HYDROLOGIC INVESTIGATION OF THE HAWTHORN AQUIFER SYSTEM IN THE NORTHWEST AREA SANIBEL, FLORIDA

PREPARED FOR

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

AUGUST, 1978

MISSIMER AND ASSOCIATES, INC.

CONSULTING HYDROLOGISTS, GEOLOGISTS, AND ENVIRONMENTAL SCIENTISTS

CAPE CORAL, FLORIDA

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August 23, 1978

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 Aquifer System in the Northwest Area of Sanibel, Florida."

Dear Mr. Watson:

Missimer and Associates, Inc. is pleased to submit this final report entitled "Hydrologic Investigation of the Hawthorn Aquifer System in the Northwest Area of Sanibel, Florida." This document is the result of an investigation to determine the suitability of the Hawthorn Aquifer System for a long term municipal water supply source, and produced many recommendations.

The investigators for Missimer and Associates, Inc. are:

Project Chief: Larry K. Holland, Hydrogeologist
Thomas M. Missimer, Hydrologist
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Lloyd E. Horvath, P.E., Hydrologist
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This project was conducted under the general supervision of Mr. Larry Snell, General Manager, Ian Watson, Assistant General Manager, 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 this report will play a major role in the Island Water Associations future plans and management. 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

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I. CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions

A northwestern Sanibel test site at Bowman's Beach Road was chosen for investigation of the lower Hawthorn Aquifer. A detailed hydrologic investigation was completed at the site. The investigation included geologic test drilling, observation and test-production well construction, a 72-hour aquifer test, and the chemical analysis of numerous water samples. The data collected during the testing program were combined with data collected from previous studies to conclude the following:

1) The aquifer coefficients for the useable part of the lower Hawthorn Aquifer are:

   Transmissity = 15,600 gpd/ft

   Storage Coefficient = 8.5×10^{-5}

   Leakance = 5.3×10^{-5} gpd/ft^3

2) Approximately 1.3×10^{10} gallons of water, with less than 2800 parts per million of total dissolved solids, are stored in the part of the Hawthorn Aquifer System tested.

3) The regional flow of useable water into the aquifer (recharge) occurs at a rate of 250,000 gallons per day.

4) Increasing concentrations of dissolved

solids with time in the lower Hawthorn production wells is caused primarily by vertical leakage. As the potentiometric water levels decline in the pumped zone, poor quality water, which is under a higher head, enters the aquifer through the confining beds.

5) Water is presently being "mined" from the lower Hawthorn Aquifer. Therefore, water quality will continue to grow worse with time under present pumping rates. And if the pumping rate is increased, water quality will degrade at an accelerated rate.

6) Spacing of lower Hawthorn production wells at the northwestern Sanibel site is of minimal importance because of the low magnitude of the aquifer coefficients. For example, there is only 5 feet of difference in maximum drawdown between wells spaced at 1000 feet compared to wells spaced at 2000 feet.

7) Water quality in the lower Hawthorn Aquifer will decline below a treatable level, utilizing the existing electrodialysis treatment plant, within a period of 8 to 10 years at projected pumping rates.

8) The present treatment facility will become progressively less economical to operate as

the quality of raw water declines and as water transport distances increase.

9) There are north-south oriented subsurface structures in the Hawthorn Formation underlying Sanibel. These structures are the probable cause of local variations in aquifer depths and in water quality. Utilizing this model, better quality water is expected to occur within the lower Hawthorn Aquifer on the northwestern part of Sanibel and perhaps in some areas of eastern Sanibel.

2. Recommendations

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

1) All new production wells should be constructed by utilizing the reverse air drilling method as much as possible. This drilling method will yield information that will permit the best possible finished well to be constructed.

2) Any additional lower Hawthorn Aquifer production wells should be constructed on the northwestern or eastern parts of Sanibel. The northwestern area will yield the better quality water. It may be possible to place a few lower

Hawthorn Aquifer wells along west Gulf Drive, because of good quality water reported in that area (U.S.G.S. observation well).

3) Any additional lower Hawthorn Aquifer wells should be constructed in a single line essentially parallel to the trend of the island. This will allow natural flow through the aquifer to be intercepted in the most efficient manner.

4) A new water treatment facility capable of treating poorer quality water should be constructed.

5) The Suwannee Aquifer System should be investigated as a potential raw water source.

6) All new production wells, constructed into either the lower Hawthorn or Suwannee Aquifers, should be logged with geophysical equipment in order to assure the best placement of casings and to add to the information base required for long-term water management.

II. INTRODUCTION

1. Authorization

Missimer and Associates, Inc. was authorized on February 27, 1978 by the Island Water Association, Inc. of Sanibel, Florida to investigate the possibility of utilizing a part of the Hawthorn Aquifer System as a source of raw water for ~~a new reverse osmosis treatment~~ the electrodialysis treatment plant. The investigation was to be based on information collected at a test site located at Bowman's Beach Road and data collected during previous studies (see Figure 2-1). The investigation was to include: 1) a survey of existing hydrologic and geologic information, 2) a review of previous reports, 3) a test drilling and observation well construction program, 4) a 72-hour aquifer test and water quality testing program, 5) specific recommendations on the maximum potential yield of water from the lower part of the Hawthorn Aquifer System, and 6) a final report with assessments of the impact of present and future pumping from the Hawthorn Aquifer System.

2. Purpose and Scope

The purpose of the investigation is to test and assess the Hawthorn Aquifer System in northwest Sanibel. The

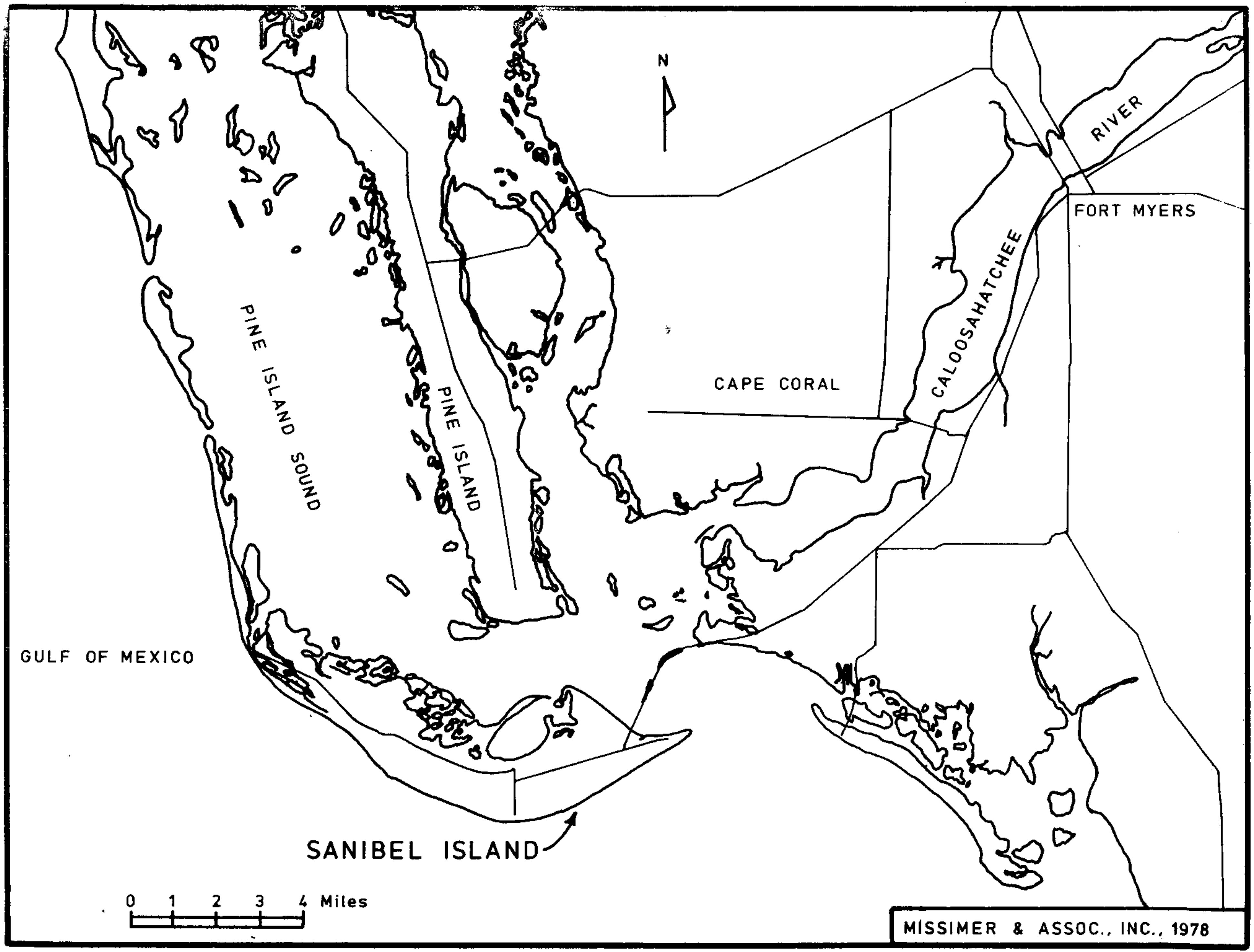


FIGURE 2-1. MAP SHOWING THE LOCATION OF SANIBEL ISLAND.

scope of the project includes completion of all the authorized tasks as above outlined.

3. Acknowledgements

We would like to thank the following persons for their fine cooperation during the course of the investigation: Mr. L. Wordsworth Snell, III., 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.

III. GEOLOGY AND HYDROLOGY OF WESTERN LEE COUNTY

1. Introduction

The geology of western Lee County is quite complex. It is a mixture of carbonate rocks subdivided by fine-grain clastic sediments (clays and sands). As many as seven distinctive water-bearing zones underlie parts of the area. Therefore, this section gives a general overview of both the geology and hydrology of western Lee County in order to place the data acquired at the test site in the proper perspective. Western Lee County is defined as all land areas located west of a north-south line running through Fort Myers (see Figure 2-1).

2. Geology

A general description of subsurface stratigraphic units underlying western Lee County is given from land surface down to a depth of about 1,200 feet in Figure 3-1. Most of this information was obtained from previous experiences of corporate personnel and from various publications and reports. The terminology used for some of the formations comes from Missimer and Associates, Inc. (1978).

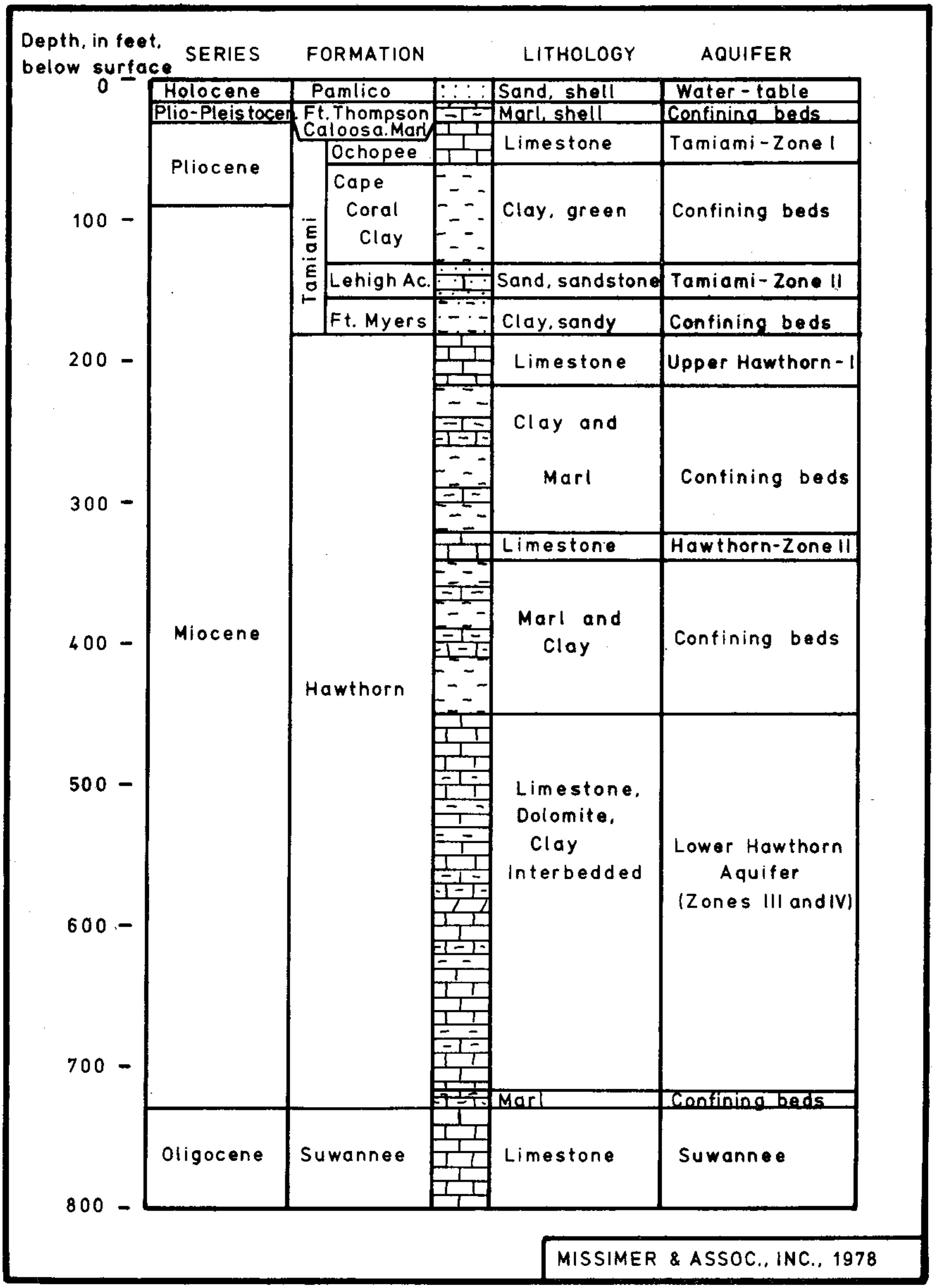


FIGURE 3-1. DIAGRAM SHOWING THE GENERAL SERIES, FORMATIONS, LITHOLOGIES, AND AQUIFER LOCATIONS IN WESTERN LEE COUNTY.

Pamlico Formation

The Pamlico Formation or Pamlico Sand is the uppermost geologic formation penetrated. It is Pleistocene in age and was deposited during the last interglacial period. It is a medium to fine-grain, quartz sand, which contains some shell and laminated, crystalline limestone. It varies in thickness from 5 feet to nearly 40 feet and is rarely uniform in thickness over large areas (more than one square mile). The upper two to four feet of the Pamlico Sand is the soil zone, which contains varying percentages of clay and organic detritus. The Pamlico Sand occurs as far west as Pine Island, but does not occur in the outer barrier islands. The barrier islands and offshore sands were deposited in more recent times.

Fort Thompson Formation - Caloosahatchee Marl

These two formations are difficult to separate in the subsurface of western Lee County. Therefore, they are grouped as a single undifferentiated unit. The Fort Thompson Formation is Pleistocene in age and the Caloosahatchee Marl ranges from late Pliocene to Pleistocene in age. These units have a collective thickness ranging from 0 to 25 feet.

Many different lithologies occur within these formations. The most common lithologies are: shell; sand and shell; marl; and light gray clay.

Tamiami Formation

The Tamiami Formation is a lithologically complex formation underlying all of western Lee County. It ranges in age from late Miocene to middle Pliocene. There are six mapable members in the formation, which occur in western Lee County (see Figure 3-1). The collective thickness of the formation ranges from 100 to 250 feet in the area.

The Ochopee limestone is the uppermost member of the Tamiami Formation. This unit occurs in segmented areas of western Lee County and is not continuous over wide areas. Where present, it ranges from 5 to about 50 feet thick. It is a light gray to tan limestone and in some areas is a calcareous sandstone.

The Buckingham limestone member lies directly beneath the Ochopee limestone in many areas. This member is absent in some of the northern areas and where present, it is only five to ten feet thick. It is a gray marl, clayey limestone, or carbonate mud with large thin shells and rock fragments.

The Cape Coral clay member underlies the Buckingham limestone member. This member underlies all of western Lee County. It ranges from 50 to 100 feet thick. The Cape Coral clay is a green carbonate mud with varying percentages of quartz sand and silt, and shell fragments. It contains angular beds which dip west to east (see Missimer and Gardner, 1975).

The Lehigh Acres sandstone member lies beneath the Cape Coral clay. In western Lee County, this unit is minor but is quite continuous. It ranges from 5 to 20 feet thick. The most common lithology is unconsolidated, fine, quartz sand, and in some areas it is a gray limestone or sandstone.

The Green Meadows clay member underlies the Lehigh Acres sandstone. It is a rather indistinct unit in western Lee County. The unit is mostly a gray to green carbonate clay with varying percentages of quartz sand. It ranges from 5 to 15 feet in thickness.

The Fort Myers clay is the basal member of the Tamiami Formation in all of western Lee County. It is a dark gray clay with a large percentage of phosphorite, quartz sand and silt. It ranges from 15 to 25 feet thick. This unit has been defined in detail by Missimer (1978).

Hawthorn Formation

The Hawthorn Formation underlies all of western Lee County. It is a middle Miocene mixed sequence of phosphatic carbonate rocks and terrestrial clays and sands. In western Lee County the upper formational contact is usually well-defined except in certain coastal areas (e.g. Sanibel Island). The formation varies in thickness from about 350 to 500 feet. The definition of the Hawthorn Formation used in this report includes all phosphatic sediments lying below the Tamiami Formation and above the Suwannee limestone. The Tampa limestone is considered to be part of the Hawthorn Formation or it is not present in Lee County.

Numerous members of the Hawthorn Formation could be defined in western Lee County, but the availability of data is insufficient to perform the task at this time. However, it is worth mentioning certain units that are known to be laterally extensive.

In western Lee County, the uppermost part of the Hawthorn is a sequence of phosphatic limestones commonly called "salt and pepper" by local well drillers. This limestone is often interbedded with various types of clay. The sequence ranges from 10 to 50 feet thick.

A carbonate clay unit lies below the upper limestone. It is gray to green in color and ranges from 50 to 100 feet in thickness. It is phosphatic and contains a considerable percentage of quartz sand. This unit sometimes is marly or is a clayey limestone. It is regionally extensive.

A minor unit of phosphatic limestone lies below the clay. It is phosphatic and sometimes water-bearing. It is not known at present whether this unit is regionally extensive, but it does occur in Cape Coral and Sanibel Island.

Another sequence of carbonate clays and marls lies below the limestone. It ranges from 30 to 50 feet thick in some areas. It is gray to green in color and it contains quartz sand and silt. It is regionally extensive.

Below the underlying clay unit, a sequence of limestones and dolomites predominates the section. Only thin clays or marls (less than 10 feet thick) occur within the Hawthorn Formation below the second clay. Lithologies in the rock sequence include the following: hard microcrystalline, gray limestones; soft white, phosphatic limestones; tan, microcrystalline dolomites; and numerous other mixed lithologies. A large percentage of the lower part of the Hawthorn Formation consists of water-bearing strata.

Suwannee Limestone

The Suwannee Limestone is another major geologic unit, which underlies all of western Lee County. It is Oligocene in age and lies comformably beneath the Hawthorn Formation. Little is known about the regional changes in the lithology of the Suwannee Limestone. It is known to contain limestones, marls, and quartz sand in Lee County. The upper part of the formation is water-bearing and it is probable that most of the unit is water-bearing. The Suwannee Limestone is between 300 and 400 feet thick in western Lee County.

3. Aquifer Descriptions

The stratigraphic positions of each water-bearing zone is shown in Figure 3-1. A general description of the aquifer properties, including geology, water levels, water quality, and hydraulic properties is given in this section for western Lee County.

Water-table aquifer

The water-table aquifer is unconfined or directly open to atmospheric pressure. It is recharged directly by rainfall.

The Pamlico Sand forms a major part of the water-table aquifer in western Lee County. In some areas, the upper part of the Fort Thompson Formation - Caloosahatchee Marl sequence is water-bearing and is hydraulically connected to the overlying Pamlico Sand. Therefore, the water-table aquifer occurs within both of these stratigraphic units. The aquifer ranges from 5 to 40 feet in thickness in western Lee County.

Water levels in the aquifer fluctuate in response to climate changes. When rainfall is abundant, water levels are high and vice-versa. In areas not affected by drainage ditches or canals, the water-table rises to near land surface in the wet season and lowers three to five feet in the dry season. Enhanced drainage in many areas of western Lee County has lowered the water-table on a more or less permanent basis.

Water quality in the water-table aquifer is good under natural conditions. It normally meets most drinking water standards except where it is affected by saline-water intrusion.

The concentration of dissolved iron and the color of the water do not meet drinking water standards. Dissolved iron concentrations range up to 8 mg/l and the water is often highly colored with organic acids such as tannin and lignin.

No actual aquifer tests have been performed on the water-table aquifer in western Lee County. Therefore, only estimates can be made on the hydraulic properties. Because of the extreme variation in thickness and sediment type, the aquifer has estimated transmissivities ranging from about 200 to about 15,000 gpd/ft and specific yields ranging from 0.01 to 0.3.

The water-table aquifer is not heavily used for potable supply or irrigation in western Lee County. However, some wells are used to supply irrigation water for individual home lawns and a few municipal supply wells produce water in the Waterway Estates Well Field.

Tamiami Aquifer System - Zone I

Tamiami Aquifer System - Zone I lies in the Ochopee limestone member of the Tamiami Formation. The Ochopee limestone member is discontinuous over western Lee County as previously discussed. The aquifer occurs beneath most of the coastal area, such as Sanibel Island, and parts of Cape Coral. Zone I is totally confined in all areas where it occurs.

Water level data on the aquifer are sparse, but where data are available, the potentiometric surface of the aquifer occurs at or slightly below the position of the water table. This relationship is caused by the leaky nature of the aquifer.

Water quality in Zone I is very poor in western Lee County. It ranges from very saline to hyper-saline. Extremely high dissolved chloride concentrations occur in Zone I wells located in south Cape Coral.

There are no existing data available on the aquifer hydraulic properties. The transmissivity is estimated to range from 2,000 to 20,000 gpd/ft. It is not possible to estimate the storage coefficient or leakance.

There is no known use of water from Tamiami Aquifer System - Zone I in western Lee County.

Tamiami Aquifer System - Zone II

Tamiami Aquifer System - Zone II, commonly known as the Sandstone Aquifer, lies in the Lehigh Acres sandstone member of the Tamiami Formation. This aquifer is fully confined by low-permeability clays from overlying units and confined to a variable degree from underlying aquifers. Zone II is not well-developed as an aquifer in western Lee County. It is essentially a thin sand facies with some sandstone. The aquifer ranges in thickness from about 5 to 20 feet. There are some isolated areas where the sands are not present and only clays occur. Zone II is absent in those areas.

Water level data are not available from Tamiami Aquifer System - Zone II in western Lee County. It is probable that the Zone II potentiometric surface lies at a position several feet below the water table.

Water quality data have been collected from a few Zone II wells in the Waterway Estates area of western Lee County. Dissolved chloride concentrations were all below 200 mg/l.

Only small quantities of water are used from Tamiami - Zone II. A few wells tap the zone in Waterway Estates and just east of Burntstore Road. Only single-family domestic supplies and lawn irrigation wells tap the aquifer. The 2-inch diameter wells yield 10 to 20 gpm, but would have greater capacities if they were properly screened.

Upper Hawthorn Aquifer (Hawthorn Aquifer System - Zone I)

The term "Upper Hawthorn Aquifer" was first formally used by Sproul, Boggess, and Woodard (1972). The Upper Hawthorn Aquifer was defined as a water-bearing zone in the uppermost part of the Hawthorn Formation. In this report, the Upper Hawthorn Aquifer is termed Hawthorn Aquifer System - Zone I. This nomenclature change is necessary because of confusion on the position of the four to six water-bearing zones which occur within the Hawthorn Formation.

Hawthorn Aquifer System - Zone I is confined from the overlying Tamiami Aquifer System and from underlying water-bearing zones by low-permeability clays and marls. There are areas of western Lee County, where there is a low degree of confinement between Hawthorn - Zone I and Tamiami - Zone II, such that a considerable volume of water can move between them in a stressed condition. Hawthorn - Zone I is quite well-confined from underlying water-bearing zones in all areas.

Zone I varies in thickness from about 5 feet up to 50 feet. The limestone sequence is often interbedded with clay and shell.

Water levels in the aquifer have shown a significant historical decline in many areas of western Lee County. The potentiometric surface decline is a result of very heavy pumping of water from the aquifer for both domestic and municipal supplies. The magnitude of the decline is up to 80 feet. Flow of water through the aquifer no longer follows any ordered regional pattern, but the flow is now directed toward local centers of pumpage.

Water quality in the aquifer is potable over large areas of western Lee County. In areas away from the coast, the natural dissolved chloride concentrations range from about 60 to 200 mg/l. Higher chloride concentrations occur in the aquifer beneath the coastal barrier islands and in areas affected by saline-water intrusion from wells. The use of steel cased wells in coastal areas has allowed entry of saline water into the aquifer through corrosion holes in the casing. Old, deep wells with an insufficient length of casing allow saline-water, under high pressure, to intrude Hawthorn Aquifer System - Zone I. These wells are the primary cause of water quality degradation in the aquifer.

Only a few aquifer tests have been performed on Hawthorn - Zone I. Transmissivity values generally range from 10,000 to 15,000 gpd/ft, but lower values are common. The storage coefficient is estimated to range from 1×10^{-4} to 1×10^{-5} and the leakance is estimated to range from 5.0×10^{-4} to 5.0×10^{-6} gpd/ft^3. These values are only approximate.

Hawthorn Aquifer System - Zone I is the most heavily used aquifer in western Lee County. There are three major well fields which tap the aquifer. These well fields collectively produce over 5 MGD. Between 15,000 and 20,000 domestic supply and lawn irrigation wells presently tap the aquifer. This pumpage from these wells is estimated to range between 1 and 3 MGD.

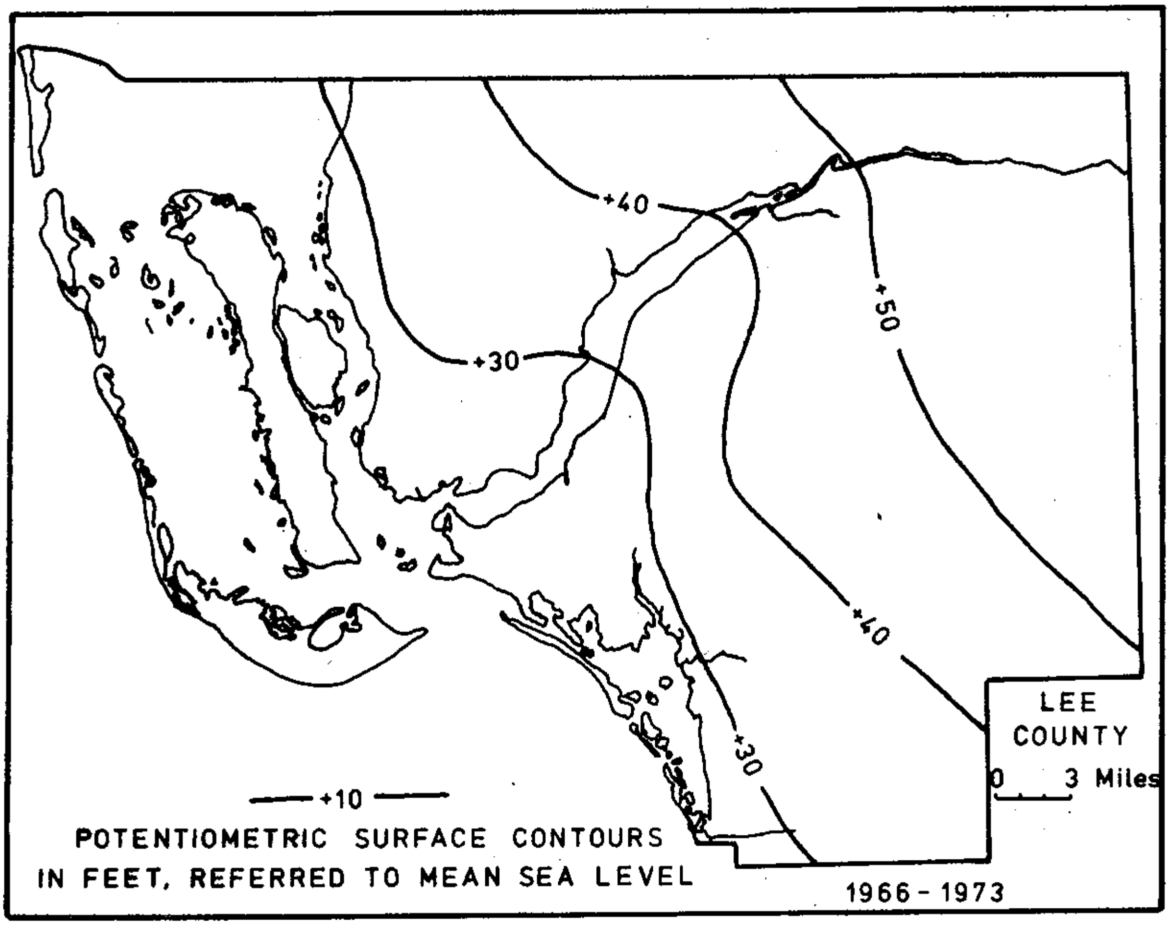
Lower Hawthorn Aquifer (Hawthorn Aquifer System-Zones II, III, and IV)

There are several fully confined water-bearing zones in the lower part of the Hawthorn Formation. In order to simplify the system, it is assumed that only four zones are present. Each zone has its own set of properties with different potentiometric surfaces, water qualities, and hydraulic characteristics. These zones have not been mapped on a regional basis over Lee County. Therefore, only general characteristics for the collective group of water-bearing zones can be described.

Hawthorn Aquifer System - Zones II to IV have a collective thickness of more than 200 feet. This system of aquifers is leaky, and a certain volume of water moves between the zones depending on the vertical permeability of the confining clays and the head differential.

The potentiometric surfaces of Zones II to IV are all well above mean sea level. In western Lee County, the potentiometric surfaces of Zones III and IV range from 20 to 40 feet above mean sea level (see Figure 3-2). The surfaces of Zones III and IV are probably very close to being equal, but the Zone II surface is probably several feet lower than Zones III and IV.

Natural quality of water in Zones II to IV ranges in dissolved chloride concentrations from 400 to 1000 mg/l in most of western Lee County. Poorer quality water lies in these zones in the coastal areas, such as Sanibel Island and Pine Island. Information available on Zone II in Cape Coral indicates that the dissolved chloride concentration is between 350 and 600 mg/l. Upward leakage of high temperature saline water from great depths has caused dissolved chloride concentrations in the McGregor Isles area, southwest of Fort Myers,



FROM BOGGESS (1974)

MISSIMER & ASSOC., INC., 1978

FIGURE 3-2. MAP SHOWING THE POTENTIOMETRIC SURFACE OF THE LOWER HAWTHORN AND SUWANNEE AQUIFERS, 1966-73.

to range up to 19,000 mg/l.

Only a few aquifer tests have been performed on Hawthorn Aquifer System - Zones II to IV. Zone II has not been tested in any area. Most of the tests have been made on wells open to both Zones III and IV. Transmissivity values have ranged from about 40,000 to 120,000 gpd/ft. Isolated tests on Zone III beneath Sanibel Island, which has a questionable correlation to mainland zones, had a transmissivity of about 6,000 gpd/ft. Storage coefficients are estimated to range from 1×10^{-3} to 1×10^{-5} and leakance is estimated to range from 1×10^{-4} to 1×10^{-6} gpd/ft^3.

A significant volume of water is presently used from Hawthorn Aquifer System - Zones II to IV. Several well fields tap these zones for raw water to supply desalination treatment plants. More than 3,000 wells tap the zones for irrigation or other uses in Lee County. Several million gallons per day is either used from the aquifers, or is wasted through improperly constructed wells.

Suwannee Aquifer System

The "Suwannee Aquifer" was first defined as water-bearing strata lying above and below the contact between the Suwannee Limestone and the Hawthorn phosphatic limestones (Sproul, Boggess, and Woodard, 1972). The specific characteristics of the aquifer or aquifer system are not presently known. Since the Suwannee Limestone is a continuous geologic formation over a large area of south Florida, it is assumed that the Suwannee Aquifer System is also a regional aquifer. The degree of confinement between the lowest Hawthorn zone and the uppermost Suwannee zone is not known and in certain areas these zones may be directly connected.

Where the Suwannee Aquifer System and the Hawthorn Aquifer System are separated by confining clays, the potentiometric surface of the Suwannee stands higher than the Hawthorn. The head difference could range up to 10 feet and could be greater if the Hawthorn system is being pumped.

Water quality in the Suwannee Aquifer System ranges considerably. Dissolved chloride concentrations range from 800 to more than 1400 mg/l. The aquifer appears to have a density stratification with poorer quality water occurring at the base of the system.

The hydraulic characteristics of the Suwannee Aquifer System are unknown. It is probably as productive or more productive than Hawthorn Aquifer System - Zones III and IV combined.

Some water is presently used from the Suwannee Aquifer System for principally irrigation purposes. There are approximately 300 to 500 wells that tap the upper part of the aquifer in Lee County. It is not possible to quantify the useage rate from the aquifer with the available data.

IV. INVESTIGATION OF THE BOWMAN'S BEACH ROAD SITE

1. Introduction

Most study of the deeper aquifers underlying Sanibel Island has been concentrated in the central portion of the island near the present Island Water Association Water Treatment Plant. Two previous aquifer tests were performed on the lower part of the Hawthorn Aquifer System with one test location east of the water plant and the other to the west of the water plant (see Figure 4-1). No test drilling or aquifer testing has previously been completed on the northwestern part of Sanibel. Therefore, the northwestern part of the island was selected for testing to give a more representative view of the Hawthorn Aquifer System beneath Sanibel. The exact position of the site at Bowman's Beach Road was chosen because of the available access.

2. Test Drilling and Well Construction

A detailed test drilling program was conceived and completed in such a manner as to maximize the amount and quality of data collected.

One test-production well was constructed into Zone III of the Hawthorn Aquifer System. The upper part of the well was drilled by the hydraulic rotary method. A

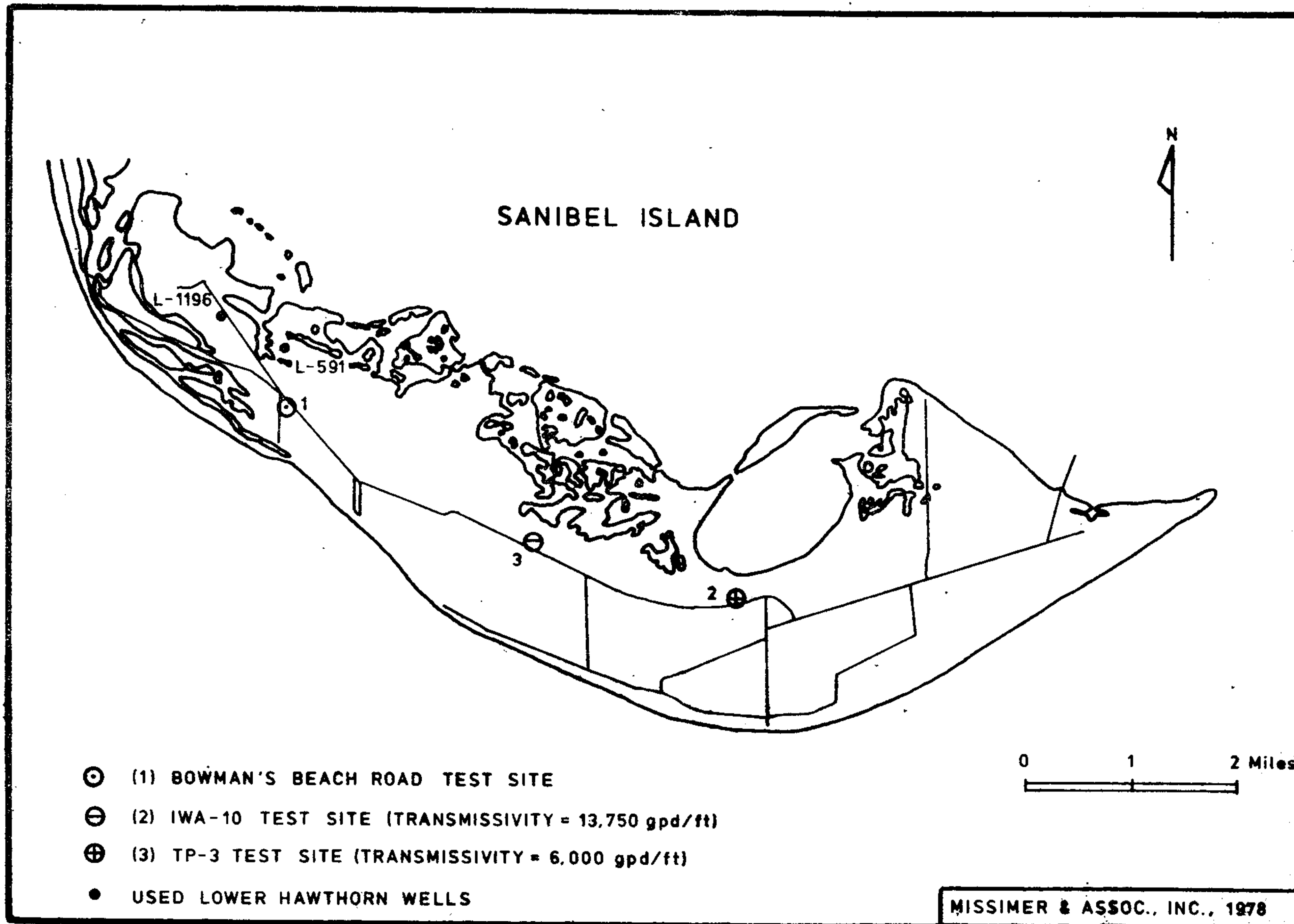


FIGURE 4-1. MAP SHOWING THE LOCATION OF THE BOWMAN'S BEACH ROAD TEST SITE AND LOCATIONS OF PREVIOUS AQUIFER TEST.

30-inch borehole was drilled to slightly more than 40 feet below land surface. A 40-foot section of 24-inch diameter steel casing was installed in the hole and the annular space was grouted with neat cement. An 8-inch diameter pilot hole was drilled with the hydraulic rotary method to a depth of about 280 feet. Drill cuttings were collected during this drilling operation. The pilot hole was then enlarged to a diameter of about 24 inches. A 16-inch diameter steel casing was installed in the borehole to 280 feet below surface. The casing contained centering guides (stabilizers) and the annular space was pressure grouted with neat cement. An attempt was made at this point to drill an 8-inch diameter pilot hole utilizing the reverse air drilling method. The pilot hole was drilled to about 310 feet with air. At this depth, a unit of quartz sand and phosphate gravel was encountered. This material caused the borehole to collapse and forced the termination of reverse air drilling. The pilot hole was drilled to about 430 feet with the hydraulic rotary-mud method. It was necessary to set a temporary bridge across the collapsing gravel. Eventually the bridge was removed and the borehole was enlarged to 16 inches. A 430-foot string of 10-inch diameter PVC casing was seated in the borehole. The annular space was pressure grouted with neat cement. An 8-inch diameter pilot hole was drilled with the reverse air method from 430 to 673 feet below surface. During this drilling, a good set of drill cuttings and numerous water samples were collected. The borehole was later enlarged to 10 inches in diameter. An attempt was then made to run packer-stem tests to isolate and pump the various zones independently. These tests were not totally satisfactory. It was decided to plug the bottom of the borehole from 673 feet back to about 600 feet in order to isolate Zone III.

Geophysical logs were run on the well at several different times. These logs were used to locate clays and limestones in order to set casings at the proper depths. A completed well diagram is given in Figure 4-2.

One additional observation well was drilled into the lower part of the Hawthorn 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. The only significant difference between the two wells is that the finished observation well is 4 inches in diameter. A diagram of the observation well is given in Figure 4-3.

3. Aquifer Test

An aquifer test was performed on part of the Hawthorn Aquifer System. Test-production well L-M-943 was pumped

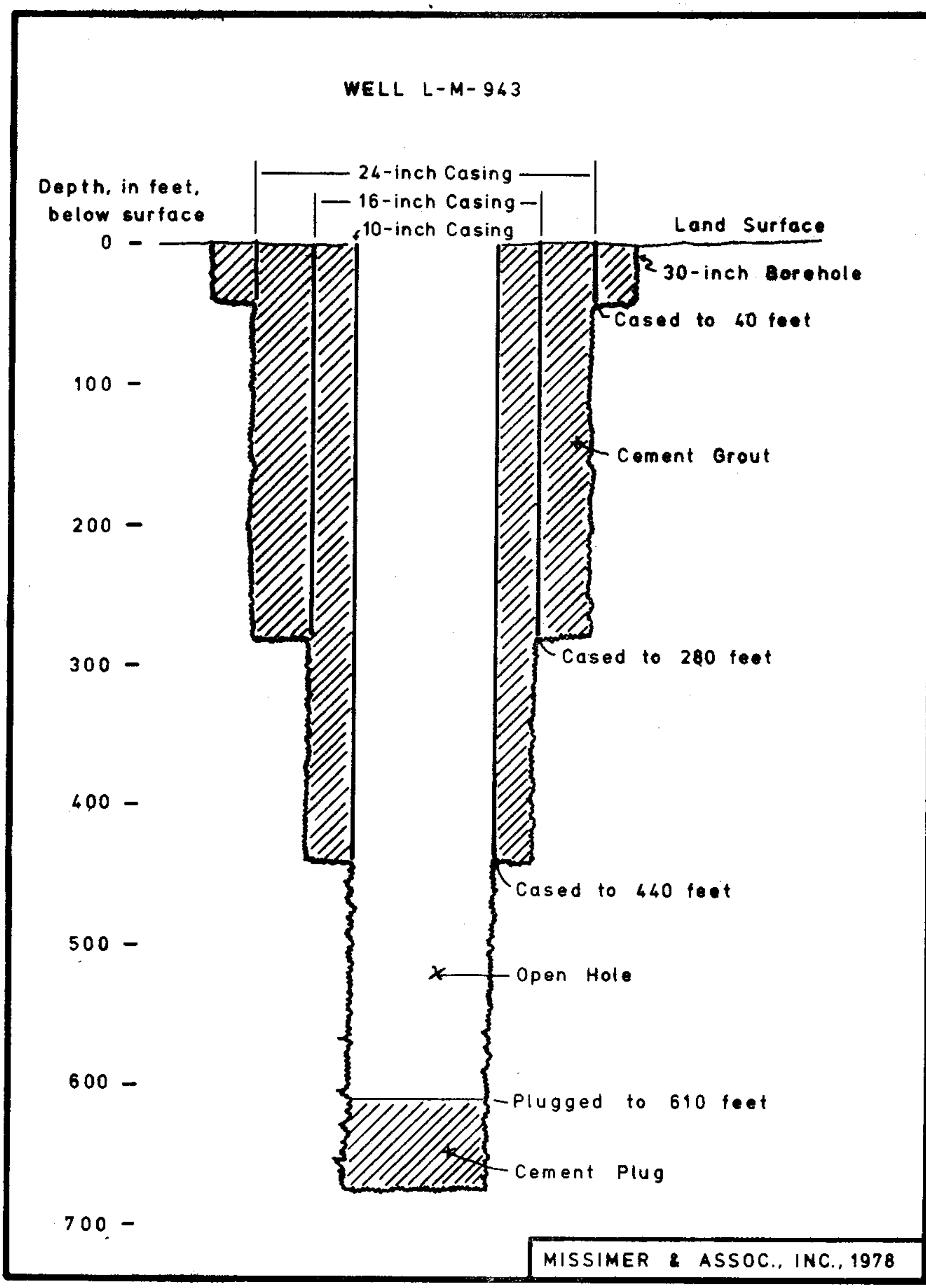


FIGURE 4-2. DIAGRAM SHOWING THE CONSTRUCTION DETAILS OF TEST-PRODUCTION WELL L-M-943.

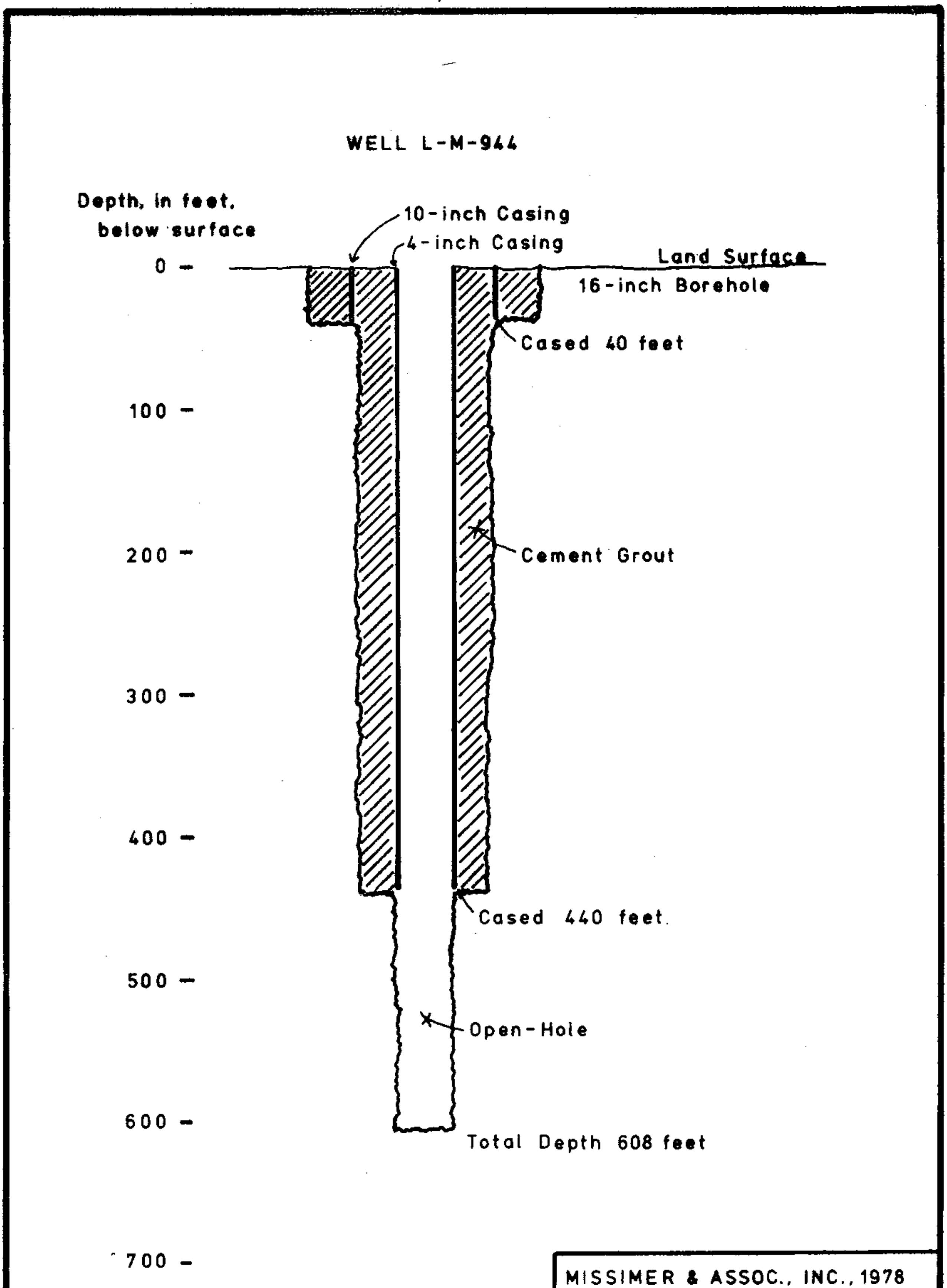


FIGURE 4-3. DIAGRAM SHOWING THE CONSTRUCTION DETAILS OF OBSERVATION WELL L-M-944.

continuously at a rate of 300 gpm for a period of 72 hours. Well L-M-943 was equipped with an extended shaft, turbine pump powered by a diesel engine. The pump bowls were set approximately 90 feet below land surface. Pump discharge was monitored with a continuous in-line digital flow meter. A secondary manometer tube was installed to insure that the fluctuation in discharge rate would be minimal.

The pumping rate for the final aquifer test was established during a 90-minute step-drawdown test conducted 72 hours prior to the initiation of the final test. The step discharges were 250 gpm, 400 gpm, and 650 gpm. Draw-downs in the test-production indicated that the optimum discharge rate should be set at 300 gpm.

From the initiation of the test, water from the pump was discharged 90 feet to the northeast on the north side of Sanibel-Captiva Road. The water flowed away from the site in a roadside drainage ditch. Water could not flow back toward the site because the road acted as a dike. Care was taken to discharge all water on the north side of the road, because the south area is designated a "fresh" water area by the City of Sanibel.

Drawdown in the test-production well was monitored using a combination pressure gage-airline set-up. Only a minimal fluctuation of the pump discharge was observed during the test. Most of the discharge fluctuation occurred during the first three minutes of the test and the rate may have temporarily approached 350 gpm.

Drawdowns of the potentiometric surface in the stressed aquifer in areas away from the pumped well were measured in two wells. These wells were equipped with Stevens Type-F water level recorders, which were manually checked. Because of the relatively high head of the Lower Hawthorn potentiometric surface (up to 18 feet above land surface), the water level recorders were mounted on approximately 20 feet of 4-inch PVC riser pipe supported by 15 feet of scaffolding.

Extraneous water level fluctuations caused by barometric pressure changes, tidal influences, and nearby pumping were monitored. A tidal gage was continuously monitored for two weeks before the aquifer test, during the test, and for one week after the test. A recording barometer was placed at the site and operated for three days before the test, during the test, and for three days following it. Pumping of nearby wells was kept to a minimum.

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

A schematic diagram of the aquifer test set-up is shown in Figure 4-4.

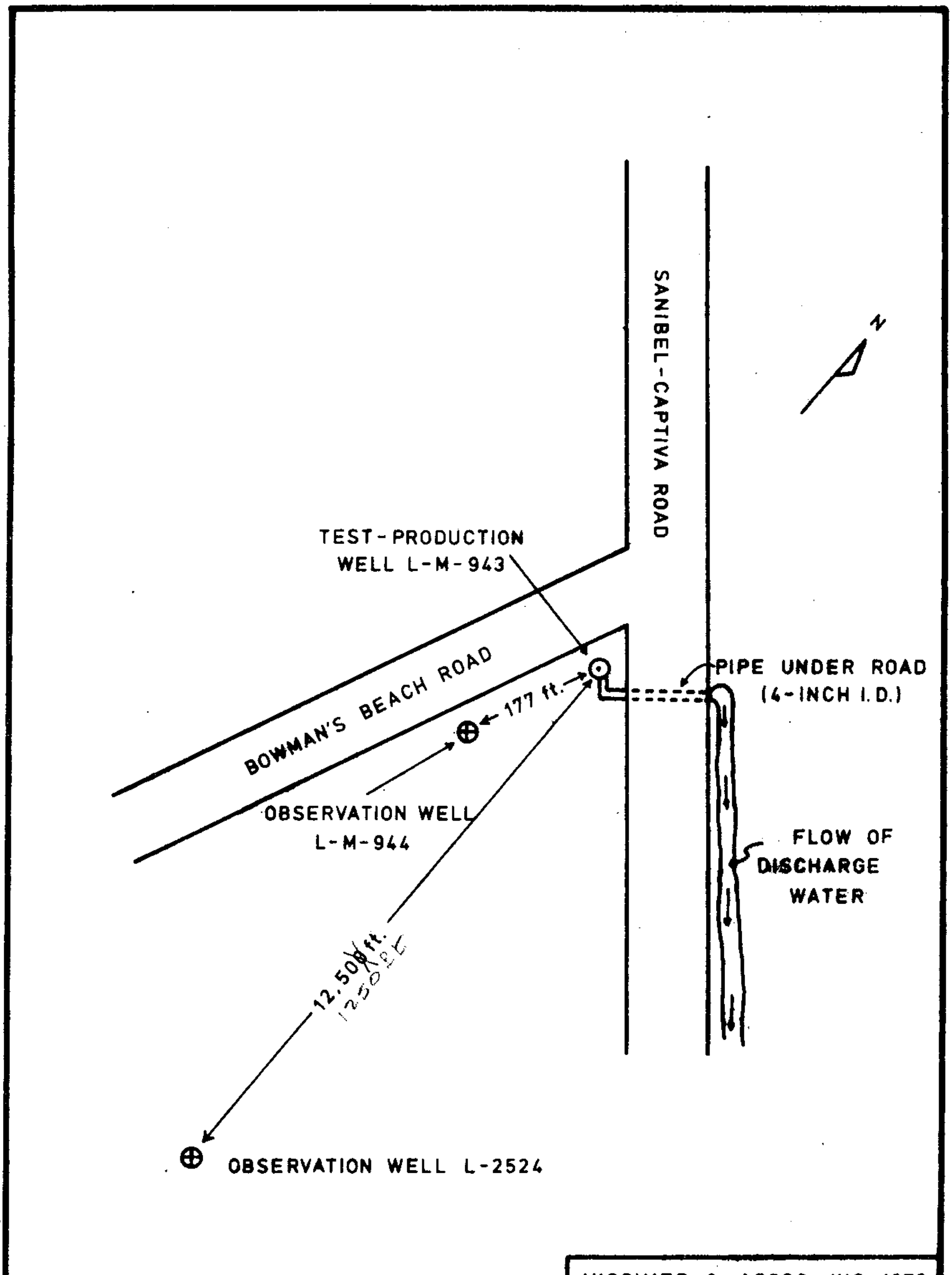


FIGURE 4-4. SCHEMATIC DIAGRAM SHOWING THE AQUIFER TEST SET-UP AT BOWMAN'S BEACH ROAD.

4. Well Inventory and Water Use Assessment

There are about seventeen wells located within a one-mile radius of the test-production well. Only two of the wells, L-469 and L-591, are constructed into the test zone. Well L-469 is used for partial domestic supply for one house and well L-591 is used to irrigate one yard. These wells were pumped only slightly, if at all, during the aquifer test and the possible pumping had no effect on the aquifer test data or calculations (see Figure 4-1 for well locations).

The U. S. Geological Survey is presently preparing a well inventory and water use assessment for the City of Sanibel. However, the data in this report are not available for release at this time. Therefore, the water use assessment completed by Volkert and Associates, Inc. (1977) is used as an estimate of withdrawals from the Hawthorn Aquifer System. The average daily withdrawal rate is about 2.4 MGD.

V. HYDROLOGY AND GEOLOGY OF THE TEST SITE

1. Geology

Several thousand feet of sediments underlie Sanibel Island. The sequence is a mixture of marine carbonates with various quantities of terrestrial clastics. Only the upper 673 feet of the geologic sequence was penetrated in the test drilling program. A complete geologic log of well L-M-943 is presented for reference in Figure 5-1.

Holocene

The uppermost 30 feet of sediment underlying the test site is a sequence of unconsolidated sands, shell, and lime mud. This sequence is divided into three basic units (Missimer, 1973): 1) quartz sand and shell, 2) fine, gray, quartz sand, and 3) clay, quartz sand and shell. The entire Holocene sequence is less than 15,000 years old.

Tamiami Formation

Tamiami Formation sediments lie uncomfortably beneath the Holocene sediments. All strata within the Fort Thompson Formation and Caloosahatchee Marl (as shown in Figure 5-1) appear to have been completely

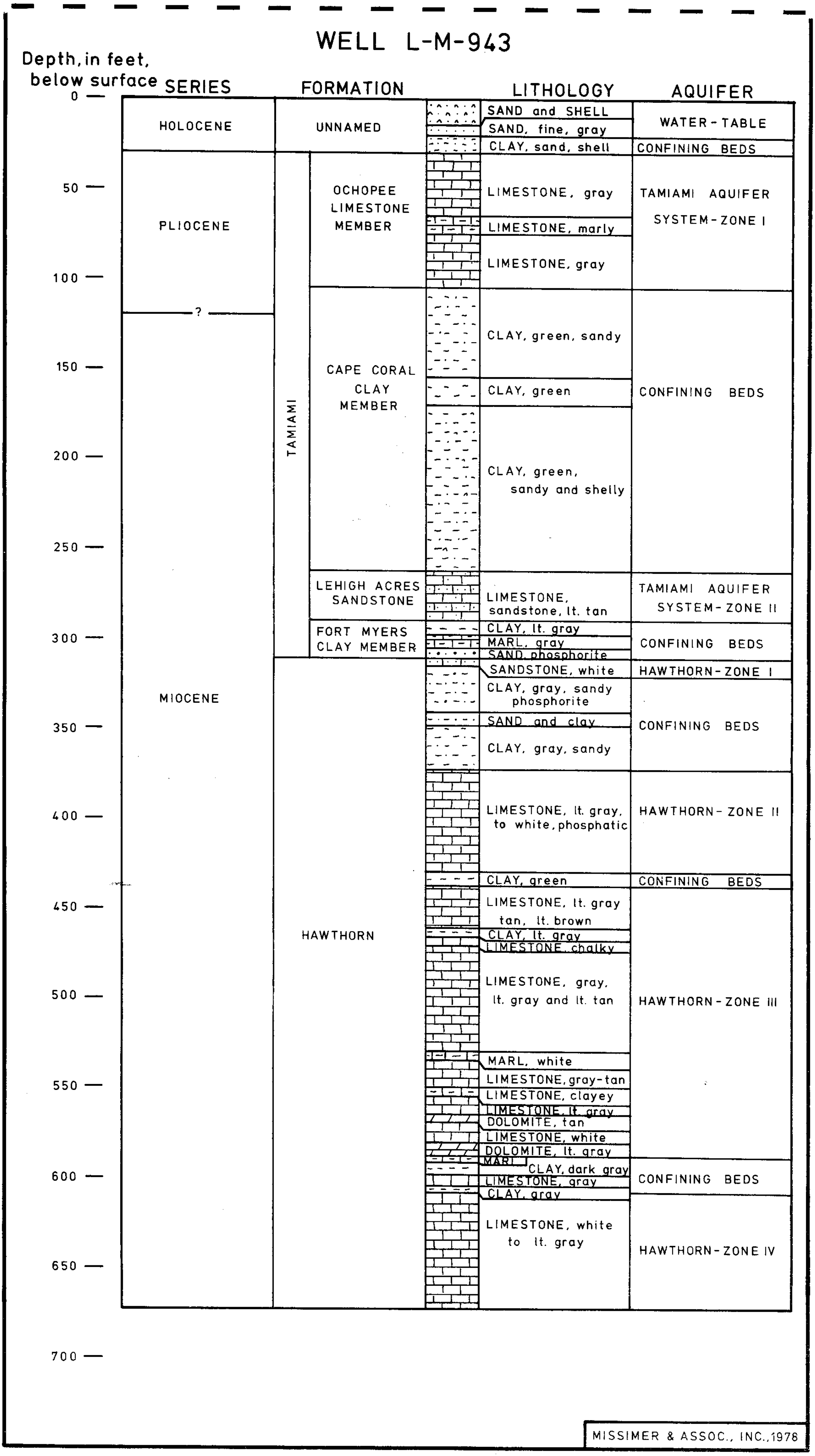


FIGURE 5-1. LOG OF TEST WELL L-M-943 SHOWING GEOLOGY AND LOCATION OF WATER-BEARING ZONES.

removed by erosion. Therefore, the erosional unconformity represents a time interval of at least four million years.

The uppermost member of the Tamiami Formation encountered is the Ochopee limestone. This unit is about 75 feet thick and consists predominantly of hard, sandy, gray limestone. Some marly limestone occurs within the unit. The limestone contains both large cavities and small vugs and is water-bearing.

The Cape Coral clay member underlies the Ochopee limestone. It is a sandy, green, lime mud which has a considerable variation in consistancy. The unit contains some beds with up to 90% matrix, lime mud and clay, and other beds with up to 85% quartz sand, phosphorite, silt and shell fragments. The unit appears to contain beds up to ten feet thick which grade upward from coarse sand to matrix clays. The entire sequence is over 160 feet thick and has a very low permeability. The Pliocene-Miocene time boundary occurs within the unit.

The Lehigh Acres sandstone member underlies the Cape Coral clay. It is a light tan, sandy limestone or perhaps could be termed a calcareous sandstone. It is slightly over 25 feet thick and is a water-bearing unit.

Most of the lower member of the Tamiami Formation present in south and east Lee County are not present below the Lehigh Acres sandstone. There units have either been eroded away or were never deposited on the up dip part of the geologic section. The basal member of the Tamiami Formation, the Fort Myers clay (see Missimer, 1978), is present beneath the test site. It is about 22 feet thick and consists of eight gray clay, marl, and a mixture of bedded phosphorite and quartz sand. The upper part of the unit has a very low permeability, but the sand portion is water-bearing.

Hawthorn Formation

The Hawthorn Formation is a complex of middle Miocene age rocks that occurs regionally over all of south Florida.

A large thickness of the Hawthorn Formation was penetrated at the test site. The test hole was terminated at 673 feet, which is still within the Hawthorn Formation. It is quite probable that the contact with the Suwannee Limestone occurs within 80 feet of the base of the test hole.

The Hawthorn Formation is basically a sequence of marine carbonates and mixed terrestrial and marine clastic sediments. A complete description of the stratigraphy is given in a geologist log in the Appendix (Table A-1) and a graphic presentation is given in Figure 5-1. It is evident that the clastic sediments, clays and sands, are thickest near the top of the Hawthorn and where present in the lower section, the clastic beds are relatively thin.

There is some question concerning the exact position of the Tamiami Formation-Hawthorn Formation contact. Based on the abundance of clastic material, quartz sand and phosphorite, derived from erosion of the Hawthorn Formation in higher areas to the north and east, the top of the Hawthorn occurs at about 321 feet below land surface in well L-M-943. The actual contact is probably comformable as suggested by Missimer (1978). The uppermost Hawthorn lithology is a calcareous sandstone, which is quite thin. More than 60 feet of gray lime mud mixed with quartz sand, clay minerals, and phosphorite nodules underlies the thin sandstone. It is evident that the clastic sediments, clays and sands, are thickest in the upper part of the Hawthorn and where present in the lower section, the clastic beds are relatively thin.

The clays which occur at 435 feet, and 590 to 605 feet, are relatively dense and probably contain a high percentage of clay minerals. These clay beds have inferred low permeabilities and they separate major limestone units.

All limestone lithologies given in the appendix tables are described in terms of classification systems developed by Folk (1968) and Dunham (1962). Most of the limestones are micrites or biomicrites, which contain variable percentages of phosphorite and quartz sand.

The Hawthorn limestones have generally medium permeability as evidenced by a lack of large cavities and a low degree of secondary alteration. There are two beds of dolomite located within the lower part of the section. These beds are massive and probably have low permeabilities.

Many investigators have separated the phosphatic limestone lithologies beneath Sanibel into the Hawthorn Formation and the Tampa Limestone. No criteria have ever been established in order to separate the two units. It is likely that only the Hawthorn Formation is present beneath Sanibel and the Tampa Limestone has either been removed by past erosion or is not a recognizable unit in south Florida.

Structural Geology

Recent high resolution seismic reflection investigations made in the vicinity of Sanibel Island have revealed some possible structural variations in the Hawthorn Formation (see Missimer and Gardner, 1976). These structural variations are a series of folds with high anticlinal areas and low synclinal areas. If in fact these folds do occur beneath Sanibel Island, there is a large probability that the structure has controlled sediment deposition in the past. Structurally higher areas appear to occur on eastern-most and western Sanibel with a synclinal low-lying trough between the highs. Since the deformation probably began during the middle part of middle Miocene time and concluded during the late Miocene or early Pliocene, the older beds of Hawthorn age occur at greater depths in the central part of the island and have perhaps a different lithologic character. The distribution of more permeable limestones at the test site compared to the greater abundance of clayey sediments in the central part of Sanibel could be explained by the subsurface structure. A considerable amount of future work will be required to properly define the detailed stratigraphy of Sanibel in terms of subsurface structural relations. The most significant aspects of the structure are the hydrologic implications - greater permeabilities occur along higher subsurface strata and better quality water occurs within the same higher areas.

2. Aquifer and Confining Bed Descriptions

Water-table aquifer

The water-table aquifer occurs in the upper 25 feet of Holocene sands and shell. It has quite high permeabilities, but it is very thin. This aquifer has been mapped and described in detail by Boggess (1973) and Missimer (1976). Further information required should be taken from these publications.

Upper Confining Beds

A mixture of lime mud, sand, and shell forms a 10-foot thick confining bed, which separates the water-table aquifer from lower artesian aquifers and confines lower aquifers from the atmosphere. These beds have some permeability and are considered leaky. Again, detailed descriptions of this bed are given in Boggess (1973) and Missimer (1976).

Tamiami Aquifer System - Zone I

Tamiami Aquifer System - Zone I lies within the Ochopee limestone member of the Tamiami Formation. It is about 75 feet thick and appears to be quite permeable. Some clayey sediments occur within the aquifer but the beds are not considered to be confining. This aquifer has been previously termed the Shallow Artesian Aquifer by Boggess (1973) and Missimer (1976). The aquifer can be traced throughout all of south and eastern Lee County, but it is rather discontinuous along the coastal part of the county. The aquifer is recharged by mostly vertical leakage from above.

Confining Beds (Middle Tamiami)

The Cape Coral clay member of the Tamiami Formation confines the Zone I aquifer from Tamiami Aquifer System - Zone II. These confining beds are more than 150 feet thick and provide a very high degree of confinement to lower aquifers. This sequence of clayey sediments permits little, if any, vertical leakage of water from the surface of Zone I into any of the underlying aquifers.

<u>Tamiami Aquifer System - Zone II</u>

Tamiami Aquifer System - Zone II lies within the Lehigh Acres sandstone member of the Tamiami Formation. It is about 30 feet thick and probably yields relatively small quantities of water. Zone II is very well confined from overlying aquifers, but has a much greater degree of hydraulic connection to underlying aquifers. As previously stated in Section 3, this aquifer is poorly developed in western Lee County. Confining strata within the Fort Myers clay member appear to have a relatively high degree of vertical permeability and therefore, water quality within Zone II is probably similar to that in the Hawthorn Aquifer System in Zone I. Tamiami Aquifer System - Zone II is recharged exclusively by vertical leakage from either above, below or both.

<u>Confining Beds (lower Tamiami)</u>

Clays and marls within the Fort Myers clay member of the Tamiami Formation separate the Tamiami Aquifer System from the underlying Hawthorn Aquifer System. These clays are only about 25 feet thick and provide a poor degree of separation between Tamiami - Zone II and Hawthorn - Zone I. Much of the Fort Myers clay is actually quartz sand and phosphorite sand and gravel, which in part is water-bearing.

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. This water-bearing zone is very thin, (less than 14 feet), and lies within the lower part of the Fort Myers clay and the uppermost part of the Hawthorn Formation. It is a sandstone and a mixture of unconsolidated quartz sand and phosphorite nodules. Hawthorn - Zone I is not well confined from Tamiami - Zone II and is quite well confined from the underlying Hawthorn - Zone II. The aquifer does yield some water, but it is not considered a major water source.

Confining Beds Between Hawthorn - Zones I and II

A gray sandy clay forms the confining beds between Zones I and II of the Hawthorn Aquifer System. This clay unit contains a large quantity of quartz sand, phosphorite nodules, shell, and various other impurities. It is about 50 feet thick and is estimated to have a low to very low vertical permeability. It will however permit the leakage of water between the two zones when there is a significant difference in potentiometric head. Under natural conditions, the leakage gradient is directed upward and under pumping conditions in the lower zones, it is directed downward. There is a certain amount of storage within these confining beds.

Hawthorn Aquifer System - Zone II

Zone II of the Hawthorn Aquifer System lies in a white to light gray limestone unit as shown in Figure 5-1. The limestone unit is about 60 feet thick. It is fossiliferous and contains various quantities of quartz sand and phosphorite nodules. Zone II has an overall medium permeability and will yield water in moderate quantities.

Confining Beds Between Hawthorn II and III

A thin clay unit separates Zone II from the underlying Zone III. This clay is only seven feet thick, but does cause a certain degree of confinement. The clay unit actually consists of lime mud with quartz silt and sand. It has a very low permeability, but it will allow leakage between the two zones at rates dependent on the relative head differential. This confining bed has a much greater vertical permeability than the beds separating Zones I and II.

Hawthorn Aquifer System - Zone III

Zone III of the Hawthorn Aquifer System contains numerous lithologies and it probably could be subdivided into several sub-zones. However, it is assumed that this zone is essentially a single hydraulically connected unit and that clays occurring within it do not provide a high degree of confinement. The upper part of Zone III is mostly a gray to light tan limestone. The lower part of Zone III is an alternating sequence of marls, limestones, and dolomites. Most water yielded from Zone III comes from the upper part.

Confining Beds Between Hawthorn - Zones III and IV

Zone III is a well confined from Zone IV by a sequence of relatively tight clays and marls. The clay has very low vertical permeabilities, but will still permit some leakage of water between the zones. The "clay" confining beds contain a high percentage of quartz sand and silt with some phosphorite. These beds provide a high degree of confinement compared to the separation of Zones II and III. The leakage rate between Zones III and IV is very low as indicated by both the geology and aquifer tests (see Section V.3).

Hawthorn Aquifer System - Zone IV

Zone IV is a white, slightly phosphatic limestone. It appears to have a greater permeability than the other Hawthorn limestones. Zone IV is very well confined from the overlying zones, but there is a question concerning its confinement from the underlying Suwannee Aquifer System. This question should be answered during the upcoming Suwannee Aquifer testing program.

3. Aquifer Characteristics

There are numerous water-bearing units underlying Sanibel Island as shown in Figure 5-1. However, the only aquifer on which hydraulic characteristics were determined was Zone III of the Hawthorn Aquifer System.

The Hawthorn Aquifer System beneath Sanibel is hydraulically very complex. An accurate determination of the hydraulic properties of the proposed production zone is required in order to predict aquifer response to long-term pumping and the perennial yield of the system.

Determination of the hydraulic properties of the aquifer requires the following types of information: 1) detailed geologic data, 2) aquifer test data, and 3) water level data. The geologic information and detailed aquifer delineation has been previously presented in this section and the water level, and potentiometric surface data is 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.

Hawthorn Aquifer System - Zone III

A detailed aquifer test was performed on Zone III of the Hawthorn Aquifer System. Zones I, II, and IV were not tested because of poor yield or water quality characteristics. Zone III is defined in considerable detail in Section V.2.

Water was pumped from a test-production well and two other smaller-diameter ovservation wells were used to continuously monitor drawdown in the aquifer. Both observation wells were equipped with Stevens Type-F recorders. A significant quantity of background water level data was collected both before and after the test. A complete description of the aquifer test set-up and procedure is given in Section IV.

Test-production well L-M-943 was pumped continuously at a discharge rate of 300 gpm for 72 hours between June 15 and June 18. An attempt was made the previous week to complete the test, but pump failure was experienced after 41 hours. Drawdown in the test-production well stabilized at 82 feet, which yields a specific capacity of 3.65 gpm/foot of drawdown. The drawdown data from the test-production well was not used for calculation of aquifer coefficients. However, the raw time and drawdown data from well L-M-943 are given in Table A-3.

Drawdown data were recorded continuously in observation wells L-M-944 and L-2524, which were located 177 feet and 1,250 feet respectively from the test-production well. After 4320 minutes of continuous pumping, a drawdown of 17.18 feet was recorded in well L-M-944 and no drawdown was recorded in well L-2524. At the termination of the test, a steady state had not been reached. However, after 66 hours into the test, the drawdown did stabilize because of a rising barometric pressure and an incoming tide. A comparison of barometric pressure fluctuations, tidal fluctuation, and the water level in well L-M-944 is given in Figure 5-2. After 71 hours of pumping, the tide was going out and the water level in well L-M-944 began to drop again.

The influence of tidal effects on Zone III was determined from comparison of water level records collected from well L-2524 and a tidal gage located along the north shore of Sanibel. Water levels in Zone III fluctuated rhythmically as much as 0.2-foot. The peaks and lows correlated perfectly with high and low ocean tides with

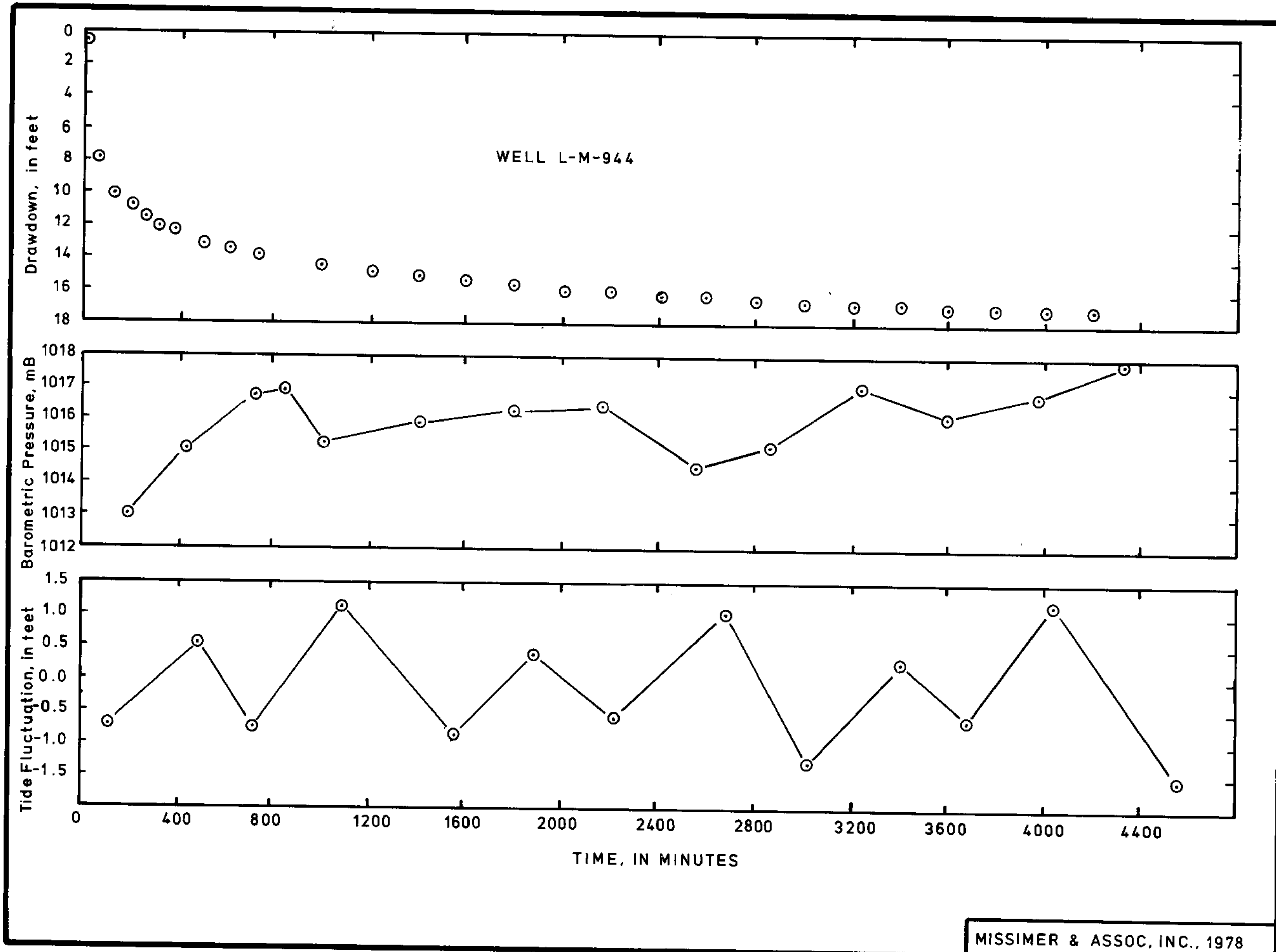


FIGURE 5-2. DIAGRAM SHOWING A COMPARISON OF DRAWDOWN IN WELL L-M-944 TO BAROMETRIC PRESSURE AND OCEAN TIDE FLUCTUATIONS.

a slight time lag caused by the difference in location between the respective recording stations. The tidal efficiency of an aquifer (after Robinson and Bell, 1971) 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 Zone III is not a unique number and varies in a non-linear manner with the magnitude of the tides. The approximate mean tidal efficiency is near 13%.

A preliminary analysis of drawdown data collected on the Hawthorn Aquifer System - Zone III 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-944 with a sample Jacob analysis is given in Figure 5-3. The analysis yielded the set of coefficients given in Table 5-1. These values are only slightly

TABLE 5-1 AQUIFER COEFFICIENTS CALCULATED FOR HAWTHORN AQUIFER SYSTEM - ZONE III USING DIFFERENT ANALYSIS METHODS

ANALYSIS METHOD	T (gpd/ft)	S	k'/b' (gpd/ft^3)
1. Jacob (Confined)	17,600	9×10^{-4}	
2. Hantush-Jacob (Semi-confined)	15,600	8.5×10^{-5}	5.0×10^{-5}

T= transmissivity

S= storage coefficient

k'/b'= leakage coefficient

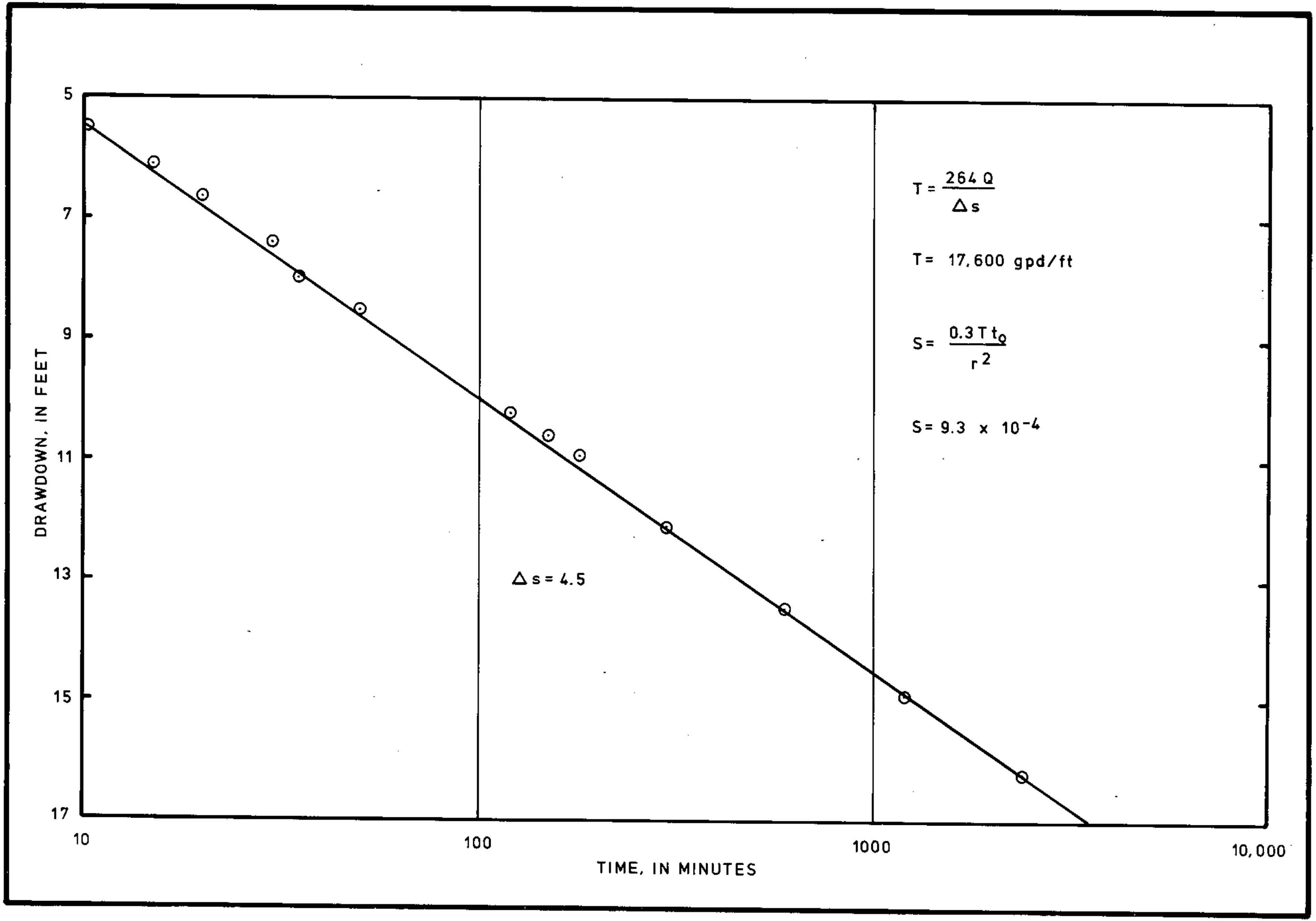


FIGURE 5-3. DIAGRAM SHOWING A SEMI-LOG PLOT OF DRAWDOWN IN WELL L-M-944 WITH TIME AND A SAMPLE JACOB ANALSIS.

higher than aquifer coefficients determined by use of the leaky aquifer equations.

A primary analysis of the drawdown data from well L-M-944 was made using the method of Hantush and Jacob (1955) for semi-confined aquifers. The drawdown data were plotted on a log plot versus time and the resultant curve was matched to the appropriate Hantush - Jacob function type-curve (see Figure 5-4). The match point was substituted into the following equations:

$$T = \frac{114.6\ Q\ H\ (\mu, \beta)}{s} \qquad (2)$$

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

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

where,

T = transmissivity (gpd/ft)

Q = discharge (gpm)

H = (μ, β) = Hantush-Jacob curve function

s = drawdown (ft)

S = storage coefficient

= Hantush-Jacob curve function

t = time

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 = Hantush-Jacob curve function

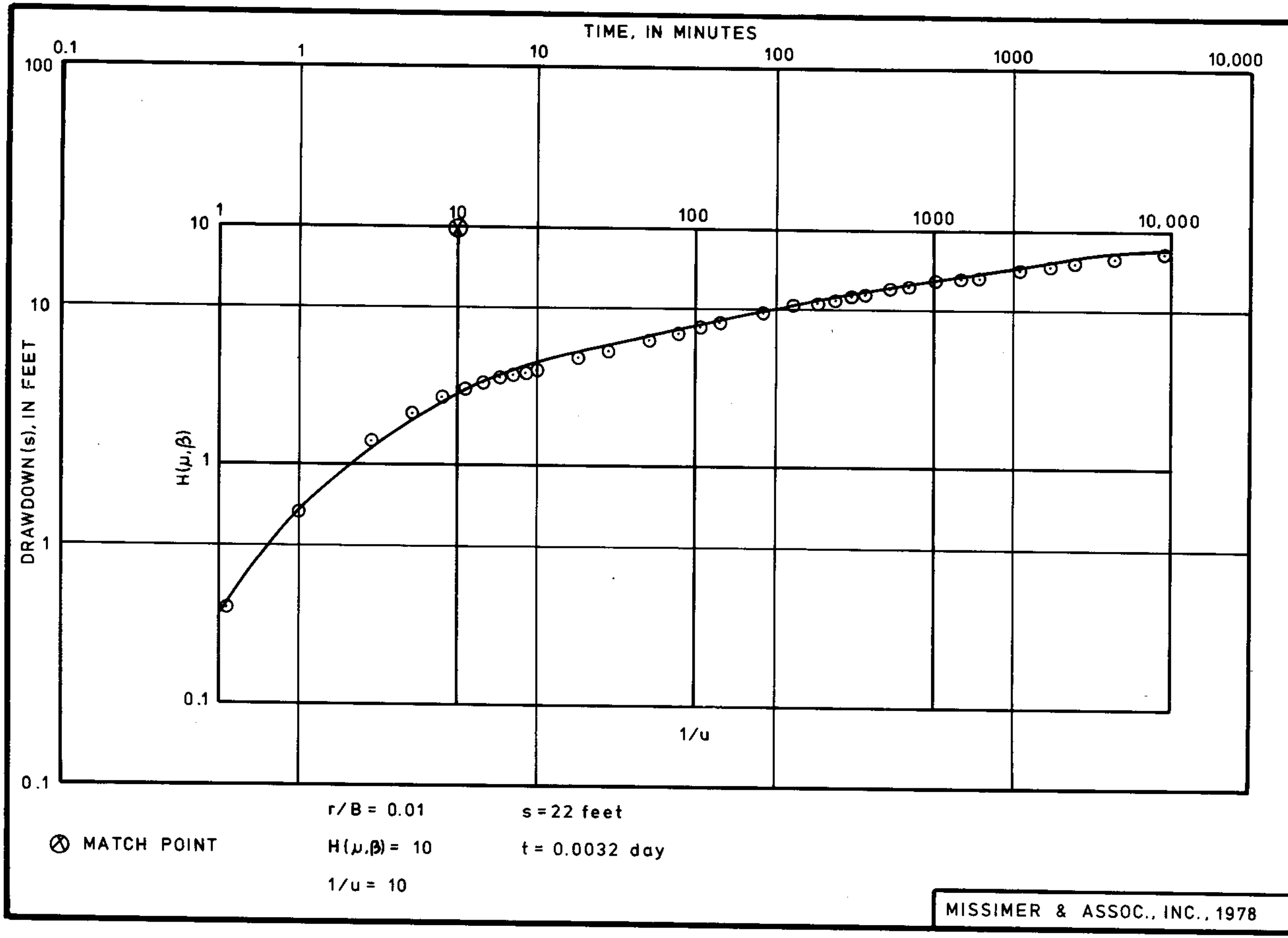


FIGURE 5-4. DIAGRAM SHOWING A LOG PLOT OF DRAWDOWN IN WELL L-M-944 WITH TIME AND THE HANTUSH-JACOB FUNCTION TYPE-CURVE MATCH.

The calculations are shown in Figure 5-4. Aquifer coefficients to be used for predictive purposes were calculated as:

Transmissivity = 15,600 gpd/ft^2

Storage Coefficient = 8.5×10^{-5}

Leakance = 5.0×10^{-5} gpd/ft^3

These coefficients are similar to those calculated from other aquifer tests on Sanibel (see Geraghty & Miller, Inc., 1978).

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. The best quality information is available from Hawthorn Aquifer System - Zone III.

Hawthorn Aquifer System - Zone III

The potentiometric surface of Hawthorn Aquifer System - Zone III responds to changes in the position of water levels in the water-table aquifer as well as fluctuations caused by barometric pressure changes, and ocean tides. The static or perhaps mean water level at the test site in Zone III was approximately 23 feet above mean sea level. This potentiometric level fits well into the regional pattern shown in Boggess (1974b).

Zone III is recharged by lateral flow through the aquifer from the mainland and by vertical leakage of water 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 Zone III will eventually take on the characteristics of the leaking water.

Regional flow or recharge to Zone III 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 (Walton, 1970). Using a cross sectional width of nine miles, a transmissivity of 15,000 gpd/ft and the regional hydraulic gradient of 0.65 1.5 feet/mile, the regional flow or recharge rate is approximately 250,000 gpd.

5. Water Quality

Previous studies have been made on the quality of water in both the shallow and deep aquifers underlying 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 and the quality characteristics are also described in detail within the above mentioned references.

In order to define the water quality characteristics of the various deep water-bearing zones, water samples were collected on a regular basis during test drilling with the reverse air method. These water samples give a semi-quantitative indication of water quality in each confined zone. The indicated quality characteristics are not precise because of mixing of the water within the borehole. Packer-stem tests were attempted in order to isolate the water quality, but these tests were unsuccessful. A graph showing the dissolved chloride concentration with depth is given in Figure 5-5. The concentration of dissolved chlorides was titrated in the field and rechecked in the laboratory. The specific conductance of each sample was also measured. Water quality in each of the aquifers discussed below is referenced to Figure 5-5.

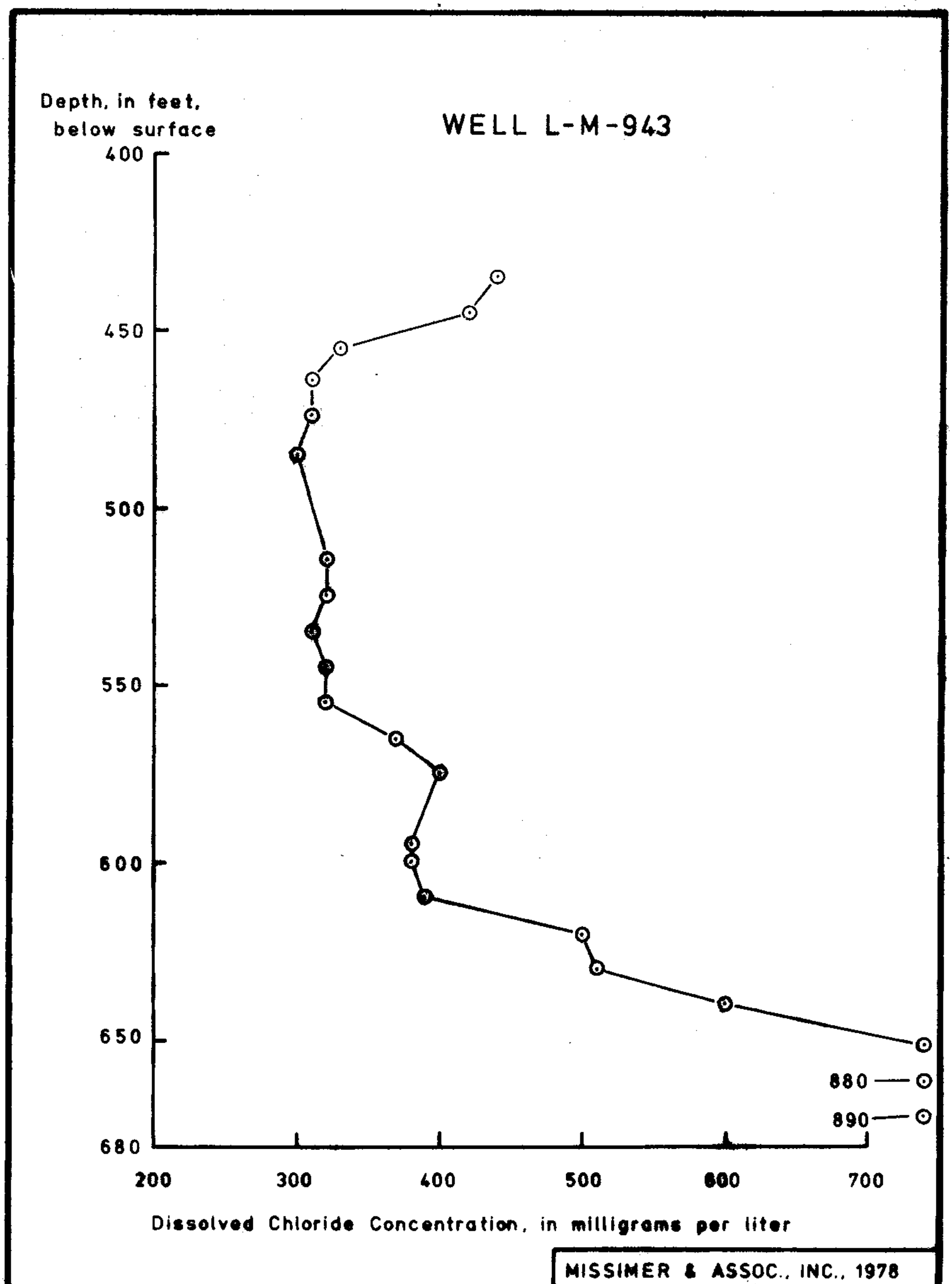


FIGURE 5-5. DIAGRAM SHOWING THE DISSOLVED CHLORIDE CONCENTRATION WITH DEPTH IN WELL L-M-943.

Tamiami Aquifer System - Zone II

Tamiami - Zone II appears to be hydraulically connected to Hawthorn Aquifer System - Zone I. Although no water samples were collected directly from it, a water sample was collected from the 310 foot level, which is in Hawthorn - Zone I, immediately beneath the Tamiami. This water sample had a concentration of 240 mg/l of dissolved chlorides. It is quite likely that the quality of water in Tamiami - Zone II is similar as indicated because of the inferred interaction of water.

Hawthorn Aquifer System - Zone I

A water sample was collected directly from Hawthorn-Zone I. It had a concentration of 240 mg/l of dissolved chlorides. This value is the lowest ever recorded in the Hawthorn Aquifer System beneath Sanibel. A test well drilled by the Island Water Association and described by Boggess (1974a) as L-1533, contained dissolved chloride concentrations between 1,000 and 2,000 mg/l in this interval. Well L-1533 was, however, located in the central part of the island.

Hawthorn Aquifer System - Zone II

Because of the collapsing problem in the gravel zone at 310 feet, it was not possible to drill through Zone II with the reverse air method. Therefore, no water samples could be collected and the quality of water remains unknown.

In certain parts of Sanibel, the water in this zone is very saline with up to 15,000 mg/l of dissolved chlorides.

Hawthorn Aquifer System - Zone III

Water quality varies considerably within Hawthorn - Zone III, which is the interval between 435 and 610 feet on Figure 5-5. The water samples collected during reverse air drilling showed concentrations of dissolved chlorides ranging from 310 to 440 mg/l. This range in values is probably only valid for the upper most permeable parts of the aquifer.

When well L-M-943 was plugged back to 610 feet with cement, and it was left in an unused state for several days, the dissolved chloride concentration raised to 880 mg/l. This could have been caused by upward migration of water from Hawthorn - Zone IV through or around the cement bottom plug. Therefore, there is a question regarding the effectiveness of the seal. The addition of some cement in the borehole to a depth of about 550 feet could cause a significant improvement in water quality.

The quality of water pumped from Hawthorn - Zone III varied considerably during the aquifer test (see Table 5-2). Dissolved chloride concentrations varied from 720 to 880 mg/l. The trend appeared to be down, but the chemical analysis made at the test termination showed only a slight decrease. Therefore, it is possible that some

TABLE 5-2 DISSOLVED CHLORIDE CONCENTRATIONS IN HAWTHORN AQUIFER SYSTEM - ZONE III DURING THE AQUIFER TEST.

DISSOLVED CHLORIDE CONCENTRATION (mg/l)

TIME (MINUTES)	MISSIMER & ASSOC.	ORLANDO LAB.
10	880	860
60	830	
120	830	
180	820	
240	790	
300	770	
360	770	
420	760	
540	760	
600	760	
720	740	
840	760	
960	760	
1080	760	
1200	740	
1320	770	
1440	810	
1800	740	
1920	740	
2160	810	
2580	730	
2640	720	
2760	740	
2820	720	
3015	740	
3240	730	
3360	730	
3480	740	
3600	750	
3960	740	
4080	720	
4320		843

poor quality water does occur within the alternating dolomite-clay-limestone sequence in the lower part of the aquifer and that some of this water is released on an unsteady basis into the well bore. This would cause a quantity fluctuation as observed. The solution to this problem would also be to cement off about 50 feet more of the lower borehole.

Complete chemical analyses on the water samples pumped from the well at the beginning and end of the test are given in Appendix Table A-5 and A-6.

Hawthorn Aquifer System - Zone IV

Water quality in Hawthorn - Zone IV is not as good as the overlying Zone III. Water samples collected during reverse air drilling showed a progressive increase in dissolved chlorides from 500 to 890 mg/l. It is possible that the quality change going from Zone III into Zone IV is much more pronounced. Some mixing of waters does occur and could have masked the true quality characteristics. A water sample collected through the drill stem, as it flowed, had a dissolved chloride concentration of 890 mg/l, which is a good indicator of bottom hole quality.

6. Summary

The Hawthorn Aquifer System beneath Sanibel Island at Bowman's Beach Road contains at least four separate water-bearing zones. Zone I occurs between 316 and 325 feet below land surface. It is a sand and calcareous sandstone unit and is probably equivalent to the Upper Hawthorn Aquifer on the mainland. Zone II occurs between 373 and 430 feet below land surface. It is the uppermost of three zones, which are collectively termed the Lower Hawthorn Aquifer. Zone II is a light gray, phosphatic limestone. Zone III occurs between 437 and 605 feet below land surface. It is a complex sequence of limestones, dolomites, marls, and some thin clays. This zone could possibly be further subdivided. Zone III occurs from 610 feet down to the bottom of the borehole and its full thickness at the site is unknown.

An aquifer test was performed on Zone III after it was isolated from the other zones by a cement plug and casing. The following aquifer coefficients were determined from the test analysis: transmissivity = 15,600 gpd/ft, storage coefficient = 8.5×10^{-5}, and leakance = 5.0×10^{-5}gpd/ft^3.

Water quality in Zone I is good and it contains water with a dissolved chloride concentration of about 240 mg/l. The quality of water in Zone II could not be determined. Zone III contains water that ranges in dissolved chloride concentration from 320 mg/l to perhaps 880 mg/l. It is probable that the real range is 320 to 440 mg/l and the higher concentrations are to result of leakage up the borehole. Zone IV contains water with about 890 mg/l of dissolved chlorides. The quality of water in Zone IV declines with depth.

VI. HAWTHORN AQUIFER SYSTEM: POTENTIAL YIELD AND WATER MANAGEMENT

1. Potential Maximum Yield

Potential maximum yield is the total quantity of water that can be withdrawn from an aquifer. The Island Water Association will require gross pumpage of 2.6 MGD by 1980 (Volkert & Associates, Inc., 1977). This withdrawal rate is far in excess of the 0.25 MGD recharge rate of Hawthorn Aquifer System - Zone III. Therefore, over 90% of the ground-water withdrawals will come from storage within the aquifer.

The quantity of water in storage is equivalent to the porosity of the zone containing acceptable quality water, which has an upper limit of 2,800 mg/l of total dissolved solids in this case. Not all of the water in storage is available for withdrawal and a large percentage of it is retained in the interstices of the formation and cannot be taken out. Water that can be withdrawn is known as the specific storage.

Meinzer (1959) developed a table for typical specific storage values for different rock types. Zone III beneath Sanibel Island has a specific storage of approximately 2.5%. This means that the equivalent of 2.5% of the total aquifer volume is available as useable water. Zone III is estimated to average 100 feet in thickness and it probably varies from 50 to more than 150 feet thick. The estimated surface area, considering all of Sanibel and adjacent tidal wetlands, is about 24 square miles. These values yield a total specific storage in Hawthorn - Zone III of 1.25×10^{10} gallons of water. Numerous additional wells would have to be constructed in order to withdraw this volume of water. This number is only a rough approximation of storage, but is the best possible number in consideration of the available data.

2. Aquifer Life Expectancy

Volkert and Associates, Inc. (1977) have estimated that 2×10^9 gallons had been pumped from the Hawthorn Aquifer System up to the end of 1976. Using data from the same report, an average annual pumping rate of 1×10^9 gallons is used for predictive purposes.

The lifetime of the aquifer is determined by dividing the total quantity of water available by the annual pumping rate. This calculation yields a predicted aquifer lifetime of ten years from January, 1977. Therefore, it is quite probable that the aquifer will not produce useable water by the end of 1986. This calculation does not consider the regional lateral recharge of 0.25 MGD or the possibility that adjacent aquifers (e.g. Hawthorn - Zones 1 and 2) may contain useable water that will leak into Zone III and recharge it. Regardless of the assumptions made, the life expectancy of the aquifer may be slightly longer, but only on the order of a few years. Because of the slow water quality deterioration expected, the water could become inadequate for use as early as the end of 1984.

3. Water Management

Wells on Sanibel in Hawthorn Aquifer System - Zone III will experience increases in total dissolved solids with time because of the finite volume of water in storage and the generally poor quality of water occurring in bordering aquifers. The rate of quality degradation is controlled by the local aquifer characteristics and pumping rates. If the aquifer were totally homogeneous, the greater the pumping rate, then the more rapid the degradation rate. Since the aquifer is not homogeneous, water quality declines will occur in various wells at differing rates.

Older wells, which are constructed with steel casings, should be closely monitored and when water quality in them becomes unusable, they should be plugged with cement. This will prevent any possible inter-aquifer leakage of poor quality water due to casing failure in the future. When the quality of water becomes unusuable in a newer well constructed with PVC casing, water quality should be monitored in it for a certain period of time in order to check if it recovers to a useable condition. Also, if a water treatment system is installed which has the capacity to treat poorer quality water, then the newer PVC wells could be again placed into production.

As the overall quality of water declines in the central IWA wells, it will be necessary to place new wells in northwestern, eastern or southern Sanibel. Since there are some significant private wells on eastern Sanibel, and the aquifer characteristics are more favorable to the west, the northwestern area should be considered the prime new well field area. After a number of the central wells go out of production, replacement wells could be drilled along West Gulf Drive on southern Sanibel.

All new wells should be constructed using the reverse air drilling technique. This allows the water-bearing zones to be accurately located and water quality can be determined. Casings can then be set at properly determined depths, which will isolate zones with the best possible water quality.

4. Monitoring Requirements

Some observation wells should be monitored to check the water levels in the aquifer, but these wells are of little use in monitoring changes in water quality. Therefore, a monitoring program should be directed toward monitoring water quality in the individual production wells. Since the transmissivity of the aquifer is relatively low and the primary cause of water quality degradation is vertical leakage, then the first sign of a quality change will occur in the production well bore. The dissolved chloride concentration and conductance of the water should be measured in each production well on a weekly basis. An extensive monitoring well network to map the potentiometric surface on Sanibel is not particularly useful as a monitoring tool.

5. Summary

Zone III of the Hawthorn Aquifer System presently contains about 1.25×10^{10} gallons of useable water in storage. At projected useage rates, the aquifer has a predicted life expectancy of about eight years with an overall range of six to twelve years. Water quality will no longer be suitable for treatment by the existing electro-dialysis plant at that time.

New wells should tap the aquifer in primarily the northwestern part of Sanibel. Certain wells may be drilled in the eastern and southern (West Gulf Drive) areas of the island. The northwestern part of Sanibel has the most productive section of Hawthorn Aquifer System - Zone III.

An extensive observation well network to monitor water levels is not particularly useful. However, a large amount of monitoring should be done on the quality of water being pumped from the production wells.

VII. IMPACT ASSESSMENTS

1. Impact on the Aquifer System.

The impact of pumping acceptable quality water from Hawthorn Aquifer System - Zone III in northwestern Sanibel was assessed by assuming continuous pumping at a constant rate to equilibrium with no recharge other than vertical leakage. This method is used to assess the worst possible drawdowns caused by pumping four equally spaced production wells each at a constant rate.

A gross pumping rate of 1.15 MGD was used for assessment, because this volume will be required by 1980 to suppliment the existing pumpage by the Island Water Association (see Volkert & Associates, 1977). The four production wells are equally spaced at 1,000 feet apart for calculation purposes. At this average pumping rate, equilibrium would be reached in 100 days at a radius of 50,000 ~~25,000~~ feet. The cone of depression in the potentiometric surface of Zone III at equilibrium is given in Figure 7-1. The maximum drawdown in the two interior wells (Nos. 2&3) would be 31 feet plus 24 feet due to interference, or a total drawdown of 55 feet. This drawdown would be greater in the well bore because of well inefficiencies. The outermost contour on Figure 7-1 is the 10-foot drawdown line, which is located at a radial distance of 12,250

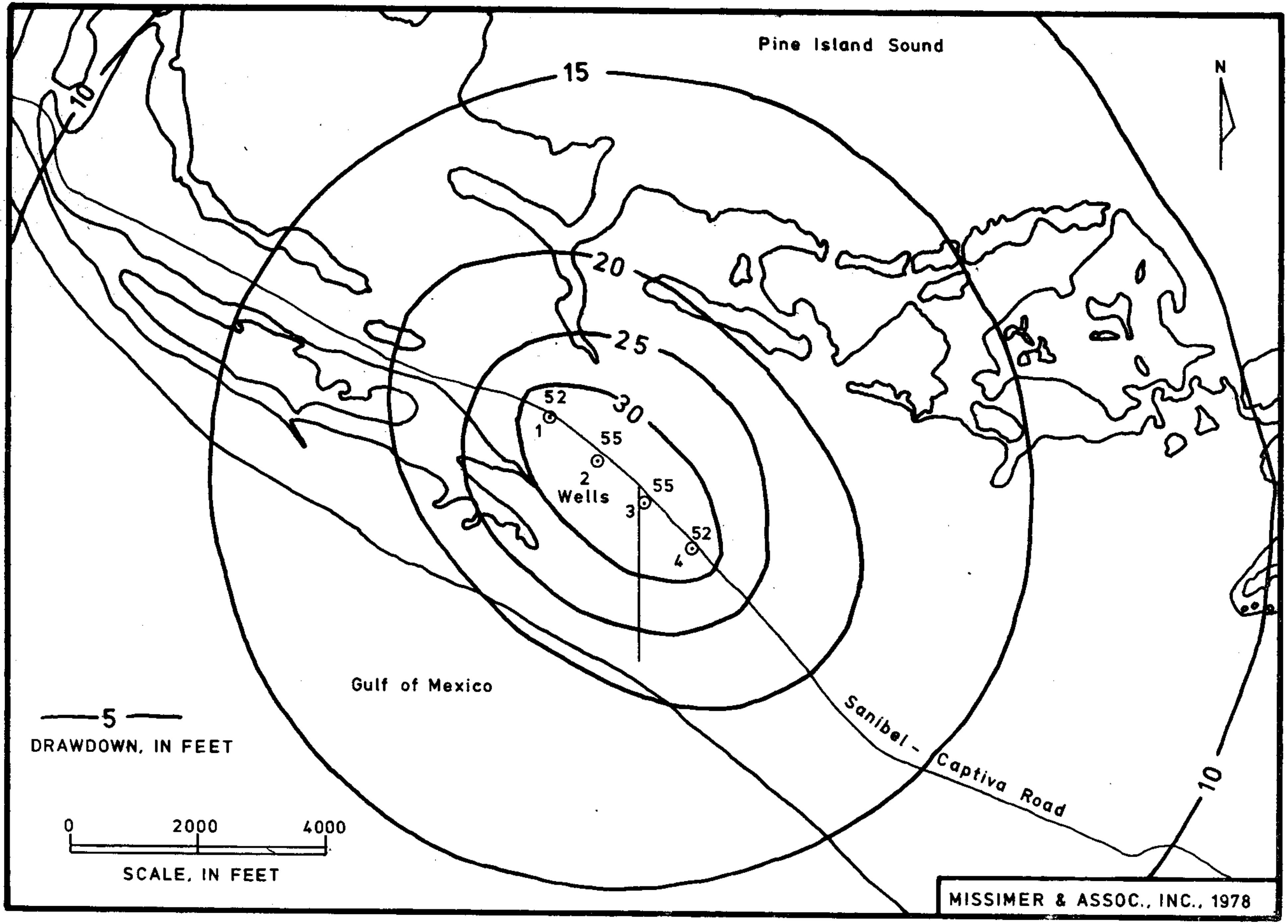


FIGURE 7-1. PREDICTED EQUILIBRIUM CONE OF DEPRESSION FOR A WITHDRAWAL RATE OF 1.15 MGD FROM 4 WELLS IN HAWTHORN AQUIFER SYSTEM - ZONE III.

feet from the center of pumpage. The 1-foot drawdown contour, which is not shown, lies at a radial distance of approximately ~~21,000~~ 42,000 feet. Withdrawals from the Bowman's Beach Road area will have a slight interference effect on the existing Zone III production wells located to the east. The drawdown effect on the nearest existing production well would be three feet.

Spacing of the production wells in the northwestern area is not very significant. As long as the distance between wells is at least 1,000 feet, the maximum drawdown in the center wells would be 55 feet and if the wells were spaced at 2,000 feet, the central drawdown would be 50 feet (see Table 7-1).

The impact of withdrawing 1.15 MGD from Zone III in northwestern Sanibel is clearly less significant than in the present well field area. Drawdowns at the existing well field site are greater because of the lower transmissivity values (see Geraghty & Miller, Inc., 1978). The Bowman's Beach Road area should be exploited for future withdrawals.

Water quality will decline in the northwest Sanibel area within Zone III because of the 1.15 MGD pumping rate Since the recharge rate of Zone III is only about 0.25 MGD for all of Sanibel and the northwest area receives only about 20 per cent of this value, most of the water pumped out will come from storage. As the useable water is with-

TABLE 7-1 COMPARISON OF EQUILIBRIUM DRAWDOWNS IN FOUR (4) WELLS LOCATED IN THE NORTHWESTERN PORTION OF SANIBEL ISLAND PUMPED AT 200 GPM WITH DIFFERENT WELL SPACINGS (r).

	DRAWDOWNS	
	AT r = 1000 FEET	AT r = 2000 FEET
WELL # 1	52	47'
WELL # 2	55	50'
WELL # 3	55	50'
WELL # 4	52	47'

drawn, it will be slowly replaced by more saline water over a period of years. This process was previously explained in Section VI.2.

2. Impact on Other Water Users.

There are less than ten wells tapping Hawthorn Aquifer System - Zone III within a 3-mile radius of the site. These wells are pumped or permitted to flow for mostly irrigation purposes. Pumping of Zone III at the 1.15 MGD rate will cause many of these wells to cease flowing at land surface and will require that a pump be installed if further useage is required. Water quality may decline in some of the wells as a result of aquifer development, but the main quality changes will occur at the center of pumpage.

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APPENDIX

TABLE A-1. GEOLOGIST'S LOG - WELL L-M-943.

Depth (ft)	Description
0-5	Sand and shell, tan quartz sand, fine to medium grain size, subangular, and mollusk shell fragments, very high permeability.
5-10	Sand and shell, tan, same generally as above, very high permeability.
10-15	Sand and shell, tan to lt. gray, quartz sand medium to very fine, well sorted, subangular, very high to high permeability.
15-20	Sand, gray, medium to very fine, moderate sorting, subangular, medium permeability.
20-25	Shell, clay, and sand, quartz sand and shell fragments with some lime mud, mud appears at base of sequence, overall permeability ranges from medium to low.
25-30	Clay and shell, unconsolidated lime mud and shell fragments, some quartz sand, general proportions - mud (15-30%), shell (25-35%), quartz (30-35%), low permeability.
30-35	Limestone, gray to lt. gray, hard, wackestone, fossiliferous micrite, very sandy, could be termed sandstone, evident secondary porosity, medium permeability.
35-40	Limestone, gray, hard, wackestone, micrite, sandy, quartz sand is medium to fine grain, medium secondary porosity, medium permeability.
40-45	Limestone, gray, hard, wackestone, micrite, sandy, with some lt. brown sparite, high secondary porosity, medium to high permeability.
45-50	Limestone, lt. tan and lt. gray, sparite, mostly crystalline, sparey calcite crystals, intergrowths, probably very high permeability.
50-55	Limestone, lt. tan, hard, wackestone, fossiliferous micrite, vugged, high secondary porosity, medium to high permeability.
55-60	Limestone, lt. tan to lt. gray, biosparite

TABLE A-1 (CON'T.). GEOLOGIST'S LOG - WELL L-M-943.

Depth (ft)	Description
55-60	or biomicrite, wachestone, mixture of micrite fragments and sparite fragments with shell, high permeability.
60-65	Limestone, lt. gray, medium hard, with some marl, wackestone, biomicrite, marly 60-62%, shelly medium permeability.
65-70	Limestone, lt. gray, medium hard to soft, slightly clayey, trace of phosphorite, marly, medium to low permeability.
70-75	Limestone, gray, and shell, wackestone, biomicrite, appear weathered, slightly clayey (1-3%), some quartz sand, medium to low permeability.
75-90	Limestone, gray, medium hard, sandstone, micrite, silty, shelly medium permeability.
90-95	Limestone, gray, some lithlolgy as above, medium permeability.
95-105	Limestone, lt. gray, mixed lithology, sandy near base, poor sample, medium to low permeability.
105-110	Clay, green, wackestone, very sandy, quartz sand and silt (50-70%), shell and rock fragments, low permeability.
110-115	Clay, green, same lithology as above, slightly more phosphatic than overlying limestone, low permeability.
115-120	Clay, green, interbedded lime mud and sandy lime mud, quartz sand content ranges from 25 to 85%, shelly phosphatic (slight), low permeability.
120-125	Clay, green, same lithology as above, low permeability.
125-130	Clay, green, same lithology as above, low permeability.

TABLE A-1 (CON'T.). GEOLOGIST'S LOG - WELL L-M-943.

Depth (ft)	Description
130-135	Clay, green slightly darker color, slightly finer sand, otherwise same general lithology, low permeability.
135-140	Clay, green, lime mud and clay minerals with quartz silt and sand, greater matrix percentage 20-60%, low permeability.
140-145	Clay, dark green-gray, lime mud and clay mineral matrix +50%, shell fragments, slight increase in phosphorite, low permeability.
145-150	Clay, dark green, same as above with less matrix, low permeability.
150-155	Clay, green, lime mud - clay mineral matrix over 70%, same impurities, minor phosphorite component, low to very low permeability.
155-160	Clay, green - gray, same generally as above, 80% matrix, very low permeability.
160-165	Clay, green, same as above, 80-90% matrix, very low permeability.
165-170	Clay, green, same as above, 80-90% matrix, less quartz than above, tighter than above, very low permeability.
170-175	Clay, green, lime mud-clay mineral matrix, 70-80%, quartz sand, shell and slightly increased phosphorite, low permeability.
175-180	Clay, green, same general lithology as ablve, clay sequence appears to have fining upward beds 10-15 feet thick, low permeability.
180-185	Clay, green, decreased matrix, increased quartz sand, low permeability.
185-190	Clay, green, increased matrix 85+%, tight, very low permeability.
190-195	Clay, green, same as above with slightly more quartz silt and phosphorite, low permeability.

TABLE A-1 (CON'T.). GEOLOGIST'S LOG - WELL L-M-943.

Depth (ft)	Description
195-200	Clay, green, same as above, low permeability.
200-205	Clay, green, unconsolidated lime mud with quartz silt and some shell fragments, earthy texture, very low permeability.
205-210	Clay, green, unconsolidated lime mud with a trace of quartz sand and a high percentage of quartz silt and probable clay minerals, trace of micro-phosphorite nodules, very low permeability.
210-215	Clay, green, same general lithology as above, slightly sandy, low to very low permeability.
215-220	Clay, green, same general lithology as above, more massive texture, fat, very low permeability.
220-225	Clay, green, unconsolidated lime mud with quartz sand and silt, clay minerals, and micro-phosphorite nodules, increased phosphorite content, low to very low permeability.
225-230	Clay, green, unconsolidated lime mud with variable percentages of terrestrial clastics, same generally as above, tight, very low permeability.
230-235	Clay, dark green, unconsolidated lime mud, some quartz silt and rock fragments.
235-240	Clay, green, sandy, unconsolidated, phosphatic, earthy texture, higher phosphorite content than above, low permeability.
240-248	Clay, gray to green, unconsolidated lime mud, sandy with a large percentage of micro-phosphorite nodules, 50-60% quartz sand, low permeability.
248-255	Clay and sand, gray, mixed lithology, unconsolidated lime mud (10%), quartz sand (25-30%), shell (10-15%), and rock fragments 5-10%), phosphorite nodules (5%), low permeability.

TABLE A-1 (CON'T.). GEOLOGIST'S LOG - WELL L-M-943.

Depth (ft)	Description
255-260	Clay, sand, and shell, unconsolidated mixed lithology, same generally as above with less quartz sand, Chlamys frag, Balanus frag., low permeability.
260-265	Clay and shell, gray, unconsolidated mixed lithology, mixture of shell fragments, rock fragments, quartz sand, and lime mud, low permeability.
265-270	Clay and shell, gray, with sandstone fragments, upper lithology to 267 feet same as above, lower lithology 267-270, shell and sandstone medium hardness, low permeability.
270-275	Limestone, lt. tan to white, mudstone perhaps sparite, some interbedded calcareous sandstone, apparent micritic matrix, sparite covering many grain-sides, apparent high secondary porosity, medium to high permeability.
275-280	Limestone and sandstone, lt. tan to white, same as above, low phosphorite content, high secondary porosity, medium permeability.
280-285	Limestone and shell, lt. tan to white limestone with high percentage of shell fragments, some lt. gray lime mud, low permeability.
285-290	Limestone and clay, gray limestone and gray limestone interbedded, limestone - mudstone, micrite, little phosphorite, medium hard to hard, clay-unconsolidated lime mud, lt. gray, slightly sandy, overall sequence, medium to low permeability.
290-295	Clay and limestone, gray lime mud and tan limestone interbedded, some shell, lithologies similar to above, clay component is dominant, low permeability.
295-298	Clay, lt. gray, wackestone, unconsolidated to a certain degree, could be termed marl, fossiliferous micrite, shelly, trace of phosphorite, low permeability.

TABLE A-1 (CON'T.). GEOLOGIST'S LOG - WELL L-M-943.

Depth (ft)	Description
298-305	Limestone, lt. gray to gray, extreme mixture of lithologies, soft, mixture of lt. gray mudstone fragments, shell, lime mud and phosphorite nodules ranging up to gravel-size, medium permeability.
305-314	Sand and gravel, black, soft, phosphorite nodules and quartz sand, nodules are well-sorted and well-rounded, coarse sand-sized quartz sand is medium to fine, high permeability.
314-316	Clay and sand, green clay and medium quartz sand, mixed lithology, 20-30% sand-size phosphorite nodules, low permeability.
316-321	Sand, fine to coarse quartz sand, 15-20% sand-size phosphorite nodules, black, well sorted, may contain some clay, medium permeability.
321-325	Sandstone, white, fine quartz sand cemented by micrite matrix, hard, low permeability.
325-330	Clay and phosphorite gravel, gray lime mud with 50% quartz sand and sand-size phosphorite nodules, low permeability.
330-341	Clay, sand, and phosphorite, interbedded sequence of extremely variable lithologies, lime mud matrix, gray in each case, unconsolidated, quartz sand 5 to 70%, phosphorite 15 to 50%, shell 1 to 15%, bed thickness about 2 to 5 feet, low permeability.
341-349	Sand and clay, gray, fine to medium size quartz with matrix of gray lime mud containing quartz silt and clay minerals, phosphorite-sand size to micro-nodules 10-15%, low permeability.
349-353	Clay, gray, lime mud with quartz sand, phosphorite nodules and clay minerals, impurities less than 50%, very low permeability.
353-361	Clay, gray, lime mud with slightly more than 50% impurities, same general lithology as

TABLE A-1 (CON'T.). GEOLOGIST'S LOG - WELL L-M-943.

Depth (ft)	Description
353-361	above, low permeability.
361-373	Clay, gray, lime mud with varying proportion of quartz sand, phosphorite and shell fragments, very low permeability.
373-383	Limestone, lt. gray to white, wackestone, fossiliferous micrite, contains well-rounded medium to fine quartz sand and 2-3% micro-phosphorite nodules, low to medium secondary porosity, medium permeability.
383-392	Limestone and sandstone, lt. gray, limestone is wackestone, fossiliferous micrite, same as above, sandstone is quartz sand and micro-phosphorite nodules cemented by micrite, medium secondary porosity, medium permeability.
392-404	Limestone, lt. gray to white, wackestone, fossiliferous micrite, disseminated quartz sand and micro-phosphorite nodules, medium secondary porosity, medium permeability.
404-414	Limestone, white to lt. gray, medium to hard, wackestone, fossiliferous micrite, disseminated fine to very fine quartz sand and micro-phosphorite nodules, low to medium secondary porosity, medium permeability (typical Hawthorn limestone).
414-425	Limestone, white and lt. gray, medium to hard, wackestone, biomicrite, mixed lithology: 1) same as above, and 2) sandy limestone, highly phosphatic, shelly, medium permeability.
425-430	Limestone, white and lt. gray, medium hardness, wackestone, biomicrite, same generally as above, some sparey calcite, medium secondary porosity, medium permeability.
430-435	Clay, lt. green, soft, lime mud, unlithified mixture of lime mud and quartz silt, some very fine phosphorite nodules, very low permeability.
435-437	Clay, dark green, soft, greasy texture, lime

TABLE A-1 (CON'T.). GEOLOGIST'S LOG - WELL L-M-943.

Depth (ft)	Description
435-437	and siliceous mud, phosphatic, some weathered limestone fragments and quartz sand, very low permeability.
437-440	Limestone, white and lt. brown, two lithologies: 1) white limestone, mudstone, micrite, very high secondary porosity, high permeability 2) lt. brown limestone, mudstone, micrite, low secondary porosity, phosphatic, low permeability.
440-445	Limestone or dolomite, lt. brown, medium hard, mudstone, micrite, 1-3% disseminated micro-phosphorite nodules, low secondary porosity, low permeability.
445-455	Limestone, lt. gray, wackestone, biomicrite, shell fragments abundant, 2-5% microphosphorite nodules, indeterminate secondary porosity, medium permeability.
455-459	Limestone, tan, mudstone, micrite or few-grain sparite, hard, vugged-solution riddled, extremely high secondary porosity, very high permeability.
459-461	Limestone, lt. gray to white, soft, mudstone, fossiliferous micrite, abundant micro-phosphorite nodules, trace of quartz sand, some shell, low secondary porosity, low permeability.
461-464	Clay, lt. gray-green, unlithified lime mud, trace of shell and quartz sand, nearly devoid of phosphorite, very low permeability.
464-466	Marl, lt. gray, semi-lithified lime mud, mudstone, micrite, few impurities, very low phosphorite content, very low permeability.
466-471	Limestone, lt. gray, soft, chalky texture, mudstone, micrite, same general composition as above, low secondary porosity, low permeability.
471-476	Limestone, lt. tan, hard, mudstone, micrite,

TABLE A-1 (CON'T.). GEOLOGIST'S LOG - WELL L-M-943.

Depth (ft)	Description
471-476	slightly phosphatic, fragments of gray-brown micro-crystalline dolomite, medium secondary porosity, medium to high permeability.
476-480	Limestone, lt. gray to gray, hard, mudstone, micrite, slightly phosphatic, medium secondary porosity, medium permeability.
480-485	Limestone, gray, hard, mudstone, fossiliferous micrite, trace of micro-phosphorite nodules, medium secondary porosity, medium permeability.
485-495	Limestone, gray, hard, mudstone, fossiliferous micrite, same general lithology as above, quartz sand, moderate to low secondary porosity, medium permeability.
495-500	Limestone lt. tan, medium hard to hard, micro-crystalline texture, highly phosphatic, black micro-phosphorite nodules cemented in matrix, 5-10% fine to very fine quartz sand, moderate to low permeability.
500-505	Limestone, gray, medium hard to hard, black and brown micro-phosphorite nodules, moderate permeability, 5% quartz sand.
505-517	Limestone, gray to lt. gray, mudstone, hard, micrite to fossiliferous micrite, some secondary porosity, medium permeability.
517-520	Limestone or marl, gray to gray-tan, soft to slightly hard, mudstone with nearly 40% non-carbonate components, quartz sand, phosphorite, minor shell, sparse biomicrite, low permeability.
520-525	Limestone, lt. tan-gray, medium hard, mudstone, micrite, contains 2 to 5% very fine quartz sand, and some dispersed micro-phosphorite nodules, tight, low permeability.
525-530	Limestone, lt. tan-gray, medium hard to soft, same generally as above, low permeability.

TABLE A-1 (CON'T.). GEOLOGIST'S LOG - WELL L-M-943.

Depth (ft)	Description
530-535	Limestone, or marl, white to lt. gray, soft, mixture of hard micrite and unconsolidated lime mud, wackestone, probable interbedded sparse biomicrite (soft) and micrite (hard), quartz sand and silt 5+% and dispersed micro-phosphorite nodules abundant, low permeability.
535-540	Limestone, separate lithologies, upper: limestone, lt. gray to gray, mudstone, sparse biomicrite, very sandy, concentrated micro-phosphorite nodules; lower: limestone, gray, tan, and lt. brown, micrite, mudstone, very hard, few impurities, overall moderate permeability.
540-545	Limestone, gray-tan, very hard, wackestone, sparse, biomicrite, heavy concentration of micro-phosphorite nodules, some phosphatized shell, some decorated vugs, medium to high secondary porosity, high permeability.
545-550	Limestone, lt. gray-tan, hard, mudstone, micrite, heavy concentration of gravel-sized phosphatized limestone gragments - angular medium to high permeability.
550-555	Limestone and marl, lt. gray to white, mixed lithology, upper: limestone, lt. gray, wackestone, packed biomicrite, more than 50% shell fragments, high permeability, lower: limestone or marl, mudstone, sparse biomicrite, chalky texture, low permeability.
555-560	Limestone, lt. gray to lt. tan, wackestone, sparse biomicrite, some phosphorite and quartz sand, some vugs with sparey calcite, moderate permeability.
560-565	Dolomite, tan to gray-tan, mudstone, micrite, some angular fragments of phosphatized lime-stone cemented in matrix, medium permeability.
565-575	Limestone, lt. gray-tan, hard, mudstone, fossiliferous micrite, small quantity of micro-phosphorite nodules and disseminated larger nodules 2-5 mm, some quartz sand,

TABLE A-1 (CON'T.). GEOLOGIST'S LOG - WELL L-M-943.

Depth (ft)	Description
575-578	Limestone, tan-gray, slightly dolomitic, very hard, mudstone, micrite (or perhaps fine sparite), trace of quartz sand and micro-phosphorite nodules, medium to high secondary porosity, high permeability.
578-582	Limestone, lt. gray to white, hard, mudstone, micrite, trace of quartz sand and phosphorite, visible secondary porosity, medium permeability.
582-587	Dolomite, lt. gray, very hard, mudstone, micrite, few impurities, low secondary porosity, medium to low permeability.
587-591	Limestone or marl, white, soft, wackestone, biomicrite, mixture of rock fragments and unlithified lime mud, 2-3% phosphatized limestone, chalky, low permeability.
591-598	Clay, dark gray, wackestone, biomicrite, unconsolidated mixture of unlithified lime mud, quartz sand and silt, shell, and phosphorite, very low permeability.
598-600	Limestone, gray, very hard, microcrystalline, slightly phosphatic, trace of quartz sand, apparent low porosity and permeability.
600-605	Limestone, gray, very hard, microcrystalline, same generally as above, phosphorite nodules mostly micro but few up to 2 to 4 mm.
605-607	Marl, white, carbonate mud with shell fragments, minor percentage of phosphorite, and rock fragments, chalky texture, poor permeability.
607-608	Clay, gray, carbonate mud, with silt, sand, and micro-phosphorite nodules, poor permeability.
608-610	Limestone, white to lt. gray, medium hard to soft, well-consolidated, minor quantity of micro-phosphorite nodules, well-rounded quartz sand 5-10%, high to moderate permeability.

TABLE A-1.(CON'T.). GEOLOGIST'S LOG - WELL L-M-943.

Depth (ft)	Description
610-620	Limestone, white to lt. gray, same as above, molds of burrows and gastropods, typical Hawthorn, moderate permeability.
620-630	Limestone, white, hard, relatively high secondary porosity, some shell fragments, 5% very fine quartz sand, marked decrease in percentage of microphosphorite nodules, high permeability.
630-640	Limestone, white, hard, same general lithology as above, minor trace of phosphorite, sandy, moderate to high permeability.
640-653	Limestone, white to lt. gray, abundant shell fragments, medium hardness, larger vugs decorated with sparey calcite crystals, trace of phosphorite, abundant fine quartz sand, very high secondary porosity and permeability.
653-663	Limestone, white to lt. gray, same as above, high permeability.
663-673	Limestone, lt. gray, micrite, increased amount of micro-phosphorite nodules, increased percentage of very fine to fine quartz sand, moderate permeability - less than above by an order of magnitude.

TABLE A-2 GEOLOGIST'S LOG - WELL L-M-944

Depth (ft)	Description
0-18	Sand, and shell, tan and gray
18-27	Clay, sandy, with shell, gray
27-40	Limestone, sandy, gray, very hard 30 to 35 feet
40-43	Limestone, sandstone, and shell, interbedded
43-53	Limestone, gray
53-59	Limestone, lt. tan and lt. gray.
59-63	Limestone, lt. gray, with shell, interbedded
63-71	Limestone, same as above
71-73	Limestone, tan, sandy, hard
73-83	Limestone, gray, shell, medium hard to soft
83-88	Limestone, gray, trace of sand, shell
88-93	Limestone, gray, silty, medium hard to soft
93-98	Limestone, gray, same as above
98-103	Siltstone, gray, carbonate matrix, shelly
103-108	Limestone, gray, silty, medium hard to soft
108-113	Siltstone, gray, carbonate matrix, minor shell
113-118	Clay, gray, soft
118-123	Clay, green, minor phosphorite content
123-138	Clay, green, sandy
138-143	Clay, green, minor phosphorite content, fat
143-156	Clay, green, same as above
156-163	Clay, green, same as above

TABLE A-2 (CON'T.) GEOLOGIST'S LOG WELL L-M-944

Depth (ft.)	Description
163-173	Clay, green
173-183	Clay, green, phosphatic
183-193	Clay, green, phosphatic
193-203	Clay, green, same as above
203-213	Clay, green, higher phosphorite content
213-223	Clay, green, silty, soft
223-233	Clay, green, same as above
233-243	Clay, green, higher phosphorite content than above
243-253	Clay, green, shell and phosphorite pebbles
253-256	Clay, green, some phosphorite pebbles
256-272	Clay, green, larger number of phosphorite pebbles
272-276	Clay, green, sandy
276-282	Clay, green, sandy, less phosphorite
282-286	Clay, green, silty
286-293	Limestone, lt. gray
293-303	Limestone, lt. tan
303-307	Limestone, lt. gray to lt. tan
307-318	Clay and limestone, gray to green, soft
318-321	Clay, dark green, phosphorite pebbles, sand
321-335	Clay, sand, phosphorite, mixed lithologies
335-345	Clay and sand mixed lithologies, same as above
345-351	Clay, gray, sandy

TABLE A-2 (CON'T.) GEOLOGIST'S LOG WELL L-M-944

Depth (ft.)	Description
351-361	Clay, gray, some phosphorite
361-363	Clay, gray
363-375	Limestone and clay, soft, gray
375-385	Limestone, silty
385-395	Limestone, sandy, lt. gray
395-400	Limestone, lt. tan and lt. gray
400-415	Limestone, gray
415-420	Limestone, gray, minor phosphorite
420-425	Limestone, gray
425-435	Limestone, lt. gray
435-436	Limestone, lt. tan-brown, medium hard
436-437	Clay, green
437-468	Limestone, tan, lt. gray, white, and lt. brown, thin beds
468-474	Clay and marl, gray
474-522	Limestone, lt. tan to gray, some dolomite
522-525	Marl, lt. gray
525-536	Limestone, lt. gray-tan
536-542	Marl, white to lt. gray
542-556	Limestone, lt. gray to lt. tan
556-560	Marl and limestone, chalky
560-565	Limestone, lt. gray
565-570	Dolomite, tan to gray-tan
570-595	Limestone, lt. gray to white

TABLE A-3 TIME AND DRAWDOWN TEST DATA FOR TEST-PRODUCTION WELL L-M-943 DURING THE AQUIFER TEST

ELAPSED TIME (MINUTES)	DRAWDOWN (FEET)
3	80.15
4	91.95
5	82.35
6	-
7	77.33
8	74.73
9	73.25
10	72.29
15	72.44
20	72.78
30	72.59
40	73.14
50	73.40
60	73.54
90	74.05
120	74.30
150	74.10
180	73.95
210	75.67
240	75.70
300	76.30
360	77.20
450	77.20
540	77.30
630	77.40
720	77.50
840	77.60
960	78.00
1080	79.70
1200	80.40
1320	80.70
1440	80.60
1560	80.80
1680	80.80
1800	81.70
1920	82.00
2040	81.90
2160	82.30
2280	82.40
2400	82.60
2640	82.40
2880	82.80
3120	82.50
3360	82.10

(Con't.)

TABLE A-3 TIME AND DRAWDOWN TEST DATA FOR TEST-PRODUCTION WELL L-M-943 DURING THE AQUIFER TEST

ELAPSED TIME (MINUTES)	DRAWDOWN (FEET)
3600	81.70
3840	82.40
4080	82.00
4320	82.30

TABLE A-4 TIME AND DRAWDOWN TEST DATA FOR OBSERVATION WELL L-M-944 DURING THE AQUIFER TEST

ELAPSED TIME (MINUTES)	DRAWDOWN (FEET)
1	1.38
2	2.74
3	3.54
4	4.14
5	4.56
6	4.84
7	5.03
8	5.20
9	5.34
10	5.46
15	6.10
20	6.62
25	7.03
30	7.38
40	7.95
50	8.40
60	8.75
90	9.59
122	10.16
150	10.55
180	10.90
210	11.20
240	11.46
270	11.70
300	12.22
360	12.38
420	12.70
480	12.94
540	13.20
660	13.64
780	13.98
900	14.28
1020	14.54
1140	14.74
1260	14.89
1380	14.99
1500	14.99
1620	15.08
1740	15.58
1860	15.78
1980	15.92
2100	16.04
2220	16.18

(Con't.)

TABLE A-4 TIME AND DRAWDOWN TEST DATA FOR OBSERVATION WELL L-M-944 DURING THE AQUIFER TEST (Continued)

ELAPSED TIME (MINUTES)	DRAWDOWN (FEET)
2340	16.30
2460	16.42
2580	16.47
2700	16.54
2820	16.61
2940	16.68
3060	16.80
3180	16.93
3300	17.02
3420	17.09
3540	17.12
3660	17.18
3780	17.26
3900	17.36
4020	17.32
4140	17.32
4260	17.32
4320	17.34

TABLE A-5 CHEMICAL ANALYSIS OF WATER FROM WELL L-M-943 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.

Date: 20 June 78

Report Number: 15282

Appearance: Clear

Sampled by: Client

Identification: Sanibel - No. 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.	2250	Total Hardness, as $CaCO_3$	x.	522
Phenolphthalein Alkalinity, as $CaCO_3$	x.	0	Calcium Hardness, as $CaCO_3$	x.	230
Total Alkalinity, as $CaCO_3$	x.	160	Magnesium Hardness, as $CaCO_3$	x.	292
Carbonate Alkalinity, as $CaCO_3$	x.	0	Calcium, as Ca	x.	92
Bicarbonate Alkalinity, as $CaCO_3$	x.	195	Magnesium, as Mg	.x	71
Carbonates, as CO_3	x.	0	Sodium, as Na	x.	500
Bicarbonates, as HCO_3	x.	195	Iron, as Fe	.x	0.05
Hydroxides, as OH	x.	0	Manganese, as Mn	.x	<0.05
Carbon Dioxide, as CO_2	x.	26	Copper, as Cu	.x	<0.1
Chloride, as Cl	x.	860	Silica, as SiO_2	x.	34
Sulfate, as SO_4	x.	360	Color, PCU	x.	0
Fluoride, as F	.x	2.3	Odor Threshold	x.	0
Phosphate, as PO_4	.x	0.37	Turbidity, NTU	x.	1.0
pH (Laboratory)	.x	7.1	Dissolved Iron, Fe		0.04
pHs	.x	7.3	Potassium, K		27
Stability Index	.x	7.5			
Saturation Index	.x	-0.2			

Signed: Gail Blank

Chemist

TABLE A-6 CHEMICAL ANALYSIS OF WATER FROM WELL L-M-943 AT THE END 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.

Date: 26 June 78

Report Number: 15318

Appearance: Clear

Sampled by: Client

Identification: #2 Water Sample No ID given

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.	2260	Total Hardness, as $CaCO_3$	x.	490
Phenolphthalein Alkalinity, as $CaCO_3$	x.	0	Calcium Hardness, as $CaCO_3$	x.	210
Total Alkalinity, as $CaCO_3$	x.	200	Magnesium Hardness, as $CaCO_3$	x.	280
Carbonate Alkalinity, as $CaCO_3$	x.	0	Calcium, as Ca	x.	84
Bicarbonate Alkalinity, as $CaCO_3$	x.	200	Magnesium, as Mg	.x	68
Carbonates, as CO_3	x.	0	Sodium, as Na	x.	490
Bicarbonates, as HCO_3	x.	244	Iron, as Fe	.x	<0.01
Hydroxides, as OH	x.	0	Manganese, as Mn	.x	<0.05
Carbon Dioxide, as CO_2	x.	17	Copper, as Cu	.x	<0.1
Chloride, as Cl	x.	843	Silica, as SiO_2	x.	39
Sulfate, as SO_4	x.	395	Color, PCU	x.	0
Fluoride, as F	.x	2.6	Odor Threshold	x.	0
Phosphate, as PO_4	.x	0.34	Turbidity, NTU	x.	0.35
pH (Laboratory)	.x	7.4	Dissolved Iron, Fe		<0.01
pHs	.x	7.4	Potassium, K		29
Stability Index	.x	7.4			
Saturation Index	.x	0.0			

Signed: Gail Blank

Chemist