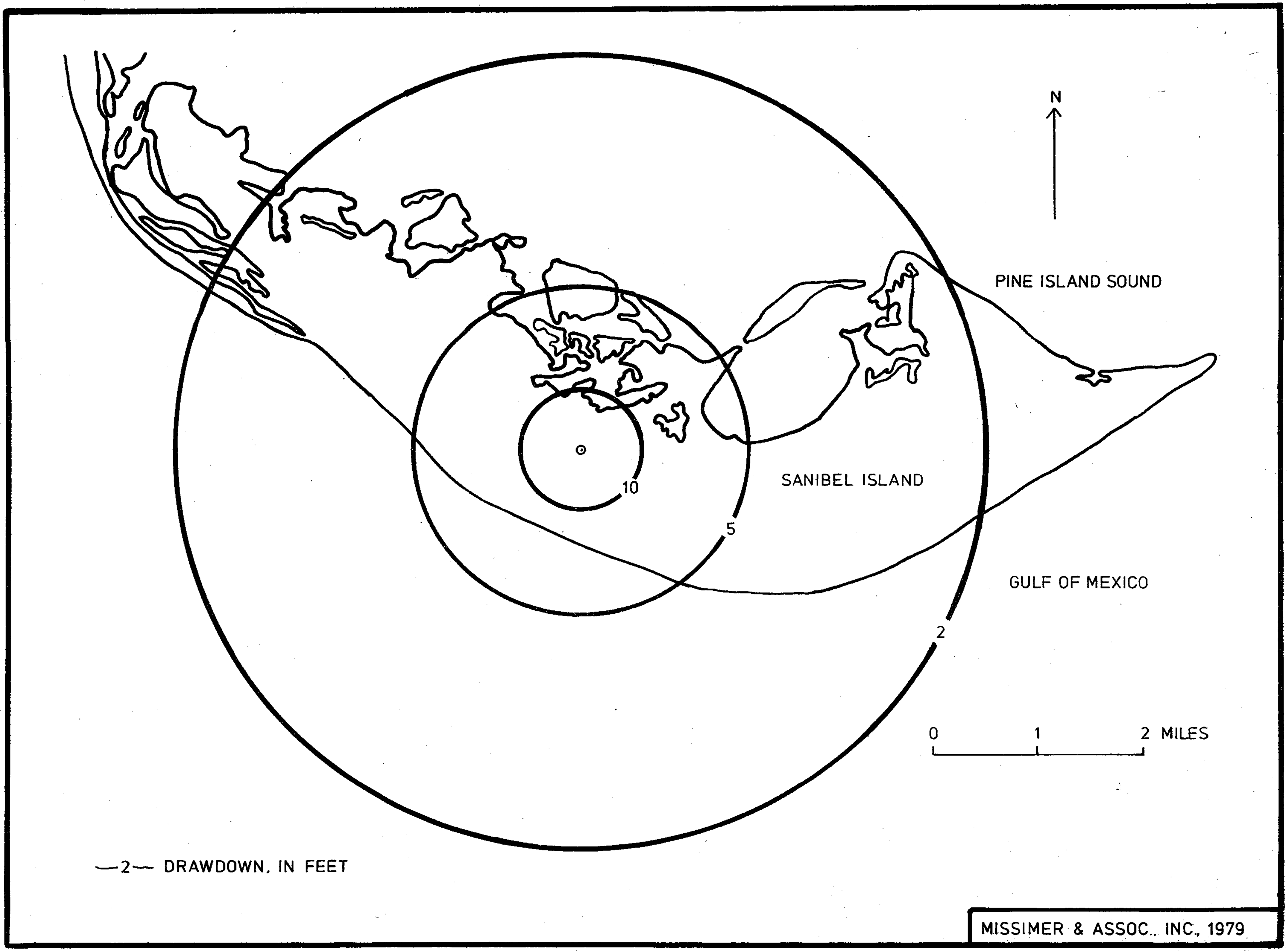

FIGURE 6-2. PREDICTED EQUILIBRIUM CONE OF DEPRESSION FOR A WITHDRAWL RATE OF 1.44 MGD FROM 2 WELLS IN HAWTHORN AQUIFER SYSTEM-ZONE IV.

Water quality in both Suwannee Aquifer System - Zone I and Hawthorn Aquifer System - Zone IV will decline gradually due to the fact that more water is being withdrawn from those zones than is being recharged from the mainland. This process was explained in Chapter V, Section 3. It is likely that for the proposed pumping plan water quality will tend toward a new equilibrium with the salinity stabilizing at a value higher than the present one, but still economically treatable. To estimate the water quality characteristics of the production zone at equilibrium would require more detailed information on the lower part of the Suwannee Aquifer.

VII. GEOLOGY AND HYDROLOGY OF SANIBEL ISLAND

1. Introduction

A discussion of the general geology and hydrology of Lee County and its relation to that of Sanibel was presented in a recent report to IWA and does not merit further discussion (see Missimer and Associates, Inc., 1978b). A large quantity of new information on the subsurface conditions beneath Sanibel is now available. It is the purpose of this chapter to summarize what is now known about the hydrogeology of the Hawthorn and Suwannee Aquifer Systems beneath western Sanibel Island. Information is utilized from the northwest test site (Missimer and Associates, 1978b), the school site (Geraghty & Miller, 1978), and the new water plant site (Chapter IV).

2. Geology

The reverse air drilling technique has facilitated the collection of very accurate geologic data. Samples of formation material have been collected at intervals as small as two feet with considerable reliability.

It is now possible to draw some specific conclusions with regard to the geology of the Miocene and Oligocene sediments beneath western Sanibel Island. There are three distinctive, homogeneous sequences of "clean" limestone within the Hawthorn Formation. These limestone bodies are separated by sequences of alternating lime muds, dolomites, and limestones of extremely diverse lithic character. Between 10 and 12 different beds, most of which are less than 10 feet thick, separate the lowermost limestone from the middle limestone unit. This multicharacter sequence ranges from 80 to 100 feet thick. Between 4 and 6 different beds, with variable lithic character, separate the uppermost limestone unit from the middle limestone unit. This sequence ranges from 40 to 50 feet thick. The "clean" limestones are distinctive, mapable geologic units and they form the major water-bearing zones within the Hawthorn Aquifer System. It should be noted that the lime mud portions of the sequence can be very accurately correlated by use of gamma ray logs, because they exhibit very low gamma activity compared to adjacent sediments. The lowermost part of the Hawthorn Formation is a bed of carbonate mud and limestone, which appears to mark the formational boundary with the Suwannee Limestone.

Many investigators have termed the lowermost major limestone in this phosphatic sequence, the Tampa Limestone. It does not appear to have a different lithic character than the overlying limestones nor does it exhibit any distinguishable fossil change. Therefore, it is considered to be a part of the Hawthorn Formation.

The upper 45 feet of the Suwannee Limestone was penetrated in well L-M-987. It is a light tan limestone, which is similar to published type lithologies occurring within this unit. It does contain some marly or clayey sediments.

3. Hydrology

The two separate hydrogeologic investigations completed to date, do tend to confirm the multi-zone concept within the Hawthorn Formation beneath Sanibel. Four distinctive water-bearing units occur, which are separated by distinct confining beds (see Figure 7-1). Each zone has a unique set of both hydraulic and water quality properties. The lower Hawthorn zones tend to slope downward from northwest Sanibel to the east and south.

The water quality in Zone III declines consistently from northwest to southeast. Dissolved chloride concentrations range from about 400 mg/l at well L-M-943 to 625 mg/l at the school well to about 1600 mg/l at well L-M-987. A similar increase can

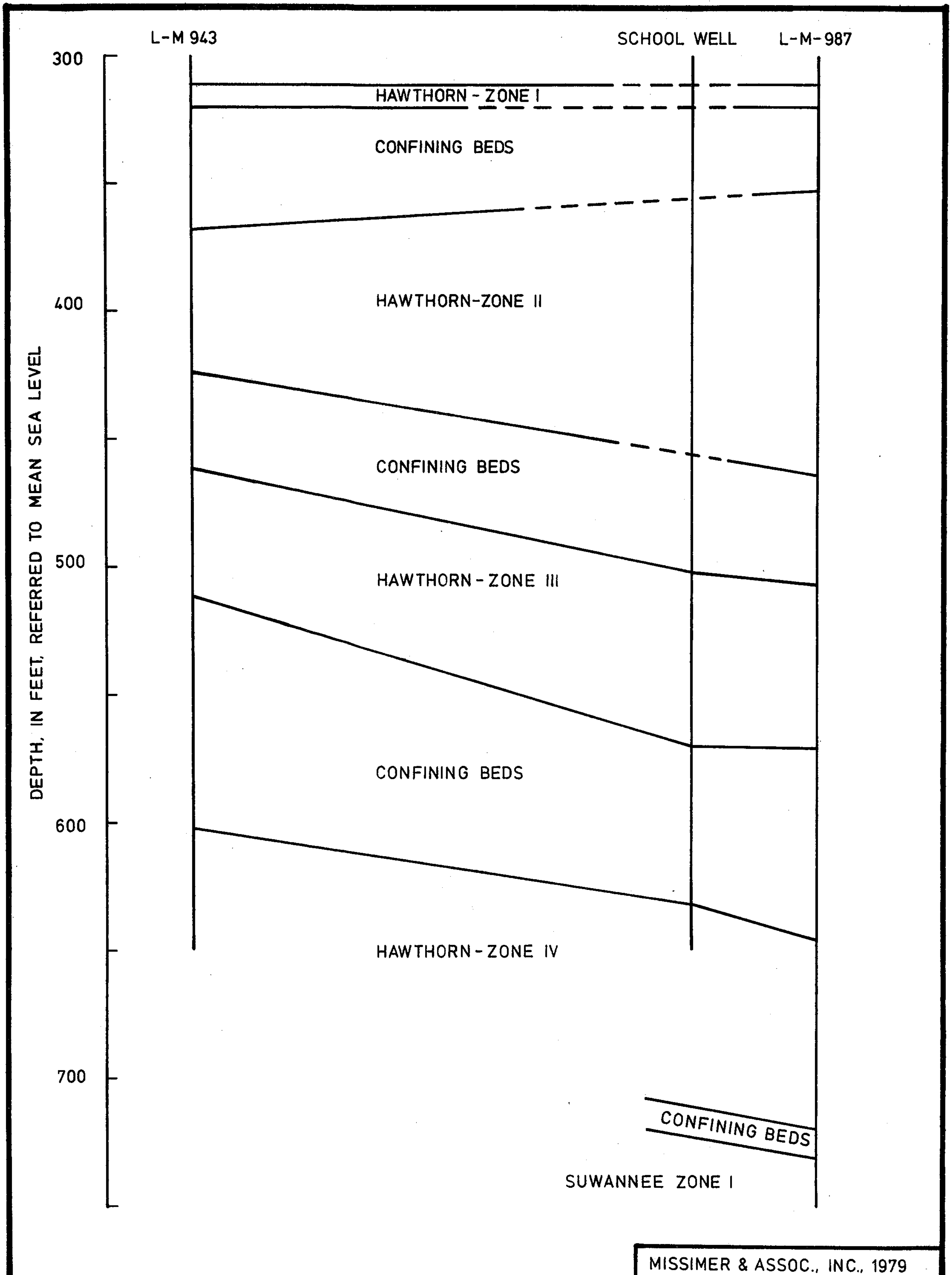

FIGURE 7-1. HYDROGEOLOGIC SECTION SHOWING THE LOCATION OF VARIOUS WATER BEARING ZONES

be observed in Zone IV. The dissolved chloride concentration at well L-M-943 is 880 mg/l and at well L-M-987 is about 1400 mg/l. The large variations in water quality observed in the IWA production wells located along Sanibel-Captiva Road is the probable result of poor well construction with the production interval in each well being open to parts of several water-bearing zones. This rather simple relationship should be confirmed by utilizing all available data before it is used for positioning wells. It is also probable that in certain areas the variation in quality of water within Hawthorn - Zones III and IV is due to vertical fracturing and changes in the effectiveness of the confining beds separating the zones.

VIII. REFERENCES

Boggess, D.H., 1974a, The shallow fresh-water system of Sanibel Island, Lee County, Florida, with emphasis on the sources and effects of saline waters: Florida Department of Natural Resources, Bureau of Geology, Rept. of Investigation No. 69, 52 p.

Boggess, D.H., 1974b, Saline ground-water resources of Lee County, Florida: U.S. Geological Survey, open-file report No. 74-247, 62 p.

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

Dunham, R.J., 1962, Classification of carbonate rocks according to depositional textures in Classification of Carbonate Rocks (ed. W.E. Ham): Am. Assoc. of Petro. Geologists, Tulsa, Oklahoma.

Folk, R.L., 1968, Petrology of Sedimentary Rocks: University of Texas, Austin, Texas.

Geraghty & Miller, Inc., 1978, Effects of ground-water withdrawals from the lower Hawthorn aquifer on Sanibel Island, Florida, Report to Island Water Association.

Hantush, M.S., and Jacob, C.E., 1955, Nonsteady radial flow in an infinite leaky aquifer, Am. Geophys. Union Trans., V. 36, No. 1, pp. 95-100.

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.

Meinzer, O.E., 1959, The occurrence of groundwater in the United States, U.S. Geological Survey, Water Supply Paper 481.

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

Missimer and Associates, Inc., 1978b, Hydrologic Investigation of the Hawthorn Aquifer System in the northwest area, Sanibel, Florida: Rept. to the Island Water Association, Inc., 101 pp.

Missimer, T.M., 1976, Sanibel Island: Hydrology in The Sanibel Report: Formulation of a comprehensive land use land plan based on natural systems (ed. John Clark): The Conservation Foundation, Washington, D.C.

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

Missimer, T.M., and Gardner, R.A., 1975, High resolution seismic reflection profiling, a useful tool in mapping shallow aquifers underlying part of Lee County, Florida, U.S. Geological Survey, Water Resources Investigation, 76-45, 30 pp.

Robinson, E.S., and Bell, R.T., 1971, Tides in confined well-aquifer systems: Journal Geophys. Research, V. 76, No. 8, 1857-1869 pp.

Sproul, C.R., Boggess, D.H., and Woodard, H.J., 1972, Saline-water intrusion from deep artesian sources in the McGregor Isles area of Lee County, Florida: Fla. Bur. of Geology Inf. Cir. No. 75, 30 pp.

Volkert & Associates, Inc., 1977, Report to the Island Water Association: Analysis of plant operations and future options.

Walton, W.C., 1960, Leaky artesian aquifer conditions in Illinois: Illinois State Water Survey, Rept. of Invest. 39.

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

APPENDIX

TABLE A-1. GEOLOGIST'S LOG - WELL L-M-987

Depth(ft.)	Description
0-2	Sand, quartz, lt. gray, fill material, medium permeability
2-10	Sand and shell, tan, interbedded sequence of quartz sand and shell, beds 0.5 to 1.0 feet thick, very high permeability
10-16	Sand and shell, gray, quartz sand - fine subangular, well sorted, interbedded sequence, high permeability
16-20	Clay, gray, and shell, mixed sequence of shell fragments, quartz sand, and lime mud, more than 30% lime mud, low permeability
20-26	Shell and clay, gray, sandy, approximately 20-25% lime mud, 50-60% lime mud, and 20-25% quartz sand, mixed sequence, medium to low permeability
26-33	Limestone, gray and tan, medium hard, mixture of sparse biomicrite and unsorted biosparite, wackestone mixed with crystalline carbonate, 5-10% quartz sand, medium to high permeability
33-34	Limestone, tan and gray, tan limestone is a biosparite, gray limestone is a dismicrite, overall rock is a wackestone, slightly sandy, vugged, high permeability
34-50	Limestone, gray to white, many different lithologies, mostly fossilferous micrite, wackestone, loss of circulation, no samples between 40 and 50 feet, very high permeability
50-55	Limestone, white, hard, fossilferous micrite, wackestone, some quartz sand and microphosphorite nodules, apparent secondary porosity, high permeability
55-60	Limestone, white, hard, dismicrite, mudstone to wackestone, some vugs filled with secondary carbonate, trace of sand and phosphorite, medium to high permeability

TABLE A-1. GEOLOGIST'S LOG - WELL L-M-987 (CON'T.)

Depth(ft.)	Description
60-62	Limestone, white, same generally as above, very little phosphorite, decorated vugs, medium to high permeability
62-64	Limestone, tan, with large fragments of phosphatized limestone, sparite, crystalline aggregate, some quartz sand and microphosphorite nodules, medium permeability
64-65	Clay, green, very pure lime mud, less than 10% shell, and quartz sand and silt, very thin bed, very low permeability
65-75	Limestone, gray, soft, mixture of shell and bedded limestone, overall biomicrite, wackestone, sandy, some phosphorite, medium permeability
75-85	Limestone, gray and tan, interbedded biomicrite and biosparite, quartz sand in biomicrite, wackestone, medium permeability
85-95	Limestone and marl, gray, biomicrite, wackestone, grades from limestone into marl from top to bottom, marl at base is a mixture of lime mud and quartz sand and silt, 25-35% matrix, medium to low permeability
95-105	Marl, gray, mixture of lime mud, quartz sand, rock fragments, and phosphorite nodules, low permeability
105-115	Marl, gray, same as above, more than 50% quartz sand and silt, low permeability
115-124	Marl, gray, lime mud (15-25%), shell (25-30%), rock fragments (25-35%), and quartz sand (15-20%), low permeability
124-127	Marl, green, lime mud and clay with shell, rock fragments, and quartz sand, greater percentage of clay, low permeability

TABLE A-1. GEOLOGIST'S LOG - WELL L-M-987 (CON'T.)

Depth(ft.)	Description
127-137	Silt and clay, green, trace of microphosphorite nodules, quartz silt and sand, lime mud, with some rock fragments and shell, low permeability
137-147	Clay, green, mixture of lime mud, quartz sand, some shell and rock fragments (may be recirculated from above), trace of phosphorite, low permeability
147-151	Clay, green, lime mud with some clay minerals, mixed with quartz sand and silt and rock fragments; 25-35% matrix, low permeability
151-159	Limestone and clay, cream to lt. gray, clay is green, sandy - either interbedded or from above, limestone - sandy micrite, mudstone, quartz sand impurity, abundant phosphatized limestone, medium to low permeability
159-169	Limestone, tan, gray, and cream, medium hard, biomicrite, wackestone, some sparrey calcite, abundant phosphorite, medium permeability
169-174	Limestone, lt. gray to gray, biomicrite and micrite, mudstone to wackestone, lighter color limestone contains quartz sand, less phosphorite than above, medium permeability
174-179	Limestone, cream to lt. gray, biomicrite, wackestone, abundant very fine, quartz sand, medium permeability
179-184	Limestone, lt. gray, dismicrite, wackestone, quartz sand abundant, some unlithified carbonate mud, medium to low permeability
184-189	Limestone, lt. gray, soft, micrite to biomicrite, wackestone, marly, some unlithified lime mud, low permeability
189-198	Marl, gray-green, lime mud-clay mixture, shell, quartz sand, and limestone fragments, about 15% interbedded limestone, low permeability

TABLE A-1. GEOLOGIST'S LOG - WELL L-M-987 (CON'T.)

Depth(ft.)	Description
198-209	Limestone, gray, biomicrite, wackestone, immature, lime mud abundant, low permeability
209-216	Limestone, lt. gray, dismicritic, wackestone, sandy limestones, appears pelleted, some phosphorite, metallic mineral, medium permeability
216-220	Limestone, lt. gray, biomicrite, wackestone, sandy, similar to above, medium permeability
220-224	Limestone, lt. gray, same generally as above, some gray-green lime mud, phosphorite nodules abundant, medium to low permeability
224-230	Clay, gray, mostly lime mud matrix, concentrated of phosphorite nodules in or above, poor sample, low permeability
230-240	Clay, gray-green, lime mud with quartz sand, most quartz grains well-rounded, phosphorite nodules abundant, low permeability
240-250	Clay, gray-green, lime mud and clay, very sandy, more than 50% quartz sand and silt, some shell, abundant phosphorite, gravel, low permeability
250-255	Clay, gray, lime mud matrix, 50-70% quartz sand and silt, less phosphate than above, low permeability
255-264	Clay, gray, lime mud matrix, 40-50% quartz sand and silt, micro-phorphorite nodules - less abundant than above, low permeability
264-270	Clay, dark gray, lime mud with 30-40% quartz sand, some phosphorite (very fine sand size), low permeability
270-282	Clay, gray-green, lime mud and quartz sand, phosphorite nodules, low permeability
282-290	Clay, gray, lime mud, quartz sand 50-60%, thin, lower density of phosphorite, low permeability

TABLE A-1. GEOLOGIST'S LOG - WELL L-M-987 (CON'T.)

Depth(ft.)	Description
290-300	Sand, gray, quartz sand (65%), lime mud (10%), phosphorite sand (15%), medium to low permeability
300-314	Sand and silt, gray, quartz, similar to above, lime mud (10-15%), low permeability
314-320	Limestone and sand, white and gray, sand ends at above 314 feet, limestone begins at 314 feet, white, soft, marly, wackestone, sandy, phosphatic, could be interbedded with some quartz sand, low permeability
320-324	Marl and sand, lt. gray, marly limestone, wackestone, sandy and quartz sand with lime mud, phosphatic, medium to low permeability
324-330	Marl, lt. gray, micrite, mudstone, lime mud with quartz sand and sand-size phosphorite nodules, low permeability
330-335	Clay and limestone, interbedded lt. gray limestone and gray, lime mud, quartz sand 15-20%, phosphorite nodules abundant, low permeability
335-344	Marl, lt. gray-green, lime mud with quartz sand and phosphorite, some bedded limestone same composition but lithified, low permeability
344-350	Clay, green-gray, lime mud and clay matrix, quartz sand and silt (35-40%), abundant phosphorite nodules (125-250), low permeability
350-360 -355-	Limestone and clay, gray, two separate lithologies, clay - lime mud, quartz sand and phosphorite, limestone (from 355 feet), white to lt. gray, soft, some shell, biomicrite, wackestone, sandy, medium to low permeability
360-370	Limestone, lt. gray, soft, biomicrite, wackestone, some unlithified lime mud, quartz sand abundant, phosphatic, medium to low permeability

TABLE A-1. GEOLOGIST'S LOG - WELL L-M-987 (CON'T.)

Depth(ft.)	Description
370-378	Limestone, lt. gray, medium hard, biomicrite, wackestone, trace of quartz sand, some sand-size phosphorite nodules, medium permeability
378-387	Limestone, lt. gray, medium hard, same as above, medium permeability
387-395	Limestone, lt. gray, medium hard, biomicrite, wackestone, 5-10% quartz sand, 1-3% phosphorite, medium to high permeability
395-420	Limestone, lt. gray, medium permeability
420-425	Limestone, white to lt. gray, hard, biomicrite, wackestone, less than 1% quartz sand, trace microphosphorite nodules, evident secondary porosity, medium to high permeability
425-430 427-429? clay	Limestone, white to lt. gray, hard, same as above, with a thin bed of green lime mud, estimated to occur between 427 and 429 feet, limestone - medium to high permeability, clay - low permeability
430-435	Limestone, white to lt. gray, hard, biomicrite, wackestone, decorated vugs, trace of quartz sand, very fine phosphorite nodules, high permeability
435-440	Limestone, white to lt. gray, same as above, medium to high permeability
440-445	Limestone, white to lt. gray, hard, biomicrite, wackestone, some intra-formation breccia - lt. gray limestone fragments in white, limestone matrix, vugged, high permeability
445-450	Limestone, white, hard, biomicrite, wackestone, low percentage of shell fragments, very little quartz sand and phosphorite, medium to high permeability
450-466	Limestone, white, lt. gray and tan, same generally as above, medium permeability

TABLE A-1. GEOLOGIST'S LOG - WELL L-M-987 (CON'T.)

Depth(ft.)	Description
466-470	Clay, green, fat, more than 90% lime mud and clay minerals, absence of quartz sand, only small trace of phosphorite, very low permeability
470-472	Clay, green, very uniform lime mud, over 95% matrix, same as above, very low permeability
472-478	Clay, lt. green, silty, appears like erosional clay remnant, more than 85% matrix, probably a higher percentage of the matrix is true clay minerals, very low permeability
478-480	Limestone, tan - lt. green, dolomitic, hard, mudstone, micrite, similar composition to overlying lime mud, very low concentration of phosphorite, low permeability
480-483	Clay and limestone, green, interbedded green limestone - mudstone, hard, and green lime mud, fragments of white, sparite, may be thin bed, low permeability
483-485	Limestone and clay, gray-tan, interbedded, biomicrite (wackestone) and bedded lime mud, reef-backreef complex, medium to low permeability
485-490 muddy	Limestone, white, soft, interbedded with some lime mud, limestone - wackestone, lime mud has some composition, the lithified limestone is just partially cemented lime mud, trace of phosphorite, challed texture, low permeability
490-495	Dolomite, tan, microcrystalline, very hard, mudstone, brown color at top, lower section vugged, medium permeability
495-499	Limestone, lt. tan, micrite, mudstone, medium hard, highly altered by secondary solution, some fragments of gray limestone cemented in matrix, very high permeability
499-506	Clay, lt. gray-tan, nearly 98% lime mud, dense, very uniform texture, very low permeability

TABLE A-1. GEOLOGIST'S LOG - WELL L-M-987 (CON'T.)

Depth(ft.)	Description
506-510	Clay, lt. gray-tan, same as above, small quantities of metallic-like mineral, very low permeability
510-512	Limestone, white to gray, two types, upper limestone - mudstone, soft, slightly lithified lime mud, lower limestone - dismicrite mudstone, crystalline, vugged, low to high permeability
512-516	Limestone, lt. tan, hard, dismicrite, mudstone, nearly all shell material selectively removed, vugged, decorated solution cavities, high permeability
557-560	Limestone, lt. gray-tan, soft, micrite, mudstone, chalky texture, poorly lithified lime mud, 5-10% phosphorite, trace of shell and quartz sand, low permeability
560-566	Limestone, lt. gray-tan, soft and medium hard, same generally as above, low permeability
566-569	Limestone, lt. tan, hard, biomicrite, wackestone, shell material selectively removed, molds and casts, some large fragments of phosphatized limestone, medium to high permeability
569-574	Limestone, lt. tan-gray, hard, biomicrite, wackestone, with some thin bedded lime mud near base, mud contains large quantity of phosphorite, limestone - medium permeability
574-578	Clay, lt. gray and gray-green, laminated lime mud, alternating bands 1 to 4 mm thick, quite phosphatic, low to very low permeability
578-579	Limestone, gray-tan, biomicrite, wackestone, appears to be lithified primary lime mud, large concentration of phosphorite, medium to low permeability
579-588	Limestone, and dolomite, tan to lt. gray, very hard, micrite and biomicrite, mudstone and wackestone, all shell material selectively removed, high phosphorite concentration, dolomite, microcrystalline, medium permeability

TABLE A-1. GEOLOGIST'S LOG - WELL L-M-987 (CON'T.)

Depth(ft.)	Description
588-589	Clay, lt. tan to cream, lime mud, some small limestone fragments and a trace of phosphorite, low permeability
589-595	Limestone, tan, medium hard, biomicrite, wackestone, recrystallized - could be termed sparrey, lithified primary mud, some shell remains, slightly phosphatic, medium to low permeability
595-599	Marl, lt. gray, lime mud and limestone gragments with phosphorite sand (very fine), low permeability
599-604	Limestone and clay, brown limetsone - microcrystalline, micrite, and gray lime mud, overall medium to low permeability
604-608	Clay, lt. gray-tan, fat, primarily lime mue with some phosphorite, very low permeability
608-610	Limestone, lt. gray-tan, medium hard, micrite to biomicrite, wackestone, widely spaced, trace of phosphorite vugs, medium permeability
610-616	Limestone, lt. gray-tan, very hard, same as above, medium permeability
616-620	Limestone, tan, medium hard, wackestone, same generally as above, higher degree of secondary alteration, medium to high permeability
620-624	Limestone, white to lt. gray, medium hard, biomicrite, wackestone, shell preserved, chalky texture, very minor quantity of phosphorite, low permeability
624-627	Limestone, white and lt. tan, hard, large shells imbedded in lithified - lime mud, shell altered, low permeability
627-632	Limestone and marl, lt. gray to white, biomicrite, wackestone, some unlithified lime mud, overall medium to low permeability

TABLE A-1. GEOLOGIST'S LOG - WELL L-M-987 (CON'T.)

Depth(ft.)	Description
632-635	Clay and limestone, white and gray, upper lithology - micrite, chalky texture; lower lithology - micrite, hard, gray; overall low permeability
635-639	Dolomite, gray, very hard, micrite, mudstone, probably secondary dolomite, some limestone, medium permeability
639-643	Clay, lt. gray, fat, unlithified lime mud, minor trace of phosphorite, some rock fragments, low permeability
643-646	Limestone, dark tan-green, soft micrite, mudstone, lithified lime mud, very little phosphorite, low permeability
646-648	Clay, olive green, same composition as above, but not lithified, very low permeability
648-652	Limestone, white, soft biomicrite, wackestone, apparent high secondary porosity, trace of quartz sand and phosphorite, medium to high permeability
652-657	Limestone, white, hard, biomicrite, wackestone, some decorated vugs, high permeability
657-662	Limestone, white, hard, same as above, molds and casts, trace of quartz sand, very sparse phosphorite, high permeability
662-667	Limestone, white to lt. gray, wackestone, same as above, some sparite, high permeability
667-672	Limestone, white, wackestone, some sparrey vug decorations, same as above, high permeability
672-677	Limestone, white, same as above, medium to high permeability
677-682	Limestone, white and lt. tan, hard, wackestone, trace of phosphorite, high permeability

TABLE A-1. GEOLOGIST'S LOG - WELL L-M-987 (CON'T.)

Depth(ft.)	Description
682-687	Limestone, white, hard, wackestone, quartz sand (well rounded, fine), trace of phosphorite, medium permeability
687-692	Limestone, white, same as above, medium permeability
692-697	Limestone, white, same as above, medium permeability
697-702	Limestone, white and lt. gray, wackestone, slightly sandy, same generally as above, med. permeability
702-706	Limestone, white, softer than above, wackestone, appears pelleted, some quartz sand, trace of phosphorite, high permeability
706-712	Limestone, white to lt. tan, medium hard, biomicrite, wackestone, Bryzoons, corals, high permeability
712-717	Limestone, white, soft, micrite, wackestone, chalky texture, little secondary diagenesis, low permeability
717-722	Limestone, white, same as above, little if any, phosphorite, low permeability
722-726	Clay and marl, white to lt. gray, unlithified lime mud with some limestone fragments, no apparent phosphorite, very low permeability
726-734	Clay and marl, white to lt. gray, unlithified lime mud, same as above, very low permeability
734-738 Suwannee	Limestone, white, medium hard, biomicrite, wackestone, pelleted, much shell selectively removed, medium permeability
738-743	Limestone, lt. tan to tan, hard, micrite, mudstone, massive, medium permeability
743-749	Limestone, tan to lt. brown, hard, sparite, massive, and some micrite, medium permeability

TABLE A-1. GEOLOGIST'S LOG - WELL L-M-987 (CON'T.)

Depth(ft.)	Description
749-754	Limestone, tan to lt. brown, same as above, medium permeability
754-759	Limestone, lt. tan, soft, micrite, mudstone, pelleted, no phosphorite, medium permeability
759-764	Limestone, lt. tan to tan, soft, wackestone, most shell selectively removed, medium permeability
764-769	Limestone, tan, medium hard, biomicrite, wackestone, some pellets, molds and casts, medium permeability
769-774	Limestone, lt. tan to white, micrite, mudstone, some nearly unlithified lime mud, medium to low permeability

TABLE A-2. GEOLOGIST'S LOG - WELL L-M-988
(drilled with mud)

Depth(ft.)	Description
0-16	Sand, quartz
16-26	Clay, shell, sand
26-45	Limestone
45-50	Limestone, dark gray, packed biomicrite, packstone, high permeability
50-55	Limestone, dk. gray, sparse biomicrite, wackestone, quartz grains adhering to limestone and shell fragments, medium to high permeability
55-60	Limestone
60-65	Clay, dark green, 10-15% shell, limestone and quartz sand, low permeability
65-70	Clay, dk. green, mixture of fine phosphorite grains, gray-white limestone with (large 15%) shell fragments
70-75	Clay, dk. green, same as above but with larger sized gray-white limestone shell fragments
75-80	Clay, dk. green, less than 10% shell and gray limestone and phosphorite, low permeability
80-85	Clay, dk. green, minor rock-fragments and shell, fine-sized phosphorite intersperced in clay
85-90	Clay, dk. green, same as above, but with large-sized clear quartz grains
90-95	Same as above, lack of large quartz grains
95-100	Clay, green, minor white-gray limestone and phosphorite, shell is less than 5%
100-105	Clay, green, minor white-gray limestone and shell
105-108	Same as above, but with larger (10%) limestone

TABLE A-2. GEOLOGIST'S LOG - WELL L-M-988 (CON'T.)

Depth (ft.)	Description
108-113	Clay, green, same as above, minor quartz
113-118	Clay, green, minor shell and quartz, interspersed phosphorite
118-123	Same as above
123-128	Clay, green, minor rock fragments (quartz rich), shell and quartz
128-133	Clay, mixture of phosphorite, minor shell and quartz grains
133-128	Same as above, but with larger phosphorite grains
138-143	Same as above, little or no shell
143-148	Same as above
148-153	Clay, lime mud, some sparry calcite and shell, minor light gray limestone
153-158	Clay, dk. green and limestone, dk. gray biomicrite, mudstone, includes shell and lime mud, phosphatized
158-163	Limestone, white to gray, wackestone, sparse biomicrite, contains shells and minor phosphatized mud
163-168	Limestone, white to light gray, biomicrite, wackestone, contains phosphorite, shell
168-173	Limestone, white to tan, biomicrite, wackestone contains shell, phosphorite
173-178	Limestone, white, biomicrite, wackestone, phosphorite
178-183	Limestone, white-tan, biomicrite, wackestone sandy, minor phosphorite
183-188	Limestone, white-gray, biomicrite, wackestone, minor phosphorite

TABLE A-2. GEOLOGIST'S LOG - WELL L-M-988 (CON'T.)

Depth	Description
188-193	Limestone, white-tan, some sparry calcite, biomicrite, wackestone
193-198	Limestone, white-lt. gray, biomicrite, wackestone, minor lime mud
198-203	Limestone, white, micrite, contains quartz sand and minor phosphorite
203-208	Limestone, lt.-dk. gray, micrite, wackestone, soft texture, phosphatized limestone, low permeability
208-213	Limestone, white-lt. gray, fossiliferous micrite, wackestone, quartz sand present, phosphorite is abundant
213-218	Limestone, lt. to dk. gray biomicrite, wackestone, highly phosphatic, sand and silt present
218-223	Clay and limestone, lt.-dk. gray, biomicrite, wackestone, highly phosphatic, abundant clayey sand
223-228	Clay and limestone, clay is gray; limestone is white, clay is hard, sandy, abundant phosphatic nodules
228-233	Clay, white to gray, limey, quartz is rounded, well-sorted phosphorite abundant and rounded
233-238	Clay, gray, lime mud, quartz sand abundant, same as above, highly phosphatic
238-243	Clay, gray, lime mud and quartz sand, highly phosphatic
243-248	Clay, gray, very sandy, highly phosphatic
248-253	Clay, gray, sand is two size fractions: fine sand and pebbles, minor shell, highly phosphatic though no nodules present
253-258	Clay, gray, lime mud, crumbly, highly phosphatic, quartz sand present

TABLE A-2. GEOLOGIST'S LOG - WELL L-M-988 (CON'T.)

Depth(ft.)	Description
258-263	Clay, lt. gray, lime mud, angular phosphate nodules, shell present
263-268	Clay, dk. gray, limey, highly phosphatic clay with minor nodules, quartz is rounded, well-sorted
268-273	Clay, dk. gray, sandy, limey, phosphatic, minor shell
273-278	Clay, dk. gray, extremely sandy, sand is 50%, limey, highly phosphatic (20%), also minor shell
278-283	Sand and clay, more sand than above, limey clay and minor shell, abundant phosphorite (20%)
283-288	Clay, sandy, gray, limey, less than 30%, highly phosphatic, minor shell
288-298	Clay, gray, greater percent of limey sand, approximately 50%, highly phosphatic, minor nodules
298-303	Clay, gray, less sandy than above, highly phosphatic, lack of phosphorite nodules
303-308	Clay, gray, sandy, highly phosphatic, limey sparse shell
308-313	Clay, gray, more limey, less sandy, minor phosphorite nodules, sparse shell
313-318	Clay, mostly gray, minor green, very limey, phosphorite nodules, sandy, sparse shell
318-323	Clay, gray, limey, quartz sand, minor white limestone, highly phosphatic
323-328	Limestone, white-lt. gray, quartz sand, present with some gray clay, murite, wackestone, phosphatic
328-333	Same as above though lighter in color, minor green marl, gray clay

TABLE A-2. GEOLOGIST'S LOG - WELL L-M-988 (CON'T.)

Depth(ft.)	Description
333-338	Limestone, white-lt. gray, green-gray lime mud present, less than 10%, quartz and phosphorite present, wackestone
338-343	Limestone, white-lt. gray, gray lime mud present, less than 5%, quartz sand present, phosphatic
343-348	Limestone, white-lt. gray, micritic and micrite-sparitic, (20%) light brown, phosphatic and quartzose, wackestone, shell present
348-353	Limestone, white-lt. gray, biomicrite, lt. tan to brown, much sparite, phosphatic, more shell than above
353-358	Limestone, white to cream, biomicrite, more shell, quartz sand, less phosphatic, minor (less than 10%), lt. brown micrite-sparite
358-363	Marl, limestone is white-cream, biomicrite, wackestone, large percent (30%) of shell, some green lime mud, phosphorite less, lt. brown micrite-sparite
363-368	Limestone, white, biomicrite, packstone, less shell, minor quartz sand than above, some sparse minor lt. brown micrite-sparite, high permeability
368-373	Limestone, white, lt. gray, same as above
373-378	Limestone, lt. gray, and shell, hard, phosphatized biomicrite, packstone, minor quartz sand
378-383	Limestone, lt. gray, biomicrite, packstone, lime mud, some phosphorite in limestone shell (10%), quartz sand
383-388	Limestone, lt. gray, same as above, trace of phosphorite nodules, minor quartz sand, less than 5%
388-393	Limestone, lt. gray, biomicrite, more shell than above (20%), minor quartz, wackestone, packstone, minor phosphorite

TABLE A-2. GEOLOGIST'S LOG - WELL L-M-988 (CON'T.)

Depth(ft.)	Description
393-398	Limestone, lt.-dk. gray, biomicrite, wackestone, more sandy and highly phosphatic, shell present, no nodules present
398-400	Shell (50%), highly phosphatized gray limestone
400-405	Limestone, lt. gray, biomicrite, wackestone, not nearly as phosphatic as above, shell is 20%
405-410	Limestone, lt. tan-gray, biomicrite, wackestone, phosphatic, less shell (10-20%), slightly sandy
410-415	Limestone, lt. gray, same as above
415-418	Limestone, lt. gray, same as above
418-421	Limestone, white to lt. gray, biomicrite, wackestone, lime mud is minor, shell, trace nodules
421-426	Limestone, white-beige-lt. gray, biomicrite, wackestone, minor quartz, trace nodules, phosphatic grains, shell
426-430	Limestone, white-beige, biomicrite, wackestone, phosphorite in some grains (10%), shell
430-435	Limestone, white-beige, biomicrite, wackestone, sparse phosphorite (1-5%), minor lime mud (1-2%)
435-438	Same as above
438-443	Limestone, white-lt. gray, biomicrite, wackestone, trace phosphorite, lime mud (5%)
443-448	Limestone, white-lt. gray, biomicrite, wackestone, minor phosphorite (1%)
448-453	Limestone, white-lt. gray, biomicrite, minor quartz sand, wackestone, shell, minor phosphorite
453-458	Limestone, white-lt. gray, biomicrite, wackestone, minor quartz sand, trace phosphorite, no nodules, shell

TABLE 2-A. GEOLOGIST'S LOG - WELL L-M-988 (CON'T.)

Depth(ft.)	Description
458-463	Limestone, white-lt. gray, biomicrite, wackestone, minor quartz, minor lime mud and phosphorite nodules, more shell than above
463-468	Limestone, white-gray, biomicrite, wackestone, greater percent phosphorite nodules, quartz sand (10%), minor lime mud
468-473	Marl, limestone is white-gray, lime mud is green, hard, quartz sand, minor sand-sized phosphorite, shell
473-478	Clay, green, lime mud is 90%, shell and white-gray limestone is 10%, no phosphorite
478-483	Clay, green-tan lime mud is 95%, white-gray limestone and shell is 5%, no phosphorite
483-488	Limestone, white-very lt. gray, biomicrite, wackestone, minor lime mud (from above), minor phosphorite in limestone
488-493	Limestone, gray-beige, biomicrite, wackestone, minor phosphorite, some dolomite, clear, beige colored (1%) shell
493-498	Limestone, white-tan, biomicrite-fossiliferous micrite, slightly greater phosphorite in limestone, no nodules, some dolomite, limestone same as above, high permeability
498-509	Clay and limestone, limestone is white, lt. gray, beige, fossiliferous micrite, lime mud is white, minor phosphorite and quartz, shell present, greater clay than limestone
509-511	Limestone, white to beige, tan, fossilferous micrite, wackestone, minor dolomite, same as above, clay, gray lime mud is 10-15%
511-513	Clay and limestone, limestone is white to beige, lime mud is gray and green, fossiliferous micrite, dolomite present as above

TABLE A-2. GEOLOGIST'S LOG - WELL L-M-988 (CON'T.)

Depth(ft.)	Description
513-518	Limestone, white, lt. gray, beige, fossiliferous micrite, wackestone, minor gray clay, limey, dolomitic
518-523	Limestone, white to lt. gray, biomicrite, wackestone, shell present, very minor phosphorite
523-528	Limestone, white to lt. gray, biomicrite, wackestone, soft-medium, minor phosphorite nodules and sand-sized phosphorite, shell
528-533	Same as above
533-538	Limestone, white to lt. gray, biomicrite, wackestone, same as above
538-543	Limestone, white, beige, lt. gray, biomicrite, wackestone, minor gray clay, increasing phosphorite, minor quartz sand, shell
543-548	Limestone, white-beige, biomicrite, wackestone, minor green lime mud, shell, less phosphorite
548-551	Limestone, same as above
551-559	Clay, gray, medium, minor limestone, gray, biomicrite, increasing phosphorite in both
559-562	Clay, gray, green lime mud with limestone, white-gray, biomicrite, wackestone, phosphatic
562-568	Limestone, white-lt. gray, biomicrite, wackestone, phosphatic, shell
568-579	Marl, clay is gray, green, lime mud, limestone is white-gray, biomicrite nodules present, shell
579-584	Limestone, more gray than above, biomicrite, wackestone, minor clay, limey mud, nodules present, shell
584-589	Marl, limestone is lt. gray-white, biomicrite, wackestone, lime green mud, phosphatic nodules

TABLE A-2. GEOLOGIST'S LOG - WELL L-M-988 (CON'T.)

Depth(ft.)	Description
589-594	Limestone, white-lt. gray, soft, biomicrite, wackestone, minor phosphatic nodules, interbedded with gray clay
594-599	Clay, white-beige, hard, limey, minor limestone and phosphorite nodules, sand-sized (minor) phosphorite
599-605	Limestone and clay, limestone is white-gray, fossilferous micrite, clay is green, limey to gray, soft, minor nodules
605-610	Clay and limestone, gray-green, limey, limestone is gray, soft, phosphorite nodules, fossiliferous micrite
610-615	Limestone and clay, gray-white, soft clay is white-beige-green, minor nodules
615-620	Limestone, gray-white, fossiliferous micrite, wackestone, minor nodules, very little sand-sized phosphorite
620-625	Limestone, white-gray, biomicrite, wackestone, minor green lime mud, shell, minor nodules
625-630	Limestone, white-gray and clay, white-lt. gray, chalky, soft, minor nodules
630-635	Limestone, white-lt. gray, clay is minor, green-gray lime mud, chalky, fossiliferous micrite, minor nodules
635-640	Limestone, white-gray, biomicrite, wackestone, minor gray lime mud, soft, very minor nodules
640-645	Limestone, white-gray, biomicrite, minor lime green mud, softer than above, greater shell, minor gray clay
645-650	Limestone, white-beige, lt. gray, soft, minor clay, gray lime mud as in above, biomicrite, shell

TABLE A-2. GEOLOGIST'S LOG - WELL L-M-988 (CON'T.)

Depth(ft.)	Description
650-655	Limestone, white-beige, gray, fossiliferous micrite, harder than above, minor nodules
655-660	Limestone, white-gray, fossiliferous micrite, medium, sparse sand-sized phosphorite, high permeability
660-665	Limestone, white-gray, biomicrite, shell, hard, minor nodules
665-670	Limestone, white-gray, biomicrite, med. minor nodules, shell
670-675	Limestone, white-gray, biomicrite, minor gray clay, minor nodules
675-680	Limestone and clay, white-beige, soft, contains shell, minor nodules, interbedded
680-685	Limestone, white-gray-beige, hard, biomicrite, sand-sized phosphorite, very sparse nodules
685-690	Limestone, white-gray-beige, biomicrite, hard, same as above
690-695	Limestone, beige and gray, biomicrite, no nodules, metallic mineral on grayer limestone, highly phosphatic
695-700	Limestone, white-beige, biomicrite, wackestone, medium hardness, less gray limestone, highly phosphatic
700-705	Limestone, white-beige-gray, fossiliferous micrite, medium-soft wackestone, minor fine-sized nodules
705-710	Limestone, white-beige, biomicrite, medium, wackestone
710-715	Limestone, white-beige, fossiliferous micrite, medium, no nodules

TABLE A-2. GEOLOGIST'S LOG - WELL L-M-988 (CON'T.)

Depth(ft.)	Description
715-720	Limestone, white-beige-gray, biomicrite, med.-hard, no nodules
720-725	Limestone, white-beige, micrite, medium, no nodules, some highly phosphatic grains
725-730	Limestone, and clay, white-lt. gray, fossiliferous micrite, soft, no phosphorite
730-735	Limestone and clay, same as above
735-740	Limestone, white-gray, medium, micritic, chalky, no phosphorite
740-745	Limestone, white-lt. gray, medium, micritic, chalky
745-760	Same as above
760-765	Limestone, white-lt. gray, soft, micritic, minor gray, lime mud
765-770	Same as above
770-774	Limestone, white-lt. gray, medium, micritic, no phosphorite, chalky texture

TABLE A-3. TIME AND DRAWDOWN DATA FOR TEST-PRODUCTION WELL L-M-987 DURING THE AQUIFER TEST.

Time Elapsed(minutes)	Drawdown(feet)
1	87.3
2	94.65
3	94.68
4	98.48
5	99.52
6	99.13
7	99.45
8	99.47
9	99.49
10	99.50
15	101.73
20	102.35
25	102.70
30	102.80
40	103.05
50	103.19
60	103.20
90	103.58
120	103.77
150	103.78
180	103.93
210	104.05
240	104.08
300	104.30
360	104.40
420	104.48
480	104.47
570	104.54
630	104.54
678	104.55
840	104.80
1080	104.95
1200	105.05
1320	104.90
1440	105.12
1680	104.84
1720	104.80
2160	104.73
2400	104.85
2640	105.18
2880	104.92
3360	104.81
3840	104.85
4080	105.10
4320	105.02

TABLE A-4. TIME AND DRAWDOWN DATA FOR OBSERVATION WELL L-M-988 DURING THE AQUIFER TEST

Time Elapsed(minutes)	Drawdown(feet)
0.5	0.05
1	0.28
1.5	0.54
2	0.76
3	1.16
4	1.48
5	1.72
6	1.93
7	2.13
8	2.31
9	2.44
10	2.57
15	3.08
20	3.47
25	3.75
30	3.98
40	4.34
50	4.60
60	4.80
90	5.22
120	5.46
150	5.63
180	5.76
210	5.84
240	5.96
300	6.12
360	6.23
390	6.29
420	6.31
480	6.33
540	6.33
600	6.33
660	6.32
720	6.32
840	6.41
960	6.63
1080	6.89
1200	6.99
1320	6.92
1440	6.89
1680	6.68
1920	6.82
2160	6.68

(Con't.)

TABLE A-4. TIME AND DRAWDOWN DATA FOR OBSERVATION WELL L-M-988 DURING THE AQUIFER TEST (CON'T.)

Time Elapsed(minutes)	Drawdown(feet)
2400	6.86
2640	7.24
2880	6.97
3120	6.71
3360	6.76
3600	6.59
3840	6.66
4080	7.10
4320	6.97

TABLE A-5. DISSOLVED CHLORIDE CONCENTRATIONS AND SPECIFIC CONDUCTANCE DATA FOR WELL L-M-987.

Depth(in feet below surface)	Dissolved Chlorides (mg/l)	Specific Conuctance (μ mhos/cm)
405	10,700	18,000
415	11,200	18,500
425	11,550	18,100
435	11,800	-
445	12,200	19,500
455	11,700	19,100
465	11,850	19,200
475	12,200	19,300
485	11,550	19,400
495	11,000	18,200
506	10,800	18,200
516	10,650	18,000
526	10,800	17,900
536	9,850	16,900
546	10,000	16,900
557	10,400	16,900
567	10,150	16,800
579	9,900	16,700
589	8,100	14,000
599	8,150	14,100
609	7,900	14,000
620	5,550	11,300
632	6,400	11,900
642	6,000	11,700
652	5,700	11,100
662	2,110	5,200

(Con't.)

TABLE A-5. DISSOLVED CHLORIDE CONCENTRATIONS AND SPECIFIC CONDUCTANCE DATA FOR WELL L-M-987 (CON'T.).

Depth (in feet below surface)	Dissolved Chlorides (mg/l)	Specific Conductance (μmhos/cm)
672	1,700	4,520
678	1,700	4,390
682	1,250	3,530
692	1,575	4,200
702	1,700	4,390
708	2,175	5,000
712	1,800	4,420
722	1,825	4,550
732	1,875	4,600
743	1,900	4,780
748	2,150	5,000
754	2,025	5,000
764	1,954	4,790
774	1,900	4,720

TABLE A-6. DISSOLVED CHLORIDE CONCENTRATIONS AND SPECIFIC CONDUCTANCE DATA FOR THE PACKER STEM TESTS ON WELL L-M-987.

Packer Interval	Dissolved Chlorides(mg/l)	Specific Conductance(μmhos/cm)
550-560	1,550	4,050
580-590	1,600	4,700
612-622	1,420	4,120
650-670	1,750	4,410
700-720	1,820	4,800
730-750	1,840	5,000

TABLE A-7. CHEMICAL ANALYSIS OF WATER FROM WELL L-M-987 AT THE BEGINNING OF THE AQUIFER TEST.

STANDARD WATER ANALYSIS REPORT

Orlando Laboratories, Inc.

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

Report to: Missimer & Associates, Inc. — Appearance: Clear

Date: 4 Dec. 78 — Sampled by: Client

Report Number: 16241-1 — Identification: S-1

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.	3400	Total Hardness, as $CaCO_3$	x.	826
Phenolphthalein Alkalinity, as $CaCO_3$	x.	0	Calcium Hardness, as $CaCO_3$	x.	304
Total Alkalinity, as $CaCO_3$	x.	166	Magnesium Hardness, as $CaCO_3$	x.	522
Carbonate Alkalinity, as $CaCO_3$	x.	0	Calcium, as Ca	x.	122
Bicarbonate Alkalinity, as $CaCO_3$	x.	166	Magnesium, as Mg	.x	127
Carbonates, as CO_3	x.	0	Sodium, as Na	x.	890
Bicarbonates, as HCO_3	x.	203	Iron, as Fe	.x	<0.01
Hydroxides, as OH	x.	0	Manganese, as Mn	.x	<0.05
Carbon Dioxide, as CO_2	x.	11	Copper, as Cu	.x	<0.1
Chloride, as Cl	x.	1570	Silica, as SiO_2	x.	16
Sulfate, as SO_4	x.	450	Color, PCU	x.	0
Fluoride, as F	.x	1.4	Odor Threshold	x.	0
Phosphate, as PO_4	.x	0.09	Turbidity, NTU	x.	0.44
pH (Laboratory)	.x	7.5	Dissolved Potassium, K		74
pHs	.x	7.2	Dissolved Iron, Fe		<0.01
Stability Index	.x	6.8			
Saturation Index	.x	0.3			

Signed: [signature]
Chemist

TABLE A-8. CHEMICAL ANALYSIS OF WATER FROM WELL L-M-987 AT THE END OF THE AQUIFER TEST.

STANDARD WATER ANALYSIS REPORT

OLI

Orlando Laboratories, Inc.

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

Report to:	Missimer & Associates, Inc.	Appearance	Clear
Date:	4 Dec. 78	Sampled by	Client
Report Number:	16241-2	Identification	S-2

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.	3400	Total Hardness, as $CaCO_3$	x.	816
Phenolphthalein Alkalinity, as $CaCO_3$	x.	0	Calcium Hardness, as $CaCO_3$	x.	320
Total Alkalinity, as $CaCO_3$	x.	154	Magnesium Hardness, as $CaCO_3$	x.	496
Carbonate Alkalinity, as $CaCO_3$	x.	0	Calcium, as Ca	x.	128
Bicarbonate Alkalinity, as $CaCO_3$	x.	154	Magnesium, as Mg	.x	121
Carbonates, as CO_3	x.	0	Sodium, as Na	x.	885
Bicarbonates, as HCO_3	x.	188	Iron, as Fe	.x	<0.01
Hydroxides, as OH	x.	0	Manganese, as Mn	.x	<0.05
Carbon Dioxide, as CO_2	x.	13	Copper, as Cu	.x	<0.1
Chloride, as Cl	x.	1550	Silica, as SiO_2	x.	14
Sulfate, as SO_4	x.	443	Color, PCU	x.	0
Fluoride, as F	.x	1.5	Odor Threshold	x.	0
Phosphate, as PO_4	.x	0.16	Turbidity, NTU	x.	0.40
pH (Laboratory)	.x	7.4	Dissolved Potassium, K		72
pHs	.x	7.2	Dissolved Iron, Fe		<0.01
Stability Index	.x	7.0			
Saturation Index	.x	0.2			

Signed: Donna Furbish
Chemist

TABLE A-9. CORRECTION TO CHEMICAL ANALYSIS OF WATER FROM WELL L-M-987 AT THE END OF THE AQUIFER TEST.

OLI

Orlando Laboratories, Inc.

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

TO:
Thomas Missimer
Missimer & Associates
1031 Cape Coral Parkway
Cape Coral, FLA. 33904

Report #	16696
Sampled by:	Client
Date Sampled:	
Date Received:	22 Feb. 79
Date Reported:	23 Feb. 79

IDENTIFICATION:

Rerun of Sample 16241-2
S-2

RESULTS OF ANALYSIS:

	Sample
Dissolved Chlorides	1400

RESULTS EXPRESSED IN mg/l UNLESS OTHERWISE DESIGNATED   < = Less Than

Respectfully submitted,

ORLANDO LABORATORIES, INC.

Donna Fusbiok

Chemist/Biologist/Bacteriologist

METHODS: "Standard Methods for the Examination of Water and Wastewater," Latest Edition, APHA, AWWA and WPCF and/or other EPA approved methods unless otherwise designated.