VOLUME 1

ENGINEERING REPORT

DEEP TEST/ INJECTION WELL

PREPARED FOR

NORTH FORT MYERS UTILITY, INC.
NORTH FORT MYERS, FLORIDA

PBS&J

POST, BUCKLEY, SCHUH & JERNIGAN, INC.

POST, BUCKLEY, SCHUH & JERNIGAN, INC.
8600 N. W. 36TH STREET
MIAMI, FLORIDA 33166-6622
305/592-7275

April 19, 1988

Mr. Vincent N. Mele
Chairman, TAC-UIC
Florida Department of Environmental Regulation
South Florida District
2269 Bay Street
Fort Myers, Florida 33901-2896

Re: North Ft. Myers Utility - Deep Injection Well

Dear Mr. Mele:

We are pleased to submit to you and to the TAC members this engineering report on the construction and testing of the deep-injection-well system at North Fort Myers, in Lee County. The report is presented in two volumes: the text (Volume 1) and the appendices (Volumes 2A and 2B).

The well was constructed and tested in complete accord with the Plan of Study and, with one exception, with the Construction Specifications approved by the TAC. Full compliance with the permit conditions was observed through construction and testing.

The only significant deviation from the original design was brought about by the inability to install the intermediate casing to the designed depth. Until that time, the construction proceeded smoothly, and with the exception of several delays caused by equipment failure, this project was otherwise problem-free. This is due in large measure to the great cooperation and assistance that we received from the members of the TAC such as yourself, Messrs. David Butler and Leslie Wedderburn of the SFWMD, Messrs. Richard Deuerling and Joseph Haberfeld of DER, Messrs Craig Hutchinson and John Hickey of the USGS, Mr. Gene Coker of the US EPA, and Mr. Roland Banks of Lee County. The timely and expedient decisions made by Mr. Philip Edwards also made it possible to complete the project within budget. We thank every one of you.

The testing results indicate that there is a good injection zone capable of accepting a 4.0-million gallon-per-day (2,780 gpm) rate of injection, as tested. The results also indicate that both the injection well and the monitor well meet all the mechanical integrity criteria, and that the casing and the cementing installations were successful. There is also unusually strong evidence that the confining zone above the injection zone is a good one. The results of the core analysis provide irrefutable confirmation; but even based solely on geologic logs, geophysical data, television surveys, water quality, and piezometric data during testing, it is quite evident that the confining zone is very tight.

The SWIP computer model, using as input the results of the core analysis and the aquifer test, showed that a high degree of confinement exists and that the injected wastewater will not affect the aquifers above the injection zone in any detrimental way. The injection zone proved to be highly permeable and contains numerous cavities and a few caverns that insure little change in the injection pressures in the future.

We trust that you will find this report complete and satisfactory to proceed with the approval of the 1-year test/operating period using effluent.

Very truly yours,

POST, BUCKLEY, SCHUH & JERNIGAN, INC.

William A.J. Pitt, Jr., P.E., P.H.
Senior Hydrologist

c. Jack Schenkman, NFMU - Miami
Ray Dixon, NFMU - North Fort Myers
William Sundstrom, Esq. - Tallahassee
Joe Haberfeld, DER - Tallahassee
David Butler, SFWMD - West Palm Beach
Gene Coker, EPA - Atlanta
Craig Hutchinson, USGS - Tampa
Roland Banks, Lee Co. Environmental Protection Services - Ft. Myers
Richard Deuerling, DER, Tallahassee
William Todd, PBS&J - Ft. Myers

Enc.

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ABSTRACT

A deep injection well was constructed and injection tests were performed in the lower zone of the Floridan Aquifer System at North Fort Myers in Lee County, Florida. The tests were performed to evaluate the potential of this zone for disposal of treated wastewater effluent from the North Fort Myers Utility, Inc. wastewater treatment plant currently nearing construction completion. Analyses of the data collected and of the monitoring programs show that the proposed injection zone is overlain by a tight confining zone and that wastewater injection at this site does not pose an environmental threat to the potential water-supply aquifers above. As indicated by the injection tests, the injection zone has more than enough potential to receive the 4.0 million gallons per day of wastewater that the well was designed to handle. The expected quality of the proposed injection wastewater is better than that of the saline formation fluid in the injection zone and the increase in piezometric differential pressure across the confining zone resulting from the injection will not create any significant leakage. The transmissivity of the injection zone is nearly 500,000 gallons per day per foot and the storage coefficient is 8.4×10^{-5}.

m:H-87/C

ENGINEERING REPORT

DEEP TEST/INJECTION WELL

NORTH FORT MYERS UTILITY

Lee County, Florida

Prepared for:

North Fort Myers Utility, Inc.
P. O. Box 2457
North Fort Myers, Florida 33902

April 1988

305-592-7275

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Engineering • Planning • Architecture
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08-093.80

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

m:H-87/D

LIST OF TABLES

LIST OF TABLES

[1] To be provided in the Engineering Report Addendum

m:H-87/E

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

[1] To be provided in the Engineering Report Addendum

m:H-87/F

GLOSSARY

AoR	Area of Review
BTOC	Below top of casing
CBL	Cement bond log
CLI	Core Laboratories Incorporated
DER	Florida Department of Environmental Regulation
DITW	Deep injection test well
DMW	Deep monitor well
ESI	Environmental Services Incorporated
FAA	Federal Aviation Administration
FAC	Florida Administrative Code
FCWC	Florida Cities Water Company
gpd	gallons per day
gpm	gallons per minute
IWOP	Injection Well Operating Permit
LCHD	Lee County Health Department
mgd	million gallons per day
mg/l	milligrams per liter
msl	mean sea level (equivalent to NGVD for all practical purposes)
NFMU	North Fort Myers Utility, Inc.
NGVD	National Geodetic Vertical Datum
NOAA	National Oceanic and Atmospheric Administration
PBS&J	Post, Buckley, Schuh & Jernigan, Inc.
PSC	Florida Public Service Commission
psi	Pounds per square inch
PVC	Polyvinyl chloride
SCS	U.S. Department of Agriculture, Soil Conservation Service
SFWMD	South Florida Water Management District
SP	Spontaneous potential
SWIP	Sub-Surface Water Injection Program
TAC	Technical Advisory Committee
TD	Total depth
TDS	Total dissolved solids
TIWCP	Test Injection Well Construction Permit

TOC	Top of casing
TTL	Travel time log (also referred to as transit time)
UIC	Underground Injection Control
USDW	Underground Source of Drinking Water
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VDL	Variable density log

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SUMMARY

North Fort Myers Utility, Inc. (NFMU), the only major franchised utility in Lee County north of the Caloosahatchee River and east of U.S. Highway 41, is building a new wastewater treatment plant to serve the growing community of North Fort Myers and the surrounding areas in north/central Lee County. Wastewater from much of that community is currently discharged to the Caloosahatchee River and to the shallow water table aquifer, thus posing a threat to that environmentally sensitive river and to the aquifer that provides the sole source of supply to many residents of the area.

To reduce the potential environmental hazard and at the same time provide treatment for the increasing wastewater disposal demands of the franchised area, NFMU elected, in 1986, to investigate the feasibility of developing a dual irrigation/deep-well injection system that could both conserve water and protect the environment. NFMU engaged the consulting engineering firm of Post, Buckley, Schuh & Jernigan, Inc. (PBS&J) to conduct the investigation, and charged it with the responsibility of drilling an exploratory/monitor well. That well was completed in the fall of 1986 and a report describing the results of the exploration was published in October of that year. The results were positive and the project proceeded to a full-scale test program. The Florida Department of Environmental Regulation (DER) issued a permit on March 13, 1987 for the construction of a full-size test/injection well and testing of the proposed injection zone.

This report presents the results of the construction and testing of the deep test/injection well, discussing the surficial hydrologic characteristics of the area, identifying the major soils and their hydrologic characteristics, and reviewing the rainfall distribution. The geological strata underlying the site are described and the capability of the proposed injection zone to accept the treated effluent is evaluated. The confining zone above the injection zone is also discussed. Descriptions of the deep test/injection well design, the injection fluid, and the area of review are included.

The monitoring data, cores, and samples collected during the construction and testing of the deep test/injection well, including geophysical logs, drilling records, television surveys, and water quality data, are all analyzed in this report. From these analyses and from the drilling and testing logs, the top of the 260-foot injection zone is identified at 2,340 feet below land surface, with a confining bed above it extending upwards for nearly 190 feet without significant interruption. A 25-foot zone of high permeability exists between 2,125 and 2,150 feet below land surface; but this zone is isolated and not connected above or below. Above that, the confining zone extends upward for another 325 feet from between 1,800 and 2,125 feet below land surface.

Two injection tests were conducted, one at a rate of approximately 2,780 gallons per minute (gpm) (4.0 million gallons per day (mgd)), and the other at approximately 1,450 gpm (2.1 mgd). Analysis of the data from the two zones of the lower Floridan Aquifer System tapped by the monitor well that was drilled in 1986 shows that these zones are not affected by the injection. The injection test analysis shows that the injection zone has a transmissivity (T) of 498,260 gallons per day per foot and a storage coefficient (S) of 8.4×10^{-5}.

Core sample data have shown that the permeability of the confining layers is very low and this has been confirmed by the geophysical logs. Typical values of permeability for some of the tighter sections of the confining zones are in the area of 1×10^{-6} darcies (1×10^{-4} gallons per square foot). Using the range of injection pressures that can be expected as the system grows to its full capacity, it is not possible to cause any measurable migration of the injected fluid across the confining zone. It is estimated that the injection pressure would have to be one order of magnitude higher than any expected value before any measurable leakage could be induced across the confining zone.

The report recommends operating guidelines and monitoring criteria, and concludes with a recommendation that a 1-year testing period using effluent begin immediately and continue for the duration of the current permit (until March 1989). At that time, should additional standby facilities be required, then those facilities could be implemented with the knowledge that the system is viable.

Section 1
INTRODUCTION

1.1 BACKGROUND

The Lee County 201 Facilities Plan, adopted in 1977 by the County for the Cape Coral/North Fort Myers Sewer District, included the installation of a central sanitary sewer collection and interceptor system. Raw wastewater collected from the system was to be transported to and treated at a proposed regional wastewater treatment plant in Cape Coral, Florida. The disposal plan included tertiary treatment with ultimate discharge to the canal system in Cape Coral. Under this plan, approximately 29 existing package wastewater treatment plants would have been abandoned and their customers connected to the regional system.

In 1979, the original plan was modified and the capacity of the facility reduced from 14 million gallons per day (mgd) to 10 mgd. In addition to reducing the capacity, the modified plan also reduced the level of treatment from tertiary to advanced secondary and changed the ultimate disposal from canal to groundwater discharge.

Design plans and specifications for the regional wastewater collection and treatment system were completed in July 1982 and Federal funds secured from the United States Environmental Protection Agency (EPA) for construction; but Lee County elected to withdraw from the project and decided not to construct the system. As a result, the wastewater management problems that existed in North Fort Myers prior to and during the time the 201 Facilities Plan was being prepared still remain. There is a definite need both for solutions to existing wastewater problems in North Fort Myers and for improved and expanded facilities to meet current high growth demands in the area.

North Fort Myers Utility (NFMU), the only major existing utility in North Fort Myers east of U.S. Highway 41 (see Figure 1-1), owns and operates a wastewater treatment plant in Lee County which serves the North Fort Myers area. NFMU was one of the 29 plants scheduled for absorption into the County's regional system; however, with the abandonment of the proposed regional system by the

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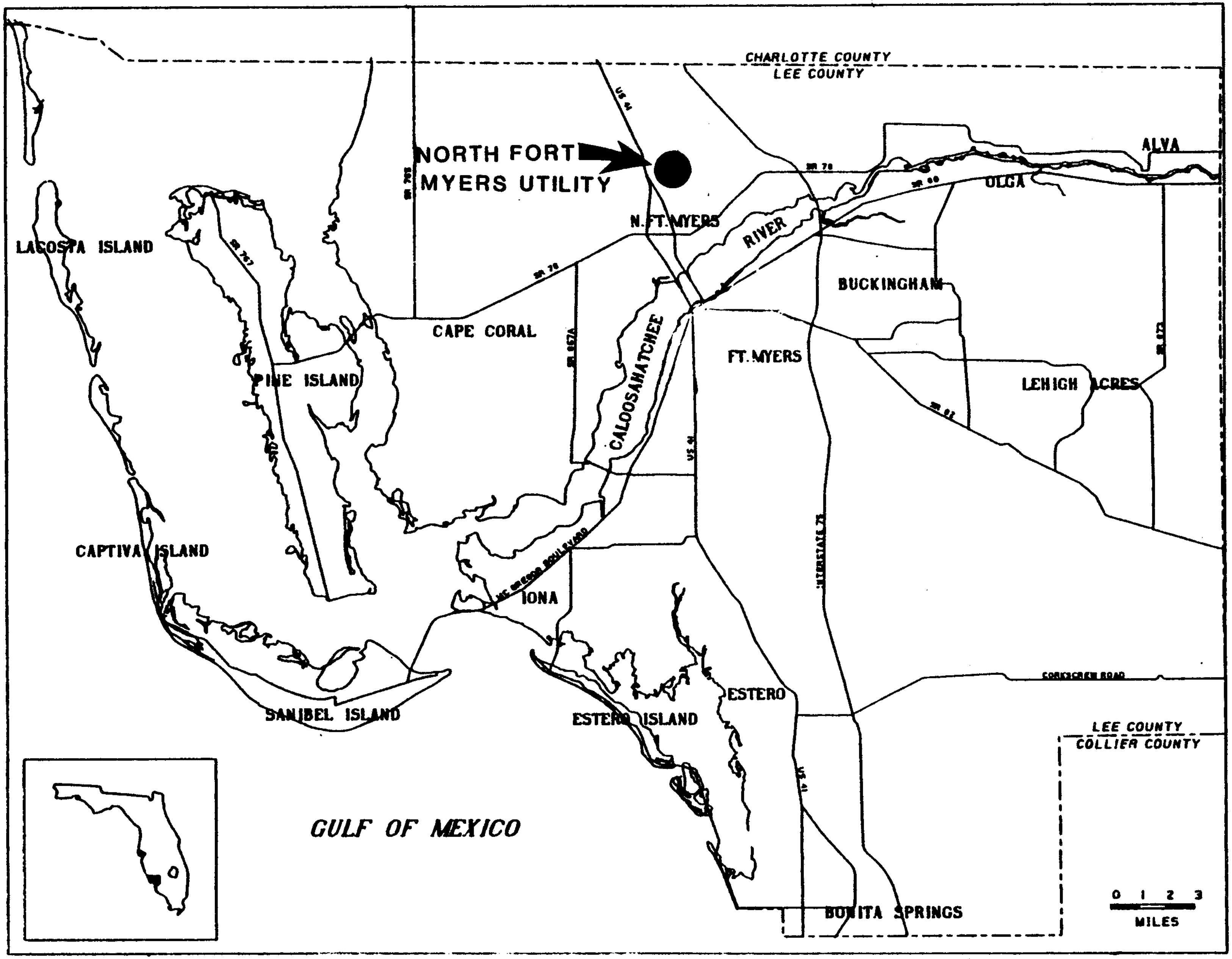
POST, BUCKLEY, SCHUH & JERNIGAN, INC.

GENERAL LOCATION MAP

FIGURE 1-1



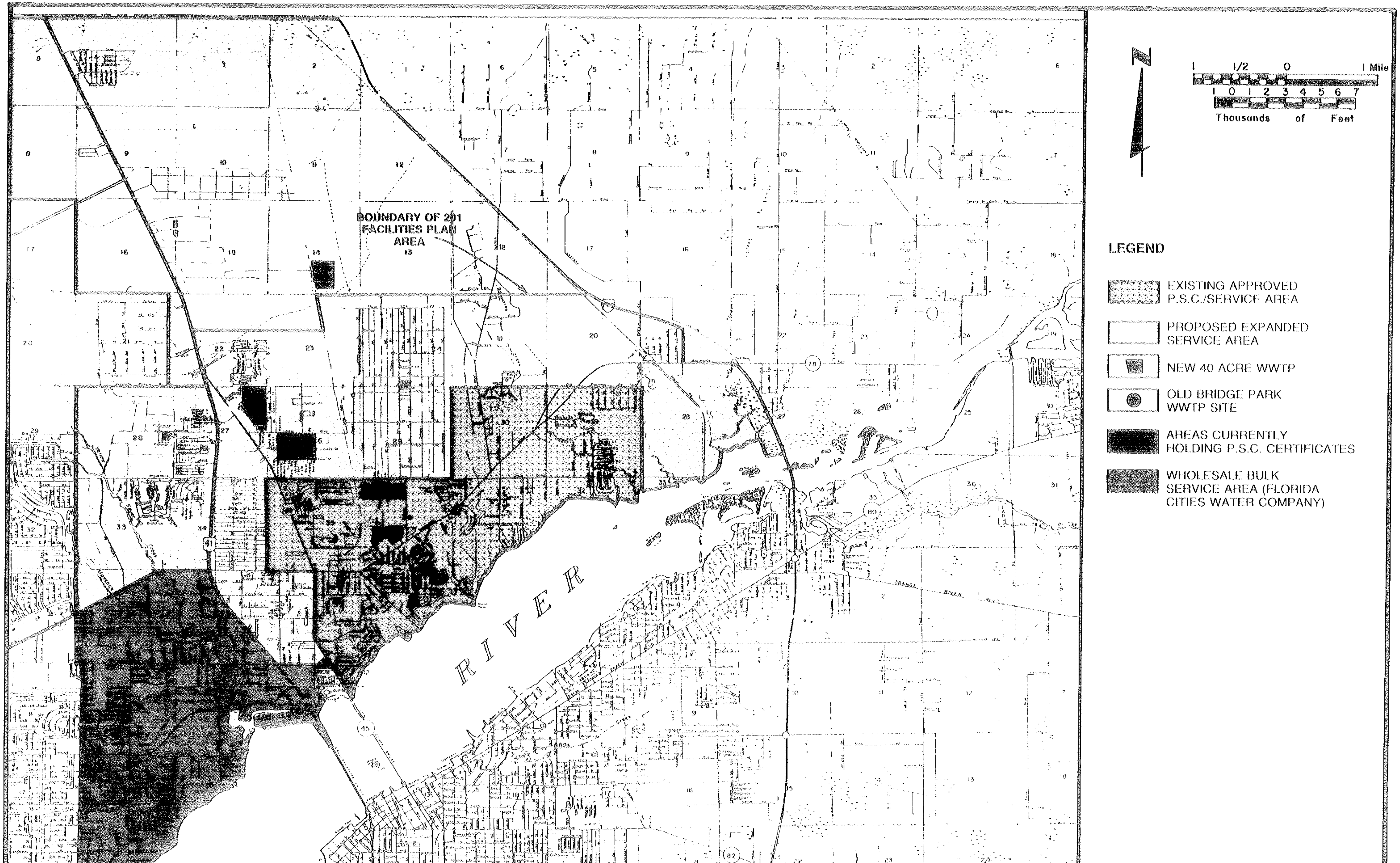
County, and the continuing growth in the North Fort Myers area, NFMU received constant requests from adjacent landowners, shopping centers, and area merchants, to provide sewer service to their properties. As a result, NFMU, with the encouragement of the Lee County Health Department and the approval of the Florida Department of Environmental Regulation (DER), expanded its Old Bridge Park plant to a capacity of 400,000 gallons per day (gpd) and increased its service area. Since then, NFMU has continued to receive numerous requests for service, the quality of which has earned it a DER award for best operated plant of its size and class in southwest Florida and, on another occasion, an honorable mention award for its high quality service.

NFMU is now operating under Florida Public Service Commission Order No. 13509, dated July 12, 1984, which extended NFMU's certificate, pursuant to Section 367.041 of the Florida Statutes. Because of its continual growth, however, NFMU no longer has the capacity to accept any new connections beyond its present commitments. Nevertheless, it continues to receive numerous requests for sewer service from existing package plant owners and developers of commercial and residential properties.

In anticipation of the growing demand for service, NFMU authorized Post, Buckley, Schuh & Jernigan, Inc. (PBS&J) in 1985 to prepare a master plan to guide expansion decisions. At the same time, NFMU began the effort to expand its service area (see Figure 1-2).

The resulting master plan of the wastewater treatment plant environs identified a flow of 2.0 mgd from existing developments connected to the system, from independent existing package treatment plants, and from undeveloped areas that should be developed with a collection system. This flow did not include the connection of the existing residences currently on septic tanks in the present service area or in the areas that could possibly come into the system in the future.

Originally, NFMU had considered building a wastewater treatment facility that would discharge the treated effluent into the tidal reaches of the Caloosahatchee River estuary via a subaqueous outfall, and had applied for and



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NORTH FORT MYERS UTILITY, INC.

LOCATION MAP AND SERVICE AREAS

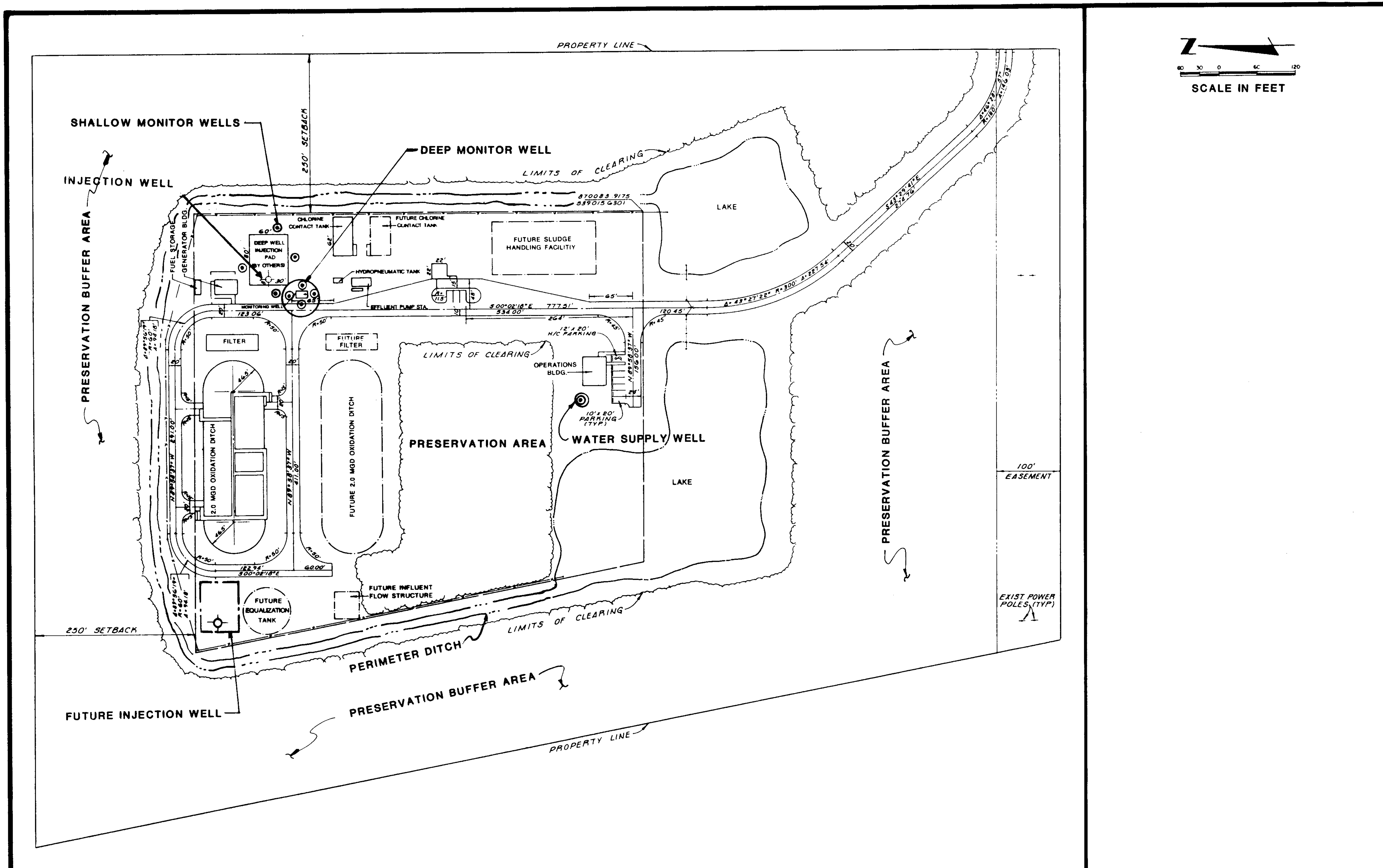
FIGURE 1-2

received a permit for this discharge. The permit allows NFMU to discharge up to 2.0 mgd of wastewater into the river daily, but requires that the waste be treated to a high degree. Not only would such treatment be costly, but there are no guarantees that an even higher degree of treatment would not be required in the future. In addition, although the 2.0-mgd discharge would meet the demand for several years, it is unlikely that future increases in the allocated discharge volume would be permitted. NFMU would, therefore, be forced to develop an additional disposal system once flows increased past 2.0 mgd.

Given this scenario, NFMU reconsidered the option of advanced wastewater treatment followed by river discharge and began instead to evaluate a new option, deep-well injection at an inland site. Under this new option, NFMU would not have to proceed with the more expensive advanced wastewater treatment plant or with an effluent pump station and force main into the river, but would instead develop a deep-well injection system that would work today and be easily expandable in the future while requiring only secondary treatment of the effluent.

Deep-well injection has been used by the oil industry for years in southwest Florida to inject returned brine from oil well drilling and production into deep formations. Nonetheless, to increase confidence that deep-well injection for sewage was feasible in North Fort Myers, NFMU completed an exploratory well drilling and testing program (see PBS&J, 1986a). The exploratory well used in this program was designed to be converted into a multi-zone monitor well for future use during operation of the injection system.

The results of the exploratory program were very positive and reasonably assured NFMU that deep-well injection would work at the its proposed new plant site (see Figure 1-3). NFMU then proceeded to develop a program for the construction of an expanded treatment plant, sewage collection main, injection system, and spray irrigation system for reuse of the treated water. The principal elements of the program were included in a two-phased project as follows:



POST, BUCKLEY, SCHUH & JERNIGAN, INC.

NORTH FORT MYERS UTILITY, INC.

SITE LAYOUT

FIGURE 1-3

- Phase I

  - Construct a 2.0-mgd secondary wastewater treatment plant expandable to 6.0 mgd as demand requires.

  - Construct and test a 4.0-mgd injection well.

  - Construct a sewage main to the new plant site and a return line for reuse of as much of the treated water as possible.

- Phase II

  - Once a capacity of 2.0 mgd is reached, construct a second 4.0-mgd injection well.

  - Expand the plant to 4.0 mgd.

The final result of this two-phase project would be a cost-effective, environmentally sound, deep-well-injection wastewater disposal system with a design capacity of 4.0 mgd.

1.2 AUTHORIZATION AND PERMITTING

Under the rules of the Florida Administrative Code (FAC), DER is the permitting agency for both the construction and the operation of deep-injection wells in Florida. To evaluate complex deep-injection projects, Technical Advisory Committees (TACs) have been established throughout the state, each TAC covering a different DER district. These TACs assist and provide advice to the local DER on the technical aspects of underground injection for wastewater disposal. The local DER representative chairs the TAC and is ultimately responsible for coordinating the TAC recommendations to the DER.

South Florida District TAC representatives for the NFMU project area are as follows:

DER - South Florida District	Mr. Vincent Mele - Chairman
DER - Tallahassee Headquarters	Mr. Richard Deuerling and Mr. Joe Haberfeld (alternate)
South Florida Water Management District (SFWMD) - West Palm Beach	Mr. David Butler
EPA - Atlanta	Mr. Gene Coker
U.S. Geological Survey (USGS)-Tampa	Mr. Craig Hutchinson

Early in the summer of 1985, NFMU authorized PBS&J to develop a plan of study for a deep-well injection system to be drilled at the NFMU site. As part of the authorization, PBS&J was to represent NFMU before the permitting agencies and the TAC; to design the well system; to conduct the construction observation, testing and sampling; and to prepare the reports on the results of the drilling and testing.

The plan of study consisted of two parts. First, an exploratory well would be drilled and tested and then converted to a monitor well. Second, a test well would be constructed and tested and then converted to an injection well. On July 15, 1985, this plan was submitted to the DER, and a meeting to discuss it was also arranged with the TAC members. At that meeting, held on August 6, 1985 at the Fort Myers office of DER, the plan was conceptually approved by the TAC, subject to comments, suggestions and revision.

On September 13, 1985, detailed design documents and specifications for the exploratory/monitor well were sent to TAC members. These documents were later revised to incorporate the recommended changes brought forward in subsequent October and November TAC meetings. The revised plan, complete with contract documents, was presented to the SFWMD Board of Governors, which approved it unanimously on December 12, 1986. On January 15, 1986, a Class I deep-injection-well permit was approved and issued by the DER (Permit Number UC36-108708). Construction began on June 6, 1986.

On October 15, 1986, the exploratory/monitor well construction was completed and, on October 21, the first engineering report on the well construction was submitted to DER and to TAC. The report identified the locations of both the injection zone and the confining zones above it, and provided a complete record of the construction process, including the sampling and testing. The report also recommended proceeding with the test/injection well.

Design documents, including specifications and drawings, for the test/injection well were formally submitted to DER together with the permit application on November 5, 1986. After comments were received from the TAC members during November and December, several well design modifications were made and finally, on January 9, 1987, DER issued notice that a complete application had been received. Public notices were published and, when no input was received during the required waiting period, DER issued a second notice on January 28, 1987. This second notice was the "Notice of Intent to Permit," in response to which the EPA made additional comments regarding the application. These comments prompted DER to schedule an extraordinary public meeting for March 3, 1987, even though it had already issued the Notice of Intent to Permit. In the meantime, on February 12, 1987, the SFWMD Board of Governors, with the recommendation of the staff, unanimously approved the NFMU deep-injection well, and one of the Board members went on to praise the water reuse feature of the project.

No one from the general public attended the DER public meeting of March 3, 1987; however, DER had also scheduled a TAC meeting that afternoon, at which EPA raised a few new concerns about the application. As a result of those concerns, several new testing requirements were discussed and eventually agreement was reached to implement them. These requirements were added to the DER permit conditions and became part of the permit issued by DER on March 13, 1987 (Permit Number UC36-127099). With the permit in hand, PBS&J issued a Notice to Proceed to Drillers, Incorporated on March 23, 1987. The deep test/injection well construction and testing began immediately thereafter and were completed on December 22, 1987.

1.3 PURPOSE AND SCOPE

This report on the NFMU deep test/injection well has several purposes. First, it gathers all the relevant data about this site into a single reference (complemented by the reports listed in the references and by the appendices).

Second, it describes the drilling program, the well construction and injection testing procedures, the events leading up to the two injection tests, and the procedures followed during the required tests. Third, it analyzes the data collected and interprets the results, thereby showing what, if any, effect the proposed injection of effluent that has received secondary treatment will have on the Floridan Aquifer System and on the underground sources of drinking water (USDWs). In so doing, the report documents and discusses all construction and testing results, as required by the special conditions of the deep test/injection well construction permit. The report presents all the information required by the SFWMD, by the DER, and by Chapter 17-28 of the FAC, describing the characteristics of the injection zone, the characteristics of both the injection and the resident fluids, and the nature of the geologic formations that confine the injection zone from overlying zones of the Floridan Aquifer System.

Based on the data presented in this report, it appears that issuance of an operating permit is justified; but, because DER normally requires full-scale, long-term testing of treated effluent use, the report recommends authorization to proceed with such testing under the current permit until March 1989. Consequently, the ultimate purpose of this report is to present all the information required by the regulatory agency to issue such authorization.

The report includes recommendations for the maximum values to be authorized, including the maximum injection pressure, daily flow, injection rate, etc. It also includes monitoring recommendations.

1.4 SITE DESCRIPTION

As shown in Figure 1-2, the NFMU treatment plant occupies a site located in the southeastern quarter of Section 14, Township 43 South, Range 24 East, approximately four miles north of the Caloosahatchee River in Lee County. The plant facilities occupy the central area of the site (see Figure 1-3), which is surrounded by a 250-foot setback buffer. The injection well and the monitor well are both located near the northeast corner of the site. The site contains ample space for future expansion of both the plant itself and the injection system. The location of the future stand-by well is shown in Figure 1-3.

This plant site is centrally located in North Fort Myers to serve the surrounding areas. If NFMU's service area is expanded, as has been requested of the Public Service Commission, NFMU will be in a perfect location to serve the new areas economically.

1.4.1 Service Area

NFMU's present 4,200-acre service area includes land use designations that the Lee County Land Use Plan Map classifies as intensive development, central urban and suburban. The existing uses consist of commercial activities, mobile homes, apartments, and condominiums. Development within the area is well mixed.

Most large commercial areas in North Fort Myers are served by NFMU as are the larger condominium-apartment complexes. The franchise area now served by NFMU's wastewater collection and treatment facilities includes the following users:

Name	Flow in mgd
Old Bridge Park	0.1490
Foxmoor	0.0203
Foxmoor II	0.0200
Foxmoor Lakes	0.0020
Foxmoor Village	0.0020
Indian Creek Village	0.0080
Indian Creek Golf Villas	0.0035
Yachtman's Cove	0.0120
Admiralty Yacht Club	0.0173
Bayshore Mobile Home Manor	0.0455
Fox's Trailer Park	0.0050
Weaver's Corner Shopping Center	0.0250
Pine Island Shopping Center	0.0340

Name	Flow in mgd
Foxmoor Shopping Center	0.0320
Naples Federal Savings & Loan	0.0025
Lee County Electrical Co-op	0.0120
TOTAL	0.3901

All wastewater collected from the areas served is transported to the existing NFMU wastewater treatment plant in Old Bridge Park.

In addition, within the existing franchise area, the following users, now served by individual package plants, could potentially be served by NFMU:

Name	Estimated Flow in mgd
Tenneco Oil Company[1]	0.0010
Bayshore Shopping Center	0.0150
J. Colin English Elementary School	0.0100
Jones Mobile Home Park	0.0200
Swift's Mobile Home Park	0.0100
Carriage Village[2]	0.0200
Forrest Park Mobile Home Park[2]	0.0500
Buccaneer Mobile Home Park	0.0120
Star Plaza	0.0033
Cost Cutters	0.0025
TOTAL	0.1438

[1]Service agreement with NFMU pending

[2]Currently holding a Public Service Commission Certificate

NFMU is negotiating a wholesale bulk service agreement with Florida Cities Water Company (FCWC) to accept all present and future wastewater flows from the FCWC's Waterway Estates, an area franchised by the Public Service Commission. FCWC is planning to remove its Waterway Estates plant from service. The initial flow will be 1,000,000 gpd; the proposed agreement provides for additional future flows of up to 1,400,000 gpd.

1.4.2 Topography

The area surrounding the site has no significant topographic relief, with the exception of the artificially created relief for buildings, structures, and roads. On the site, however, a natural wetland depression has been set aside as a preservation area. The site also contains two man-made lakes created as borrow pits for the fill material needed to build it up (see Figure 1-3).

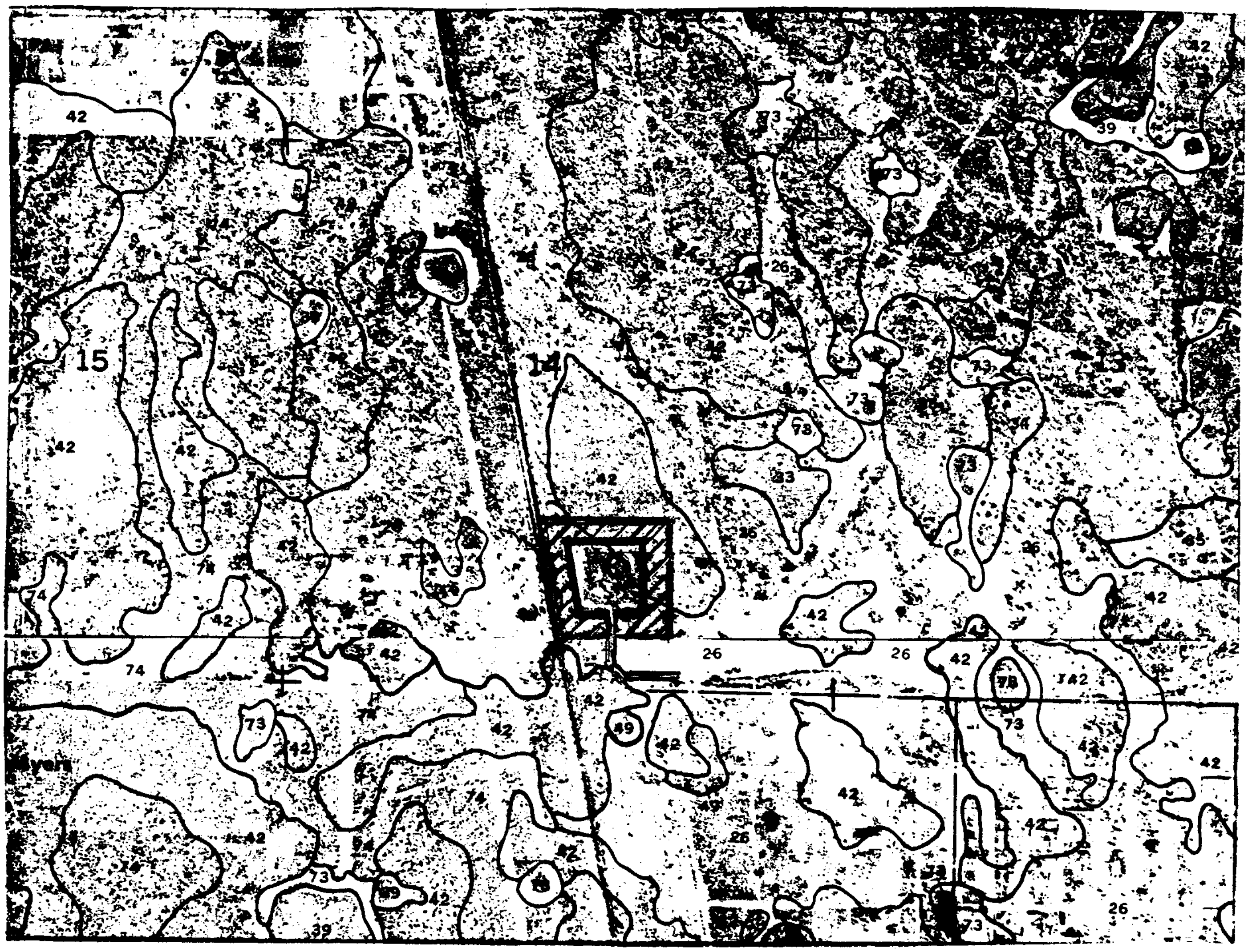
The natural elevations are slightly above 17 feet above mean sea level (msl) throughout the site except at the above-mentioned depression and lakes. In the northeast corner of the site, natural elevations average 18 feet above msl and even reach 18.5 feet above msl in a few places. Artificially filled elevations are about 20 feet above msl, except at the site of the operations building, where the fill is at 21 feet above msl.

Surrounding the site is a shallow ditch that is connected to both lakes. This ditch serves as a runoff collection system. The lakes are interconnected through a culvert across the entrance road and receive the runoff from the ditch. A man-made berm surrounds the entire site.

1.4.3 Soils

The soils in the area were mapped in 1977 and again in 1981 by the United States Department of Agriculture, Soil Conservation Service (SCS), in cooperation with the Florida Agricultural Experiment Station. An interim report was issued in 1979 and a final report in 1984 (Department of Agriculture, SCS, 1984). The natural soils at the NFMU site consist of fine sand and are associated with two soil series, the Wabasso and the Pineda (see Figure 1-4).

The poorly drained sandy soils found in the buffer area around the site and in the depressions on site are Pineda Fine Sands and are well identified in the soil map prepared from the 1977 aerial photographs. In the depression area set aside as a preserve, the soils maintain a natural vegetation consisting of slash pine and cabbage palm in the upper story, and water-tolerant grasses, saw palmetto, weeds and rushes at ground level.



1 ¾ ½ ¼ 0 1 Mile

5000 4000 3000 2000 1000 0 5000 Feet

LEGEND

7 ARENTS–URAN LAND COMPLEX

12 FELDA FINE SAND

26 PINEDA FINE SAND

33 OLDSMAR FINE SAND

39 BOCA VARIANT FINE SAND

42 WABASSO VARIANT FINE SAND

45 CHOBEE VARIANT FINE SAND

49 FELDA FINE SAND, DEPRESSIONAL

50 OLDSMAR FINE SAND, LIMESTON SUBSTRATUM

59 URBAN LAND

69 ARENTS

73 PINEDA FINE SAND, DEPRESSIONAL

74 BOCA FINE SAND, DEPRESSIONAL

PRESERVE SETBACK

PROPERTY BOUNDARY

PLANT SITE

INJECTION WELL

PBSJ POST, BUCKLEY, SCHUH & JERNIGAN, INC.

SOILS MAP

FIGURE 1–4

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REPRO PRODUCTS INC. 7A

The soil map also shows that the Wabasso Fine Sands predominate in the northeast corner of the site, where the natural land elevations are higher, while the rest of the site is covered by Pineda Fine Sand. Both of these soils are nearly level, poorly drained soils; however, the Wabasso Fine Sand has higher permeability and drains somewhat faster than the Pineda.

m:H-87/I

Section 2
REGIONAL HYDROGEOLOGY

2.1 RAINFALL AND EVAPORATION

In the Fort Myers area, the yearly average rainfall is higher near the coast and decreases slightly inland. This pattern becomes even more pronounced in summer. A similar characteristic pattern can be observed north and south of the Caloosahatchee River. During summer, rainfall is more intensive south of the river, but in winter the opposite is true (Fernald, 1981).

With the exception of the short-term record for the temporary rain gage used during the aquifer pump tests performed starting December 12, 1987, there are no on-site rainfall records for the NFMU site. Data from nearby rainfall stations had to be used to develop an approximate local rainfall pattern for the site synthetically. One such nearby station is a Federal Aviation Administration (FAA) weather station that has been in continuous operation since January 1953 at Fort Myers' Page Field airport. Transferable records near this site go back to 1894. The U.S. Department of Commerce, National Climatic Data Center in Asheville, North Carolina, provided the data for this station, located approximately 12 miles south of the NFMU site, and across the Caloosahatchee River.

SFWMD also collects rainfall data from several stations in the Fort Myers area, but these stations have shorter periods of record than the FAA station. The nearest SFWMD weather station (#MRF5004) is located 7 miles east of the site. Its record is from May 1978 to the present. It was expected that the data from this station would show lower values than the FAA substation; however, it was found that they do not significantly differ from the data collected at that location. Figure 2-1 shows the locations of the Fort Myers airport station and the SFWMD station with respect to the NFMU site.

Because they do not significantly differ from the SFWMD station data and because they cover a longer period of record, the rainfall data collected at Fort Myers' Page Field are expected to provide the best surrogate for rainfall

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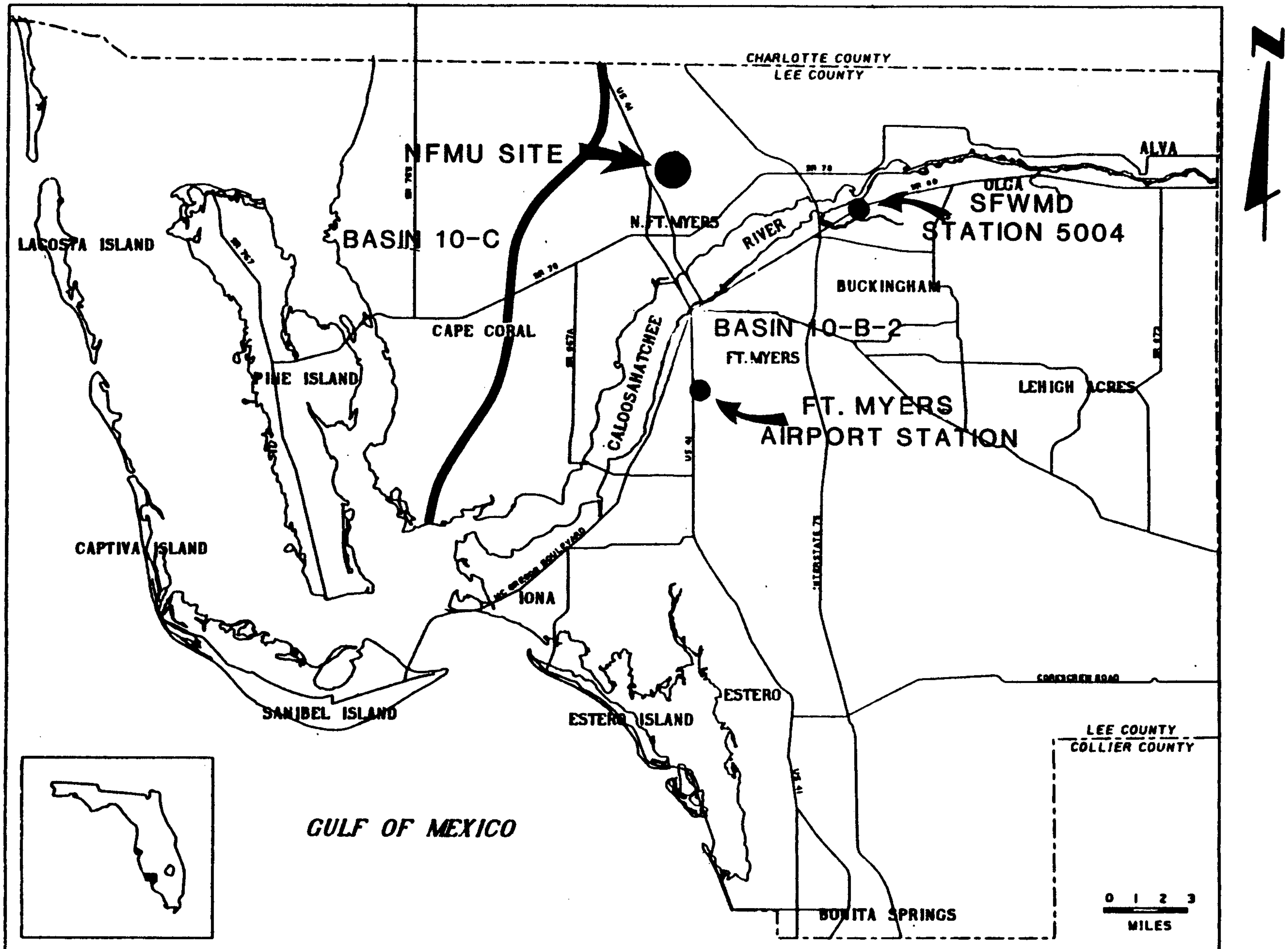

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RAIN GAGE LOCATIONS AND DRAINAGE BASIN BOUNDARIES

FIGURE 2-1

data at the NFMU site. Table 2-1 shows the average monthly and annual rainfall (53.6 inches) for the Page Field station, and Figure 2-2 shows the monthly rainfall pattern. These values can be applied without site corrections to the NFMU site. The average wet season occurs from June to September; the dry season, from October to May. The dry season months are expected to show higher water usage and sewage production, particularly those months towards the middle of the period, when the tourist season is at a peak. It is during those months that the treatment plant will operate at high rates; however, since water reuse for irrigation will be in greatest demand at that time, the injection well will probably be used less.

Since the greatest injection volumes are expected in the wet season (June to September), when frequent rains reduce the need to irrigate with the effluent, and since the aquifer levels are highest at those times, it is probable that the injection pressures will exhibit a natural cyclical increase at that time. Because the injection test was conducted in winter, it can be expected that, during continuous injection pressures will be somewhat higher than those shown by the injection test.

Evaporation for surface water bodies is, for all practical purposes, the same as lake evaporation as long as the surface water is not moving rapidly, which is the case for the NFMU site. The average annual lake evaporation for the NFMU site is estimated to be 53 inches (Kohler et al., 1959). Figure 2-3 shows the evaporation contours of the area.

2.2 SURFACE HYDROLOGY

As shown in Figure 2-1, the NFMU site lies wholly within Drainage Basin 10-B-2 (Kenner et al., 1967), which is the Lake Okeechobee and Everglades Basin. The drainage boundary with Drainage Basin 10-C (the Coastal Areas Basin) is four miles to the west.

The natural land elevations throughout the site vary from about 18.5 feet above msl in the extreme northeast corner of the site (the higher elevations) to 17 feet above msl in the depressions and 16.5 above msl in the swales. The

Table 2-1

AVERAGE RAINFALL DATA
(January 1894 - December 1986)[a]

RAINFALL STATION NAME:	Fort Myers Airport (Page Field)	
AVERAGE MONTHLY RAINFALL:		
January	1.89	
February	2.06	
March	2.85	
April	1.52	
May	4.11	
June	8.72	
July	8.57	
August	8.58	
September	8.56	
October	3.86	
November	1.35	
December	1.57	
AVERAGE ANNUAL RAINFALL:	53.64	
MINIMUM ANNUAL RAINFALL:	31.87	
(Year)	(1964)	
MAXIMUM ANNUAL RAINFALL:	74.85	82.64[b]
(Year)	(1983)	(1853)

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[a] All data in inches

[b] Prior to continuous records

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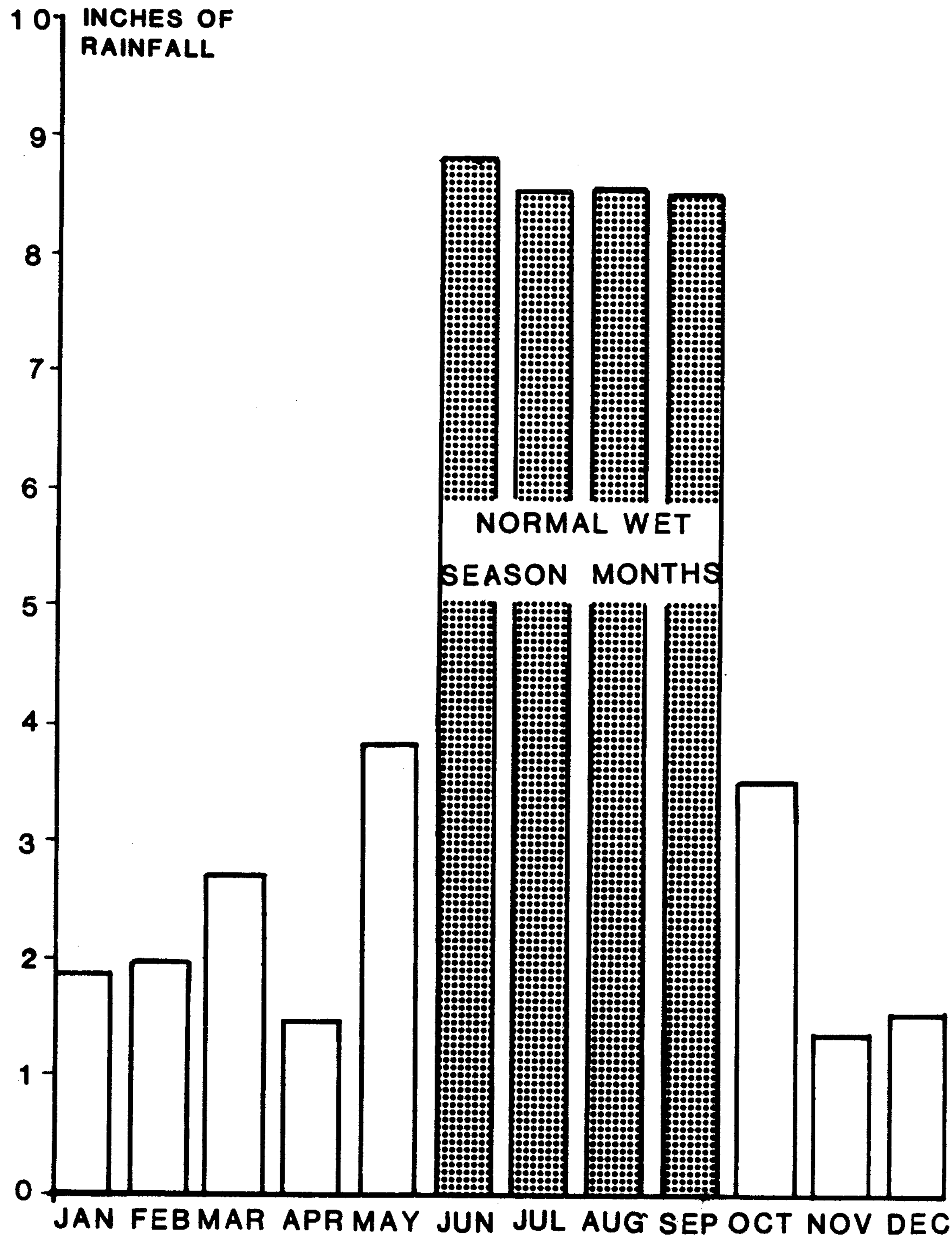

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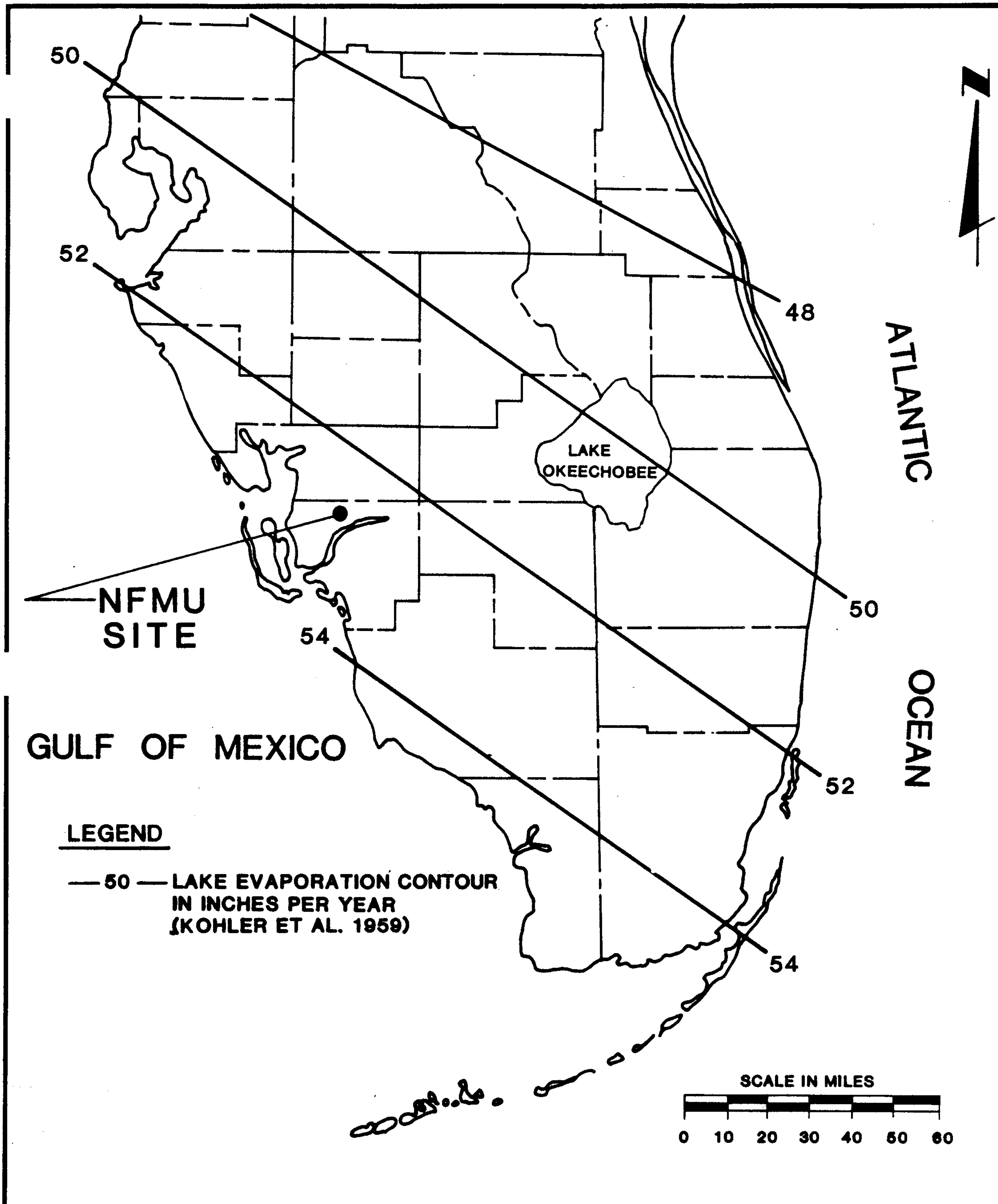
RAINFALL PATTERN AT THE NFMU SITE

FIGURE 2-2



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EVAPORATION CONTOURS

FIGURE 2-3

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natural land surface can best be described as fairly flat; but man-made alterations have created artificially higher and lower areas. Drainage from the site is towards the swales and then to the man-made lakes at the entrance to the site. From there, the drainage moves generally southward in ditches that eventually discharge to the Caloosahatchee River.

The only major drainage features on the site are the swale, which borders the whole site, and the two interconnected lakes, which discharge southward overland through a control structure on the western entrance lake. The site contains no natural continuously flowing body of surface water, and the only areas that qualify as surface waters are the two entrance lakes. The shallow depressions, some of which have bottom elevations of 17 feet, pond only in the wet season.

2.3 GEOLOGY

Geologic data discussed in this portion of the report are based on the site-specific geophysical logs, field records, drill cuttings, and core samples collected during the drilling and construction of the test/injection well.

The field hydrologists supervising the construction of the wells were responsible for collecting representative formation samples and preparing field descriptions of them. The composite lithologic descriptions prepared in the field during the drilling of the exploratory/monitor well are contained in the North Fort Myers Utility Data Report (PBS&J, 1986c). Similar descriptions for the deep test/injection well are contained in Appendix 23. A detailed microscopic description of the lithologic samples and their relative positions in the geologic units penetrated by the well is contained in Appendix 24.

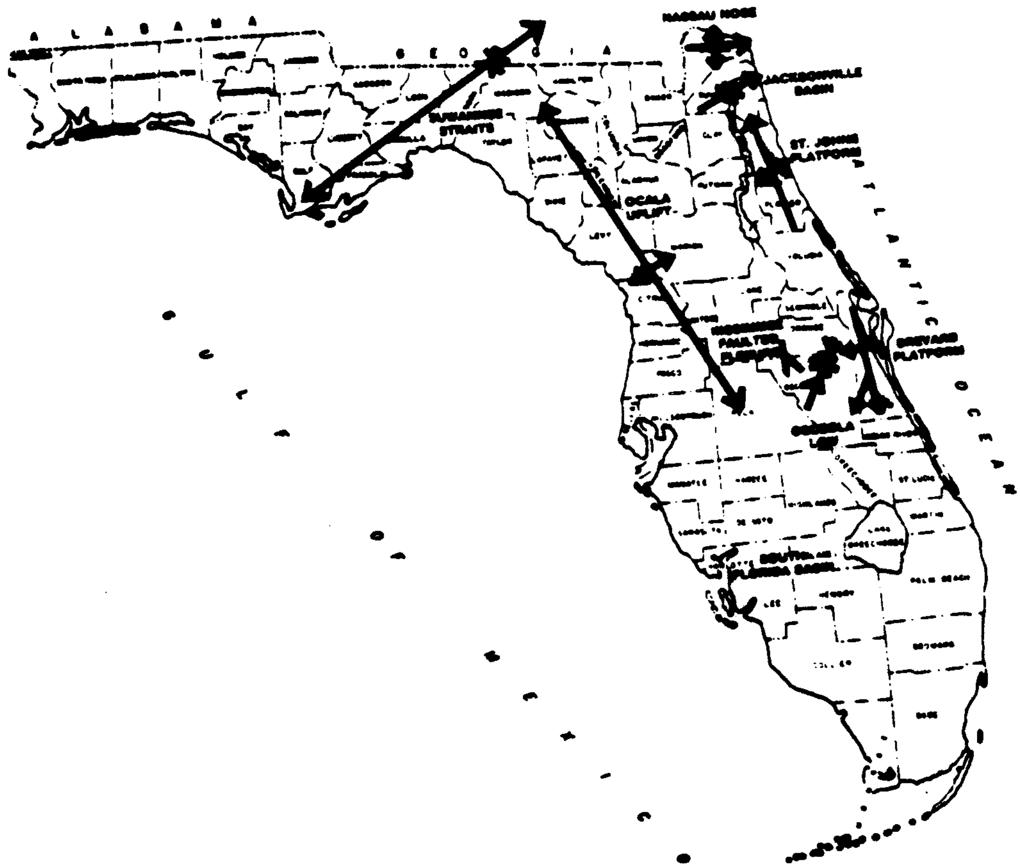
The above data were used to develop a detailed hydrogeologic description of the formations penetrated by the deep test/injection well. The subsurface data collected from this well confirm and closely correlate with the data from the deep monitor well that was drilled earlier and aid in adequately describing the hydrogeology of the formations underlying the NFMU site.

The stratigraphic units penetrated by the deep test/injection well range in age from Recent to Eocene. From youngest to oldest, they include: Undifferentiated Terrace Deposits (Recent to Pliocene), Tamiami Formation (Pliocene to Miocene), Hawthorn Formation (Miocene), Tampa Formation (Miocene), Suwannee Limestone (Oligocene), Ocala Group (Late Eocene), and Avon Park, Lake City, and Oldsmar Limestone (Middle to Early Eocene). The older formations at the bottom (Tampa to Oldsmar) are composed primarily of limestones and dolomites, and the younger formations at the top, of silts, sands, clays and sandy limestones. The stratigraphic sequence of interest beneath the NFMU site consists predominantly of carbonates with clastic materials being present in the Miocene and younger formations. The Miocene section is reported to be approximately 600 feet thick. Oligocene and younger formations account for 1,300 feet or half the total thickness of the section penetrated by the well. The Eocene beds are reportedly over 2,300 feet thick (Chen, 1965), but only 1,300 feet of that sequence were penetrated at the site. In this report, the Paleocene Age Cedar Key Formation is briefly described for continuity, and because the top of this formation forms the base of the theoretical permeable zones of the Floridan Aquifer System.

The major structural features in Florida are shown in Figure 2-4. The most prominent structure is the Ocala Uplift (Vernon, 1951), which is described as a gentle flexure trending northwest to southeast along its crest. Southwest Florida is well down the crest within the South Florida Basin, in an area where the strata gently dip to the south and southwest.

The geologic formations of primary concern at the NFMU site are discussed in the following subsections. They range in age from Eocene to Recent, and include the whole thickness of materials penetrated by the deep test/injection well. At the test/injection site these formations, which are depicted in Figure 2-5, are located at the depths shown in Table 2-2.

Data from the NFMU deep test/injection well and from other wells in Lee County, including three very deep oil exploration wells drilled over 30 years ago and several shallower irrigation wells, were used to prepare a geologic cross-section of Lee County (see Figure 2-6). The actual data points used for the cross-section are shown in Figure 2-7.



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MAJOR STRUCTURAL FEATURES IN FLORIDA

FIGURE 2-4

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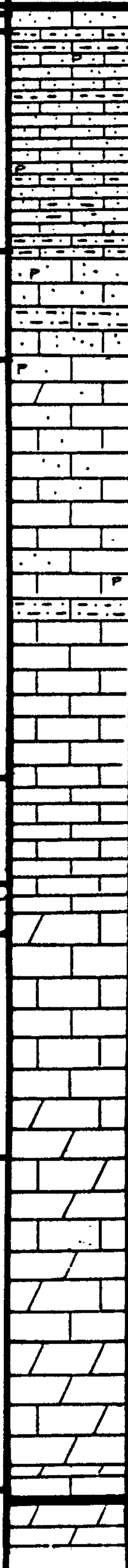

AGE	FORMATION	DEPTH	LITHOLOGY
Pleistocene	Undiff.	10 – 38	Unconsolidated sand and shell in upper part. Sandy biogenic limestone in lower portion
Pliocene	Tamiami	38 – 100'	
Miocene	Hawthorn	200' – 300' – 400' – 420'	Predominantly moderately indurated, sandy limestones interbedded with phosphatic dolosilt.
	Tampa	420' – 500' – 600'	Sandy, slightly phosphatic biogenic limestone with archais floridanus.
Oligocene	Suwannee	600' – 700' – 800' – 900' – 1000' – 1100' – 1200' – 1300' – 1310'	Moderately indurated, biogenic and calcakentic limestone with minor amounts of sand and phosphate.
Eocene	Ocala Group: Crystal River; Willis-ton	1310' – 1400' – 1500' – 1570'	Micritic, fossiliferous limestone containing many of the larger eocene foraminifera (esp. lepidocyclina and heterestigina)
	Avon Park	1570' – 1600' – 1700' – 1800' – 1900' – 1940'	Highly recrystallized limestones and dolomites interbedded with dolomitic limestones. This unit contains dictyoconus cookei , milliolids and peronella dalli (echinoid).
	Lake City	1940' – 2000' – 2100' – 2200' – 2300' – 2400' – 2490' – 2500'	Predominantly dolomitic limestone in the upper portion containing dictyoconus americanus. Dolomite is the primary lithology in the lower part.
	Oldsmar	2500' – 2600'	Biogenic limestone containing pseudophragmina and helicostigina. With dolomite in the lower portion.

GEOLOGY BASED ON TEST/INJECTION WELL DATA

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SITE GEOLOGY

FIGURE 2-5

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Table 2-2

GEOLOGIC UNITS UNDERLYING THE STUDY AREA

Geologic Units	Depths (feet below land surface)	Thickness (feet)
Undifferentiated (Caloosahatchee)	0 to 8	8
Caloosahatchee Formation	8 to 10	2
Tamiami Formation	10 to 38	28
Hawthorn Formation	38 to 420	382
Tampa Formation	420 to 600	180
Suwannee Formation	600 to 1,310	710
Crystal River Formation (Ocala Group)	1,310 to 1,500	190
Williston Formation (Ocala Group)	1,500 to 1,570	70
Avon Park Limestone	1,570 to 1,940	370
Lake City Limestone	1,940 to 2,490	550
Oldsmar Limestone (Part)	2,490 to 2,606	116

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GEOLOGIC CROSS-SECTION OF LEE COUNTY

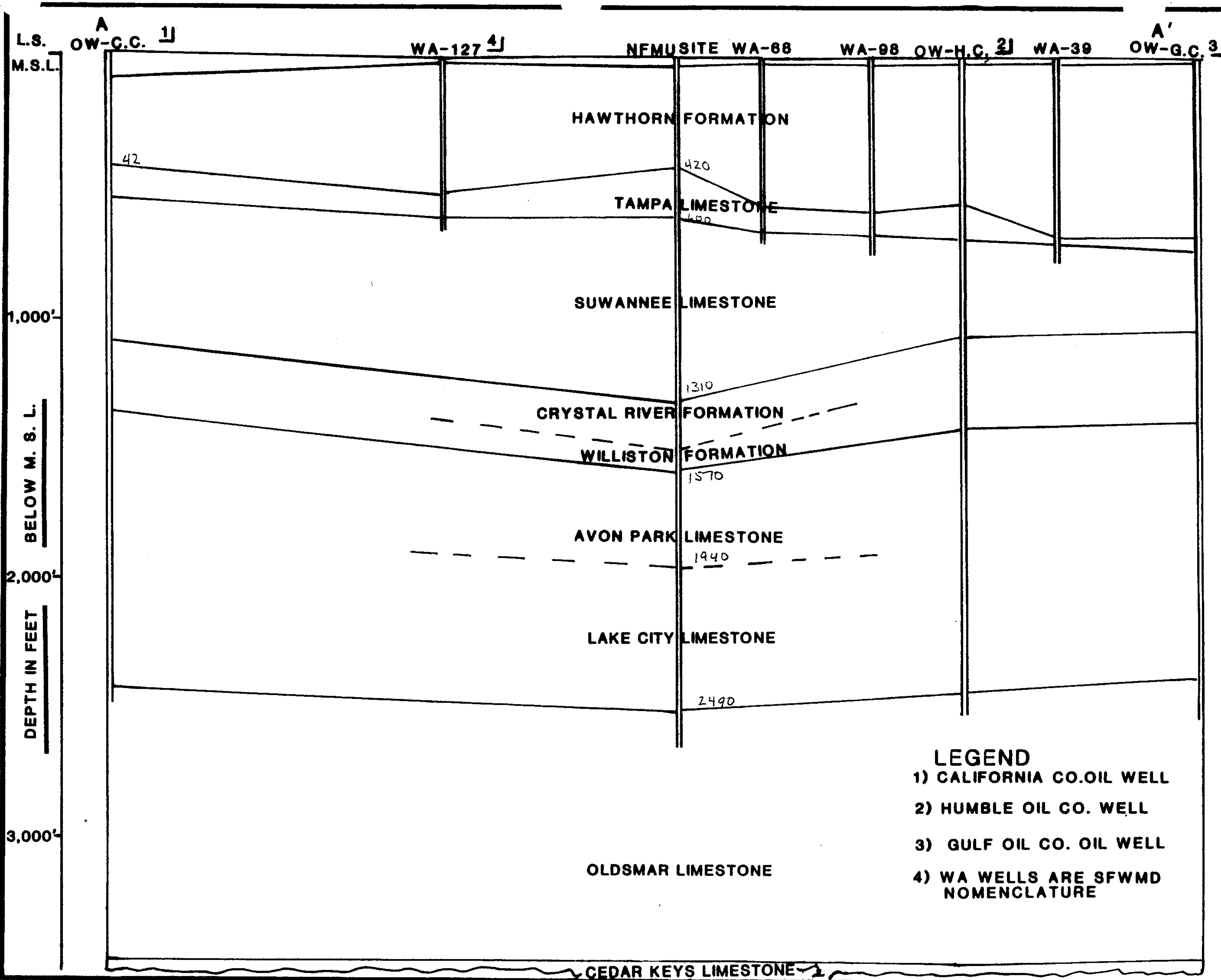

FIGURE 2-6

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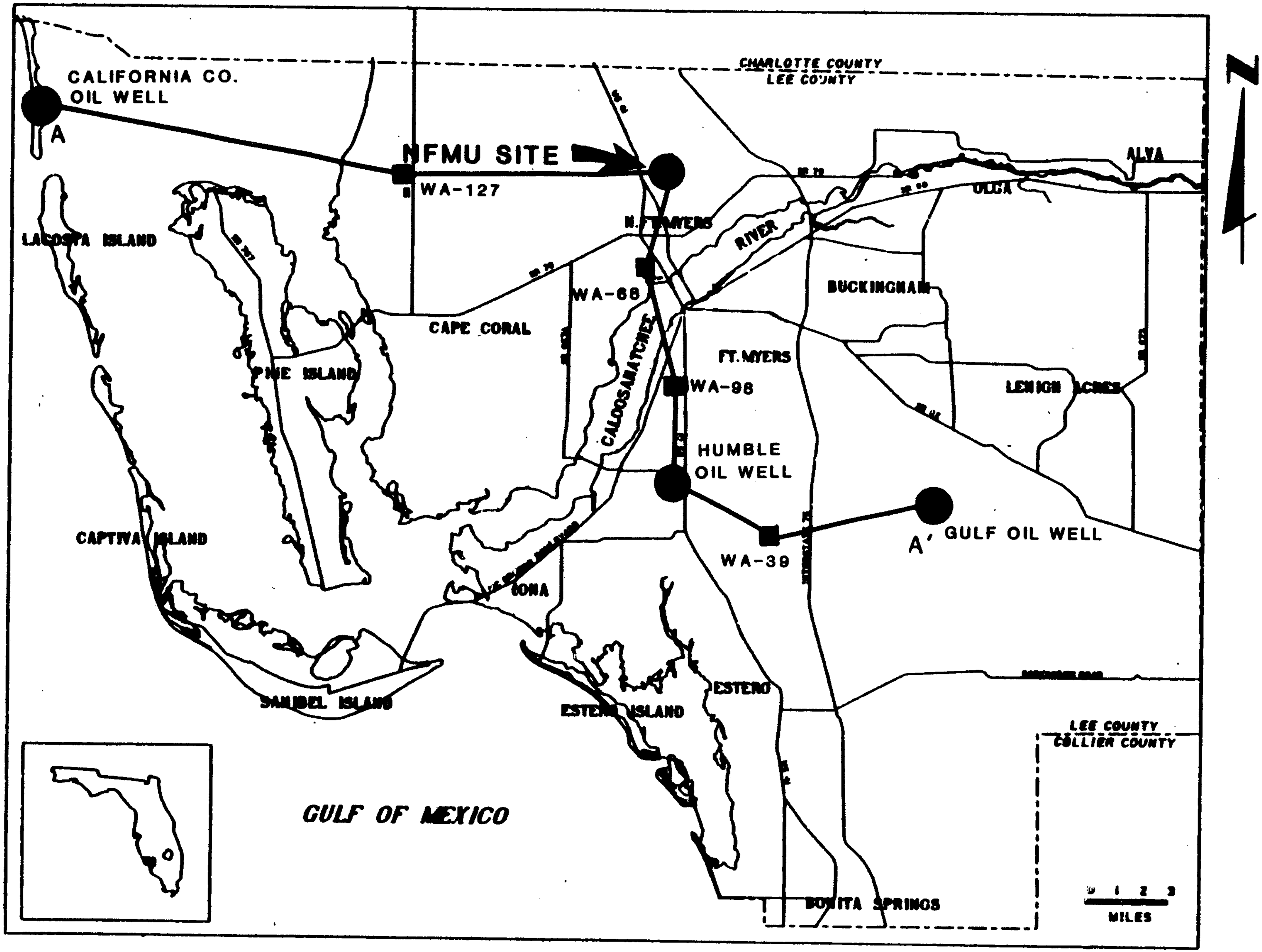

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CROSS-SECTION LOCATIONS

FIGURE 2-7

2.3.1 Recent to Pleistocene Series Undifferentiated Terrace Deposits Caloosahatchee Formation

The uppermost or surficial formations of Lee County are made up of undifferentiated deposits that vary in thickness and lithology from site to site (see Table 2-3). Some of these heterogeneous deposits are of late Pleistocene Age and several investigators have associated them with the Caloosahatchee or with the Fort Thompson Formations that outcrop in Hendry and Collier Counties. Some of these deposits are, however, recognized as of Holocene Age, particularly in the western parts of the County near the coast.

A subangular, spherical, lusterless quartz sand forms a large portion of these deposits. Shell and clay form the remaining portion. In the part of the County with the highest elevations, the percentage of sand increases. Occasionally small phosphate grains and even a trace of opaque heavy minerals are present.

The continuity of the sand layer is intermittent. Sometimes it is replaced by interfingered layers of sandstones, shell beds, and even limestone; but this is a localized phenomenon.

At the NFMU site, this interfingering was not strong, but a shell bed was found. The upper 10 feet of sediment encountered in the deep test/injection well may be easily correlated in part to the Caloosahatchee Formation, as described by Dubar (1958) along the banks of the Caloosahatchee River in Hendry County, Florida. The material from this interval was composed of medium to fine quartz sand and the shell bed was found at 8 feet below lake surface. The shell bed was 2 feet thick and underlain by the sandy limestones of the Tamiami Formation.

2.3.2 Pliocene Series - Tamiami Formation

The name "Tamiami Formation" has a long history, but it appears that each investigator has given the name to different stratigraphic units. Mansfield (1939) proposed the term "Tamiami Limestone" for a fossiliferous, sandy

Table 2-3

DESCRIPTION OF GEOLOGIC UNITS OF NORTHERN LEE COUNTY

System	Series	Formation	Member	Lithologic Characteristics
Quaternary	Holocene and Pleistocene	Undifferentiated (Caloosahatchee Formation)	Undifferentiated	Upper part consists of fine to medium-grained quartz sand with varying percentages of shell and clay. Hardpan frequently occurs at the base of the quartz sands. The lower section consists of shell beds with interbedded limestones
Tertiary	Pliocene	Tamiami Formation	1) Ochopee Limestone 2) Buckingham Limestone	Sandy and biogenic limestones with minor percentage of sparry calcite and dolomite. Quartz sand varies from 3 to 25 percent and traces of phosphate are present at base.
	Miocene	Hawthorn Formation	Upper Member 1) LaBelle Clay 2) Alva Clay 3) Lehigh Acres Sand	Overall very sandy and phosphatic lithology. Upper and lower zones are dolosilts with interbedded limestones and dolomites. Middle zone is quartz sand, sandstone, and sandy limestone. Reworking at the base is characterized by large percentages of coarse phosphate and quartz sand.
			Lower Member	Phosphatic limestone and dolomites with interbeds of dolosilt, sand, and phosphate. The lowermost beds are a biogenic, micritic, and very fine-grained limestone, sandy and slightly phosphatic throughout.
		Tampa Limestone	Undifferentiated	Light orange biogenic limestones and dolomites containing up to 10 percent quartz sand and silt size phosphorite. Increased quartz sand occurrence at base of unit.
	Oligocene	Suwannee Limestone	Undifferentiated	Medium-grained, moderately indurated, biogenic calcarenite with minor percentages of quartz sand. Interbeds consist of very sandy and sometimes phosphatic limestone and dolomite.
	Eocene	Ocala Limestone	Crystal River Formation	Moderately indurated biogenic, very micritic, coquinoid limestone with many larger foraminfera.

Table 2-3 (Continued)

System	Series	Formation	Member	Lithologic Characteristics
			Williston Formation	Biogenic and medium-grained calcarenitic limestone. Occasional interbeds of highly recrystallized dolomite.
		Avon Park Limestone	Undifferentiated	Fossiliferous dolomites and highly recrystallized biogenic limestones.
		Lake City Limestone	Undifferentiated	Highly recrystallized dolomites with a trace of gypsum.
		Oldsmar Limestone	Undifferentiated	Finely fragmented fossiliferous limestone evaporites constitute 5 percent of the formation. Bottom of the Oldsmar is a dark brown crystalline dolomite.
	Paleocene	Cedar Keys Limestone	Undifferentiated	A dolomite and evaporite formation with limited limestone. The upper parts are a micro-crystalline, slightly gypsiferous dolomite. The bottom parts are non-fossiliferous crystalline pure dolomite.

Source: Wedderburn et al. (1982)

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limestone penetrated in shallow ditches along the Tamiami Trail (U.S. Route 41) in parts of Collier and Monroe Counties, Florida. Parker and Cooke (1944) used the name "Tamiami Formation" for the first time. More recently, Knapp et al. (1986) described the Tamiami Formation in southwest Florida as a moderately indurated, sandy and sometimes slightly phosphatic fossiliferous limestone. The nomenclature selected for this report is the one presented by SFWMD (Wedderburn et al. 1982), which in turn followed a description proposed by Hunter and Wise (1980, 1980a).

The Tamiami Formation was present at the deep test/injection well site from 10 feet to 38 feet below land surface. The unit occurred as a very pale orange (10 Y R 8/2), fossiliferous and moderately indurated limestone. It was underlain by the uppermost bed of the Hawthorn Formation which was an olive gray calcareous clay, a definite color change that was easily identified.

2.3.3 Miocene Series

2.3.3.1 Hawthorn Formation

Dall and Harris (1892) first used the term "Hawthorn beds" for phosphatic sediments being quarried near the town of Hawthorne, Alachua County, Florida. These beds were designated the "Hawthorn Formation" by Matson and Clapp (1909). In recent work by Scott (1981) and Scott and Knapp (in press), the Hawthorn was described as consisting of "...various mixtures of clay, quartz sand, carbonate (dolomite to limestone), and phosphates...".

This formation has long been a unit difficult to differentiate at its contacts, particularly in south Florida where it is overlain by the Tamiami Formation. This difficulty is due to the heterogeneous lithologies associated with the Hawthorn and the exclusion of certain beds from that formation based upon geologic age. The contact between the Tamiami Formation and the Hawthorn Formation consists of the gray to greenish phosphatic, very sandy, clayey dolosilts that form the upper part of the Hawthorn.

The Hawthorn is divided into two members: the upper and the lower. The upper member is a primarily clastic deposit which in turn comprises three recognizable units: LaBelle Clay, Alva Clay, and Lehigh Acres Sandstone. The lower member, primarily carbonate deposits, is undifferentiated, but may also be subdivided into three zones (upper, middle and lower). Wedderburn's 1982 report described these members in detail, and PBS&J's report on the exploratory well at the NFMU site (PBS&J, 1986a) included that description.

At the test/injection site, the Hawthorn was penetrated at 38 feet below land surface and extended 382 feet down the well to the top of the Tampa Formation at 420 feet below land surface. The upper 110 feet of the formation was quite variable and the uppermost bed was a pale olive (10 YR 6/1) very phosphatic and sandy dolosilt. From the base of this bed, at 48 feet below land surface, to a depth of 170 feet below land surface, the dolosilt was interbedded with light gray (N7) to very pale orange (10 YR 8/2) poor to moderately indurated, sandy limestones and sandstones and with light olive gray (5 Y 5/2) clayey sands. These beds were all very sandy and phosphatic. The formation from 170 feet to 380 feet below land surface was consistently logged as a very pale orange (10 YR 8/2) sandy, phosphatic limestone. The basal 40 feet of the Hawthorn from 380 to 420 feet below land surface consisted of a very pale orange (10 YR 8/2) to yellowish gray (5 Y 8/1) sandy and phosphatic limestone intermixed with pale olive (10 Y 8/2) dolosilt.

The natural gamma ray logs (see Appendices 1 and 3) showed very high activity throughout the Hawthorn Formation due in large part to the concentration of uranium in the phosphorites; but the condition was highly localized. Large peaks in the deep test/injection well bore occurred near 160, 245, 265, 270, 305, 370 and 390 feet below land surface; while at the exploratory/monitor well, located less than 100 feet away, there were large peaks at 165, 225, 280, 380 and 400 feet below land surface. Phosphate rubble beds encountered in the formation are probably causing these peaks, so it is obvious that the rubble is unequally distributed or that the uranium is not equally distributed within the rubble. The well cuttings and geophysical data indicated the presence of an unconformity between the Hawthorn and Tampa Formations.

2.3.3.2 Tampa Formation

The name "Tampa Formation" was first used by L.C. Johnson in 1888 for limestones that crop out in and near the city of Tampa in Hillsborough County, Florida; but the Tampa Limestone Formation has undergone a series of definitions and redefinitions by various authors. In Lee County, some authors have associated the deposits referred to by some as "Tampa," with those referred to by others as "Hawthorn." Nevertheless, some of those authors who have not recognized the Tampa as a formation in Lee County still have recognized a Tampa water-producing zone.

Sproul et al. (1972) described the Tampa Limestone in Lee County as a greyish, yellow, sandy limestone with some black phosphorite. In Charlotte County, Sutcliffe (1975) referred to an interbedded grey to sandy limestone and grey to white clay with some phosphorite as Tampa Limestone. Missimer and Banks (1981) found a somewhat similar zone in Lee County, but included it at the bottom of the Hawthorn. In 1982, Wedderburn et al. followed the Missimer and Banks lead in Lee County and included that zone in the Hawthorn. In 1983, however, SFWMD (Burns, 1983) published a generalized column for Lee County which included the Tampa Limestone. Burns described this limestone as light orange biogenic limestones and dolomites containing up to 10 percent quartz sand and silt size phosphorite, with an increased quartz sand occurrence at the base of the unit.

Earlier, King and Wright (1979) had proposed a formal definition of the Tampa Formation in accordance with the American Code of Stratigraphic Nomenclature (1970). They described the formation as a limestone with a content of at least 10 percent fine quartz sand and less than 1 percent phosphate, bounded at the top and bottom by unconformities.

The Tampa Formation was penetrated in the deep test/injection well at 420 feet below land surface and extended to the top of the Suwannee Limestone at 600 feet. The upper 70 feet was predominantly a very pale orange (10 YR 8/2) to yellowish gray (5 Y 6/1) sandy and phosphatic, fossiliferous limestone. The formation from 490 to 560 feet below land surface was interbedded with light olive gray (5 Y 6/1) dolosilts. The lower 40 feet of the bed was a biogenic limestone. The guide fossil Archias floridanus occurred near the top of the formation.

The Tampa Formation showed high activity on the natural gamma ray log. This activity was probably due to the large percentage of phosphate in the matrix of the rock and interbedded clayey phosphatic dolosilts.

Some of the highest gamma ray peaks at the deep test/injection well occurred at 460, 550 and 560 feet below land surface. These peaks correlate with the phosphatic dolosilt encountered in the well cuttings between 480 and 560 feet below land surface. At the exploratory/monitor well, these high peaks were found at 470, 545 and 580 feet below land surface.

2.3.4 Oligocene Series - Suwannee Limestone

Cooke and Mansfield (1936) introduced the name "Suwannee Limestone" to describe an interval of yellowish limestone exposed on the banks of the Suwannee River from Ellaville to White Springs, Florida. This name has been used by popular convention to describe all the Oligocene Age sediments in Florida.

The Suwannee Limestone is a pale orange or yellowish nodular limestone bed containing numerous fossil foraminifera, mollusks, and echinoids, such as Rhyncholampas (formerly Cassidulus) gouldii, and Bouve as well as a distinctive assemblage of benthonic foraminifera including Dictyoconus cookei. Wedderburn et al. (1982) described the Suwannee Limestone in Lee County as a "...very light orange to tan (brown) medium-grained, moderately indurated, biogenic limestone (calcarenite) with minor percentages of quartz sand." They reported the unit to be between 350 and 620 feet thick in wells they studied in Lee County.

The Suwannee Limestone was present at the test/injection site from 600 to 1,310 feet below land surface. The unit was predominantly a very pale orange (10 YR 8/2), moderately indurated, biogenic and calcarenitic limestone. The uppermost beds between 600 and 680 feet below land surface were white (N9) to very light gray (N8) limestone with minor percentages of sand and phosphate. Overall, the unit was very fossiliferous with numerous echinoids, bryozoans, mollusks and an abundant assemblage of benthonic foraminifera. The formation from 680 to 1,310 feet below land surface was consistently logged as a white (N9) to very pale orange (10 YR 8/2) fossiliferous, sandy, slightly phosphatic, poor to moderately indurated limestone.

The natural gamma ray log showed low to medium activity throughout this formation, with more activity in the upper section of the formation between 600 and 730 feet below land surface where most of the sand and phosphate in the unit were detected in the cuttings. An attenuation in activity occurred in this log at 1,200 to 1,320 feet below land surface, directly above the contact with the Ocala Group. The gamma ray activity recorded from 600 to 730 feet was due to the small percentages of phosphate present.

At the exploratory/monitor well site adjacent to the test/injection well site, the top of the Suwannee had been identified earlier at 605 feet below land surface and its bottom, at 1,320 feet. The new data from the deep test/injection well now showed the bottom at 1,310 feet below land surface. After a detailed review of all the data, it also appears that the top of the Suwannee should have been originally placed at 600 feet below land surface instead of at 605 feet.

2.3.5 Eocene Series

2.3.5.1 Ocala Group

The term "Ocala Limestone" was first used by Dall and Harris (1892) in a discussion of limestones being quarried near the town of Ocala, in Marion County, Florida. Later in a study of the subsurface stratigraphy of Florida, Applin and Applin (1944) identified an upper and lower member of the "Ocala Limestone." This usage is still followed by the USGS and a few others; but ever since Vernon (1951) identified three distinct units within the Ocala Limestone, nearly every recent author has followed that identification. Puri

(1953) also proposed three formations to be included; but he grouped them in what he called the "Ocala Group Formations." Puri (1953) proposed the names Crystal River, Williston, and Inglis for those three formations, with Crystal River at the top and Inglis at the bottom.

In the 1982 SFWMD study of Lee County, Wedderburn et al. (1982) did not identify the Inglis Formation in any of the strata that were examined; however, the Crystal River Formation was identified in every well and the Williston in several. These formations were described as follows:

> The Crystal River Formation is a very pale orange to very light gray, moderately indurated, biogenic, very micritic, coquinoid limestone with a fauna that includes abundant larger foraminifera, especially Lepidocyclina sp. and Heterostegina sp.
>
> The Williston Formation is a medium-grained calcarenitic limestone. The unit is fossiliferous but not coquinoid, and the fossils are usually small in size. Large foraminifera present in the wells, especially Operculinoides sp. and Amphistegina sp. are small for their types and are poorly preserved.
>
> The boundary between the Williston and the underlying Avon Park Formation is marked by an abrupt lithologic change and dolomitization of the upper part of the Avon Park strata, combined with a change in the fossil fauna. The contact between the Williston Formation and the overlying Crystal River Formation is also marked by an abrupt lithologic and paleontologic change. The presence of unconformities (or diastems) at both boundaries is suggested by the differences.

Wedderburn logged a total thickness of 290 feet for the Ocala Group in a well located about 8 miles to the east of the test/injection site.

At the test/injection site, the Ocala Group was penetrated at 1,310 feet below land surface. Two of the three formations within the group were identified: the Crystal River Formation at the upper boundary of the group and the Williston Formation at 1,500 feet below land surface.

The Crystal River Formation was penetrated at 1,310 feet below land surface and extended down the well to 1,500 feet. It was characterized by white (N9) to very pale orange (10 YR 8/2), very micritic and coquinoid limestone. The unit was very fossiliferous, containing many of the larger Eocene foraminifers including Lepidocyclina ocalana, Heterestigina ocalana and many species of Operculinoides.

Little radioactivity was shown on the natural gamma ray logs, and fairly uniform but rather long travel times (slow acoustic velocity) were shown on the sonic logs. The formation has a high content of very pure calcium carbonate and is poorly to moderately indurated, which accounts for the low radioactive reading and the long travel times (slow acoustic velocity) recorded by the geophysical logs.

The Williston Formation was much more granular (calcarenitic) than the overlying Crystal River. The presence of the key guide foraminifers Operculinoides moodybranchensis and Amphistigina pinnarensis cosdeni aided in the differentiation of this formation from the overlying Crystal River and the underlying Avon Park Limestone. The total thickness of the formation was 70 feet and its base occurred at 1,570 feet.

The natural gamma ray log showed very little activity throughout this formation; but the acoustic log of the exploratory well showed a slight increase in travel time with increase in depth throughout the formation. This increase was probably due to the slightly higher porosity in the more granular formation, though the porosity of the Williston still remained low. The Williston Formation is immediately underlain by the Avon Park Limestone.

2.3.5.2 Avon Park Limestone/Lake City Limestone

Applin and Applin (1944) first used the terms "Avon Park Limestone" and "Lake City Limestone" for rocks of Late Middle Eocene Age and Early Middle Eocene Age, respectively, in peninsular Florida. They described the Avon Park Limestone as a cream-colored fossiliferous and chalky limestone, and the Lake City Limestone as a chalky limestone interbedded with dark brown dolomite, both with distinctive faunas.

Chen (1965) treated these two units as one undifferentiable group in Florida and felt that they were essentially biozones, as proposed by the Applins. He reported a highly carbonaceous bed separating the two units in south Florida. Wedderburn et al. (1982) described both of these units in a well just west of the test/injection site, but indicated that differentiation between them was tentative and difficult because of the lithologic similarities.

The Avon Park and Lake City Limestones were identified as separate formations in the deep test/injection well, based upon faunal and lithologic differences. The major difference between the two formations is that the Avon Park is essentially a limestone with interbedded dolomite, and the Lake City, a dolomite with interbedded limestone. The units overall are similar, however, and could be combined into one formation or group.

Avon Park Limestone - A sharp dividing line exists in Lee County between the calcarenite of the overlying Williston Formation and the formation immediately below it, the Avon Park Limestone. The Avon Park is highly microfossiliferous and dolomitic, and includes echinoids, foraminifera, mollusks, and other fossil fragments. The lithologic change is sharp and abrupt and is accompanied by a faunal discontinuity.

At the NFMU site, the top of the Avon Park was easily identified by the very pale orange color (10 YR 8/2) of the formation and by the foraminifera which includes Miliolids and *Dictyoconus cookei*. The top of the Avon Park Limestone at the NFMU site was at a depth of 1,570 feet below land surface. The upper dolomite beds of the Avon Park Limestone gradated downwards into a highly recrystallized biogenic limestone containing numerous foraminifera. They also became more micritic with depth.

From 1,760 to 1,790 feet, the Avon Park was interbedded with a dense dolomite bed. The sonic, gamma, dual induction, and caliper logs verified the presence of this dense dolomite, which showed a small travel time (fast acoustic velocity), increased radioactivity, high resistivity and a tight borehole, respectively (see Appendix 8). The limestone continued from this interbed down to 1,890 feet where thin light olive gray (5 Y 3/2) dolomite beds began interlayering with a very pale orange (10 YR 8/2) dolomitic limestone. At 1,906 feet below land surface, the interlayering became more massive and distinct, continuing that way down to the bottom of the formation at 1,940 feet. Overall, this basal unit has a high overall permeability and porosity because of the high permeability of the limestone layered between the interfingered tight dolomite beds; but, individually, each dolomite bed is of extremely low permeability and there is little chance that vertical movement of water across this zone is possible.

The gamma ray log showed an increase in radioactivity from each of the dense dolomite beds, while the sonic log snowed both long and short transit times, indicating the presence of voids filled with water and confinement, respectively, in the limestone and in the dolomite beds.

As a whole, the Avon Park Limestone is composed of limestone and dolomite, with small amounts of evaporite. The limestone is usually light brown, finely fragmented, rather porous, and highly fossiliferous; the dolomite is brown to dark brown, rather porous, very fine to medium crystalline and saccharoidal in texture (Chen, 1965). On the average, there is more dolomite than limestone within the Avon Park in the area around the NFMU site. The Avon Park is underlain by the upper limestone unit of the Lake City Limestone.

Lake City Limestone - Applin and Applin (1944) also proposed the name for the Lake City Limestone, using it to identify the rocks of early Middle Eocene Age. They described the Lake City Limestone as a chalky limestone, interbedded with dark brown dolomite containing gypsum, and occasionally chert. The boundary between the Avon Park and Lake City Limestones is unconformable, but some authors have regarded it as conformable with a tendency to be locally unconformable. Dolomitization frequently obscures any possible lithologic boundary and destroys any fossils that might otherwise assist in distinguishing the two formations.

The Lake City Limestone is generally made up of brown to dark brown dolomite, with small amounts of evaporite. The limestone is usually light brown to brown, fragmented, highly fossiliferous and slightly carbonaceous and cherty.

The dolomite is generally brown, rather porous, finely crystalline, and saccharoidal in texture. The occurrence of evaporite within the Eocene Limestones reported by Wolansky et al. (1979a) was not recorded as being significant by Puri and Winston (1974) and Chen (1965). The latter reported an almost negligible amount of evaporite -- less than 3 percent -- in the lithology of the Lake City Limestone. The anhydrite encountered within the Lake City Limestone is confined to the western portions of the west coast counties (Puri and Winston, 1974); however, at the NFMU site which is located in the western half of Lee County, no anhydrite was encountered in the Lake City Limestone.

The Lake City Limestone was best estimated to have been penetrated at 1,940 feet below land surface by the deep test/injection well; however, because of the unconformity of the contact which makes differentiation from the Avon Park difficult, it could also be estimated to be as much as 20 feet higher. Assuming that 1,940 feet is the correct depth, then the unit extended downward 550 feet to the top of the Oldsmar Limestone at 2,490 feet. The uppermost bed, from 1,940 to 2,000 feet below land surface, was a very pale orange (10 YR 8/2), dolomitic, fossiliferous limestone containing the index fossil Dictyoconus americanus. From 2,000 to 2,110 feet below land surface, this limestone became interbedded with a yellowish gray (5 Y 7/2) to olive gray (5 Y 5/2) crystalline dolomite. These two units from 1,940 to 2,110 feet showed fast acoustic velocities (short travel times) on the sonic log and increasing resistivity on the dual induction log. They form one of the confining units of the injection system.

The lower unit of the Lake City was principally composed of dolomite beds with varying degrees of crystallinity and alteration. From 2,110 to 2,130 feet, a dense and extremely tight interbed of dolomite was encountered that showed distinct signatures on the geophysical logs. The sonic log indicated very short travel times (high acoustic velocity) and the dual induction log showed highly resistive beds. This dolomite interval was the bottom of a confining unit extending upwards to 1,800 feet below land surface. The dolomite in this interval became coarsely crystalline to 2,150 feet. Immediately below the 2,150-foot depth and down to 2,190 feet, a dense dolomite section provided additional confinement.

Three limestone beds were encountered throughout the basal dolomites. The thickest interbed was detected at 2,190 feet below land surface. This interbed was 72 feet thick, with its base at 2,262 feet, and was a micritic, dolomitic limestone of very low permeability which provided confinement above the injection zone. From 2,260 to 2,370 feet below land surface, the formation was almost pure dolomite of extremely high density and low permeability. This section contains some of the best confining layers above the injection zone.

Two smaller interbeds of minor thickness were encountered at 2,370 feet and 2,390 feet below land surface. Diagnostic microfossils were unidentifiable in the limestone beds. The dolomites from 2,150 to 2,490 feet below land surface varied in color from light olive gray (5 Y 6/1) to pale yellowish brown (10 YR 6/2). Individual dolomite crystals were euhedral and very fine to medium grained. From 2,400 feet to the base of the Lake City Limestone at 2,490 feet, the unit was principally dolomite. The sonic log showed very short travel times and the dual induction log showed good confinement throughout this basal unit down to 2,340 feet below land surface (see Appendix 11). Below 2,370 feet, the sonic and induction logs began to change quickly with depth, indicating the start of the broken and cavity zones that are interspersed between tight beds. The first large cavity (6 feet) was detected by the logs at 2,424 feet below land surface.

2.3.6 Eocene Series - Oldsmar Limestone

The Lake City Limestone lies conformably over the Oldsmar Limestone, which is similar to it. The Oldsmar Limestone is made up of a chalky white to light brown, rather pure, finely fragmented fossiliferous limestone, overlain by the thick dolomite section at the bottom of the Lake City Limestone. The bottom of the Oldsmar is reportedly marked by a thick, dark brown, rather pure and clean, fine to coarse crystalline dolomite; however, at the NFMU site this layer was never reached. Evaporites within the Oldsmar Limestone are a minor component of the overall lithology of the formation.

Like the Lake City Limestone, evaporite is reported as constituting up to 5 percent of the formation (Chen, 1965); but in the Oldsmar Limestone underlying the NFMU site to the depth drilled, none was found. The percentage of evaporite, even when small, is important. Rocks containing evaporite within the lithology are usually of low porosity and relatively impermeable because the evaporite crystals grow within the pore spaces, which, in effect, does not permit the rock to transmit water.

The Oldsmar Limestone overlies the Cedar Keys Formation at the test/injection site. The term "Oldsmar Limestone" was originally used by Applin and Applin (1944) to denote nonclastic rocks of Early Eocene age in peninsular and northern Florida. Lithologically, the unit consists of limestone and dolomite with evaporite and glauconite being minor accessory minerals. The formation is marked at the top by numerous specimens of the foraminifer *Helicostegina gyralis*. This formation is well known in many areas of Florida for the presence of highly dissolutioned cavernous beds known as "Boulder Zones" (see Section 2.4.3.3).

Part of the Oldsmar Limestone was penetrated by the test/injection well from 2,490 feet to the base of the well at 2,606 feet. The top of the formation was identified by 10 feet of dolomitic limestone containing the index fossil *Helicostigina gyralis*. The unit occurred as a very pale orange (10 YR 8/2) highly recrystallized and fossiliferous limestone. From 2,500 to 2,524 feet, the unit was composed predominantly of a medium-grained crystalline dolomite that showed good intracrystalline porosity. A black lignite bed was present from 2,524 to 2,533 feet. This 9-foot-thick and highly carbonaceous bed was easily identified by very high radioactivity on the gamma log and long transit times on the sonic log. From the base of this lignite to the total depth of the well at 2,606 feet below land surface, a very fossiliferous, micritic limestone, containing many benthonic forams, including *Pseudophragmina sp.* and *Helicostigina gyralis*, was evident. The Oldsmar Formation was easily identified on the geophysical logs by faster travel times (sonic log) and lower resistivity (dual induction log).

2.3.7 Paleocene Series - Cedar Keys Formation

The term "Cedar Keys Formation" was originally applied by Cole (1944) to a carbonate facies he recognized in peninsular and northern Florida. The formation consists primarily of dolomite and evaporites (anhydrite and gypsum) with only minor amounts of limestone (Chen, 1965). Although the Cedar Keys was not penetrated at the test/injection site, it is believed to lie at about 3,400 feet below land surface in this area of Florida, and consist primarily of bedded anhydrites with low permeability. Evaporite is estimated to constitute nearly 30 percent of the whole formation underlying the NFMU site, according to Chen (1965). Therefore, the Cedar Keys Limestone is largely impermeable.

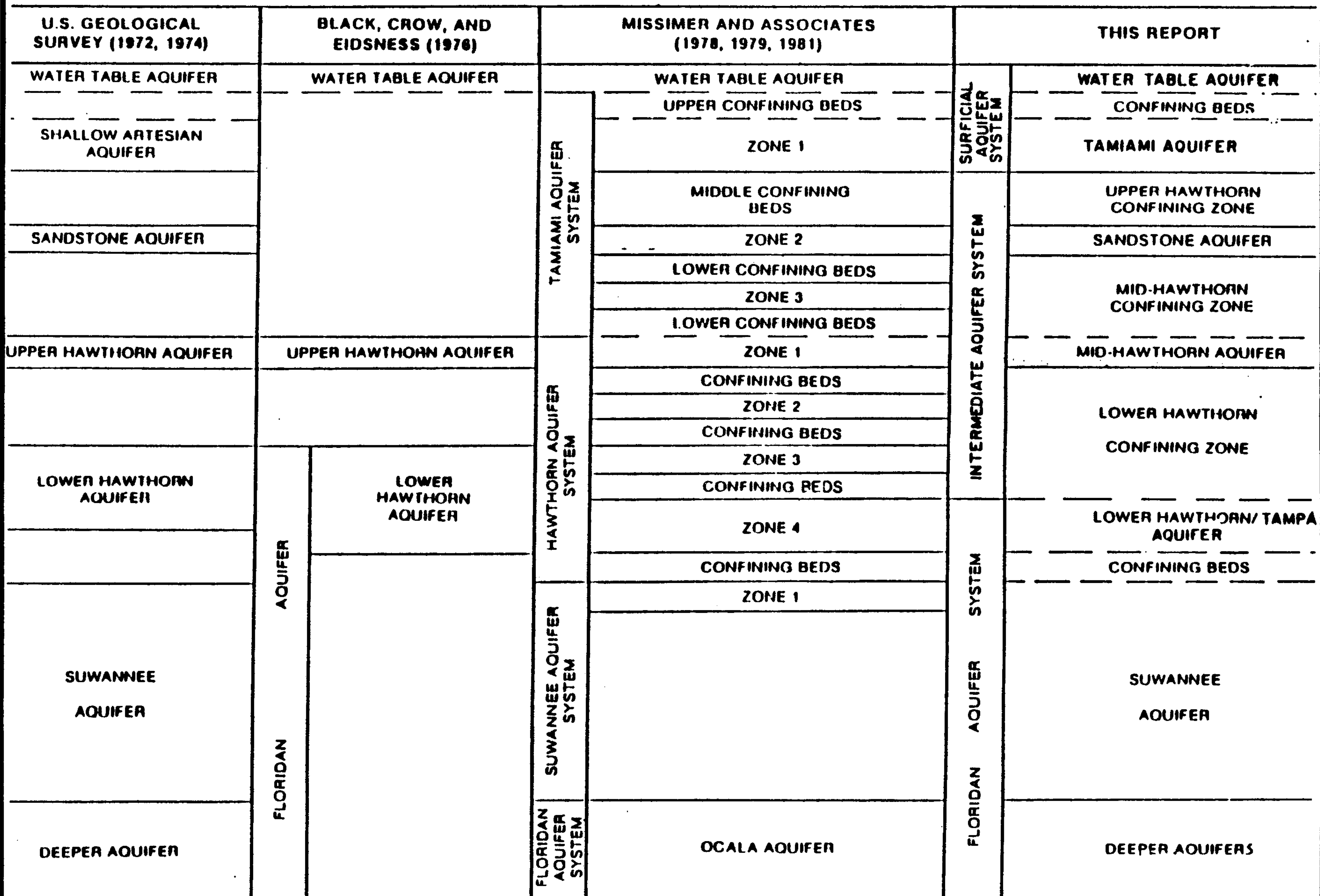
2.4 GROUNDWATER HYDROLOGY

The groundwater hydrology at the NFMU injection site, or at any other site for that matter, is directly related to the geology and to the characteristics of the materials that make up the water-producing and the confining zones at the site. As such, it is a fixed condition. The interpretation of the hydrologic system is subjective, however, and can vary depending on the interpreter and on what information and data are available to that interpreter at the time.

To facilitate an understanding of the various interpretations of the hydrogeologic regime prepared by other investigators in the past, this report identifies the different aquifer nomenclatures, and compares the nomenclatures selected by others between 1972 and 1981 with that used in this report. The nomenclature selected for this report is identical to that used in 1982 by the SFWMD (Wedderburn et al., 1982) but has been slightly modified to include the most recent changes approved by the Committee on Hydrostratigraphic Nomenclature of the Southeastern Geological Society (Vechiolli et al., 1986).

The nomenclature shown in Figure 2-8 applies to the hydrogeologic characteristics of Lee County. It can be tied in directly to the geology not only of the County in general, but also of the NFMU site in particular (see Figure 2-9).

At the NFMU site, three major aquifer systems are present, as defined by Vechiolli et al. (1986). These systems are the Surficial Aquifer System, the Intermediate Aquifer System and the Floridan Aquifer System. At the NFMU



NOT TO SCALE

SOURCE: WEDDERBURN et al., 1982.

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AQUIFER NOMENCLATURE IN LEE COUNTY

FIGURE 2-8

ERA	SYSTEM	SERIES	FORMATION	MEMBER	HYDROLOGIC SYSTEM	HYDROLOGIC UNIT	K	DEPTH	WATER CLASSIFICATION
CENOZOIC	QUATERNARY	HOLOCENE	UNDIFFERENTIATED	UNDIFFERENTIATED	SURFICIAL AQUIFER SYSTEM	WATER TABLE (UNCONFINED)			CLASS G-II
		PLEISTOCENE				CONFINING BEDS			
	TERTIARY	PLIOCENE	TAMIAMI FORMATION	OCHOPEE Lm BUCKING Lm		TAMIAMI PRODUCING ZONE (SEMI-CONFINED)		38	
		MIOCENE	HAWTHORN FORMATION	UPPER MEMBER: LA BELLE CLAY	INTERMEDIATE AQUIFER SYSTEM	UPPER HAWTHORN CONFINING ZONE		90	CLASS G-II
						SANDSTONE AQUIFER		110	
				ALVA CLAY		MID-HAWTHORN CONFINING ZONE		170	
				LEHIGH ACRES SANDSTONE		MID-HAWTHORN AQUIFER		210	
				LOWER MEMBER: UNDIFFERENTIATED		LOWER HAWTHORN CONFINING BEDS		420	
					FLORIDAN AQUIFER SYSTEM	LOWER HAWTHORN TAMPA PRODUCING ZONE			CLASS G-II
			TAMPA	UNDIFFERENTIATED		CONFINING BEDS		600	
		OLIGOCENE	SUWANNEE LIMESTONE	UNDIFFERENTIATED		SUWANNEE AQUIFER		1,310	
		EOCENE	OCALA LIMESTONE	CRYSTAL RIVER FORMATION		ALTERNATING CONFINING OCALA LIMESTONE PORTION OF LAYERS		1,500	
				WILLISTON FORMATION		OF FLORIDAN AQUIFER THROUGHOUT		1,570	CLASS G-IV
			AVON PARK LIMESTONE	UNDIFFERENTIATED		ALTERNATING AVON PARK LIMESTONE CONFINING PORTION OF LAYERS FLORIDAN AQUIFER THROUGHOUT		1,940	
			LAKE CITY LIMESTONE	UNDIFFERENTIATED		ALTERNATING LAKE CITY LIMESTONE CONFINING PORTION OF LAYERS FLORIDAN AQUIFER THROUGHOUT		2,490	
			OLDSMAR LIMESTONE	UNDIFFERENTIATED		ALTERNATING OLDSMAR LIMESTONE CONFINING PORTION OF LAYERS FLORIDAN AQUIFER THROUGHOUT		3,450	
		PALEOCENE	CEDAR KEYS LIMESTONE	UNDIFFERENTIATED	?	?	?		

SITE SPECIFIC TO NFMU

NOT TO SCALE

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HYDROGEOLOGIC CLASSIFICATION

FIGURE 2-9

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site, the Surficial Aquifer System contains the water table aquifer and the hydraulically connected units of the Tamiami Aquifer. It is underlain by the Intermediate Aquifer System, which acts principally as a confining zone for the Floridan Aquifer System below, although it does produce significant quantities of water in some areas of Florida.

At the NFMU site, the Intermediate Aquifer System can produce water from two zones: the Sandstone Aquifer and the Mid-Hawthorn Aquifer. The remaining zones of the Intermediate Aquifer System are essentially confining in their entire thickness and produce no water.

The Floridan Aquifer System is the major aquifer system in the southeastern United States and is composed of early Miocene to late Eocene Age limestones. At the NFMU site, this is the system of greatest importance because the treated wastewater will be injected into its deeper layers.

The Floridan Aquifer System contains several aquifers with good producing zones; but water from this system is usable for potable water supply in Lee County only after desalination treatment, usually by reverse osmosis. The major aquifers within this system are the Lower Hawthorn/Tampa, the Suwannee and the deeper units. The latter are unnamed, and are usually referred to as the middle and lower parts of the Floridan Aquifer System.

The deep test/injection well penetrates all three of these aquifer systems, ending in the lower part of the Floridan. Consequently, although the systems have been well documented and described in southwest Florida by Wedderburn et al. (1982) and Knapp et al. (1986), site-specific descriptions are required for the NFMU site.

Figure 2-9 associates the hydrogeologic column depicting the aquifer systems with the geologic formations, and shows the relative permeabilities within the section. Table 2-4 identifies the depth ranges of the various hydrogeologic units, and Figure 2-10 illustrates the hydrogeology of the site.

Table 2-4

HYDROLOGIC UNITS UNDERLYING THE STUDY AREA

Hydrologic Units	Depths (feet below land surface)	Thickness (feet)
Surficial Aquifer System	0 to 38	38
Intermediate Aquifer System	38 to 420	382
Sandstone Aquifer	90 to 110	20
Mid-Hawthorn Aquifer	170 to 210	40
Floridan Aquifer System (Part)	420 to 2,606	2,186
Lower Hawthorn/Tampa Aquifer	420 to 600	180
Suwannee Aquifer	600 to 1,310	710
"Deeper Aquifers"	1,310 to 2,606	1,296
High Transmissivity Zone	1,750 to 1,760	10
High Transmissivity Zone	2,130 to 2,150	20
High Transmissivity Zone	2,420 to 2,450	30

m:H-87/N

FORMATION	DEPTH	COLUMN	R.P.*	HYDROGEOLOGY	COMMENTS
Undiff.	10'			Surficial Aquifer System	consists of water table and Tamiami aquifer. Overall moderate permeability.
Tamiami	38', 100'				
Hawthorn	200', 300', 400'			Intermediate Aquifer System	Low permeability throughout caused by very fine grained silts and clays. Acts as confining unit for the Floridan.
Tampa	420', 500', 600'			Floridan Aquifer System — Lower Hawthorne/Tampa Aquifer	Principally, sandy fossiliferous limestone interbedded with dolosilt. Overall moderate permeability.
Suwannee	700', 800', 900', 1000', 1100', 1200', 1300'			Floridan Aquifer System — Suwannee Aquifer	Composed of a medium-grained, biogenic limestone with a high permeability in its upper portion. Becomes more micritic and of lower permeability towards the bottom.
Ocala Group — Crystal River	1310', 1400', 1500'			Floridan Aquifer System — Deeper Aquifer	Limestones in the upper portion of this sequence are micritic and of an overall low permeability. Solutioned dolomite is the the primary lithology in the high permeability zones of the Avon Park and Lake City limestones. The oldsmar exhibits an overall moderate permeability.
Ocala Group — Williston	1570'				
Avon Park	1600', 1700', 1800', 1900'				
Lake City	1940', 2000', 2100', 2200', 2300', 2400'				
Oldsmar	2490', 2500', 2600'				

*Relative Permeability: Low / Moderate / High

BASED ON TEST/INJECTION WELL DATA

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SITE HYDROGEOLOGY

FIGURE 2-10

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2.4.1 Surficial Aquifer System

The Surficial Aquifer System occurs within sediments of the Tamiami Formation and the undifferentiated deposits above it. The Tamiami Formation is composed principally of sandy biogenic limestones, while the undifferentiated deposits consist of quartz sand, shell beds, and calcareous clays, occasionally interbedded with thin seams of limestones. The calcareous clays, where present in sufficient thickness, act as semi-confining beds, dividing the system into the water table and the Tamiami producing zones. The base of the Tamiami Aquifer is formed by the clayey dolosilts at the top of the Hawthorn Formation.

The thickness of the Surficial Aquifer System varies between 25 and 50 feet in central Lee County. The aquifer thickens west of Cape Coral and in the southeastern part of the County. It is very thin in an area just south of the Caloosahatchee River in the northeastern and central parts of the County.

The Surficial Aquifer System is hydrogeologically complex, due to changes in the lateral facies of the strata and variations in the thickness of the beds. Over much of the area, the sands, shell beds, and limestones exhibit sufficient hydraulic continuity to be considered a single producing zone. In areas where the aquifer system is relatively thick, interbedded clayey beds create semi-confined or semi-unconfined conditions within the system.

Within the Surficial Aquifer System, porosities and permeabilities vary vertically and laterally, depending mainly on lithologies. In areas of similar lithologies, the transmissivity is dependent on the thickness of permeable rocks. Where sand is the dominant lithology, permeability is intergranular, due to the lack of cementation of the grains. The sands vary in grain size from fine to medium and, based on Lohman (1972), would be expected to have relatively low permeabilities of 15 to 50 feet per day. Shell beds have variable permeabilities depending on the matrix materials present. Porosities are normally intergranular and occasionally moldic. Reef tracts have mainly moldic porosity, with some solution porosity, and would be expected to have relatively higher permeabilities. The highest permeabilities in the Surficial Aquifer System are expected in the coraline reef limestone facies. The calcareous clays are apparently of low permeability, due to the fine-grained nature and cohesiveness of the material.

The Surficial Aquifer System is 38 feet thick at the NFMU site (see Table 2-4). The upper 10 feet is composed of moderately permeable sand and shell from the Caloosahatchee Formation. Underlying these clastic beds are fairly permeable limestones of the Tamiami Formation. No intervening calcerous clays were found. The Tamiami Formation interval extends from 10 feet to the base of the aquifer system at 38 feet below land surface. The system is underlain by low permeability dolosilts of the Hawthorn Formation. No confining beds were detected in this system, which behaves as a water table aquifer at the NFMU site. Shallow monitor wells drilled at the site yielded good quality water suitable for potable supply.

2.4.2 Intermediate Aquifer System

The Intermediate Aquifer System consists of five zones, as shown on Figure 2-8. All of these zones tend to be sandy, phosphatic, calcareous and dolomitic. The confining zones are predominantly clayey dolosilts, usually interbedded with shell beds or poorly indurated limestones.

The Intermediate Aquifer System is 382 feet thick at the NFMU site. It occurs wholly within the Hawthorn Formation and is of an overall low permeability due to the very fine-grained texture of the sediment within that formation. It is layered with only two permeable beds.

The water-producing zones are formed by limestone, calcareous quartz sand, sandstone, and dolomite, and they make up the Sandstone and Mid-Hawthorn Aquifers. The system is underlain by the Tampa Formation, which is the first permeable bed within the Floridan Aquifer System.

2.4.2.1 Upper Hawthorn Confining Zone

In most of Lee County, the Upper Hawthorn confining zone separates the Surficial Aquifer System from the Sandstone Aquifer, the uppermost aquifer in the Intermediate Aquifer System. The beds associated with this zone are dolosilts, which have very low permeabilities owing to the silt size and dense packing arrangement of matrix components. Some vertical permeability does exist; however, this zone is considered to be confining.

This zone is equated with the uppermost beds of the Hawthorn Formation. It occurs between 0 and -25 feet National Geodetic Vertical Datum (NGVD) over most of central Lee County. The unit dips gently to the west from Cape Coral and occurs at elevations between -50 feet and -75 feet NGVD in the Sanibel Island area. In the southeastern segment of the County, an apparent area of subsidence in the lower part of the Hawthorn Formation causes this zone and most other zones in that formation to be structurally low. The thickness of this zone generally varies between 10 and 100 feet in Lee County; but the zone thins out and is absent in the extreme southern portion of the County near Bonita Springs. Near Cape Coral, where the Sandstone Aquifer is absent, the upper Hawthorn confining zone directly overlies the Mid-Hawthorn confining zone; due to their similarities, differentiation of these two units is difficult in that area.

2.4.2.2 Sandstone Aquifer

The Sandstone Aquifer is the uppermost water-producing unit of the Intermediate Aquifer System. It underlies the Upper Hawthorn confining zone in nearly all of Lee County with the notable exception of Cape Coral as explained above. Boggess and Missimer (1975) used the term "Sandstone Aquifer" when describing the hydraulically interconnected sand, sandstone, and limestone members of the Tamiami Formation in the Lehigh Acres area. In this report, the Sandstone Aquifer is considered to be within the Hawthorn Formation because of the overall phosphatic and dolomitic nature of these members.

Lithologically, this aquifer is composed of sandy limestones, sandstones, sandy dolomites, and calcareous sands confined above and below by clayey dolosilts. Individual beds of sandstone and limestone are highly permeable where intergranular and moldic porosities are well developed. The beds are sometimes interbedded with poorly indurated limestone and clayey dolosilts, creating several producing zones.

The top of the Sandstone Aquifer occurs between -21 feet and -167 feet NGVD in Lee County. It is structurally high in Lehigh Acres and adjoining areas, where it is encountered between -25 feet and -50 feet NGVD. It dips in a southerly direction from this area and occurs at -150 feet NGVD in the southeastern portion of the County. There the Sandstone Aquifer thickens to over 200 feet and the overlying confining zone is thin or absent. Within a large portion of this area, the Surficial Aquifer System directly overlies and is in hydraulic communication with the Sandstone Aquifer.

At the NFMU site, the Sandstone Aquifer is present from 90 feet to 110 feet below land surface (see Table 2-4). It is overlain by low permeability dolosilts and clayey sands that separate this aquifer from the Surficial Aquifer System. The aquifer is composed of very sandy phosphatic limestone with well-developed moldic and intergranular porosities. The unit is artesian, but does not flow above land surface in this area of the County.

2.4.2.3 Mid-Hawthorn Confining Zone

The Mid-Hawthorn confining zone is composed of a relatively thick sequence of clayey dolosilts, locally interbedded with thin seams of porous limestone, sand, and dolomites. It occurs between -75 and -150 NGVD over most of the central and northern portions of the County, dipping to the southeast from the vicinity of Corkscrew Road and to the west from Pine Island. Although there is some vertical and horizontal movement of water in this zone, the permeability contrast with the overlying and underlying aquifers is considered sufficient for it to be designated as a confining bed. The thickness of this unit varies from approximately 20 feet to more than 180 feet. The unit is consistently thin in the Cape Coral area (less than 50 feet) due to a structural high in the Lower Hawthorn carbonate member.

The thin seams of limestone, sand, and dolomite are locally capable of producing small quantities of water under artesian pressure; however, due to the random occurrence of these beds, they are not considered a significant groundwater source and are normally cased off in wells tapping the underlying aquifers.

2.4.2.4 Mid-Hawthorn Aquifer

The water-producing limestones, sandstones, and dolomites that lie below a regional disconformity (Missimer, 1978) within the Hawthorn Aquifer are referred to in this report as the Mid-Hawthorn Aquifer. This unit was also referred to as the "Upper Hawthorn Aquifer" by the USGS (e.g., Sproul et al., 1972; Boggess, 1974) and as "Zone 1, Hawthorn Aquifer system" by Missimer and Associates (1979) (see Figure 2-8). The term "Mid-Hawthorn Aquifer" is used in this report in recognition of the position of the aquifer in the stratigraphic column as well as of the fact that the Sandstone Aquifer is included in the Hawthorn Formation and is, therefore, the uppermost aquifer in this formation.

Lithologically, the Mid-Hawthorn Aquifer is composed primarily of limestones, dolomites, and sandstones which exhibit intergranular, moldic, and possible fracture and solution porosity. At the NFMU site, the top of the aquifer is found at 170 feet below land surface (approximately -152 feet NGVD) (see Table 2-4) and here the aquifer is composed primarily of sandy and phosphatic dolomitic limestone.

A reworked zone at the base of the Mid-Hawthorn confining zone, consisting of quartz and phosphatic sand, may also act as part of the aquifer. Phosphatic sand, quartz sands, and fossiliferous clayey dolosilts are also interbedded with the major lithologies in the aquifer. These interbeds are normally of lower permeability than the limestones, dolomites, and sandstones.

This aquifer is separated above and below from other aquifers by the same type of confining dolosilts and clayey sands that separate the Sandstone Aquifer from the Surficial Aquifer. These confining beds cause the aquifer to be artesian; but, at the NFMU site, the artesian head is below land surface. The bed immediately above the Mid-Hawthorn Aquifer is a phosphatic rubble that showed a distinctive peak on the natural gamma ray log.

The thickness of the aquifer is variable, but rarely exceeds 80 feet. At the NFMU site, it is only 40 feet thick. The relatively thin section of aquifer, coupled with the interbedding of low permeability beds, results in an overall low aquifer transmissivity.

The base of this aquifer is often difficult to identify because the interbedded dolosilts and clay occur erratically throughout the unit. Where they occur close to the base of the aquifer, the distinction between these and the lithologies in the underlying Lower Hawthorn confining zone is not clear. At the NFMU site, it has been determined that the bottom of the aquifer is at a depth of 210 feet below land surface (192 feet below NGVD).

2.4.2.5 Lower Hawthorn Confining Zone

The Lower Hawthorn confining zone lies below the Mid-Hawthorn Aquifer, and consists principally of sandy, phosphatic, poorly indurated limestones interbedded with phosphatic dolosilts. The low permeability of this zone results from the fine-grained nature of the rocks. The lithology of this zone is not uniform, however, and several well-indurated porous limestone, dolomite, and sandstone beds occur within it. At some localities in Lee County, these beds may produce water under artesian pressure; but this is not the case at the NFMU site. In western coastal Lee County, Missimer (1979) identified two relatively thick beds (Zones 2, 3, see Figure 2-8) which could yield significant quantities of water.

In most of Lee County, the thickness of the Lower Hawthorn confining zone varies between 180 and 350 feet. It is significantly thinner in the northern

Pine Island area, as a result of a structural high in the Suwannee Limestone there. At the NFMU site, it is approximately 210 feet thick.

2.4.3 Floridan Aquifer System

In Lee County, the water-producing beds that can be correlated with the upper section of the "Floridan Aquifer," as defined by Parker et al. (1955), have been referred to as the Lower Hawthorn Aquifer and the Suwannee Aquifer (Sproul et al., 1972; and Boggess, 1974). These authors indicated that these aquifers should be treated as individual hydrologic units, separated above and below by confining beds. Later work by Black, Crow, and Eidsness (1976) (now called CH_2M Hill) placed the Lower Hawthorn and Suwannee Aquifers in the Floridan Aquifer.

In this report, Parker's Floridan Aquifer (1955) is referred to as the Floridan Aquifer System. It consists of an areally thick sequence of interbedded limestones and dolomites of Eocene to Lower Miocene Age, which show large differences in vertical and horizontal porosity and permeability. This system is divided into three major zones: the Lower Hawthorn/Tampa Aquifer producing zone, the Suwannee Aquifer producing zone, and the producing zones of the deeper aquifers. Permeability differences exist within each of these zones, and some intervals produce significantly more water than others. The top of the Floridan Aquifer System is equated with beds associated with the Lower Hawthorn Formation and, by some geologists, with the Tampa Formation. The major producing zones within this system normally occur near the contacts of the geologic formations. These zones have higher porosities and permeabilities due to the reworking or dissolution of the carbonate rocks in these intervals and the dolomitization process.

The Floridan Aquifer System in Lee County is well documented by Wedderburn et al. (1982), although only limited data on the deeper parts of the system are available. The top of the Floridan is recognized in the lower intervals of the Hawthorn Formation or at the top of the Tampa Formation. The base of the system has been defined by Miller (1982) as occurring in the bedded anhydrite sequence of the Cedar Keys Limestone.

Wedderburn et al. (1982) recognized three aquifers or producing zones within the system in Lee County: the Lower Hawthorn/Tampa producing zone (Lower Hawthorn/Tampa Aquifer), the Suwannee Aquifer, and the deeper aquifers (unnamed). Water within the Floridan Aquifer System is under artesian pressure and the upper aquifers will flow freely at land surface in properly cased wells. The water is brackish, and the salinity increases with depth, but the shallower sections contain water that is usable for agriculture and for potable supply after desalination or blending.

2.4.3.1 Lower Hawthorn/Tampa Aquifer

In this report, the term "Lower Hawthorn/Tampa producing zone" is used to describe the water-bearing units within the base of the Lower Hawthorn Formation, including those beds referred to by previous authors as the Tampa Limestone. This zone includes the lowermost part of the "Lower Hawthorn Aquifer" as defined by Sproul et al. (1972), and extends to near the top of the Suwannee Limestone. This extension is justified on the basis of recent data showing that major water-producing zones consistently occur below the base of Sproul's Lower Hawthorn Aquifer and above the Suwannee Aquifer.

Lithologically, this unit is composed of sandy and phosphatic biogenic limestones with intergranular and moldic porosity. It is interbedded with well-indurated crystalline dolomites and phosphatic clayey dolosilts. The variability of the porosity within the limestones and the presence of lower permeability dolomites and dolosilts cause the water-producing zones to be isolated into intervals of different productivity. The major production zone within this unit occurs near its top in a well-indurated, sandy limestone. Although the majority of the water from the Lower Hawthorn/Tampa producing zone comes from the top of the unit, several smaller producing intervals occur elsewhere in the unit.

Beds of lower permeability are present at the base of the Lower Hawthorn/Tampa producing zone. These low permeability beds are composed of compact (indurated) micrites which act as semi-confining beds to the underlying Suwannee Aquifer. At the NFMU site, moderately indurated micrites were found in the bottom 10 feet of the Tampa Formation (see the geologic description of the well cuttings in Appendix 24).

The top of the Lower Hawthorn/Tampa producing zone is an undulatory surface that ranges from -350 feet NGVD in northwestern Lee County to -700 feet NGVD in the southern portion of the County. The thickness of this unit varies from 80 to 275 feet and regional highs occur in the Cape Coral and east Fort Myers areas.

The Lower Hawthorn/Tampa Aquifer at the NFMU site is penetrated at 420 feet below land surface (-402 feet NGVD) at the top of the Tampa Formation, and as such, is wholly within the Tampa Limestone at this site (see Figure 2-10). The aquifer is composed of sandy fossiliferous limestones with moderate to high permeability. Low permeability limestone and dolosilts are interbedded and high radioactivity was detected by the natural gamma ray log in several of these intervals. The Lower Hawthorn/Tampa Aquifer is underlain by the Suwannee Aquifer at 600 feet below land surface. The last 10 feet, between 590 and 600 feet below land surface, are the only confining beds between these two units at the NFMU site, and a degree of hydrologic connection is assumed between the Lower Hawthorn/Tampa Aquifer and the Suwannee Aquifer below it.

2.4.3.2 Suwannee Aquifer

The Suwannee Aquifer occurs within beds that are assigned to the Suwannee Limestone. The lithology of the Suwannee Limestone in Lee County is complex due to the interbedding of poorly indurated micrite, slightly phosphatic dolosilt, sand, and sandstone. The major producing zones within the Suwannee Aquifer occur in isolated beds of relatively high porosity and permeability which are normally composed of calcarenitic limestones and occasional sandstones.

The top of the Suwannee Aquifer occurs between -500 feet NGVD in northwestern Lee County and -850 feet NGVD in the extreme southern and northeastern portions of the County. The thickness of the aquifer is consistently more than 350 feet. The major producing intervals in this aquifer are located near its top. Several other producing intervals occur at greater depths.

The Suwannee Aquifer is present at the NFMU site from 600 feet to 1,310 feet below land surface, wholly within the Suwannee Limestone. The aquifer is composed of slightly sandy granular limestone with moderate to high permeability in the upper part (see Figure 2-10). Beds of high permeability occur from 600 feet to 610 feet below land surface at the contact of the Suwannee and Tampa Formations and slightly below that from 650 to 675 feet below land surface. Two other zones of high permeability occur from 740 feet to 755 feet and from 955 to 965 feet below land surface. Both these zones are found in very granular (calcarenitic) limestones. Beds of low permeability are present directly above both of these horizons. The lower portion of the Suwannee Aquifer, from 965 feet to 1,310 feet below land surface, is predominantly low permeability limestone. These beds are very micritic, poorly indurated and sometimes sandy.

2.4.3.3 Deeper Aquifers

The deeper aquifers are associated with porous beds of limestones and dolomites that occur in the Ocala Group, Avon Park Limestone, Lake City Limestone, and Oldsmar Limestone. Puri and Winston (1974) described several zones of high permeability within these strata.

The deeper aquifers are contained within the Eocene Age limestone formations, in zones of high transmissivity that occur throughout the Eocene section, but most frequently in the dolomitic sequences of the Avon Park, Lake City and Oldsmar Formations. Nearly all the limestones in the Eocene tend to be very micritic and of low permeability; but some of the dolomite intervals exhibit very low permeabilities as well, and it is in the dolomitic intervals that the most confining beds are found.

The lithology of the Ocala Group is characterized by very micritic coquinoid limestones with intergranular and moldic porosities. The Avon Park Limestone and the Lake City Limestones are commonly dolomitized with correspondingly lower intracrystalline and vugular porosities.

Zones of high transmissivity, commonly called "Boulder Zones," typically occur at several horizons within the lower parts of the Lake City Limestone and parts of the Oldsmar Limestone. The high transmissivities are the result of diagenetic changes related to dolomitization and/or carbonate dissolution which create caverns in those zones. The term "Boulder Zone" is a misnomer. There are no boulders in the zone; but, during drilling, there are cave-ins that fall to the floor of the caverns, giving a driller the impression of drilling through boulders, and hence the name "Boulder Zone."

The deeper aquifers are not used to supply water for human consumption in Lee County; consequently, the Wedderburn study (1982) did not discuss those aquifers in detail. The best information available on the deeper aquifers is found in the works of Puri and Winston (1974), and in the work of Chen (1965). According to these sources, the Ocala Limestone in Lee County consists of alternating layers of varying permeability, sandwiched between layers of low permeability and layers with practically no permeability. The same condition also occurs in the deeper formations in the Avon Park Limestone and in the Lake City Limestone. These alternations of low permeability layers with layers of no permeability at all isolate the highly permeable zones where large cavities make it possible to inject large volumes of water.

The uppermost geologic unit in the section is the Ocala Group, which, at the NFMU site, occurs at 1,310 feet below land surface. The upper 190 feet of the Ocala Group (Crystal River Formation) is very micritic and of an overall low permeability.

At the NFMU site, the contact of the Crystal River and the underlying Williston Formation from 1,495 to 1,505 feet below land surface has well-developed moldic and intergranular porosities; however, the section of the Williston Formation from 1,515 to 1,570 feet is of overall very low permeability. The 16-inch and 64-inch normal resistivity logs run on the exploratory well (PBS&J, 1986a) attenuated dramatically near the base of the

Williston Formation, and the lithologic samples and other geophysical logs also indicated a very low permeability limestone that serves as a confining layer throughout this interval. The attenuation of the electric logs in this interval coincided with an increase in the chloride and total dissolved solids (TDS) content of the water, and led to the conclusion that this confining layer separates the low TDS waters of the Crystal River and Williston Formations from the high TDS waters of the Avon Park Formation below.

The Avon Park Limestone contains a bed of high permeability near the contact with the Ocala Group in a highly altered dolomitic limestone. Data from the deep test/injection well indicated that this bed extends from 1,570 to 1,600 feet below land surface (see the geologic descriptions of the well cuttings in Appendix 24). Below this bed, to a depth of 1,750 feet below land surface the unit was consistently logged as a moderately permeable limestone. The acoustic log showed relatively low values for travel times in this interval, indicating relatively dense formations and thus low permeability.

At 1,750 feet, a cavernous dolomitic limestone of extremely high permeability was found, extending 10 feet to the top of a highly altered dolomite at 1,760 feet below land surface. This dolomite showed major effects in the geophysical logs (see Appendix 8). The acoustic velocity log showed rapid long travel times in this interval, coupled with abrupt decreases in resistance in the dual induction log, probably caused by the highly conductive saltwater in the caverns. The gamma ray log indicated little activity since there are no sources of radioactive emission in the cavernous zone.

Underlying these cavernous dolomites from 1,765 to 1,780 or 1,790 feet below land surface, depending on what geophysical log is used, were the lowest permeability dolomites of the Avon Park Formation. Fairly dense and very fine-grained limestones, with visual porosity not exceeding 10 percent were found below that. A dense dolomite was penetrated from the 1,890-foot level of the Avon Park Limestone to the top of the Lake City, at 1,940 feet below land surface. In this interval, the acoustic log showed short travel times. This is a dense, impermeable confining zone.

At the NFMU site, the Lake City Limestone is of overall very low permeability in its upper portion, between 1,940 and 2,110 feet below land surface. Low permeability micritic limestone and dense microcrystalline dolomite in this interval form a thick confining bed with only one small break, a high permeability area between 1,990 and 2,005 feet below land surface. Another high permeability dolomite is present within the interval from 2,130 to 2,150 feet below land surface, and cavities were indicated by the induction and the acoustic logs and by the television survey in the zones between 2,133 and 2,135 between 2,141 and 2,144, and between 2,053 and 2,156 feet below land surface. One other zone of high permeability is present in the upper portion of the Lake City, between 2,191 and 2,193 feet below land surface.

These high permeability zones were easily identified on the electric and acoustic velocity logs by their drop in resistivity and long travel times, respectively. They are confined above and below by thick sequences of low permeability limestone and dolomite and by practically impermeable sequences of low permeability limestone and dolomite and by dense, practically impermeable dolomites occurring in thinner layers within the overall thick confining layer.

From 2,193 to 2,350 feet below land surface, the Lake City offers extremely low permeability and functions as a truly confining unit. Within this zone there are several sub-zones of even lower permeability. These zones, identified from the dual induction and the sonic logs, lie between 2,245 and 2,298 feet, and between 2,310 and 2,345 feet below land surface.

The lower portion of the Lake City formation, from 2,350 feet below land surface to its contact with the Oldsmar formation at 2,490 feet below land surface exhibits the characteristics of the cavernous Boulder Zone, as explained earlier; but in between cavernous zones, the formation shows layers that are extremely dense. Two of these dense layers were observed, one from 2,400 to 2,420 feet below land surface and the other from 2,449 feet below land surface to the bottom of the Lake City at 2,490 feet. Within the lower 100 feet of this formation, cavities were found at 2,362, 2,421, 2,425, 2,430, 2,447, and 2,473 feet below land surface. The cavity at 2,447 feet measured nearly eight feet from top to bottom, and the typical fallen-in boulders could be seen at its floor in the television survey.

The Oldsmar Limestone is present from 2,490 to 2,606 feet below land surface, and continues on below beyond the limit of drilling for the deep test/injection well. At the NFMU site, it occurs as a well-indurated, highly recrystallized carbonaceous limestone with intergranular and moldic porosities in the 10 percent range. The acoustic log showed transit times in a variety of ranges. The unit is of very high permeability in the section to 2,524 feet, as penetrated by the deep test/injection well, but from 2,524 feet to the bottom of the well at 2,606 feet below land surface, the permeability decreases considerably.

A soft but low permeable lignite bed underlying this dolomite at 2,524 feet was easily identified on the gamma, sonic and dual induction logs by its very high radioactivity, long travel times and high resistivity. The unit is of low to moderate permeability.

2.5 UNDERGROUND SOURCES OF DRINKING WATER

Chapter 17-28 of the FAC classifies injection wells using guidelines presented in Article 17-28.13. Based on those guidelines, the DER found the NFMU well to be a Class I injection well. This classification requires that the effluent from the NFMU wastewater treatment plant served by this well be injected beneath the lowermost formation containing an underground source of drinking water (USDW) with one quarter mile of the well bore. Furthermore, it also requires that at least one confining zone exist above the injection zone to prevent injected fluid from migrating upward into the USDW.

As defined in Chapter 17-28 of the FAC, an USDW is an aquifer or a portion thereof that satisfies any one of the following criterion:

- Supplies drinking water for human consumption
- Is classified by Section 17-3.403 (FAC) as Class G-I or G-II waters

o Is not an "exempted aquifer."

Because none of the aquifers underlying the NFMU site have been declared "exempted aquifers" by DER, under the provisions of Chapter 17-28.13(3) of the FAC, all the above three criteria are applicable to the site, and are discussed below.

The aquifers that supply drinking water for human consumption in the one quarter of a mile area of Lee County that includes the NFMU plant site are the Surficial Aquifer System and the Intermediate Aquifer System. Therefore, those zones qualify as USDWs under the provisions of the first criterion above. The Floridan Aquifer System is too saline in this area and does not supply drinking water.

The second criterion for an USDW is applicable if the water meets the criteria specified for Class G-II water. As defined by Chapter 17-3.403 of the FAC, Class G-II water has a TDS content of less than 10,000 mg/l, unless otherwise classified by the Environmental Regulation Commission, which has not been done as of this date. Waters within confined aquifers that have a TDS content greater than 10,000 milligrams per liter (mg/l) are classified as Class G-IV waters.

Under this second criterion, the upper part of the Floridan Aquifer System at the NFMU site qualifies as an USDW. The Floridan Aquifer System at the site contains waters of 10,000 mg/l of TDS or less, above a depth of 1,550 feet below land surface, and waters of 10,000 mg/l of TDS or more below that. Thus, the Tampa, Suwannee, and Ocala portions of the Floridan Aquifer System are USDWs; but the Avon Park, Lake City and Oldsmar portions are not (see Figure 2-10).

The last criterion is important only when the DER exempts an aquifer. Since this has not been the case, then the aquifers determined to be USDWs by the first two criteria remain USDWs.

Based on Chapter 17-28 of the FAC and on the criteria above, the wastewater effluent from the treatment plant at the NFMU site must be injected beneath the lowermost formation containing an USDW within one quarter mile of the well bore and beneath a confining layer capable of keeping the injection waste from migrating into the USDW. Consequently, since the proposed injection must be into a confined aquifer in which the formation fluid has TDS concentrations greater than 10,000 mg/l (i.e., Class G-IV water), the injection must take place into the Floridan Aquifer System (see Figure 2-9). Those conditions are found at a depth of only 1,550 feet below land surface, but the top of the selected injection zone has actually been identified at a depth of 2,350 feet below land surface. The selection of this much deeper zone is beneficial to the protection of the USDWs by providing additional separation and additional confining layers between them and the injection zone.

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Section 3
DEEP TEST/INJECTION WELL

3.1 WELL CLASSIFICATION

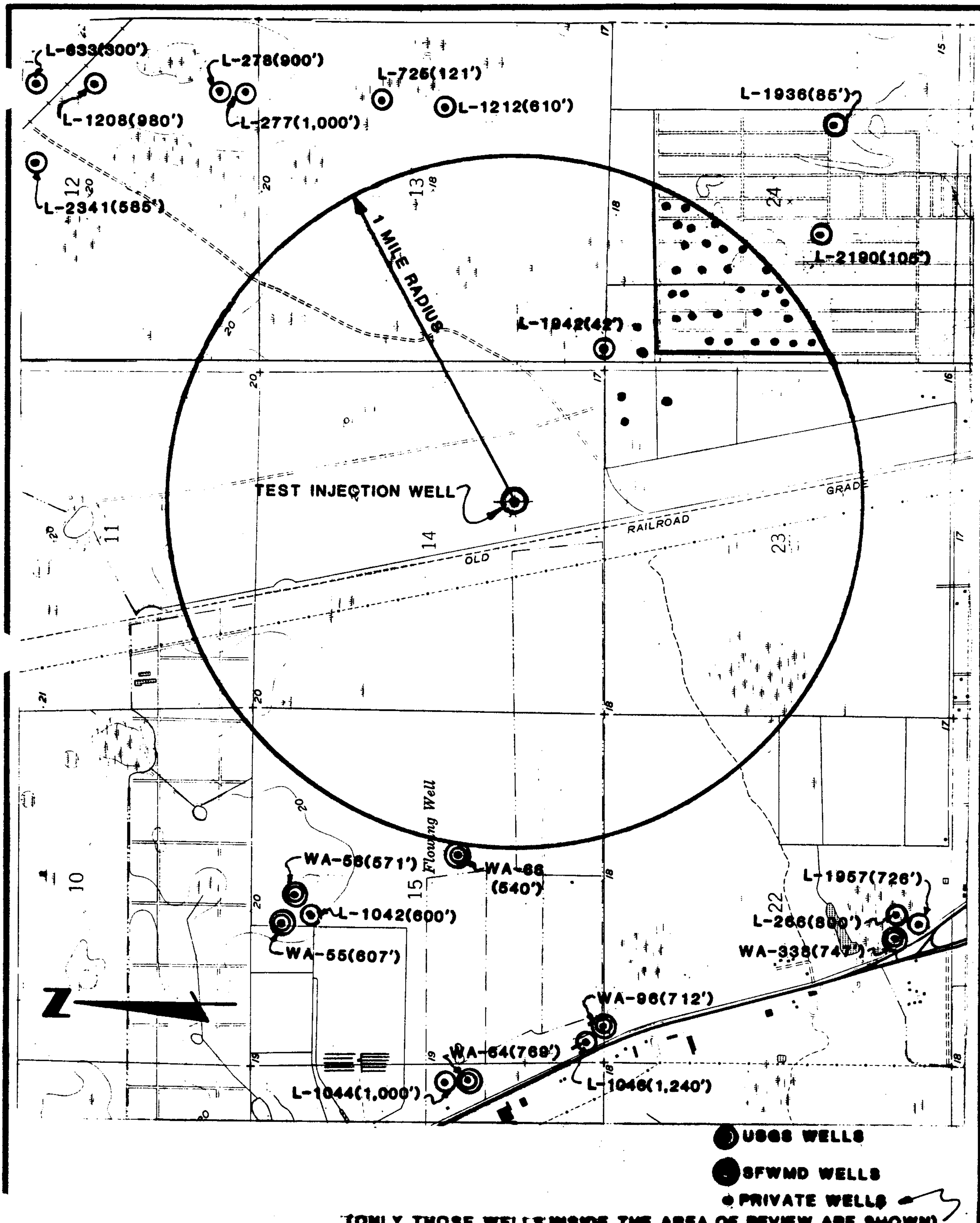
The Underground Injection Control (UIC) regulations included in Chapter 17-28 of the FAC identify five classifications for injection wells in Florida. As noted in Section 2.5, the DER has classified the NFMU well as a Class I injection well. Thus, the technical specifications for the deep test/injection well at NFMU incorporated the design features required for a Class I injection well, as specified by Chapter 17-28, and the construction and testing of the deep test/injection well included all the parameters required for that class of well.

3.2 AREA OF REVIEW

For each Class I well, the DER requires that an Area of Review (AoR) on the land surface be defined and submitted before a construction and testing permit can be granted. Such an AoR must overlie the prospective "zone of endangering influence" of the injection well and its determination must be based on the following considerations:

- Hydrogeology of the injection zone
- Formation fluid characteristics
- Injection fluid characteristics
- Population
- Groundwater use and dependence
- Historical practices in the area.

A 1-mile-radius AoR for the deep test/injection well at the NFMU site was identified and a map of the AoR transmitted to the TAC on December 16, 1986, before the construction permit was issued. On this map, the area of 1-mile radius from the well was circled; but the map itself covered a much greater area (see Figure 3-1). Although numerous wells lie inside the AoR, especially in the trailer park southeast of the site, none of these wells are deep. Most



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AREA OF REVIEW

FIGURE 3-1

REPRO PRODUCTS INC. 7A

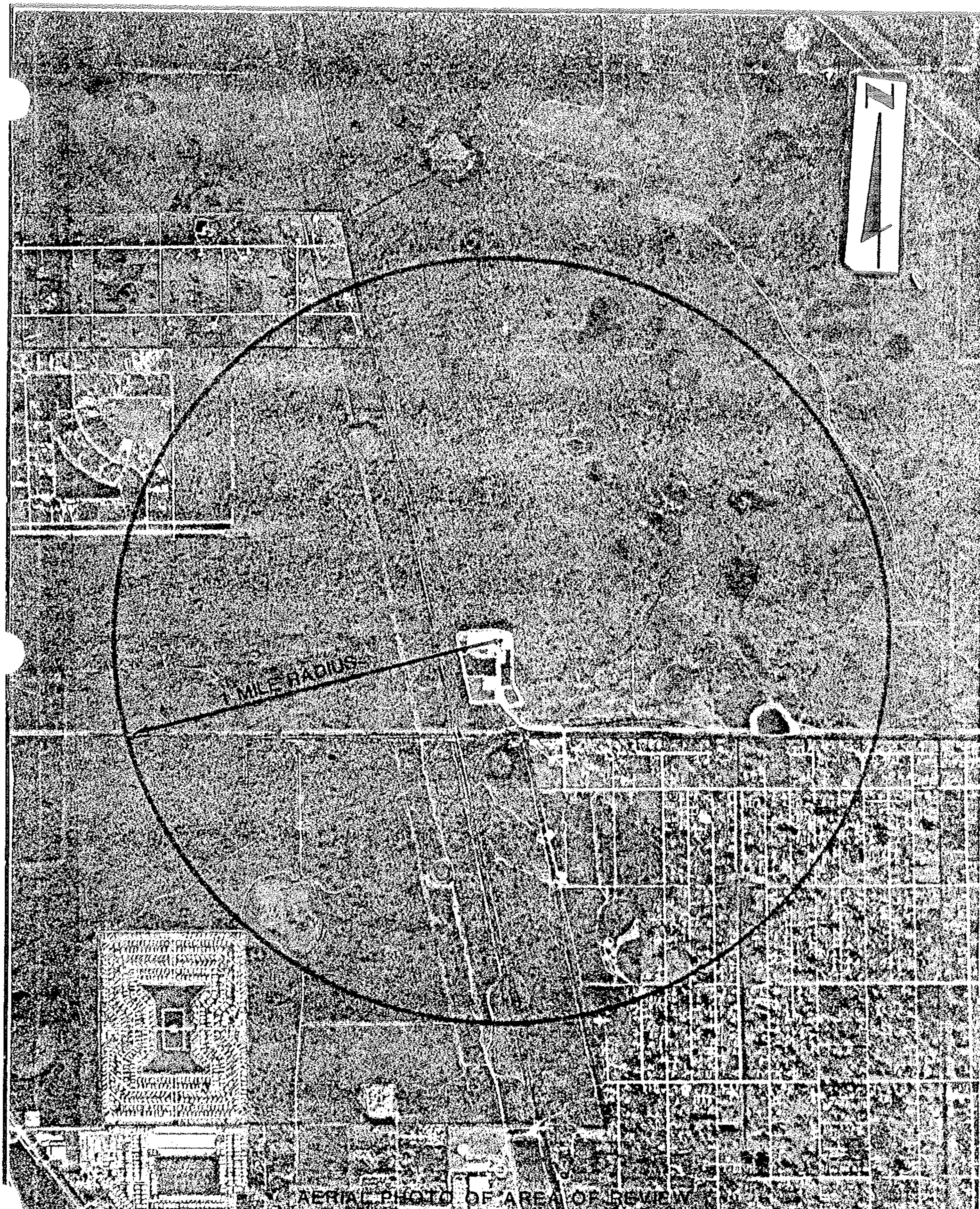
are private supply wells drilled into the Surficial Aquifer System; only a few are drilled into the Intermediate Aquifer System.

An aerial photograph of the site on which the AoR has been superimposed (see Figure 3-2) shows that, at the southeast and the northwest quarters of the AoR, there are numerous house trailers, each of which is connected to a shallow water supply well. Groundwater use around the NFMU site (within the AoR) is restricted to the potable water supply for individual house trailers and non-community systems that withdraw their supplies from the Surficial Aquifer System.

At present, the Floridan Aquifer System is used only by local farmers, outside the AoR, for irrigation; their irrigation wells usually tap no deeper than the top of the Suwannee Aquifer of the Floridan Aquifer System. There are no known users of groundwater from below 1,200 feet around the NFMU site. In all of Lee County, there are no known users of groundwater from the deeper aquifers of the Floridan Aquifer System. Historically, the land for two or three miles around the NFMU site has never been cultivated or farmed, probably because of the need for extensive drainage. There are no wells within the AoR which penetrate into either of the two monitor zones of the deep monitor well at the NFMU site, into the confining zone, or into the injection zone.

A review of well records from the SFWMD and the USGS shows that a number of deep wells have been drilled in the North Fort Myers area; but, as shown in Figure 3-1, they are all outside the 1-mile radius of the AoR. None of these wells penetrate beyond the Suwannee Aquifer. The deepest of the wells is Well L-1046, which is 1,240 feet deep and is located a mile and a half from the NFMU injection well. There are no other wells deeper than 1,000 feet within a 4-mile radius, and there are no wells that penetrate the depth of the monitor zone within a 10-mile radius.

Figure 3-1 shows wells around the drill site, but not on the site itself. At the NFMU site, in addition to the deep test/injection well and the deep monitor well, there are two sets of shallow monitor wells around each of the two drilling pads, the deep monitor well drilling pad and the deep



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AERIAL PHOTOGRAPH OF AREA OF REVIEW

FIGURE 3-2

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test/injection well drilling pad (see Figure 1-3). There is one additional well on site, a water supply well into the Surficial Aquifer System which provides water to the office building at the plant (see Figure 1-3).

Figure 3-1, in addition to showing the AoR around the injection well at the NFMU site, also shows the surface bodies of water and roads within the AoR and outside it. All other physiographic and political features around the AoR can be seen on the aerial photograph (Figure 3-2). Underground features such as faults or sinkholes are not identified in the literature of the area and there are no indications of them on site. No new developments have taken place in the AoR since it was initially identified in 1986, and no changes are needed in the documents. The adjacent property owners are shown in a map prepared by the property appraiser and reproduced here as Figure 3-3.

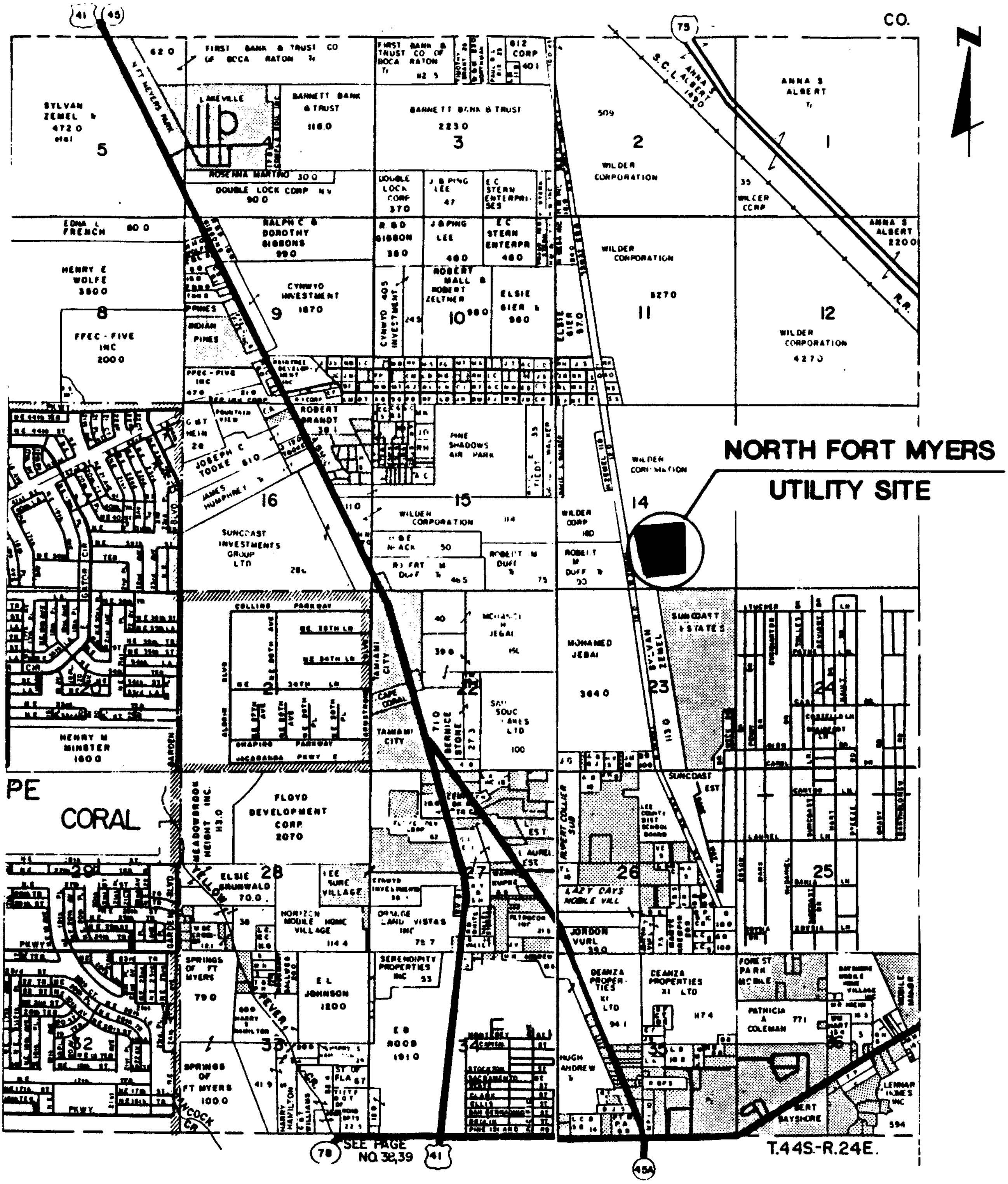
At present, no one is living within one-third of a mile of the well site. The centralized location of the well on the site and the buffer around the site itself result in minimum distances from the well to the nearest residential unit of approximately 2,050 feet to the southeast, and 4,560 feet to the northwest.

None of the above factors used in assessing conditions in the AoR can be described as critical or as an endangering influence to either the public or the surrounding environment. Therefore, the 1-mile radius AoR, as selected and approved by the TAC, has been used in a computer model to assess the effects of injection pumpage with time. The results of this modelling effort are discussed in Section 9.6 of this report.

3.3 INJECTION FLUID

3.3.1 Chemical and Biological Characteristics

The existing NFMU wastewater treatment plant currently accepts wastewater from the various users within the utility service area. The wastewater is largely residential and commercial in nature and does not include any hazardous wastes. No industrial waste connections exist. As the service area increases



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OWNERS OF ADJACENT PROPERTY

FIGURE 3-3

and additional connections are made to the new plant, the composition of the wastewater is not expected to change, although it is expected that the strength of the sewage will vary with changes in the proportion contributed by commercial users.

Even with the enlarged service area, the wastewater will still be fairly typical residential effluent, and the composite wastewater characteristics are expected to be as shown in Table 3-1. The wastewater is expected to be free of any radioactive substances, and to have no more than trace levels of oil and greases. The wastewater is also not expected to contain any non-degradeable organic solvents, degreasers, and like substances. Arrangements have been made to collect periodic wastewater samples for complete analyses once the treatment plant is operational, as part of the procedures included in the operation of the plant.

The final wastewater effluent, prior to discharge from the new plant site, is expected to have the characteristics of typical filtered and chlorinated secondary effluent, that is, low in suspended solids and biochemical oxygen demand. The new plant will use a state-of-the-art process to achieve this degree of treatment (see Figure 3-4). In this process, the sewage will be oxidized as it travels through an elliptical concrete tank called an oxidation ditch. A series of revolving aerators/mixers provide the oxygen required to oxidize the sewage and convert it into a mixed liquor. This liquor is then separated into clean liquid and sludge in a flow-through clarifier constructed inside the oxidation ditch. This clarifier is called a boat clarifier because of its shape and because it "floats" at the top of the inflowing waste stream. From the boat clarifier, the supernatant goes to a filter and is then disinfected by chlorination prior to being injected down the well (see Figure 3-5).

3.3.2 Physical Characteristics

The physical characteristics of the injection fluid are required as part of the data base for the injection computer model (SWIP), and for the other analytical work that is part of this study. Table 3-2 lists each of the

Table 3-1

EXPECTED WASTEWATER CONCENTRATIONS

Constituent	Concentration (mg/l)
Total Suspended Solids (TSS)	5
BOD (5-day)	10
Coliform Bacteria (MPN/100 ml)	100
Total Nitrogen	15
Total Phosphorus	2
Carbonate	0
Heavy Metals	0.8
Bicarbonate	100
Calcium	50
Sulfate	80
Sodium	50
Potassium	10
Magnesium	18
Iron	0.1
Total Organic Carbon	25
pH	7.4
Chloride	40
Total Dissolved Solids (TDS)	350

Sources: (PBS&J, 1985)
(Tchobanoglous, 1979)

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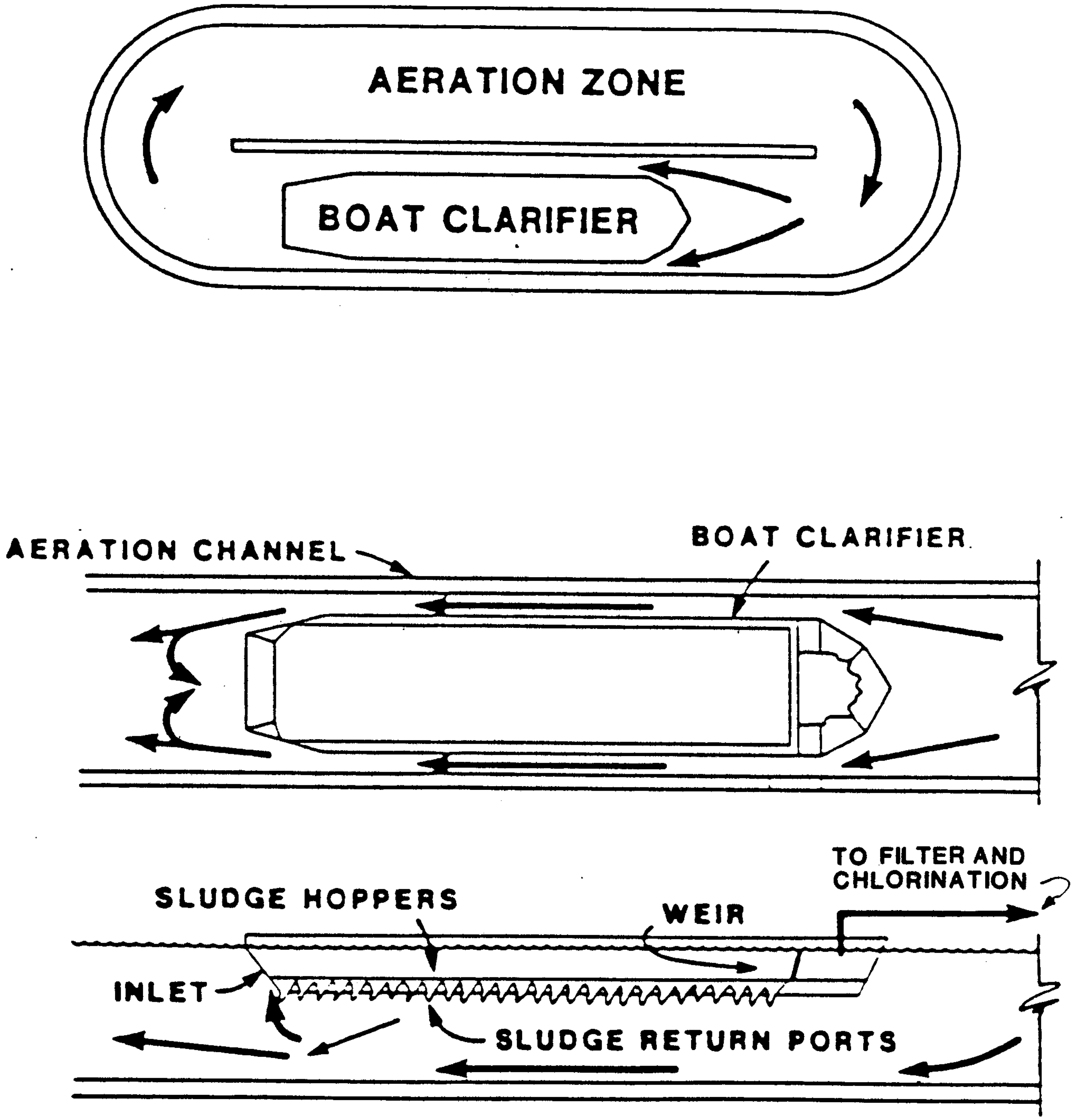

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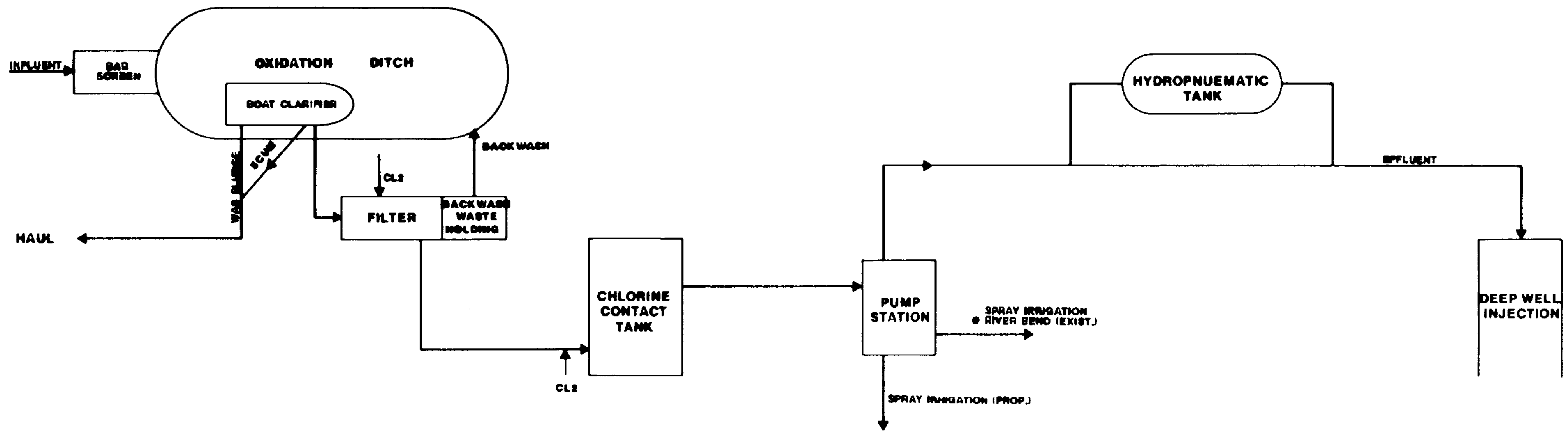
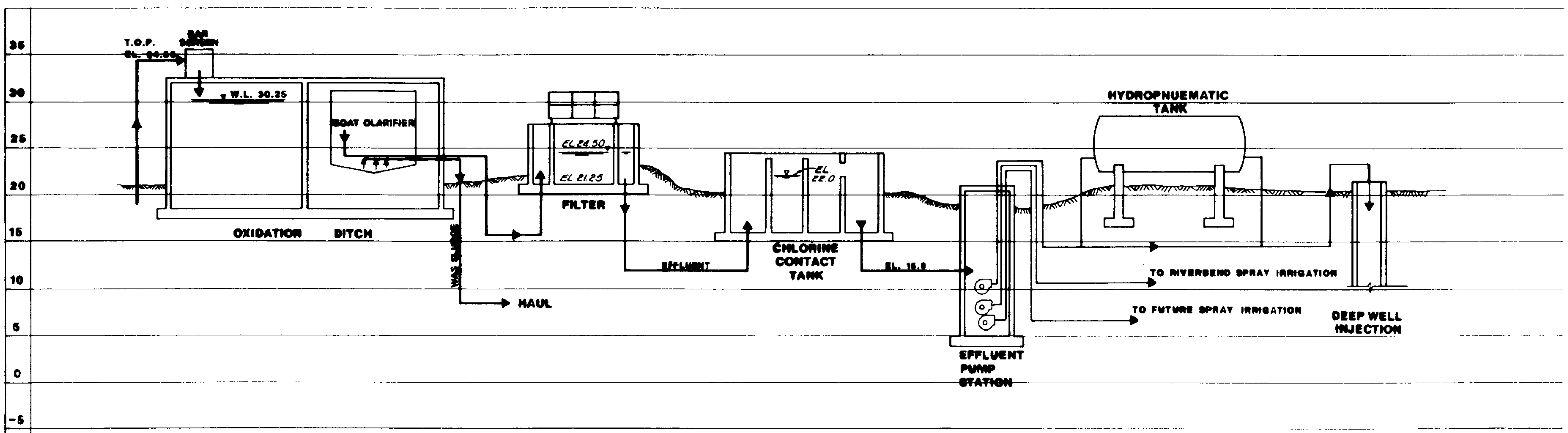
TREATMENT PLANT PROCESS TRAIN

FIGURE 3-4



PROCESS FLOW DIAGRAM



HYDRAULIC PROFILE

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PROCESS FLOW DIAGRAM
& HYDRAULIC PROFILE

FIGURE 3-5

Table 3-2

ANTICIPATED INJECTION FLUID: PHYSICAL CHARACTERISTICS[a]

Physical Parameter	Value and Parametric Unit
Acoustic Velocity	4,800 (feet/sec.)
Coefficient of Thermal Expansion	2.4×10^{-4} ($^{o}F^{-1}$)
Compressibility	3.2×10^{-6} (psi^{-1})
Conductivity	680 (μmhos/cm)
Density	62.290 ($lbs/ft.^{3}$)
Heat Capacity	0.99828 ($Btu/lbs/^{o}F$)
Resistivity	1,660 (ohms - cm)
Transit Time	210 (μsec/ft)
Viscosity, Absolute	1.00 (centipoise)

[a]All parameters are at 25 degrees Centigrade and atmospheric pressure

Source: Myers et al., 1969; Weast, 1979; Neumann and Pierson, 1966; and Hodgman, 1955.

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physical parameters and the values assessed for the injection fluid that is expected to be produced by the wastewater treatment plant. These parameters are based on a temperature of 25 degrees Centigrade and atmospheric pressure. Some of the parameters are sensitive to changes in either the temperature or the pressure, as indicated in the following discussion:

- The acoustic velocity with a 2,340-foot column of the proposed injection fluid will not vary by more than 0.5 percent and is largely insensitive to pressure and salinity changes (Myers et al., 1969; and Weast, 1979).

- The coefficient of thermal expansion is for the net volumetric expansion of a fluid and represents the standard coefficient β, in the volumetric expansion equation (Neumann and Pierson, 1966). The coefficient of thermal expansion is susceptible to temperature and salinity changes, but insensitive to changes in fluid pressure (Neumann and Pierson, 1966; and Weast, 1979).

- The compressibility of the fluid is relatively insensitive to changes in the fluid pressure and slightly less insensitive to changes in the temperature (Weast, 1979).

- The conductivity is the reciprocal of the resistivity; therefore, both parameters react in a similar, but reverse, manner to changes in temperature and pressure. Temperature has a relatively significant effect upon these two parameters, but pressure changes have a negligible effect on them (Neumann and Pierson, 1966).

- The density and heat capacity of the fluid both change with temperature and pressure, but not at a significant rate.

- The transit time is derived directly from the acoustic velocity within the fluid medium. Essentially, the transit time is the length of time it takes a sound wave to propagate through the medium for a distance of one foot. Transit time is utilized in the evaluation of the geophysical logs (Schlumberger, 1972).

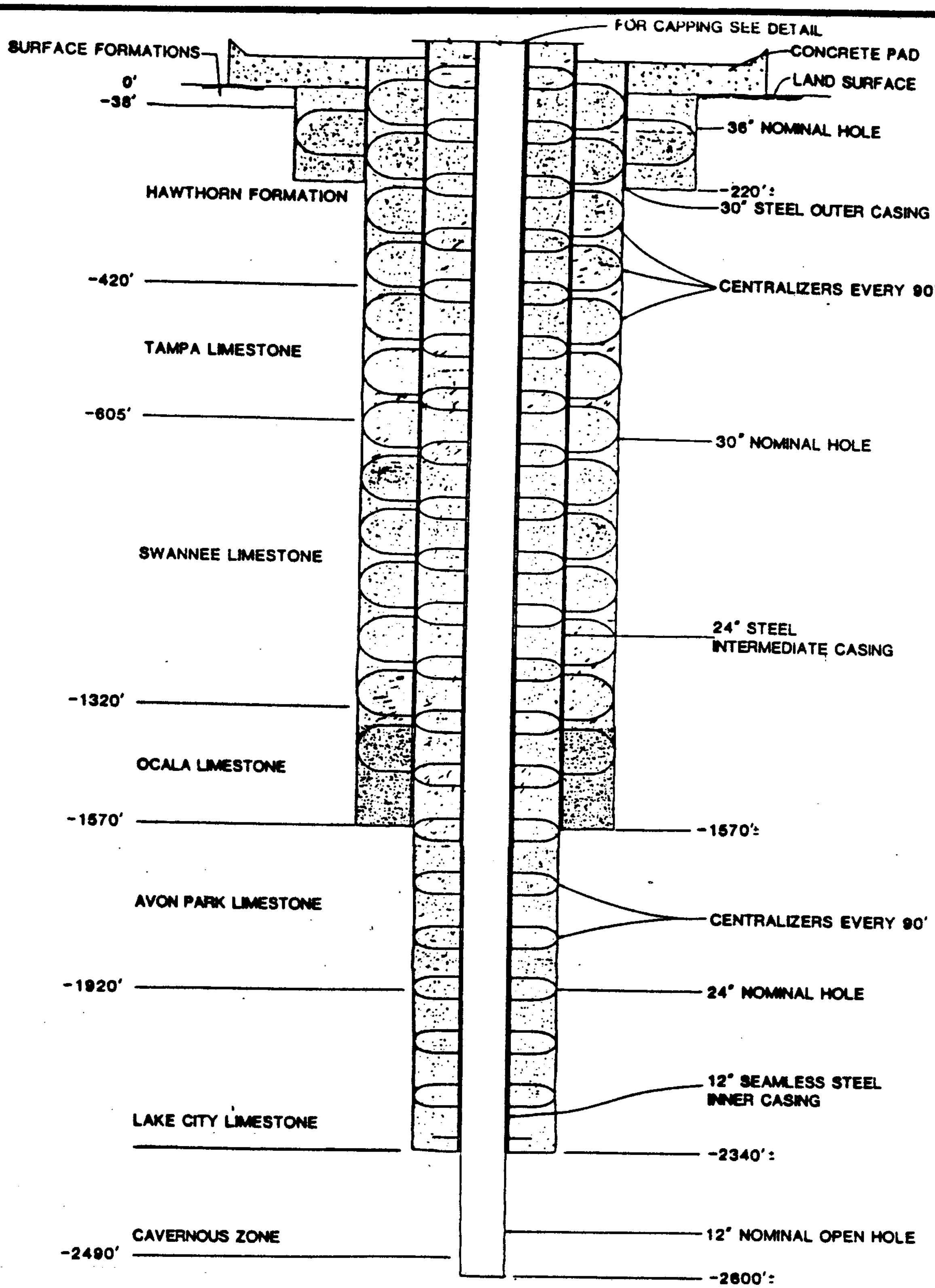
- The viscosity of the fluid is the absolute viscosity rather than the kinematic viscosity and is relatively sensitive to temperature changes, but insensitive to changes in pressure (Neumann and Pierson, 1966; and Weast, 1979).

3.4 DESIGN SPECIFICATIONS

The initial deep test/injection well design, shown in Figure 3-6, is presented here to provide a basis for comparing the initial design with the as-built well shown in Figure 4-2 (see Section 4). This initial design included three steel casings, whose setting depths were selected to protect the various zones through which the drilling had to pass to reach the injection zone. Also included in the initial design was an option for a pit or surface casing if the driller felt he needed it. This turned out to be the case and, on April 22, 1987, the drilling contractor installed a 48-inch surface casing to a depth of 10 feet below land surface.

The outer casing prevents the movement of fluids into or between the Surficial Aquifer System and the Intermediate Aquifer System. Initially, it was to be set and grouted to a depth of 200 feet, but SFWMD requested that it be placed to a depth of 220 feet to fully isolate the highly permeable Mid-Hawthorn Aquifer and fully case off the Intermediate Aquifer System (see Figure 2-9). This 30-inch-diameter outer casing is made of steel with a wall thickness of 0.375 inches. The nominal annular space between this outer casing and the surficial casing is 9 inches and the nominal overdrill in the hole is 6 inches. As set at the requested depth of 220 feet below land surface, this casing seals off the Surficial and the Intermediate Aquifer Systems not only from each other, but also from the Floridan Aquifer System.

The intermediate casing was designed to seal off the upper Floridan Aquifer System, including the Tampa Aquifer, the Suwannee Aquifer, and the Ocala Group Aquifer, and the depth of setting was specified accordingly at 1,570 feet



NOTE:
ALL GROUTING IS TO BE TYPE II CEMENT GROUT (SULFUR RESISTANT) FLORIDA CLASS H

NOT TO SCALE

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WELL DESIGN
(DEEP TEST/INJECTION WELL)

FIGURE 3-6

below land surface. When grouted, this casing was to prevent the movement of water from and to the upper parts of the Floridan Aquifer System. The 24-inch-diameter casing is made of steel, with a thickness of 0.375 inches. The nominal overdrill is 6 inches, and the annular space was to be grouted with Type II sulfate-resistant cement (Florida Class H, which is equivalent to API-Class B cement (API, 1975)), the same as all the other casings.

The intermediate casing was also designed to seal off and protect the USDWs for the area from possible contamination from the saline water of the lower Floridan Aquifer System and from the injection fluid as well. It was to be set at 1,570 feet below all USDWs.

Unforeseen difficulties were encountered during installation of the intermediate casing. After the casing had been lowered to 893 feet below land surface, the clutch that controls the draw works on the rig failed. For nearly 12 hours, while repairs were under way, the drilling mud could not be circulated around the casing. The next day, after the rig was repaired, an additional 207 feet of casing were lowered into the hole; but by then, the delays of the previous day had caused the pipe to stick to the walls of the well bore by differential pressures. This event is described in full detail in Section 4. Differential pressure sticking is caused by the breakdown of the mud circulation system (Campbell and Lehr, 1973); this mechanism is explained in a write-up reproduced from the weekly reports in Appendix 21.

The above difficulties with the intermediate casing necessitated a change in the well design in order to continue to protect the USDWs. The solution was to cement the intermediate casing where it stood at 1,100 feet and to install a fourth steel casing which would fit between the intermediate casing and the inner casing to offer the needed protection for the USDW. This protective casing was installed to a depth of 1,582 feet below land surface, some 12 feet lower than the originally designed setting depth for the intermediate casing. The protective casing has a wall thickness of 0.375 inches and the nominal annular space between it and the intermediate casing is 2 inches, while in the open hole, the nominal overdrill is 10 inches.

The inner casing was designed to seal off the saline waters in the lower part of the Floridan Aquifer System and keep them from mixing with USDWs and with waters from the injection zone. This 12-inch diameter casing is also made of steel, but with a wall thickness of 0.5 inches. The nominal overdrill is 12 inches and the annular space between it and the protective casing is a nominal 4 inches. The depth of setting is 2,340 feet below land surface.

The inner casing setting was dependent upon the results of the new data from the pilot hole drilling and the geophysical logs. The final depth of this setting was decided jointly by PBS&J and the TAC at a meeting held in Fort Myers specifically for that purpose; but the new data confirmed the decision that had been made the previous year based on the data from the exploratory well. Consequently, the initial design depth of 2,340 feet was selected for the actual depth of the inner casing.

The inner casing, also known as the injection casing, is the casing through which the injection fluid is pumped down to the injection zone. This zone lies below the bottom of the injection casing, beginning at a depth of 2,350 feet below land surface and continuing to the full depth of the open hole at 2,606 feet. From 2,524 to 2,606 feet, however, the injection zone offers lower permeability and, therefore, the greater volume of the injected wastewater is expected to enter the injection zone between the depths of 2,350 and 2,524 feet below land surface.

The design discussed above protects the USDWs (see Section 2.5) as follows: the well construction prevents the migration of formation water from one aquifer to another; the casings are designed to last throughout the expected life of the well; and the Florida Class H (Type II) cement, used in every phase of grouting, is sulfate-resistant. The design provides for a safe and sound structure that will be able to safely transmit the treated effluent from the land surface to the top of the injection zone. The tests required to confirm the integrity of the well and the well casings are discussed in Section 4.

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Section 4
DRILLING PROGRAM AND CASING PLACEMENT: DEEP TEST/INJECTION WELL

The drilling program for the deep test/injection well at the NFMU site is described in this section. This description is based on PBS&J's daily observation reports, which are too voluminous for inclusion in this document. PBS&J's weekly observation reports, which were condensed from the daily reports, are, however, contained in Appendix 20. Copies of the daily reports are available on request to PBS&J. All the TAC member agencies have file copies available as well.

Construction events are listed in chronological order in Table 4-1, which forms the basis for the following description of the deep test/injection well construction. Figure 4-1 shows the layout of the drill site; Figure 4-2 shows the well as built.

The drilling contract for the deep test/injection well was awarded to Drillers Incorporated of Houston, Texas, doing business in Florida as Drillers Incorporated of Florida. The contractor was issued the Notice to Proceed on March 23, 1987.

The following companies were used on the project as subcontractors to the driller:

- Schlumberger for geophysical logging and radioactive tracer tests
- Southern Resource Exploration for geophysical logging and downhole pressure transducers
- Woodward-Clyde for geophysical logging
- Dowell Schlumberger for grouting the casings
- Deep Venture for television surveys.

Reputable and well known in their fields of expertise, these subcontractors were accepted by PBS&J on behalf of NFMU.

Table 4-1

DRILLING PROGRAM CHRONOLOGY: DEEP TEST/INJECTION WELL

Date	Event
March 23, 1987	Issued the notice to proceed to Drillers, Inc.
March 24, 1987	Began mobilization and preparation of drilling site
March 24-April 22, 1987	Soil compaction and filling. Preparation of forms and steel reinforcement for the pad.
April 15, 1987	Installed 48-inch-diameter pit casing to 10 feet below land surface.
April 22, 1987	Poured concrete drilling pad and finished mud pit construction.
April 29, 1987	Set up the drilling rig on the pad.
May 8, 1987	Began drilling the 12-1/4-inch pilot hole. Reached 241 feet below land surface.
May 9, 1987	Performed geophysical logging on pilot hole (Appendix 1). Reamed a 19-inch hole to 230 feet.
May 10-11, 1987	Reamed 36-inch hole to 225 feet.
May 11, 1987	Performed geophysical logging on reamed hole (Appendix 2). Installed 30-inch outer casing to a depth of 220 feet. Pressure-grouted casing. Began drilling the four shallow monitor wells.
May 12, 1987	Completed pressure test on outer casing. Installed emergency flow control device.
May 13, 1987	Began drilling 12-1/4-inch pilot hole. Completed installing fourth and final shallow monitor well.
May 15, 1987	Began weekly sampling of both zones of the deep monitor well. Collected first set of samples from the four shallow monitor wells.
May 20, 1987	Collected Core 1 from Ocala (1,333 to 1,343 feet) and water samples to go with it. Recovered 55 percent (1,337.5 to 1,343 feet).
May 22, 1987	Collected Core 2 from Ocala (1,435 to 1,447.5 feet) and water samples to go with it. Recovered 100 percent.

Table 4-1 (Continued)

Date	Event
May 25, 1987	Collected Core 3 from Avon Park (1,605 to 1,616 feet) and water samples to go with it. Recovered 100 percent.
May 27, 1987	Completed 12-1/4-inch pilot hole to 1,660 feet. Performed geophysical logging on pilot hole (Appendix 3).
June 5, 1987	Collected first straddle packer water sample at 1,560 to 1,570 feet.
June 7, 1987	Collected second straddle packer water sample at 1,479 to 1,489 feet.
June 8-12, 1987	Reamed nominal 20-inch hole for the intermediate casing to 1,590 feet.
June 13-22, 1987	Reamed nominal 30-inch hole for the intermediate casing to 1,590 feet.
June 24, 1987	Performed geophysical logging on reamed hole (Appendix 4).
June 24, 1987	Tripped back in hole to re-ream the 30-inch hole to reduce drag.
June 25, 1987	Began running in the 24-inch intermediate casing.
June 27, 1987	The intermediate casing got stuck at 1,100 feet. Could not be moved up or down.
June 27-August 3, 1987	Attempts to move the casing fail. Meetings held during this period with TAC and with DER to request change in well design (see Section 3-4). Monitoring continued on site.
August 3, 1987	DER approved design changes and issues modified permit for those changes.
August 5, 1987	Cemented the 24-inch intermediate casing at a depth of 1,100 feet below land surface datum.
August 6, 1987	Completed pressure test on the intermediate casing. Performed geophysical logging on the intermediate casing (Appendix 5).
August 6-15, 1987	Reamed by using a 30-inch under-reamer for the installation of the 20-inch protective casing.

Table 4-1 (Continued)

Date	Event
August 12, 1987	Performed geophysical logging on the reamed hole (Appendix 6).
August 15, 1987	Spot checked reamed hole with caliper log while circulating during waiting for the delivery of the 20-inch casing to the site.
August 21-22, 1987	Installed the 20-inch casing (used expandable centralizers below 1,100 feet).
August 23, 1987	Cemented the 20-inch protective casing to a depth of 1,582 feet below land surface.
August 24, 1987	Completed pressure test on the protective casing. Performed geophysical logging on the protective casing (Appendix 7).
August 31, 1987	Began drilling 12-1/4-inch pilot hole. Switched to reverse air circulation drilling method. Began collection of water samples at 30-foot intervals.
September 3-4, 1987	Collected Core 4 from Avon Park (1,875 to 1,885 feet). Recovered 65 percent.
September 7-8, 1987	Collected Core 5 from Lake City (2,160 to 2,163 feet). Recovered 100 percent. Lost slips down the hole.
September 11, 1987	Removed slips from hole using a magnet (succeeded on fourth attempt). Cored from 2,163 to 2,167 feet. Recovered two feet or a 55 percent recovery overall from Core 5. Collected water sample to go with core.
September 15-16, 1987	Collected Core 6 from Lake City (2,260 to 2,270 feet). Recovered 95 percent. Collected water sample to go with core.
September 19, 1987	Collected Core 7 from Lake City (2,320 to 2,330 feet). Recovered 96 percent. Collected water sample to go with core.
September 21, 1987	Reached full depth of pilot hole (2,354 feet).
September 22, 1987	Performed geophysical logging on the pilot hole (Appendix 8).
September 27, 1987	Performed television survey.

Table 4-1 (Continued)

Date	Event
September 26-28, 1987	Collected straddle packer water samples as follows: No. 3 from 1,950 feet (Straddle 1,947 - 1,954) No. 4 from 2,110 feet (Straddle 2,107 - 2,114) No. 5 from 2,250 feet (Straddle 2,248 - 2,255) No. 6 from 2,275 feet (Straddle 2,272 - 2,279) No. 7 from 2,340 feet (Straddle 2,337 - 2,244) Samples were collected at the bottom first (No. 7).
September 28, 1987	Began reaming the pilot hole with a 17-1/2-inch bit.
October 6, 1987	TAC meeting was held and depth of casing setting was selected at 2,340 feet.
October 7, 1987	Began under-reaming the pilot hole with a 24-inch bit.
October 16, 1987	Cores 1-7 were shipped to the laboratory together with the water samples from the cored zones. Selected samples from Core 1: 1,341 feet; Core 2: 1,443 feet; Core 3: 1,608 feet; Core 4: 1,880 feet; Core 5: 2,163 feet; Core 6: 2,261 feet; and Core 7: 2,362 feet.
October 21, 1987	Jim Winters replaced Randy Cape as driller.
November 8, 1987	Reamed hole to 2,354 feet below land surface. Re-reamed and dredged section between Nov. 8 and Nov. 11, 1987.
November 11-12, 1987	Reran temperature log of Sept. 22, 1987. Performed geophysical logging of the reamed hole (Appendix 9).
November 12-14, 1987	Installed the 12-inch inner (injection) casing (used expandable centralizers for the lower eight centralizers)
November 15-18, 1987	Cemented the 12-inch inner casing to a depth of 2,340 feet below land surface.
November 19, 1987	Completed pressure test on inner casing. Performed geophysical logging on the inner casing (Appendix 10).

Table 4-1 (Continued)

Date	Event
November 21, 1987	Began drilling of the open hole in the injection zone.
November 25-26, 1987	Collected Core 8 from the Lake City Limestone representative the injection zone (2,450 to 2,463 feet). Recovered 65 percent. Water sample would not be collected until the well was developed.
November 30, 1987	Open hole reached full depth at 2,600 feet below land surface. Well was initially developed and readied for logging.
December 1, 1987	Performed geophysical logging on the open hole (Appendix 11).
December 1-2, 1987	Developed the well.
December 2, 1987	Held open house for the press and public on site.
December 2-3, 1987	Performed television survey.
December 3, 1987	Collected point samples using downhole logger at 2,350, 2,450, and 2,550 feet below land surface. Performed geophysical logging on the injection zone (Appendix 12).
December 4, 1987	Completed radioactive tracer test of the well using Iodine 131 as a tracer. Logs were run (Appendix 13).
December 7, 1987	Core 8 shipped with its water sample to the laboratory. Selected sample from 2,453 feet.
December 7-12, 1987	Prepared for the injection test. Inserted pressure transducer to the bottom of the well; installed flowmeter and test gages; installed rain gage; and began background data collection. Completed capping of well.
December 12-13, 1987	Started and discontinued 2-mgd test after pump failed.
December 15-16, 1987	Completed the 24-hour 2-mgd injection test.
December 17-18, 1987	Completed the 24-hour 4-mgd injection test.
December 18, 1987	Performed geophysical logging of the injection well (Appendix 14).

Table 4-1 (Continued)

Date	Event
December 22, 1987	Completed radioactive tracer test of the deep monitor well using Iodine 131 as a tracer. Ran logs (Appendix 15).
December 23, 1987	Drillers began demobilization from site.
December 24, 1987	Painted well head. Moved office trailer from site.

Source: PBS&J daily and weekly reports
Drillers, Inc. billing reports

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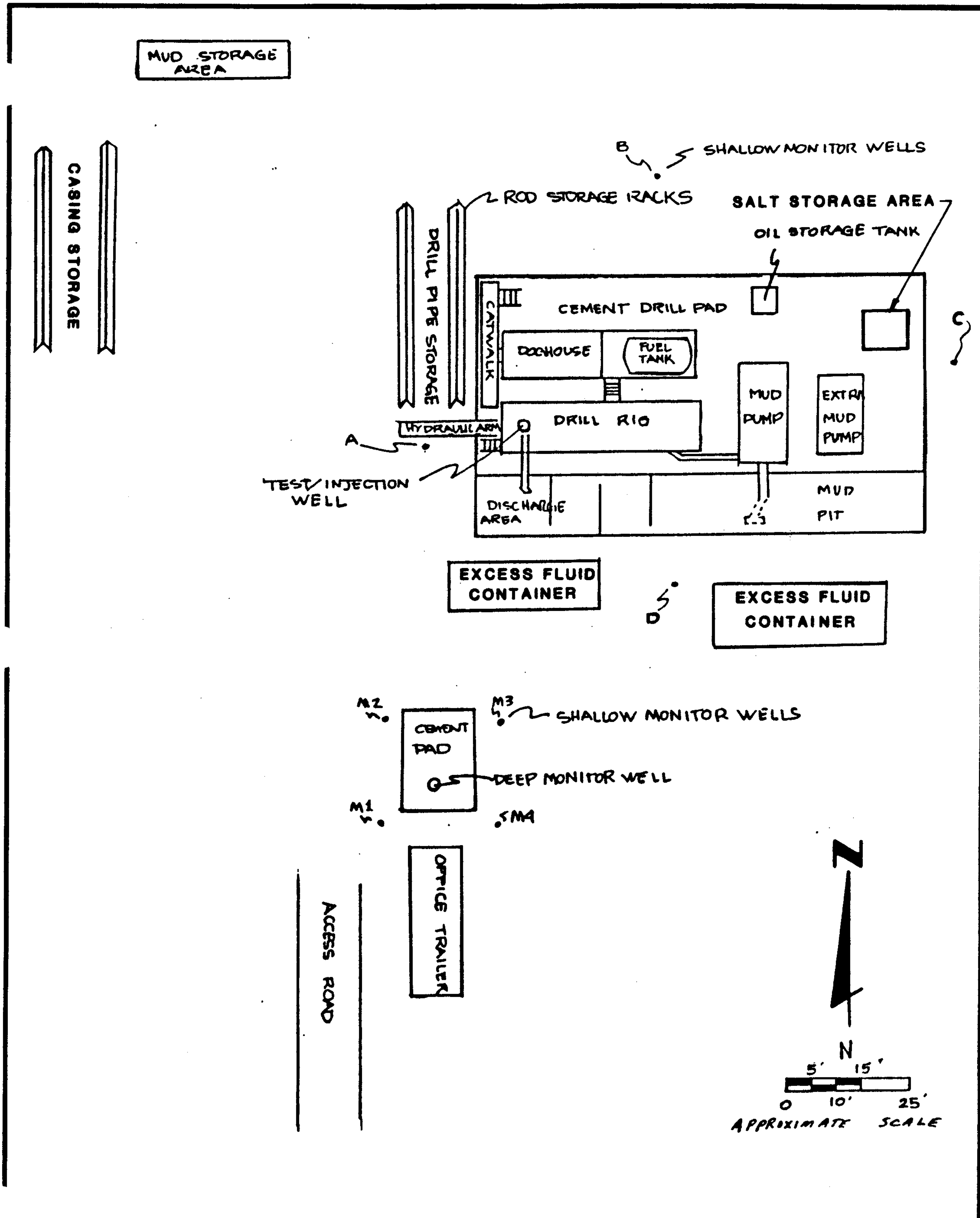

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MAP OF DRILL SITE LAYOUT

FIGURE 4-1

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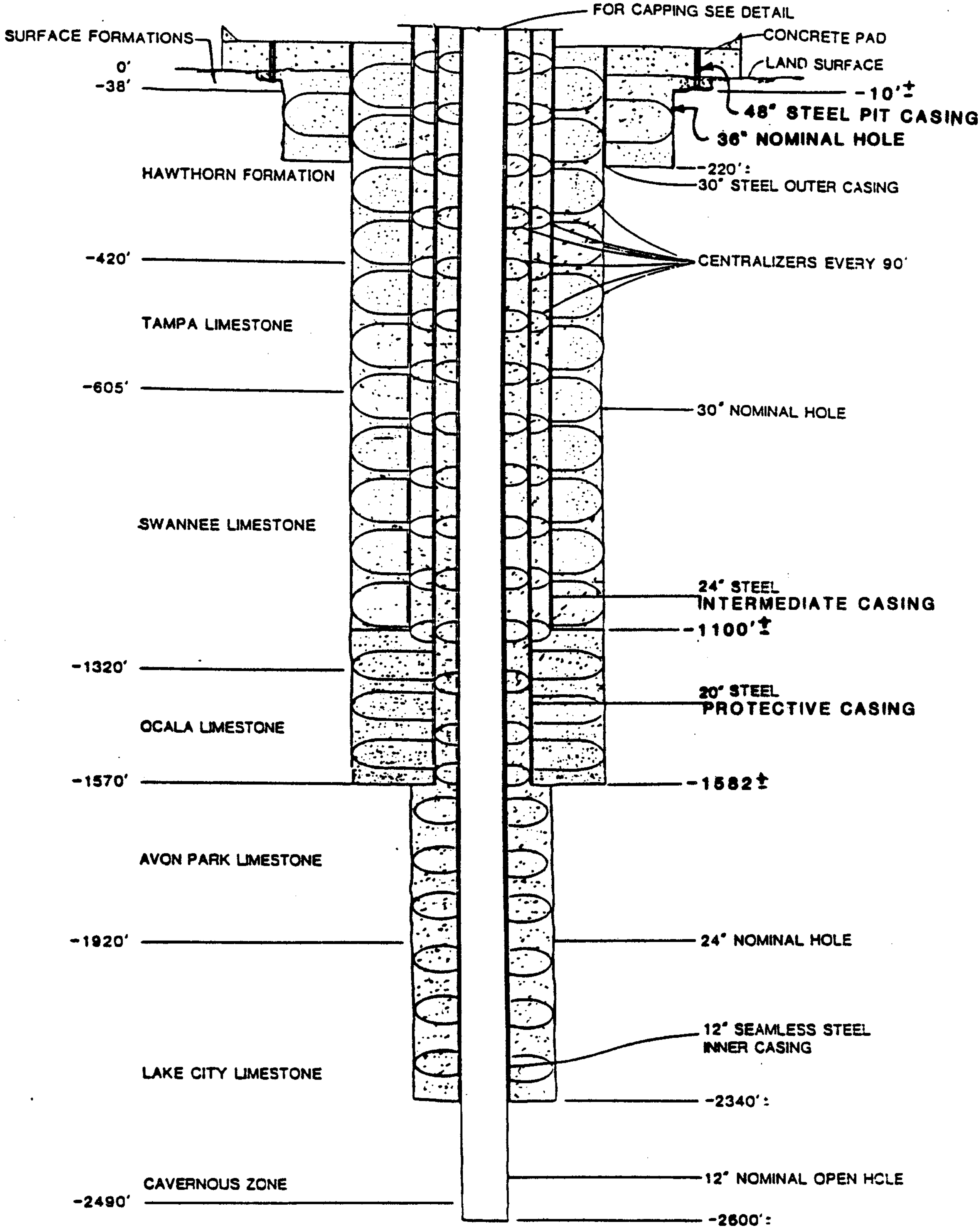
REPRO PRODUCTS INC. 7A



NOTE:
ALL GROUTING IS TO BE TYPE II CEMENT GROUT (SULFUR RESISTANT) FLORIDA CLASS H

NOT TO SCALE

PBS&J POST, BUCKLEY, SCHUH & JERNIGAN, INC.

DEEP TEST/INJECTION WELL (AS BUILT)

FIGURE 4-2

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REPRO PRODUCTS INC. 7A

4.1 DRILLING PAD

Before the drilling pad was constructed at the well site, a 48-inch-diameter pit casing was installed to a depth of 10 feet. This surface casing was installed only to prevent ravelling of the soil around the drilled hole prior to installation of the outer casing. This casing is a construction feature optional with the driller and is not part of the well design.

The drilling pad was formed and reinforcement steel was installed before the concrete was poured around the 48-inch casing (see Figure 4-1). Four shallow monitor wells were then installed around the drilling pad. The concrete drilling pad was allowed to cure before the drill rig was located on the pad on April 29, 1987.

The pad measures 90 by 40 feet and is 8 inches thick, with a 4-inch curb on three sides. On the fourth side was a built-in concrete recirculation system or mud pit to capture any fluids flowing from the pad. The mud pit measured 90 feet by 12 feet and was 4 feet deep. It was baffled at three sections to help settle the cuttings suspended in the return flow from the well. This mud pit has now been filled with clean sand and cemented over.

4.2 OUTER CASING

The drilling rig, a Walker-Neer "Apache" equipped with a top head drive, was set on the drilling pad on April 29, 1987 and drilling of the pilot hole began on May 8, 1987. The pilot hole was drilled with a 12-1/4-inch tricone bit using bentonite as the drilling mud. That same day the pilot hole reached a depth of 241 feet below land surface.

During the drilling, the drillers conducted a series of deviation surveys. Three deviation checks were carried out within the pilot hole for the outer casing: the first was made at 86 feet below land surface, where a deviation of 25 minutes was recorded; the last was made at 241 feet below land surface, where a deviation of 30 minutes was recorded. All readings were within the regulatory deviation limit of one degree. Appendix 17 shows the disks of the deviation surveys or sure-shots taken during drilling. Table 4-2 lists the results of the deviation surveys.

The geophysical logger, Woodward-Clyde from Tallahassee, Florida, arrived on site on May 9, 1987 and ran the following geophysical logs on the pilot hole: acoustic, caliper, deviation, natural gamma, long and short normal, and spontaneous potential. Copies of these logs, which are discussed in Section 7, are contained in Appendix 1.

The pilot hole was then reamed out. Two reaming passes were made: one with a 19-inch reamer, and the other with a 36-inch reamer. On May 11, reaming with the 36-inch reamer reached 235 feet below land surface and the geophysical logger came back to the site to run a caliper log and a directional log on the reamed hole. Copies of these logs are in Appendix 2. Deviation (sure-shot surveys) results, included in Appendix 17, showed a maximum deviation of 45 minutes at the bottom of the hole.

The 30-inch outer casing was set and centered in the reamed hole at a depth of 220 feet. (The outer casing specifications have been discussed in Section 3.4, and the mill certificate for this casing is presented in Appendix 18.) Dowell proposed to pressure-grout the casing in a single stage by cementing through the casing and filling up the annular space from the bottom up. Cement calculations were made using the caliper log of the reamed hole as the basis for the hole size.

The cement calculations indicated that a total of 475 cubic feet of cement would be required (see Appendix 16); but, in fact, only 465 cubic feet had to be pumped before good returns showed up at the surface. The cement mixture included 2 percent of calcium-chloride ($CaCl_2$) as a cement-hardening accelerator.

Table 4-3 presents a chronology of the grouting operations as well as a summary of the cement volumes and additives used in construction of the test/injection well. Florida Class H (ASTM Type II - sulfate-resistant) cement was used. The following additives were employed when needed:

Table 4-2

SURE-SHOT DEVIATION READINGS

Drilling Operation	Depths (feet)	Inclination (minutes)
Outer Casing		
Pilot Hole	86	25
	179	40
	241	30
Reamed Hole	90	30
	185	45
Intermediate Casing		
Pilot Hole	274	30
	367	10
	460	30
	554	30
	649	35
	741	20
	835	30
	926	5
	1,020	30
	1,111	50
	1,203	35
	1,297	30
	1,391	30
	1,484	15
	1,574	30
Reamed Hole	340	55
	432	30
	525	30
	614	30
	713	30
	806	30
	898	30
	993	40
	1,084	40
Protective Casing	1,174	30
Reamed Hole	1,175	15
	1,269	50
	1,363	25
	1,458	35
	1,548	30
Inner Casing	1,737	30
Pilot Hole	1,832	30
	1,895	60
	1,955	15

Table 4-2 (Continued)

Drilling Operation	Depths (feet)	Inclination (minutes)
	2,019	20
	2,134	10
	2,169	15
	2,232	30
	2,293	30
	2,354	30
Reamed Hole	1,640	30
	1,700	30
	1,760	30
	1,826	20
	1,880	15
	1,940	20
	2,000	30
	2,070	30
	2,130	30
	2,203	30
	2,263	30
Open Hole	2,324	15
	2,386	15
	2,447	25
	2,509	30
	2,600	30

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Table 4-3

SCHEDULE OF GROUT EMPLACEMENT: DEEP TEST/INJECTION WELL

Date	Casing (diameter and type)	No. of Barrels	Volume (FT^3)	Lift No.	Additives (See Notes)
May 11, 1987	Outer Casing (30-inch steel pipe) (0.375-inch walls)	83		1	2% Calcium chloride
		83	465		
August 5, 1987	Intermediate casing (24-inch steel pipe) (0.375-inch walls)	241		1	4% Gel and 100 pounds of Celloflakes
		41		1	2% Calcium chloride
		282	1,595		
August 23, 1987	Protective Casing (20-inch steel pipe) (0.375-inch walls)	50		1	4% Gel and 10 pounds of Celloflakes
		155		1	Neat
		160		1	Neat
		-21		1	4% Gel and 2 pounds of Celloflakes (recirculated out)
November 18, 1987		20		1	Neat
		364	2,036		
November 15-18, 1987	Inner Casing (Injection Casing) (12-inch steel pipe) (0.500-inch walls)	39		1	4% Gel; 12-1/2 lbs. Kolite per sack
		254		1	4% Gel

Table 4-3 (Continued)

Date	Casing (diameter and type)	No. of Barrels	Volume (FT^3)	Lift No.	Additives (See Notes)
November 15-18, 1987 (continued)		98		1	Neat
		50		2	4% Gel
		45		2	4% Gel
		39		3	4% Gel
		66		3	12 pounds of kolite per sack and 100 pounds of Celloflakes
		41		3	4% Gel
		42		4	4% Gel; 100 pounds of Celloflakes
		94		5	4% Gel
		30		6	Neat
		70		7	Neat
		90		7	Neat
		76		8	Neat
		70		8	Neat
		1,113	6,232		

Kolite is Dowell's proprietary name for crushed coal graded to 0.04- and 0.08-inch-diameter particles. Gel is always western bentonite. Celloflakes are Dowell's trade name for cellophane flakes. Cement is always Type II Sulfate-Resistant (Florida Class H).

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- Cellophane flakes
- Kolite
- Bentonite
- Calcium chloride.

Cellophane flakes usually range in size from three-eighths to one-half inch. These flakes are primarily used for bridging cavities and fractures within the rock formations. In addition, the flakes increase the volume of the cement grout and create a light weight slurry. Cellophane flakes also reduce the flow capabilities of the cement grout, thereby reducing circulation loss.

Kolite is Dowell's proprietary name for a graded and sized crushed-coal product, with a particle-size diameter of 0.04 to 0.08 inch. It is similar to asphaltite, is water-insoluble, does not affect setting time, and is impervious to corrosion or degradation by chemical action. Kolite is used for controlling lost circulation by reducing slurry weight and increasing fill-up.

Bentonite clay also increases the viscosity of the grout, and decreases its density. In general, adding bentonite retards the setting time of the mixture and decreases the compressive strength of the grout.

Calcium chloride is used in the cement mixture to accelerate cement hardening and further reduce cement loss to the formation. It gives the cement a high early strength.

On May 12, a pressure test was conducted on the casing. The test lasted for one hour and the casing held a pressure of 125 psi during that time with no drops in pressure whatsoever. The cement grout was allowed to sit undisturbed until May 13, 1987, giving it nearly 30 hours to harden before drilling operations resumed.

4.3 INTERMEDIATE CASING

Drilling for the intermediate casing began on May 13, 1987 when the 12-1/4-inch pilot hole bit broke through the cement plug at the bottom of the outer casing. Mud rotary methods were used and drilling was interrupted on only three occasions (see Table 4-1); these interruptions were to allow the driller to collect two core samples from the Ocala and one from the Avon Park. At 90-foot intervals, however, drilling stopped to run the sure-shot deviation surveys required by the specifications (see Appendix 17 and Table 4-2).

A total of 15 sure-shots were taken in the 1,440-foot interval between 220 and 1,660 feet below land surface. Of these, the one showing the greatest deviation (50 minutes) was made at 1,111 feet. All others were less than 35 minutes from true vertical.

On May 27, the pilot hole reached a depth of 1,660 feet below land surface and the geophysical logger was called to the site. Copies of the logs run at this time are contained in Appendix 3; the logs are evaluated in Section 7. Copies of the results of the analyses performed on the cores are presented in Appendix 19 and are discussed in Section 7.

After the geophysical logging was completed, the drillers installed inflatable packers for the collection of water samples. Two water samples were collected, one from the Crystal River Formation and the other from the Williston Formation. The results of the analyses performed on these two samples are discussed in Section 7.

Reaming of the pilot hole was a two-stage process. The first stage used a 20-inch reamer; in the second stage, the hole was increased by using a 30-inch reamer. Throughout this reaming operation, sure-shot readings were made to insure a straight hole (see Table 4-2). Fifteen sure-shots were taken; these ranged from 15 to 55 minutes from vertical, with the largest deviation showing at the very top of the reamed hole (340-foot depth).

Reaming was completed on June 22, 1987 and the geophysical logger arrived on site on June 24 to run a caliper log and a directional log on the reamed hole (see Appendix 4). Also on this occasion, a cement bond log was run on the outer casing; however, due to the large diameter of that casing, the results were inaccurate.

Installation of the intermediate casing began uneventfully on June 25, 1987; but on June 26, with the casing sitting at 893 feet below land surface, the draw-works of the rig failed (see Section 3.4). This failure precipitated problems which, after lengthy review and consideration in several meetings with DER and the TAC, culminated in setting the intermediate casing at a depth of 1,100 feet instead of the planned 1,570 feet. In addition, as part of the decisions reached with the DER and the TAC, it was agreed to set another casing, a protective one, to the full 1,570-foot depth.

Cementing of the intermediate casing to 1,100 feet was accomplished on August 5, 1987 in one lift by pressure-grouting through the center of the casing. A total of 1,595 cubic feet of sulfate-resistant cement was used, a volume close to that estimated from the caliper log by the drillers (1,587 cubic feet). The composition of the cement mixture is identified in Table 4-3, and a more complete description of the cement properties, as contained in a letter dated July 14, 1987 from the cement company to the driller, is included in Appendix 16. Mill certificates for the 24-inch casing are presented in Appendix 18.

On August 6, 1987, the one-hour pressure test on the intermediate casing was successfully completed, with a continuous pressure of 138 psi held for that period. Right after that, the geophysical logger arrived on site to run the cement evaluation logs. These logs are discussed below.

4.3.1 Grouting Log Results (Intermediate Casing)

Schlumberger conducted geophysical logs on the intermediate casing, running a temperature log and a cement bond log on August 6, 1987, approximately 26 and 28 hours, respectively, after the completion of the grouting on August 5. Copies of both of these geophysical logs are included in Appendix 5.

In conjunction with the cement bond log, Schlumberger also ran a travel time log, which records the travel time of the signal between the transmitter and signal detector, a variable density log, and a gamma ray log. The gamma ray log is discussed in Section 7.

4.3.2 Cement Bond Log

The cement bond log, used to assess the quality of the bond between the intermediate casing and the cement grout around the casing, is a function of casing size and thickness, cement strength and thickness, degree of cement bonding, and tool centering. The travel time of the return signal on the travel time log should be a constant for a perfectly centered logging tool.

The calculation of the constant travel time includes the sonic travel times for both the casing material and the drilling mud. The 24-inch intermediate casing is made of steel, which has a sonic travel time of 61 microseconds per foot (Hodgman, 1955), while the drilling mud within the intermediate casing has a sonic travel time of 189 microseconds per foot (Schlumberger, 1972). These sonic travel times equate to a constant travel time of 560 microseconds for the intermediate casing.

The travel time log showed that the recorded travel time ranged from 545 to 575 microseconds, except for the portions of the log at the top and bottom of the hole, where extraneous influences affected the readings. These deviations or changes of the travel time recorded on the log are indicative of logging tool fluctuations about the centerline of the cased hole. The maximum fluctuation from the centerline was recorded at a depth of 1,016 feet where the logging tool was only 0.62 inches off center, which is usually regarded as very good. In other words, the logging tool maintained a fairly good position on the hole centerline as it recorded both the cement bond and the variable density logs. This tool did have a centering guide to help maintain its center location within the intermediate casing.

The range of the readings recorded on the cement bond log for the intermediate casing, as shown in Appendix 5, was 5 to 20 millivolts. The fluctuations recorded on the log reflect the deviations of the tool from the centerline of the hole. With an average cement bond log value of approximately 10 millivolts, the average compressive strength of the cement grout after 24 hours was calculated at about 250 psi. Usually the 24-hour compressive strength of cement represents about 10 to 15 percent of the 28-day compressive strength. Therefore, the final compressive strength of the grout around the intermediate casing is expected to be about 2,500 psi.

4.3.3 Variable Density Log

The variable density log shows the sonic wave trains recorded at a receiver located on the logging tool 5 feet from the transmitter and, when associated with the cement bond log, can be used to confirm the quality of the cementing. Sound can travel from the transmitter to the receiver along several different paths (Schlumberger, 1972):

- Through the mud within the casing
- Along the casing
- Along the cement behind the casing
- Through the formations beyond the cement grout.

The first signal travel path in the variable density log (see Appendix 5) exhibited a travel time of about 950 microseconds (i.e., 5 times 189 microseconds); however, this return signal from the mud within the casing is not important in the cement evaluation and is not discussed further.

The second signal travel path, along the casing, is a strong indicator of the quality of the cement bond to the casing and is the primary determinant as to whether a good bond exists between the casing and the cement grout. The travel time of this path includes the time for a sonic wave train to travel from the transmitter to the casing, through the mud, along the intermediate casing, and back through the mud to the receiver. The total travel time for the second path is 683 microseconds for a 24-inch casing.

The travel time response recorded first on the VDL is usually from the signal travel path along the steel casing. The first travel time response recorded on the August 6 variable density log was about 685 microseconds, and the return signal was clearly shown in the log (see Appendix 5). Due to the large diameter of the casing, however, the energy loss usually associated with a well-cemented casing was not clearly evident.

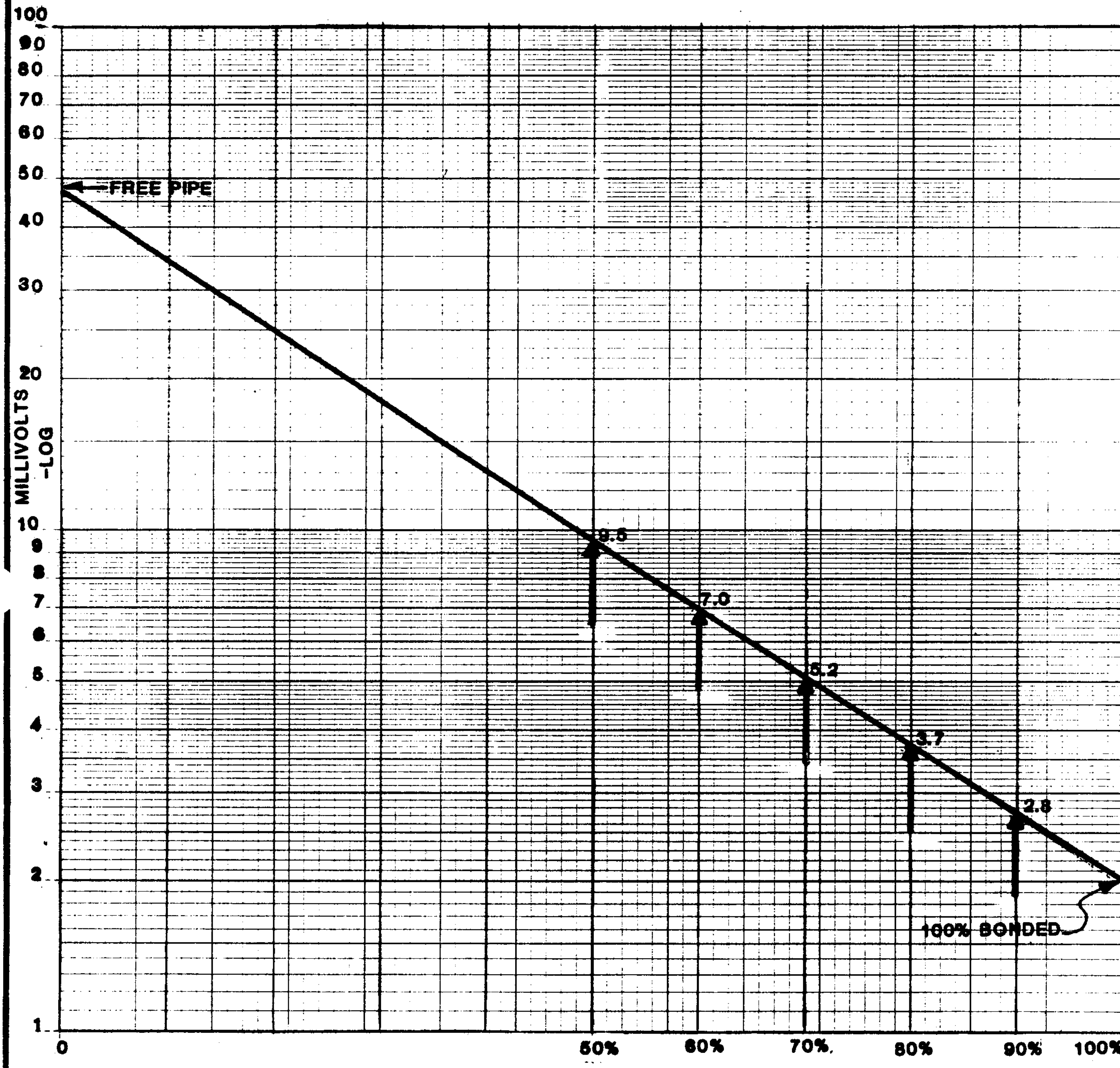
The return signal on the variable density log for the casing, at about 685 microseconds, was somewhat stronger than would be seen in a smaller diameter casing. In a well-cemented casing, most of the sound energy or sonic wave trains will be transferred to the cement or formations (Schlumberger, 1972). Because of the large hole size and diameter of the intermediate casing, the formation return signal (i.e., the stronger Rayliegh shear waves) does not appear to be suitable for conventional bond index evaluation although qualitatively it is clear that a good cement bond exists. An interpretive report prepared by Schlumberger Well Services (see Appendix 22), indicated that there was no free pipe anywhere in the hole. This report also showed that, despite doubts about the suitability of using a bond index evaluation for casings larger than 10 or 12 inches, the cement bond averages still exceeded 50 percent and, in 35 percent of the total depth of the well, exceeded 70 percent (see Figure 4-3).

The return signal from the cement grout, traveling via the third path, was 828 microseconds (i.e., using a travel time of 90 microseconds per foot for cement grout with 4 percent bentonite). The return signal on the variable density log clearly showed signal attenuation from the cement grout and the intermediate casing as well as varying sound or signal travel paths resulting from combinations of the four signal travel paths.

In summary, the intermediate casing has a good bond with the cement grout, and the cement grout has an excellent bond with the formations, as evidenced by the attenuated return from the signal travel path through the cement grout.

4.3.4 Temperature Log

The temperature log for the intermediate casing was taken about 24 hours after the cementing of the annular space around the casing (see Appendix 5). The heat of hydration emanating from the cement grout had already reached its peak (usually at 12 hours) and was beginning to cool; but even then, the cement still showed well in the temperature log. Good evidence of cement in the process of hydrating was found between 20 and 420 feet, between 452 and 760 feet, between 800 and 820 feet, and between 900 and 1,020 feet. In those



SOURCE: SCHLUMBERGER, 1987

ESTIMATED BOND INDEX 20– INCH CASINGS OR LARGER

PBSJ POST, BUCKLEY, SCHUH & JERNIGAN, INC.

BOND INDEX

FIGURE 4–3

intervals, this log showed temperatures well above the background temperature. The other intervals (760 to 800 feet, 820 to 900 feet, and 1,020 to 1,070 feet) exhibited cooler temperatures; but these temperatures do not indicate the absence of cement. The first two of these cooler intervals are areas of high permeability and high circulation, where the flow of cooler groundwater dissipates heat rapidly. The last of the cooler intervals is at the bottom of the cased portion; but the open hole below is filled with cooler waters that also help dissipate heat.

4.4 PROTECTIVE CASING

The permit modifications allowing for the installation of the protective casing were received on August 3. Thus, immediately after the 24-inch intermediate casing had been installed and tested, the reaming for the 20-inch protective casing began.

A 30-inch under-reamer was used in a mud circulation system. The under-reamer had a 20-inch nominal configuration and fit easily through the 24-inch-diameter casing. Hydraulic pressure and the weight of the drill collars and the drill pipe would force it to open to its full 30-inch size once the bit entered the open hole below the 24-inch casing.

Reaming began August 6 and continued for 9 days. At 90-foot intervals, deviation surveys were conducted (see Table 4-2); although it would have been very unlikely that, with the extreme weight used to keep the under-reamer open, the hole would not have been straight. In all, up to six drill collars were used during this reaming operation. On August 12, the under-reaming had reached full depth and the geophysical logger was brought on site.

The first caliper log run in this hole showed that, regardless of all the extra drill collars and other provisions made to insure full opening of the under-reamer, the hole was only 28 inches in diameter (see Caliper Log 1 in Appendix 6). After two more reaming passes and two more caliper logs, the hole finally measured the required nominal 30 inches.

For the next nine days, until August 21, the hole was reamed and rereamed several times while mud was continuously circulated. These nine days of circulation were not intentional, but rather were forced by the fact that the 20-inch casing had not arrived on site. The circulation did, however, help to keep the hole open, and running the under-reamer up and down several times a day increased the hole size slightly. On August 15, the loggers came back to the site and conducted spot checks on the parts of the hole that had shown the smallest sizes during the August 12 logging. Everywhere it was checked, the hole was 30 inches or larger.

Installation of the 20-inch protective casing began on August 21 and proceeded without difficulties. The casing selected by the driller and approved by the engineer meets the wall size requirements and construction characteristics of the other casings, that is, its wall size is 0.375 inches and it is a single longitudinal welded pipe. The mill certificates indicate that the pipe meets ASTM standard A-53 for Grade B pipe, has beveled edges at all joints, and is brand new (see Appendix 18).

The lower 482 feet of the protective casing were centered in the 30-inch hole by the use of expandable centralizers; above the 1,100-foot depth, the centralizers were fixed and non-expandable. The expandable feature of the centralizers was discussed at the August TAC meeting and a description of their installation was sent to DER (see July 31 summary in Appendix 20).

By August 23, the last joint was in the hole and the 1,582-foot casing was ready for cementing. The cementing method and composition had been formulated by Dowell on July 14, 1987 (see Appendix 16), and approved by engineers after presentation to DER.

On August 21, 1987, the detailed cement program was prepared from the caliper log. The in-hole volume was estimated to be 2,183 cubic feet; but the actual volume used to fill the hole was 2,036 cubic feet (see Table 4-3 for a summary of the operation, and the cementing tickets in Appendix 16 for full details).

The pressure test on the protective casing was performed on August 24, 1987. The casing was pressurized to 149 psi and the pressure was measured for the next hour without any change. After the test, the air pressure was bled out and the cementing head was removed to make the well ready for logging.

4.4.1 Grouting Log Results (Protective Casing)

All the geophysical logs run on the protective casing were made by Schlumberger (Mr. Rudy Buchel) out of its Fort Myers office. The temperature log was run first to minimize temperature upsets resulting from the mixing of fluids during lowering and raising of the tools.

4.4.1.1 Temperature Log

The temperature log showed that cement was hydrating everywhere from land surface to the full depth of the casing at 1,582 feet below land surface. From land surface down to 270 feet, the temperature increased considerably from the background levels up to 106°F; but from there down to 980 feet, the temperature remained steady, although much higher than the background levels. The only sharp drop appeared to occur at a depth of about 830 feet, which coincided with the high permeability zone. This sharp drop also followed the pattern described earlier on the temperature log of the intermediate casing, and was not indicative of absence of cement, but rather of the heat dissipation in that zone.

At a depth of 1,140 feet, the temperature log exhibited a pronounced increase, from 122°F to 140°F. This increase continued down to 1,300 feet, at which point the temperature decreased slightly. Since the pronounced increase coincided with the open hole, which is 30 inches in diameter, it appeared that the large temperature increase was due to the large mass of cement hydrating in the open hole.

4.4.1.2 Cement Bond Log

The cement bond log quantitative interpretation is not applicable to the 20-inch casing anymore than it is to the 24-inch casing (see Section 4.33); however, since the diameter is somewhat smaller, it is reasonable to expect an accompanying improvement in the log. This was indeed, the case, and the cement bond log for the protective casing showed much better bonding than that for the intermediate casing. From approximately 200 feet to 830 feet, there was good bonding; but between 850 and 990 feet, the degree of bonding was less. Even if a numerical value were to be computed for the latter section (by extrapolating data beyond the technical limits of the methodology), it would appear that a 40 percent bond existed. These results are still indicative of a cement bond and, even in the worst part of that section, there would not be any free-standing pipe without any cement around it. From 1,160 feet all the way down to full depth at 1,582 feet, the log showed less than 50 percent bonding; however, it is clear from the bond between the cement and the formation, which is obviously excellent, that such a calculation is extremely inaccurate and should be closer to 80 to 90 percent.

Recognizing the inability of its equipment to provide accurate readings from these logs, Schlumberger submitted a qualitative evaluation of the log. This evaluation indicated good bonding, but did not go beyond that to explain the degree of bonding (see Appendix 22).

Using the fluctuations recorded by the cement bond log for the protective casing, the average compressive strength of the cement grout can be calculated from the 24-hour value. At a value of 10 to 15 at 24 hours of the 28-day compressive strength, the final compressive strength was calculated to be about 2,500 psi, the same as for the intermediate casing.

4.4.1.3 Variable Density Log

The variable density log exhibits the same problems as the cement bond log when used in calculating casing-to-cement bonding in large casings. The variable density log is not, however, just another representation of the same wave; it also represents the returning signal from beyond the casing. It does thus give a better qualitative indication than the cement bond log, because it also shows the bonding of the cement to the formations. When the variable density log shows a fully cemented annular space and a 100 percent bond between the cement and the formations, it would be illogical to expect no bond between the casing and the cement. Accepting that premise would be equivalent to saying that cement hardens without slumping and this, of course, is not possible.

The protective casing of the injection well is well cemented. The bond between the cement and the formation was evident in the log and the annular space was also shown to be filled fully through the length of the well from 170 feet to full depth. A complete casing-to-cement bonding was not evident from the log; but neither was it evident that the pipe was standing free. In fact, by extrapolating beyond the efficient range of the logging tool, it is clear that the 20-inch casing is indeed bonded to the cement.

4.5 INNER (INJECTION) CASING

The 12-1/4-inch pilot hole below the protective casing was begun on August 31, 1987; but since the pilot hole had been previously drilled to 1,675 feet, no new sample returns were available until a depth of 1,675 feet was reached. The 12-1/4-inch pilot hole was drilled using reverse air circulation through the drill stem. On three occasions drilling was stopped while cores were collected. One core was collected from the lower part of the Avon Park Limestone and three cores were collected from the upper and middle parts of the Lake City Limestone. The only other interruptions during drilling were for the drift indicator (deviation) surveys.

Table 4-2 indicates that the pilot hole deviation from vertical did not exceed 30 minutes except at a depth of 1,895 feet below land surface where it reached 60 minutes (the maximum allowable under the permit conditions). This 60-minute reading at 1,895 feet was the only occasion during the project that either the pilot hole or the reamed hole deviated that much from vertical. The actual sure-shot disks are duplicated in Appendix 17.

On September 21, 1987, the pilot hole finally reached full depth at 2,354 feet below land surface. Although the first 500 feet were drilled in only a week, the last 200 feet took nearly two weeks as the drilling went through the hard dolomitic confining layers above the injection zone. The next day, on September 22, 1987, a complete suite of logs was run by Schlumberger (see Appendix 8), and on September 24, a request was made to convene the TAC for the purpose of reviewing the data and approving the setting depth of the injection casing. Copies of the logs were made for the TAC members and the meeting was set for October 6, 1987. The evening of September 23, the first television video of the well was conducted. A copy of the video was delivered to DER on September 24, 1987. Copies of the video were hand-delivered to the other TAC members on October 6.

The following week a series of five packer tests was conducted to provide assurances that there were no zones with a 10,000-mg/l-or-less concentration of TDS. Table 4-4 shows the setting depths for the packers and the sample depth identified with each. The results of the water quality analyses are discussed in Section 7.

During the interval before the TAC meeting of October 6, reaming of the pilot hole to accommodate the injection casing began. Two passes were planned, one with a 17-1/2-inch reamer and the other with a 24-inch under-reamer. Reaming with the 17-1/2-inch bit went smoothly and had already reached 2,315 feet when the TAC meeting was held.

At the TAC meeting, the geophysical logs were reviewed in detail. From the sonic log and the dual induction log (see Appendix 8), it became evident that a thick confining zone extends almost unbroken from 2,193 feet to 2,350 feet (see Section 2.4.3.3) in the Lake City Limestone. Other confining zones were also made evident from these logs, not only in the Lake City, such as from 2,150 to 2,190 feet, and from 2,030 to 2,120 feet; but also in the Avon Park such as from 1,600 to 1,720 feet, from 1,765 to 1,790 feet, and from 1,800 to 2,020 feet (except for a cavity at 1,912 feet) in both formations.

Table 4-4

PACKER TESTS (SETTING DEPTHS)

Packer Test	Straddled Zone (feet)	Sample Identification (depth in feet)
1	1,479-1,489	1,484
2	1,560-1,570	1,565
3	1,947-1,954	1,950
4	2,107-2,114	2,110
5	2,248-2,255	2,250
6	2,272-2,279	2,275
7	2,337-2,344	2,340

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The TAC members also reviewed the cores stored on site and correlated them with the geophysical logs. This correlation gave further proof of the high degree of confinement provided by the thick confining layers above the injection zone; but to provide additional backup information, the September 23 television video was viewed. A narration of this video was later prepared, a copy of which is duplicated as Table 4-5. The television video reinforced the other data, and ultimately the TAC approved the setting of the injection casing at 2,340 feet, as requested. The TAC members also approved the sections of cores to be sent to the core laboratory for analysis.

The day after the TAC meeting, reaming with the 24-inch under-reamer began; but this process was hard and long because of the dense hard formations and the large size of the hole. It was not until November 8, a month later, that the reamed hole was finally completed. Throughout the reaming, sure-shots were taken at 90-foot intervals, which showed a maximum deviation of 30 minutes (see Table 4-2).

On November 11 and 12, geophysical logs were run on the reamed hole (see Appendix 9). These included a caliper log, which was used to calculate the cement volumes for the injection casing. The calculations (see Appendix 16) indicated that an estimated 3,883 cubic feet of cement would be required; but in the end, nearly twice that volume (6,232 cubic feet) was used. The inner casing was inspected and tallied on November 9, 1987 (see Appendix 18) and was found to meet all the requirements of the specifications. The pipe is seamless pipe and has a wall diameter of 0.500 inches. It meets ASTM 106 requirements, is brand new, and its ends are all bevel-edged at 60 degrees.

The cementing program was accomplished in eight stages (see Table 4-3) and pumping in of the cement was slow and gradual; nevertheless, considerable losses to the formation cavities were encountered (see Table 4-5). The first indication that large quantities of cement would be needed came when the first lift ended only 300 feet up the hole instead of at the calculated 560 feet, even though two times the theoretical volume of cement had been used. At that time, consideration was given to a request from the driller to gravel through the largest cavities rather than pump expensive cement into them; however, it

Table 4-5

TELEVISION SURVEY NOTES ON THE PILOT HOLE
BEFORE THE INJECTION CASING WAS SET

SEPTEMBER 23, 1987

	Depth (in feet)	Comment
	0 - 1,582	Casing
	1,582	Out of casing
	1,595 - 1,600	Moldic limestone
	1,609 - 1,618	Moldic limestone - IMPERMEABLE CORE SAMPLE
*	1,636	Small cavity
*	1,657 - 1,663	Dolomite. Discoloration on white limestone/vugs
	1,670	Dolomite. Discoloration on white limestone/vugs
*	1,710	Dolomite
*	1,727	Small cavity
*	1,743 - 1,745	Cavity (water interface?)
	1,745	Fossil molds
	1,755	High porosity
*	1,760 - 1,762	Cavity
	1,770	Dense dolomite
	1,780	Dense dolomite
*	1,793	Cavity (1 foot)
	1,794 - 1,850	Dolomite with molds
	1,875	Limestone and dolomite - IMPERMEABLE CORE SAMPLE
	1,908	Color change - more dolomite
*	1,911 - 1,913	Two-foot cavity
	1,920	Darker formation. Appears broken up.
	1,930	Very tight formation - gage hole size
	1,940	Tighter
	1,958 - 1,961	Vertical fractures
	1,961	Tight hole
	1,992 - 1,994	Broken up
*	2,005	Small cavity

Table 4-5 (Continued)

	Depth (in feet)	Comment
	2,038 - 2,040	Broken
	2,040	Tight
*	2,095 - 2,097	Small cavity
*	2,117 - 2,118	Vertical fractures - (80 gpm) -
*	2,133 - 2,135	Large cavity - shows well in caliper logs -
*	2,141 - 2,144	Largest cavity - walls are still visible
	2,147	Tight hole
*	2,153 - 2,156	Large cavity - temperature log shows it -
*	2,163	Broken - IMPERMEABLE CORE SAMPLE -
	2,169	Tight
*	2,191 - 2,193	Large cavity - walls are still visible
	2,207	Tight
*	2,228 - 2,270	Extremely tight - IMPERMEABLE CORE SAMPLE -
	2,270	Tight - some molds
*	2,320 - 2,330	Some porosity - PERMEABLE CORE SAMPLE -
	2,330 - 2,362	Tight - some molds
*	2,362	Cavity at bottom

* During the October 6th TAC meeting, those sections marked by an asterisk were commented on and looked at in more detail.

m:H-87/X

was decided that, because the integrity of the well could be compromised if accurate measurements of the needed gravel could not be made, it would be better technically, if not economically, to grout through the whole section with cement, regardless of the cost.

The soundness of the decision not to use gravel was confirmed in Lift 2 when only 28 percent of the cement was lost to the formations as opposed to a 66 percent loss for Lift 1. The next lift, 3, was, however, of low return (49 percent), and Lift 4 was the worst of all, with an 82 percent loss of cement to the formation. Lift 5 brought the cement up to 1,645 feet, with a loss of only 17 percent. After that, all the other lifts were inside the protective casing and no further losses occurred. Cementing was completed November 17, 1987.

On November 19, the pressure test on the casing was conducted. The purpose of this test was to determine whether the injection casing had mechanical integrity. The regulations in Chapter 17-28 (FAC) call for a pressure test of a minimum one-hour duration, at a pressure of at least 1.5 times the expected operational pressure. Since the injection pressure was unknown at the time, it was decided that the test should be run at more than 120 psi and held for the required one hour. As it turned out, the injection pressure was only 46 psi at 4.0 mgd.

A pressure of 130 psi was built up and held without any change for three hours; but the formal test was conducted at 129 psi and held for the required one hour. Results from the pressure test indicated that the inner casing was able to retain the pressurized water column, and it was concluded that the mechanical integrity of the inner casing was satisfactory. At the end of the hour, the pressure was realized and the well was made ready for geophysical logging.

4.5.1 Grouting Log Results (Inner Casing)

After the pressure test was completed on November 19, the geophysical logs were run on the inner casing. The logging operation was carried out by

Schlumberger who ran a temperature log and a cement bond log within the inner casing, approximately 19 and 23 hours, respectively, after the completion of the grouting operation. Copies of both of these geophysical logs are included in Appendix 10.

In conjunction with the cement bond log, Schlumberger also recorded a travel time log (i.e., the travel time of the signal between the transmitter and the signal detector), a variable density log and a gamma ray log.

4.5.2 Cement Bond Log

The calculation of the constant travel time includes the sonic travel time for both casing material and the water. The 12-inch inner casing is made of steel, which has a sonic travel time of 61 microseconds per foot (Hodgman, 1955), while the saltwater in the inner casing has a travel time of 203.5 microseconds per foot (Hodgman, 1955). The constant travel time for the inner casing was, therefore, calculated at 390 microseconds. The travel time log recorded an actual travel time of about 365 microseconds throughout, confirming that the tool was properly centered in the hole and that the return signal recorded on the travel time log was not that for the inner casing. The latter observation indicated that the return signal from the inner casing was too weak for pick-up on the logging tool; this is why a cement bond log does not provide accurate data, but only qualitative data on casings this large.

Because the return signal from the inner casing was so weak, especially inside other casings in the upper part of the well, it can be qualitatively said that the inner casing is well bonded to the cement grout in the annular space. This bond was also confirmed by the variable density log, as described below (see Appendix 10); but, since the source of the travel time log was not the inner casing and could be any combination of travel paths, this log could not be used to do more than provide this qualitative evaluation.

Variations in voltage within the cement bond log usually reflect, among other factors, cement strength. The average value of the cement bond log was approximately 8 millivolts in the depth range from 0 to 1,400 feet. Since it is known that this whole section had been cemented for only a day when the cement bond log was run, it was possible to calculate the ultimate cement strength. The average compressive strength of the cement grout after about 20 to 36 hours was approximately 700 psi. On this basis, the expected 28-day compressive strength of the cement grout around the inner casing was calculated to be about 2,800 psi, which is somewhat higher than that for the grout around both the intermediate casing and the protective casing. Bentonite and volume additives reduce the compressive strength of cement grout (Campbell and Lehr, 1973). The grout around the inner casing had no additives in the last three lifts (see Table 4-3), which, in all probability, was the reason for its higher compressive strength.

4.5.3 Variable Density Log

As described in Section 4.3.1, sound can travel along several paths from the transmitter to the receiver (Schlumberger, 1972). The signal travel path along the inner casing is an indicator of the quality of the cement bond to the casing and is the primary determinant as to whether a good bond exists. When the casings are of large diameter (12 inches or larger), however, the travel time of the path along the casing becomes a smaller percentage of the total travel time and the accuracy is lost in the fluid travel.

The time for the signal to travel through the casing fluid (i.e., salty artesian aquifer water in this instance) and the casing and back again to the receiver can be calculated. The calculated total travel time of 490 microseconds can be compared with the first return signal on the variable density log. That comparison showed bonding everywhere except at a section from 1,882 to 1,886 feet and from 2,304 to 2,306 feet. If only this indicator were used, it would seem possible that the casing was free in these two sections; but other data such as the cement-to-formation bond and the temperature log indicated otherwise.

The return signal from the cement grout was similarly calculated at about 760 microseconds. The cement signal was easily followed in the variable density log and clearly showed complete cementation everywhere in the annular space.

Oddly enough, the return signals for the intermediate and the protective casings were easy to follow in this log and offered confirming evidence that the conclusions of Sections 4.3.1 and 4.4.1 in regard to the good bonds between these casings and the cement grout were correct.

In summary, the inner casing has a good bond with the cement grout, and the cement grout also has a good bond with the formations, as evidenced by the return signal from the cement grout. The variable density log also showed that the other casings are very well bonded; and in fact, when the data were quantitatively analyzed, they showed more than 90 percent bonding for the outer, intermediate and protective casings. Nonetheless, this quantitative analysis is not technically defensible on pipes this large, and the only conclusion should be that the bond is qualitatively good.

4.5.4 Temperature Log

The temperature log for the inner casing was run on the whole casing after the completion of the grouting operation and the pressure test, about 99 hours after the first lift and 20 hours after the last lift. When the temperature log was run, the first cement lift had been in place nearly 99 hours and, therefore, had already generated 87 percent of its thermal energy. Similarly, the second lift had been in place 70 hours and had expelled approximately 75 percent of its thermal energy in that time. Lift 3 was completed at 4:20 p.m., November 16, 1987; when the temperature log was run, it had been in place nearly 69 hours, thus having expelled about 78 percent of its thermal energy. Lift 4 had generated 69 percent of its thermal energy in the 47 hours since it had been placed. All other lifts from then on (5 through 8) had lost less than 50 percent of their thermal energy when the logs were run.

A comparison of the temperature log with the measured depth of the tag of the cement (see Table 4-6) showed the effect of time on the heat given off, and clearly established not only the top of each cementing lift (at approximately 720, 1,420, 1,600, 1,740, 1,750, 1,880 and 2,050 feet (see the temperature log in Appendix 10), but also the individual batches within the lifts. These data, therefore, in addition to confirming the tagging results, also increased the degree of confidence in the cementing.

Table 4-6

CEMENTING RESULTS
(INJECTION CASING)

Lift	Type (%)	Cement Pumped Sacks	Cement Pumped Ft3	Actual Cement Fill Linear Feet	Actual Cement Fill Ft3	Tag (ft.)	Loss to Formation (%)
1	4	1,105	1,674.4				
	Neat	466	705.6	298	800	2,042	66
2	4	350	532	152	380	1,890	28
3	4	521	790	139	405	1,751	49
4	4	156	235	9	42	1,742	82
5	4	347	526	137	436	1,605	17
6	Neat	143	168	188	260	1,417	No Loss
7	Neat	666	784	691	780	726	<1
8	Neat	695	817	726	817	0	<1

Totals 4,449 sacks 6,232 ft^3 pumped

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While the temperature log was being run, the computer-generated graphics from Schlumberger also produced a differential temperature graph which appears with the temperature log (see Appendix 10). This differential temperature graph is particularly useful because it shows the derivative of the temperature curve (the slope of the temperature gradient) and, therefore, is a better indicator of the continuity of cement in the annular space. The differential temperature graph for the inner casing showed no sharp changes anywhere down the hole except, of course, at the contact between cement lifts where sharp changes would be expected to occur. This graph then was conclusive evidence of cement hydrating everywhere outside the casing from land surface to full depth. Together with the cement bond and variable density logs, it reinforced the conclusion that the cement placement around the inner casing is satisfactory. The data clearly gave no indication of voids or uncemented sections anywhere outside the casing.

4.6 OPEN HOLE

Drilling of the open hole below the inner casing began on November 21, 1987. Although a small size hole (12 inches) was drilled, progress was slow. Cavities were encountered at 2,375, 2,379, 2,423, and 2,441 feet below land surface and required extensive dredging. Also, broken rocks and "boulders" falling from the roof of the cavities caused high torques on the bit and reduced the drilling speed.

By November 24, a depth of 2,450 feet had been reached. After consideration of just how mineralogically representative this depth was of the injection zone, it was decided that it would be a good depth from which to collect the last core sample. Core 8 was thus taken from the zone between 2,450 and 2,463 feet; but it was collected in two separate runs, with a recovery of 65 percent.

Drilling below the cored section resumed November 26. After drilling through numerous cavity zones, the drillers reached full depth at 2,600 feet. On November 30, following initial development, the well was made ready for television surveying and geophysical logging. Sure-shots taken every 90 feet during the open hole drilling from 2,340 to 2,600 feet had a maximum deviation of 30 minutes (see Table 4-2 and Appendix 17).

The geophysical logging of the open hole began December 1 and consisted of sonic, dual induction, spherically focused, caliper, deviation and temperature logs (see Appendix 11). An open house was then held at the site on December 2 when visitors from County and City governments as well as County, State and Federal agency representatives were able to tour the site, inspect the facilities, and observe the cores and other data from the well. The next day, December 3, the final television survey was conducted (see Section 4.7). The last suite of geophysical logs on the open hole was collected on December 3 also; these consisted of flowmeter (spinner), temperature, and fluid resistivity (mud) logs (see Appendix 12).

The logger also collected three one-liter point samples from the open hole at 2,350, 2,450, and 2,550 feet. These samples were analyzed for complete ionic balance in the laboratory. The results of this laboratory analysis are discussed in Sections 7 and 9.

4.7 TELEVISION SURVEY

The television survey of the completed well was performed the night of December 3, starting at 2:00 a.m. The video showed the entire length of the 12-inch casing and the 260 feet of open hole (injection zone). The bottom of the 12-inch casing was initially recorded at 2,337 feet; but, before the open hole was surveyed, the video counter was reset to 2,340 feet to agree with all the other field data.

4.7.1 Injection Casing

The video in the cased portion of the well was viewed to evaluate the condition of the injection casing. In the video tape, the portion inside the casing was somewhat cloudy, but the casing was visible and every weld could be easily inspected. The only other features shown were some scratches on the inside of the casing caused by the lowering and raising of the drill bit during drilling of the open hole. The evidence of scratching was seen in a few sections of the pipe, but there was no pattern to the occurrence. There certainly was no gouging, grooving or physical damage anywhere. In effect, throughout the total length of the injection casing, the scratch marks were all superficial. Such superficial scratches do not detract from the physical and mechanical integrity of the casing.

4.7.2 Open Hole

A narrative of the video tape was prepared for the open hole portion of the tape. This narrative (see Table 4-7) describes the relative ability of parts of the open hole to receive the injection water by identifying cavities, fractures, and porous zones.

The television survey identified these cavities at 2,379 and 2,423 feet which, as described earlier, required extensive dredging (see Section 4.6). The survey also confirmed that the core collected at 2,450 feet is representative of the section, based on the texture and appearance of the well walls. The television survey below the casing showed the first series of small openings at a depth of 2,353 feet. The open hole then became hard and with solid walls until a series of small holes appeared at 2,363 to 2,364 feet. The next section with good porosity and probably high permeability was encountered between 2,375 and 2,376 feet. At 2,379 feet, a large two-foot cavity was found. From 2,381 to 2,397 feet, the whole section was porous and contained a series of holes and small cavern. At 2,397 feet, a good-sized cavern was found.

Below 2,414 feet, the open hole passed through several broken sections with numerous holes and fractures, but it was at 2,423 feet that the camera showed the largest cavern of the injection zone. This cavern extended down to 2,429 feet, but was so large in the upper four feet that the side walls of the cavern could not be seen. This cavern can handle several times the flow proposed for the deep-injection well (4.0 mgd as designed).

Table 4-7

TELEVISION SURVEY NOTES ON THE OPEN HOLE
AFTER WELL CONSTRUCTION WAS COMPLETED

DECEMBER 3, 1987

Depth (feet)	Comments
0 - 2,340	Casing.
2,340	Out of casing.
2,341 - 2,349	Tight round hole with smooth walls and little, if any, porosity.
2,351 - 2,353	Rougher walls - some porosity.
2,353 - 2,357	Small openings (smaller than cavities).
2,363 - 2,364	Openings are bigger but still cannot be called cavities. High permeability.
2,368 - 2,375	Tight round hole (no visible porosity).
2,375 - 2,376	Broken section good porosity. Probably high permeability. Fractures.
2,379 - 2,381	Large cavern. Very good injection potential
2,381 - 2,384	Rough porous walls.
2,384 - 2,385	Broken sections. Good porosity and permeability.
2,387	Very rough walls. Small openings.
2,393	Rough walls.
2,395 - 2,397	Small cavities.
2,397	Small cavern.
2,398 - 2,405	Smooth walls.
2,408 - 2,410	Vertical fracture (not interconnected).
2,410 - 2,414	Smooth walls.
2,414 - 2,418	Broken section - numerous holes. Good permeability.
2,420 - 2,423	Fair porosity.
2,423 - 2,427	Very large cavern. Light does not reach the walls. The whole 4.0 mgd can easily be injected into this cavity alone.
2,427 - 2,429	Same cavern as above, but here the walls are seen to be very fractured.
2,430	Still extremely fractured zone, but here a horizontal fracture is seen to bridge the well bore and continues into the formation.
2,431 - 2,434	Very broken section. Large permeable zone.

Table 4-7 (Continued)

Depth (feet)	Comments
2,434 - 2,437	Tight hole - low porosity.
2,437 - 2,438	Rough walls - some porosity.
2,444 - 2,446	Rough walls - porous zone.
2,450 - 2,463	Rough walls - some porosity.
	THIS IS THE SECTION OF CORE 8.
2,458	Small hole (cavity).
2,464 - 2,465	Some cavities, but not much interconnection.
2,465 - 2,478	Fairly smooth hole. Almost as tight as some confining sections above the injection zone.
2,478 - 2,480	Fractured zone. Horizontal and vertical openings criss-cross the open hole.
2,491	Large hole.
	THIS IS THE LAKE CITY - OLDSMAR CONTACT ACCORDING TO SAMPLES.
2,493 - 2,506	Very tight round hole. No porosity. Walls are dense and non-porous.
2,506 - 2,507	Porosity starts increasing.
2,507	Hole
2,509	Hole
2,511 - 2,514	Some cavities are present. Hole loses roundness and the formation is obviously broken up. Small cavern.
2,514 - 2,518	Numerous small cavities. Lots of fractures. Could be considered a cavern that is not well developed.
2,518 - 2,520	Small cavities.
2,520 - 2,527	Dense and tight formations. Very low porosity.
2,527 - 2,529	This is the carbonaceous layer reported as lignite in the cuttings description. This material burns when fired.
2,529 - 2,533	Traces of thin lignite beds still visible.
2,533 - 2,536	More lignite layers. This is so dark that it almost looks like a cavern.
2,537	Another lignite layer.
2,539 - 2,555	Light-colored limestone. Very tight and dense - low porosity and probably impermeable.
2,555 - 2,578	Picture is cloudy, but same as above.
2,580 - 2,603 (TD)	Same as above but cloudier.

Below 2,429 feet, the video showed a cavity-riddled zone of very broken and fractured walls down to 2,434 feet. Another porous zone was found between 2,444 and 2,446 feet, the last highly permeable zone until a depth of 2,506 feet was reached. At 2,506 feet, another highly permeable zone was encountered which continued down to 2,520 feet.

The section from 2,527 to 2,533 contained the dark lignite beds reported in the geologic description (see Appendix 24). Other lignite layers could be seen down to 2,537 feet. Below the lignite layers, from 2,539 to the total depth of the hole at 2,605 feet, the video showed a tight round hole with smooth walls and low permeability. The rocks in this section appeared to be dense and massive, but the picture taken by the video camera became cloudy at about 2,555 feet and remained that way to total depth.

In summary, the video tape of the open hole from 2,340 to 2,603 feet below land surface exhibited an extensive array of cavities and caverns. The largest one, found at 2,423 feet, qualifies as a large cavern. Other smaller caverns were found at 2,379, 2,397, and 2,514 feet. Cavity-riddled zones were shown by the video at depths of 2,395, 2,464, 2,511, 2,514, and 2,518 feet.

4.8 MECHANICAL INTEGRITY TRACER TESTS AND TEMPERATURE TESTS

At two of the early TAC meetings, the possibility of using a radioactive tracer to examine the mechanical integrity of both the deep test/injection well and the deep exploratory/monitor well was discussed; as a result, the March 13, 1987 DER permit gave NFMU the option of using this alternative. On May 12, 1987, PBS&J issued a change order to include running radioactive tracer tests on both wells. It was felt that, since these tests provide a direct proof of mechanical integrity (as opposed to other tests which are only indirect), they would eliminate any lengthy arguments that could delay approval and increase the cost of the project.

4.8.1 Deep Test/Injection Well Tracer Test

The tracer test of the deep test/injection well was conducted on December 4, 1987. Schlumberger filled two ejectors with radioactive Iodine 131 and assembled one gamma ray detector above the ejectors and two gamma ray detectors below them. The tool assembly was then lowered down the well to full depth and a background (base log) was run up the hole into the casing (see Appendix 13). The background gamma ray log showed an API count of 50 units or less everywhere in the open hole except at depths between 2,341 and 2,348 feet, where the count increased to 70 API units, and between 2,524 to 2,540 feet where it increased to nearly 250 API units (one API unit represents 16.5 micrograms of radium equivalent per ton of formation).

After the base log was completed, the ejectors were brought up to just inside the casing (2,329 feet) and the water injection pump was turned on; it pumped water continuously throughout the rest of the test at a rate of 300 gpm. One ejector was then opened and the Iodine 131 entered the water stream.

The upper gamma tool (the one above the ejectors) did not show any upward movement of the radioactive tracer and remained well below the background of 40 API units; however, the two gamma ray tools below the ejector clearly showed the passing of the iodine tracer, and recorded readings as high as 1,000 API units.

After the ejection was completed, the tool assembly was dropped to the bottom of the hole and the radioactive material was traced up the hole. The Iodine 131 was found at 2,440 to 2,495 feet and moving down the hole. Once again, the tool assembly was dropped to the bottom and a second trace was made up the hole. This trace found the radioactive Iodine 131 at between 2,490 and 2,520 feet, still moving down the hole. A third trace was then made, but the material had continued to move down the hole and had been lost to the lignite layers between 2,524 and 2,540 feet.

A second injection of tracer material was then performed. The ejectors were brought up inside the casing to a depth of 2,315 feet and the procedure described above was repeated. During this second tracer test, the upper gamma log tool above the ejectors failed to show any radioactive increase, thus indicating that all the tracer material had moved down the hole. A trace was then run from the bottom of the hole to 100 feet inside the casing for comparison with the original base log. This trace failed to detect any radioactive material above the injection depth; but, in fact, showed it at a depth of 2,500 to 2,520 feet, giving convincing evidence that there was no upward movement outside the casing and, consequently, that the well had mechanical integrity.

The injection test was then concluded, but pumping of water down the well continued for the next hour to insure that all the radioactive material was out of the well bore. The conclusion from the test was that the casing and cement are satisfactory and that no fluid circulates up around the well on the outside of the casing in the annular space.

4.8.2 Deep Test/Injection Well Temperature Test

The temperature test of the deep test/injection well was conducted on December 18, 1987, six days after the injection of fresh water was started for the injection test and sixteen hours after it ended.

The temperature log (see Appendix 14) showed a steady increase in temperature, except for a few statistically insignificant drops of 0.25^{o}F at 1,590 feet, 1^{o} at 1,720 feet, 0.5^{o}F at 1,880 feet, and 0.5^{o}F at 2,000 feet, and an increase of 1.5^{o}F at 2,140 feet. These fluctuations are minor and not representative of any real changes, but rather are interpreted to be the result of stratification in the well bore. A really significant change in temperature did occur at the end of the casing, a drop of almost 11^{o}F. A sharp increase of 12^{o}F occurred at 2,425 feet, followed by another gradual but sharp increase between 2,520 and the bottom of the hole.

The sharp drop was caused by the invasion of low temperature injection water into the formations. In this section, the formations are not permeable enough to bring in warmer formation water quickly enough to counteract the effect of the cooler injected water.

The opposite occurs at 2,425 feet, where the temperature log increased by 12^{o}F very quickly. Here the formations are extremely cavernous and highly permeable so that the fresh cool water quickly dissipates and mixes with the much warmer formation water. Below that, from 2,520 down to the bottom of the well, there is little porosity and very little injected water enters the aquifer; consequently, the natural pattern of the aquifer quickly re-exerted itself and the temperatures climbed to the background level around 100°F.

4.8.3 Deep Exploratory/Monitor Well Tracer Test

At a TAC meeting held October 6, 1986, the integrity of the deep exploratory/monitor well, hereinafter referred to as just the deep monitor well, was questioned. After the TAC members explained their concerns, it was agreed that a series of pressure tests would be conducted in the well to answer the question of integrity. The main concern was that there might not be separation between the two monitor zones.

In response to those concerns, pressure tests were conducted on the deep monitor well casings on October 15, 1986. These tests were in addition to the standard pressure tests already run on the casings, with successful results. The new tests were run to determine if there was separation of the two monitor zones. To accomplish this, it was necessary to monitor one casing while the other was pressurized. The results of the new tests were also satisfactory and proved that complete separation exists between the two zones (see Section 3.7.2 of the Exploratory/Monitor Well Report, PBS&J, 1986a).

The TAC's concern thus appeared to have been answered and the project continued; however, at the extraordinary TAC meeting held March 3, 1987, the issue was brought up again by a new TAC member. To put the issue to rest, it was agreed that the two zones of the monitor well would be sampled once a week during construction. Since the monitored zones tap into different quality waters, it would be easy to show separation of the two casings if the water quality from one casing was different from that of the other.

This sampling was done, and the results were successful (see Section 6); but this type of proof could always leave room for doubt since it is an indirect answer to the question of separation. Consequently, it was decided that a radioactive tracer test would be the only test that would ultimately answer this question directly and put the issue to rest. Such a test was authorized by change order on May 12, 1987 and conducted on December 22, 1987. The procedure was the same as that for the deep test/injection well described in Section 4.8.1, but the methodology was slightly different since the test purpose was not the same.

The deep monitor well taps into two zones of the Floridan Aquifer System. The first monitor zone begins at 1,318 feet below land surface and extends down for approximately 100 feet (to 1,422 feet). It is wholly within the Crystal River Formation of the Ocala Group. The second monitor zone starts at 1,930 feet and extends down to 2,004 feet. It primarily monitors the uppermost zone of the Lake City Limestone. (A more detailed description of the monitor well is presented in Section 5. Figure 5-1 is an as-built representation of the well.) The upper monitor zone is accessed through the annular space between the 10-inch intermediate casing and the 4-inch inner casing. The lower monitor zone is accessed through the 4-inch inner casing and a 2-inch monitor tube inside the 4-inch casing. This monitor tube was installed because a separation was found in the 4-inch casing (PBS&J, 1986-a), and it is because of this separation and the monitor tube addition, that the integrity of the monitor well has been questioned.

A gamma ray base log was run first. This log, run inside the 2-inch casing, consisted of three gamma ray scans: one above the ejector and two below it. The log showed two natural peaks in gamma radiation above an otherwise average level of about 20 API units from 1,010 feet to 700 feet. One peak was at a depth of 815 feet and the other at a depth of 720 feet. Above 700 feet, the natural radiation increased to about 35 API units and several peaks could be seen, the most significant of which occurred at 690, 670, 642, 630, and 614 feet.

After the base log was completed, the Iodine 131 tracer was ejected at a depth of 1,001 feet and the upper monitor zone was discharged into the holding tanks on site at the same rate as the injection of the tracer. The two gamma tools below the ejector picked up the tracer on its downward movement inside the 2-

inch casing. The gamma tool above the ejector did not pick up the tracer. This was repeated two more times with the same result; that is, no upward movement was detected.

Finally, the base log was rerun to compare any changes from the original base log. With the exception of the high gamma count at the 1,001-foot depth where the tracer was ejected, there had been no upward movement in the well bore. Consequently, it was concluded that there can be no interconnection between the two casings and that the deep monitor well has mechanical integrity.

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Section 5
DRILLING PROGRAM AND CASING PLACEMENT: DEEP EXPLORATORY/MONITOR WELL

The drilling program for the deep exploratory/monitor well (referred to as the deep monitor well in this section) was described in detail in an earlier engineering report (PBS&J, 1986a) and all the construction and testing field information was presented in the associated data report (PBS&J, 1986c). This section is a condensed version of the program presented in those two reports. A chronology of the drilling program is presented in Table 5-1.

The drilling contract for the monitor well was awarded to Cape Drilling Co. (Cape) in April 1986. After receiving the required local drilling permits, Cape began mobilization and construction activities on June 26, 1986.

5.1 DRILLING PAD AND SHALLOW MONITOR WELLS

The time from June 26 to July 1, 1986 was used to prepare the drilling pad, and install four shallow monitor wells around it (see Figure 4-1). The drilling pad was formed and poured around a 26-inch surface casing (pit casing), set to a depth of 8 feet. After the drilling pad was finished, the four shallow monitoring wells, cased with 3-inch-diameter polyvinyl chloride (PVC) pipe and finished with 5 feet of PVC screen, were each drilled to a depth of 20 feet. These wells were located around the drilling pad to monitor any saltwater spills on land surface during construction.

5.2 OUTER CASING

With the drilling rig set up in position and mobilization completed on July 5, 1986, Cape was ready to start drilling on July 6. The pilot hole was taken to a depth of 150 feet that same day, using a 7 5/8-inch bit. The following day, it reached 200 feet (see Figure 5-1).

A 22-inch bit was used for reaming the hole, and the 200-foot reamed depth was reached July 9. The 16-inch outer casing was then set at 200 feet below land surface and centered in the reamed open hole. The outer casing is seamless and has a 3/8-inch wall thickness.

Table 5-1

DRILLING PROGRAM CHRONOLOGY: DEEP MONITOR WELL

Date	Event
June 26 - July 5, 1986	Mobilized and prepared site, setting pit casing, pad construction; drilled shallow monitor wells
July 6-7	Drilled 8-inch pilot hole to 200 feet
July 7-9	Reamed 22-inch hole to 200 feet
July 9	Set and grouted 16-inch outer casing to depth of 200 feet
July 11	Sampled shallow monitoring wells, with sampling done periodically from then on
July 12-15	Drilled to 1,360 feet by mud rotary
July 15-16	Set and grouted 10-inch intermediate casing to depth of 1,360 feet; set cement plug at 1,360 feet
July 18	Performed pressure test of casing (held 90 pounds per square inch (psi) for 1 hour with no change)
July 19-24	Performed rig maintenance
July 25	Drilled out cement plug; switched to reverse air drilling using 9 3/4-inch bit
August 1	Reached total depth of 2,526 feet below top of casing (BTOC); performed geophysical logging
August 4-7	Attempted television surveys
August 7	Encountered 42-foot section of 10-inch casing lodged in hole at 1,708 - 1,750 feet
August 10-11	Milled out top of casing fallen in the hole
August 12	Completed television survey
August 12	Gravel-packed proposed injection zone from 2,526 to 2,275 feet BTOC; plugged the confining layer from 2,275 feet to 2,004 feet
August 14	Gravel-packed cavities in lower monitor zone
August 15-16	Set 4-inch casing plus slotted screen (monitor zone 2,004 feet to 1,930 feet (BTOC)

Table 5-1 (Continued)

Date	Event
August 17-22	Cemented 4-inch casing above lower monitor zone (cement from 1,930 - 1,422)
August 22	Ran pressure test on casing (held 62 psi for 1 hour)
August 27-28	Developed upper and lower monitor zones
August 29	Ran television survey of 4-inch casing
August 29 - September 4	Flowed 4-inch casing to clear it and reran television survey
September 4	Fabricated and installed well head
September 5-10	Cleaned up site and demobilized
September 11	Inspected site; collected samples
September 16	Suspected break in 4-inch casing
September 27	Confirmed break in pipe by logs
September 29	Informed DER of break
October 6	Commenced repairs
October 15	Completed repairs.

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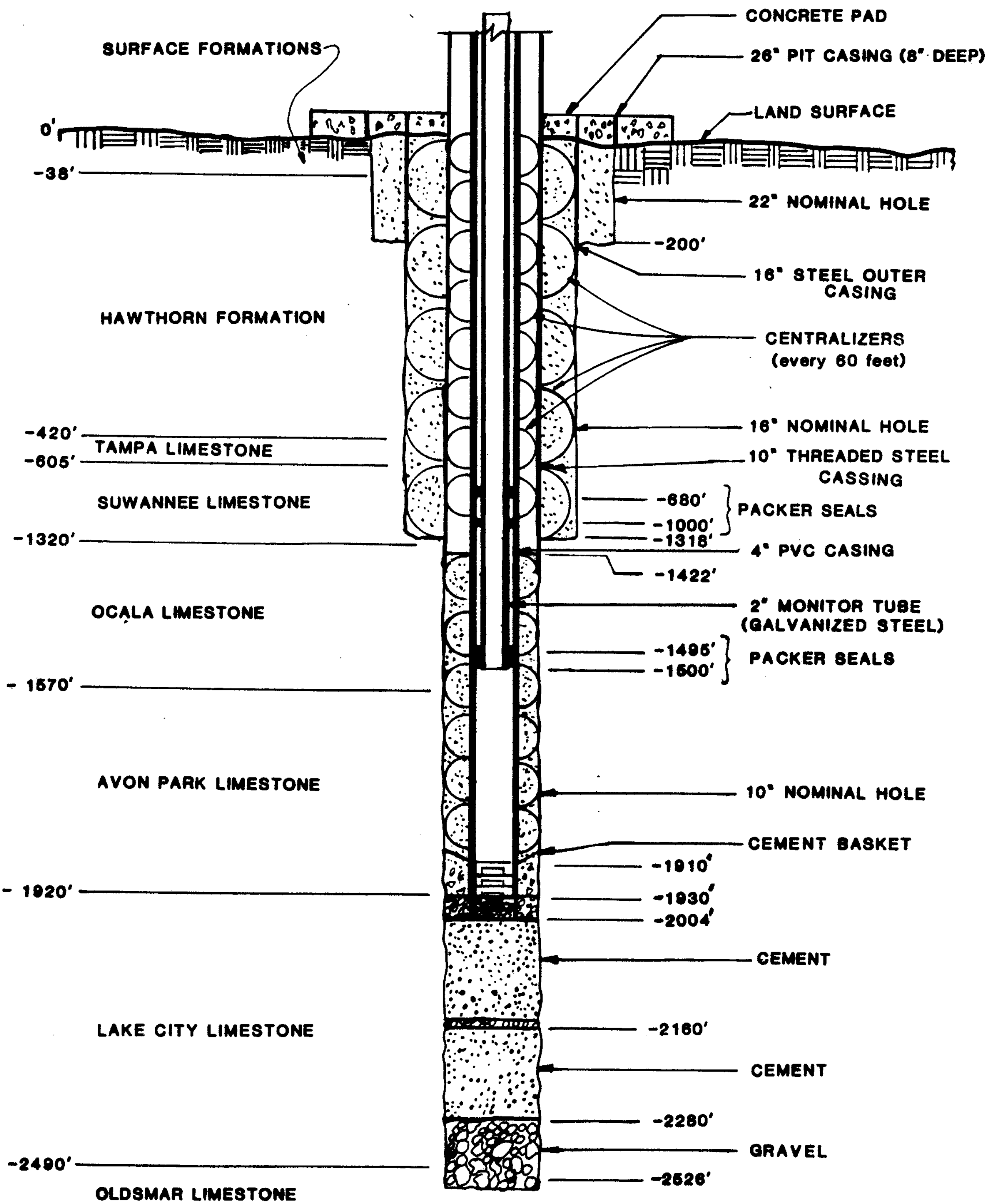

DEEP MONITOR WELL
AS BUILT

NOT TO SCALE

PBS&J POST, BUCKLEY, SCHUH & JERNIGAN, INC.

DEEP MONITOR WELL (AS BUILT)

FIGURE 5-1

Haliburton Company used 235 94-pound bags of Type II moderate sulfate-resistant Florida Class H neat cement grout without additives to cement the 16-inch casing. The cement was mixed on site and pressure-grouted through the center of the 16-inch surface casing and up the annular space around the casing. A good return was obtained from the annular space before the grouting operation ended on July 9, 1986.

5.3 INTERMEDIATE CASING

Drilling of the hole for the intermediate casing began on July 12, utilizing a mud-circulation rotary system to a final depth of 1,360 feet. A 10.75-inch threaded steel casing was then installed and pressure-grouted in place, and a cement plug was left at the bottom. A total of 145 barrels of cement, with 2 percent CaCl additive to speed-up hardening, were used for cementing the casing. After 48 hours of curing time, the casing was successfully pressure-tested at 90 psi for one hour on July 18, 1986.

Sure-shot rings and shallow monitoring well readings were taken periodically throughout the drilling process and the results reported in the daily observation reports (PBS&J, 1986c). All sure-shot rings were well within the one degree inclination allowed.

5.4 DRILLING TO TOTAL DEPTH

The cement plug was drilled out and the drilling process was converted to a reverse-air rotary system on July 25. On August 1, the final well depth of 2,526 feet below top of casing (BTOC) was reached and the crew came on site to perform the geophysical logging.

5.4.1 Geophysical Logs

The following geophysical logs were run by Woodward-Clyde prior to setting the 4-inch casing: gamma ray, acoustic velocity, short and long normal resistivity, caliper and spontaneous potential. A deviation survey was conducted by Schlumberger, and a television survey by Deep Venture. Of the above logs, the television survey contributed the most to the evaluation of the deep monitor well construction, and so it alone is discussed in this section.

Copies of all geophysical logs were included in Appendix C of the PBS&J 1986a report; television survey tapes were provided to the TAC members.

5.4.2 Television Survey

On August 4, the television survey was initiated; however, cloudy hole conditions necessitated further well development. During the process of tripping the drill string into the well for development, two drill rods and a drill collar were dropped from the string. After several attempts, the rods and collar were retrieved on August 6, but the effort had damaged the well.

When the television survey was rerun on August 7, an obstruction was encountered at 1,729 feet BTOC. The television survey showed a fallen section of 10.75-inch casing lodged at a slight angle on a ledge. It was determined from the television survey and the geophysical logs that the lower 42-foot section of casing had fallen from the casing string and that the intermediate casing now ended at 1,318 feet. A milling tool was constructed and used to cut through the obstruction.

The television survey was finally completed on August 12. It showed the position of the dropped casing and the total length of the fallen section. It also showed the full 1,318-foot length of the 10.75-inch casing and confirmed its good condition.

5.4.3 Plugging below Monitor Zone

To convert the well from an exploratory to a monitoring function, the bottom 522 feet of the well were sealed off. The highly permeable zone from the bottom of the well (2,526 feet) up to a depth of 2,280 feet was gravel-packed and the cement plug in the confining zone was installed from 2,280 feet up to 2,004 feet on August 13. A cavity-riddled zone at 2,160 feet was also gravel-packed during the cementing of the plug.

5.5 INNER CASING

Gravel was placed in a cavity at the base of the monitor zone, and the 4-inch Schedule-80 PVC inner casing, complete with 40 feet of slotted screen and a cement basket above the slotted screen, was then lowered into the well to monitor the zone from 2,004 to 1,930 feet.

The cement volume necessary to grout the 4-inch casing was calculated using the caliper log and lithologic descriptions, and the cementing program was also prepared using these data. Cementing was begun on August 17. A total of 880 cubic feet of cement, with 2 to 4 percent CaCl to speed hardening and 10 to 12 percent gel additives to increase volume, were used to cement the 4-inch casing.

Twenty-four hours after the final lift of cement had cured, the drillers set up the well-head for the pressure test on the 4-inch inner casing. The purpose of the pressure test was to determine whether the inner casing had mechanical integrity. On August 21, a pressure test was run at 62 psi, and the pressure held without change for one hour.

5.6 WELL DEVELOPMENT AND CONVERSION TO DEEP MONITOR WELL

5.6.1 Well Development

The final steps in completing the deep monitor well were the development of the two monitor zones and fabrication of the well-head, complete with valves and 6-inch pressure gages. Well development for the lower zone began with air lifting for 20 hours at approximately 1 to 2 gallons per minute (gpm). The upper zone was developed with a centrifugal pump for 6 hours at approximately 10 gpm (August 27).

On September 8, water samples were taken and the valves closed and locked. The drilling rig and attending equipment were demobilized and the site cleaned up by September 11. Final site inspection was performed on September 11 and water samples were collected that day.

On September 16, PBS&J conducted a test to determine the range of the 6-inch pressure gages that would be required. At that time, it was found that both monitor zones had the same pressure head. This, of course, implied a cross connection and a second set of water quality samples were collected. Both water samples had the same conductivity and TDS.

A temperature log and a fluid resistivity log were then run on September 27. The fluid resistivity log confirmed that there was an interconnection (a break in the 4-inch PVC casing) at an estimated depth of 650 feet BTOC.

5.6.2 Well Repairs and Testing

Repairs began on October 8. These consisted of inserting a new 2-inch galvanized casing inside the 4-inch-thick PVC casing and sealing it by setting it inside the 4-inch-thick casing at a depth of 1,500 feet, with two expandable packers. Two other packers were installed at 680 feet and 1,000 feet BTOC as additional backup.

On October 15, the driller indicated that the repairs had been completed and a test of the repairs was conducted. Field manometers were installed on both the upper annular sampling zone and the lower sampling zone. The pressure on both zones was measured and then the two zones were alternately shut off and on.

Water quality samples from both zones yielded completely different results, indicative of full separation between the two zones. Similarly, the manometer pressure tests were successful. The conclusion, therefore, was that the repairs had been effective and that the well was producing representative data from the two monitoring zones. Table 5-2 shows the results of the pressure tests on the two monitor zones and includes water quality annotations.

Following the successful tests, the monitor well was capped and the well-head was installed the following day. The final as-built design of the deep monitor well is shown in Figure 5-1.

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Table 5-2

WATER-LEVEL MEASUREMENTS ON MONITOR ZONES

(PRESSURE TESTS)

October 15, 1986 (Time)	Upper Monitor Zone (from 1,318 to 1,422 feet BTOC) Water Level (feet above msl)	Lower Monitor Zone (from 1,910 to 2,004 feet BTOC) Water Level (feet above msl)	
11:20	45.4	10.4	
11:30	45.4	10.3	
11:45	45.5	10.2	
11:55	45.5	10.2	
12:08	45.5	10.1	
12:14	45.5	-[a]	K=42,500 mmhos T=29.5°C
12:15	45.5	-	
12:16	45.5	-	
12:17	45.6	-	
12:20	45.6	-	
12:23	45.6	-	
12:24	45.7	-[b]	
12:25	45.7	8.4	
12:27	45.7	8.5	
12:35	45.7	8.7	
14:00	45.7	9.6	
14:05	45.7	-[a]	K=50,000 mmhos T=29.8°C
14:07	45.7	-	
14:12	45.7	-	
14:16	45.8	-	
14:20	45.8	-	
14:24	45.8	-	
14:30	45.8	-	
14:32	45.8	-	
14:34	45.9	-[b]	
14:35	45.8	-	
14:36	45.8	-	
14:38	45.8	-	
14:41	45.8	-	
14:42	45.8	-	
14:48	45.8	-	
14:50	45.8	-	
15:10	-K=3,300 mmhos T=29°C		

[a] Started pumping the lower zone at 10 gpm
[b] Stopped pumping

m:H-87/c

Section 6
MONITORING PROGRAMS

6.1 DOCUMENTATION

The drilling procedures and order of construction for the deep test/injection well were prescribed in the technical specifications for the deep-well system (PBS&J, 1986d). These specifications also included requirements for a reporting program on the progress of drilling operations. The primary components of this program are the field records and daily drilling reports, all of which were utilized in describing the well construction and the problems encountered during the 10-month construction period. The formation description records prepared by PBS&J field supervisors are discussed in Section 7 along with the geolograph recordings from the drillers, while the casing length, casing installation, and grouting description records are discussed throughout Section 4.

The field reports submitted by the drillers were made part of the daily construction records maintained by PBS&J, and as such were submitted to the TAC members on a weekly basis through the construction phase. The weekly reports submitted to the members of the TAC also included a summary of information from the daily PBS&J construction records (see Appendix 20).

The PBS&J field supervisors at the drilling site carried out three separate monitoring programs on various aspects of the construction of the NFMU well. In the first of these three programs, they monitored the effect of drilling operations on the deep monitor well and collected water quality data from this well to show that the two monitor zones were not mixed. This monitoring program, which consisted of weekly readings and samplings from the upper and lower monitor zones, is described in Section 6.2.

The second monitoring program conducted by PBS&J was carried out on the surficial aquifer monitor wells located around the drilling pad. The concept of surficial aquifer monitoring relied on the use of four monitor wells as an early warning system should a saline spill occur in the area around the drilling pad. This program is described and discussed in Section 6.3.

The third monitoring program was conducted on the deep test/injection well itself before and after reaming. This monitoring, which is discussed in Section 4, was designed to ascertain the straightness of the well during the well construction phase of the work.

Water quality samples collected during the drilling of the pilot hole were submitted to Environmental Services Incorporated (ESI), a division of Gridley Environmental, by PBS&J for testing, as required. ESI is a State of Florida registered water quality testing laboratory. Some of these samples were collected by grab sampling and others by packer pumping. The results of this monitoring program are discussed in Section 7.

Other monitoring programs conducted throughout the 10-month drilling program are discussed elsewhere in this report in conjunction with the descriptions of the work to which the monitoring activities pertained.

6.2 DEEP MONITOR WELL PROGRAM

On May 15, 1987, a weekly sampling of the two zones tapped by the deep monitor well was started. The procedure was to flow the upper zone into the return circulation tank for the injection well and to pump out the non-free-flowing lower zone into that same tank.

Before the program was started, it was determined that the in-casing volumes for the casings tapping the upper and lower monitor zones of the aquifer system were 4,550 and 1,260 gallons, respectively; and it was also determined that the upper zone flowed freely at 2 gpm while the lower zone could be pumped at 15 gpm. Using these values, it was determined that samples should be collected no earlier than 38 hours and 2 hours into the development of the upper and lower zones, respectively.

The first samples from the deep monitor well were collected without first removing the in-casing water. This was done to provide samples that would have been sitting in the well for several months. Those samples would surely have had ample time to show a cross-connection of the casings if they were indeed cross-connected. Other samples taken every week thereafter were collected after the lower casing water had been evacuated several times and after half the volume in the upper casing had been evacuated.

The results of this monitoring program are presented in Table 6-1. The two zones exhibited completely different water quality as evidenced by all the parameters measured, including salinity, conductance, temperature and TDS.

A further comparison between the water from the two monitor zones in the monitor well and the water collected from the same zones in the deep test/injection well was also made (see Table 6-2). This comparison showed that the water analyses from the two monitor zones closely resembled those taken from the same zones when each was penetrated during drilling of the deep test/injection well. For the lower zone, the specific conductance and the salinity are within 10 percent of each other and the TDS and chlorides, within 20 percent. The temperatures are identical. For the upper zone data are even closer. This similarity provides additional verification that the deep monitor well does indeed monitor the zones it is intended to monitor, and that the casings tapping those zones are not interconnected.

6.3 SURFICIAL AQUIFER MONITORING PROGRAM

At the drilling site, PBS&J carried out a daily monitoring program on the surficial aquifer monitor wells located around the deep test/injection well drilling pad and, on several occasions, extended this program to include the surficial aquifer wells located around the drilling pad for the deep monitor well. This program, based on the use of eight monitor wells, represented an early warning system to detect any saline spills around the drilling pad.

The four monitor wells installed around the injection well drilling pad (see Figure 4-1) were developed by May 13, 1987. Each well consisted of a 17-foot 4-inch PVC casing, with a 5-foot screen at the bottom. The wells were designated A, B, C and D. The wells around the monitor well drilling pad had been designated 1, 2, 3 and 4. The purpose of these wells was to identify any saltwater spills resulting from the deep test/injection well construction.

Table 6-1

WATER QUALITY ANALYSES (DEEP MONITOR WELL)

Date	Upper Zone			Lower Zone		
	Conductivity	Chloride	TDS	Conductivity	Chloride	TDS
5/15/87	3,100	850	1,680	42,000	20,120	34,060
5/22/87	2,800	750	1,590	21,000[a] 63,000	6,420[a] 19,260	11,890[a] 35,670
5/29/87	3,000	770	1,800	41,000	20,220	37,350
6/9/87	3,200	730	1,790	40,000	22,980	36,060
6/12/87	3,100	870	1,720	46,000	19,700	35,030
6/22/87	3,100	500	1,490	45,000	16,740	33,690
6/29/87	3,200	640	190[c]	52,000	14,400	37,620
7/3/87	3,200	633	3,440[c]	50,000	20,380	35,260
7/13/87	3,300	640	5,580[c]	48,000	19,350	35,690
7/17/87	2,720	560	1,640	56,800	19,850	36,050
8/7/87	2,260	1,160[c]	1,840	67,200	18,995	40,172
8/14/87	2,330[b] 3,100[b]	570	1,586	20,450 53,000[b]	17,540	35,776
8/20/87	2,740 3,200[b]	580	1,585	21,680 53,000[b]	18,700	35,161
8/27/87	2,700 4,800[b,d]	790	840[c]	47,000 54,000	27,190[c]	27,800[c]
9/4/87	3,100	569	1,586	53,000	17,542	35,770
9/11/87	2,900	550	1,360	50,000	19,640	38,520
9/18/87	2,900	598	1,537	56,100	18,692	35,389
9/25/87	3,000	529	1,864	56,500	19,092	36,240
10/9/87	2,950	625	1,528	61,200	19,367	35,946
10/16/87	3,500	594	2,422	57,000	18,992	34,986
[illegible]/22/87	3,200	579	2,542	58,100	19,192	34,220

Table 6-1 (Continued)

	Upper Zone			Lower Zone		
Date	Conductivity	Chloride	TDS	Conductivity	Chloride	TDS
10/23/87	3,000	720	1,768	53,000	18,540	32,490
10/30/87	2,900	674	2,034	56,000	19,392	35,594
11/6/87	2,800	649	2,112	55,000	18,992	34,786
11/13/87	2,800	599	1,640	53,000	17,343	35,052
11/19/87	3,200	649	1,554	58,000	18,242	33,838
11/29/87	2,700	749	2,610	53,500	18,642	33,710
12/7/87	2,700	899	2,636	54,000	17,992	35,634
August	2,990	660	1,830	53,050	18,890	35,550
Maximum	3,500	899	2,636	67,200	22,980	40,172
Minimum	2,260	500	1,360	40,000	14,400	32,490

[a] Error in dilution factor (values should be x3) - (value x3 used in averages)
[b] Lab analysis rerun on same sample - (used in averages)
[c] Obvious error (data do not agree with other values for same sample) - (not included in averages)
[d] Used first results for averages

m:H-87(II)/r

Table 6-2

WATER SAMPLE COMPOSITIONS OF THE MONITOR ZONES

	Deep Monitor Well Upper Monitor Zone (1,318-1,422 feet)	Deep Monitor Well Lower Monitor Zone (1,930-2,004 feet)	Deep Test/ Injection Well (1,341 feet)[a]	Deep Test/ Injection Well (1,950 feet)[b]
Chlorides (mg/l)	600	20,000	555	24,990
TDS (mg/l)	1,750	35,000	1,500	33,340
Specific Conductance (mmhos/cn	3,500	53,000	3,900	56,500
Salinity (0/100)	1.4	33	1.3	33
Temperature (°C)	27	31	27	31

[a] From analysis of water sample corresponding to the core from that depth.
[b] From analysis of water sample corresponding to the straddle packer from that depth.

m:H-87/e

One sample per day was collected from each well throughout the drilling period and tested in the field for salinity, temperature and conductivity. The complete results of the surficial aquifer monitoring program are shown in Appendix 26.

The surficial aquifer monitoring program began on May 17, 1987. The first few weeks of daily readings, used to establish background water quality, showed that, even within the small distances between wells, the water quality in the aquifer can vary significantly. In addition, the early data also showed that large fluctuations occur naturally from day to day. On August 31, the drilling operation was changed from the mud-rotary to the reverse-air system, increasing the possibility of saltwater spills. After this time, the monitoring program results were watched more closely to detect any saline water contamination of the Surficial Aquifer System.

The drillers worked carefully throughout the drilling of the deep test/injection well, and the shallow well data indicated that no spills escaped off the drilling pad. The lack of saline water spills was confirmed by the conductivity and salinity readings recorded at each of the monitor wells around the drilling pad. The last readings, taken from the monitor wells on December 10, showed conductivity levels from 1,300 to 1,700 umhos per centimeter, as compared with the starting range of 1,100 to 1,320 umhos per centimeter. These small changes are within the natural fluctuations and follow a cyclical pattern in which conductivity of the water increases slightly during the dry season. Salinity values ranged from 0.5 to 0.9 parts per thousand in these final readings, well within the range found in the background readings. These readings thus confirmed that there were no saline water spills off the pad, and that the quality of water in the Surficial Aquifer System was not compromised during well construction or anytime thereafter during testing.

6.4 DEVIATION AND DIRECTIONAL SURVEYS

The construction specifications also included requirements for a true and straight well that meets the regulatory criteria of Chapter 17-28 (FAC). Two methods were utilized to check on the departure from vertical of the deep test/injection well. The first of these methods, deviation checks during drilling using a sure-shot tool, was discussed in Section 4 as it applied to pilot hole drilling and reaming for each of the casings, and is again discussed below in the overall context of the total well. The other method, directional surveys using a logging tool, was used as a back-up to the sure-shots to increase the reliability of the results.

Sure-shots were taken in the pilot hole and in the reamed open hole every 90 feet during construction, and deviation surveys were taken in these two holes after reaching full depth. The sure-shot deviation results are presented in the form of xerographic copies of the sure-shot disks in Appendix 17 and in tabular form in Section 4 (see Table 4-2). The directional surveys are presented with the other geophysical logs in the Appendix.

The regulatory requirements specify that the maximum deviation at any point of measurement shall not exceed one degree from the true vertical (Chapter 17-28; FAC). The two maximum angular deviations recorded during the two phases of drilling were 60 minutes, at a depth of 1,895 feet in the pilot hole, and 55 minutes, at 340 feet in the reamed hole (see Table 4-2). The average deviation during the pilot hole phase of drilling was about 0.4 degrees, or 27 minutes. The average during the reaming phases was 0.5 degrees, or 31 minutes. These values represent an exceptionally straight hole, overall.

In summary, based on sure-shot data, both the pilot and the reamed open holes satisfy the Chapter 17-28 criterion of a maximum point deviation of one degree.

The directional surveys were conducted after pilot hole drilling and again after reaming. Three logging companies were involved and each company used a different kind of tool and a different way of presenting the data.

The first two sets of directional surveys were run on the pilot hole and on the reamed hole for the outer casing by Woodward-Clyde. The Woodward-Clyde system produces a continuous log on the display panel in the field, but retains only a small number of points on the actual print-out of the log. The data show not only the actual deviation in degrees, but also the map direction (azimuth) in degrees from north. In the pilot hole, the Woodward-Clyde log (see Appendix 1) showed a maximum deviation of 0.2 degrees at a depth of 90 feet and in a south-southwest direction (190^{o} azimuth). In the reamed hole (see Appendix 2), it showed a maximum deviation of 0.3 degrees at three depths: 60, 180, and 210 feet.

The next two sets of directional surveys were run on the pilot hole and the reamed hole for the intermediate casing by Southern Resource Exploration. The Southern Resource Exploration system produces a graph that indicates deviation in feet from vertical; consequently, at each point, this distance must be divided by the depth to obtain the cosine of the angle of deviation. From the cosine, the angle can then be calculated. This calculation is done by a computer program that looks at the data from the tape. When this program was run on the pilot hole, it showed a maximum deviation of 0.82 degrees at a depth of 295 feet, and deviations of 0.72 degrees at 655 feet, and 0.60 degrees at 1,195 feet (see Appendix 3). All other deviations were less than 0.60 degrees. The azimuth angle for each of these measurements can also be determined from the distances from north and east. A second computer program was used to do this, the results of which are also shown in the print-out of the log (see Appendix 3).

A similar analysis of the data from the Southern Resource Exploration directional logs was performed for the reamed hole (see Appendix 4). This analysis showed a maximum deviation of 1.0 degrees at a depth of 892 feet and 0.9 degrees at 952 feet. Deviations of 0.5 degrees were calculated at 592 feet and at 1,192 feet.

Two sets of directional surveys were run on the pilot hole and the reamed hole for the inner casing by Schlumberger. The Schlumberger system is the only one of the three used that produces a continuous graph of the deviations and azimuths (as opposed to the others, which produce a digitized computer output) and consequently yields the most amount of information. For the pilot hole, the Schlumberger log showed a maximum deviation of 1 degree at 2,128 feet and again at 2,136 feet. At 2,141 feet, it showed a deviation of 1.2 degrees; however, this was a reading inside of the largest cavern in the hole and the centralizers around the logging tool were not large enough to centralize it in the hole. This reading at 2,141 feet should not be taken at face value. A large cavity such as this (see television survey) cannot possibly be gaged; in effect the cavity is not drilled, but rather the drilled hole passes through it.

For the reamed hole, the Schlumberger deviation log showed that every part of the hole was less than 1 degree from the vertical. The maximum recorded value was about 45 minutes at a depth of 2,280 feet. A "blip" in the deviation log at 2,342 feet was outside the reamed hole and was not a valid measurement.

In summary, based on the directional survey data, both the pilot and reamed hole satisfy the Chapter 17-28 criterion of a maximum deviation of one degree.

The net closure at the bottom of the hole and, consequently, the location of the casing can be calculated by integrating all the individual deviations and azimuths. The net closure is the deviation of the center point at the bottom of the reamed hole from the true vertical suspended from the center point of the top of the well. In the north-south direction, this closure is 0.7 feet north; in the east-west direction, it is 2.4 feet east, for a net closure of 2.5 feet. This represents a total hole angular deviation over the 2,340 feet of cased hole of 0.06 degrees or 3.5 minutes. The center point of the bottom of the casing (assuming the casing is perfectly centered in the reamed hole) is located 2.5 feet northeast of the top of the hole.

m:H-87/d

Section 7
SITE HYDROGEOLOGY

The geolograph records, the geophysical logs, the lithologic samples, the geologic cores, and the water quality samples collected from the drilling operation were used in Section 2 to develop the detailed descriptions of the geology and hydrogeology of the formations underlying the site. In this section, however, these data are analyzed.

Discrepancies exist in the depths of various features from one set of data to the next. These discrepancies result from different starting data, cumulative errors, etc. For example, the differing data used by the drillers and the geophysical loggers at each visit can be seen in the various geophysical logs in the Appendices. Consequently, the depths of various formations, caverns, water quality changes, and other important hydrogeolgical features are sometimes slightly different from the true depths below land surface. These variations should not be viewed as mistakes in the data base, but rather as errors inherent to the data acquisition equipment.

7.1 LITHOLOGIC SAMPLES

The PBS&J site supervisors collected representative formation samples every five feet during drilling, and each sample was described and recorded in a lithologic log (see Appendix 23). These field descriptions were later supplemented by detailed microscopic descriptions in the office (see Appendix 24).

From the sample descriptions and the lithologic logs, and with the help of data from other investigations, the depths and nomenclatures of the various formations and hydrologic divisions were identified in Section 2. For the lower geological units, which are of primary interest in this study, cuttings from the lower parts of the well provided the principal source of data, although data from the exploratory/monitor well were also used. Core samples collected by the drillers and sent to Core Laboratories Inc. (CLI) in Texas for analyses were also used. For the upper geologic units, of secondary concern in this study, geologic and hydrologic identification was largely based on previous work at the site and on the lithologic descriptions in Appendices 23 and 24.

From the lithologic sample analysis, the mineralogical analyses, and existing literature, a column of the geologic units penetrated at the NFMU site was developed. Figure 2-5 shows the estimated depth ranges of the geologic units underlying the NFMU site (see Section 2).

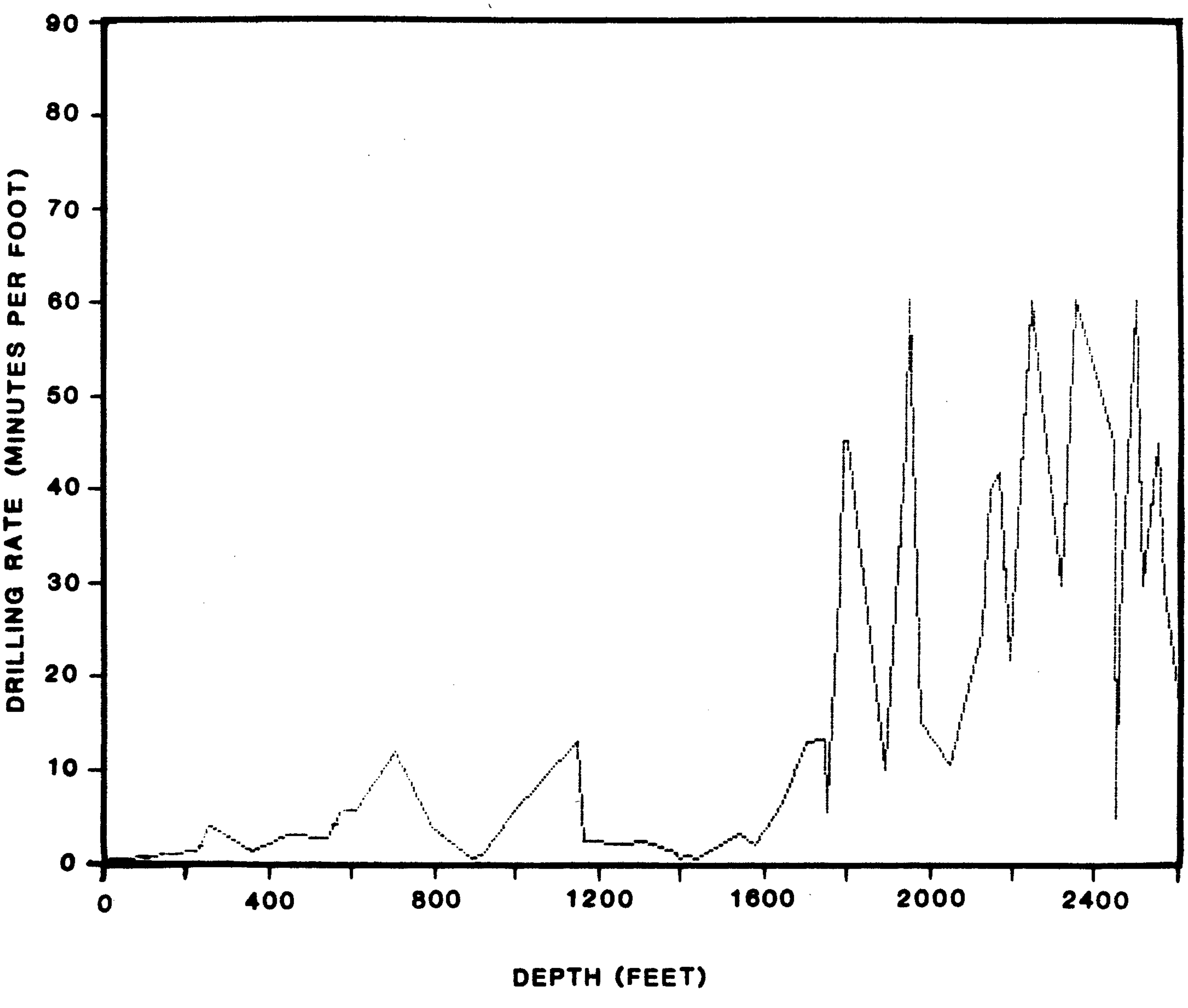
7.2 GEOLOGRAPH RECORDS

As drilling progressed through the various formations, starting on May 8, 1987 at 25 feet below land surface, the drillers recorded the rate of progress. From the geolograph records, PBS&J plotted the rate of drilling against hole depth, as shown in Figure 7-1. The drilling rates shown in Figure 7-1 provide an indication of the degree of formation hardness when the drilling weight is the same. Only the pilot hole data have been plotted since these data are for the same size bit.

Reaming data are affected by the size of the bit and, therefore, do not offer good comparative information. When all other factors remain constant, formation hardness is somewhat related to the intergranular porosity of the rock. Therefore, the geolograph record is a useful tool in assessing the nature of the various strata, especially when it is utilized in conjunction with other data such as those derived from the lithologic sample analyses.

In the pilot hole, drilling rates initially increased, reaching a peak at 700 feet below land surface, then declined to a low at 900 feet below land surface only to increase again at 1,150 feet below land surface. These low drilling rates at 700 and 1,150 feet correspond to the harder limestones in the Suwannee Formation and are a good gage by which to measure the density and degree of cementation of the limestone.

The next series of low drilling rates recorded correspond to the first dolomitic layers of the Avon Park at about 1,750 feet. From 1,750 feet



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DRILLING RATE VERSUS DRILLING DEPTH

FIGURE 7-1

downward, there was a very sharp decrease in the drilling rate, attributable to the dolomitic layers occurring from there to the bottom of the well.

One feature that clearly stands out in the graph of the geolograph data is a sharp increase in the drilling rate at around 2,100 feet deep. This is where the cavernous zones are found and where drilling was relatively faster.

The drilling rates at the 2,420-foot depth exhibited a large increase. This increase is indicative of the extreme softness of the material that composes the lignite bed found at that depth.

In general, the geolograph record shown in Figure 7-1 corroborates the findings of the lithologic sample analysis described in Appendices 23 and 24, and no significant discrepancies were identified. The raw geolograph data are in the form of long charts, not easily reproduced, and, therefore, have not been included in the Appendix; however, the charts are available on loan from PBS&J, if so requested.

7.3 CORE ANALYSIS

In compliance with the technical specifications for the NFMU deep test/injection well, eight 10-foot (minimum) cores were taken during the drilling of the pilot hole. All eight cores were 4 inches in diameter and samples from each were selected for analysis by CLI. These core sets are described in Section 7.3.1, followed by a detailed discussion of the core analysis in Section 7.3.2. The coring operations have been described as they occurred in Section 4, and are outlined in Table 4-1. Geologic and lithologic descriptions of the cores are included in Appendix 25 and the results of the special core analysis study conducted by CLI are presented in Appendix 19.

7.3.1 Core Description

The first coring was into the Ocala Limestone from a depth between 1,333 and 1,343 feet below land surface; but only 55 percent recovery was achieved. The recovered section represented the zone between 1,337.5 and 1,343 feet (see

Table 7-1). The core showed two very slightly different lithologies, one in the upper two feet of the core and the other in the lower three feet. The slight difference between the upper and lower part of the core was the presence of a higher percentage of allochems in the lower three feet of the core. Both the upper and lower parts showed moldic porosity. The core was a chalky and soft limestone, white to very pale orange in color, and of very low permeability (see Appendix 25). A representative sample of the core from 1,341 feet was sent to the core laboratory for analysis.

The second core was drilled out of the Ocala Limestone also. This core was obtained from between 1,435 and 1,448 feet below land surface and the full 13 feet of core (100 percent) was recovered. The core was homogeneous from top to bottom, its only slight difference being an increase in moldic porosity with depth. This moldic porosity, however, was not interconnected and, therefore, the permeability was very low. The core was a moderately indurated white chalky limestone. A sample from 1,443 feet was sent to the laboratory for analysis.

The third core, taken in the 1,605- to 1,617-foot depth range, consisted of a white to pale orange colored limestone from the upper part of the Avon Park Formation. The core was relatively uniform from top to bottom and its most significant features were that it was slightly recrystallized and very fossiliferous. The core was moderately indurated and appeared to have low permeability; but, it did show moldic porosity. The core recovery was 100 percent and the section sent to the laboratory for analysis was from a depth of 1,608 feet.

The fourth coring was from the lower part of the Avon Park from a depth between 1,875 and 1,885 feet below land surface; but, only 15 percent of the core was recovered. The section sent to the laboratory was from 1,880 feet. This core was identified in the field as a dolomitic limestone ranging in color from a very pale orange to a yellowish gray. It was very well indurated, and less porous than the core collected in the upper part of the Avon Park. That core, from 1,605 to 1,617 feet, had moldic porosity, whereas this core had intercrystalline porosity instead. The permeability was very low.

Table 7-1

CORE RECOVERY DATA

Core	Formation	Depth Cored (in feet)	Footage	Depth Retrieved (in feet)	Footage	Recovery (%)	Tested Interval (in feet)
1	Ocala	1,333 - 1,343	10	1,337.5 - 1,343	5.5	55	1,340 - 1,341
2	Ocala	1,435 - 1,448	13	1,435 - 1,448	13.0	100	1,442 - 1,443
3	Avon Park	7,605 - 7,617	12	1,605 - 1,617	12.0	100	1,607 - 1,608
4	Avon Park	1,875 - 7,885	70	1,875 - 1,881.5	6.5	65	1,880 - 1,881
5	Lake City	2,160 - 2,163	3	2,160 - 2,163	3.0	100	2,163 - 2,164
	Lake City	2,163 - 2,167	4	2,163 - 2,165	2.0	50	
6 a & b	Lake City	2,260 - 2,270	10	2,260 - 2,269.5	9.5	95	2,261 - 2,263 2,263 - 2,264
7	Lake City	2,320 - 2,330	10	2,320 - 2,329.5	9.5	95	2,325 - 2,326
8	Lake City	2,450 - 2,453	3	2,450 - 2,453	3.0	100	2,453 - 2,454
		2,453 - 2,463	10	2,453 - 2,458	5.0	50	

m:H-87(II)/b

The fifth core came from a depth of between 2,160 and 2,167 feet in the Lake City Limestone. Two separate coring runs were made; the first, from 2,160 to 2,163 feet, was into a dolomite colored light olive brown at the top and changing to a yellowish brown at the bottom, and the second, from 2,163 to 2,167 feet, was into a very pale orange to yellowish gray limestone. The extremely dense and hard dolomite section was fully recovered (100 percent); but only 50 percent of the limestone section was recovered. The porosity was vugular and crystalline; no moldic porosity was exhibited. The permeability was extremely low. A section from 2,163 feet was selected for analysis in the core laboratory.

The sixth core was also from the Lake City. It came from a zone 2,260 to 2,220 feet below land surface. The first two-and-a-half feet of the core were dolomitic limestone and the other seven feet, dolomite. Ninety-five percent of the core was recovered and two samples, one from 2,261 feet and the other from 2,263 feet, were sent to the laboratory for further study. Both parts of the core were extremely dense. There was no porosity to speak of and when there was, the pores were filled with micrite. There were no distinguishable fossils either; although some fossil ghosts were found. For all practical purposes, this core can be said to be impermeable.

The seventh coring, taken from 2,320 to 2,530 feet, was just above the injection zone. This section was originally going to be included in the open hole, but was not because a very low permeability zone just below made casing through it desirable. This was the most permeable of the cores collected at the site and its higher permeability was due to interconnected granular and vugular porosity. This higher permeability is, however, relative to the lower permeability of the other cores; it was still too low to qualify the core as anything but a core from a confining zone. The sample sent to the laboratory was from a depth of 2,326 feet.

The last core collected, the eighth, came from a section of the Lake City between 2,450 and 2,463 feet below land surface. This core was also collected in two attempts: one section was from 2,450 to 2,453 feet and yielded 100 percent recovery; the other was from 2,453 to 2,458 feet and yielded 50 percent recovery. This core was collected to provide the heat capacity and thermal conductivity data for the injection zone needed for input into the SWIP computer model.

7.3.2 Core Testing Results

As noted in Section 7.3.1, eight samples selected from the corings made at NFMU were submitted to CLI for testing. These core samples were accompanied by water samples from the zones the cores were taken from. The depths from which the samples were selected are shown in the last column in Table 7-1.

The testing program on the samples included:

- o Air permeability
- o Porosity
- o Liquid permeability
- o Formation resistivity factor
- o Resistivity index
- o Accoustic velocity (compressive velocity and shear velocity)
- o Dynamic moduli (shear modulus, bulk modulus, and Young's modulus).

Sample 8 was also tested for its rock heat capacity and thermal conductivity for use in the SWIP (see Section 9). In addition, rock compressibility was determined for Samples 3, 6 and 7 at the request of the USGS to help compare this test site with other sites investigated by USGS. Finally, X-ray diffraction (XRD) analyses were conducted on the eight samples to determine the mineral content of the various cores.

7.3.2.1 Air Permeability and Porosity

Sample plugs from each core were obtained using a diamond drill bit with water as the bit coolant and lubricant. The sample plugs were cleaned in a reflux soxhlet with methyl alcohol and dried in a convection oven at 240°F until stable weights were obtained. Permeability to air and Boyle's law porosity (using helium) measurements were then taken on the cleaned and dried samples.

The results for both measurements are shown in Table 7-2. The permeability to air is given in darcy units, as it is meaningless to convert these units to the usual gallons per day per square foot (gpd/ft^2) because the dimensional requirements of the latter include the permeant characteristics. The darcy unit does not include permeant characteristics and different permeants can, therefore, be compared directly.

Table 7-2 indicates consistently greater permeability in the horizontal direction than in the vertical direction for all of the test samples, except Sample 8F. This difference can be as much as three orders of magnitude. In the x-y directions within the horizontal plane, there is also little difference in permeability except in Sample 3B. Despite the higher horizontal than vertical permeability in every direction, the horizontal permeability in most samples is still extremely low.

Sample porosity appears to be directly related to permeability. Figure 7-2 shows a plot of the porosity versus permeability of the samples. A straight line relationship through the best fit of the points has a correlation coefficient of 0.78 and, if the three samples with porosity above 35 percent are removed, the fit is 0.89.

The plot in Figure 7-2 is not a mathematical or theoretical derivation, but only an empirical relationship and should be applicable only for similar types of rock samples extracted from the NFMU site. The porosity has a direct semilogarithmic relationship with the permeability to air for these samples, but this relationship might not hold true for other samples.

The relationship developed in Figure 7-2 for porosity and permeability can be presented in the form of an equation, as follows:

$$\text{Log } P = 0.1708\ \emptyset - 1.98$$

where P is the permeability to air (in millidarcys) and
$\emptyset$ is the porosity (in percent)

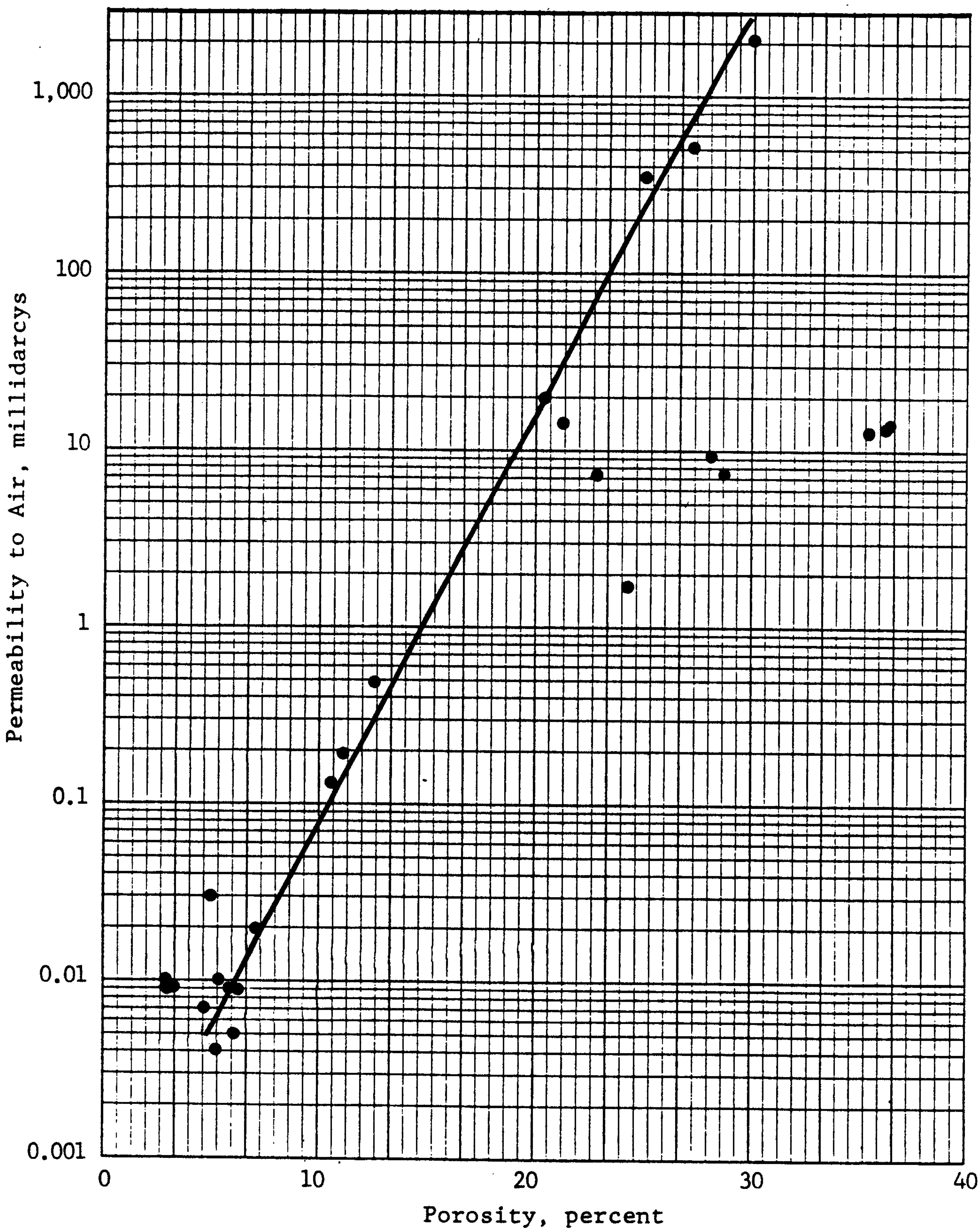
Table 7-2

AIR PERMEABILITY AND POROSITY

Sample Number	Depth (feet)	Permeability to Air (millidarcys)[a]	Porosity (percent)
Ocala Formation			
1A	1,341	7.5	28.7
1B	1,341	9.2	28.1
1C	1,341	1.8	24.3
1V	1,341	b	b
2A	1,443	15	36.5
2B	1,443	13	35.5
2C	1,443	14	36.3
2V	1,443	b	b
Avon Park Formation			
3A	1,608	7.2	22.8
3B	1,608	502.0	27.2
3V	1,608	b	b
4A	1,880	15.0	21.3
4B	1,880	20.0	20.4
4V	1,880	b	b
Lake City Formation			
5A	2,163	0.19	11.1
5B	2,163	0.49	12.6
5C	2,183	0.13	10.6
5V	2,163	b	b
6A	2,261	0.01	5.4
6B	2,261	0.004	5.3
6C	2,261	0.03	5.0
6V	2,261	b	b
6D	2,263	0.005	6.1
6E	2,263	0.009	5.9
7A	2,326	2,100.0	30.0
7B	2,326	352.0	25.0
7V	2,326	b	b
8A	2,453	0.009	3.3
8B	2,453	0.009	3.0
8C	2,453	0.01	2.9
8D	2,453	0.007	4.7
8E	2,453	0.02	7.1
8F	2,453	b	b
8V	2,453	0.009	6.3

[a] 400 psi confining stress
[b] Value too low for measurement
[c] A through F represent x and y directions in the horizontal plane and V represents the z direction in the vertical plane.

m:H-87(II)/c



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POROSITY VERSUS PERMEABILITY TO AIR

FIGURE 7-2

7.3.2.2 Liquid Permeability (Permeability to Water)

The eight samples of formation water from the zones of interest were analyzed (see Appendix 19) and an equivalent TDS/sodium chloride brine was calculated from the water analysis for each zone and used in all subsequent tests. Eight horizontally oriented sample plugs (one from each zone) were then selected for specific-permeability-to-water measurements. Horizontal samples were selected instead of vertical samples because the vertical samples had already shown such a low permeability to air that it was known ahead of time that they would not show any permeability to water.

The eight horizontal samples were then evacuated and pressure-saturated with the corresponding formation brine equivalent. Each sample was individually placed in a hydrostatic core holder and injected, under back pressure, with the saturant to assure 100 percent saturation. Following this step, specific permeabilities to water were determined.

Specific permeability to water was measured only on one plug sample from each zone, and only on horizontal samples. CLI regarded the vertical test samples as impermeable to water. The results of the tests for specific permeability to water are shown in Table 7-3. As expected, the laboratory analysis results for permeability to water were much less than the permeability-to-air results shown in Table 7-2.

The water-to-air permeability ratios are also given in Table 7-3. Assuming that the ratio of permeability to air and the specific permeability to water are equal, the probable maximum permeability to water can be calculated from the data in Table 7-2 for the remaining test samples. The true permeabilities to water are probably much less than any maximum possible values calculated in this manner.

The layers encountered from below the 1,800-foot depth down to 2,130 feet were comparatively impermeable. Though this section showed vug porosity, the permeability data indicated no interconnection of the vugs. The permeability of the core samples from 1,880 feet was only 12 millidarcys. Hence these layers are effective aquicludes. The layers between 2,150 and 2,320 feet were also of low permeability. The core samples from 2,160 feet were impermeable in nature, totally separating the injection zone from the USDWs 800 feet above.

7.3.2.3 Formation Resistivity Factor and Index

The next two parameters for which the samples were tested, the formation factor and the resistivity index, are interrelated. Both of these parameters are related to resistivity measurements as follows:

$F = R_o/R_w$

where F is formation factor (dimensionless)

R_o is resistivity of saturated formation (ohms-cm)

R_w is resistivity of formation fluid (ohms-cm)

$S^n = R_o/R_t = 1/RI$

where RI is resistivity index (dimensionless)

S is the fraction of the pore space occupied by formation water

n is saturation exponent

R_t is resistivity of clean formation (ohms-cm)

The formation factor can be redefined in terms of the formation porosity by Archie's Equation (Kovacs, 1981) as follows:

$$F = a\,\phi^{-m}$$

where m is the cementation factor

a is an empirical constant usually taken as unity

The eight horizontal samples, along with a selected companion sample from each zone (also saturated with the appropriate brine), were used for formation-resistivity-factor testing. A liquid resaturation porosity was calculated for each sample and was used in all electrical property evaluations. The resistivities of the brines and the brine-saturated samples were measured over a period of several days until stable, indicating that ionic equilibrium within the samples had been achieved.

Using the formation resistivity factor values developed by CLI (see Table 7-4 and Appendix 19), eight formation resistivity factor versus porosity graphs were plotted for the eight zones of interest (see Figures 7-3 through 7-10). The Archie parameter "a" was constrained to a value of 1.00 due to the limited sample populations. Cementation exponents, "m," ranging from 1.53 to 2.48, were calculated using Archie's relationship and the data trends generated by the best-fit-least squares method. These values were then used to evaluate the geophysical logs, as described in Section 7.4.

After the formation resistivity factor measurements were completed, one sample from each zone was desaturated using humidified air in a porous-plate cell. At selected saturations, determined gravimetrically, the resistivities of the core plugs were measured to provide a correlation between the formation resistivity index and water saturation. The samples selected from 2,163, 2,261, and 2,453 feet did not desaturate sufficiently for confident measurement. The results for the other five samples are tabulated with the formation factor results in Table 7-4.

Saturation exponents, "n," determined from the lines of best fit to the data points, ranged from 0.77 to 1.77 (see Figures 7-11 through 7-17). Two composite graphs containing the samples saturated with low salinity brines and the samples saturated with high salinity brines yielded 1.02 and 1.71, respectively. These graphs are found in Figures 7-13 and 7-17.

The low saturation exponents for Samples 1A and 2A, saturated with 1,500-parts per-million (ppm) sodium chloride brine and a 2,100-ppm sodium chloride brine, respectively, may not reflect the true electrical properties of the rock and may be a result of testing with low salinity saturants. Only those results from the other samples should be used in evaluating the geophysical logs.

7.3.2.4 Acoustic Velocity

A 1-inch-diameter vertically oriented sample plug from each zone of interest was selected for use in acoustic velocity testing. The eight samples were pressure-saturated with the formation brine equivalent, and mounted in

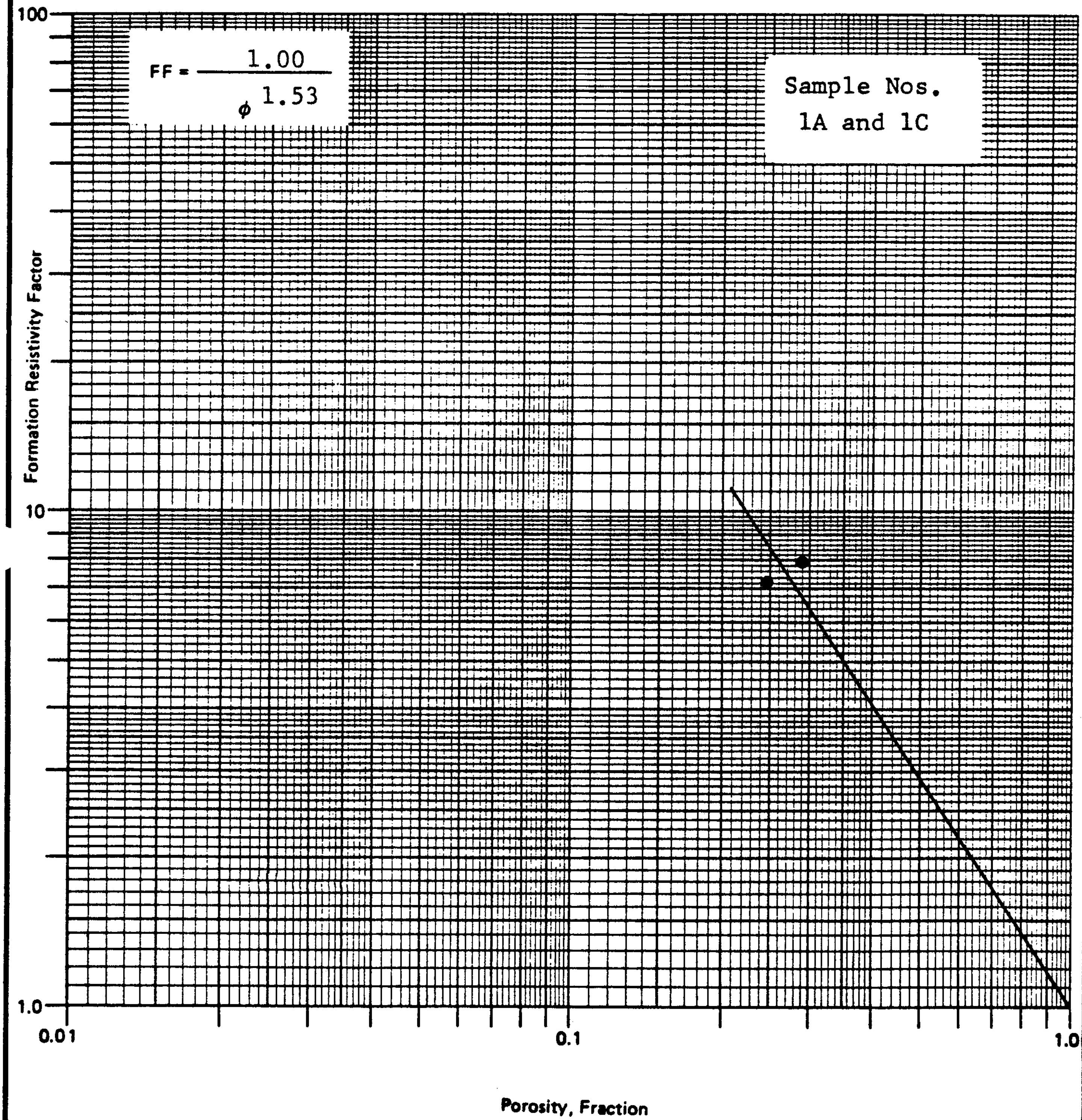
Table 7-4

FORMATION RESISTIVITY FACTOR AND INDEX

Sample Number	Depth (feet)	Permeability to Air (millidarcys)	Porosity (percent)[a]	Formation Resistivity Factor	Water Saturation (percent pore space)	Formation Resistivity Index
1A	1,341	7.5	28.9	7.92	100.0	1.00
					82.2	1.14
					73.4	1.28
1C	1,341	1.8	24.7	7.21	100.0	1.00
2A	1,443	15.0	36.5	6.96	100.0	1.00
					86.7	1.18
					79.1	1.32
					70.6	1.52
2B	1,443	13.0	35.5	7.34	100.0	1.00
3A	1,608	7.2	22.8	22.4	100.0	1.00
3B	1,608	502.0	27.2	16.6	100.0	1.00
					68.5	1.77
					55.4	2.67
					47.0	3.62
					41.1	4.93
4A	1,880	15.0	21.3	24.1	100.0	1.00
4B	1,880	20.0	20.4	24.0	100.0	1.00
					67.6	1.87
					51.0	2.99
					40.0	4.62
5B	2,163	0.49	12.6	67.1		
5C	2,163	0.13	10.7	93.7		
6A	2,261	0.01	5.5	240.0		
6B	2,261	0.004	5.3	220.0		
7A	2,326	2,100.0	30.2	16.0	100.0	1.00
7B	2,326	352.0	25.2	36.5	100.0	1.00
					45.7	4.34
					25.1	11.8
					20.0	17.3
					18.0	20.3
					16.2	24.7
8B	2,453	0.009	4.5	884.0		
8E	2,453	0.02	7.7	692.0		

iquid resaturation porosity

m :H-87(II)/e



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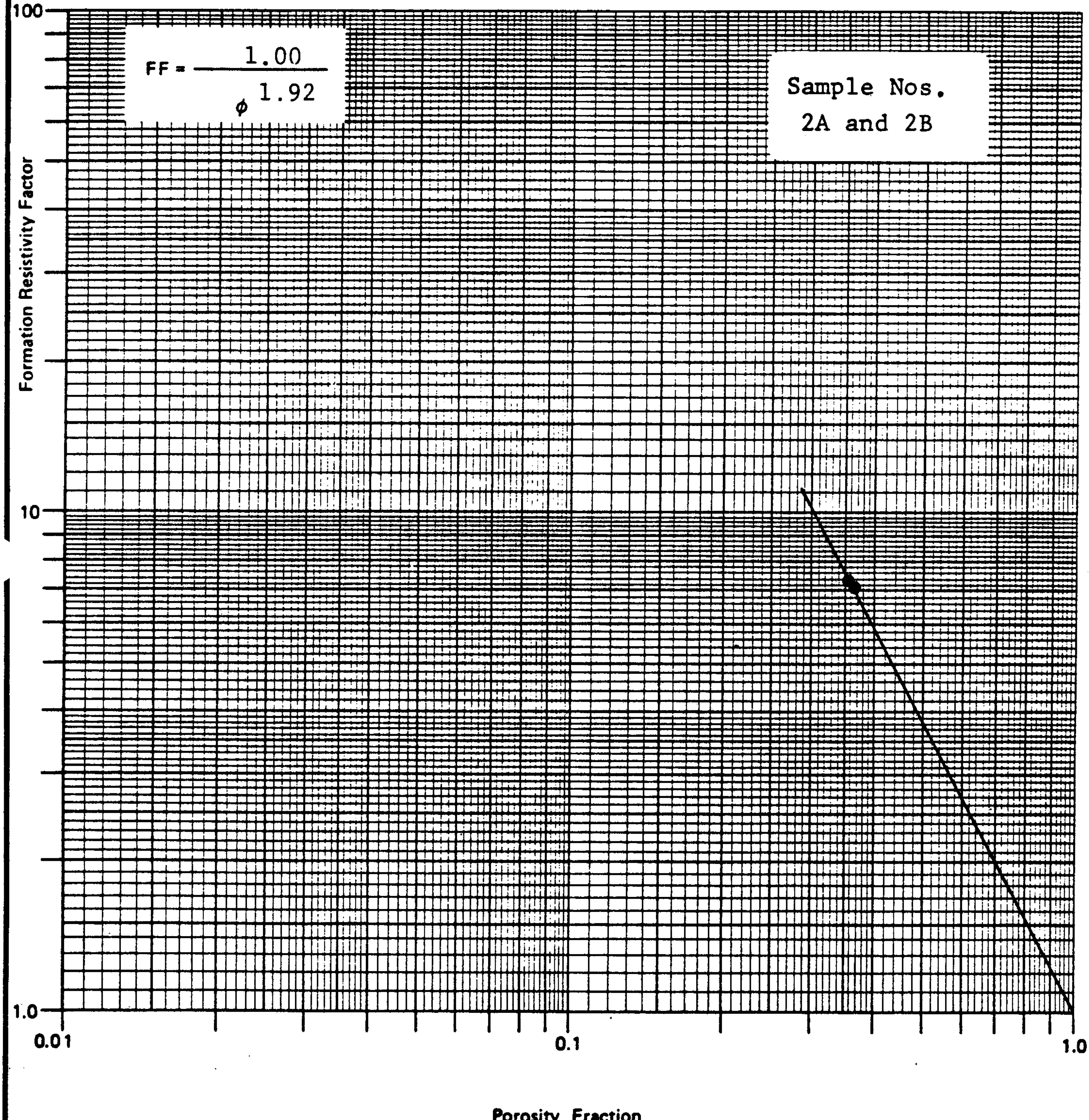
FORMATION RESISTIVITY VERSUS POROSITY

FIGURE 7-3



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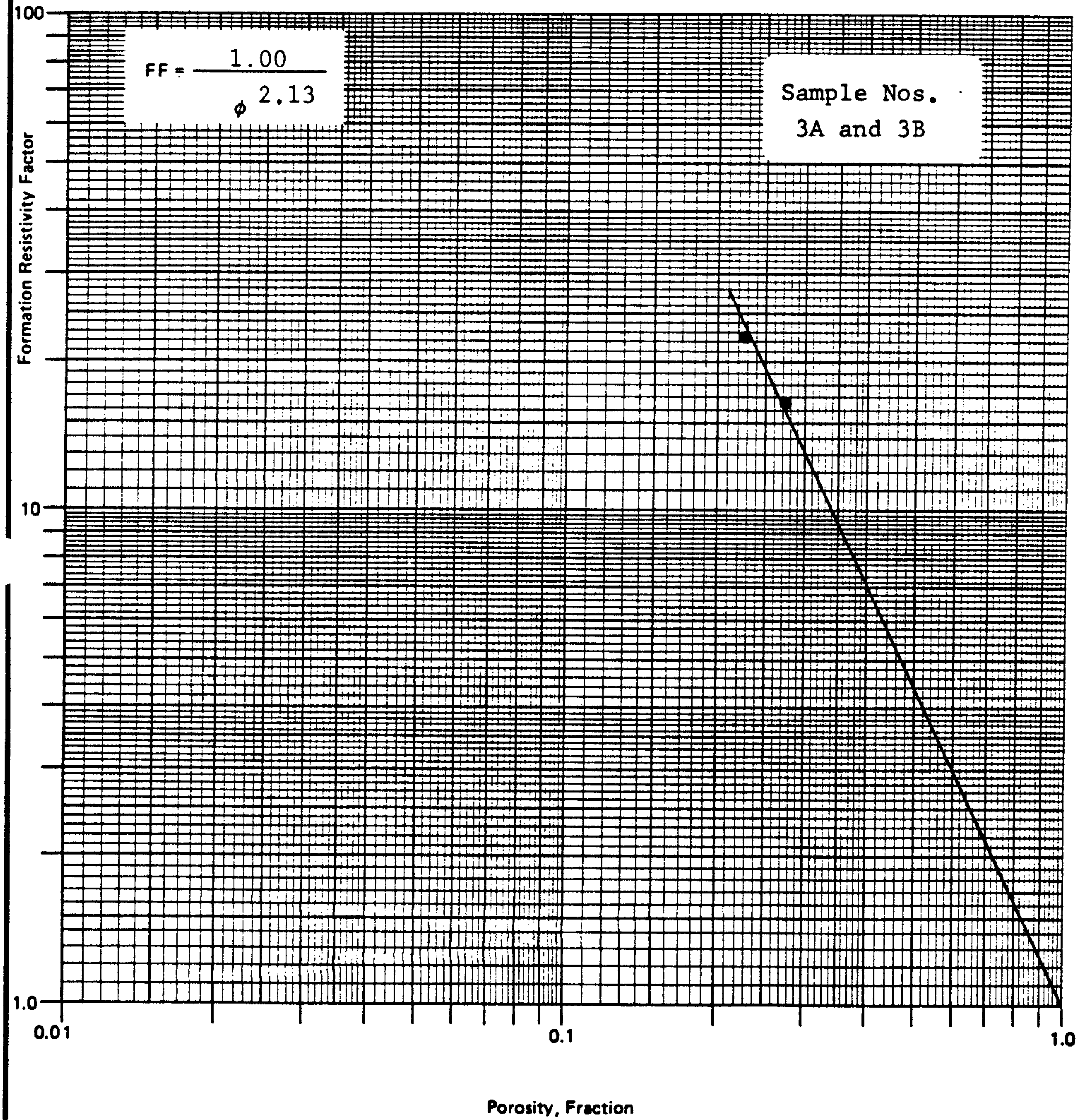
FORMATION RESISTIVITY VERSUS POROSITY

FIGURE 7-4



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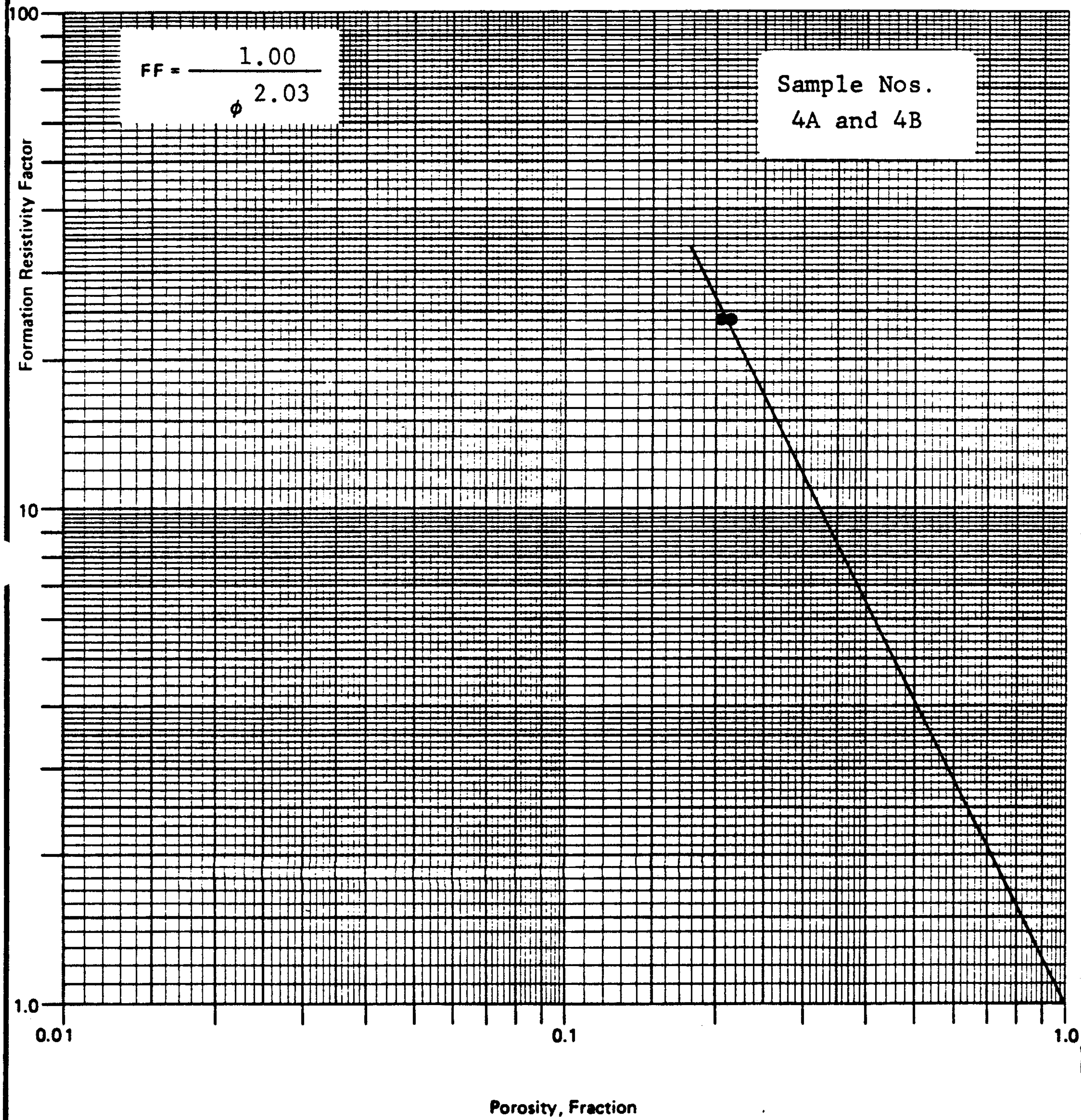
FORMATION RESISTIVITY VERSUS POROSITY

FIGURE 7-5



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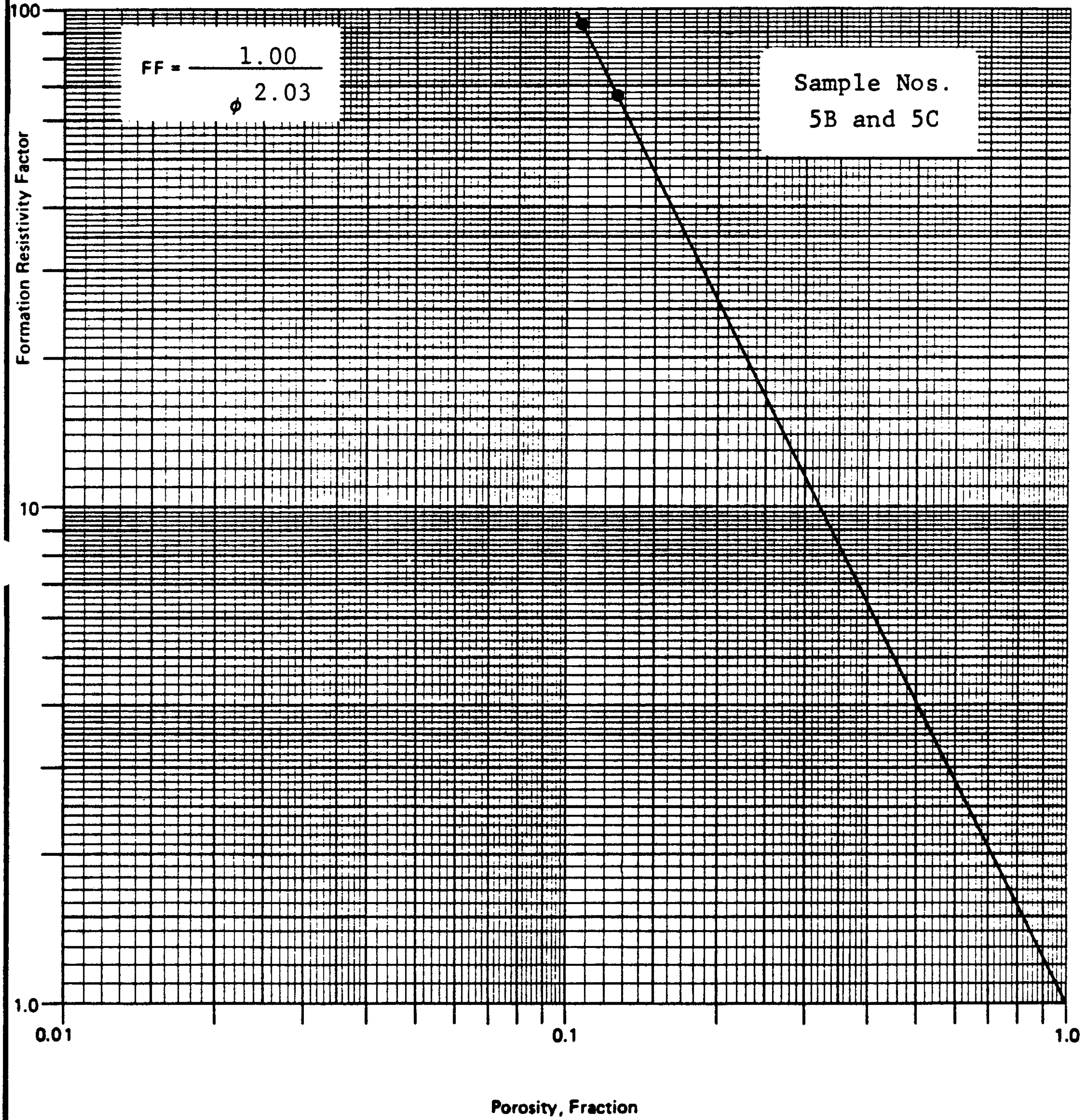
FORMATION RESISTIVITY VERSUS POROSITY

FIGURE 7-6

201872

REPRO PRODUCTS INC. 7A



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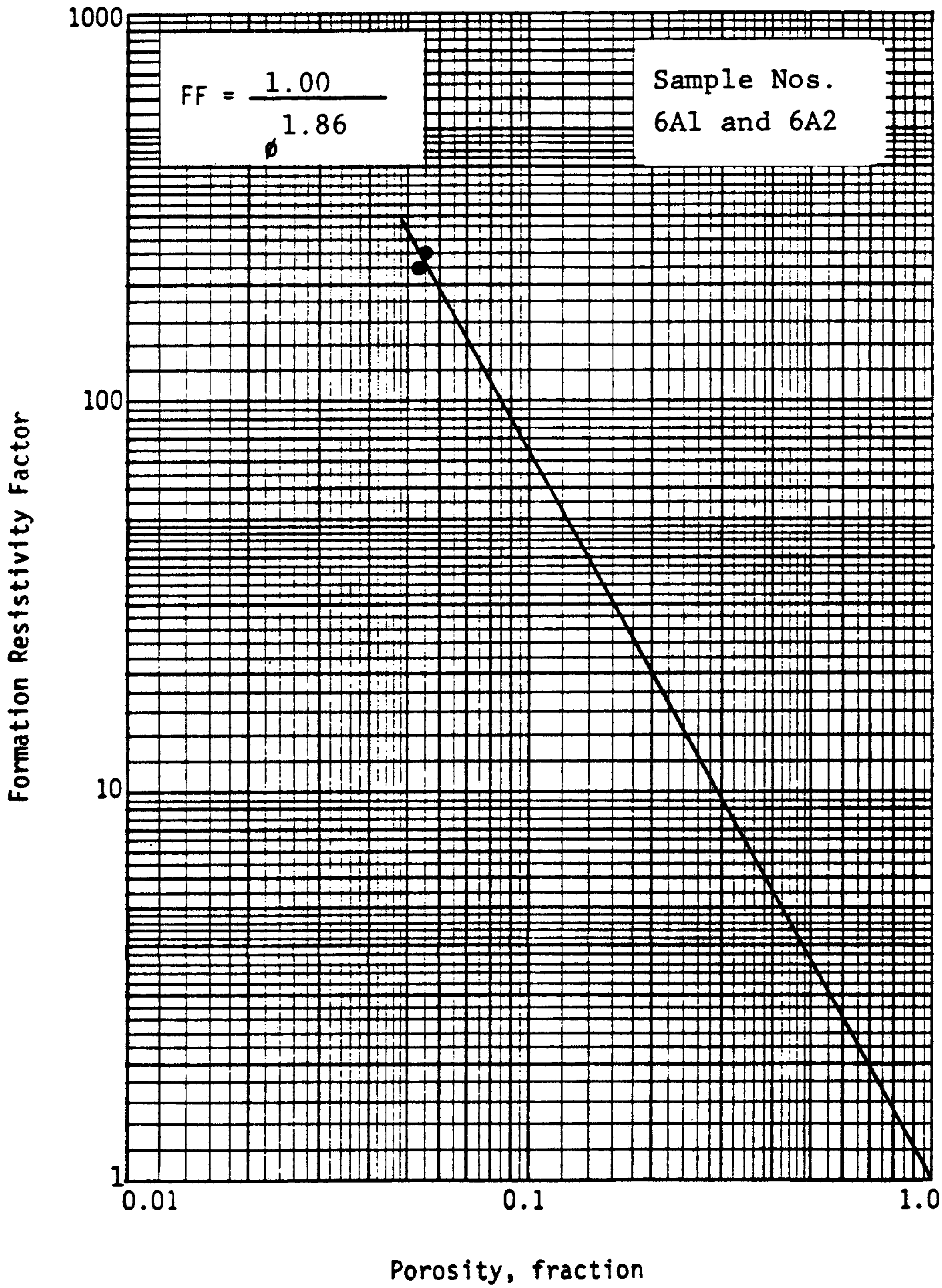
FORMATION RESISTIVITY VERSUS POROSITY

FIGURE 7-7



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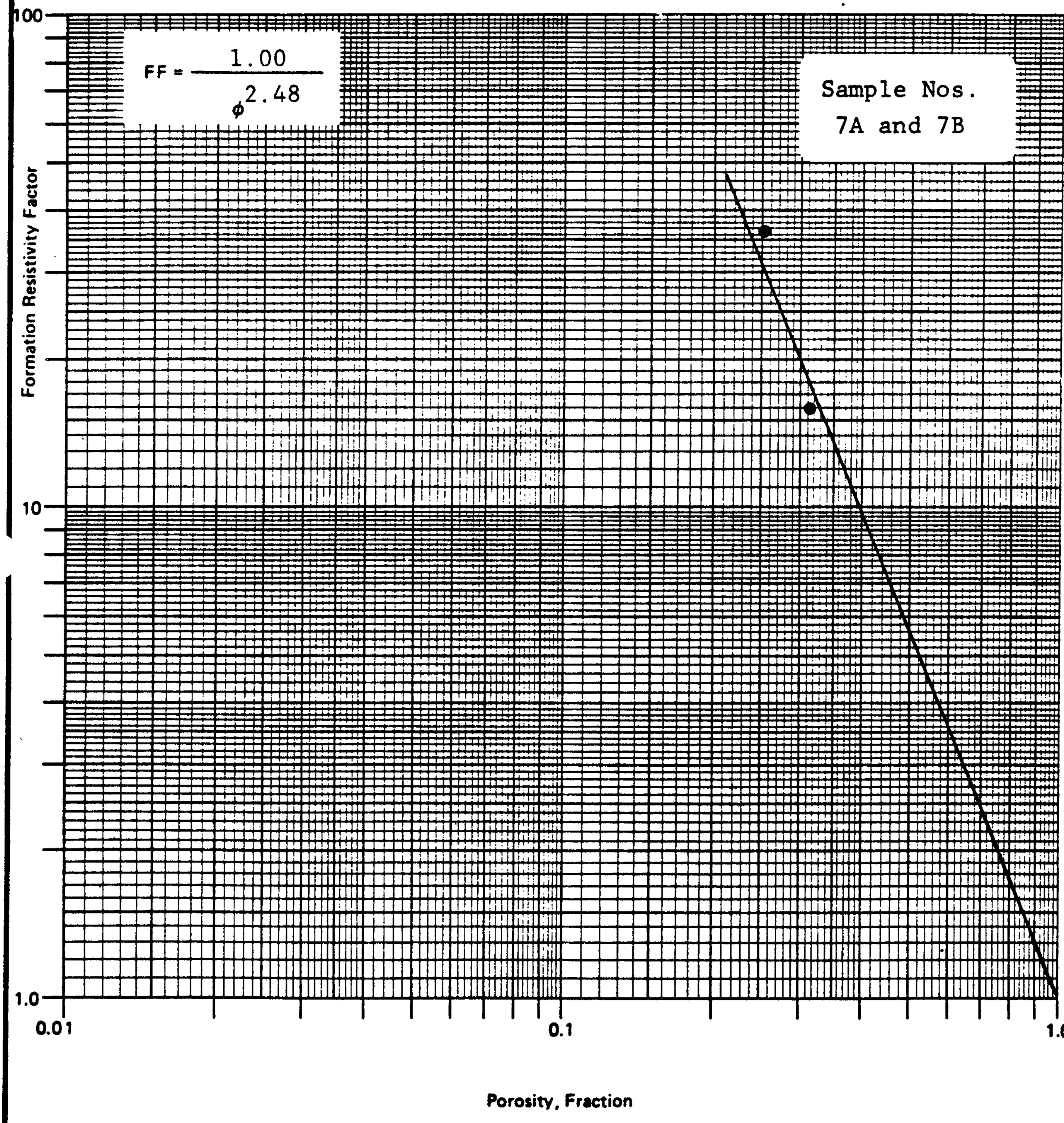
FORMATION RESISTIVITY VERSUS POROSITY

FIGURE 7-8

301072

REPRO PRODUCTS INC. 7A



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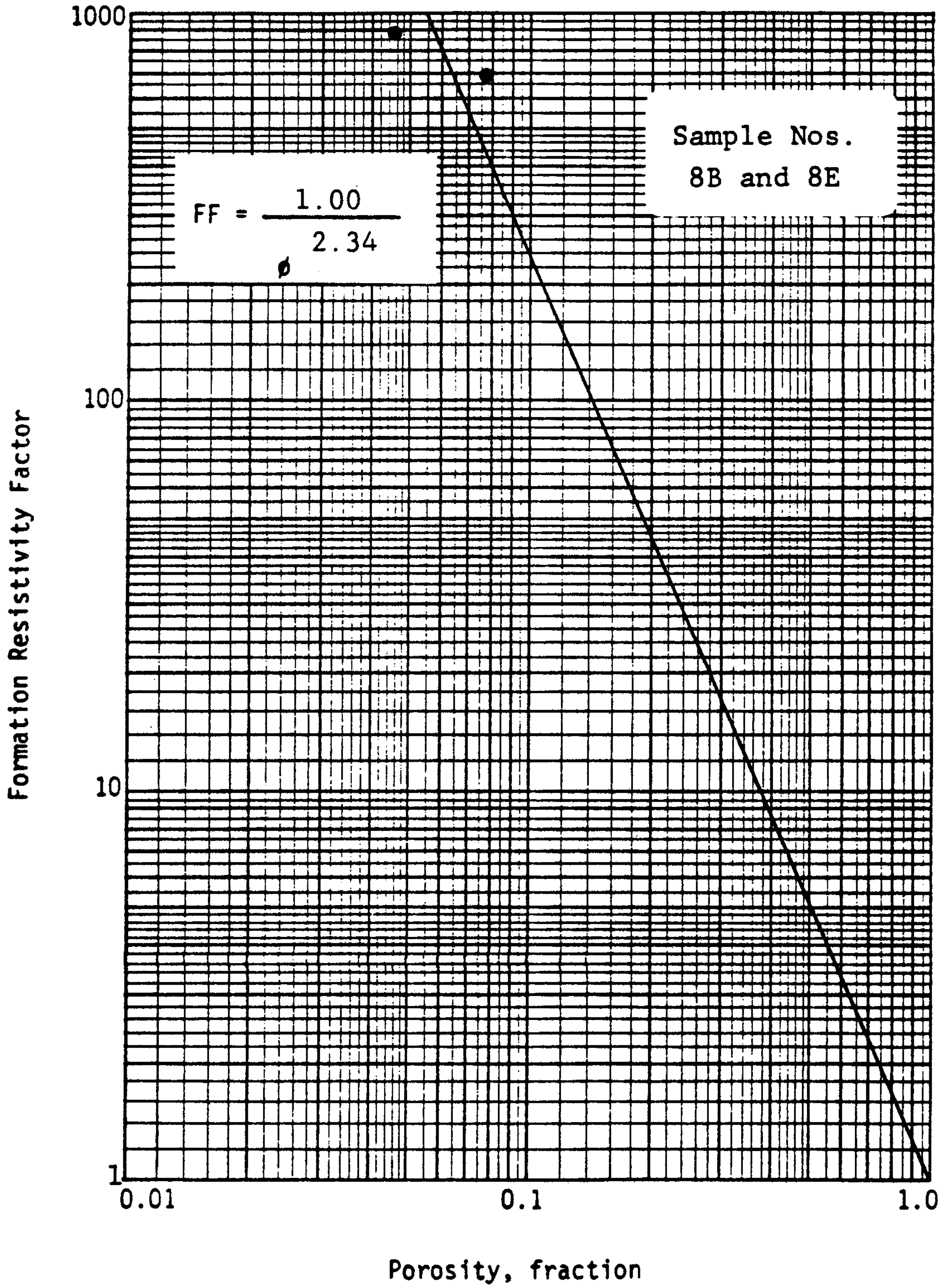
FORMATION RESISTIVITY VERSUS POROSITY

FIGURE 7-9



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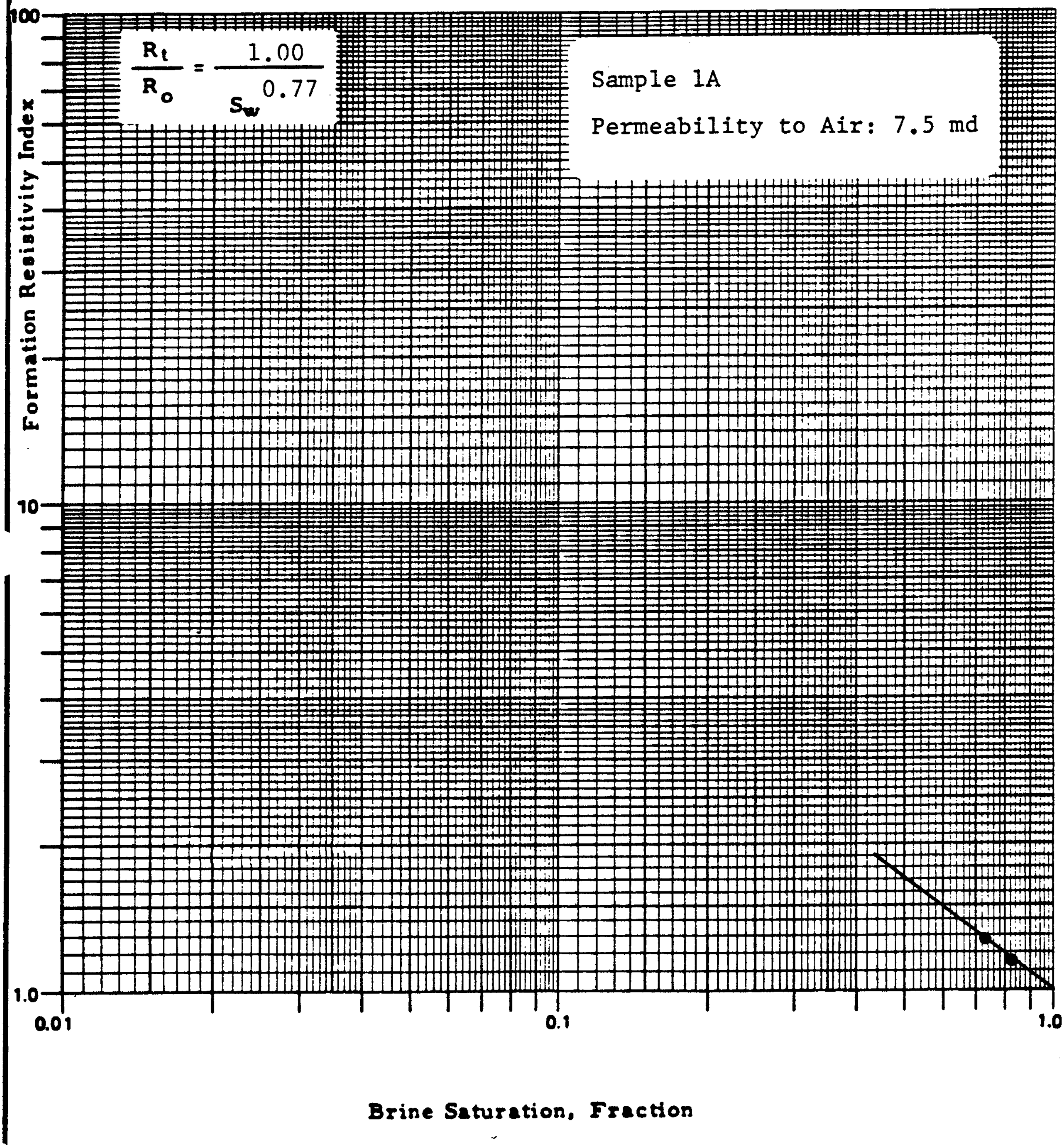
FORMATION RESISTIVITY VERSUS POROSITY

FIGURE 7-10



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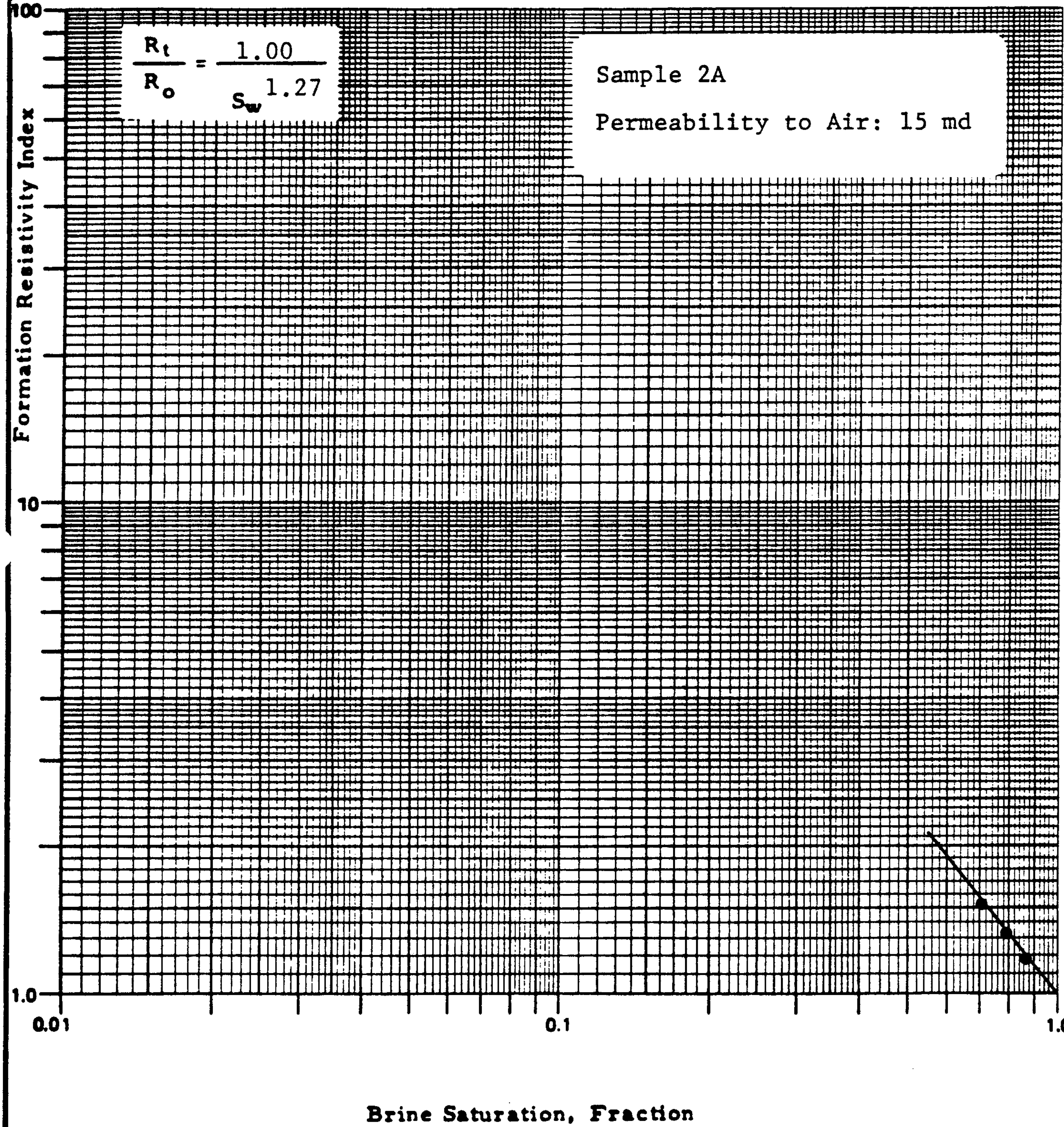
FORMATION RESISTIVITY INDEX
VERSUS SATURATION

FIGURE 7-11



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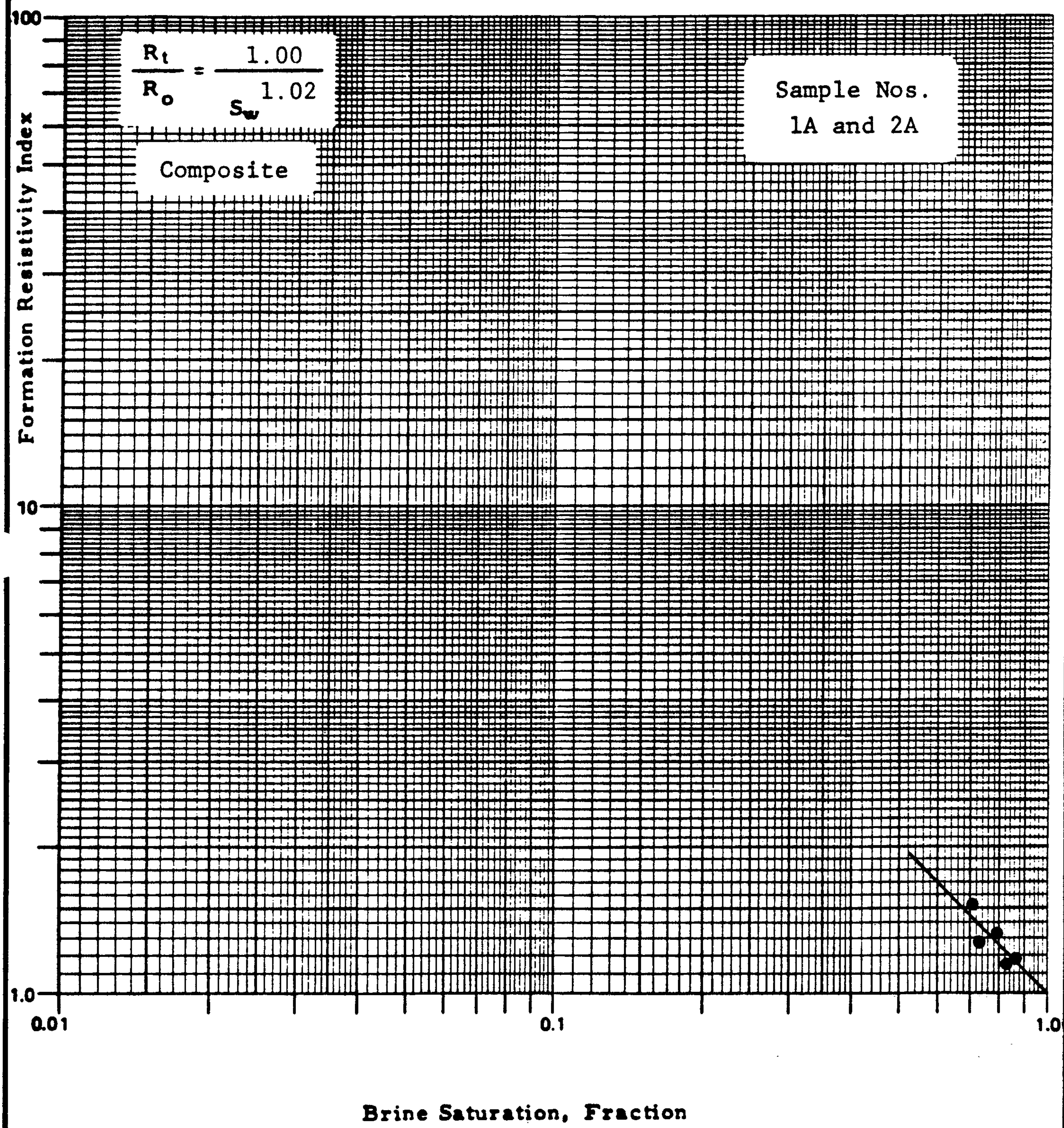
FORMATION RESISTIVITY INDEX VERSUS SATURATION

FIGURE 7-12



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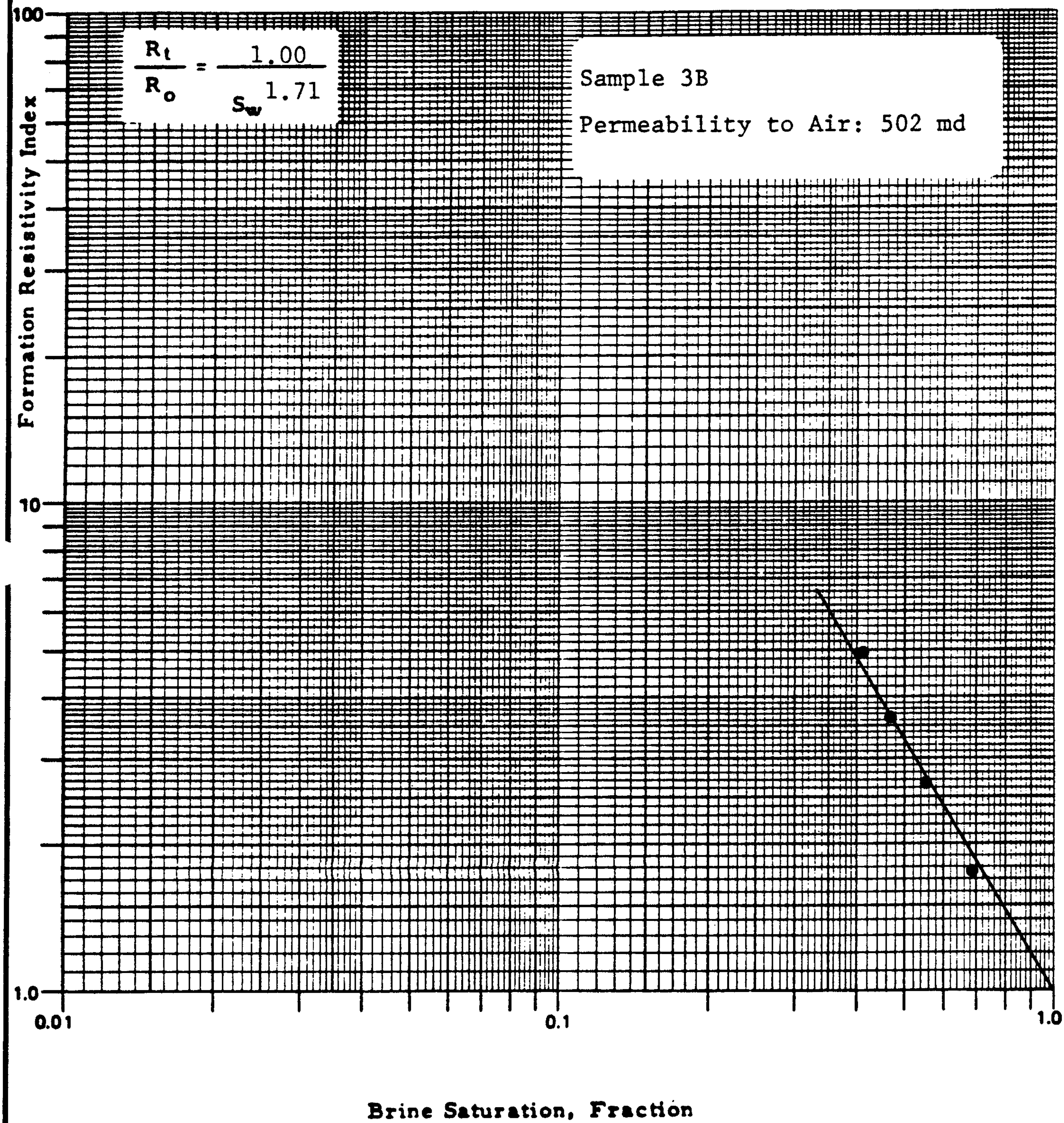
FORMATION RESISTIVITY INDEX VERSUS SATURATION

FIGURE 7-13



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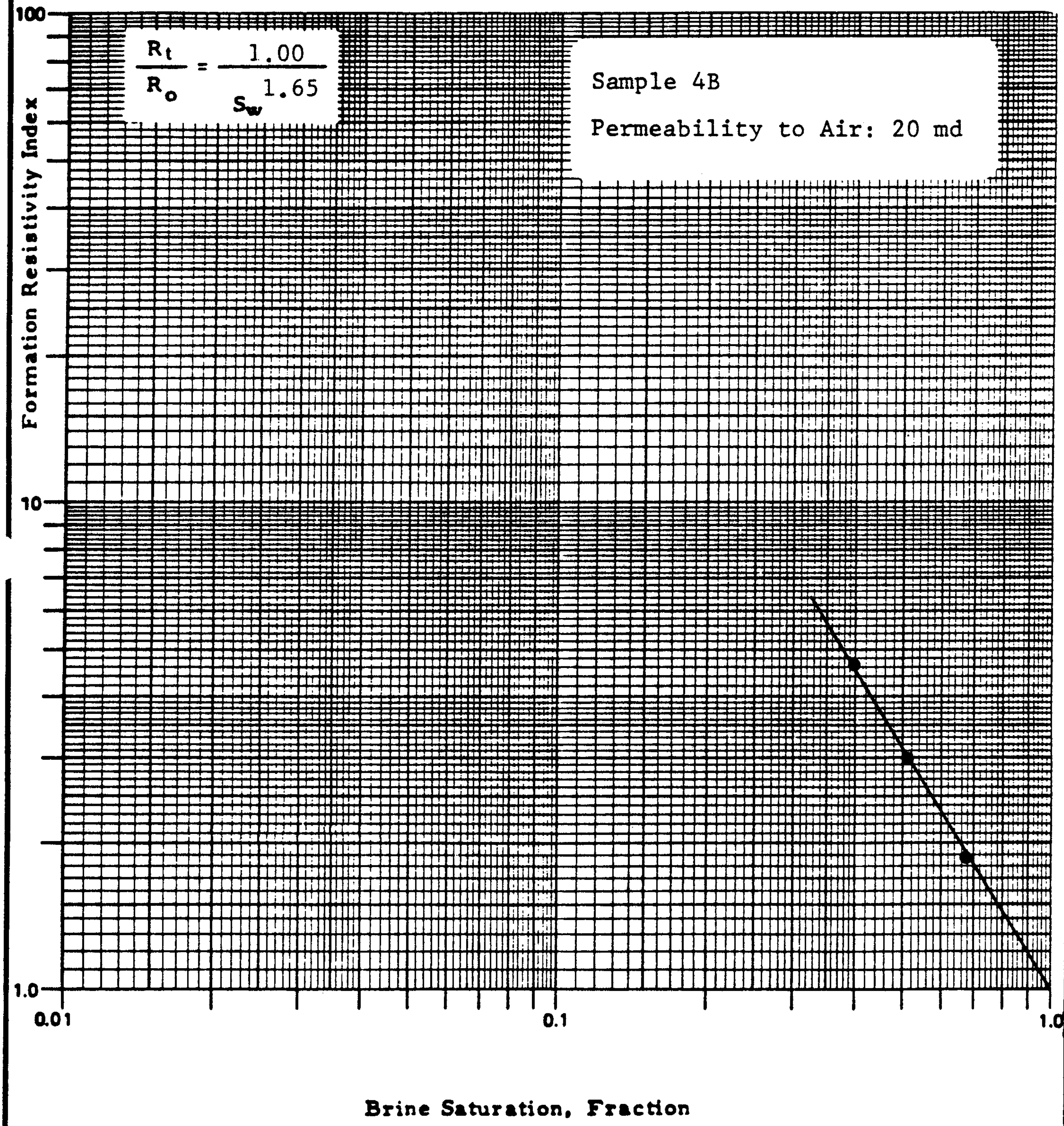
FORMATION RESISTIVITY INDEX
VERSUS SATURATION

FIGURE 7-14



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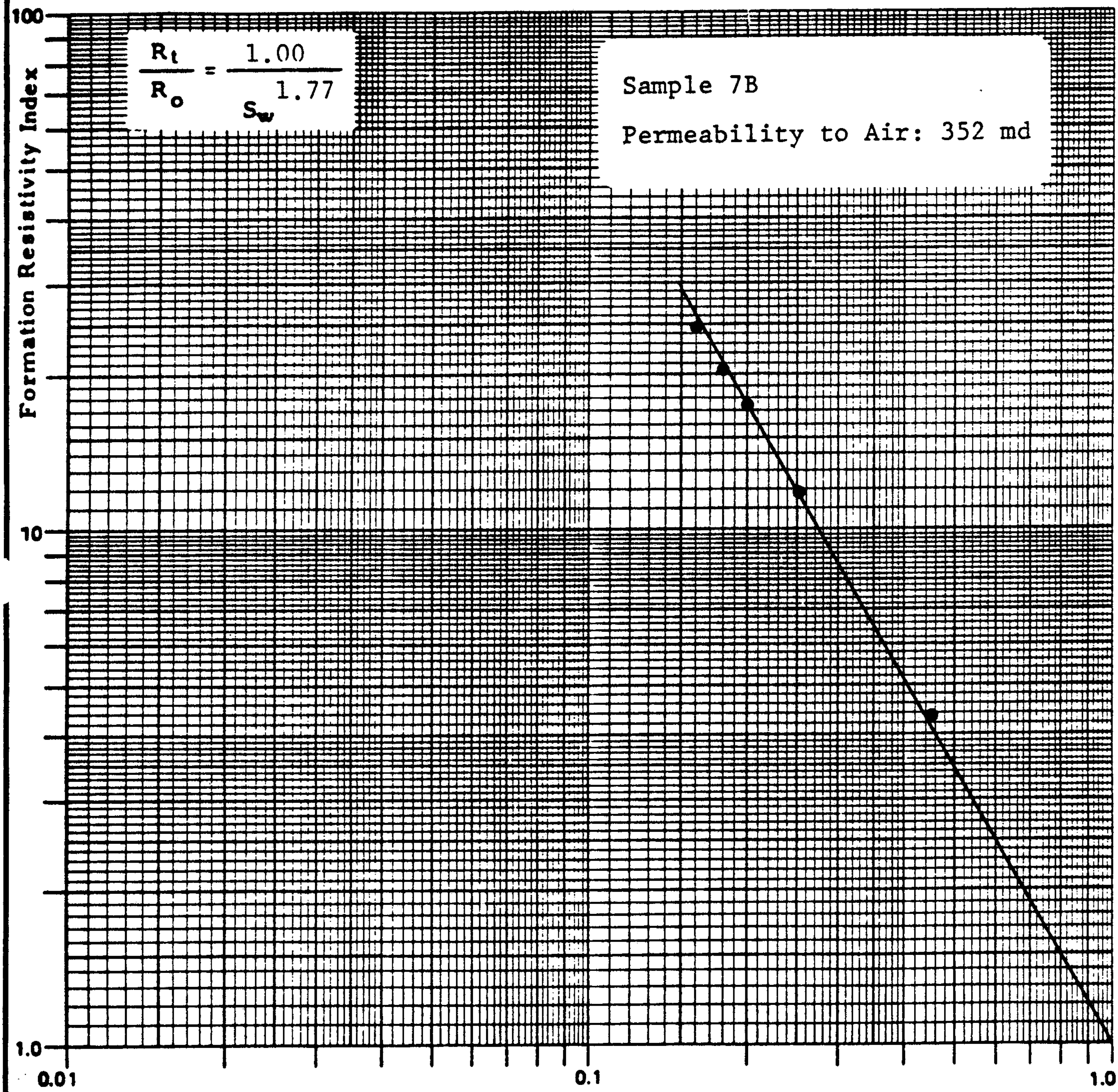
FORMATION RESISTIVITY INDEX
VERSUS SATURATION

FIGURE 7-15

301872

REPRO PRODUCTS INC. 7A



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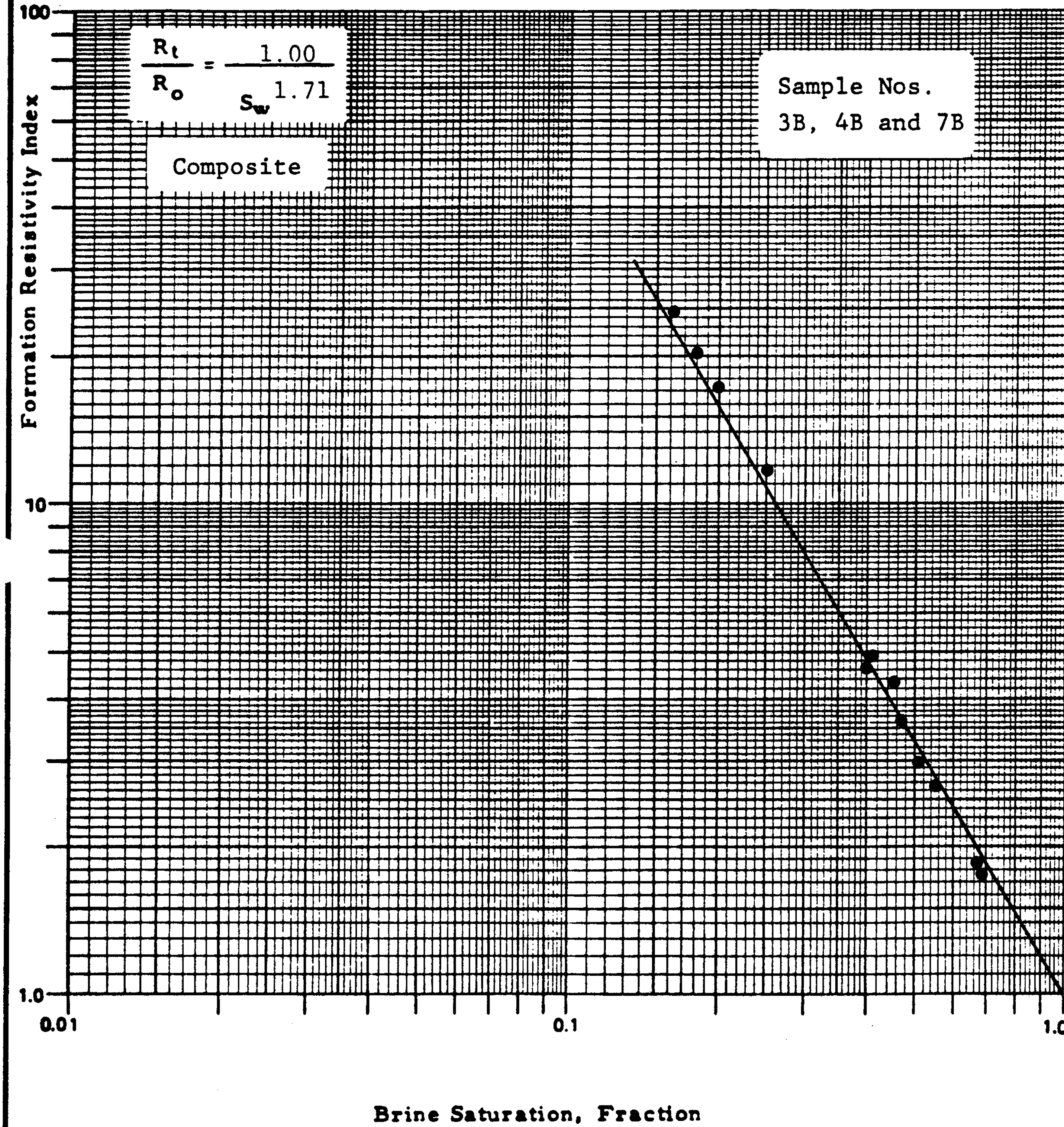
FORMATION RESISTIVITY INDEX
VERSUS SATURATION

FIGURE 7-16



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FORMATION RESISTIVITY INDEX
VERSUS SATURATION

FIGURE 7-17

acoustic velocity apparatus. Shear and compressional velocities were determined at a net overburden pressure equal to 0.5 psi times the depth of the samples. Internal (pore) pressure was maintained at 1,000 psi to assure 100 percent saturation of the samples at all times. The results of these measurements varied (see Table 7-5) due to the diverse lithologies of the samples; in general, the acoustic transit times for all the samples were directly related to the horizontal sample porosities shown in Table 7-4, although the transitions were measured in vertical plugs.

From the borehole compensated sonic logs (see Appendices 8 and 11), transit times were obtained for each test sample depth; these are shown with the sample porosity in Table 7-6. The relationship between transit time and porosity for each sample can be expressed in the form of a linear relationship (Schlumberger, 1972). The data presented in Table 7-6 are plotted in Figure 7-18.

A linear regression analysis of the data points shown in Figure 7-18 produced the following function with a correlation coefficient of 0.938:

$$\phi = 0.406\ (\Delta t) - 11.94$$

where ϕ is the rock porosity (percent)

Δt is acoustic transit time of saturated rock matrix (microseconds/foot).

The relationship expressed in Figure 7-18 shows that acoustic transit time increases with increasing void space within the rock, because of the higher transit time of the water in the saturated void spaces. The equation derived from these data is utilized in Section 7.4 to evaluate the strata porosities from the sonic log. The use of this equation is, however, restricted to those formations from which it was originally developed (Schlumberger 1972). Lignite layers known to exist below the 2,520-foot depth preclude the use of the equation anywhere throughout that material.

Table 7-5

ULTRASONIC VELOCITY AND DYNAMIC MODULI

Sample Number	Compressive Velocity (ft/s)	Shear Velocity (ft/s)	Poisson's Ratio	Shear Mod. (psi)	Bulk Mod. (psi)	Young's Mod. (psi)
Ocala Formation						
1V	10,742	5,456	0.32873	0.8880×10^6	2.2965×10^6	2.3599×10^6
2V	9,433	4,569	0.34673	0.5821×10^6	1.7049×10^6	1.5678×10^6
Avon Park Formation						
3V	14,460	7,455	0.31896	1.7767×10^6	4.3148×10^6	4.6867×10^6
4V	13,592	7,207	0.30446	1.6163×10^6	3.5941×10^6	4.2167×10^6
Lake City Formation						
5V	16,818	9,120	0.29175	2.8849×10^6	5.9649×10^6	7.4532×10^6
6V	17,694	9,428	0.30175	3.1122×10^6	6.8117×10^6	8.1025×10^6
7V	13,806	7,505	0.29027	1.7261×10^6	3.5397×10^6	4.4542×10^6
8V	20,887	11,511	0.28189	4.8248×10^6	9.4524×10^6	12.3697×10^6

m:H-87(II)/f

Table 7-6

ACOUSTIC TRANSIT TIME

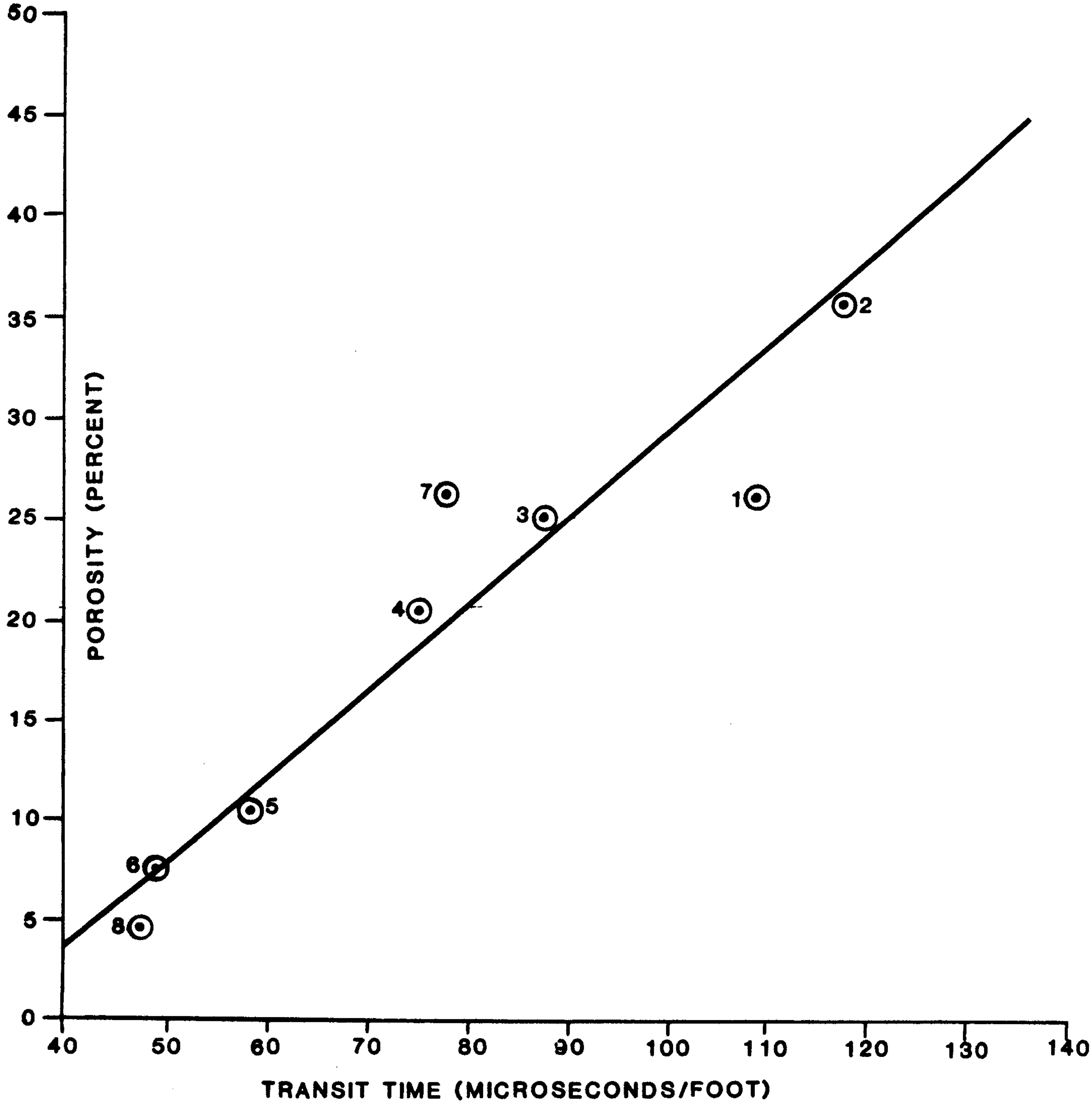
Sample Number	Average Porosity (percent)	Acoustic Transit Time - t (microseconds/foot)	Regression Porosity (percent)
1	26.80	109.00	32.382
2	36.10	118.00	36.042
3	25.00	88.00	23.842
4	20.90	75.00	18.556
5	11.40	58.00	11.643
6	5.50	49.00	7.983
7	27.50	78.00	19.776
8	4.60	48.00	7.576

Regression Output:

Constant	-11.9425884065
Std Error of Y Est	4.334791063
R Squared	0.8758718655
No. of Observations	8
Degrees of Freedom	6

X Coefficient(s)	0.406646001
Std Error of Coef.	0.0624965628

m:H-87(II)/g



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ACOUSTIC TRANSIT TIME VERSUS POROSITY

FIGURE 7-18

7.3.2.5 Heat Capacity

Sample 8C was selected for heat capacity measurements. A calorimeter bucket was filled with a known mass of heat transfer oil and maintained at 25°C. After the sample weight, length, and diameter, were recorded, the sample was placed in a constant-temperature oven set to the test temperature of 80°F. Sample temperature was monitored continuously and, at temperature equilibrium, the sample was lowered into the calorimeter bucket to minimize heat loss. The temperature of the heat transfer oil in the bucket was recorded every five minutes until consecutive readings were within 0.001°F. The final equilibrium temperature was then recorded and heat capacity calculated.

The result of the heat capacity measurement was 0.2479 BTU/lb.-°F for the dry rock (see Appendix 19). Heat capacity for the water-saturated sample, derived by calculation, was also 0.2479 BTU/lb.°F because of the very small pore volume. Standard average values of heat capacity for a limestone, dry and water-saturated, are 0.202 and 0.266 BTU/lb.°F, respectively (Hodgman, 1955), well within the values measured for this sample. The measured value was used in the SWIP program.

7.3.2.6 Thermal Conductivity

A 1-1/2-inch-diameter horizontally oriented sample plug, Sample 8F, was selected for thermal conductivity measurement. The sample was cut to approximately 1.5 inches in length and placed in a sample holder between pyroceram standards. The core assembly was then surrounded by a guard heater. The heat source and sink were mounted above and below the top and bottom standards. Axial and pore pressures of approximately 1,000 and 300 psi, respectively, were applied to the core sample. The guard heater was set to the initial test temperature (80°F), while the heat source and sink (top and bottom heaters) were set 33.8°F above and below the test temperature, respectively.

Temperatures were monitored and recorded at seven locations: inside the guard heater (midpoint of sample), at the top and bottom heater, below the top standard and above the bottom standard, and the top and bottom of the core sample. At a steady state condition (temperature equilibrium), temperature values were recorded and thermal conductivity values computed. The entire procedure was repeated for the sample after it was saturated with water. The results of both measurements came within 6 percent of each other, at 1.37 and 1.46 BTU/hr/ft/^{o}F, respectively, for the dry and water-saturated sample (see Appendix 19). These were the values used in the SWIP mode.

7.3.2.7 Rock (Pore Volume) Compressibility

Three samples, 3A, 6B, and 7A, were used in the rock-compressibility testing. These were the core samples selected by USGS. Samples 3A and 7A, used in the formation-resistivity testing, were restored to 100 percent saturation under vacuum, whereas Sample 6B was evacuated and pressure-saturated with a 39,000-ppm sodium chloride brine. The samples were loaded into hydrostatic core holders and confining pressures were incrementally increased from 100 to 2,800 psi. At each pressure, the volume of water produced from reduction in pore volume was monitored until stable. Pore volume reduction as a function of effective overburden was thus determined.

Rock compressibilities before matrix collapse were calculated from these data. The results of these measurements, shown in Appendix 19, indicated matrix collapse after 2,200 psi for Sample 3A and after 1,300 psi for Samples 6E and 7A. Compressibility values after the matrix collapsed were not calculated and the tests were stopped at the 2,800-psi overburden except for the testing of Sample 7A, which was ended earlier at 2,500 psi. For Sample 3A, the porosity was reduced nearly 5 percent before collapse. Sample 6E collapsed when porosity decreased 10 percent, and Sample 7A exhibited a 3.3 percent reduction in porosity before collapse.

7.3.2.8 X-ray Diffraction

The eight samples selected for quantitative XRD analysis were disaggregated with a mortar and pestle, weighted, and transferred to deionized water, where further disaggretation was performed with a sonic probe. The samples were centrifugally size-fractionated into sand/silt (>4 microns) and clay-size (<4 microns) fractions. The suspended clay-size fractions were decanted and vacuum-deposited on silver metal membrane filters to produce oriented mounts. Each clay mount was analyzed dry (relative humidity = 50) and after treatment with ethylene glycol. If necessary, samples were analyzed a third time following heat treatment (375^{o}C for one hour).

The sand/silt fractions of each sample were dried and weighed to determine weight loss due to the removal of clay-size material. The dried sand/silt fractions were mixed with alumina (Al_2O_3) as an internal standard and ground in water to a fine powder using a micronizing mill. The resultant slurries were dried, disaggregated and packed into aluminum powder holders using a modified pellet press.

Quantitative XRD analyses were performed using an automated powder diffractometer. The weight percentages of minerals present in the sand/silt fractions were determined using internal standard ratio techniques. The weight percentages of the various clay minerals (and other clay-size rock forming minerals) in the clay-size fractions were determined by Lorentzian profile-fitting/empirical peak-area-ratio methods. The whole-rock compositions were calculated by mathematically combining the XRD data from both size fractions.

Compositions and species of clay minerals detected in the clay-size fractions were then determined. The detectability limit is 0.5 to 1.0 percent for crystalline phases present in the size fractions analyzed. The results of the analyses are tabulated in Appendix 19 and summarized in Table 7-7.

7.4 GEOPHYSICAL LOGS

The pilot hole geophysical logs whose interpretation adds to the understanding of the hydrogeology underlying the site of the deep test/injection well are discussed in this section. The others, such as the caliper, the cement bond, the temperature, and the hole deviation logs, run on the reamed hole or in the cased hole, which do not contribute to the site hydrogeology data, but rather

Table 7-7

X-RAY DIFFRACTION TEST DATA

Sample	1A	2A	3A	4A	5A	6A	7A	8A
				Bulk Mineralogy (Calculated)[a]				
Quartz	TR	01	01	--	01	TR	TR	01
Calcite	85	85	88	92	72	88	02	01
Dolomite	--	05	--	02	--	--	--	95
Fe-Dolomite	--	--	02	--	22	02	94	--
Clay Size Material[b]	15	09	09	06	05	10	04	03
				Relative Clay Abundances (Normalized to 100%)				
Illite	09	TR	TR	TR	TR	TR	TR	--
Mixed-layer[c] Illite/Smectite	91(45)	TR	TR	--	TR	--	TR	--

[a] Weight in percent
[b] Predominantly clay-size carbonate minerals.
[c] Numbers in ( ) are percent expandable smectite interlayers in mixed-layer clays.

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to the evaluation of the well construction, have been described where pertinent, in Section 4.

The geophysical logs are divided into four groupings, each of which is discussed separately in the following four subsections. The logs on the pilot hole to a depth of 241 feet below land surface are discussed in Section 7.4.1; those continuing from 241 to 1,660 feet are discussed in Section 7.4.2. Logs run on the pilot hole from 1,660 to 2,354 feet below land surface are described in Section 7.4.3, while those run on the open hole below the injection casing are described in Section 7.4.4. Throughout Section 7.4, discrepancies exist between the depths measured by the drillers, which are represented by the lithologic samples and the cores, and those measured by the logging company on the geophysical logs and by the television surveys. These discrepancies are as great as 10 feet in some places; care must thus be taken when the depths from the geophysical logs and television surveys are compared with those from the lithologic samples and the cores.

7.4.1 Pilot Hole - First Stage

The first stage of the pilot hole below the steel pit casing was logged on May 9, 1987, and the geophysical logs run over the land surface to the 232-foot depth range included the following:

- Caliper
- Gamma ray
- Acoustic
- Long and short normal (64-inch and 16-inch) resistivity
- Spontaneous potential
- Deviation.

A copy of these geophysical logs is contained in Appendix 1.

7.4.1.1 Caliper Log

Knowledge of hole diameter, measured with caliper probes, is essential. It makes available information that helps in the interpretation of other logs, such as the extraneous effect of hole geometry on the acoustic signal return, the effect of fluid-filled holes on the electric log, etc.

The pilot hole was drilled with a 12-1/4-inch drill bit. The caliper log, which was run concurrently with the acoustic log, for the most part showed a 13-3/4-inch-diameter hole. In the upper section of the hole, at a depth of 50 feet, the caliper log indicated a slight constriction within the pilot hole where the diameter was reduced to less than 12-1/4 inches.

7.4.1.2 Gamma Ray Log

The gamma ray log records the amount of natural-gamma radiation emitted by the rocks. This log is particularly useful for defining clay beds and tight dense layers that usually contain gamma-emitting radioactive elements.

The gamma ray log, run from land surface to 232 feet at the NFMU site, was useful in detecting high levels of phosphate in sandy limestones and clay minerals. Sandy and clayey materials tend to act as sinks for the phosphate with which radium is associated. This NFMU gamma log clearly revealed clayey formations and strata, as in the Hawthorn Formation, where the clays clearly showed up between the 150- and the 170-foot depths. These clays belong to the middle unit of the Hawthorn Formation. Above the 150-foot depth were a few other strata, notably one between 100 and 110 feet and another between 18 and 28 feet, which affected the gamma ray log. The layer between 18 and 28 feet is the phosphatic section of the Tamiami Formation. Below the 170-foot depth, two other layers consisting of sandy limestone concentrate the phosphate of the Hawthorn Formation. These layers were found between 194 and 200 feet, and between 216 and 230 feet.

7.4.1.3 Sonic Log

Sonic logging involves the recording of the time required for a sound wave to travel through a definite length of formation. Speed of sound in subsurface formations depends upon the elastic properties of the rock matrix, the porosity of the formations, and their fluid content and pressure.

The sonic log evaluation must be conducted in unison with the caliper log evaluation for the results to be valid. As a recording of the time of travel (transit time) of the acoustic signal moving through the formations, the sonic log is greatly influenced by the size of the borehole where the sonic tool is inserted. When compensated for borehole size, the interpretation of the sonic log can be used in conjunction with other logs to give a good indication of the tightness (confining quality) or looseness (open spaces or cavities) of the formations.

The sonic log run on the NFMU well on May 9, 1987 indicated the presence of numerous layers that alternate from high to low porosity. Porosity by itself is not conclusive of the confining or water-producing potential of each layer; but rather should be correlated with the lithologic description of the layer and with other geophysical logs before such a conclusion is made.

The acoustic or sonic log recorded numerous fluctuations below the surface casing. These fluctuations ranged from a minimum of 72 microseconds per foot at 16, 36, 65 and 67 feet below land surface to more than 170 microseconds per foot at numerous depths. The large transit time values encountered on the sonic log, particularly below the 90-foot depth, are indicative of the fresh-water saturated high porosity layering identified from the lithologic samples (see Appendix 24) and represent the middle unit of the Hawthorn Formation. The sonic log indicated the existence of such layering to a depth of 230 feet below land surface.

7.4.1.4 Resistivity Logs

Electric resistivity logging is a method of measuring the resistivity (reciprocal of conductivity) of formations by means of logging induced alternating currents (induction logging). The advantage of electric logging is its ability to investigate the thickness of beds, due to its focusing properties and its great radius of investigation.

One characteristic of resistivity logs is that, when a short and a long penetration signal are sent, both return at essentially the same time when the material through which they travel is soft and porous; however, when the material is very hard and dense (impermeable), or when the material is stratified and has porosity in only one plane (clays), the long penetration signal returns at a different time.

Using this characteristic of the log, it is possible to identify those zones where the denser structure of the rock facilitates the travel of the electric signal, and by comparing this log with other logs (the acoustic log, for example), it is possible to interpret the degree of confinement that a formation can provide.

The electric resistivity log utilizes two induction devices for measuring the resistivities of the formations: 1) a deep-reading induction device, and 2) a shallow investigation device, whose readings are more influenced by the borehole and the invaded zone around it. Variations in the signals from the two devices are good indicators of the degree of mud invasion within the formations, with such invasions more likely to occur in the more permeable formations. Signal variations at the NFMU site occurred at the 40-foot depth and at the 90-foot depth, corresponding to the contact between the Tamiami and the Hawthorn Formations and to a high permeability zone, respectively.

7.4.1.5 Spontaneous Potential Log

The spontaneous potential log is a record of the naturally occurring differences in the electric potential between a surface electrode and an electrode in the column of conductive fluid as the latter electrode is pulled up past different formations. Analysis of the spontaneous potential log at the NFMU well indicated that the spontaneous potential current in the column followed the inverse of the graph of the resistivity log, confirming the earlier evaluation of the formations from the resistivity log.

The spontaneous potential log was run simultaneously with the dual induction log on the same tool string. The spontaneous potential within the pilot hole exhibited no potential value down to about 90 feet. Below 90 feet, an average spontaneous potential of -20 millivolts was recorded down to about 150 feet, with -30 millivolts below that. The change in the average spontaneous potential at the 90-foot depth is probably representative of the boundary between the unconsolidated clay and dolosilts and the firmer limestone units of the Hawthorn Formation.

7.4.2 Pilot Hole - Second Stage

The second stage of the pilot hole below the steel outer casing was logged on May 27, 1987. The geophysical logs run over the 220- to 1,660-foot depth range included the following:

- o Caliper
- o Gamma ray
- o Borehole compensated sonic
- o Temperature
- o Spontaneous potential
- o Long and short normal (64-inch and 16-inch) resistivity
- o Deviation
- o Cement bond log.

A copy of these geophysical logs is contained in Appendix 3.

7.4.2.1 Caliper Log

The caliper log was run with two sets of calipers, oriented at 90 degrees to each other. Below the outer casing, the pilot hole was drilled with an 12-1/4-inch bit; but the average pilot hole diameter proved to be 14 inches below the outer casing down to a depth of 500 feet below land surface. The average pilot hole diameter decreased to 12-1/4 inches at a depth of 505 feet and remained that way except at 670 to 740 feet, 920 to 970 feet, and 1,140 to 1,170 feet, where the hole opened to 15 inches.

The increasing hardness of the rocks encountered below the 500-foot depth showed up on the caliper log through a decreasing hole diameter, and the only other large holes detected by the caliper log below 500 feet were due to cavities in the limestone. The primary cause of this rock hardening below 500 feet is the increasing degree of pure limestone within the rock matrix and the reduction of sand. The caliper log for the reamed open hole also highlighted the increasing hardness of the rock below the 500-foot depth (see Appendix 4).

7.4.2.2 Gamma Ray Log

The gamma ray log is particularly useful for defining silt-filled holes and clay beds which usually contain gamma-emitting radioactive elements. The gamma ray log for the pilot hole below the outer casing had a series of large fluctuations (ranging from 40 to 240 API units) down to the 600-foot depth. From 600 feet down, except for a very large increase in the 710- to 760-foot range, the gamma ray activity decreased considerably, remaining below 60 API units.

The fluctuating gamma ray activity above 600 feet is representative of the numerous phosphatic layers interbedded within the limestone matrix, which were also evidenced in the lithologic description (see Appendix 24). The sharp increase between 710 and 760 feet is due to the phosphate held in the sandy limestone found within that range.

Gamma ray activity occurred at a relatively steady rate between 760 and 1,660 feet. There was, however, a slight increase in gamma activity at 1,580 to 1,590 feet, concurring with the identification of this depth range as the contact between the Avon Park and the Williston Formations.

7.4.2.3 Borehole Compensated Sonic Log

From just below the outer casing to the contact between the Hawthorn and the Tampa Formations at just below 400 feet, the acoustic log closely paralleled the gamma ray log and, as discussed later, the resistivity log as well. Relatively long travel times coincided with the high porosity, high permeability zones from which the radioactive phosphates have been washed out, while in the tighter sections, where the phosphates are still in place and the gamma activity is high, the travel times were short and indicated lower porosity. Typically a clay lens, though confining by nature, will exhibit a high porosity (Terzaghi & Peck, 1967).

The limestone of the upper part of the Tampa is for the most part of relatively low porosity. From 420 to 500 feet, the sonic log was rather uniform. At 500 to 600 feet below land surface, several high porosity layers of limestone were encountered (at 515 and 550), corresponding with the findings of the caliper log; but low porosity limestone lenses were also present and these changes were evident in the sonic log at 505, 520, 580 and 590 feet. Below 600 feet, in the Suwannee Limestone, the sonic log exhibited higher overall porosity and the lithologic description confirmed that (see Appendix 24). The fluctuations in the sonic log between the 620- and the 780-foot depths are primarily the result of alternating high porosity and low porosity layers. The high porosity zones shown by the log at 630 to 640 feet, 690 to 700 feet, and at 730 to 740 feet were well identified in the geologic descriptions (see Appendix 24 and Figure 2-10).

Between 780 and 1,660 feet, the sonic log was relatively constant, with an average travel time reading that ranged from 100 to 120 microseconds per foot. The only significant exception was a section between 1,100 and 1,160 feet where the acoustic log indicated low porosity.

The derivation of the porosity equation in Section 7.3.2.4 (see Table 7-6 and Figure 7-18) is based on the analysis of the core samples taken from the pilot hole between 1,337 and 2,460 feet. The equation is thus applicable only to those portions of the sonic log in which similar formations are encountered, that is, in the Floridan Aquifer System above the Oldsmar Formation. It can not be used for the clayey Hawthorn, the dolosiltic Tampa, or the sandy Suwannee since the acoustic travel times in those zones would not fit the empirical relationship.

Based on this equation, it is possible to calculate porosity from the acoustic log in the last 300 feet of the hole drilled into the Ocala. Table 7-8 shows this porosity, with values ranging from 23 to 37 percent, but averaging close to 30 percent.

Table 7-3

WATER PERMEABILITY

Sample Number	Depth (feet)	Specific Permeability to Water, (millidarcys)	Permeability Ratio, water/air
Saturant: 1,500 ppm NaCl brine			
1A	1,341	2.6	0.347
Saturant: 2,000 ppm NaCl brine			
2A	1,443	8.9	0.593
Saturant: 37,000 ppm NaCl brine			
3B	1,608	400	0.797
Saturant: 35,000 ppm NaCl brine			
4B	1,880	12	0.600
Saturant: 39,000 ppm NaCl brine			
5B	2,163	0.30	0.612
6A	2,261	0.005	0.050
Saturant: 38,000 ppm NaCl brine			
7B	2,326	199	0.565
Saturant: 27,000 ppm NaCl brine			
8E	2,453	0.0001	0.005

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The sonic log records the arrival of the first sonic wave trains emitted from two transmitters located above and below the receivers; but the presence of secondary porosity can obliterate that first wave. Thus the travel times recorded on the sonic log are more representative of the primary porosity than of the secondary porosity. Primary porosity reflects intergranular porosity and is dependent upon the pore structure and pore-size distribution. Secondary porosity often consists of vugs, fractures and large cavities with dimensions larger than the pores of the primary porosity. The relatively large sonic travel times recorded on the sonic log at NFMU at 630 to 640 feet, 690 to 700 feet, and 730 to 740 feet indicate largely secondary porosity because of the large cavities; hence, the sonic log results can also be used to identify the presence of highly permeable zones elsewhere at the site, although a quantitative analysis would not be possible. A sonic log reading equivalent to the formation fluid transit time or higher would obviously indicate the absence of the formation matrix and, therefore, confirm the presence of a cavity or hole.

The average travel time for the 1,300- to 1,600-foot depth range was about 100 microseconds per foot which corresponds to an average porosity of 29 percent (see Figure 7-18). For that depth range, the transit time is never above 120 microseconds per foot. This low transit time would, therefore, indicate the presence of matrix everywhere and lead to the conclusion that no cavities exist within that depth range.

7.4.2.4 Temperature

The temperature of the water within the pilot hole ranged from 33.2°C (91.8°F) immediately below the casing to a high of 34.7°C (94.4°F) at a depth of 1,600 feet below land surface. This small increase was very gradual and no sharp temperature changes were identified anywhere in the hole.

The water temperature slowly increased with hole depth, rising 1-1/2 degrees Centigrade in the 1,400 feet. This temperature change is the result of the natural increase in temperature with greater depth within the earth's crust; however, it is well below the widely accepted average of 6 degrees Centigrade per thousand feet. This lower than average temperature increase is frequently found in Florida due to the circulation of groundwater, the proximity of the ocean on both sides of the peninsula, and the presence of cavernous zones deep within the Floridan Aquifer System.

7.4.2.5 Spontaneous Potential Log

The spontaneous potential log exhibited few deflections throughout the length of the pilot hole. The spontaneous potential remained constant between -150 to -180 millivolts from below the outer casing down to full depth at 1,600 feet. At 1,500 feet, the spontaneous potential began a sharp shift and the voltage increased to -150 millivolts at 1,540 feet. This trend, as discussed later, also appeared on the other electric log, the resistivity log.

The spontaneous potential increases between 1,500 and 1,550 feet reflect the distinct difference in the formation water above and below that zone. In fact, as shown through the packer test data (see Section 7.5), it is at that zone that the water quality increased beyond 10,000 mg/l TDS.

7.4.2.6 Resistivity Log

The last log run on the pilot hole which yielded information useful in the evaluation of the site hydrogeology was the resistivity log. This electric log is run with two sounds, and produces a long normal signal (64-inch) and a shallower inductive signal (16-inch) that does not penetrate as deep into the formation. The resistivity readings from the induction log are dependent upon a combination of factors rather than on one single physical attribute of the formations.

The induction log can be analyzed by utilizing the equations shown in Section 7.3.2.3 and assuming that the underlying formations are 100 percent saturated and, therefore, that the resistivities of the saturated formation and the clean formation are equal. For each of the selected depth ranges, the resistivity of the formation fluids may be averaged from the water quality data shown in Section 7.5. Using this average, it is then possible to obtain a porosity value from Archie's equation.

The induction log for the pilot hole in the 220- to 1,600-foot depth range showed five distinctive segments, as discussed below.

In the section between 220 and 440 feet below land surface, the long normal inductive signal encountered very high resistivity and thus indicated that the formation offers much more resistance than the near mud-filled wall. It was, therefore, concluded that the formations are not very porous in this section and that the drilling mud did not penetrate deeply enough into them to reduce the resistivity recorded by the deep penetrating 64-inch signal.

Between 450 and 770 feet, the two induction signals appeared to closely parallel each other and the resistivities were not too far apart. In several places, the short normal actually met the long normal, indicating that both signals were encountering high resistance and probably porous zones.

The next distinct section of the resistivity log occurred from 770 to 1,060 feet below land surface. This section showed even closer values for both sondes and indicated slightly higher overall porosity.

Immediately below 1,060 feet, the two signals began to separate. That separation continued down to 1,500 feet.

At 1,500 feet, once again the two signals became closer and, 1,520 feet, they actually joined. This change would at first appear to be caused by a highly permeable zone, but when the acoustic log for this zone was examined, no such indication was obvious. The alternative explanation for this drop in resistivity is a water quality change, and the latter was indeed the case, as later confirmed by the packer tests.

7.4.3 Pilot Hole - Third Stage

The third stage of the pilot hole between the bottom of the protective casing at 1,582 feet and the total depth of the pilot hole at 2,354 feet was logged on September 22, 1987. The geophysical logs run over the full depth range of the pilot hole included the following:

- Temperature
- Borehole compensated sonic
- Dual induction - spontaneous potential
- Caliper
- Gamma ray
- Flowmeter
- Directional.

A copy of these geophysical logs is contained in Appendix 8.

7.4.3.1 Temperature Log

The pilot hole temperature log was found to be defective and the log was rerun in this section of the hole after it was reamed (see Appendix 9). The temperature log for the reamed upper 1,600 feet exhibited a similar overall temperature gradient as that for the pilot hole of that section (see Appendix 3) and the net temperature ranges were also similar, although starting from a colder temperature. Below 1,550 feet, the temperature log of the reamed hole showed a reverse temperature gradient. The temperature at a depth of 1,550 feet was recorded at 94.2°F, whereas that at 1,750 feet was recorded at 92.5°F. This is a significant drop, probably caused by cool water circulation, although there is no absolute explanation of exactly how it is caused. Below 1,750 feet, the normal geothermal gradient reestablished itself.

7.4.3.2 Flowmeter

A double flowmeter log was run for the pilot hole: one as the flowmeter descended the hole and the other as it ascended. The rate of descent and ascent for the flowmeter was held at a constant 190 feet per minute.

The descent flowmeter log started out at the top of the hole with an average spin of 6.5 revolutions per second, reducing slightly to an average of 6.2 revolutions per second at 1,880 feet. At 2,100 feet, there was another slight decrease to an average of about 5.5 revolutions per second. There were no other changes in spin velocity for the entire remaining length of the hole.

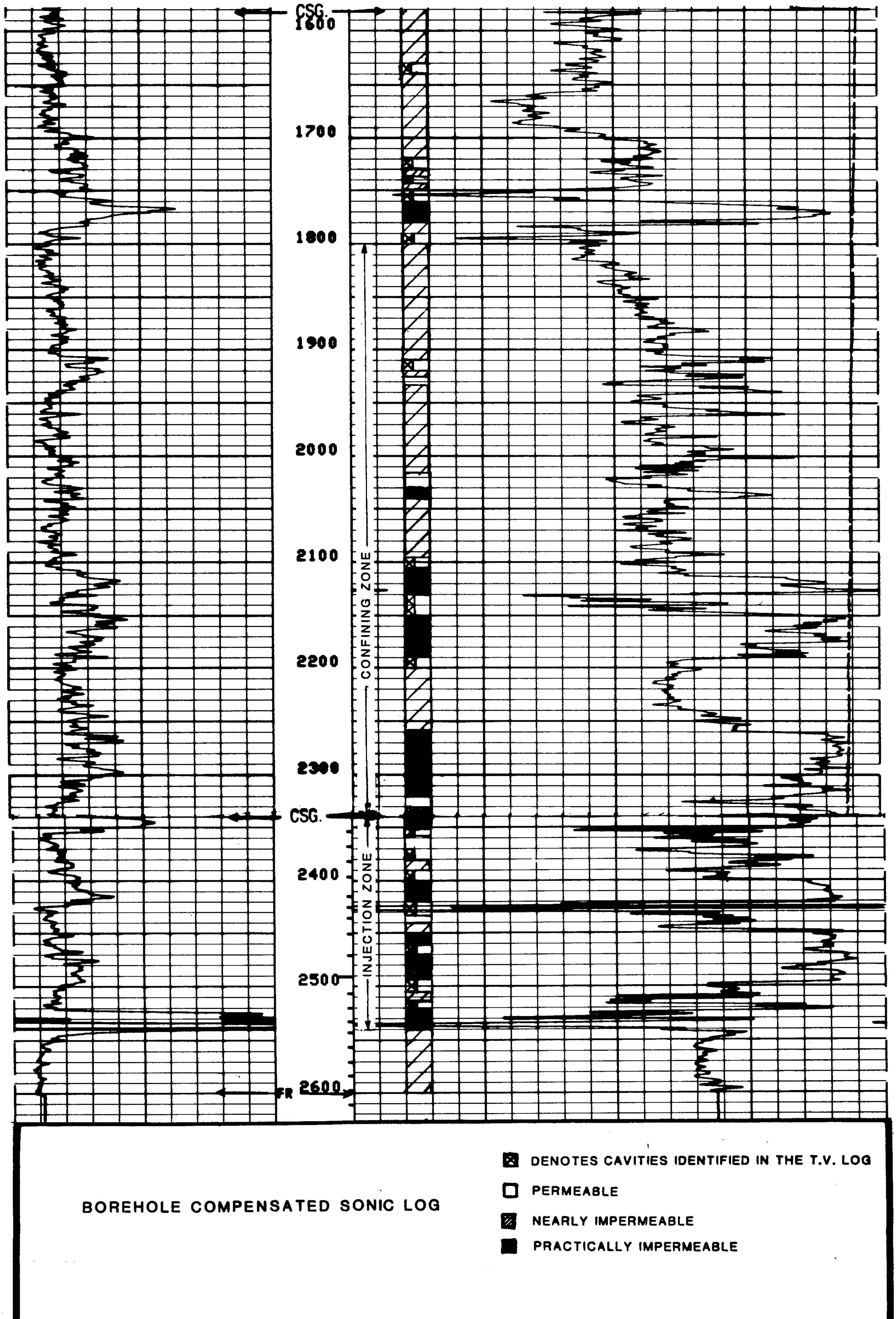
The ascent flowmeter log showed some disturbance at the bottom of the hole. This disturbance was caused by the lowering of the flowmeter before the well could be logged upwards, but it still showed the same overall pattern as the descent log.

The narrow change in the revolution counts recorded by the flowmeter in both the ascent and descent logs indicated that the well has no internal flow. The small variations in the flowmeter log were due entirely to the size of the hole and eddy currents created by the tool and that is why the ascent log run after the disturbance showed more fluctuations.

7.4.3.3 Borehole Compensated Sonic Log

The borehole compensated sonic log, run in the pilot hole prior to its being reamed out for the inner casing, provided the best geophysical logging information about the confining layers above the injection zone. A copy of that log is included in Appendix 8; but a reduced-scale version of it is reproduced in Figure 7-19.

The sonic log exhibited a zone of very low transit times (100 microseconds per foot or less) between 1,800 feet and 2,340 feet below land surface, the 540-foot zone that has been identified as the confining zone. There were, however, some intervals within that depth range which showed high transit times, and in fact, the transit time log showed great variation within the confining zone. In the interval between 2,130 and 2,150 feet, for example, the transit time increased to nearly 120 microseconds per foot, while in the interval between 2,260 and 2,300 feet, it decreased to about 45 microseconds per foot. At a depth of 2,128 feet, the formation was so tight and dense that the travel was less than 35 microseconds per foot.



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BOREHOLE COMPENSATED SONIC LOG

FIGURE 7-19

The permeability of the cores collected from zones representative of the same transit times as those shown by the geophysical logs can be used to determine the relative permeability of the various layers of the confining zone. For example, the transit time from the sonic log at 1,880 feet is 80 microseconds per foot. Using the data in Table 7-3 to show that the formation porosity is 12 millidarcys at 1,880 feet below land surface, it is possible to determine that 80 microseconds per foot is the limiting level for that permeability value.

In the depth interval between (1,800 and 2,110 feet), it is estimated that more than 60 percent of the matrix (186 feet) has travel times faster (numerically lower) than 80 microseconds per foot (some as fast as 55 microseconds per foot) and hence a permeability value of less than 12 millidarcys. Similarly, the zone between 2,200 and 2,260 feet is also estimated to be nearly impermeable, adding another 60 feet, for a total of 246 feet of confining zone in this interval.

In the same manner, the cores from 2,163 and 2,261 feet can be used to show that those zones with transit times of 55 and 50 microseconds per foot are practically impermeable (0.3 and 0.0005 millidarcys, respectively). Thus, it can be inferred that the sections between 2,115 and 2,125 feet, between 2,150 and 2,190 feet, between 2,260 and 2,320 feet and between 2,320 and 2,340 feet are confining zones that together add up to another 120 feet of practically impermeable strata.

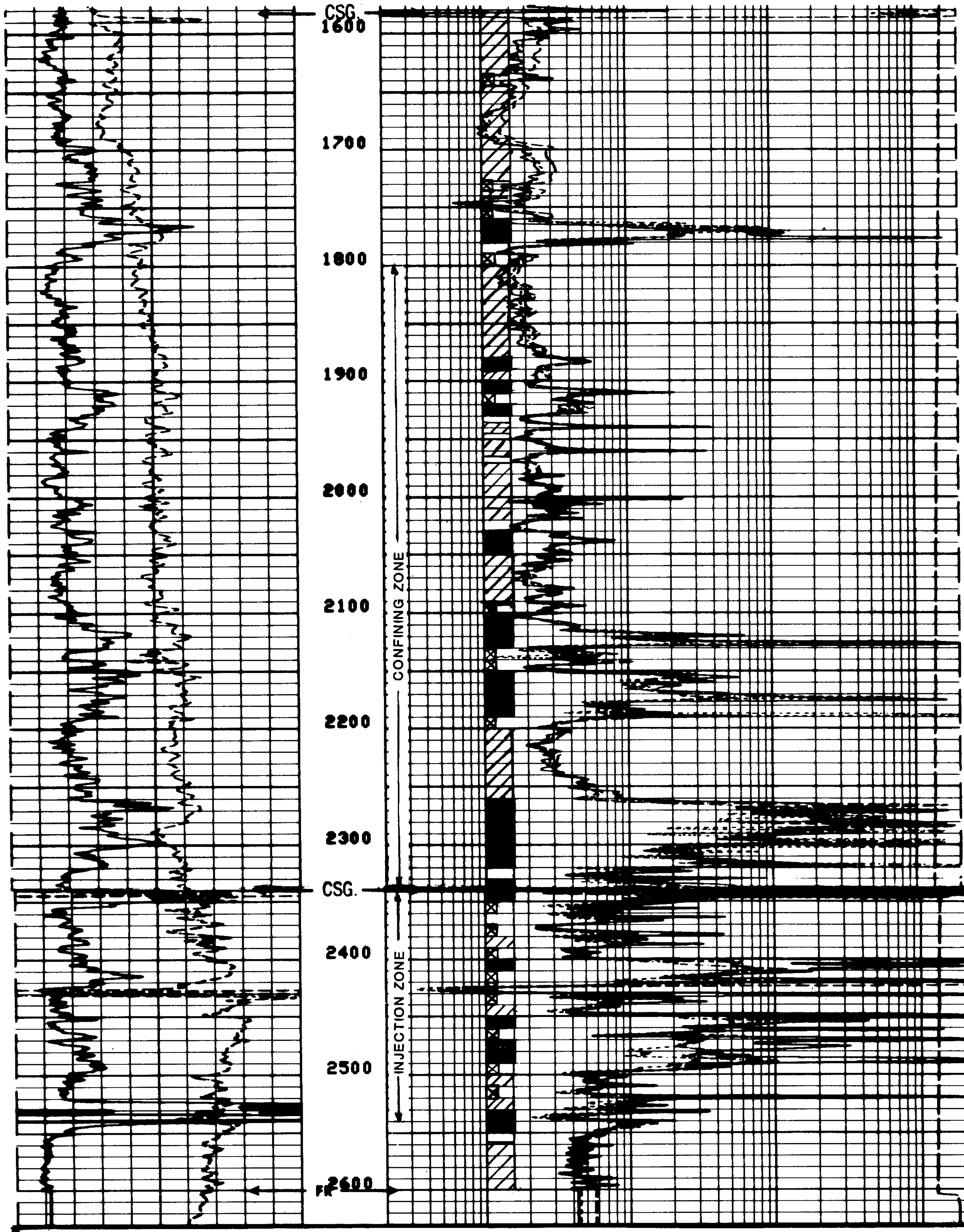
7.4.3.4 Dual Induction Log

Another log that provides much information on the confining beds above the injection zone is the dual induction log. A copy of this log is included in Appendix 8 also, and has been reproduced as Figure 7-20. This figure also shows the spontaneous potential log and the gamma ray log, both of which correlate well with the induction log.

The zone from 1,600 to 2,600 feet contains water with a high level of dissolved solids; consequently, it is a highly conductive zone and easily transmits the electric signals of the electric logs (spontaneous potential and dual induction). It is this characteristic that makes the induction log so reliable in identifying confining zones. Since the confining zones have low porosity and low permeability, the conductive water is not in continuous contact and, therefore, the electric signal has to travel through the matrix, which produces a much higher resistance than the free-standing water does.

The zones of high resistivity and thus low permeability were easily identifiable from the dual induction log (see Figure 7-20). The log showed extremely resistive layers at several depths, including the zones from 2,105 to 2,130 feet, from 2,150 to 2,190 feet, from 2,260 to 2,320 feet, and from 2,330 to 2,340 feet. These zones coincided exactly with the low permeability zones identified in the sonic log. The log also showed highly resistive layers between 1,880 and 1,890 feet, between 1,900 and 1,910 feet, between 1,920 and 1,930 feet and between 2,030 and 2,050 feet. These zones were also identified in the sonic log and coincided almost exactly, except for the induction log of the zone around 1,900 feet. In that zone, the dual induction log appeared to indicate that many of the formations were practically impermeable whereas the sonic log identified those same formations as having some permeability, however small.

The best method of identifying cavities is through a television survey; however, the dual induction log and the sonic log also help to confirm the presence of cavities. At NFMU, the sonic log and the induction log were in perfect agreement, confirming the majority of the cavities identified in the television survey. There was, however, a slight discrepancy in the depth indicator on the television videos. Therefore, the locations of the cavities and caverns, as shown by the geophysical logs and by the television survey differed; these locations may vary by as much as three feet in the lower part of the 260-foot open hole (below the inner casing) and five feet in the upper part of the 780-foot pilot hole below the protective casing. The cavity locations, as identified by the television survey and confirmed by the sonic and dual induction logs, are shown in Figures 7-19 and 7-20.



DENOTES CAVITIES IDENTIFIED IN THE T.V. LOG

PERMEABLE

NEARLY IMPERMEABLE

PRACTICALLY IMPERMEABLE

DUAL INDUCTION - SFL LOG

GR (GAPI)		TENS(LB)
0.0 — 100.00		11000. — 1000.0
SP (MV)		ILD (OHMM) .20000 — 2000.0
-160.0 — 40.000		ILM (OHMM) .20000 — 2000.0
		SFLU(OHMM) .20000 — 2000.0

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DUAL INDUCTION-SFL LOG

FIGURE 7-20

Table 7-8

BOREHOLE COMPENSATED SONIC LOG -
POROSITY RESULTS (1,300 - 1,600 feet)

Depth Range (feet)	Sonic Travel Time (microseconds/foot)			Calculated Porosity - (%)		
	Minimum	Average[a]	Maximum	Minimum	Average[a]	Maximum
1,300-1,350	100	110	112	29	33	34
1,350-1,400	98	102	110	28	30	33
1,400-1,450	97	109	117	28	33	37
1,450-1,500	92	105	110	26	31	33
1,500-1,550	92	-	110	26	-	33
1,550-1,600	87	-	108	23	-	32

[a] Average values were evaluated only when the resistivities on the induction log did not exhibit either a declining or a rising trend; otherwise only the limits of the trend were evaluated.

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7.4.4 Pilot Hole - Open Hole

The pilot hole for the open hole was drilled after the installation and grouting of the inner steel casing and was subsequently logged on December 1, 1987. The geophysical logs run over the full length of the open hole, from 2,340 to 2,600 feet below land surface, included:

- Caliper and deviation
- Gamma ray
- Borehole compensated sonic
- Temperature
- Spontaneous potential
- Dual induction.

A copy of these geophysical logs is contained in Appendix 11.

7.4.4.1 Caliper Log

The caliper log was run in the pilot hole of the open hole from below the inner casing to the 2,600-foot depth. The pilot hole below the 2,343-foot depth of the inner casing was drilled with an 11-inch drill bit.

The caliper tool used to run the log had a maximum arm length of 19 inches; therefore, the full sizes of cavities larger than this tool size were not visible on the caliper log. Similarly, the caliper was unable to record the full size of any cavities extending less than 38 inches from roof to floor because the caliper arms could not be fully extended. The caliper arms did not record the cavities known to exist between 2,379 and 2,381 feet or between 2,450 and 2,500 feet, and underestimated the sizes of most others.

The caliper log highlighted two significant cavity-riddled zones within the open hole section in the 2,353- to 2,400-foot, and the 2,425- to 2,434-foot depth ranges. The cavities in the 2,353- to 2,400-foot depth range are less than two feet in height, but the cavities interspersed in the 2,425-to 2,434-foot depth range are interconnected and in one particular section, a cavern is four feet high. All of these cavity zones are a significant part of the proposed injection zone, probably the most important. Nevertheless, there are other high permeability intervals that, although they show no cavities, still provide good receiving strata for injection.

7.4.4.2 Gamma Ray Log

The gamma ray log was run with both the borehole compensated sonic log and the dual induction log so it could serve as a comparative base for both. Immediately below the inner casing, the level of gamma activity picked up to about 50 API units before dropping at the 2,350-foot depth to less than 35 API units. The level of gamma activity remained low for the next 170 feet, but dropped to a minimum of 8 API units within the large cavern encountered at the 2,425- to 2,429-foot depth range. The gamma activity rose slightly from this low to the maximum of 32 API units; but, at a depth of 2,520 feet, the gamma ray log increased sharply, reaching more than 120 API units. At 2,545 feet, the activity dropped off to what it was above this sharp peak, and at 2,560 feet, it dropped further to less than 8 API units, the lowest recorded anywhere in the well.

The gamma ray log for the open hole did not substantially add to the knowledge of the strata below the 2,340-foot depth; but it did provide a backup for the other geophysical logs. In general terms, the gamma ray activity tended to rise in the more constricted sections of the open hole, and decrease where water fills cavernous voids. The large increase in gamma ray activity between 2,520 and 2,545 feet is associated with the lignite bed observed in the television survey from 2,527 to 2,537 feet below land surface.

2.4.4.3 Temperature

On December 1, 1987, the water temperature was recorded within the open hole. This recording showed a water temperature of 100.5°F except between 2,350 and 2,430 feet where it was 99.5°F, and between 2,510 and 2,520 feet, where it was 101°F. The temperature change in the 2,510- to 2,520-foot section of the open hole was attributed to mechanical error; however, the change measured in the interval between 2,350 and 2,430 feet was a real natural change. On December 3, the temperature log was repeated and it too showed a temperature drop of 1°F in that interval (see Appendix 12). This interval coincided with the most permeable part of the injection zone, between 2,350 and 2,440 feet, and was likely caused by the free movement of water in that zone of the aquifer.

The temperature log, therefore, can be said to corroborate the depth range for the interval most likely to receive the wastewater in the proposed injection zone.

7.4.4.4 Spontaneous Potential Log

The spontaneous potential log for the open hole section of the well exhibited a relatively slow changing pattern from below the inner casing to the 2,600-foot depth of the open hole. The pattern closely paralleled that of the induction log, but failed to indicate much else. It did, however, clearly outline two very significant features: the large cavernous zone at about 2,430 feet, and the lignite bed at 2,535 feet.

The signal deflections exhibited by the log appeared to be fully explainable by the lithologic changes and so they indicated no significant sharp changes in water quality within the open hole. It is, however, known that water quality gradually worsens with depth in the open hole (see Section 9-3) and this log confirmed that fact. From 2,430 feet to full depth at 2,600 feet, a steady increase was observed in the log (see Figure 7-20).

7.4.4.5 Summary

Besides the television survey log, the sonic and the induction logs are the best logs from which to interpret the presence of high permeability sections in the injection zone. Although neither of these logs can attach a numeric value to permeability when large cavities are present, they nevertheless show where those cavities are. The sonic log is particularly useful because the single graph of this log gives a quick visual answer. The induction log results are harder to visualize since both the positions of each of the three graphs and their relative positions to each other must be evaluated.

The sonic log of the open hole section of the NFMU deep test/injection well showed numerous sections where the travel time graph indicated the presence of cavernous zones; but the principal one was found in the section between 2,420 and 2,450 feet. Another cavernous zone was shown by the graph between 2,350 and 2,375 feet, and yet another between 2,515 and 2,520 feet.

The sonic log also showed very slow travel times in the section between 2,520 and 2,555 feet. If viewed in total isolation, the log would appear to indicate that this was another cavernous zone; however, in context with other data, it was seen that the slow travel time was due to the soft lignite layer found in that section.

The sonic log did fail to conclusively identify other cavities that were recorded in the television log; nevertheless, it did show a sharp reduction of travel time on each occasion. Table 4-7 (see Section 4) shows the locations of those cavities, and Figure 7-19 identifies them in relation to the sonic log.

The dual induction log, like the sonic log, clearly identified the largest of the cavernous zones, but showed it to be a lot thinner than it really is. The induction log showed a thickness of only 8 feet (from 2,422 to 2,430 feet below land surface), while in reality, this zone extended from 2,423 to 2,434 feet, according to the television survey.

Other cavities identified in the television survey were also confirmed by the induction log. This confirmation, however, was based solely on a sharp change in resistivity, particularly for the deep induction sonde, and no indication of size was provided by the induction log.

In conclusion, then it can be said that the sonic log and the induction log are excellent tools for identifying confining zones and zones of low permeability, but that they need to be used in conjunction with the television survey and/or drilling data to identify all the cavernous zones at the NFMU site.

7.5 WATER QUALITY PROFILE

To develop a water quality profile of the waters encountered as drilling progressed, several types of water samples were collected. These samples were collected from the kelly discharge at the end of each drill rod, beginning once the drilling operation switched from mud drilling to reverse air drilling at 1,582 feet. The first such sample was collected at 1,703 feet and successive samples were collected at approximately 30-foot intervals. In addition, as part of the coring program, water samples were collected with each of the cores drilled. Straddle packer samples were also collected at preselected depths (see Table 7-9).

The kelly discharge water samples were analyzed for the following indicator field parameters at the drill site: conductivity, salinity, pH and temperature, and those field results were presented in the field notes (see Appendix 23). The samples were then shipped to ESI laboratories for more extensive analyses. The water samples submitted with the cores were analyzed by CLI. The results of the ESI laboratory analyses are contained in Appendix 27; the CLI results are in Appendix 19.

All water quality data collected from the deep test/injection well during construction are included in the above three appendices (19, 23, and 27). There are, however, some important limitations on the accuracy of the data obtained from the kelly samples. The formation water present at the depth of the drill bit was drawn into the drill stem along with the cuttings, but mixed with it was uphole water. Kelly samples yielded a mixed, and usually diluted, sample. More reliable results were obtained from the packer samples and from the samples collected with the cores.

Two graphical methods were chosen to present the water quality data: the Stiff diagram and the Piper diagram. These diagrams are complementary in their respective presentations of water quality data.

Table 7-9

STRADDLE PACKER SAMPLE RESULTS

Parameters (in mg/l)	Depth (in feet)						
	1,484	1,564	1,950	2,110	2,250	2,275	2,300
Carbonate - CO_3	0.9	0	0.2	0.2	0.2	0.1	0.1
Chloride - Cl	3,300	7,150	24,990	27,500	36,240	15,620	18,740
Conductivity - SC	3,700	20,000	56,500	60,200	59,000	58,500	56,000
Fluoride - F	0.84	0.56	22	21	25	22	20
Total Dissolved Solids - TDS	2,140	11,690	33,340	34,490	35,200	34,300	34,850
Calcium - Ca	8.0	480	680	720	760	680	720
Magnesium - Mg	56	900	1,130	1,130	1,130	1,000	1,100
Potassium - K	1,330	5,500	600	580	610	610	620
Sodium - Na	900	3,600	3,460	3,480	3,450	3,460	3,500
pH (units)	7.8	6.3	7.8	7.5	7.8	7.6	7.3
Sulfate - SO_4	460	260	2,180	2,020	2,340	2,320	2,230
Bicarbonate - HCO_3	1 10	100	42	67	63	36	30
Field Parameters							
Temperature (^oC)	28.5	30.0	30.0	32.0	31.5	30.0	31.0
Conductance (mmhos)	3,350	18,800	50,000+	50,000+	50,000+	50,000+	50,000+
Salinity (0/00)	2	10	30	33	33	32	35

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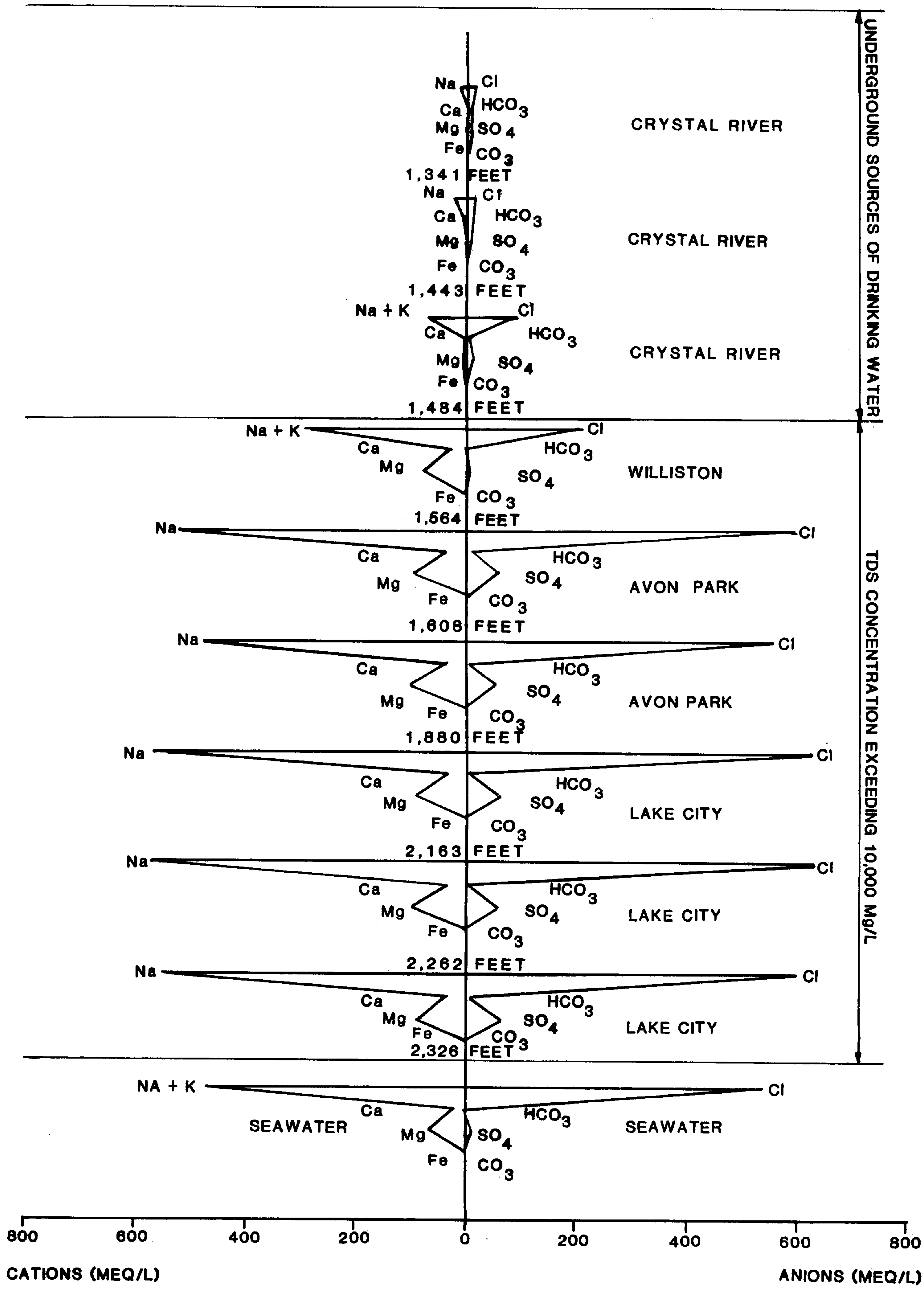
The Stiff diagram is useful in showing both differences and similarities within the water composition (Hem, 1970), and readily expresses any trends in the water quality data with sampling depth. Stiff diagrams for several samples collected at various depths are displayed in Figure 7-21. Samples 1, 2 and 3 are representative of the USDW in the upper portion of the Ocala Group (Crystal River Formation). Sample 4 is from a zone in the Williston Formation with more than 10,000 mg/l TDS. Samples 5 and 6 are from the Avon Park Formation, and Samples 7, 8 and 9 are from the Lake City Formation. Figure 7-21 also shows a Stiff diagram of typical seawater. This diagram is included for the purpose of comparison.

A trilinear diagram developed by Piper (Hem, 1970) represents each water quality sample by a single point, including a large number of samples on the same diagram. Since the Piper diagram does not, however, quantify the level of cations and anions found within a sample, it does not replace the Stiff diagrams. The same nine water quality samples described above were selected for inclusion on the Piper diagram shown in Figure 7-22.

The water quality of the first two samples shown in Figure 7-21 is very similar, except for a slight increase in the level of calcium at the 1,443-foot depth. The third sample, at a depth of 1,484 feet, shows a significant increase in the sodium-chloride content, but the TDS content is still below 10,000 mg/l (see Figure 7-22). The water quality shown for the 1,564-foot depth indicates that the water in the well has increased considerably in sodium and chloride content and is only slightly better than that from the sea. The water quality samples collected in the 1,608- to 2,326-foot depth range plot as more mineralized than seawater in the Stiff diagram (see Figure 7-21).

From the Stiff diagrams, it is clear that a very significant change in the water quality occurs between 1,484 feet and 1,564 feet. This change is marked not only by the large increase in sodium and chloride, but also by a noticeable increase in magnesium. This kind of change had been predicted by the resistivity log (see Appendix 3) and was the basis for the decision to set the intermediate casing at 1,582 feet. Below 1,564 feet, the water quality



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WATER QUALITY–STIFF DIAGRAMS

FIGURE 7–21

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WATER QUALITY-PIPER DIAGRAM

FIGURE 7-22

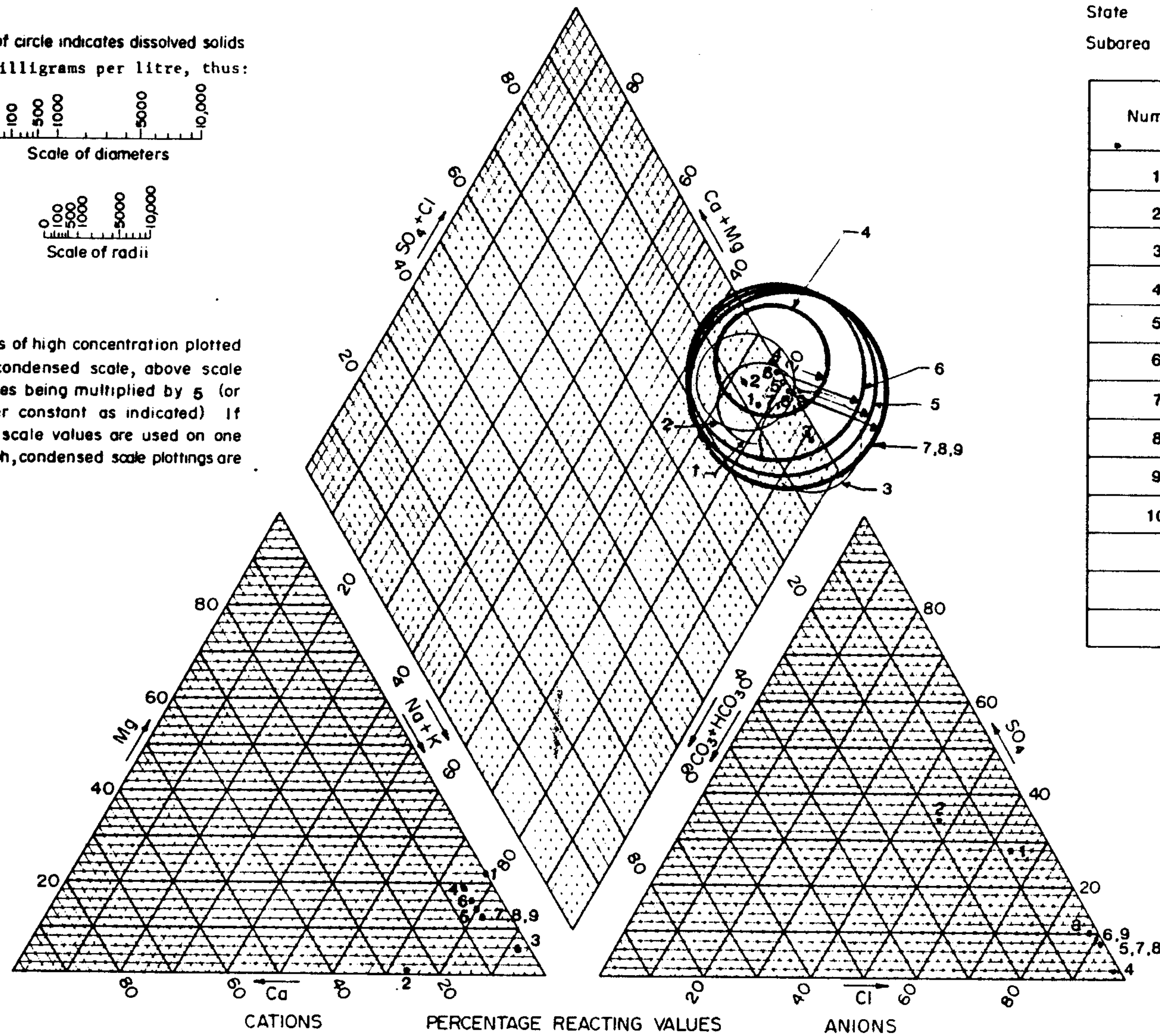
WATER-ANALYSIS DIAGRAM

✱ Area of circle indicates dissolved solids in milligrams per litre, thus:

0 100 500 1000 5000 10,000
Scale of diameters

0 100 500 1000 5000 10,000
Scale of radii

✱ Waters of high concentration plotted at condensed scale, above scale values being multiplied by 5 (or other constant as indicated) If two scale values are used on one graph, condensed scale plottings are —



State Florida

Subarea Lee County

Number	Date	Depth	Floridan Aquifer System
1	5/20/87	1,341	Crystal River
2	5/22/87	1,443	Crystal River
3	6/7/87	1,484	Crystal River
4	6/5/87	1,564	Williston
5	5/25/87	1,608	Avon Park
6	9/4/87	1,880	Avon Park
7	9/11/87	2,163	Lake City
8	9/16/87	2,262	Lake City
9	9/19/87	2,326	Lake City
10	—	Seawater	—

becomes increasingly saltier, and at 1,608 feet, as shown by the Stiff diagram, the water within the aquifer has become even saltier than seawater. This condition continues down to 2,326 feet.

The water represented by the Stiff diagrams in Figure 7-21 between 1,564 and 2,326 feet is predominantly a sodium-chloride type of water. Its composition closely resembles seawater, but the sulfate content is disproportionately higher than in seawater.

The Piper diagram in Figure 7-22 shows a similar pattern as the Stiff diagrams. The first three samples, 1, 2, and 3, all show low TDS waters, while the other six samples show much higher TDS concentrations. Figure 7-22 clearly demonstrates that the principal difference between the last six water samples is the concentration of salts and not the kind of salts. In fact, the plots of Samples 4, 5, 6, 7, 8 and 9 form a straight line and the plotting point for Samples 7, 8 and 9 is the same.

One other important characteristic highlighted by the Piper diagram is seen in the anion and cation triangles of the diagram. Those triangles show that Samples 1 and 2 are somewhat apart from the others, and that even Sample 3 is more closely associated with the other samples than with Samples 1 and 2. The conclusion, from the position of the plots for Samples 1 and 2 on the triangles, is that the waters from 1,341 and 1,443 feet are also sodium-chloride type waters, but with an observable correlation to the calcium carbonate waters found in waters from the Floridan Aquifer System in other parts of the State.

The data from the Stiff diagrams (Figure 7-21) and the Piper diagram (Figure 7-22) clearly demonstrated that, somewhere between the 1,484-foot depth of Sample 3 and the 1,564-foot depth of Sample 4, the water quality changes from less than 10,000 mg/l TDS to more than that amount; but, the exact location of the 10,000 mg/l TDS line cannot be narrowed any closer than those 80 feet using these data. The geophysical logs did, however, provide a good indication that the change in water quality below 1,484 feet does not begin until a depth of 1,500 feet, and that the sodium chloride probably increases at 1,530 to 1,550 feet, causing the TDS to increase beyond 10,000 mg/l.

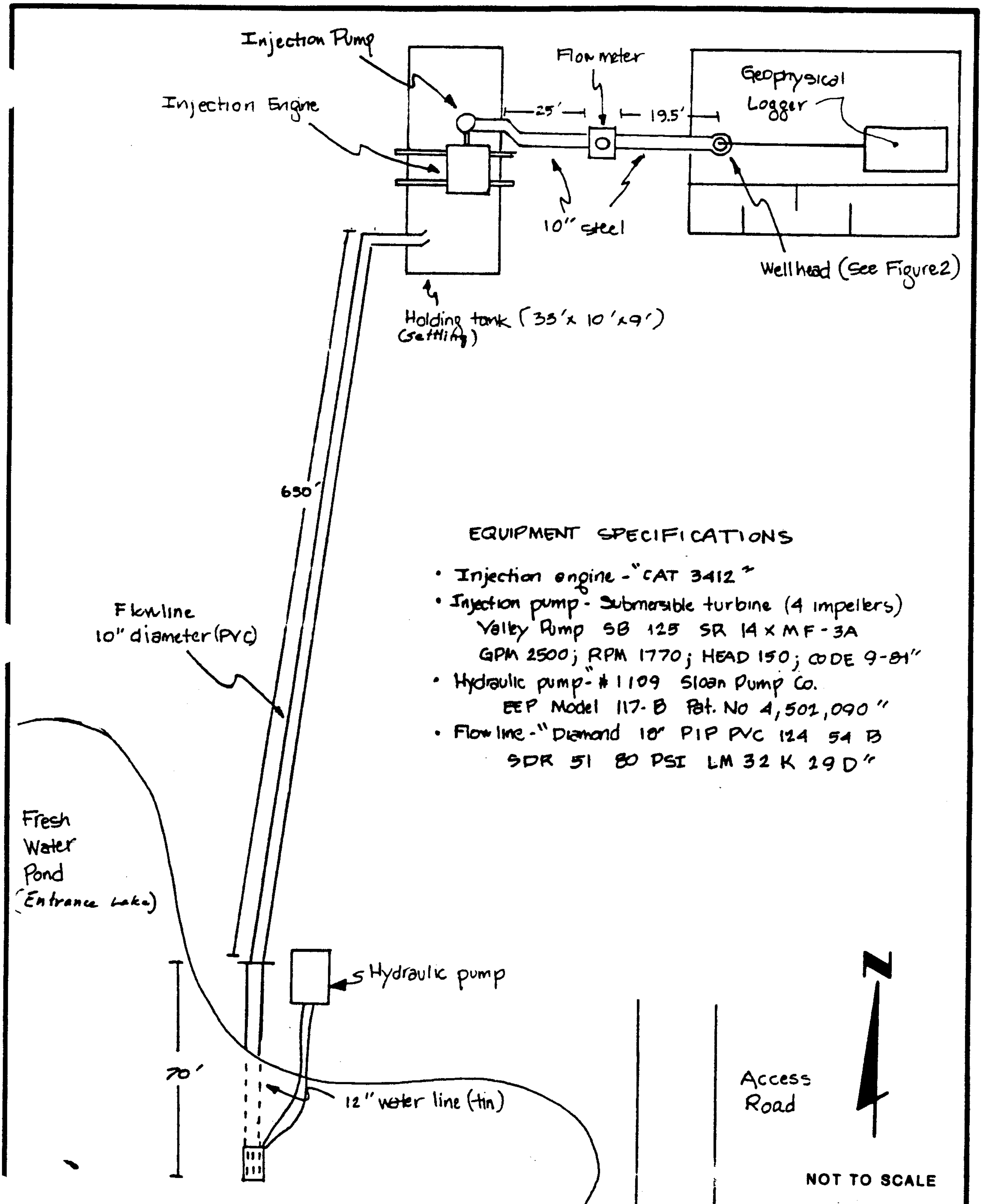
Section 8
INJECTION ZONE TESTING

The testing of the injection zone consisted of one 24-hour, 2.0-mgd and one 24-hour, 4.0-mgd injection test. The injection tests are described in Section 8.1. During testing, the piezometric heads of the upper and lower monitor zones of the deep monitor well were observed. Data were also collected on factors that could potentially influence the test results. These factors included: barometric pressure, tidal fluctuation, rainfall, and injection water quality. The barometric pressure effects and tidal effects are discussed in Sections 8.2 and 8.3, respectively. Section 8.4 discusses rainfall, Section 8.5 contains an analysis of the monitor well data, and Section 8.6, an analysis of the injection-well data and injection water quality. An injection test summary is given in Section 8.7. All the data collected throughout the 8-day duration of the various phases of the injection tests are listed in Appendix 28.

8.1 INJECTION TEST DESCRIPTION

The injection test on the deep test/injection well started on December 12, 1987. The four days between well development and the injection test were spent running the final geophysical logs, installing the down-hole pressure transducer and setting up the injection pump and pipeline necessary to inject water from a nearby lake into the deep test/injection well (see Figure 8-1). Background water level readings were taken on the deep monitor well during the four days preceding the actual start of the injection test.

The volume of water injected was continuously recorded by an in-line cumulative flowmeter. The injection pressure was monitored using a down-hole pressure transducer installed at the bottom of the open hole. The transducer equipment recorded psi values to three decimal places, but only the first two decimal values are reliable. As a backup, in case of transducer failure, an 8-inch diameter Bourdon tube pressure gage which read in psi to one decimal place, and an auxilary 2-inch pressure gage which read in psi to the nearest pound were also monitored.



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PIPING SET UP FOR INJECTION SYSTEM TESTS

FIGURE 8-1

The injection water quality was tested throughout the test period. Water from a lake located at the entrance to the NFMU site was used as the injection fluid in those tests. The intake line was installed several feet above the bottom of the lake to avoid lifting sediments and the injection water was fresh water of homogeneous quality throughout the injection test. A sparse rainfall occurring during the evening of December 15 and the morning of December 16 was not sufficient to affect the water quality. The average temperature of the water was 17 degrees Centigrade, and the average conductivity was 2,150 µmhos/cm.

The injection test began at 10:09 p.m. on December 12, 1987. The injection rate was 1,450 gpm (2.0 mgd) and the bottom hole pressure stabilized at approximately 2 psi (4.6 feet of water) above the pre-injection hydrostatic pressure within several minutes. At 3:09 a.m. on December 13, the injection test was discontinued due to a pump malfunction; but the recovery was measured for the next 12 hours.

At 3:11 p.m., December 15, following pump repairs, the 2.0-mgd injection test was restarted. The second injection test went for the full 12 hours, followed by 12 hours of recovery. The new pressure data duplicated the data from the earlier attempt, with a total increase again of approximately 2 psi (4.6 feet of water).

The 24-hour, 4.0-mgd injection test began at 12:44 p.m., December 17. The pressure in the injection zone stabilized very quickly at about 5 psi (11.5 feet of water) above the pre-injection hydrostatic pressure. The injection phase was scheduled for 24 hours, but was completed 16 hours later when the injection water in the lake supplying that water was depleted. A total of 2.63×10^6 gallons of water was injected during the 4.0-mgd injection phase at an average rate of 2,740 gpm (3.95 mgd). A 12-hour recovery phase began at that time and was completed on December 18 at 5:00 p.m.

The results from all three injection events exhibited very similar characteristics:

- The injection pressure rose and stabilized within several minutes of startup

- The injection pressure showed slight variations due to minor variations in the injection rate

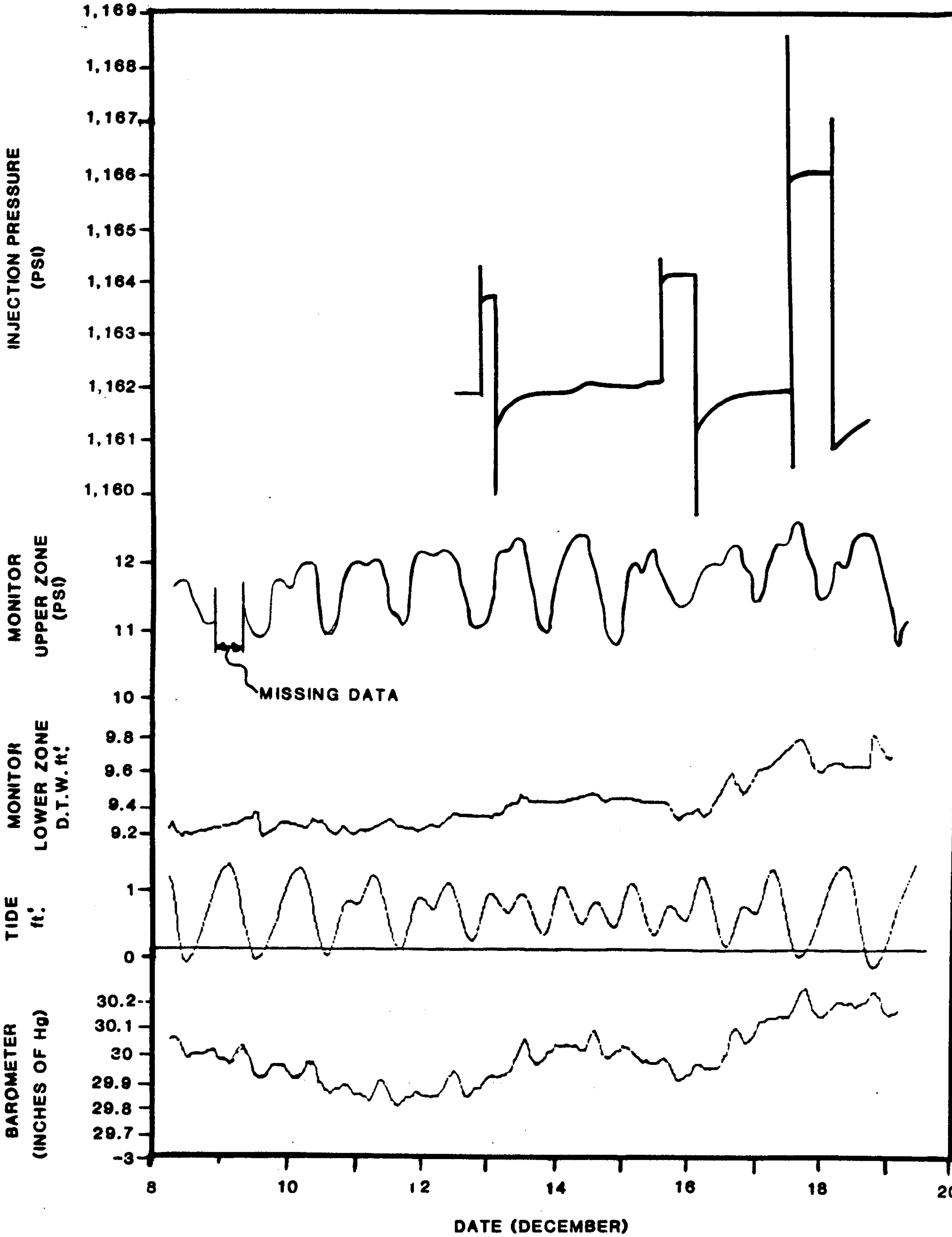
- During recovery, the pressure in the injection zone increased slightly over a period of about 12 hours. During this time, the injection and formation fluid mixed until they reached uniform density and temperature.

The results of the aborted 2.0-mgd test were essentially the same as those of the completed 2.0-mgd test. Only the results of the completed tests are discussed in this report. The data discussed in this section are represented graphically in Figure 8-2.

8.2 BAROMETRIC PRESSURE EFFECTS

Barometric pressure data for December 8 to 18, 1987 were obtained from NOAA for the station nearest to the site; that station is at Page Field, Fort Myers, nine miles to the south. The barometric pressure data are shown in Figure 8-2 and are included in Appendix 28.

Figure 8-2 shows a close parallel relationship between the barometric pressure fluctuation (bottom graph) and the lower monitor zone (middle graph), not only in the long-term fluctuations over several days, but also within a single day. The diurnal barometric pressure change caused by the warming and cooling of the atmosphere each day and night can be seen clearly in the barometric data and in the graph for the lower monitor zone. The pattern exhibited in both graphs shows the usual barometric pressure pattern of two maxima (i.e., about 10:00 and 22:00 hours) and two minima (i.e., about 4:00 and 16:00 hours) within each daily cycle (Weisner, 1970). Rising barometric pressures produced a distinct lowering of the water levels (increasing depth to water); the reverse was true for falling pressures.



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INJECTION TEST DATA SUMMARY

FIGURE 8-2

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A similar parallel relationship between barometric pressure and water level occurred in the injection zone; but the changes there were not as pronounced as in the lower monitor zone. A very distinct increase in bottom hole pressure occurring the afternoon of December 14 in the injection well (see Figure 8-2 - top graph) is, however, easily attributed to a sharp drop in barometric pressure in the early afternoon that same day when a high-pressure cold front moved through the area. The barometric changes also affected the upper monitor zone; however, the tidal effect there masked the barometric effect (see Section 8.3).

The changes in piezometric head that can be expected in an aquifer as a result of changes in the atmospheric pressure can be calculated from the following relationship:

$$\Delta h = \frac{-B\Delta p}{\gamma}$$

where Δh is change in piezometric head (feet)

B is barometric efficiency, usually ranging from 0.2 to 0.7 (Todd, 1980)

Δp is change in atmospheric pressure (lb/feet^2)

γ is specific weight of water (lb/feet^3).

The daily piezometric head fluctuation, obtained by using this equation and applying the maximum limiting barometric efficiency of 70 percent to the data in Appendix 28, averaged about 0.35 feet. That fluctuation, obtained using the 70 percent efficiency, is probably greater than the actual fluctuation.

The piezometric readings for the deep test/injection well varied throughout the injection test. Following an initial rise at the start of the 4.0-mgd test, the increase in piezometric head due to injection fluctuated between 3.72 psi (8.58 feet) and 4.35 psi (10.04 feet) during the remainder of the test. The effects of changes in the barometric pressure on piezometric levels from December 12 to December 18 (the period of maximum barometric change) represent 3.3 percent of the piezometric head range recorded during the major part of the test. The barometric pressure is thus not a significant contributor to the fluctuations exhibited in the deep test/injection well (see Section 8.5).

The piezometric head data from the upper and lower monitor zones were analyzed for barometric pressure influence. The regression of the upper zone barometric pressure data yielded a correlation coefficient of 0.002, which suggests that virtually no relationship exists between the two series of data. The same situation existed with the deep test/injection well; i.e., no correlation was observed between water level changes and changes in barometric pressure. Regression of the lower zone barometric pressure data yielded a correlation coefficient of 0.90. This strong correlation coefficient indicates that barometric pressure changes result in predictable changes in the piezometric head in the lower monitor zone. The regression equation is:

$$LMZ = 1.14\ BAR - 25.0$$

where LMZ is depth to water in the lower monitor zone (in feet)
BAR is barometric pressure (in inches of mercury).

In summary, barometric pressure was not a significant contributor to the piezometric head fluctuations in either the deep test/injection well or the upper zone of the deep monitor well. Consequently, water levels in those wells were not corrected for variations in the piezometric levels caused by barometric pressure effects. Although the change is very small, the piezometric head data for the lower monitor zone presented in Appendix 28 has been corrected for barometric effects.

8.3 TIDAL EFFECTS

There are no continuous tidal recording stations along the nearby coastline of Lee County. The nearest such station is operated and maintained by NOAA in St. Petersburg (i.e., Station No. 3087). Tidal data were obtained from NOAA for the St. Petersburg tidal recording station covering the period of the injection test and were corrected by established factors and ratios published in the NOAA tide tables (NOAA, 1988) to obtain tidal data for the Caloosahatchee River in Fort Myers. These data, calculated for the periods of the injection test, are shown in Figure 8-2.

The effects of the tidal fluctuations upon the piezometric heads within the Floridan Aquifer System at the NFMU site can be calculated from the following relationship:

$$H_x = H_o \cdot e^{-x \sqrt{\pi S / t_o T}} \qquad \text{(Todd, 1980)}$$

where H_x is change in piezometric head (feet)

H_o is tidal amplitude (feet)

x is distance from injection test site to point of contact between aquifer and ocean (feet)

S is storage coefficient of aquifer

T is aquifer transmissivity (ft^2/day)

t_o is tidal period (days)

The distance of the injection-well site from the point of contact between the aquifer and the tidal influence of the ocean is fairly difficult to estimate. Assuming that the elevation of the deeper formations does not change much with distance from the NFMU site, the distance from the well site to that point of contact can be best estimated from bathymetric contours for the Florida peninsula (Chen, 1965; and Fernald 1981). The 600-fathom bathymetric contour is about 80 miles both west and east of the well site and, therefore, the NFMU site is located approximately in the center of the continental shelf around the Florida peninsula. The drop at the edge of the continental shelf is sharp; thus the point of contact between the two monitor zones and the injection zone are approximately 80 miles from the injection-well site. This distance is so large numerically, that it results in an extremely low number for Hx; so small in fact, that it would be impossible to measure it at the well site.

Ocean tides, therefore, were concluded to have a negligible effect on piezometric heads in the lower parts of the Floridan Aquifer System at the NFMU site. Although the Boulder Zone is probably hydraulically connected with the Straits of Florida (Meyer, 1974), the energy losses, due to the large distance to the point of connection, dissipate the fluctuations in pressure head and no tidal effect was observed in the deep test/injection well. No tidal fluctuations were observed in the lower zone of the deep monitor well either.

The amount of tidal influence was quantified using linear regression analysis. The regression of tide data on the lower monitor zone data and on the data from the deep test/injection well determined that piezometric head fluctuations in those two wells were unrelated to tidal fluctuation.

The upper monitor zone did, however, exhibit a tidal influence. When regression analysis was applied to the upper monitor zone data, a good correlation was obtained; but even without any statistical analysis, this correlation was obvious, based solely on a visual comparison (see Figure 8-2). Explaining how this zone can be affected by tides when the zone of contact is 80 miles away is beyond the scope of this report; but it is possible that these tidal fluctuations in the upper monitor zone are caused by tidal loading and compaction of the aquifer in the Caloosahatchee estuary and not by tidal effect at the contact between the formation and the ocean. Another possibility is that there might be sinkholes or other channels through which, at that depth, the distance to the contact with the ocean is shortened.

8.4 RAINFALL

A rain gage was set up to collect site-specific data during the injection test. A total of 0.38 inches of rain fell during that time. Although this amount of rain could not possibly influence the injection test data, it is identified to complete the record of events related to the injection test. The rainfall occurred from 8:00 p.m., December 15, to 3:20 a.m., December 16, 1987.

8.5 DEEP MONITOR WELL ANALYSIS

The piezometric heads in the upper and lower monitor zones of the deep monitor well were recorded for several days prior to the injection test. The piezometric heads in the two zones were also monitored during the injection and recovery phases of the injection tests. The following discussion analyzes the background fluctuations and the influence of the injection test on each monitor zone.

8.5.1 Upper Monitor Zone

The piezometric data, recorded in the upper monitor zone (1,318 to 1,422 feet) and representing the piezometric head fluctuations in the USDW portion of the Floridan Aquifer System, ranged from 10.7 to 12.1 psi and exhibited a maximum daily change of 1.3 psi, observed on December 14 (see Appendix 28). These fluctuations do not represent an overall increase or decrease in piezometric head; they rose and fell throughout the injection test independently of the status of the injection well pumping, and followed essentially the same pattern during the tests as they did before and after the tests.

Section 8.3 shows that tidal change was a major cause of the observed head fluctuations. Other than the apparent tidal influence, no discernible trend is noted was the upper monitor zone.

Section 8.2 shows that barometric influence was negligible. Fluctuations in piezometric head of the same range and frequency were recorded prior to, during, and following the injection phase of the test, and so the injection of fluid into the injection zone was ruled out as a cause of fluctuating piezometric head. The small percentages of the total fluctuations that cannot be attributed to tidal changes were probably caused by pumpage from this zone by others in Lee County.

8.5.2 Lower Monitor Zone

The piezometric data recorded in the lower monitor zone (1,910 to 2,004 feet) represent the piezometric head fluctuations immediately above the lower portion of the confining zone. Since the artesian pressure of this zone is below land surface, the readings were obtained using a chalked steel tape graduated in hundredths of a foot, and the data were recorded as depth to water BTOC. The data are presented in Appendix 28 and illustrated in Figure 8-2.

Prior to the start of the injection tests, the background readings, shown in Figure 8-2, indicated a continuous fluctuation in piezometric head. There was an overall range of 9.16 to 9.28 feet prior to injection. During the injection phase of the 4.0-mgd injection test, the lower monitor zone showed an overall range of 9.52 to 9.61 feet. During the recovery phase of the 4.0-mgd injection test, the piezometric head of the lower monitor zone showed an overall range of 0.18 feet from 9.55 feet to 9.73 feet.

The fluctuation ranges were obviously essentially the same before, during, and after the tests. Like those seen in the upper monitor zone, they were not caused by the injection of fluid into the injection zone. Rather, they can be attributed only to natural background fluctuations of small magnitude, fully accountable by the barometric changes.

8.6 INJECTION TEST ANALYSIS

The injection zone at the NFMU site is highly permeable and will accept much larger quantities of injection fluid, at higher rates, than are planned for this well. Consequently, the 2.0-mgd injection test showed almost no stress in the aquifer, while the 4.0-mgd injection test only marginally stressed it. Since the accuracy of a pump-test increases as the degree of aquifer stress increases, the data from the 4.0-mgd test are expected to be more accurate than the data from the 2.0-mgd test, and for this reason, only the 4.0-mgd test is discussed in detail herein.

The pressure transducer data gathered during the injection test exhibited a series of minor fluctuations throughout the test duration. These fluctuations were attributed to minor variations in the injection rate and did not affect the interpretation of the data.

8.6.1 Transmissivity

Since only one injection well has been constructed, the only test data available for the analysis of the injection zone were those data obtained from that well. This in turn restricted the method of calculating the aquifer characteristics to single-well methods of analysis. Several different aquifer analysis methods were considered and tried; but the only acceptable method of analysis proved to be standard curve-matching techniques applied to the injection phase only. The natural return of the water in the well to thermal equilibrium following injection masked the aquifer recovery characteristics and made it impossible to separate the actual water level changes due to recovery from those due to temperature and density changes. These difficulties are not inherent in the injection phase of the injection test; thus the aquifer characteristics can be accurately determined using those injection phase data.

8.6.1.1 Type Curve Solution

Type curves are standard curves that represent the relationship between the well function W(u) and u, where u is defined as follows:

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

where r is distance from point of discharge or recharge in the case of injection to the observation well (feet), which in this case is taken as the radius of the well bore.

S is storage coefficient

T is aquifer transmissivity (gal/day/ft)

t is time of observation and discharge (days).

From the deep test/injection well pressure transducer data, a log-log plot was developed with s, the drawdown (in this case a negative drawdown since injection is occurring in feet, and t, in minutes, on the vertical and horizontal axes, respectively. The curve represented by the data points was matched to the standard type curves and the values of s and t were read from the data plot at the same point as were both u and W(u). This point, which is called the match point, was marked on the data plot for future reference. The values of s, t and w(u) obtained from the match point were used in conjunction with the following equation to obtain the aquifer transmissivity.

$$T = \frac{Q}{4\pi} \cdot \frac{W(u)}{s}$$

The type curve solution for the 4.0-mgd test is presented in Figure 8-3. To corroborate the results of the 4.0-mgd test analysis, the type curve method was applied to the 2.0-mgd injection test data. This type curve solution is presented in Figure 8-4.

The results of the type curve solution are as follows:

Injection Test	Transmissivity (gpd/ft)
4.0-mgd	514,232
2.0-mgd	482,287

The close match of these values supports the use of an average transmissivity of 498,260 gpd/ft as a representative value for the injection zone at the NFMU site.

8.6.2 Storage Coefficient

Because the injection test was conducted on a single well, it was impossible to relate the dependent variable (drawdown) to the second independent variable (distance) and, consequently, it was also impossible to evaluate the storage coefficient for the injection zone by conventional means, such as curve matchings, straight line method, the Hantush method, etc. The difficulty in evaluating the storage coefficient arose in determining the distance from the center of recharge in the deep test/injection well.

The storage coefficient can be calculated by two methods in such a case.

The first method for calculating the storage coefficient was developed by Jacob (1940) and is defined as follows:

$$S = \theta \lambda b \, (\beta + \alpha/\theta)$$

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TYPE CURVE SOLUTION
(4 MGD TEST)

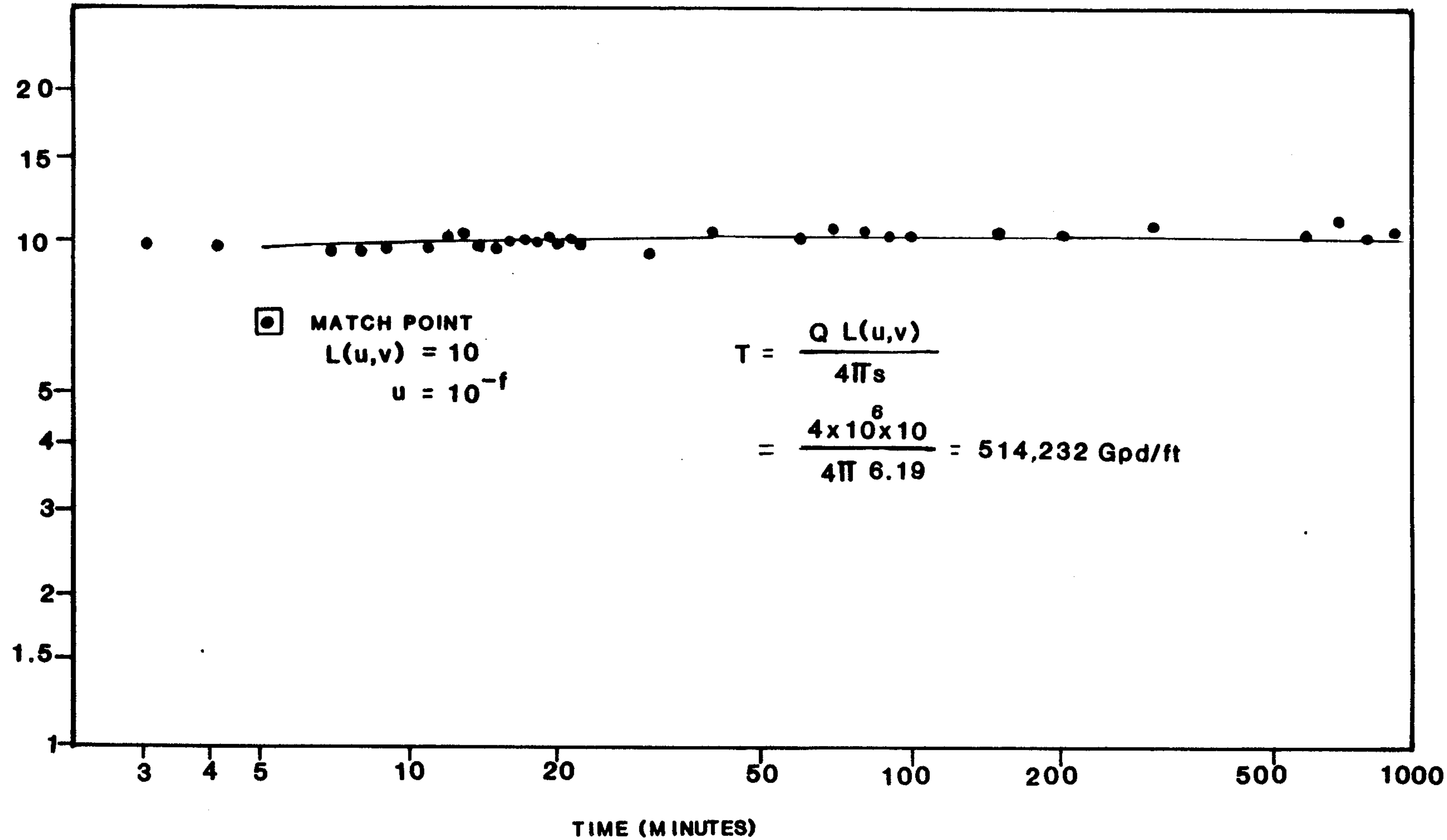

FIGURE 8-3

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TYPE CURVE SOLUTION

(2 MGD TEST)

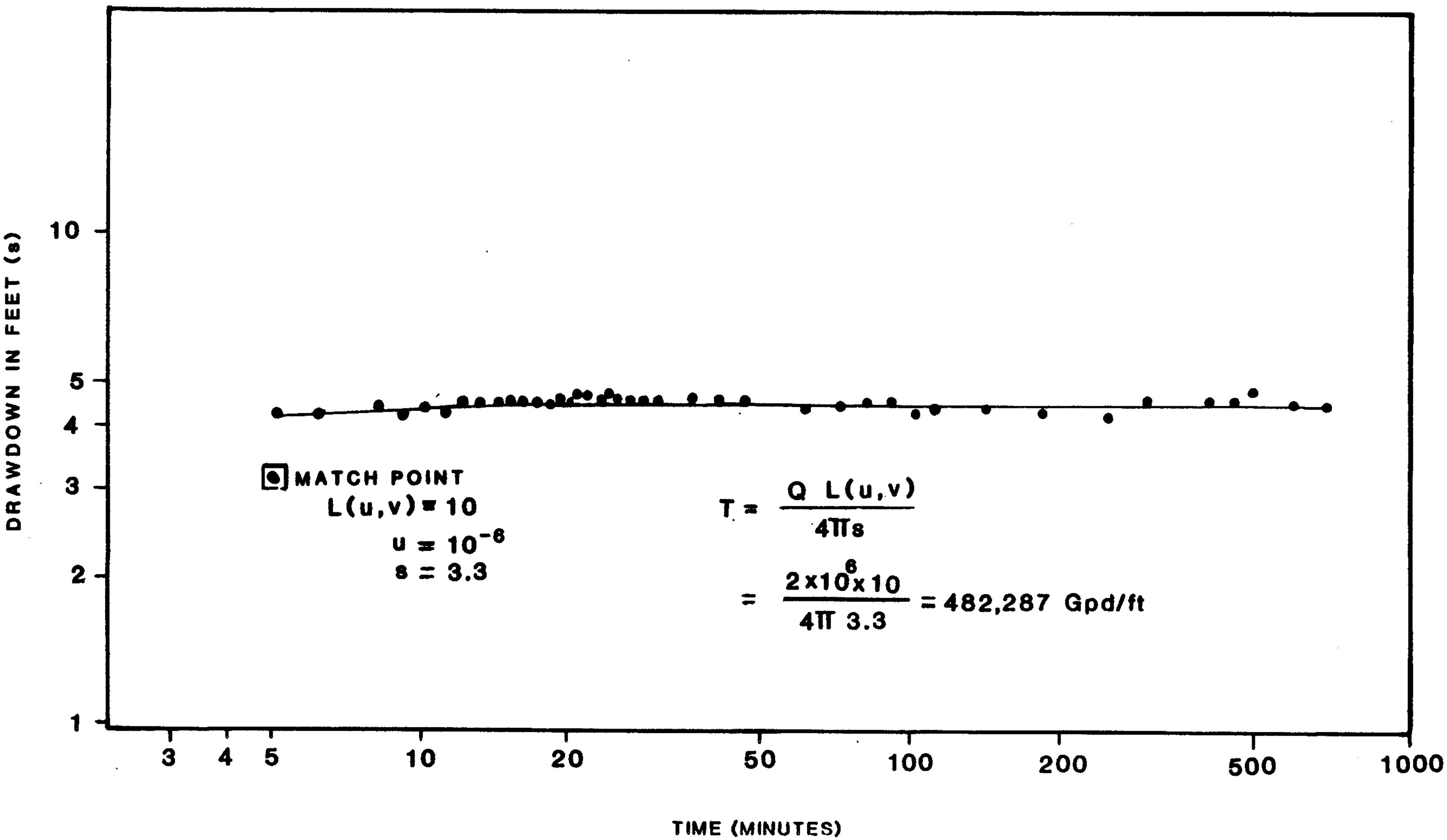

FIGURE 8-4

where Θ is porosity as a fraction

λ is specific weight of water ($lb/in^{-2}/ft^{-1}$)

β is modulus of compressibility for water ($in^{-2}lb^{-1}$)

α is modulus of compressibility for rock matrix ($in^{-2}lb^{-1}$)

Both the specific weight and the modulus of compressibility for the formation fluid are given in Section 9 (see Table 9-3). The average porosity of the injection zone as a whole, evaluated from the geophysical logs and television survey, was estimated to be 35 percent (see Section 9.1). The modulus of compressibility for dolomite is about 7.09×10^{-7} ($in^{-2}lb^{-1}$)(Freeze and Cherry, 1979; and Hodgman, 1955). Consequently, the value of the storage coefficient was calculated at 7.3×10^{-5}.

The second method was defined by Lohman (1972) as follows:

$$S = b \times 10^{-6}$$

where S is storage coefficient

b is aquifer thickness (feet)

This equation is only an approximation and by itself has a limited basis for use, although Meyer (1974) used this method with reasonable success at a deep-injection well in southeast Florida. Since the injection zone is separated from the whole thickness of the aquifer above by a confining zone, it has been assumed that the effective thickness is only that of the highly permeable section of injection zone, in this case, 95 feet. Therefore, the storage coefficient, determined by this equation, is 9.5×10^{-5}, a value in agreement with that of 1×10^{-5} determined for the lower parts of the Floridan Aquifer System elsewhere in South Florida, and close to the approximate value calculated by Jacob's method.

based on the average of the results of these two equations, the storage coefficient for the injection zone is estimated to be 8.4×10^{-5}.

8.6.3 Leakage Coefficient

As with the storage coefficient, the single-well injection test does not permit the leakage coefficient to be determined from the piezometric data. Instead, a differential analysis of the borehole compensated sonic log was carried out to determine the leakage coefficient for the overlying confining layers. The results of this analysis are presented in Section 9.2.

8.7 TEST RESULT SUMMARY

The 24-hour, 2.0-mgd injection test was started twice and only the second test ran for the required 12 hours of injection and 12 hours of recovery. Following the 2.0-mgd test, a 24-hour, 4.0-mgd test was run. The data obtained during the first two tests did not differ from the data obtained in the final 4.0-mgd injection test; but, since the latter stressed the aquifer more, the emphasis of this report is on the 4.0-mgd injection test.

The problems caused by friction losses, and the resulting gage fluctuations during the injection phase of the injection test, were alleviated by the use of a down-hole pressure transducer. This equipment allowed accurate measurements of pressure changes within the injection zone during the injection tests. Backup gages at the wellhead yielded the same data; but those data were not analyzed since the transducer did not fail. Based on the transducer data from the injection phase, the transmissivity of the injection zone was calculated at 498,260 gpd/ft. The storage coefficient was calculated at 8.4×10^{-5}. Since there are deep-injection wells operating efficiently in Florida with injection zone transmissivity values of the same order of magnitude as the transmissivity at NFMU site, it is expected that this well system will also function efficiently.

During the injection test, data were collected from two monitoring horizons above the injection zone. Those data showed that the injection zone is completely separate from the monitor zones and that the two monitor zones are separate from each other.

In summary, the deep test/injection well at NFMU penetrates a suitable injection zone and an excellent confining zone above it. Hence, this NFMU well can be described as capable of accepting up to 4.0 mgd of treated wastewater from the treatment plant.

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Section 9
CHARACTERISTICS OF INJECTION ZONE AND CONFINING ZONE

9.1 INJECTION ZONE - PHYSICAL LIMITS AND HYDROLOGIC CHARACTERISTICS

9.1.1 Physical Limits

Based on the television survey (see Section 4.7), the core data (see Section 7-3), water quality (see Section 7.5), and the geophysical logs (see Section 7.4), the full extent of the proposed injection zone has been identified in the 2,340- to 2,600-foot depth range. This 260-foot zone comprises the lower part of the Lake City Limestone, and the upper part of the Oldsmar Limestone, both of which have experienced severe dissolution and dolomitization.

Both the geophysical logs and the television survey showed that the proposed injection zone is made up of five major cavity-riddled sections, which are themselves separated by interspersed thin layers of low permeability. These cavity-riddled sections are found between 2,353 and 2,364 feet, between 2,375 and 2,397 feet, between 2,414 and 2,434 feet, between 2,478 and 2,480 feet, and between 2,506 and 2,520 feet (see Figure 7-19 and Table 4-7). The results of the television survey through the 260 feet of injection zone indicated that approximately 35 percent of the open hole is cavernous or cavity-riddled; however, for the proposed injection zone as a whole, the section between 2,414 and 2,434 feet is the most cavernous and the interval between 2,423 and 2,427 feet includes the largest cavern of all.

The definition of cavity and cavern as used in this discussion is taken from Special Publication No. 20 (Puri and Winston, 1974) of the Florida Bureau of Geology. In that publication, a cavern is defined as an opening whose smallest dimension is more than two feet, and a cavity is defined as an opening whose largest dimension is less than two feet, but more than three inches. A vug is an opening whose largest dimension is three inches or less.

9.1.2 Hydrologic Characteristics

The hydrologic characteristics of the injection zone were evaluated from the data collected during the injection test. The transmissivity of the injection zone was determined to be 498,260 gpd/ft (see Section 8) which, when compared with other deep-well injection zones in Florida, can be described as good. The storage coefficient of the injection zone was estimated to be 8.4×10^{-5}, a fairly typical value for other injection zones in south Florida.

This transmissivity is made up primarily of the individual permeabilities of the cavernous and cavity-riddled sections in the injection zone. Using 70 feet as the additive thickness of these sections, the nominal permeability of the receiving zones was estimated to be 7,100 gpd/ft^2. With this permeability, the effective porosity was then calculated from the empirical relationship of porosity versus permeability (see Figure 7-2) to be approximately 35 percent.

The cavities are also considered to be extensive and increasing in size, particularly towards the south and east, where other oil-field deep-injection wells have penetrated much more developed cavernous systems (Vernon, 1970). It is this cavity-riddled zone below 2,400 feet in the Lake City and Oldsmar Limestones that has been locally referred to as the Boulder Zone.

9.2 OVERLYING CONFINING ZONE

Chapter 17-28 (FAC) requires that a confining zone be present above the injection zone, and that it should be able to prevent the upward migration of injected fluid from the injection zone. In practice, however, no natural soil or rock is totally impermeable and, therefore, able to totally prevent the migration of fluid from any aquifer system (Todd, 1980; Bear, 1979; Freeze and Cherry, 1979; etc.). All rocks are permeable to one degree or another; therefore, the issue addressed in this section is the degree of fluid migration rather than its complete prevention. As seen in Section 7, however, the confining layers of the confining zone are for all practical purposes impermeable. The decision by the regulatory authorities as to whether the injection well at NFMU should be permitted largely depends on the level of acceptability of fluid migration from the proposed injection zone.

In the following subsections, the confining layers above the proposed injection zone are discussed in terms of their mineralogical and hydraulic characteristics. Their physical limits are also discussed.

9.2.1 Physical Limits

The boundary between the injection zone and the overlying confining zone (that is, the bottom of the confining zone) was determined by means of the geologic cuttings, the geophysical logs and the water quality data to be at a depth of 2,340 to 2,350 feet. At that depth, a sharp change was seen in the acoustic log and in the electric logs (both spontaneous potential and induction), indicating an increase in porosity and permeability. The television survey also indicated an increase in secondary porosity.

The top of the confining zone was similarly identified at 1,800 feet. Confinement begins in the lower 140 feet of the Avon Park Limestone and continues 400 to 410 feet into the Lake City Limestone, for a total confining thickness of 540 feet. However, not all of the confining zone is confining; several intervals are cavity-riddled and one interval, between 2,130 and 2,150 feet, contains a 3-foot cavern.

9.2.2 Mineralogical Characteristics

The lower interval of the Avon Park Limestone, from 1,800 to 1,890 feet, is composed of a moderate to well-indurated limestone. From 1,890 feet to the base of the Avon Park at approximately 1,940 feet, the formation consists of a well to moderately indurated, very micritic dolomite and dolomitic limestone (see Appendix 24).

The remaining 400 to 410 feet of confining zone consist of the upper section of the Lake City Limestone. In the interval from 1,940 to 2,060 feet, the formation consists of very fine to fine-grained, well to moderately indurated dolomite and/or dolomitic limestone. From 2,060 to 2,110 feet, the formation is moderately indurated limestone intermixed with medium-grained, highly recrystallized biogenic limestones which show some dolomitization. The lower 230 to 240 feet of the confining zone contain a mixture of dolomite and dolomitic limestone. The dolomite is microcrystalline to very fine grained and is well indurated with dolomite cement. The dolomitic limestone is moderately indurated and its grain type is micritic and crystalline.

Four cores from the confining zone were collected and analyzed in the laboratory through X-ray diffraction. The results are available in Appendix 19, but are reproduced here as Table 9-1. This table shows that the calcite fraction is predominant in the limestone sections, as would be expected, and that the dolomite fraction increases with depth as the dolomite sections become predominant. At 2,326 feet, the formations are only 2 percent calcareous.

9.2.3 Hydraulic Characteristics

The confining characteristics of the limestone formations of the confining zone are determined by the degree of cementation and by the vugular and intergranular porosity of the individual layers. While the confining characteristics of the dolomitic formations are largely determined by the percentages of dolomite found within the various strata throughout the full thickness of the formations. In general, the higher the percentage of dolomite, the lower the porosity, which in turn is directly related to the permeability of the rock samples. The larger the fraction of dolomite within the rock, therefore, the lower the permeability. This relationship, however, as is the case with the limestone as well, is only applicable where the dolomite layers are unbroken and no cavities or caverns are present.

The resulting empirical relationships between transit time and porosity and between porosity and permeability developed in Section 7 from the laboratory analyses of the cores, and their comparison with the geophysical logs, can now be used to better define the confining characteristics of the confining zone (see Figures 7-2 through 7-18). The equations for the lines in Figure 7-2

Table 9-1

X-RAY DIFFRACTION DATA
(Weight Percent)

Sample Depth	4A 1,880	5A 2,163	6A1 2,261	7A 2,326
	Bulk Mineralogy (Calculated)[a]			
Quartz	--	01	TR	TR
Calcite	92	72	88	02
Dolomite	02	--	--	--
Fe-Dolomite	--	22	02	94
Clay Size Material[b]	06	05	10	04
	Relative Clay Abundances (Normalized to 100%)			
Illite	TR	TR	TR	TR
Mixed-layer Illite/Smectite	--	TR	--	TR

[a]Bulk mineralogy is calculated from sand/silt-size and clay-size XRD data.

[b]Predominantly clay-size carbonate minerals.

m:H-87(II)/n

and Figure 7-18, for example, can be solved together to yield a function as follows:

$$\text{Log } P = 0.07\ (\Delta t) - 4.19$$

where P is the permeability to air (in millidarcys)
and Δt is the transit time (in microseconds/foot)

Using this empirical relationship, and applying it to the confining zone everywhere except where cavity-riddled zones and caverns appeared in the television survey, the permeability to air of the various layers of the confining zone was calculated.[1] The highest permeability to air within the formation is 400 millidarcys at a depth range of 1,800 to 1,820 feet below land surface. This value is equivalent to a specific permeability to water of about 4.5 gpd/ft^2.

The leakage coefficient for the confining layers of the confining zone was also calculated by integrating the sonic log with the equation above. The results of this calculation provided a value for the permeability to air for each interval thickness. When added together, these permeabilities produced the following overall vertical permeability to air for the whole confining zone:

$$K_T = H_T / \left\{ \frac{h_1}{k_1} + \frac{h_2}{k_2} + \frac{h_3}{k_3} + \cdots\cdots + \frac{h_n}{k_n} \right\}$$

where k_1, k_2, etc. are vertical permeabilities to air for each interval
thickness (millidarcys)
h_1, h_2, etc. are interval thickness (feet)
H_T is total layer thickness (feet)
K_T is vertical permeability to air for layer (millidarcys)[a]

[1] In these calculations it has been assumed that the vertical and horizontal permeabilities are equal and the horizontal permeability has been used as vertical permeability. In reality, it is very likely that vertical permeability is much lower; therefore, all these values for leakage and permeability should be as much as one order of magnitude smaller.

The permeability to air for the lower section of the confining layers in the confining zone (i.e., 190 feet) is about 0.006 gpd/ft^2, while the permeability to water was estimated to be 0.003 gpd/ft^2, less than the permeability to air. The leakage coefficient for the lower 120 feet of the confining zone was estimated to be 2.5×10^{-5} gpd/ft^3 (i.e., 3.3×10^{-6} days^{-1}). For the upper section of the confining zone (i.e., 330 feet) the permeability to water is 0.1 gpd/ft^2 and the leakage coefficient was estimated to be 3.0×10^{-4} gpd/ft^3, (i.e., 4.1×10^{-5} days^{-1}).

The piezometric head differentials between the top and bottom of the confining zone at varying distances from the well are difficult and time consuming to calculate. Many factors are involved in that calculation, such as injection pressure changes with distance from the well, differences in salinity and temperature in the formation and in the injection fluid and above and below the confining zone, etc. Consequently, the calculation is ideally suited for computer computation.

One widely used model is the SWIP model developed for the USGS specifically for water-injection analyses. It is this model that was used in this project (see Section 9.5).

The piezometric heads for equivalent waters were computer-calculated on each side of the confining zone, while fresh water was being injected. The average piezometric differential between the two zones was determined and the annual leakage through the confining zone at various distances from the well head was estimated.

9.3 FORMATION FLUID

The formation fluid in the proposed injection zone is essentially a saline solution, with some parameter concentrations as high as those for seawater. Samples of the original formation fluid were collected during the development of the deep test/injection well prior to the dilution of that fluid with injection water. The original formation fluid samples were transmitted to the water quality laboratory for extensive analysis. Duplicate samples were provided to DER and to the USGS.

The characteristics of the formation fluid can be subdivided into the following three categories:

- o Chemical
- o Biological
- o Physical.

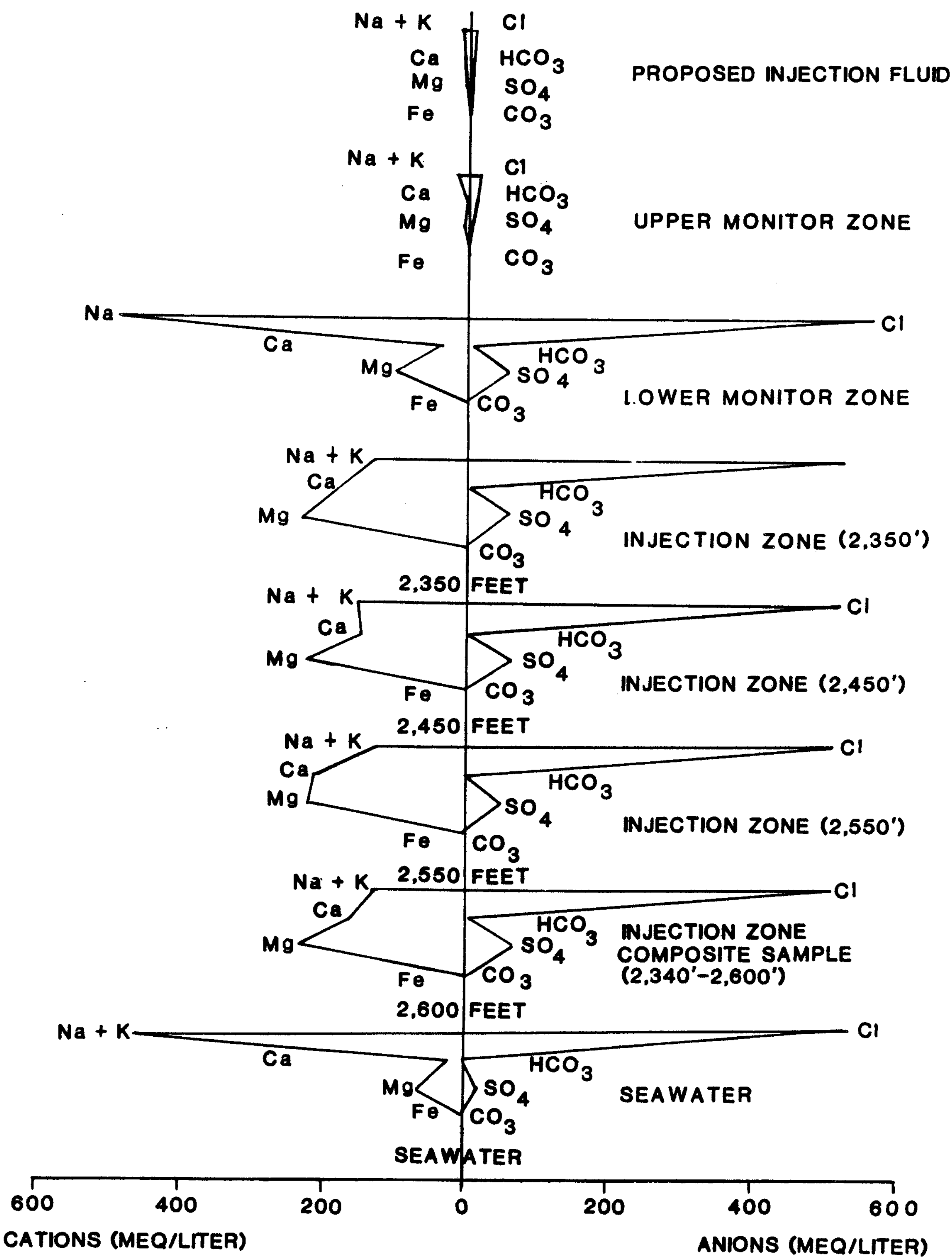
These categories are discussed below.

9.3.1 Chemical Characteristics

Appendix 29 lists concentrations of the chemical characteristics tested for which the composite formation fluid pumped from the open hole of the test/injection well during well development was tested. The formation fluid is a stable solution with very high concentrations of calcium, potassium, magnesium, sodium, chloride, and sulfate. These six constituents make up 86 percent of the TDS found within the formation fluid.

Essentially, water quality is determined by two factors: rock type and the original water source. Stiff diagrams for the formation fluids, for fluids in the two monitor zones, for typical seawater, and for the proposed injection fluid (see Table 3-1) are shown in Figure 9-1. The concentrations of the elements used for the Stiff diagrams are shown in Table 9-2. Those for typical seawater are taken from Gross (1972).

Figure 9-1 shows quite a different type of water in the injection zone than in the lower monitor zone. When this figure is compared with the diagrams for water in the zones above (see Figure 7-21), it can be seen that this sharp change occurs just as the injection zone is entered. A notable overbalance in the cation region of the injection zone graphs is evident. The formation fluid has higher concentrations of calcium, sodium and magnesium than typical seawater; but the chloride content is still recognizable and the right side of the graph (anions) are still representative of seawater. The calcium and magnesium ions have replaced the sodium ions and the high magnesium concentration is indicative of the dolomitic limestone rock types found within the injection zone.



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WATER QUALITY-STIFF DIAGRAMS
(RECEIVING ZONE)

FIGURE 9-1

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Table 9-2

INJECTION ZONE WATER QUALITY
(100-foot intervals)[a]

Parameter	2,350	2,450	2,550	Composite 2,340 to 2,600
Sodium	920	1,160	1,040	740
Magnesium	2,780	2,720	2,600	2,850
Potassium	3,600	3,920	3,050	3,940
Calcium	3,560	2,900	4,140	3,120
Chloride	18,840	18,840	18,440	18,192
Sulfate	2,920	3,070	2,410	3,470
Bicarbonate	128	126	124	134
Carbonate	0	0	0	0

[a]Expressed as mg/l, except for pH expressed in units

m:H-87(II)/o

As the limestone was originally laid down below sea level, seawater was the original source of the formation fluid; hence the high chloride content. With time, however, the magnesium ions dissolved from the dolomitic formations and the calcium from the earlier limestone have altered the original ionic composition. The Stiff diagrams for the formation fluid show a striking similarity at all depths, but enough differences can still be seen to account for the impervious intervals within the injection zone. On the other hand, the Stiff diagram for the proposed injection fluid reveals distinct salinity differences between that fluid and the formation fluid.

The saturation index for the formation fluid is +0.55, which indicates that the fluid is saturated with and has a tendency to precipitate calcium carbonate. The formation fluid is thus nonaggressive.

The level of nutrients within the formation fluid is very low, and what has been observed is probably the result of fluids from the surface introduced during drilling. The man-made organic chemicals are all below the detectable or reportable limits. In summary, the quality of the formation fluid is poor; but this condition is natural and not man-made.

9.3.2 Biological Characteristics

The formation fluid samples collected at the end of the well development were tested for the presence of coliform bacteria. Laboratory tests carried out to determine the number of fecal and streptococcal bacterial colonies within these samples showed levels below the detectable limits; but the total coliform bacteria colonies were too numerous to count. This high level of total coliform bacteria is attributed to artificially introduced surface water during drilling.

It is envisaged that a complete microbiological world will develop within the mixing zone in time. One of the dependent factors required for the development of such a microbiological world is the presence of bacteria and the nutrients to sustain them. Although the water quality analysis did not include testing for other common bacteria within the injection zone, it is possible that iron- or sulfur-reducing bacteria might be present. There is every likelihood that both iron- and sulfur-reducing bacteria exist within the proposed injection zone; but, since the proposed injection fluid is devoid of iron and has very small concentrations of sulfate, the status quo within the injection zone is not expected to change in regard to the number of colonies of these bacteria.

With its very high total salinity, the water from the Boulder Zone is unsuitable for all domestic and industrial purposes. Since the quality of the formation fluid is so poor, it would certainly pose a serious threat to the surrounding environment. Thus, it is reasonable to expect that water from this zone will not be of use in the foreseeable future and injection of the better quality treated wastewater into this zone is, therefore, acceptable.

9.3.3 Physical Characteristics

The physical characteristics of the formation fluid are used in the SWIP computer model to determine the fate of the injected fluids. Table 9-3 lists each of the physical parameters required for operating the SWIP. All of the parameters shown in Table 9-3 were evaluated at a temperature of 25 degrees Centigrade and at atmospheric pressure. Some were found to be sensitive to changes in either the temperature or the pressure or both.

The formation fluid is extremely saline, while the proposed injection fluid is fresh, with all of its parameters differing in value from those shown in Table 9-3. The greater salinity of the formation fluid implies higher density, greater conductivity, and higher viscosity than in the proposed injection fluid. The greater density and temperature of the formation fluid also leads to implementation in the SWIP model of subroutines that calculate their effect in the hydraulic head exerted across the confining zone.

9.3.4 Radiological Characteristics

The radiological characteristics of the formation fluid are shown in Table 9-4, reproduced here from Appendix 28.

Table 9-3

FORMATION FLUID: PHYSICAL CHARACTERISTICS[a]

Physical Parameter	Value and Parametric Unit
Acoustic Velocity	5,022.2 (ft/sec)
Coefficient of Thermal Expansion	2.957 x 10^{-4} ($^{o}F^{-1}$)
Compressibility	2.875 x 10^{-6} (psi^{-1})
Conductivity	57,600 (µmhos/cm)
Density	64.820 (lbs./$ft.^{3}$)
Heat Capacity	0.95517 (Btu/lb/^{o}F)
Transit Time	199.1 (µsec/ft)
Viscosity, Absolute	0.9810 (centipoise)

---

[a]All parameters are at 25 degrees Centigrade and atmospheric pressure

Source: Myers et al, 1969; Weast, 1979; Neumann and Pierson, 1966; and Hodgman, 1955.

m:H-87(II)/p

Table 9-4

FORMATION FLUID:

RADIOLOGICAL CHARACTERISTICS

Parameter	Radiological Count (pCi/l)	Counting Error
Gross Alpha	18.2	± 14.6
Gross Beta	303	± 64.8
Radium 226	64.4	± 9.7
Radium 228	3.7	± 0.6

m:H-87(II)/q

The gross alpha count of only 18.2 pCi/l in Table 9-4 indicates that the mean count of the alpha activity is less than the standard deviation of the counts taken. Therefore, when the gross alpha activity and the radium 226 are compared, it is clear that almost if not all of the gross alpha activity is produced by the radium 226. The low level of radium 228 and the high gross beta activity are incompatible, implying that the gross beta activity, besides being contributed by radium 228, has also a more important contributor, possibly uranium 235.

The levels of radiological activity within the formation fluid from the injection zone are relatively high. Radium 226 and 228 activity exceeds the Federal drinking water standards by a factor of 14. The radiological activity of the undiluted formation fluid can be described as a probable health hazard to the public at large if the public were subjected to long-term exposure to the water. Radioactivity renders the water practically useless for any purpose in the foreseeable future and increases the acceptability of this zone for wastewater injection.

9.4 FLUID COMPATIBILITY

When the proposed injection commences, a zone of mixing will develop between the injection fluid and the resident formation fluid. Because these fluids are both water, the injection into the deep test/injection well will not lead to any immiscibility problems. Rather, it is envisaged that, within the mixing zone, a good mix will result between the resident fluid and the proposed injection fluid, resulting in a dilution of the wastewater. The degree of dilution depends on the distance from the deep test/injection well as the location of the mixing zone moves radially from the well. In time, the mixing zone will become nearly stationary as the increase in radius becomes incrementally smaller and smaller, as the perimeter of the zone becomes larger and larger.

The nature of the fluid within the mixing zone will be variable, with characteristics somewhere between those of the proposed injection fluid and the resident fluid. A Piper diagram (see Figure 9-2) illustrates this point. The major ions within each fluid are represented in the Piper diagram,

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WATER QUALITY–PIPER DIAGRAM (RECEIVING ZONE)

FIGURE 9-2

* Area of circle indicates dissolved solids in milligrams per litre, thus:

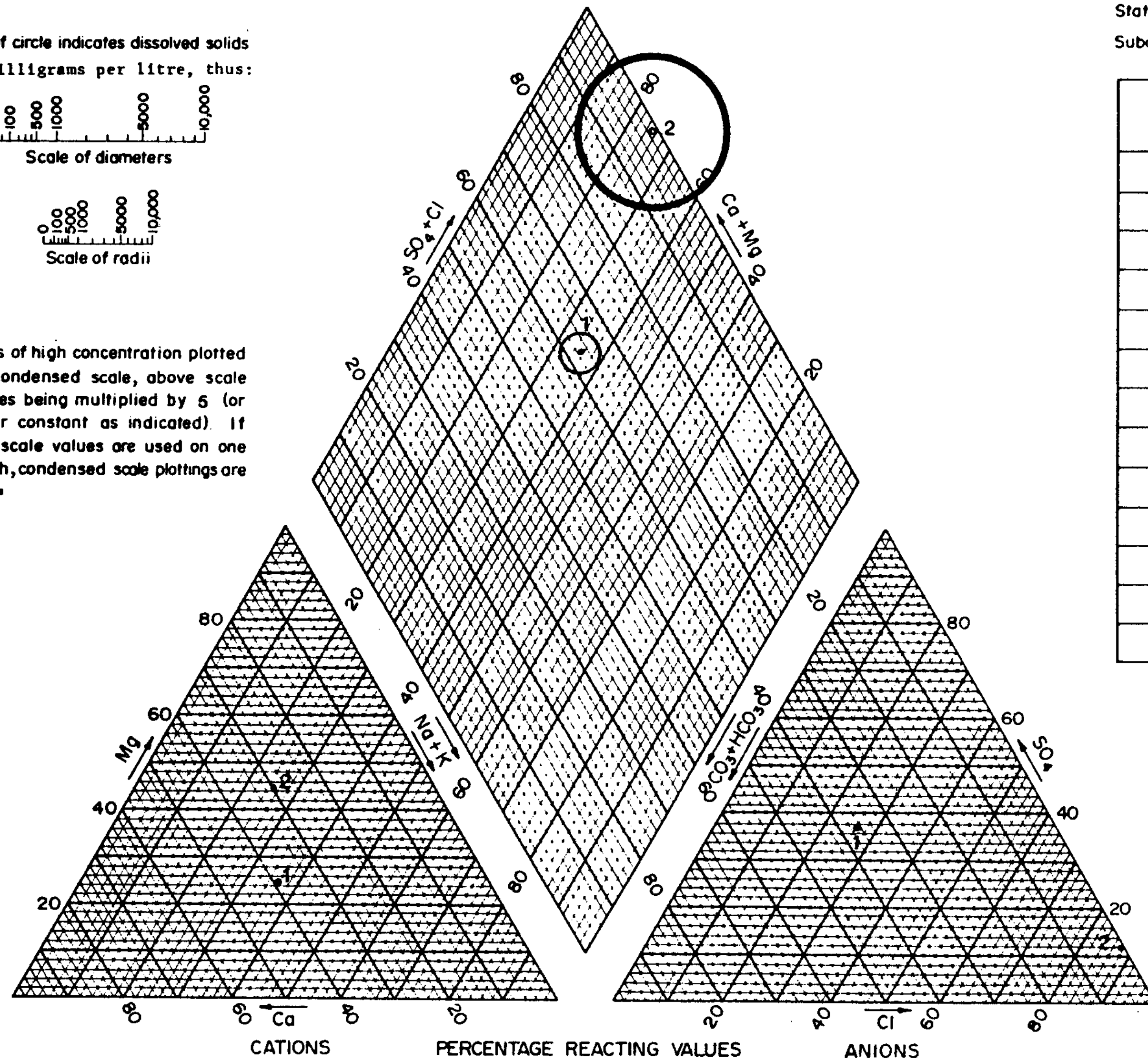
0 100 500 1000 5000 10,000

Scale of diameters

0 100 500 1000 5000 10,000

Scale of radii

* Waters of high concentration plotted at condensed scale, above scale values being multiplied by 5 (or other constant as indicated). If two scale values are used on one graph, condensed scale plottings are ▬



State Florida

Subarea Lee County

Number	Date	Depth	Floridan Aquifer System
1	—	—	Injection Fluid
2	12-2-87	2,600'	Injection Zone

allowing direct comparison of both fluids. The concentration values of each of the ions in the proposed injection fluid are much less than those in the formation fluid; however, the bicarbonate fraction is proportionately larger in the injection fluid since this fluid is primarily a calcium-carbonate-type water, while the injection zone water is primarily a magnesium-chloride-type water.

The overall difference between the dissolved ions in the two fluids is best shown by comparing TDS levels, represented by the logarithmic size of the circle in the Piper diagram (the diameter of the circle for the formation fluid has been reduced fivefold). The concentrations of the TDS in the formation fluid are about 125 times higher than those in the proposed injection fluid.

The stability index of the formation fluid is 6.35, almost the same as the neutral value of 6.50, and thus indicates little likelihood that the formation fluid will form any scales or corrosion. The saturation index, however, is +0.55 and indicates a very slight propensity for carbonate deposition. There is thus a slight potential for calcium and magnesium to precipitate, and this potential will increase when the calcium-carbonate type injection water is mixed with the formation fluid. This potential to form a precipitate would occur if the pH of the mixture were to become higher than it was originally. Since the pH of the injection fluid (7.4) is lower than that of the receiving waters (7.45), mixing should lower the pH and, therefore, it is not expected that any deposition will take place. The Langelier index for the formation fluid is positive, which indicates that the formation fluid is saturated with $CaCO_3$, which it would have a tendency to precipitate; however, since the calcium levels of the injected fluid are also lower than those of the native waters, this is not likely to take place either.

In summary, the proposed injection fluid is in every respect a much better quality water than that existing within the proposed injection zone. The two fluids are wholly compatible and together will produce a mixing zone with better water quality than that already there.

9.5 INJECTION MODELLING

9.5.1 Surface Water Injection Program

The SWIP is a three-dimensional transient mathematical model designed to simulate the behavior of liquid waste injection into deep saline aquifers (Intercomp Resource Development and Engineering, Inc. (Intercomp), 1976). The model recognizes fluid properties as functions of pressure, temperature, and waste concentration. Its general purpose is to delineate the pressure responses and fluid displacement fronts in the vicinity of the deep-injection well open hole through the injection zone.

The SWIP was originally developed by Intercomp under contract to the USGS. Since the original model was developed and the user's manual published (Intercomp, 1976), the model was revised by Intera Environmental Consultants, Inc. (Intera) and revised documentation published (Intera, 1979).

The SWIP consists of two interlinked parts:

- A three-dimensional finite-difference injection zone submodel
- A well-bore submodel.

Both parts are coupled together within the iterative cycle of the model. Essentially, the well-bore submodel relates the surface pressure and enthalpy to the calculated bottom-hole pressure and enthalpy from the reservoir submodel. Simultaneously, the bottom-hole parameters must also satisfy the material and energy balance relationships taking place in the reservoir.

9.5.1.1 Injection Zone Submodel

The finite-difference reservoir submodel solves three coupled partial differential equations describing the behavior of a liquid injected into an aquifer system. These equations are:

- o Conservation of liquid mass
- o Conservation of energy
- o Conservation of contaminant mass.

The first equation describes the three-dimensional Darcy flow of a fluid within a porous aquifer, with formation fluid density a function of temperature, pressure and contaminant concentration. The second equation describes the convection and dispersion of energy due to injection of a fluid with a different temperature and pressure than the formation fluid. The third equation describes the convection and hydrodynamic dispersion of a contaminant in the injection fluid, which permits the injection of different salinities (lower in this case) than those of the formation fluid. These equations can be used to predict the concentration, temperature, and pressure patterns resulting from the injection of a fluid whose density, due to temperature and dissolved solids concentration, differs from that of the receiving formation.

The reservoir submodel can be operated with a three-dimensional rectangular Cartesian grid or with a two-dimensional radial grid system. Use of the cylindrical coordinate system is extremely well suited to single well interpretations and was used for the model runs for the deep test/injection well at NFMU.

Using the SWIP implies that the model assumptions are known and that they are largely applicable to the system being modelled. The basic assumptions in the injection zone submodel are as follows:

- o The flow is three-dimensional, transient, and laminar.
- o Fluid density is a function of pressure and temperature.
- o Fluid viscosity is a function of temperature and dissolved solids concentration.
- o The injection fluid is miscible with the formation fluid.
- o Aquifer properties vary with position.
- o Hydrodynamic dispersion is a function of fluid velocity.
- o The energy equation is "enthalpy in minus enthalpy out equals change in internal energy of the system." Both kinetic and potential energy are neglected.

- Boundary conditions permit natural water movement to and from the aquifer and heat losses to the adjacent formations.

9.5.1.2 Well-bore Submodel

The well-bore submodel simulates injection well conditions and provides the boundary conditions for the reservoir submodel. Energy losses in the injection well are calculated to obtain the bottom-hole pressure and temperature values. The pressure drop between the well and the center of the grid block is also calculated and the rate is allocated between each vertical layer.

The model user has the option of specifying surface or bottom-hole conditions. If the option of specifying bottom-hole conditions is adopted, the well-bore submodel calculates both the surface pressure necessary to achieve the desired rate and the enthalpy of the injection fluid as it enters the injection zone of the aquifer. The heat losses to the surrounding formations, the frictional pressure drop, and the gravity head are calculated by the well-bore submodel. If the model user specifies the surface pressure and temperature, the model calculates the rate that can be injected, limited by the specified surface conditions. In this case, an iterative procedure is required to calculate the bottom-hole pressure and the injection rate.

The following assumptions are used in the well-bore submodel:

- Viscous heat dissipation is neglected in the well-bore calculations.
- Initial ground temperature surrounding the well is known and can be expressed as a function of depth only.
- Flow within the well-bore is incompressible and under steady-state conditions.
- The well-bore is treated as a constant flux line source for the purposes of heat loss calculations.
- Fluid properties, heat capacity, viscosity, and density can vary with pressure and temperature in the well-bore.

- o The enthalpy of the injection fluid can be expressed as a simple proportionality to the enthalpy of pure water at the same temperature and pressure.

Both sets of assumptions are compatible with the data for the deep test/injection well at the NFMU site and no serious discrepancies were observed when the SWIP was run.

9.5.2 Data Requirements

The input data for the SWIP are separated into five groups, each of which is read in by different sections of the program.

The first input data cards are designated as M cards; this group contains 4 card types. Besides the title for the run, the data within the M card group consist mostly of control parameters such as the aquifer solution method, the output map orientation, plotting control parameters, the well-bore calculation option, the selection of model solutions (i.e., for temperature, contaminant concentrations, and pressure), etc. The only physical parameters defined within the M card group are the aquifer type (i.e., confined or unconfined), the number of rock types, and the number of aquifer recharge boundaries. The number of grid cells is also entered within the M card group in conjunction with the geometry of the modelled aquifer (i.e., radial or rectangular coordinate systems).

The second input data cards are designated as R1 cards; this group contains 33 card types, most of which are mutually exclusive. The data within the R1 card group consist mostly of the physical attributes of the injection fluid (see Section 3.3), the formation fluid (see Section 9.3), the injection zone (see Section 9.1), and the rock from the injection zone.

The rock parameters utilized within the model are compressibility, heat capacity, thermal conductivity and thermal diffusivity (see Appendix 19). The rock heat capacity, determined for dolomite as part of the laboratory analysis carried out by CLI, is 0.2479 Btu/lb-^{o}F (41.390 Btu/ft^{3} ^{o}F). The thermal conductivity for the dolomitic limestone is 1.46 Btu/hr/ft/^oF (35 Btu/ft day-^oF). A rock thermal diffusivity of 0.04 ft^2/hour was used in the injection model, and the rock compressibility is 14.9 x 10^{-6} volumes per psi. All of the other physical parameters required within the R1 card group are found in this report in the sections specified above. The radius of the modelled aquifer was taken at 50,000 feet, because of the high transmissivity of the injection zone.

The third input data cards are designated as I cards; this group contains 4 card types. These cards are solely for describing nonzero contaminant concentrations, temperature variations, and initial fluid velocities within the injection zone.

The fourth input data cards are designated as R2 cards; this group contains 15 card types. This card group is the only recurring group within the data input and may be repeated to change parameters such as well-injection rates, time increments, allowable number of well-bore iterations, contaminant concentrations of injection fluid, etc.

The aquifer and well-bore solution methods are defined in the R2 card group in conjunction with iterative tolerances for pressure and temperature. The injection well is located within the grid network and the physical characteristics of the well, such as injection rate, length of injection casing, well diameter, casing roughness, rock temperature, vertical angle of inclination for the well, and casing thermal conductivity are each assigned a value. Also included in the R2 card group are the printout control indicators.

9.6 MODEL RESULTS

The SWIP model was used to simulate the well at the NFMU site for the period of the injection test and also for long-term injection. The results of the first few model runs were used to calibrate the model to the actual observed values during the injection test. The results of additional runs were used to predict the effects of the continuous injection of 4 mgd for up to 5-1/2 years. The results of these later model runs are discussed in this section.

From the SWIP model results, an initial sharp increase was seen in the injection pressure, with a gradual increase thereafter. The model predicted that, within 100 days of the start of continuous pumpage at 4 mgd, the injection pressure would increase by 2 psi. After 200 days, it would again increase by another 2 psi, but the next 2 psi-increase would not occur until 500 days after the start of pumpage. From that time until the end of the modeling period at day 2000 (5-1/2 years), the injection pressure would be in equilibrium and no further increases were predicted. A total 6-psi increase in the injection pressure was predicted by the model over the next 5-1/2 years.

The model also showed the progressively diminishing rate of radial movement of the injected wastewater within the injection zone. These data indicated that, in the first 100 days of injection the leading edge of the injected fluid would have moved as far as 358 feet from the well. In the next 200 days, however, it would move only an additional 250 feet, and in the next 400 days, only an additional 400 feet, and so on. After 2,000 days (5-1/2 years), the model showed that background water quality would again be encountered at a distance of 1,680 feet from the injection well.

This model was stopped after 2,000 days; but, using the model results, it can be predicted that the injected water will not reach the perimeter of the AoR (determined to be one mile from the injection well) until the year 2011. These data are conservatively estimated, because they were derived from the assumption that the 4.0-mgd injection will start in 1988. In fact, that rate of injection may not be reached for several years.

The zone of endangering influence is defined as the zone in which there exists a potential for wastewater leakage through the overlying confining zone. For leakage to occur, the piezometric potential must be higher in the injection zone than in the zone above the confining zone. In effect, the zone of endangering influence is a circular area around the NFMU site. The model projections indicated that, at a distance of 1,000 feet from the well, this zone would be nonexistent until about 400 days after the start of continuous 4.0-mgd injection. At the end of the model run in day 2,000 (5-1/2 years), the zone extended to 1,700 feet from the well. The projected leakage after 5-1/2 years of continuous injection at 4.0 mgd was estimated at 2.1 gallons per acre per year over an area of 207 acres, a truly low value, when viewed as a volume of 0.005 gallons leaking through one acre in a day.

The leakage of 0.005 gallons in a day per acre then would mix with the water in the permeable section of the confining zone (see Figure 7-19), which was encountered from 2,230 to 2,350 feet, and become greatly diluted. The head across these 330 feet of the upper part of the confining zone was also computed by the SWIP model and the model projections indicated that the leakage of this diluted water after 5-1/2 years of continuous pumping would be 13 gallons per acre per year over the same 207 acres. Assuming a conservative dilution factor of 1,000 to 1, the 13-gallons-per-acre-per-year leakage would be equivalent to a total leakage of 0.00004 gallons per acre per day of undiluted treated sewage, an insignificant value.

The AoR, defined and described in Section 3.2 as one mile in radius, is more than adequate in covering the defined zone of endangering influence. Although the very name of the zone implies a threat to the formation fluids above the confining zone, it has been shown in Section 9.2 and above that, in fact, the insignificant volume of expected leakage and the relative quality of the leakant are harmless to the quality of the water in the zone above the confining zone.

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Section 10
CONCLUSIONS AND RECOMMENDATIONS

10.1 CONCLUSIONS

The evaluation of the hydrogeology at the NFMU site, based upon previous studies conducted in the area, provided an excellent insight into the nature of the underlying upper hydrogeological strata. The geologic and hydrologic data gathered during the construction of the deep test/injection well were evaluated in conjunction with other data from the core analysis to provide an understanding of the lower geologic units penetrated by the well. Further data were also gathered during injection testing.

The hydrologic data obtained from the injection tests performed at the project site, in conjunction with other data, permitted a comprehensive evaluation of the nature and characteristics of the injection zone, known as the Boulder Zone, and the overlying confining zone. The hydrogeologic characteristics of the overlying confining zone indicate that there will not be any measurable effect on the zones above it when wastewater is injected into the Boulder Zone. The injection test data clearly showed no change in the overlying zones during injection into the Boulder Zone.

Numerous data were collected throughout the construction of the well and, in some cases, after its completion, in an effort to monitor the local environment so as to ensure that the actual construction, testing and operation of the deep test/injection well did not and would not have any deleterious effects. These data and the subsequent analyses enabled the development of operation and maintenance guidelines for the well.

Based upon PBS&J's analyses of the site-specific data, the following conclusions were reached:

<u>Hydrogeological Data</u>

o The average annual rainfall at NFMU site is estimated at 53.6 inches, with the wet season restricted to only four months, from

June through September. The average annual lake evaporation is estimated at 53.0 inches.

o The soil at the site consists of fine sand (Wabasso and Pineda Series). The NFMU plant site is located in Drainage Basin 10-B-2 (Lake Okeechobee and Everglades Basin), but it is near the eastern boundary of Drainage Basin 10-C (Coastal Areas Basin).

o The site is underlain by a water table aquifer and two artesian aquifer systems: the Intermediate Aquifer System and the Floridan Aquifer System. The Floridan Aquifer System consists of an upper and lower zone separated by a distinct confining layer.

o The top zone of the Floridan Aquifer System is used in Lee County for irrigation and, after demineralization, for public water supplies.

o The middle zone of the Floridan Aquifer System is too saline for drinking water and is not used for that purpose.

o The lower zone of the Floridan Aquifer System is not used in Lee County. It is confined by overlying dolomitic limestone, and is a good injection zone.

o The formation fluid from the injection zone is more mineralized than seawater and satisfies the regulatory minimum requirements for injection, with TDS levels much greater than 10,000 mg/l.

o The proposed injection zone is made up of numerous cavity-riddled zones; but two cavernous zones found between 2,350 and 2,400 feet and 2,420 and 2,450 feet form the best receiving sections. Other cavities have been identified; but these two sections will provide most of the injection capacity at the site.

Deep Test/Injection Well Construction Data

- The intermediate steel casing set at 1,100 feet, and the protective steel casing set at 1,582 feet have excellent cement-casing bonds and good cement-formation bonds.

- The inner steel casing, also called the injection casing, set at 2,340 feet, has excellent cement-casing and cement-formation bonds. The mechanical integrity pressure test of the inner casing was satisfactory, and the radioactive tracer showed no leakages around the casing.

- The proposed injection fluid is compatible with the formation fluid, and is not expected to precipitate any potentially clogging chemicals.

- The injection casing is set at 2,340 feet below land surface, casing off the full 540 feet of the confining zone. The protective casing is set at 1,582 feet, which is below the 10,000-mg/l TDS concentration, as recommended by the TAC.

- The maximum deviation within the pilot hole was 60 minutes at the 1,895-foot depth, within the allowable deviation of one degree, and this deviation was straightened out when the hole was reamed.

- The maximum deviation within the reamed hole was 55 minutes at 340 feet.

- The surficial aquifer monitoring program confirmed that no salt water contaminated the aquifer at any time during or after well construction.

Well Development and Injection Testing Data

- Neither the upper nor the lower monitor zone tapped by the deep monitor well was affected by the injection into the Boulder Zone of the Floridan Aquifer System. The piezometric head fluctuations recorded in the upper and lower monitor zones during the injection test are accounted for by extraneous pressure effects, the principal ones being the daily tidal and barometric changes, respectively.

- The well-head injection pressures during the injection test were largely dependent upon the injection rates. The well-head injection pressure reached 46 psi during the 4.0-mgd test.

- The proposed injection zone is capable of receiving all the wastewater treatment plant effluent and has sufficient capacity to receive much larger volumes than the 4.0-mgd used during the testing phase, although the injection well is designed only for 4.0 mgd.

<u>Analytical Data</u>

- The quality of the injection fluid is much better than the quality of the formation fluid from the lower Floridan Aquifer System.

- The transmissivity for the injection zone is nearly 500,000 gpd/ft and the storage coefficient is 8.4×10^{-5}.

- The lower section of the confining layer overlying the injection zone is 120 feet thick and has an extremely low permeability (0.003 gpd/ft^2).

- The upper section of the confining zone is 330 feet thick and also has an extremely low permeability (0.1 gpd/ft^2).

- The projected well-head injection pressure after continuous operation at 4.0 mgd is not expected to increase more than 6 psi after 5-1/2 years. The SWIP model also showed that no leakage will reach the perimeter of the AoR until the year 2011, with so little leakage that it could not be measured.

- A slight cyclical pressure increase in summer may be expected due to naturally higher aquifer levels and higher injection when irrigation water is under lesser demand.

10.2 RECOMMENDATIONS

Based on the preceding conclusions drawn from all the data available, the deep test/injection well at NFMU meets all of the regulatory requirements for Class I injection wells. Thus it is recommended that this well be granted an injection-well operating permit.

The recommended maximum daily injection volume for inclusion in the permit should be 4.0 mgd, based on the actual tested injection rate of 2,800 gpm. The recommended maximum well-head injection pressure over and above the static piezometric pressure, for inclusion in the permit, should be 204 psi at the well-head.

The manual provided at the end of this volume identifies the operation and maintenance required for the deep-injection well. It is recommended that the monitoring guidelines in the manual become the actual requirements of the permit and that the reporting criteria and forms in the manual be used.

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STATE OF FLORIDA
DEPARTMENT OF ENVIRONMENTAL REGULATION

March 13, 1987

Ray Dixon, Vice President
North Fort Myers Utility, Inc.
Post Office Box 2547
Fort Myers, Florida 33902

RE: Lee County - UIC
N. Ft. Myers Util.

Dear Mr. Dixon:

Enclosed is Permit Number UC36-127099 to construct a Class I test/injection well at the referenced utility, issued pursuant to Section(s) 403.087, Florida Statutes.

Persons whose substantial interests are affected by this permit have a right, pursuant to Section 120.57, Florida Statutes, to petition for an administrative determination (hearing) on it. The petition must conform to the requirements of Chapters 17-103 and 28-5.201, FAC, and must be filed (received) in the Department's Office of General Counsel, 2600 Blair Stone Road, Tallahassee 32399-2400, within fourteen (14) days of receipt of this notice. Failure to file a petition within the fourteen (14) days constitutes a waiver of any right such person has to an administrative determination (hearing) pursuant to Section 120.57, Florida Statutes. This permit is final and effective on the date filed with the Clerk of the Department unless a petition is filed in accordance with this paragraph or unless a request for extension of time in which to file a petition is filed within the time specified for filing a petition and conforms to Rule 17-103.070, FAC. Upon timely filing of a petition or a request for an extension of time this permit will not be effective until further Order of the Department.

When the Order (Permit) is final, any party to the Order has the right to seek judicial review of the Order pursuant to Section 120.68, Florida Statutes, by the filing of a Notice of Appeal pursuant to Rule 9.110, Florida Rules of Appellate Procedure, with the Clerk of the Department in the Office of General Counsel, 2600 Blair Stone Road, Tallahassee, Florida 32399-2400; and by filing a copy of the Notice of Appeal accompanied by the applicable filing fees with the appropriate District Court of Appeal. The Notice of Appeal must be filed within 30 days from the date the Final Order is filed with the Clerk of the Department.

Executed in Ft. Myers, Florida.

STATE OF FLORIDA DEPARTMENT
OF ENVIRONMENTAL REGULATION

Philip R. Edwards
District Manager
2269 Bay Street
Ft. Myers, FL 33901-2896

PRE/VNM/ls
Copies furnished to:

Wm. Pitt, P.E.
B. Conlon, P.E.
J. Coker
C. Hutchinson
R. Deurling
D. Butler
R. Banks

CERTIFICATE OF SERVICE

This is to certify that this NOTICE OF PERMIT and all copies were mailed before the close of business on March 17, 1987 to the listed persons.

Clerk Stamp

FILING AND ACKNOWLEDGMENT
FILED, on this date, pursuant to § 120.52 Florida Statutes, with the designated Department Clerk, receipt of which is hereby acknowledged.

Darlene Auell 3/17/87
CLERK DATE

STATE OF FLORIDA
DEPARTMENT OF ENVIRONMENTAL REGULATION

SOUTH FLORIDA DISTRICT
2269 BAY STREET
FORT MYERS, FLORIDA 33901-2896
(813)332-2667.

BOB MARTINEZ
GOVERNOR
DALE TWACHTMANN
SECRETARY
PHILIP R. EDWARDS
DISTRICT MANAGER

PERMITTEE: Ray Dixon, Vice President
North Fort Myers Util., Inc.
P. O. Box 2547
Fort Myers, FL 33902

I.D. Number: 5236P00249
Permit/Certification Number: UC36-127099
Date of Issue: March 13, 1987
Expiration Date: March 13, 1989
County: Lee
Latitude/Longitude: 26°43'58"/81°52'54"
Section/Township/Range: 14/43S/24E
Project: North Fort Myers Utilities, Inc.
Class I Test/Injection Well

This permit is issued under the provisions of Chapter(s) 403, Florida Statutes, and Florida Administrative Code Rule(s) 17-3, 17-4 and 17-28. The above named permittee is hereby authorized to perform the work or operate the facility shown on the application and approved drawings(s), plans, and other documents attached hereto or on file with the department and made a part hereof and specifically described as follows:

To construct a Class I test/injection well as depicted on Post, Buckley, Schuh & Jernigan, Inc. drawings for job number 08-093.80 sheets C-1, C-2 and C-3 received Novemer 10, 1986, Drillers, Inc. drawing for job number 217,200 sheet one, received February 26, 1987, engineering and data reports received Octoer 27, 1986, specification received November 10, 1986 applications dated November 6, 1986 and received November 12, 1986 with other documents submitted in support of this permit. Project is located on the (North Fort Myers Utilities, Inc.) utility site approximately 1700 feet to Tucker Lane, Suncoast Subdivision, North Fort Myers.

PERMITTEE: North Fort Myers
Utility, Inc.

I.D. Number: 5236P00249
Permit/Certification Number: UC36-127099
Date of Issue: March 13, 1987
Expiration Date: March 13, 1989

GENERAL CONDITIONS:

1. The terms, conditions, requirements, limitations, and restrictions set forth herein are "Permit Conditions" and as such are binding upon the permittee and enforceable pursuant to the authority of Section 403.161, 403.727, or 403.859 through 403.861, Florida Statutes. The permittee is hereby placed on notice that the department will review this permit periodically and may initiate enforcement action for any violation of the "Permit Conditions" by the permittee, its agents, employees, servants or representatives.

2. This permit is valid only for the specific processes and operations applied for and indicated in the approved drawings or exhibits. Any unauthorized deviation from the approved drawings, exhibits, specifications, or conditions of this permit may constitute grounds for revocation and enforcement action by the department.

3. As provided in Subsections 403.087(6) and 403.722(5), Florida Statutes, the issuance of this permit does not convey any vested rights or any exclusive privileges. Nor does it authorize any injury to public or private property or any invasion of personal rights, nor any infringement of federal, state or local laws or regulations. This permit does not constitute a waiver of or approval of any other department permit that may be required for other aspects of the total project which are not addressed in the permit.

4. This permit conveys no title to land or water, does not constitute state recognition or acknowledgement of title, and does not constitute authority for the use of submerged lands unless herein provided and the necessary title or leasehold interests have been obtained from the state. Only the Trustees of the Internal Improvement Trust Fund may express state opinion as to title.

5. This permit does not relieve the permittee from liability for harm or injury to human health or welfare, animal, plant or aquatic life or property and penalties therefor caused by the construction or operation of this permitted source, nor does it allow the permittee to cause pollution in contravention of Florida Statutes and department rules, unless specifically authorized by an order from the department.

6. The permittee shall at all times properly operate and maintain the facility and systems of treatment and control (and related appurtenances) that are installed or used by the permittee to achieve compliance with the conditions of this permit, as required by department rules. This provision includes the operation of backup or auxiliary facilities or similar systems when necessary to achieve compliance with the conditions of the permit and when required by department rules.

PERMITTEE: North Fort Myers Utility, Inc.

I.D. Number: 5236P00249
Permit/Certification Number: UC36-127099
Date of Issue: March 13, 1987
Expiration Date: March 13, 1989

GENERAL CONDITIONS:

7. The permittee, by accepting this permit, specifically agrees to allow authorized department personnel, upon presentation of credentials or other documents as may be required by law, access to the premises, at reasonable times, where the permitted activity is located or conducted for the purpose of:

a. Having access to and copying any records that must be kept under the conditions of the permit;

b. Inspecting the facility, equipment, practices, or operations regulated or required under this permit; and

c. Sampling or monitoring any substances or parameters at any location reasonably necessary to assure compliance with this permit or department rules.

Reasonable time may depend on the nature of the concern being investigated.

8. If, for any reason, the permittee does not comply with or will be unable to comply with any condition or limitation specified in this permit, the permittee shall immediately notify and provide the department with the following information:

a. a description of and cause of non-compliance; and

b. the period of noncompliance, including exact dates and times; or, if not corrected, the anticipated time the non-compliance is expected to continue, and steps being taken to reduce, eliminate, and prevent recurrence of the non-compliance.

The permittee shall be responsible for any and all damages which may result and may be subject to enforcement action by the department for penalties or revocation of this permit.

9. In accepting this permit, the permittee understands and agrees that all records, notes, monitoring data and other information relating to the construction or operation of this permitted source, which are submitted to the department, may be used by the department as evidence in any enforcement case arising under the Florida Statutes or department rules, except where such use is proscribed by Sections 403.73 and 403.111, Florida Statutes.

10. The permittee agrees to comply with changes in department rules and Florida Statutes after a reasonable time for compliance, provided however, the permittee does not waive any other rights granted by Florida Statutes or department rules.

11. This permit is transferable only upon department approval in accordance with Florida Administrative Code Rules 17-4.12 and 17-30.30, as applicable. The permittee shall be liable for any non-compliance of the permitted activity until the transfer is approved by the department.

PERMITTEE: North Fort Myers Utility, Inc.

I.D. Number: 5236P00249
Permit/Certification Number: UC36-127099
Date of Issue: March 13, 1987
Expiration Date: March 13, 1989

GENERAL CONDITIONS:

12. This permit is required to be kept at the work site of the permitted activity during the entire period of construction or operation.

13. This permit also constitutes:

( ) Determination of Best Available Control Technology (BACT)
( ) Determination of Prevention of Significant Deterioration (PSD)
( ) Certification of Compliance with State Water Quality Standards (Section 401, PL 92-500)
( ) Compliance with New Source Performance Standards

14. The permittee shall comply with the following monitoring and record keeping requirements:

a. Upon Request, the permittee shall furnish all records and plans required under department rules. The retention period for all records will be extended automatically, unless otherwise stipulated by the department, during the course of any unresolved enforcement action.

b. The permittee shall retain at the facility or other location designated by this permit records of all monitoring information (including all calibration and maintenance records and all original strip chart recordings for continuous monitoring instrumentation), copies of all reports required by this permit, and records of all data used to complete the application for this permit. The time period of retention shall be at least three years from the date of the sample, measurement, report or application unless otherwise specified by department rule.

c. Records of monitoring information shall include:

__ the date, exact place, and time of sampling or measurements;
__ the person responsible for performing the sampling or measurements;
__ the date(s) analyses were performed;
__ the person responsible for performing the analyses;
__ the analytical techniques or methods used; and
__ the results of such analyses.

15. When requested by the department, the permittee shall within a reasonable time furnish any information required by law which is needed to determine compliance with the permit. If the permittee becomes aware that relevant facts were not submitted or were incorrect in the permit application or in any report to the department, such facts or information shall be submitted or corrected promptly.

PERMITTEE: North Fort Myers Utility, Inc.

I.D. Number: 5236P00249
Permit/Certification Number: UC36-127099
Date of Issue: March 13, 1987
Expiration Date: March 13, 1989

GENERAL CONDITIONS:

16. In the case of an underground injection control permit; the following permit conditions shall also apply.

a. All reports or information required to be submitted to the department shall be certified as being true, accurate and complete.

b. Reports of compliance or non-compliance with, or any progress reports on, requirements contained in any compliance schedule of this permit shall be submitted no later than 14 days following each schedule date.

c. Notification of any non-compliance which may endanger health or the environment shall be verbally submitted to the department within 24 hours and again within 72 hours and a final report provided within two weeks.

(1) The verbal reports shall contain any monitoring or other information which indicates that any contaminent may cause an endangerment to an underground source of drinking water and any non-compliance with a permit condition or malfunction of the injection system which may cause fluid migration into or between underground sources of drinking water.

(2) The written submission shall contain a description of and cause of non-compliance and if not corrected, the anticipated time the non-compliance is expected to continue, steps being taken to reduce, eliminate, and prevent recurrence of the non-compliance and all information required in accordance with Florida Administrative Code Rule 17-28.23(4)(b).

d. The department shall be notified at least 180 days before conversion or abandonment of an injection well, unless abandonment within a lesser period of time is necessary to protect waters of the state.

SPECIFIC CONDITIONS:

1. This permit approval is based upon evaluation of the data contained in the application dated Novemer 6, 1986, and the plans and/or specifications submitted November 10, 1986, in support of the application. Any changes in the plans and/or technical specifications, except as provided elsewhere in this permit, must be approved by the Department before being implemented.

2. This project shall be closely monitored by the Department with the assistance of a Technical Advisory Committee (TAC) consisting of representatives of the following agencies:

Department of Environmental Regulation, Tallahassee
Department of Environmental Regulation, South Florida District, Fort Myers
South Florida Water Management District, West Palm Beach
U. S. Geological Survey, Tampa
U. S. Environmental Protection Agency, Groundwater Section, Atlanta

SPECIFIC CONDITIONS:

3. Members of the TAC shall receive a weekly summary of the daily log kept by the contractor. The weekly reporting period shall run Friday through Thursday and reports shall be mailed each Friday. The report shall include but is not limited to the following:

   a. Description of daily footage drilled by diameter of bit or size of hole opener or reamer being used;

   b. Description of formation and depth encountered; and specific conductance of water samples collected during drilling. Description of work during installation and cementing of casings include amounts of casing and actual cement used versus calculated volume required.

   c. Lithological description of drill cuttings collected every ten (10) feet or at every change in formation. Description of work and type of testing accomplished geophysical logging, pumping tests, and coring results.

   d. Description of any construction problems that develop and their status to include a description of what is being done or has been done to correct the problem.

   e. Description of the amount of salt used.

   f. Results of any water quality analyses performed as required by this permit.

4. The permittee shall contact the TAC chairman so that he may schedule progress review meetings at appropriate times with the TAC and permittee for the purpose of reviewing the results of tests, geophysical logging, surveys, drilling records and construction problems. At a minimum, meetings shall be scheduled for the purpose of selecting final setting depth for the 12 inch casing.

5. A professional engineer registered pursuant to Chapter 471, Florida Statutes (F.S.) shall be retained throughout the construction period to be responsible for the construction, operation and to certify the application, specifications, completion report and other related documents. The Department shall be notified immediately of any change of engineer.

6. The Department shall be notified immediately of any problems that may seriously hinder compliance with this permit, construction progress, or good construction practice. The Department may require a detailed written report describing the problem, remedial measures taken to assure compliance and measures taken to prevent recurrence of the problem.

7. After completion of construction and testing, a final report shall be submitted to the Department and the TAC. The report shall include, but not be limited to, all information and data collected under Section 17-28.33(2) and Section 17-28.33(3), Florida Administrative Code (F.A.C.), with appropriate interpretations.

PERMITTEE: North Fort Myers Utility, Inc.

I.D. Number: 5236P00249
Permit/Certification Number: UC36-127099
Date of Issue: March 13, 1987
Expiration Date: March 13, 1989

SPECIFIC CONDITIONS:

8. Deviation surveys (sure short or equivalent) shall be performed at 60-foot intervals in both pilot and reamed holes. Inclination survey shall be performed continuously in the cased portion of the well.

9. The background water quality of the injection and monitor zone(s) shall be established prior to commencement of any injection testing.

10. Either ASTM Type II, API Class B or Florida Class H sulfate resistant cement with approved additives shall be used for cementing all casings in injection and monitor wells at the site. A cement bond log shall be run in the injection well after the 12 inch casing has been cemented in place. Copies of the log shall be distributed directly to all TAC members.

11. Centralizers shall be placed at about 10 feet and 100 feet from the bottom of the final string of casing and every 90 feet thereafter.

12. A drilling pad shall be provided to collect spillage of contaminants and to support the heaviest load that will be encountered during drilling.

13. The disposal of drilling fluids, cuttings, formation water or waste shall be in a sound environmental manner that avoids violation of surface and ground water quality standards. The disposal method shall be approved by the Department prior to start of construction.

14. A video television survey shall be run on the cased and open hole portions of the injection well prior to the start of injection. The well shall be pumped at a sufficient rate to assure the proper clarity of waters contained in both the casing and the open borehole. If the Department determines that the completed TV survey is unusable due to excessive turbidity in the borehole or for any other reason, the Department may order the completion of another TV survey prior to commencement of effluent injection. A DER representative will be on site to witness the video survey and affirm the clarity of the pictures.

15. The final string of casing shall be pressure tested at 125 psi for one hour, with no pressure drop after temperature correction. A representative of the Department shall witness this testing.

16. The permittee shall meet with the TAC to discuss all data obtained, proposed depth of casing and cementing options before reaming out the pilot hole for the final casing.

17. A certification of construction (well completion report) shall be submitted upon completion and prior to effluent injection testing.

18. The final string of casing shall have a normal overdrill of ten inches. Remaining casings must have a minimum thickness of 2 1/2 inches of cement surrounding the casings with no less than 5 inches of overdrill.

SPECIFIC CONDITIONS:

19. The injection and monitor well(s) at the site shall be abandoned when no longer usable for their intended purpose, or when posing potential threat to the quality of the waters of the State. The permittee shall devise a plan for plugging and abandonment of the injection and monitor wells at the site and submit this information in the Final Report.

20. Wastewater effluent injection is not authorized under this permit. Under no circumstances, shall effluent injection commence without prior approval (permit) from the Department to inject effluent.

21. The permittee shall investigate lateral water quality changes within the disignated injection zone and determine the long-term effect, if any, that injection will have on portions of the receiving zone which are classified as G-II groundwater aquifers by the standards of Chapter 17-3, F.A.C. This information shall be submitted with the Final Report.

22. Drawings, plans, documents or specifications submitted by the Permittee, not attached hereto, but retained on file at the South Florida District Office are made a part hereof.

23. The applicant shall retain the engineer of record or obtain the services of any professional engineer registered in the State of Florida for the inspection of the construction of this project. Upon completion the engineer shall inspect for conformity to construction permit applications and associated documents. A Certificate of Completion shall be submitted within 30 days after completion of construction of this project and Department approval shall be obtained prior to placement in operation.

24. The pilot hole shall be plugged above the injection zone with cement prior to beginning reaming out for the injection casing at a depth which will be agreed upon during the TAC meeting (see Specific Condition #16). The injection string shall be set above the pilot hole cement plug with a sufficient interval to allow pressure grouting of the entire final casing string.

25. A survey indicating the exact location in metes and bounds of all wells authorized by this permit shall be provided prior to application for an operating permit.

26. The permittee shall provide a satisfactory demonstration of mechanical integrity upon completion of construction pursuant to Section 17-28.13(6), F.A.C., and Section 17-28.22(7), F.A.C.

27. The outer (conductor) casing shall be set beneath the Mid-Hawthorn aquifer and into the lower Hawthorn confining zone prior to drilling into the Florida Aquifer. This depth is estimated to be approximately 220 feet.

SPECIFIC CONDITIONS:

28. All salt used in well drilling shall be stored in an environmentally sound manner. Accurate records shall be kept on the amount of salt used.

29. Provide record of the pressure change at the bottom of the casing during the 24-hour injection test.

30. Rock cores shall be analyzed for effective porosity, vertical permeability, and three (3) cores for rock compressibility. A sample of the formation water shall accompany each core sample so formation factor and resistivity index calculations are representative of natural conditions. Reprints of all laboratory test results should be included in the summary report.

31. A one gallon representative water sample from the injection zone for water quality analysis shall be delivered to the TAC. The laboratory shall prepare an ionic balance to ensure quality control on the tested sample.

32. Water levels in the monitoring well and injection well shall be monitored for a period of 48 hours prior to the 24 hour injection test. Top of casing shall be surveyed in and water levels reported to the nearest 0.01 foot referenced to mean sea level.

33. All injection well welding shall be performed by a certified welder.

34. All drilling below 220 feet will be inside a blow out preventer.

35. The location of all wells of public record within the area of review shall be provided to the Department before drilling commences.

36. The injection test should be conducted at the maximum future capacity of the well without exceeding the 8 ft./sec. velocity in the casing.

37. Provide specific drilling pad dimensions and design details prior to commencing construction and shortly after selection of drilling contractor.

SPECIFIC CONDITIONS:

38. The parameters listed below will be analyzed in the monitor zones prior to the injection of any effluent into this well. Included in these parameters are the primary and secondary water quality standards and the minimum criteria list. These parameters shall also be analyzed in the treated effluent prior to submitting application for an operating permit.

Inorganic

chloride
sulfate
sulfide (field measurement)
nitrate
soluble orthophosphate
ammonium
organic nitrogen

Metals

arsenic
cadmium
chromium
copper
lead
mercury
zinc
iron
antimony
silver

biological

fecal coliform

Volatile Organics

benzene
toluene
1,2 dichlorobenzene
1,1,1 trichloroethane
chloroform
1,2 dichloroethylene
chloroethane
trichloroethylene
tetrachloroethylene

Pesticides

aldrin
dieldrin
lindane

Base/Neutral Organics

diethylphthallate
dimethylphthallate
butylbenzylphthallate
napthalene
anthracene
phenanthrene

Acid Extractables

phenol
2,4,6-trichlorophenol
2-chlorophenol

39. The mechanical integrity temperature (and/or noise) logs shall be run after the initial injection tests with fresh water and prior to any injection of effluent. A radioactive tracer survey may be used for this purpose in addition to the temperature or noise log.

PERMITTEE: North Fort Myers Utility, Inc.

I.D. Number: 5236P00249
Permit/Certification Number: UC36-127099
Date of Issue: March 13, 1987
Expiration Date: March 13, 1989

SPECIFIC CONDITIONS:

40. Rule 17-28.27(7), F.A.C. requires that the inner casing be plugged from bottom to land surface with neat cement. Other fillers may be used in the open-hole portion of the well. The cement must be placed from a point below the bottom of the injection string to land surface in order to provide a complete seal of the injection casing that will not allow any upward migration of injected fluids after abandonment.

41. All financial responsibility issued shall be resolved before drilling begins. A financial mechanism that is deemed equivalent to a performance bond must be provided.

42. Issuance of a Class I Test/Injection well construction and testing permit does not obligate the Department to authorize operation of the injection or monitor wells, unless the wells qualify for an operation permit applied for by the permittee and approved by the Department.

43. The monitoring well shall be sampled weekly to establish background prior to injection. Sampling shall include TDS, specific conductance and chloride.

Issued this 13 day of March, 1987.

STATE OF FLORIDA
DEPARTMENT OF ENVIRONMENTAL REGULATION

Philip R. Edwards
District Manager

PRE/VNM/ls

_____ Pages Attached

TRANSMITTAL SHEET

environmental engineers, scientists, planners & management consultants **CDM**

Date JAN. 30, 1995

Job N.F.M. D.I.W.

NORTH FT. MYERS, FL.

To MR. MICHAEL BENNETT

S.F.W.M.D.

WEST PALM BEACH, FL.

Att.

we are sending
- herewith ☑
- under separate cover ☐
- by messenger ☐

1 print(s) each of the following WATER QUALITY REPORTS BY ESI, INC. (LAB.)

1 " " " BY CORE LAB.

which are
- approved ☐
- approved as noted ☐
- returned to you for correction and resubmittal ☐
- for your information ☑
- ☐

TABLE 7-9 IN THE REPORT AGREES WITH THE DATA REPORTED BY THE WATER QUALITY LAB. (ESI). OBVIOUSLY ANY DATA ERROR IS IN THE LAB AND NOT IN THE TRANSPOSITION OF THE DATA FROM THE LAB TO THE REPORT. THIS MEANS THAT WE REALLY CAN'T TELL WHAT THE CORRECT VALUES WOULD HAVE BEEN. HOWEVER WE ALSO COLLECTED WATER QUALITY DATA FROM THE ZONES WHERE CORE SAMPLES WERE COLLECTED. THOSE WATER QUALITY SAMPLES WERE ANALYSED INDEPENDENTLY OF ESI BY CORE LABORATORY IN HOUSTON, TEXAS. INTERESTINGLY ENOUGH CORE LAB ALSO REPORTS LOW SODIUM, CALCIUM AND MAGNISUM BELOW 1484 FEET. CORE LAB DID NOT ANALYZE FOR POTASSIUM.

By [signature]

Table 7-9

STRADDLE PACKER SAMPLE RESULTS

Parameters (in mg/l)	Depth (in feet) 1,484	1,564	1,950	2,110	2,250	2,275	2,300
Carbonate - CO_3	0.9	0	0.2	0.2	0.2	0.1	0.1
Chloride - Cl	3,300	7,150	24,990	27,500	36,240	15,620	18,740
Conductivity - SC	3,700	20,000	56,500	60,200	59,000	58,500	56,000
Fluoride - F	0.84	0.56	22	21	25	22	20
Total Dissolved Solids - TDS	2,140	11,690	33,340	34,490	35,200	34,300	34,850
Calcium - Ca	8.0	480	680	720	760	680	720
Magnesium - Mg	56	900	1,130	1,130	1,130	1,000	1,100
Potassium - K	1,330	5,500	600	580	610	610	620
Sodium - Na	900	3,600	3,460	3,480	3,450	3,460	3,500
pH (units)	7.8	6.3	7.8	7.5	7.8	7.6	7.3
Sulfate - SO_4	460	260	2,180	2,020	2,340	2,320	2,230
Bicarbonate - HCO_3	110	100	42	67	63	36	30
Field Parameters							
Temperature (°C)	28.5	30.0	30.0	32.0	31.5	30.0	31.0
Conductance (mmhos)	3,350	18,800	50,000+	50,000+	50,000+	50,000+	50,000+
Salinity (0/00)	2	10	30	33	33	32	35

m:H-87(II)/1

STRADDLE PACKER SAMPLE

ESI

GRIDLEY ENVIRONMENTAL SERVICES INC.

12693-110 McGREGOR BLVD. • FT. MYERS, FL 33907 • (813) 481-5878

Name: Driller's Inc.
1225 U.S. Hwy 1, Suite 220
Juno Beach, FL 33408

Sample Number W-113

Attn:

768-1366

Env. system services. 275-4777

FIELD DATA

Date: 6/7/87

Time: 22:45

Well: T/I well 1479'-1489'

Location: N. Ft. Myers Utilities (straddle packer) (1,484')

Temp °C:

Cond,umhos/cm:

pH:

Collector: T. Newman

HRS Certification Numbers: T85094 & 85283

Marks:

BARAMETER	RESULTS, mg/l
CO_3 (CARBONATE)	0.9
Cl (CHLORIDE)	3300
CF (CONDUCTIVITY)	3700
F (FLUORIDE)	0.84
HCO_3 (BICARBONATE)	110
TDS (TOTAL DISSOLVED SOLIDS)	2140
Ca (CALCIUM)	8.0
Mg (MAGNESIUM)	56
K (POTASSIUM)	1330
Na (SODIUM)	900
SO_4 (SULFATE)	460
pH	7.8

Laboratory Director [signature] Date 6/30/87

All testing is performed according to APHA Standard Methods or EPA testing methods.
(Results are in mg/L unless otherwise specified.)

ESI

GRIDLEY ENVIRONMENTAL SERVICES INC.

12693-110 McGREGOR BLVD. • FT. MYERS, FL 33907 • (813) 481-5878

Name: Driller's Inc.
1225 U.S. Hwy 1, Suite 220
Juno Beach, FL 33408

Sample Number W-112

Attn:

FIELD DATA

Date: 6/5/87

Time: 13:00

Well: ~~Deep monitoring~~ T/I well 1560'-1570'

Location: n. Ft. Myers Utilities (straddle Packer) (1,569')

Temp °C:

Cond,umhos/cm:

pH:

Collector: W.P.

HRS Certification Numbers: T85094 & 85283

Marks:

PARAMETER	RESULTS, mg/l
CO_3 (CARBONATE)	0
Cl (CHLORIDE)	7150
CF (CONDUCTIVITY)	20,000
F (FLUORIDE)	0.56
HCO_3 (BICARBONATE)	100
TDS (TOTAL DISSOLVED SOLIDS)	11,690
Ca (CALCIUM)	480
Mg (MAGNESIUM	900
K (POTASSIUM)	5500
Na (SODIUM)	3600
SO_4 (SULFATE)	260
pH	6.3

Laboratory Director [signature] Date 6/30/87

All testing is performed according to APHA Standard Methods or EPA testing methods.
(Results are in mg/L unless otherwise specified.)

ESI

GRIDLEY ENVIRONMENTAL SERVICES INC.

12693-110 McGREGOR BLVD. • FT. MYERS, FL 33919 • (813) 481-5878 • FAX 8134810182

Name: Driller's Inc.
1225 US Hwy 1, Suite 220
Juno Beach, FL 33408

Sample Number: 870268

RECEIVED
DEC 0 1 1987
DRILLERS INC.

Attn:

FIELD DATA

Date: 9/28/87
Time: 00:30
Well: # 9 N.F.M.U. T/I Well 1950 ft.
Location: Straddle Packer Setting N.F.M.
Temp °C: (1,950')
Cond, umhos/cm:
pH:
Collector:

HRS Certification Numbers: E85094 & 85283 * E84100 & 84147
Marks.

PARAMETER	RESULTS, mg/1
CARBONATE	0.2
CHLORIDE	24,990
CONDUCTIVITY	56,500
FLUORIDE	22
TOTAL DISSOLVED SOLIDS	33,340
CALCIUM	680
MAGNESIUM	1130
POTASSIUM	600
SODIUM	3460
pH	7.8
SULFATE	2180
BICARBONATE	42

Laboratory Director Sandra Bodbacker-Chemist Date 10/30/87

All testing is performed according to APHA Standard Methods or EPA testing methods.
(Results are in mg/l unless otherwise specified).

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GRIDLEY ENVIRONMENTAL SERVICES INC.

12693-110 McGREGOR BLVD. • FT. MYERS, FL 33919 • (813) 481-5878 • FAX 8134810182

RECEIVED
DEC 0 1 1987
DRILLERS INC.

Name: Driller's Inc.
1225 US Hwy 1, Suite 220
Juno Beach, FL 33408

Sample Number: 879267

Attn:

FIELD DATA

Date: 9/27/87
Time: 20:10
Well: #15 N.F.M.U. T/I Well 2210 ft.
Location: Straddle Packer Setting N.F.M. (2,110)
Temp °C:
Cond, umhos/cm:
pH:
Collector:

HRS Certification Numbers: E85094 & 85283 * E84100 & 84147
Marks:

PARAMETER	RESULTS, mg/1
CARBONATE	0.2
CHLORIDE	27,500
CONDUCTIVITY	60,200
FLUORIDE	21
TOTAL DISSOLVED SOLIDS	34,490
CALCIUM	720
MAGNESIUM	1130
POTASSIUM	580
SODIUM	3480
pH	7.5
SULFATE	2020
BICARBONATE	67

Laboratory Director [signature] Chemist Date 10/30/87

All testing is performed according to APHA Standard Methods or EPA testing methods.
(Results are in mg/l unless otherwise specified). construction • operation • maintenance

ESI LABORATORIES • (813) ...

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RECEIVED
DEC 0 1 1987
DRILLERS INC.

Name: Driller's Inc.
1225 US Hwy 1, Suite 220
Juno Beach, FL 33408

Sample Number: 870266

Attn:

FIELD DATA

Date: 9/27/87
Time: 16:15
Well: N.F.M.U.I/I Well 2250 ft.
Location: Straddle Packer Setting NFM (2,250')
Temp °C:
Cond,umhos/cm:
pH:
Collector:

HRS Certification Numbers: E85094 & 85283 * E84100 & 84147
Marks:

PARAMETER	RESULTS, mg/l
CARBONATE	0.2
CHLORIDE	36,240
CONDUCTIVITY	59,000
FLUORIDE	25
TOTAL DISSOLVED SOLIDS	35,200
CALCIUM	760
MAGNESIUM	1130
POTASSIUM	610
SODIUM	3450
pH	7.8
SULFATE	2340
BICARBONATE	63

Laboratory Director Sandra Bodhacker Chemist Date 10/30/87

All testing is performed according to APHA Standard Methods or EPA testing methods.
(Results are in mg/l unless otherwise specified).

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RECEIVED
DEC 01 1987
DRILLERS INC.

Name: Driller's Inc.
1225 US Hwy 1, Suite 220
Juno Beach, FL 33408

Sample Number: 870265

Attn:

FIELD DATA

Date: 9/26/87
Time: 10:10
Well: # 20 N.F.M.U/I Well 2270 ft.
Location: STRADDLE PACKER SETTING N.F.M. (2,275')
Temp °C:
Cond, umhos/cm:
pH:
Collector:

HRS Certification Numbers: E85094 & 85283 * E84100 & 84147
Marks:

PARAMETER	RESULTS, mg/l
CARBONATE	0.1
CHLORIDE	15,620
CONDUCTIVITY	58,500
FLUORIDE	22
TOTAL DISSOLVED SOLIDS	34,300
CALCIUM	680
MAGNESIUM	1000
POTASSIUM	610
SODIUM	3460
pH	7.6
SULFATE	2320
BICARBONATE	36

Laboratory Director Sandra Bodhacker - Chemist Date 10/30/87

All testing is performed according to APHA Standard Methods or EPA testing methods.
(Results are in mg/l unless otherwise specified).

GROSSEY ENVIRONMENTAL SERVICES INC.

12593-110 McGREGOR BLVD. • FT. MYERS, FL 33919 • (813) 481-5378 • FAX 8134810182

RECEIVED
DEC 0 1 1987
DRILLERS INC.

Name: Driller's Inc.
1225 US Hwy 1, Suite 220
Juno Beach, FL 33408

Sample Number: 870264

Attn:

FIELD DATA

Date: 9/26/87
Time: 06:00
Well: #22 N.F.M.U.?/I Well 2340 ft.
Location: Straddle Packer Setting N.F.M.
Temp °C: (4,300)
Cond,umhos/cm:
pH:
Collector:

HRS Certification Numbers: E85094 & 85283 * E84100 & 84147
Marks:

PARAMETER	RESULTS, mg/1
CARBONATE	0.1
CHLORIDE	18,740
CONDUCTIVITY	56,000
FLUORIDE	20
TOTAL DISSOLVED SOLIDS	34,850
CALCIUM	720
MAGNESIUM	1100
POTASSIUM	620
SODIUM	3500
pH	7.3
SULFATE	2230
BICARBONATE	30

Laboratory Director [signature] Chemist Date 10/30/87

All testing is performed according to APHA Standard Methods or EPA testing methods.
(Results are in mg/l unless otherwise specified). construction • operation • maintenance

DRILL STEM SAMPLES

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GRIDLEY ENVIRONMENTAL SERVICES INC.

12693-110 McGREGOR BLVD. • FT. MYERS, FL 33919 • (813) 481-5878 • FAX 8134810182

Name: Driller's Inc.
1225 US Hwy 1, Suite 220
Juno Beach, FL 33408

Sample Number: 870269

Attn:

FIELD DATA

Date: 8/31/87
Time: 20:51
Well: # 1 N.F.M.U. T/I Well 1703 ft.
Location: N.F.M.
Temp °C:
Cond,umhos/cm:
pH:
Collector:

HRS Certification Numbers: E85094 & 85283 * E84100 & 84147
Marks:

PARAMETER	RESULTS, mg/l
CARBONATE	3870
CHLORIDE	5620
CONDUCTIVITY	5850
FLUORIDE	8.4
TOTAL DISSOLVED SOLIDS	2960
CALCIUM	280
MAGNESIUM	0.0
POTASSIUM	180
SODIUM	250
pH	11.7
SULFATE	180
BICARBONATE	79

Laboratory Director Sandra Sodhacker-Chemist Date 10/30/87

All testing is performed according to APHA Standard Methods or EPA testing methods.
(Results are in mg/l unless otherwise specified.)

construction • operation • maintenance

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GRIDLEY ENVIRONMENTAL SERVICES INC.

12693-110 McGREGOR BLVD. • FT. MYERS, FL 33919 • (813) 481-5878 • FAX 8134810182

Name: Driller's Inc.
1225 US Hwy 1, Suite 220
Juno Beach, FL 33408

Sample Number: 870270

Attn:

FIELD DATA

Date: 9/1/87
Time: 04:00
Well: #2 N.F.M.U. T/I Well 1730 ft.
Location: N.F.M.
Temp °C:
Cond,umhos/cm:
pH:
Collector:

HRS Certification Numbers: E85094 & 85283 * E84100 & 84147
Marks:

PARAMETER	RESULTS, mg/l
CARBONATE	6690
CHLORIDE	2750
CONDUCTIVITY	3000
FLUORIDE	8.5
TOTAL DISSOLVED SOLIDS	2070
CALCIUM	400
MAGNESIUM	260
POTASSIUM	5
SODIUM	180
pH	11.4
SULFATE	110
BICARBONATE	280

Laboratory Director [signature] Chemist Date 10/30/87

All testing is performed according to APHA Standard Methods or EPA testing methods.
(Results are in mg/l unless otherwise specified.) construction • operation • maintenance

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12693-110 McGREGOR BLVD. • FT. MYERS, FL 33919 • (813) 481-5878 • FAX 8134810182

Name: Driller's Inc.
1225 US Hwy 1, Suite 220
Juno Beach, FL 33408

Sample Number: 870271

Attn:

FIELD DATA

Date: 9/1/87
Time: 11:31
Well: #3 N.F.M.U. T/I Well 1760 ft.
Location: N.F.M.
Temp °C:
Cond,umhos/cm:
pH:
Collector:

HRS Certification Numbers: E85094 & 85283 * E84100 & 84147
Marks:

PARAMETER	RESULTS, mg/1
CARBONATE	0.1
CHLORIDE	36,230
CONDUCTIVITY	55,000
FLUORIDE	19
TOTAL DISSOLVED SOLIDS	36,990
CALCIUM	760
MAGNESIUM	890
POTASSIUM	610
SODIUM	3330
pH	7.2
SULFATE	2200
BICARBONATE	54

Laboratory Director [signature] Chemist Date 10/30/87

All testing is performed according to APHA Standard Methods or EPA testing methods.
(Results are in mg/l unless otherwise specified). construction • operation • maintenance

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12693-110 McGREGOR BLVD. • FT. MYERS, FL 33919 • (813) 481-5878 • FAX 8134810182

Name: Driller's Inc.
1225 US Hwy 1, Suite 220
Juno Beach, FL 33408

Sample Number: 870272

Attn:

FIELD DATA

Date: 9/2/87
Time: 06:30
Well: # 4 N.F.M.U. T/I well 1790 ft.
Location: N.F.M.
Temp °C:
Cond,umhos/cm:
pH:
Collector:

HRS Certification Numbers: E85094 & 85283 * E84100 & 84147
Marks:

PARAMETER	RESULTS, mg/l
CARBONATE	0.8
CHLORIDE	15,620
CONDUCTIVITY	55,000
FLUORIDE	21
TOTAL DISSOLVED SOLIDS	35,490
CALCIUM	800
MAGNESIUM	1150
POTASSIUM	470
SODIUM	2910
pH	7.5
SULFATE	2200
BICARBONATE	260

Laboratory Director Sandra Sandhacker - Chemist Date 10/30/87

All testing is performed according to APHA Standard Methods or EPA testing methods.
(Results are in mg/l unless otherwise specified) construction • operation • maintenance

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12693-110 McGREGOR BLVD. • FT. MYERS, FL 33919 • (813) 481-5878 • FAX 8134810182

Name: Driller's Inc.
1225 US Hwy 1, Suite 220
Juno Beach, FL 33408

Sample Number: 870273

Attn:

FIELD DATA

Date: 9/2/87
Time: 19:05
Well: # 5 N.F.M.U. T/I Well 1820 ft.
Location: N.F.M.
Temp °C:
Cond,umhos/cm:
pH:
Collector:

HRS Certification Numbers: E85094 & 85283 * E84100 & 84147
Marks:

PARAMETER	RESULTS, mg/l
CARBONATE	0.1
CHLORIDE	21,870
CONDUCTIVITY	51,500
FLUORIDE	17
TOTAL DISSOLVED SOLIDS	31,930
CALCIUM	640
MAGNESIUM	930
POTASSIUM	500
SODIUM	3320
pH	1820
SULFATE	67
BICARBONATE	

Laboratory Director [signature] Chemist Date 10/30/87

All testing is performed according to APHA Standard Methods or EPA testing methods.
(Results are in mg/l unless otherwise specified). construction • operation • maintenance

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Name: Driller's Inc.
1225 US Hwy 1, Suite 220
Juno Beach, FL 33408

Sample Number: 870274

Attn:

FIELD DATA

Date: 9/3/87
Time: 01:00
Well: # 6 N.F.M.U. T/I Well 1850 ft.
Location: N.F.M.
Temp °C:
Cond,umhos/cm:
pH:
Collector:

HRS Certification Numbers: E85094 & 85283 * E84100 & 84147
Memo:

PARAMETER	RESULTS, mg/1
CARBONATE	0.2
CHLORIDE	11,870
CONDUCTIVITY	47,000
FLUORIDE	17
TOTAL DISSOLVED SOLIDS	24,480
CALCIUM	680
MAGNESIUM	1000
POTASSIUM	350
SODIUM	2150
pH	7.3
SULFATE	2700
BICARBONATE	92

Laboratory Director [signature] Chemist Date 10/30/87

All testing is performed according to APHA Standard Methods or EPA testing methods.
(Results are in mg/l unless otherwise specified).

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GRIDLEY ENVIRONMENTAL SERVICES INC.

12693-110 McGREGOR BLVD. • FT. MYERS, FL 33919 • (813) 481-5878 • FAX 8134810182

Name: Driller's Inc.
1225 US Hwy 1, Suite 220
Juno Beach, FL 33408

Sample Number: 870275

Attn:

FIELD DATA

Date: 9/4/87
Time: 10:00
Well: # 7 N.F.M.U. T/I Well 1885 ft.
Location: N.F.M.
Temp °C:
Cond,umnos/cm:
pH:
Collector:

HRS Certification Numbers: E85094 & 85283 * E84100 & 84147
Marks:

PARAMETER	RESULTS, mg/1
CARBONATE	0.2
CHLORIDE	15,620
CONDUCTIVITY	49,500
FLUORIDE	16
TOTAL DISSOLVED SOLIDS	27,980
CALCIUM	680
MAGNESIUM	720
POTASSIUM	440
SODIUM	2730
pH	7.4
SULFATE	1830
BICARBONATE	92

Laboratory Director [signature] Chemist Date 10/30/87

All testing is performed according to APHA Standard Methods or EPA testing methods.
(Results are in mg/l unless otherwise specified).

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GRIDLEY ENVIRONMENTAL SERVICES INC.
12693-110 McGREGOR BLVD. • FT. MYERS, FL 33919 • (813) 481-5878 • FAX 8134810182

Name: Driller's Inc.
1225 US Hwy 1, Suite 220
Juno Beach, FL 33408

Sample Number: 870276

Attn:

FIELD DATA

Date: 9/4/87
Time: 16:00
Well: # 8 N.F.M.U. T/I Well 1910 ft.
Location:
Temp °C:
Cond, umhos/cm:
pH:
Collector:

FRS Certification Numbers: E85094 & 85283 * E84100 & 84147
Marks:

PARAMETER	RESULTS, mg/1
CARBONATE	0.4
CHLORIDE	14,990
CONDUCTIVITY	52,000
FLUORIDE	18
TOTAL DISSOLVED SOLIDS	30,500
CALCIUM	800
MAGNESIUM	890
POTASSIUM	460
SODIUM	2860
pH	7.5
SULFATE	1900
BICARBONATE	150

Laboratory Director Sandra Bordhacker - Chemist Date 10/30/87

All testing is performed according to APHA Standard Methods or EPA testing methods.
(Results are in mg/l unless otherwise specified).

ESI

GRIDLEY ENVIRONMENTAL SERVICES INC.

12693-110 McGREGOR BLVD. • FT. MYERS, FL 33919 • (813) 481-5878 • FAX 8134810182

Name: Driller's Inc.
1225 US Hwy 1, Suite 220
Juno Beach, FL 33408

Sample Number: 870277

Attn:

FIELD DATA

Date: 9/5/87
Time: 10:00
Well: # 10 N.F.M.U. T/I Well 1970 ft.
Location:
Temp °C:
Cond, umhos/cm:
pH:
Collector:

HRS Certification Numbers: E85094 & 85283 * E84100 & 84147
Marks:

PARAMETER	RESULTS, mg/1
CARBONATE	0.3
CHLORIDE	18,740
CONDUCTIVITY	51,000
FLUORIDE	13
TOTAL DISSOLVED SOLIDS	28,640
CALCIUM	680
MAGNESIUM	890
POTASSIUM	410
SODIUM	2870
pH	7.5
SULFATE	1290
BICARBONATE	100

Laboratory Director [signature] Date 10/30/87

All testing is performed according to APHA Standard Methods or EPA testing methods.
(Results are in mg/l unless otherwise specified).

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GRIDLEY ENVIRONMENTAL SERVICES INC.

12693-110 McGREGOR BLVD. • FT. MYERS, FL 33919 • (813) 481-5878 • FAX 8134810182

Name: Driller's Inc.
1225 US Hwy 1, Suite 220
Juno Beach, FL 33408

Sample Number: 870278

Attn:

FIELD DATA

Date: 9/5/87
Time: 16:00
Well: # 11 N.F.M.U. T/I Well 2000 ft.
Location:
Temp °C:
Cond, umhos/cm:
pH:
Collector:

HRS Certification Numbers: E85094 & 85283 * E84100 & 84147
Marks:

PARAMETER	RESULTS, mg/1
CARBONATE	0.1
CHLORIDE	28,110
CONDUCTIVITY	51,000
FLUORIDE	16
TOTAL DISSOLVED SOLIDS	34,650
CALCIUM	680
MAGNESIUM	760
POTASSIUM	450
SODIUM	2900
pH	7.0
SULFATE	1510
BICARBONATE	54

Laboratory Director [signature] Chemist Date 10/30/87

All testing is performed according to APHA Standard Methods or EPA testing methods.
(Results are in mg/l unless otherwise specified).

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GRIDLEY ENVIRONMENTAL SERVICES INC.

12693-110 McGREGOR BLVD. • FT. MYERS, FL 33919 • (813) 481-5878 • FAX 8134810182

Name: Driller's Inc.
1225 US Hwy 1, Suite 220
Juno Beach, FL 33408

Sample Number: 870279

Attn:

FIELD DATA

Date: 9/5/87
Time: 21:30
Well: # 12 N.F.M.U. T/I Well 2030 ft.
Location:
Temp °C:
Cond,umhos/cm:
pH:
Collector:

HRS Certification Numbers: E85094 & 85283 * E84100 & 84147
Marks:

PARAMETER	RESULTS, mg/1
CARBONATE	0.3
CHLORIDE	29,990
CONDUCTIVITY	57,000
FLUORIDE	23
TOTAL DISSOLVED SOLIDS	35,940
CALCIUM	760
MAGNESIUM	1030
POTASSIUM	560
SODIUM	3440
pH	7.1
SULFATE	1780
BICARBONATE	240

Laboratory Director [signature] Date 10/30/87

All testing is performed according to APHA Standard Methods or EPA testing methods.
(Results are in mg/l unless otherwise specified).

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Name: Driller's Inc.
1225 US Hwy 1, Suite 220
Juno Beach, FL 33408

Sample Number: 870280

Attn:

FIELD DATA

Date: 9/6/87
Time: 03:00
Well: # 13 N.F.M.U. T/I Well 2060 ft.
Location:
Temp °C:
Cond,umnos/cm:
pH:
Collector:

HRS Certification Numbers: E85094 & 85283 * E84100 & 84147
Marks:

PARAMETER	RESULTS, mg/1
CARBONATE	0.2
CHLORIDE	17,490
CONDUCTIVITY	56,500
FLUORIDE	20
TOTAL DISSOLVED SOLIDS	36,630
CALCIUM	760
MAGNESIUM	1100
POTASSIUM	560
SODIUM	3460
pH	7.4
SULFATE	2000
BICARBONATE	85

Laboratory Director Sandra Leadbacker-Chemist Date 10/30/87

All testing is performed according to APHA Standard Methods or EPA testing methods.
(Results are in mg/l unless otherwise specified).

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12693-110 McGREGOR BLVD. • FT. MYERS, FL 33919 • (813) 481-5878 • FAX 8134810182

Name: Driller's Inc.
1225 US Hwy 1, Suite 220
Juno Beach, FL 33408

Sample Number: 870281

Attn:

FIELD DATA

Date: 9/6/87
Time: 11:30
Well: # 14 N.F.M.U. T/I Well 2090 ft.
Location: N.F.M.
Temp °C:
Cond,umhos/cm:
pH:
Collector:

HRS Certification Numbers: E85094 & 85283 * E84100 & 84147
Marks:

PARAMETER	RESULTS, mg/l
CARBONATE	2.1
CHLORIDE	28,110
CONDUCTIVITY	55,000
FLUORIDE	17
TOTAL DISSOLVED SOLIDS	34,360
CALCIUM	860
MAGNESIUM	1660
POTASSIUM	530
SODIUM	3260
pH	7.5
SULFATE	2670
BICARBONATE	710

Laboratory Director: Sandra Rodlinker—Chemist Date 10/30/87

All testing is performed according to APHA Standard Methods or EPA testing methods.
(Results are in mg/l unless otherwise specified). construction • operation • maintenance

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GRIDLEY ENVIRONMENTAL SERVICES INC.

12693-110 McGREGOR BLVD. • FT. MYERS, FL 33919 • (813) 481-5878 • FAX 8134810182

Name: Driller's Inc.
1225 US Hwy 1, Suite 220
Juno Beach, FL 33408

Sample Number: 870282

Attn:

FIELD DATA

Date: 9/7/87
Time: 06:30
Well: # 16 N.F.M.U. T/I Well 2150 ft.
Location:
Temp °C:
Cond,umhos/cm:
pH:
Collector:

HRS Certification Numbers: E85094 & 85283 * E84100 & 84147
Marks:

PARAMETER	RESULTS, mg/l
CARBONATE	0.3
CHLORIDE	29,360
CONDUCTIVITY	56,000
FLUORIDE	17
TOTAL DISSOLVED SOLIDS	32,410
CALCIUM	760
MAGNESIUM	1420
POTASSIUM	370
SODIUM	2160
pH	7.5
SULFATE	2240
BICARBONATE	79

Laboratory Director Sandra [signature] - Chemist Date 10/30/87

All testing is performed according to APHA Standard Methods or EPA testing methods.
(Results are in mg/l unless otherwise specified)

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GRIDLEY ENVIRONMENTAL SERVICES INC.

12693-110 McGREGOR BLVD. • FT. MYERS, FL 33919 • (813) 481-5878 • FAX 8134810182

Name: Driller's Inc.
1225 US Hwy 1, Suite 220
Juno Beach, FL 33408

Sample Number: 870283

Attn:

FIELD DATA

Date: 9/12/87
Time: 20:00
Well: # 17 N.F.M.U. T/I Well 2180 ft.
Location:
Temp °C:
Cond,umhos/cm:
pH:
Collector:

HRS Certification Numbers: E85094 & 85283 * E84100 & 84147
Marks:

PARAMETER	RESULTS, mg/l
CARBONATE	0.1
CHLORIDE	24,990
CONDUCTIVITY	57,000
FLUORIDE	21
TOTAL DISSOLVED SOLIDS	36,450
CALCIUM	40
MAGNESIUM	1860
POTASSIUM	390
SODIUM	2400
pH	7.4
SULFATE	1910
BICARBONATE	61

Laboratory Director [signature] Chemist Date 10/30/87

All testing is performed according to APHA Standard Methods or EPA testing methods.
(Results are in mg/l unless otherwise specified).

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GRIDLEY ENVIRONMENTAL SERVICES INC.

12693-110 McGREGOR BLVD. • FT. MYERS, FL 33919 • (813) 481-5878 • FAX 8134810182

Name: Driller's Inc.
1225 US Hwy 1, Suite 220
Juno Beach, FL 33408

Sample Number: 870284

Attn:

FIELD DATA

Date: 9/13/87
Time: 18:00
Well: # 18 N.F.M.U. T/I Well 2210 ft.
Location: N.F.M.U.
Temp °C:
Cond,umhos/cm:
pH:
Collector:

HRS Certification Numbers: E85094 & 85283 * E84100 & 84147
Marks:

PARAMETER	RESULTS, mg/l
CARBONATE	0.2
CHLORIDE	47,840
CONDUCTIVITY	57,000
FLUORIDE	21
TOTAL DISSOLVED SOLIDS	30,110
CALCIUM	800
MAGNESIUM	1180
POTASSIUM	540
SODIUM	3350
pH	7.4
SULFATE	1380
BICARBONATE	92

Laboratory Director Sandra [signature] - Chemist Date 10/30/87

All testing is performed according to APHA Standard Methods or EPA testing methods.
(Results are in mg/l unless otherwise specified).

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GRIDLEY ENVIRONMENTAL SERVICES INC.

12693-110 McGREGOR BLVD. • FT. MYERS, FL 33919 • (813) 481-5878 • FAX 8134810182

Name: Driller's Inc.
1225 US Hwy 1, Suite 220
Juno Beach, FL 33408

Sample Number: 870285

Attn:

FIELD DATA

Date: 9/18/87
Time: 08:00
Well: # 21 N.F.M.U. T/I Well 2300 ft.
Location: N.F.M.
Temp °C:
Cond,umhos/cm:
pH:
Collector:

HRS Certification Numbers: E85094 & 85283 • E84100 & 84147
Marks:

PARAMETER	RESULTS, mg/1
CARBONATE	0.4
CHLORIDE	24,990
CONDUCTIVITY	57,000
FLUORIDE	17
TOTAL DISSOLVED SOLIDS	35,700
CALCIUM	720
MAGNESIUM	1400
POTASSIUM	550
SODIUM	3360
pH	7.6
SULFATE	2430
BICARBONATE	98

Laboratory Director [signature] Chemist Date 10/30/87

All testing is performed according to APHA Standard Methods or EPA testing methods.
(Results are in mg/l unless otherwise specified) construction • operation • maintenance

CORE LABORATORIES
Special Core Analysis

DRILL STEM SAMPLED

File SCAL 305-87054

FORMATION WATER ANALYSIS

Post, Buckley, Schuh & Jernigan, Inc.
North Ft. Myers Utility, Inc.
Deep Injection Well

Fluid Sample 1 - from cored depth 1341 feet

Analytical Results

Cations	Mg/L	Meq/L	Anions	Mg/L	Meq/L
Sodium (Na)	419	18	Chloride (Cl)	555	16
Calcium (Ca)	6	0	Sulfate (SO4)	326	7
Magnesium (Mg)	66	5	Bicarb. (HCO3)	93	2
Iron (Fe)	0	0	Carbonate (CO3)	0	0
Barium (Ba)	0	0			
TDS	1500		Salinity Eq.	1300	

pH 8.00
Specific Gravity, 75°F 1.002
Resistivity, Ohm-M, 75°F 3.900

Stiff Davis Stability Index: -0.54 at 85°F; +0.41 at 195°F
A positive number over 2 indicates CaCO3 scaling tendency.
A negative number over 2 indicates a corrosive tendency.

FORMATION WATER ANALYSIS

Post, Buckley, Schuh & Jernigan, Inc.
North Ft. Myers Utility, Inc.
Deep Injection Well

Fluid Sample 2 - from cored depth 1443 feet

Analytical Results

Cations	Mg/L	Meq/L	Anions	Mg/L	Meq/L
Sodium (Na)	531	23	Chloride (Cl)	536	15
Calcium (Ca)	163	8	Sulfate (SO4)	506	11
Magnesium (Mg)	6	0	Bicarb. (HCO3)	371	6
Iron (Fe)	0	0	Carbonate (CO3)	0	0
Barium (Ba)	0	0			
TDS	2100		Salinity Eq.	1600	

pH	7.90
Specific Gravity, 75°F	1.002
Resistivity, Ohm-M, 75°F	3.200

Stiff Davis Stability Index: +1.39 at 85°F; +2.34 at 195°F
A positive number over 2 indicates $CaCO_3$ scaling tendency.
A negative number over 2 indicates a corrosive tendency.

FORMATION WATER ANALYSIS

Post, Buckley, Schuh & Jernigan, Inc.
North Ft. Myers Utility, Inc.
Deep Injection Well

Fluid Sample 3 - from cored depth 1608 feet

Analytical Results

Cations	Mg/L	Meq/L	Anions	Mg/L	Meq/L
Sodium (Na)	12000	523	Chloride (Cl)	21100	595
Calcium (Ca)	790	39	Sulfate (SO4)	2800	58
Magnesium (Mg)	1125	93	Bicarb. (HCO3)	117	2
Iron (Fe)	0	0	Carbonate (CO3)	0	0
Barium (Ba)	0	0			
TDS	38000		Salinity Eq.	37600	

pH	7.60
Specific Gravity, 75°F	1.030
Resistivity, Ohm-M, 75°F	0.210

Stiff Davis Stability Index: +0.00 at 85°F; +1.82 at 195°F
A positive number over 2 indicates CaCO3 scaling tendency.
A negative number over 2 indicates a corrosive tendency.

CORE LABORATORIES
Special Core Analysis

File SCAL 305-87054

FORMATION WATER ANALYSIS

Post, Buckley, Schuh & Jernigan, Inc.
North Ft. Myers Utility, Inc.
Deep Injection Well

Fluid Sample 4 - from cored depth 1880 feet

Analytical Results

Cations	Mg/L	Meq/L	Anions	Mg/L	Meq/L
Sodium (Na)	11000	480	Chloride (Cl)	19800	559
Calcium (Ca)	729	36	Sulfate (SO4)	2750	57
Magnesium (Mg)	1239	102	Bicarb. (HCO3)	161	3
Iron (Fe)	0	0	Carbonate (CO3)	0	0
Barium (Ba)	0	0			
TDS	35700		Salinity Eq.	35400	

pH	7.80
Specific Gravity, 75°F	1.030
Resistivity, Ohm-M, 75°F	0.220

Stiff Davis Stability Index: +0.36 at 85°F; +2.16 at 195°F
A positive number over 2 indicates $CaCO_3$ scaling tendency.
A negative number over 2 indicates a corrosive tendency.

CORE LABORATORIES
Special Core Analysis

File SCAL 305-87054

FORMATION WATER ANALYSIS

Post, Buckley, Schuh & Jernigan, Inc.
North Ft. Myers Utility, Inc.
Deep Injection Well

Fluid Sample 5 - from cored depth 2163 feet

Analytical Results

Cations	Mg/L	Meq/L	Anions	Mg/L	Meq/L
Sodium (Na)	13100	570	Chloride (Cl)	22300	629
Calcium (Ca)	639	32	Sulfate (SO4)	2900	60
Magnesium (Mg)	1093	90	Bicarb. (HCO3)	137	2
Iron (Fe)	0	0	Carbonate (CO3)	0	0
Barium (Ba)	0	0			
TDS	40200		Salinity Eq.	39700	

pH	7.30
Specific Gravity, 75°F	1.030
Resistivity, Ohm-M, 75°F	0.210

Stiff Davis Stability Index: -0.32 at 85°F; +1.50 at 195°F
A positive number over 2 indicates CaCO3 scaling tendency.
A negative number over 2 indicates a corrosive tendency.

CORE LABORATORIES
Special Core Analysis

File SCAL 305-87054

FORMATION WATER ANALYSIS

Post, Buckley, Schuh & Jernigan, Inc.
North Ft. Myers Utility, Inc.
Deep Injection Well

Fluid Sample 6 - from cored interval 2261-2263 feet

Analytical Results

Cations	Mg/L	Meq/L	Anions	Mg/L	Meq/L
Sodium (Na)	13100	570	Chloride (Cl)	22300	629
Calcium (Ca)	614	31	Sulfate (SO4)	2830	59
Magnesium (Mg)	1093	90	Bicarb. (HCO3)	127	2
Iron (Fe)	0	0	Carbonate (CO3)	0	0
Barium (Ba)	0	0			
TDS	40100		Salinity Eq.	39600	

pH	7.40
Specific Gravity, 75°F	1.030
Resistivity, Ohm-M, 75°F	0.200

Stiff Davis Stability Index: -0.27 at 85°F; +1.55 at 195°F
A positive number over 2 indicates $CaCO_3$ scaling tendency.
A negative number over 2 indicates a corrosive tendency.

CORE LABORATORIES
Special Core Analysis

File SCAL 305-87054

FORMATION WATER ANALYSIS

Post, Buckley, Schuh & Jernigan, Inc.
North Ft. Myers Utility, Inc.
Deep Injection Well

Fluid Sample 7 - from cored depth 2326 feet

Analytical Results

Cations	Mg/L	Meq/L	Anions	Mg/L	Meq/L
Sodium (Na)	12500	542	Chloride (Cl)	21100	595
Calcium (Ca)	631	31	Sulfate (SO4)	3000	62
Magnesium (Mg)	1050	86	Bicarb. (HCO3)	124	2
Iron (Fe)	0	0	Carbonate (CO3)	0	0
Barium (Ba)	0	0			
TDS	38400		Salinity Eq.	37800	

pH	7.10
Specific Gravity, 75°F	1.020
Resistivity, Ohm-M, 75°F	0.210

Stiff Davis Stability Index: -0.56 at 85°F; +1.26 at 195°F
A positive number over 2 indicates $CaCO_3$ scaling tendency.
A negative number over 2 indicates a corrosive tendency.

CORE LABORATORIES
Special Core Analysis

File SCAL 305-87054

FORMATION WATER ANALYSIS

Post, Buckley, Schuh & Jernigan, Inc.
North Ft. Myers Utility, Inc.
Deep Injection Well

Fluid Sample 8 - from cored depth 2453 feet

Analytical Results

Cations	Mg/L	Meq/L	Anions	Mg/L	Meq/L
Sodium (Na)	4000	176	Chloride (Cl)	15400	434
Calcium (Ca)	5170	258	Sulfate (SO4)	2290	48
Magnesium (Mg)	610	50	Bicarb. (HCO3)	163	3
Iron (Fe)	0	0	Carbonate (CO3)	0	0
Barium (Ba)	0	0			
TDS	27600		Salinity Eq.	26700	

pH	7.200
Specific Gravity, 75°F	1.020
Resistivity, Ohm-M, 75°F	0.280

Stiff Davis Stability Index: +0.61 at 85°F; +2.41 at 195°F
A positive number over 2 indicates $CaCO_3$ scaling tendency.
A negative number over 2 indicates a corrosive tendency.

POST, BUCKLEY, SCHUH & JERNIGAN, INC.

PBSJ

NORTH FORT MYERS UTILITY
DEEP-INJECTION-WELL SYSTEM

OPERATIONS AND MAINTENANCE
MANUAL

NORTH FORT MYERS UTILITY
DEEP-INJECTION-WELL SYSTEM

OPERATION AND MAINTENANCE MANUAL

Prepared for:

NORTH FORT MYERS UTILITY INC.

April 1988

POST, BUCKLEY, SCHUH & JERNIGAN, INC.

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TABLE OF CONTENTS

m:H-87(II)/C

LIST OF FIGURES

m:H-87(II)/D

SUMMARY

The details of the operations and maintenance procedures for the deep-injection well described within this manual are summarized as follows:

- The maximum operational well-head injection pressure for the deep-injection well is 204 pounds per square inch.
- The maximum operational injection rate into the deep-injection well is 2,810 gallons per minute.
- The injection pressure and the injection rate must be monitored daily at the deep-injection well, and the flow volume totalized each day.
- Water sampling must be carried out on both the deep-injection well and the monitor well every month (after the first few months of shakedown operation the sampling frequency may be reduced if allowed under the final permit).
- The water quality samples must be tested monthly for the parameters shown in Figures 4-3 and 4-4, and the results reported to FDER once every month.
- The piezometric heads in the deep monitor well must be read daily. These values must be reported to FDER once every month.
- The daily operational data for the deep-injection well must be reported to FDER on a monthly basis.
- The County and FDER must be notified within 24 hours of the occurrence of an abnormal event.
- The mechanical integrity of the deep-injection well may need to be tested every five years.

- The deep-injection well must be inspected with a television survey every five years.

- FDER may require either or both a mechanical integrity test and a television survey in conjunction with a controlled injection test whenever circumstances warrant such testing.

Sections 1 and 2 are informational sections that discuss the rationale for the assignment of limiting pressure and volumes to the well. Sections 3 and 4 discuss the specific operational requirements and the reporting criteria. Sections 5, 6 and 7 discuss plans for dealing with problems that may occur. The plant operator will be primarily involved with Sections 3 and 4 of this manual; however, the other sections are presented in the interest of the owner and the regulating agencies.

m:H-87(II)/E

Section 1
INJECTION PRESSURE

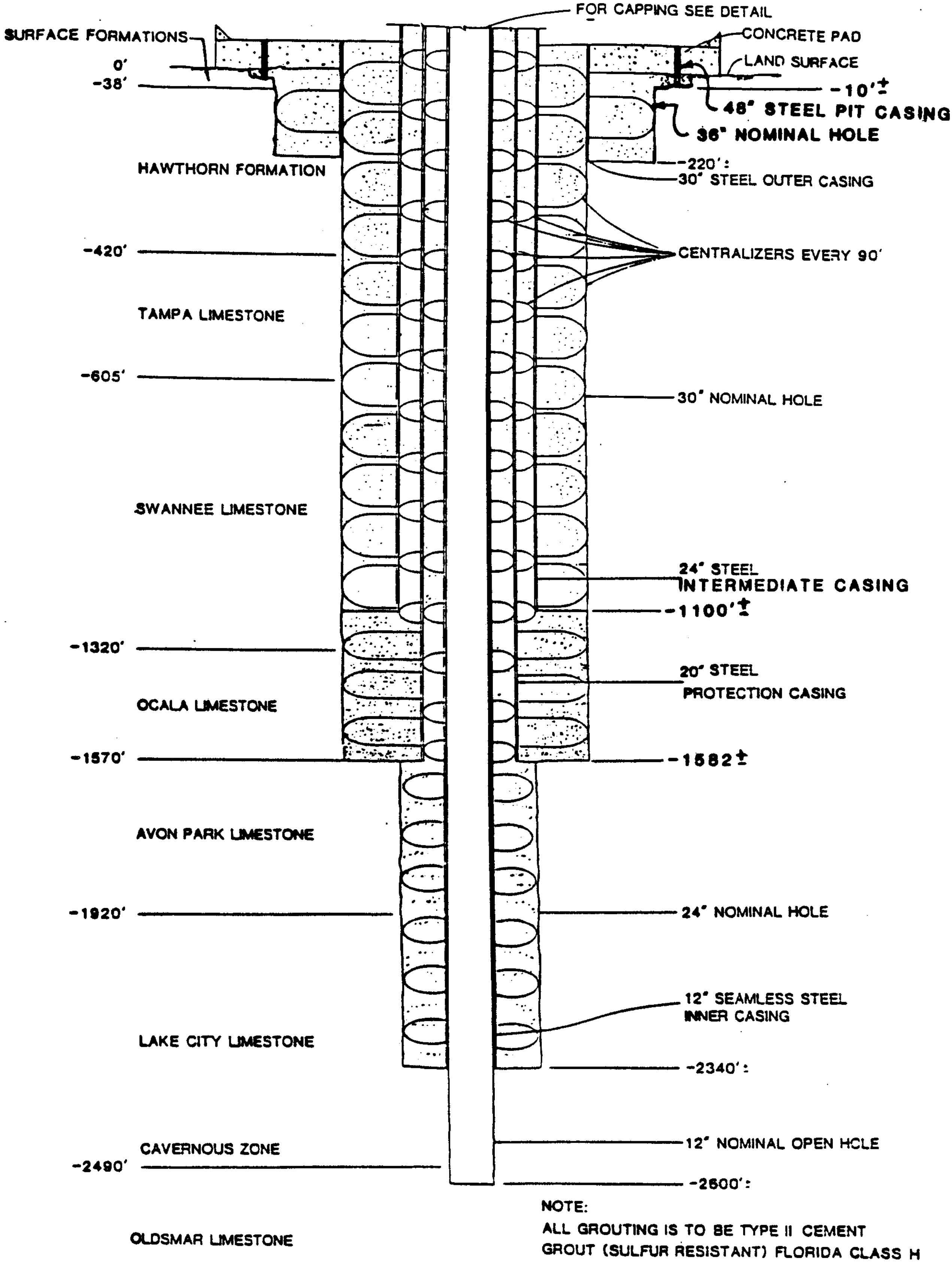
The operating program for any injection system must be suited to the hydrogeological characteristics of the injection zone and to the volume and chemistry of the injection fluids. Injection pressures and injection rates are interrelated, with the pressure the dependent variable for the injection system. Therefore, at the North Fort Myers Utility (NFMU) site, the pressures used to inject the effluent from the wastewater treatment plant into the injection zone are a direct result of the injection rate.

Though injection pressures are dependent on injection rates, there is a maximum permissible well-head injection pressure for any system. The criteria utilized in determining this pressure are as follows:

- <u>Preservation</u> of the integrity of the formations in both the injection zone and the overlying confining zone.
- <u>Prevention</u> of a significant change in the fluid movement capabilities of the overlying confining zone.
- <u>Protection</u> of the mechanical integrity of the well structure.

1.1 PRESERVATION

Unless fracture tests are conducted on the formations within the injection zone, it is impossible to determine with absolute certainty the safe operating pressure for the receiving formations. The maximum bottom-hole injection pressure, which is commonly specified on the basis of well depth, ranges from about 0.5 to 1.0 pounds per square inch (psi) per foot of well depth. The value chosen from this range is largely dependent upon geological conditions within the open hole. The normal value for the maximum bottom-hole injection pressure in the state of Florida is 0.6 psi per foot of well depth. In the deep-injection well at the NFMU site, the depth to the bottom of the open hole is 2,600 feet (see Figure 1-1) and, therefore, the maximum bottom-hole injection pressure would be 1,560 psi.



NOTE:
ALL GROUTING IS TO BE TYPE II CEMENT GROUT (SULFUR RESISTANT) FLORIDA CLASS H

NOT TO SCALE

INJECTION WELL (AS BUILT)

PBS&J POST, BUCKLEY, SCHUH & JERNIGAN, INC.

FIGURE 1-1

The maximum permissible well-head injection pressure represents the difference between the maximum bottom-hole injection pressure and the pressure losses. The bottom-hole hydrostatic pressure is calculated at 1,206 psi, assuming a specific gravity of 1.07 and a constant temperature over the well length. The difference between the maximum bottom-hole injection pressure and the bottom-hole hydrostatic pressure yields a maximum well-head injection pressure of 354 psi. With a safety factor of 2.0, the maximum bottom-hole injection pressure is 177 psi. The friction losses incurred by the ultimate expected average flow of 4.0 million gallons per day (mgd) into the deep-injection well at the NFMU site will be no more than 2.7 psi (i.e., about 61 feet of head); therefore, the maximum permissible well-head injection pressure for this well, based on the first criterion above, is 204 psi.

1.2 PREVENTION

The second criterion is somewhat more difficult to evaluate because of the interpretation of the word "significant." The model runs made with the Surface Water Injection Program (SWIP) for the deep-injection well at North Ft. Myers Utility site were for a 50,000-foot cone of influence or an area of 282 square miles centered around the injection zone. The piezometric heads were integrated over the modelled cone of influence, assuming the piezometric heads in all directions from the deep-injection well were equal. According to the model results, the leakage after 2,000 days (5-1/2 years) of 4-mgd operation will be restricted to a radial distance of 1,700 feet from the well. The estimated leakage, based on these calculations and taking into account the piezometric differences across the confining zone, will be 2.1 gallons per year per acre distributed over an area of 207 acres (a 1,700-foot radius around the well-head). No leakage is predicted beyond that area, and, therefore, there will be no effect beyond the area of review.

1.3 PROTECTION

The third criterion for establishing the maximum permissible well-head injection pressure for the deep-injection well at NFMU site is the bursting pressure of the 12-inch steel pipe used for the injection casing within the well. The bursting pressure for water-filled, unsupported, 12-inch diameter, 0.5-inch-wall-thickness, carbon steel pipe is 1,650 psi (ASTM A-53). Except for one-and-a-half-feet above the drilling pad, the casing is encased in cement grout for the entire length within the deep-injection well; therefore, within the deep-injection well, the maximum permissible pressure inside the casing is much larger than the bursting pressure for the unsupported casing. Nevertheless, the criterion established by the pipe itself is 1,650 psi.

In summary, the first of the three criteria above is the limiting criterion. The maximum theoretically permissible well-head injection pressure for the deep-injection well at the NFMU site is 204 psi, which includes a safety factor of 2.0.

Regardless of this theoretical maximum, The Florida Department of Environmental Regulation (FDER) has the option of regulating the maximum permissible injection pressure. This regulatory maximum is based on a multiplier applied to the predicted injection pressure and is usually below the permissible maximum derived from the technical computations. <u>At the NFMU injection well, the FDER permit conditions will limit the wellhead injection pressure to 204 psi</u>.

The data reporting program described in Section 4 of this manual requires that the maximum well-head injection pressures be reported on a regular basis. Therefore, if the injection pressures show a rapid increase towards the maximum, measures must be taken to alleviate the impending violation prior to its occurrence. Based on the current knowledge of the characteristics of this injection well, injection pressures at the well-head are not envisioned to exceed 80 psi with the proposed injection volumes planned for the foreseeable future.

If, under normal operating conditions, the well-head injection pressure suddenly starts to approach the permitted maximum of 204 psi, the injection pumps and deep-injection well must be shut down until an emergency evaluation program can be conducted on the well, and the contingency plans described in Section 6 are put into operation. On the other hand, if the well-head injection pressure suddenly starts to exceed the maximum of 204 psi as a result of excessively high injection rates, the injection should be throttled back immediately to a rate that will reduce the well-head injection pressure to the maximum of 204 psi. The limiting injection rate is discussed in Section 2.

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Section 2
INJECTION RATE

The injection fluid for the deep-injection well at the NFMU site is the secondarily treated effluent from the wastewater treatment plant. In this case, the injection fluid is piped from the plant through the injection pumps and hydropneumatic tank into the deep-injection well. No additives can be mixed with the injection fluid prior to injection and no other material or any other waste fluids are to be injected into the deep-injection well.

The injection rate for the deep-injection well at Century Village is also dependent on the following criteria:

- Protection of the mechanical integrity of the well structure.
- Preservation of the integrity of the formations within the injection zone.
- Capabilities of the injection zone.

2.1 PROTECTION

As with the injection pressure, testing the injection zone with excessive injection rates for a damage analysis is not possible because such testing is destructive in nature. This precludes the evaluation of a specific permissible injection rate for the deep-injection well at NFMU. Therefore, various agencies, including FDER, after consulting with other TAC member agencies, and in conjunction with private engineering consultants and well drillers, have informally agreed to establish a maximum injection velocity of 8 feet per second. This velocity is now adopted as part of Chapter 17-28 (FAC) and is the ruling criterion for maximum injection rates. Within the 12-inch-diameter steel injection casing installed in the deep-injection well, the maximum permissible injection rate is thus 6.26 cubic feet per second (i.e., 2,810 gallons per minute (gpm) or 4.05 mgd).

The current design capacity of the wastewater treatment plant is 2.0 mgd, which is equivalent to 1,388 gpm or 49.4 percent of the maximum permissible injection rate. The injection pumps may be operated 12 hours per day at an injection rate of 2,776 gpm, which is still below the maximum permissible rate; however, the deep-injection well will operate more efficiently under a relatively stable injection rate over a 24-hour day because of the friction losses, which increase at a parabolic rate relative to increases in the injection rate.

This criterion limits the injection rate as a means of protecting the injection well from large flow velocities that can lower the fluid pressure close to the saturated vapor pressure at the injection pump or at any other flow obstructions (e.g., sudden enlargements, constrictions, etc). Lowering the fluid pressure within the injection line can lead to cavitation within the injection line, and the resulting fluid flow interruption can damage the line. Higher injection rates within the well require larger injection pressures; hence, there is less chance of any pressure reductions to below the saturated vapor pressure.

2.2 PRESERVATION

Stable operating conditions are also beneficial to the integrity of the injection zone. Pressure fluctuations under variable injection rates create variable stress-strain relationships within the rocks, particularly the rock shelves separating the caverns, inducing cyclical flexing of the rock matrix. Such flexing can affect the rock matrix and may result in collapses of the cavern roofs. To prevent the possible fracturing of this matrix within the injection zone, cyclical injection should be kept to a minimum. This is accomplished through the use of the hydropneumatic tank.

2.3 CAPABILITIES

The third criterion is directly related to the transmissivity of the injection zone and the ability of this zone to receive the injection fluid. The maximum rate of injection that can be received by the injection zone is largely limitless as long as the well structure and the rock matrix within the injection zone are able to receive the fluid.

While the injection zone is capable of receiving many times the proposed injection volume and rate, and while the mechanical integrity of the well would not be impaired by a high injection pressure, there are definite economic incentives for maintaining a low injection pressure. The frictional head loss increases exponentially with an increasing flow rate. The frictional head losses for the well, at 2.0 mgd, are approximately 18 psi; while at 4.0 mgd, they would be about 27 psi.

In summary, the limiting criterion for increasing the injection rate is more a matter of economics than the threat to the well structure, or the ability of the injection zone to receive the injected fluid. The maximum safe injection rate for the deep-injection well at NFMU is, however, determined by the 8-foot-per-second limiting velocity of flow within the injection pipe, and is thus 2,810 gpm. This represents a large redundancy of 51 percent in well capacity when injecting at 1,388 gpm (2.0 mgd). The maximum allowable injection rate, however, is set by the permit conditions. Those conditions specify a maximum instantaneous injection rate of 2,810 gpm at NFMU.

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Section 3
MONITORING REQUIREMENTS

During the time that the deep-injection well is operational, some monitoring programs must be conducted on a regular basis and others must be carried out on an "as-needed basis," as follows:

Regular Monitoring Programs

- o Regular injection well monitoring program
- o Regular monitor well sampling program

Special "As-Needed" Monitoring Programs

- o Special injection well monitoring program
- o Specific injectivity monitoring program.

These programs are described below.

3.1 REGULAR MONITORING PROGRAMS

3.1.1 Regular Injection-Well Monitoring Program

The regular monitoring program for the deep-injection well at NFMU consists of three variables: flow rate, pressure, and injected wastewater quality.

A continuous record of the variable nature of the flow rate for each 24-hour period must be kept, and the daily flow volume must also be recorded. Data on the daily flow rate and the totalized monthly flow, together with the average and maximum daily flow and the maximum instantaneous rate must be reported monthly, as described in Section 4 of this manual.

A record of the variable nature of the well-head injection pressures, as a result of any fluctuations within the flow rate, must also be kept. Daily average and daily maximum injection pressures must be recorded for each 24-hour period and reported monthly.

The water quality of the treatment plant effluent must be monitored in accordance with Chapter 17-19 FAC and reported monthly on FDER Form 17-1.205(7). A copy of this article and the required form is included in Appendix B; however, use of this form is associated with the treatment plant and not with the operation of the well itself.

The injected fluid must also be tested weekly. For testing, a sufficient quantity of injection fluid should be taken from the pipeline from the treatment plant to the deep-injection well. The injection fluid samples must be analyzed for the following parameters:

- o pH (hourly)
- o BOD
- o Total suspended solids
- o Total dissolved solids
- o Conductivity
- o Chloride
- o Sulfate
- o Temperature
- o Fecal coliform bacteria.

The temperature reading must be taken immediately after the sample has been collected from the injection pipeline. The remaining water quality parameters may be determined later in the water quality testing laboratory. An on-going record of the various parameters must be maintained at the plant office.

All the data must be retained on site and kept available for inspection by the regulatory authorities on request. The log sheets must include any annotations and will constitute the record of operation (see Section 4).

At the time of sample collection or sample analysis, the following monitoring information must be provided:

- Date, exact place, and time of sampling or measurements
- Person responsible for performing the sampling or measurements
- Date(s) analyses were performed
- Person responsible for performing the analyses
- Analytical techniques or methods used
- Results of the analyses.

3.1.2 Regular Monitor-Well Sampling Program

Two water-producing zones above the injection zone are tapped by the monitor well (see Figure 3-1):

- The upper monitor zone, from 1,318 feet to 1,422 feet

- The lower monitor zone, from 1,930 feet to 2,004 feet.

As part of the overall monitoring of the groundwater in the area, these two zones must be monitored on a monthly basis and the results reported to FDER and the TAC members.

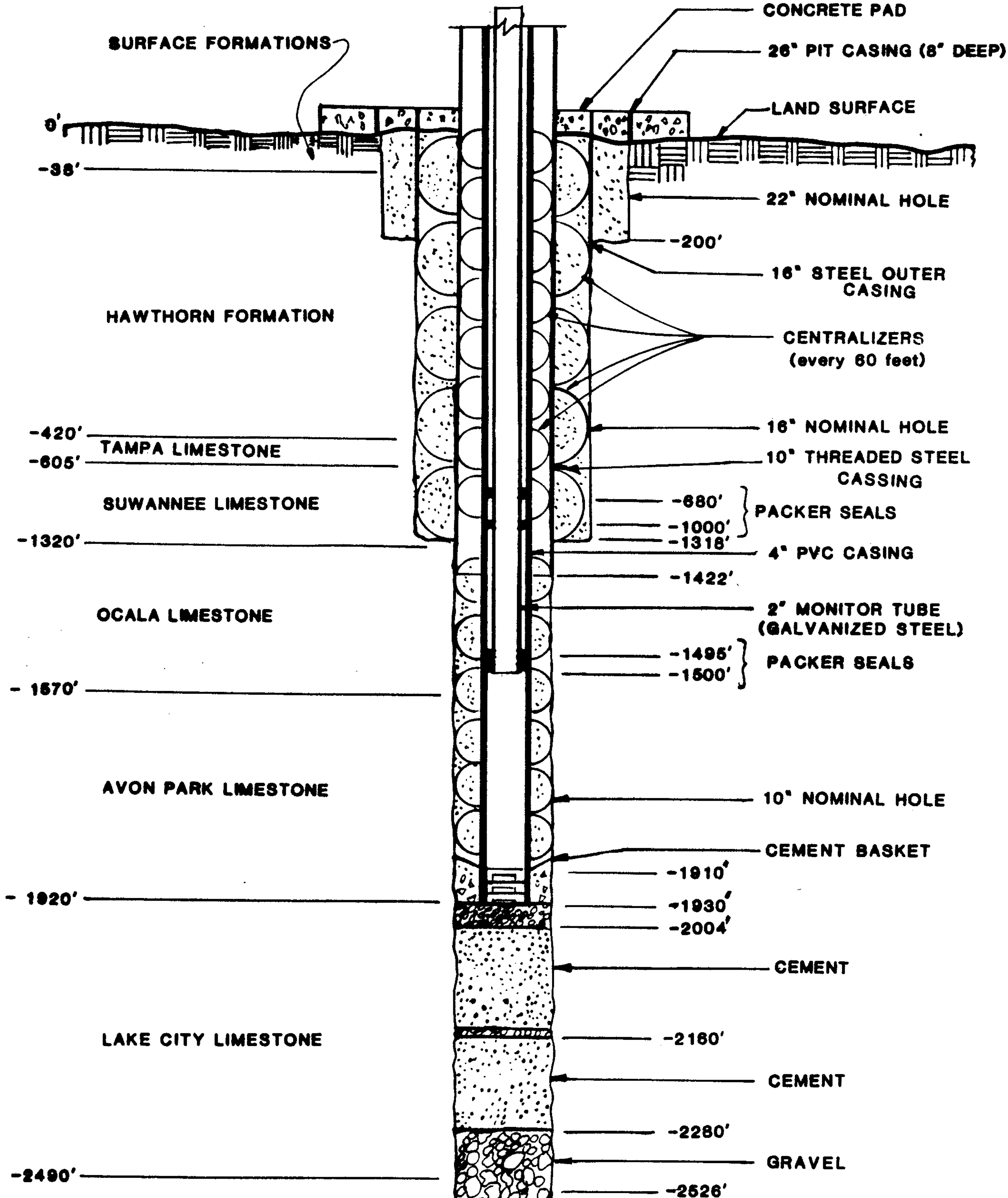
The monthly monitoring program for these two monitor zones must include the following steps:

- Record the pressure on both zones, noting monthly daily highs and lows on the monthly form (see Section 4)

- Collect a monthly water quality sample from each zone.

The water quality samples collected monthly from each of the two zones must be taken to a water quality testing laboratory for testing of the following parameters:

- BOD_5
- Total dissolved solids
- Specific conductance
- Chloride



DEEP MONITOR WELL
AS BUILT

NOT TO SCALE

PBSJ POST, BUCKLEY, SCHUH & JERNIGAN, INC.

FIGURE 3-1

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REPRO PRODUCTS INC. 7A

- Sulfate
- Fecal coliform bacteria
- Total nitrogen.

Records of monitoring information shall include:

- Date, exact place, and time of sampling or measurements
- Person responsible for performing the sampling or measurements
- Date(s) analyses were performed
- Person responsible for performing the analyses
- Analytical techniques or methods used
- Results of the analyses.

The results from the water quality analyses must be submitted to FDER and to all the TAC members (see Apendix A) on a monthly basis. The format for reporting the water quality data is given in Section 4.

3.2 SPECIAL "AS-NEEDED" MONITORING PROGRAMS

3.2.1 Special Injection-Well Monitoring Program

The special injection-well monitoring program may consist of the following tests or a combination thereof:

- Controlled injection test
- Pressure test
- Television survey.

The mechanical integrity of the deep-injection well may have to be checked every five years by a one-hour pressure test on the injection casing. If such testing is required, a temporary packer must be installed at the bottom of the injection casing prior to the test. Within three months, the results of the pressure test must be submitted to the regulatory authorities, including the FDER, with an interpretative letter. Copies of the results must also be retained at the plant office. This requirement will be only implemented if there is a reasonable suspicion that the integrity of the casing has deteriorated.

A television survey of the deep-injection well must be made every five years by running a vertical television camera down to the maximum depth possible within the open hole. Within three months of the survey, a copy of the survey videotape must be submitted to FDER with an interpretative letter, and a copy of the videotape must be retained on site. If the submitted records indicate significant rises in the well-head injection pressures over time, a controlled injection test and/or the television survey may be called for by FDER to ascertain the probable cause of the increasing well-head injection pressures.

If a sudden significant increase occurs in the well-head injection pressures, the FDER must be notified within 24 hours. A testing program then must be established for the deep-injection well, which will probably include a controlled injection test and a television survey. The results from these tests must be analyzed and an interpretative report submitted to FDER within three months of such tests. If the results of these tests require any working over in the deep-injection well, the results of the working over must also be submitted to FDER within three months.

3.2.2 Specific Injectivity Monitoring Program

A specific injectivity test must be performed every other month during the test period until the permanent operating permit is obtained. Subsequently, the injectivity test must be performed yearly only.

For meaningful comparisons between tests, the standard test procedures must be followed exactly each time the test is conducted. These procedures are as follows:

- o Once a month, the final effluent storage tank must be allowed to fill sufficiently to allow the injection system to operate at the maximum permissible injection rate (2,810 gpm) for up to two hours continuously. In other words, there must be a minimum storage of 336,000 gallons prior to starting the test.

- The injection pump must then be connected directly to the injection well (bypassing the hydropneumatic tank) and operated at the pre-determined revolutions per minute that will result in a 2,810-gpm injection rate.

- After one hour of injection at the rate of 2,810 gpm, the injection pressure at the well head must be recorded. This must be repeated again just prior to the end of the test, at the end of the second hour.

- The two pressure readings must be averaged together to determine the specific injection pressure for an injection rate of 2,810 gpm.

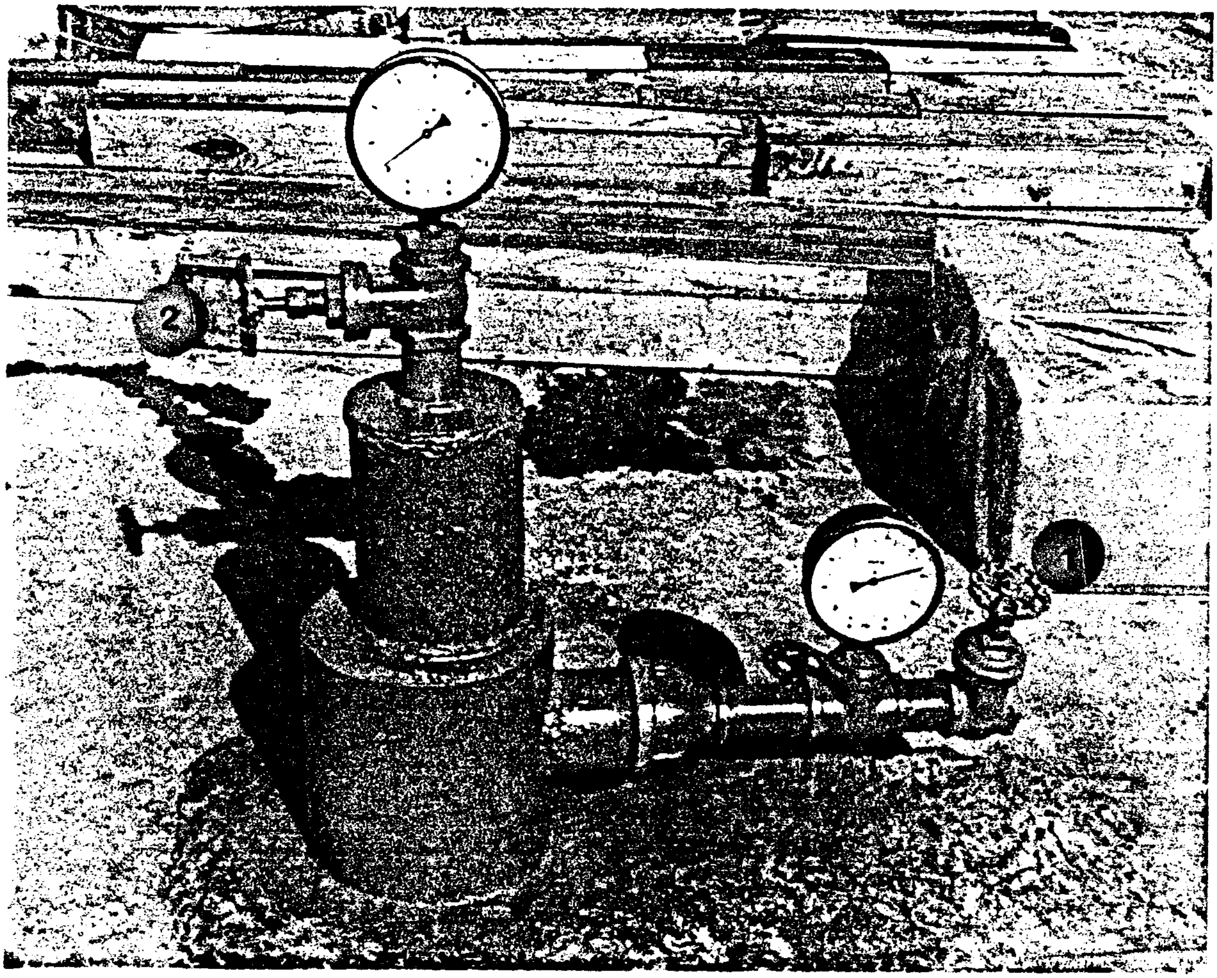
- The specific injectivity index must then be reported as the ratio of the fixed volumetric rate (2,810 gpm) to the specific pressure (the average of the two readings). This result is the specific injectivity index (gpm/specific pressure).

- A chart must be prepared by plotting the locations of the monthly results. In the chart, the x and y coordinates will represent the gpm and the pressure, respectively.

3.3 SAMPLING PROCEDURES

The water quality monitoring of the treatment plant effluent has been discussed in Section 3.1.1; consequently, it will not be repeated in this section. The sampling procedures for the deep monitor well, however, require that the samples be collected after the system has been properly evacuated and a discussion of that methodology is required. Figure 3-2 shows the capping details of the deep monitor well and the piping arrangements designed to ease the collection of water quality samples from the two zones.

The upper monitor zone is tapped by the outer casing through the valve marked (1) in Figure 3-2. Opening this valve allows the monitor zone to flow freely since this zone is under high artesian pressure. Opening valve (1) will



DEEP MONITOR WELL PHOTOGRAPH
(FINAL CAPPING)

PBSJ POST, BUCKLEY, SCHUH & JERNIGAN, INC.

FIGURE 3-2

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induce immediate flow and a hose must be connected to the well to allow the flow to be routed back to the treatment plant. This procedure must be followed before a water sample is collected, because a large volume of water must be evacuated from the casing before a representative formation-water sample can be obtained.

It is calculated that the annular space between the casings contains 4,550 gallons of water. A minimum of 1.5 times that volume (6,825 gallons) should be allowed to flow out before a sample is collected. As this upper zone flows at a rate of 2 gpm, the water should be allowed to flow a full 2-1/2 days before a sample is collected.

A similar procedure must be followed to evacuate the inner casing (lower monitor zone). In this case, the pressure gage must be removed and valve (2) must be opened. This, however, will not allow water from the lower monitor zone to flow out because the artesian pressure in this zone is too low. To obtain a sample from this well, a pump or an air compressor must be used.

The lower monitor casing contains 1,260 gallons of water and, to allow 1.5 times that volume to flow out before a sample is collected, 1,890 gallons must be evacuated before sampling starts. The time of pumpage depends on the rate of pumpage of the pumping system selected.

3.4 SHUT-DOWN AND START-UP PROCEDURES

3.4.1 Normal Operation

Once the well is put in operation, the system is designed to work fully automatically without the need to open or close any valves. The air-release and vacuum-release valves on the well-head are the only valves that open and close with any regularity and they do that automatically.

The hydropneumatic tank, acting as a buffer, also creates redundancy so that even the automatically operated air- and vacuum-release valves need not be controlled in any way. In fact, the control valves to the air-release and vacuum-release valves should always be in the open position whether the well is in operation or not. In other words, valves (1) and (2), shown in Figure 3-3, should always remain open. Valve (3), which connects the release valves to the well, should always be open also. Valve (4), on the other hand, should always be closed. Valve (4) is used only when the well-head must be opened for logging or for TV inspections. Its only function is to prevent sewage spills while the logging tools on the TV camera are being inserted into the well.

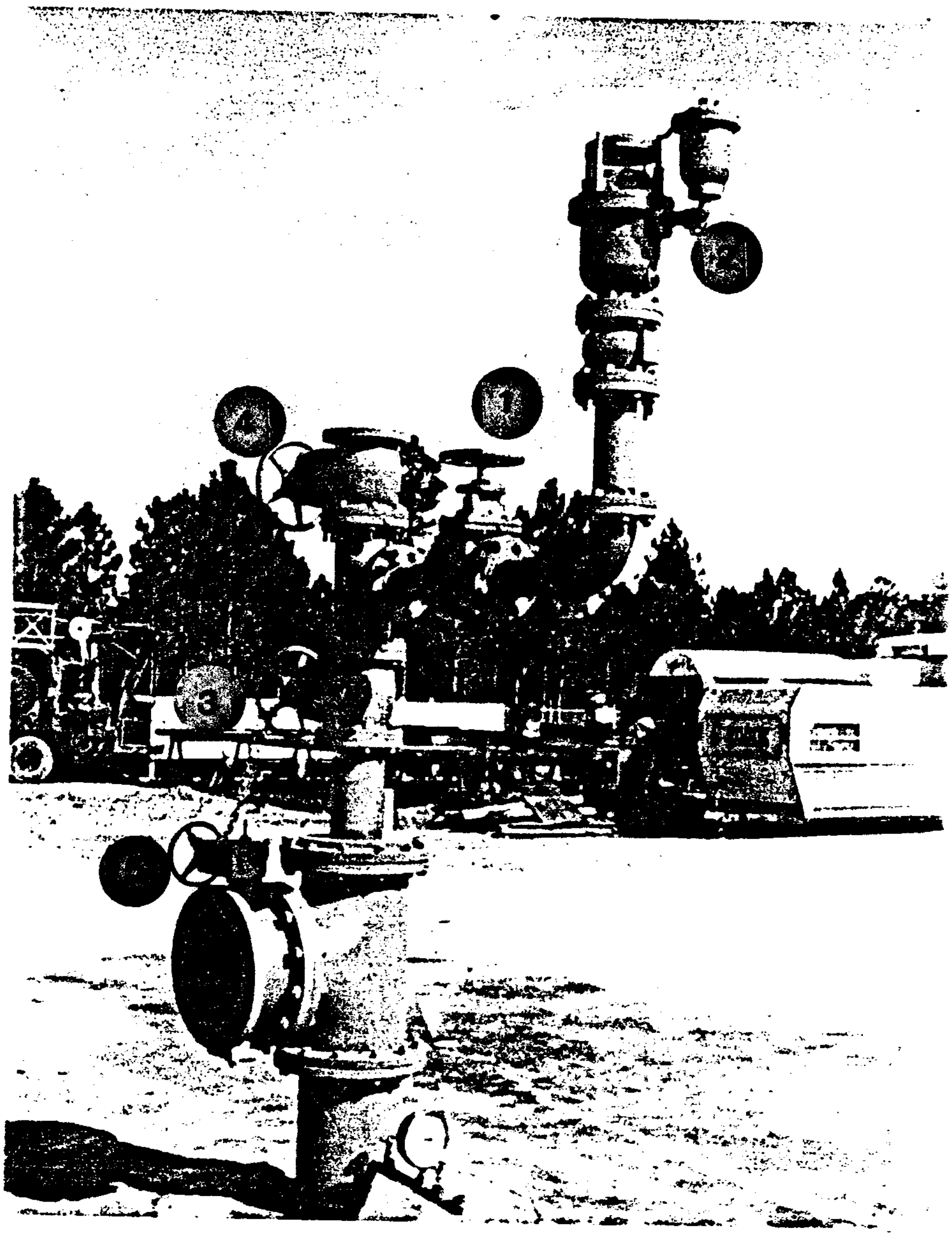
3.4.2 Start-Up

The master valve is valve (5), a slow-closing butterfly valve that connects the well to the plant. When the well is shut down and before it is put into operation, all the valves (1) through (5) should be closed. To put the well into operation, valves (1), (2), and (3) should be opened in that order (valve (4) should remain closed). Once the injection pump is turned on, valve (5) should be opened within 0.5 minutes to prevent buildup of pressure in case the hydropneumatic tank is bypassed. If the hydropneumatic tank is not bypassed, then the capacity available in the tank reduces this urgency; however, valve (5) must still be opened before the hydropneumatic tank fills up (within 5 or 10 minutes).

3.4.3 Shut-Down

Shutting down the well is a straightforward operation, requiring only that valve (5) be closed. If the shut-down is temporary, valves (1), (2), and (3) may be left open. If the shut-down is going to be lengthy, then valves (1), (2), and (3) should also be closed.

It is strongly recommended that a lockable chain be attached to valves (1), (3), and (4) to prevent vandals from changing their settings. An alternative to chains is to remove the handles. Valve (5) should also be protected from vandalism by chain-locking it, or by removing the hand-wheel operator.



INJECTION WELL PHOTOGRAPH
(FINAL CAPPING)

PBSJ POST, BUCKLEY, SCHUH & JERNIGAN, INC.

FIGURE 3-3

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3.5 SCHEDULES AND PROCEDURES FOR CALIBRATION OF MONITORING INSTRUMENTS

The frequency of calibration and the procedures that must be followed to calibrate the various pressure gages and water quality probes depend primarily on the type of equipment and the manufacturers' recommendations. Each equipment manufacturer has his own specific procedures, and it is beyond the scope of this manual to explain them all. The operator is referred to the manufacturers' manuals for these purposes. These manuals are to be retained on site at all times.

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Section 4
DATA-REPORTING

The data-reporting for the deep-injection well at the NFMU site consists of:

- Regular monthly operational reports
  - Pressures and volumes
  - Water quality and pressures
- Special interpretative reports
- Noncompliance reports.

The formatting and the requirements of these reports are discussed in Sections 4.1 through 4.3.

4.1 REGULAR OPERATIONAL REPORTS

Operational reports for each calendar month must be submitted to FDER and to all the TAC members not later than the 15th day of the next month.

4.1.1 Pressures and Volumes Report

This report consists of two pages, as shown in Figures 4-1 and 4-2, derived from the EPA-suggested reporting format. The names and addresses of current TAC members are shown in Appendix A.

Page 1 of the monthly pressures and volumes operational report contains four sections. Sections I and II are self-explanatory. Section III details the restrictions for the maximum daily injection volume, the maximum injection rate, and the maximum well-head injection pressure. The maximum and average daily injection volumes, and the cumulative total volume for the month are to be recorded in Section III-A. In Sections III-B and III-C, the deep-injection-well operator records the maximum, average, and minimum injection rates and the well-head injection pressures for the month of record. Section IV provides the instructions for filling out the report.

NORTH FT. MYERS UTILITY DEEP-INJECTION WELL

MONTHLY OPERATIONAL REPORT - Page 1

I. OPERATING PERIOD MONTH____________ YEAR_______________

II. INJECTION WELL OPERATOR

1. Name ____
2. Address ____
3. City ________________________ State ____________________
4. Phone number ____
5. Permit number ____

III. SUMMARY OF OPERATIONAL DATA

A. Injected Volumes

1. Maximum daily volume specified in permit _______________ gal/day
2. Maximum daily volume during operating period ___________ gal/day
3. Present average daily volume ___________________________ gal/day
4. Total volume injected to date __________________________ gal

B. Injection Rate

1. Maximum injection rate specified in permit ________________ gpm
2. Maximum injection rate during month _______________________ gpm
3. Minimum operational injection rate during month ____________ gpm
4. Average injection rate during month _______________________ gpm

C. Injection Pressure

1. Maximum well-head injection pressure specified in permit ____ psi
2. Maximum well-head injection pressure during month __________ psi
3. Minimum operation well-head injection pressure during month ______ psi
4. Estimated average well-head injection pressure during month _________ psi

IV. INSTRUCTIONS

A. The operator of the injection system shall furnish information on this form not later than the 15th day of the month following the month reported.

B. Report any irregularities relative to daily injection practices on reverse side of this page.

C. All data will be retained on site and made available upon request.

D. All operational problems and significant changes in injection systems or wastes are to be reported when they occur.

Signed ______________________________ Date _________________________

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PBSJ POST, BUCKLEY, SCHUH & JERNIGAN, INC.

FIGURE 4-1

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FIGURE 4-2

NORTH FT. MYERS UTILITY DEEP-INJECTION WELL

MONTHLY OPERATIONAL REPORT - Page 2

1. CONTINUOUS OPERATING PERIOD					2. INJECTION RATE (GPM)			3. WELL-HEAD INJECTION PRESSURE (PSI)			4. TOTAL CUMULATIVE FLUID INJECTED (GAL)	
Start		End		Length of Operating Period (Days:Hours)								
Date	Time	Date	Time		Max.	Min.	Average	Max.	Min.	Estimated Average	Daily	Cumulative
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
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31												

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The maximum daily injection volume during the operating period is the largest of the average daily injection volumes calculated for each of the operating periods during the month. The present average daily volume for the month is calculated from the total volume injected for the month divided by the sum of the length of the operating periods during that month. The total volume injected to date is taken directly at the end of the month from the daily volumes recorded.

The maximum injection rate during the month is the largest of the daily maximum injection rates. The minimum operational injection rate is the lowest of the daily minima. The average injection rate during the month is equivalent to the present average daily volume recorded in Section III-A-3 (in Figure 4-1), except for a change in the time dimensions.

The maximum well-head injection pressure during the month is the largest of the daily maxima. The minimum operational well-head injection pressure is the lowest of the daily minima. The estimated average well-head injection pressure during the month must be estimated for each operating period from the daily values. The time-weighted average is calculated from the various estimated average well-head injection pressures for the month.

Column 1, on page 2, records the start, end, and length of each operating period during the month. The maximum and minimum injection rates are read for each day and entered in Column 2. The average injection rate is calculated from the daily totalized flow at the end of each day, dividing the difference by the operational time for the day. Both the maximum and minimum well-head injection pressures are recorded for each day and entered in Column 3. The average daily well-head injection pressure is estimated for each day and entered in Column 3. The totalized volumes are recorded at the end of each day whenever the operating periods exceed one day. If the operational period is less than a day, the flow at the end of the period is recorded.

4.1.2 Water Quality and Pressures Report

This report consists of three pages, which are shown in Figures 4-3, 4-4, and 4-5.

PBS&J POST, BUCKLEY, SCHUH & JERNIGAN, INC.

FIGURE 4-3

NORTH FT. MYERS UTILITY DEEP-INJECTION WELL

MONTHLY OPERATIONAL REPORT
INJECTION WELL

I. Operating Period: ______________________ 19 ____

II. Sampled By: 1. Name ____________________ Address ____________________

City ______________ State ______________ Phone Number ______________

2. Permit Number ______________

Signed ______________________ Date ______________

Month	Date of Sample	BOD (mg/l)	Total Dissolved Solids (mg/l)	Total Suspended Solids (mg/l)	Chloride (mg/l)	Sulfate (mg/l)	Conduct-ivity (umhos/cm)	Temper-ature (°C)	Fecal Coliform (Colonies/100 ml)	pH* (range)
______ Starting ______ Ending										
______ Starting ______ Ending										
______ Starting ______ Ending										
______ Starting ______ Ending										
______ Starting ______ Ending										

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REPRO PRODUCTS INC.

PBS&J POST, BUCKLEY, SCHUH & JERNIGAN, INC.

FIGURE 4-4

NORTH FT. MYERS UTILITY DEEP-INJECTION WELL

MONTHLY OPERATIONAL REPORT

MONITOR WELL

I. Operating Period: ______________________________ 19 _____

II. Sampled By: 1. Name _________________________ Address _________________________________

City _________________ State ____________ Phone Number ____________________

2. Permit Number ____________________

Signed ______________________________ Date _________________

Month		Date of Sample	Monitor Zone	BOD (mg/l)	Total Dissolved Solids (mg/l)	Chloride (mg/l)	Sulfate (mg/l)	Conductivity (umhos/cm)	Total Nitrogen (mg/l)	Fecal Coliform (Colonies/ 100 ml)
			Upper							
_____ Starting	_____ Ending		Lower							
			Upper							
_____ Starting	_____ Ending		Lower							
			Upper							
_____ Starting	_____ Ending		Lower							
			Upper							
_____ Starting	_____ Ending		Lower							
			Upper							
_____ Starting	_____ Ending		Lower							

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NORTH FT. MYERS UTILITY DEEP-INJECTION WELL

MONTHLY OPERATIONAL REPORT

DAILY PRESSURE READINGS AND WATER LEVELS
DEEP MONITOR WELL

(PAGE 5*)

Measured By: 1. Name ____________________ Address ____________________

City ____________________ State __________ Phone Number __________

2. Permit Number ____________________

Signed ____________________ Date __________

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
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23												
24												
25												
26												
27												
28												
29												
30												
31												

NOTE: **READINGS ARE IN PSI (GAGE) FOR THE UPPER ZONE AND IN DEPTH TO WATER IN FEET FOR THE LOWER ZONE**

*First number in the box is the upper monitor zone. Second number is the lower monitor zone.

MONTHLY OPERATIONAL REPORT FORMAT
(PAGE 5)

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FIGURE 4-5

The operator or the person conducting the water quality sampling program or reading the monitor well pressures and water levels fills in the top two sections of the report whenever the piezometric measurements are taken and the water samples are collected. Piezometric data are reported daily on the two monitor zones of the deep monitor well in the artesian aquifer system. The reporting form for these piezometric data is shown in Figure 4-5. The piezometric data for the upper zone of the deep monitor well are measured from a pressure gage in units of pounds per square inch (psi). The piezometric data for the lower zone of the deep monitor well are measured by tapping down to the water surface and recording the distance as depth to water in feet below the measuring point (M.P.).

The remaining water quality forms include columns for the water quality parameters. The temperature of the injection fluid is the only temperature reading taken for the samples, as it has a bearing on the density of the injection water. The water quality samples should be sent to a water quality testing laboratory, which will submit the testing results to the operator for inclusion in the appropriate columns of the table.

4.2 INTERPRETATIVE REPORTS

Interpretative reports are usually submitted when any special monitoring program has been carried out (see Section 3.2). These reports are normally letter reports whose format depends on the nature of the special monitoring program; they are usually established by the engineering consultants for the water treatment facility and submitted to FDER within three months after the special monitoring program has been carried out.

4.3 NONCOMPLIANCE REPORTS

Noncompliance reports are required in the case of abnormal events (e.g., equipment breakdown, power failure, etc.). In such cases, a verbal report is made to FDER and then followed by a preliminary report to be submitted to the FDER within three days of the event, and by a comprehensive report submitted within two weeks of the event. These reports must describe the nature and cause of the event, the period of noncompliance (dates and times), steps taken or planned to correct the problem and prevent its recurrence, emergency procedures in use pending correction of the problem, and the estimated time when the facility will again be functioning in accordance with permit conditions.

If the deep-injection well is abandoned, the owner and/or the operator must provide adequate documentation indicating that the well was properly abandoned. Such documentation must describe the method of abandonment and evaluate the results of the operation.

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Section 5
STIMULATION PROGRAM

If the deep-injection well at NFMU becomes clogged or is blocked off and, therefore, becomes less receptive to the injection fluid, it may be necessary to enact a well-stimulation program. In addition, FDER may also request that a special monitoring program be conducted on the deep-injection well, unless the cause of the reduced intake is already known. An interpretative report on the deep-injection well must then be submitted to FDER, discussing the problem and reporting on the special monitoring program, if one was conducted. In addition, the report should recommend corrective action designed to rehabilitate the well. Such corrective action must include a stimulation program for the deep-injection well.

A well-stimulation program may include surging or acidizing or a combination of the two methods, as approved by FDER. Other stimulation techniques, used primarily within the petroleum industry, include shooting, hydraulic fracturing, vibratory explosions, etc. are destructive in nature, however, and are not recommended for use within the deep-injection well at NFMU.

Surging to stimulate the deep-injection well involves the use of a pump that can either inject or discharge water into or from the well at continuously fluctuating rates. Such action is designed to loosen any matter that may be clogging the rock pores. Well-acidization is designed to chemically break down any matter clogging the rock pores and, hence, induce an improved flow movement through the injection zone. Surging was utilized to develop the injection well and the monitor well after the completion of construction and testing.

The injection zone intersected by the open hole in the deep-injection well at NFMU comprises numerous large cavities. These cavities are not usually susceptible to clogging, unlike the pores within the rock matrix itself. Therefore, it is not envisaged that the injection zone will be susceptible to any serious clogging effects. Even so, observing the restrictions that apply to the composition of the injection fluid is essential to the successful operation of the well.

The results of a stimulation program must be tested by a special monitoring program, as approved by FDER (see Section 3.2). Both the stimulation program and the special monitoring program should then be fully described and analyzed in an interpretative report to be submitted to FDER (see Section 4.3).

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Section 6
CONTINGENCY PLANS

An abnormal event that may incapacitate a section of, or the whole treatment plant facility can happen at any time. Such events may include not only a well failure, but also power failures, equipment breakdown, fire, inclement weather, etc. Any of these events, either individually or together, can render the wastewater treatment plant inoperable, cutting off the means of treating the wastewater for disposal.

The contingency plans for such an occurrence consist of completely shutting down the injection system, including the pumps, hydropneumatic tank and deep-injection well. Wastewater will then be routed to the irrigation holding pond until plant operation is resumed. Once the emergency is over, the holding pond discharge will be discontinued.

It is estimated that the maximum probable out-of-service period will arise solely from regulatory testing requirements, and will be approximately one day per year. Standby replacements such as valves, pumps, pipes, etc., are provided for the surface equipment, in the event of failure. The only facility that will not have a standby replacement will be the injection well; but, because this well is known to have a potential capacity many times greater than the proposed injection volumes, it is unlikely that the well will ever fail. The annual testing requirements will provide an early warning of any potential well failure, thus permitting the timely enactment of remedial measures.

Whenever the above contingency plans are enacted, both FDER and officials from the County must be notified within 24 hours of the breakdown or malfunction. Interpretative reports are required in the event of such a breakdown or malfunction for submittal to FDER.

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Section 7
PROPOSED ABANDONMENT PLAN

If, at some time in the future, the deep-injection well is found to be beyond repair and unable to safely accept any more wastewater from the treatment plant, FDER may order the well to be abandoned. The legal abandonment of a deep-injection well consists of shutting in or plugging the well. The purpose of this closing-off of the well is to prevent the mixing of fluids from other geologic strata above the injection zone and to maintain existing pressures within the subsurface strata.

Whenever the abandonment of the deep-injection well is agreed to by both FDER and the owners, based on justification submitted by FDER to the owner or by the owner to FDER, the well will be permitted to remain undisturbed until the piezometric heads have stabilized. This period will comprise a minimum of 180 days, following the submittal of notice of abandonment to FDER, unless there is an apparent threat to state waters, in which case the 180-day period will be waived.

The first step in the abandonment process will be to kill the flow potential within the deep-injection well with drilling mud. Next, a cement plug will be inserted, by either the balance or the dump bailer method. The cement plug will be located at the bottom of the injection casing at the 2,340-foot depth. Neat cement grout, Type II (sulfate resistant) cement, will be used to entirely fill the remainder of the injection casing from the bottom up. The cement grout will be placed in the casing by tremie pipe. Grouting will continue until a satisfactory return is evident at the top of the injection casing, at land surface. Approximately 295 barrels of neat cement grout will be needed to carry out the well-plugging operation.

The deep-injection well abandonment procedure must be documented and the documentation must be submitted to FDER as proof of well abandonment. The owner of the deep-injection well will retain all records and documents collected during the life of the well for 5 years after the plugging and abandonment of the well. Thereafter, FDER may wish to retain these records and documents.

APPENDIX A
LIST OF TAC MEMBERS

LIST OF TAC MEMBERS (4/15/88)

Agency	Representative	Address	Telephone No.
Florida Dept. of Environmental Regulation	Mr. Vincent Mele*	2269 Bay Street Ft. Myers, Florida 33901	(813) 332-2667
Florida Dept. of Environmental Regulation	Mr. Joseph Haberfeld	2600 Blairstone Road Tallahassee, FL 32301	(904) 488-3601
South Florida Water Management District	Mr. David Butler	3301 Gun Club Road West Palm Beach, FL 33406	(305) 686-8800
U.S. Geological Survey	Mr. Craig Hutchinson	4710 Eisenhower Boulevard Suite B-5 Tampa, FL 33614	(813) 228-2124
U.S. Environmental Protection Agency	Mr. Gene Coker	345 Courtland Street Atlanta, Georgia 30308	(404) 347-3866
Lee County Environmental Protection Services	Roland Banks	P.O. Box 398 Ft. Myers, FL 33902	(813) 939-2163

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* TAC Chairman

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APPENDIX B

CHAPTER 17-19 FAC & FORM 17-1.205(7)

TABLE OF CONTENTS

17-19.01 Purpose. This chapter is adopted to ensure that owners and operators of domestic wastewater treatment plants will submit timely, accurate, cost-effective and uniform reports to the department concerning the composition, concentration and treatment of wastewater.

Specific Authority: 403.061(7), F.S.
Law Implemented: 403.061(15), 403.101, F.S.
History: New 1-1-75, Amended 6-10-76.

17-19.02 Definitions.

(1) "Approval by the department" shall mean written approval provided by the Secretary or the Secretary's designee upon written request by an owner or an owner's authorized representative.

(2) "ASTM" means Annual Book of Standards, Part 23, Water Atmospheric Analysis, 1972. This publication is available from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania, 19103, and is published herein by reference pursuant to Chapter 1-1.04, Florida Administrative Code.

(3) "EPA Methods" means Methods for Chemical Analysis of Water and Wastes, 1974, Environmental Protection Agency. This publication is available from the U.S. Environmental Protection Agency, Office of Technology Transfer, Cincinnati, Ohio 42268, and is published herein by reference pursuant to Chapter 1-1.04, Florida Administrative Code.

(4) "Flow proportioned composite sample" shall consist of samples collected at hourly intervals. The volume of each individual sample which is used to form the composite shall be proportional to the flow at the time of collection. Equal volume composite sampling may be used provided that the time between samples is inversely proportional to the cumulative flow since the previous sample, and provided that the number of individual samples is equivalent to the number which would be required if hourly samples were used for composite samples formation.

(5) "Flow" shall mean the following:

(a) Flow values obtained from a flow measuring device having a recorder and an integrator or totalizer for waste treatment facilities having a design capacity of 100,000 gallons per day or greater flow.

(b) For waste treatment facilities having a design capacity of less than 100,000 gallon per day, flow values obtained by one of the following methods:

1. Elapsed time measurements on pumps where pumps are responsible for the flow and where a means of calibrating the pumping rate is available.

2. Consumptive water use measurements may be used upon approval by the department where elapsed time measurements on pumps cannot be made.

3. Flow meters, calibrated weirs or other means using established engineering techniques.

(6) "Fraudulent data" means data which are produced with an intention to deceive, and include but are not limited to the following:

(a) Apparent measurement results for which no measurement or test results were actually made as determined by the absence of the supporting records which are usually made;

(b) Measurement or test results obtained by deliberately and knowingly making measurements or collecting samples at places and times other than as specified in this section;

(c) Test results obtained through use of unapproved and erroneous sampling, preservation, storage, or analysis procedures.

Computational errors, misunderstandings of required procedures and other common errors are excluded from this definition.

(7) "Total nitrogen" shall mean total kjeldahl nitrogen (with ammonia) plus ntirate plus nitrite reported as N.

(8) "Standard Methods" means Standard Methods for the Examination of Water and Waste Water, 13th Edition, 1971. This publication is available from the American Public Health Association, 1015 18th Street, N.W., Washington, D.C. 20036, and is published herein by reference pursuant to Chapter 1-1.04, Florida Administrative Code.

(9) "Nutrients" shall mean the separately reported values of total nitrogen, total phosphorus, ammonia, nitrate plus nitrite and orthophospate.

Specific Authority: 403.061(7), F.S.
Law Implemented: 403.061(15), F.S.
History: New 1-1-75, Amended 6-10-76.

17-19.03 General Requirements-Violations.

(1) All owners of domestic wastewater treatment plants shall provide all analytical results detailed in this Chapter to the appropriate district office of the Department of Environmental Regulation on a monthly

1. Elapsed time measurements on pumps where pumps are responsible for the flow and where a means of calibrating the pumping rate is available.

2. Consumptive water use measurements may be used upon approval by the department where elapsed time measurements on pumps cannot be made.

3. Flow meters, calibrated weirs or other means using established engineering techniques.

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(a) Apparent measurement results for which no measurement or test results were actually made as determined by the absence of the supporting records which are usually made;

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(c) Test results obtained through use of unapproved and erroneous sampling, preservation, storage, or analysis procedures.

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Specific Authority: 403.061(7), F.S.
Law Implemented: 403.061(15), F.S.
History: New 1-1-75, Amended 6-10-76.

17-19.03 General Requirements-Violations.

(1) All owners of domestic wastewater treatment plants shall provide all analytical results detailed in this Chapter to the appropriate district office of the Department of Environmental Regulation on a monthly

basis. Such results shall be submitted in a timely manner so as to be received by the district office by the fifteenth (15th) of the month following the month of operation. This information shall be provided on the form shown in Figure 17-19.03 #1. which shall be signed by a certified operator. Copies of the above form shall be available at the district and subdistrict offices of the department.

(2) Violation of any of the provisions of this Chapter shall be considered grounds for permit suspension or revocation pursuant to 403.087, F.S., or under Section 17-4.10, Florida Administrative Code.

(3) The owner shall retain treatment facility operating records for the preceeding five (5) calendar years and shall make such records available for inspection upon request by department personnel.

Specific Authority: 403.061(7), F.S.
Law Implemented: 403.101, 403.061(15), F.S., Section 8, Chapter 75-22 (Laws of Florida, 1975).
History: New 1-1-75, Amended 6-10-76.

17-19.04 Sampling and Testing Methods.

(1) (a) Field testing, sample collection and preservation and laboratory testing, including quality control procedures, shall be in accordance with methods approved by the department and the United States Environmental Protection Agency. Copies of the approved procedures shall be available for public inspection at the offices of the Department of Environmental Regulation. Copies of materials not protected by copyright laws shall be provided upon request for the cost of reproduction. References to approved procedures are given in Figure 17-19.04 #2.

(b) Equivalent, alternative methods may be approved by the Secretary. Such approval of alternate methods shall be based upon a technical demonstration, through comparison of analysis of duplicate samples, that the proposed alternate method measures the relevant value and parameters with the degree of accuracy of the approved methods. The written approval and technical justification upon which it is based shall be executed by the Secretary, filed, and available for public inspection at the Department's Tallahassee, subdistrict and district offices.

(c) As a quality control procedure the department may require persons who submit test data to the department to analyze a reasonable number of reference samples not to exceed one percent of the tests performed on an annual basis for parameters tested by those persons. These samples shall be provided by the department.

(d) Any of the following conditions may be grounds for determining that self-monitoring data do not meet the requirements of this section:

1. Failure to maintain those laboratory tests records commonly maintained by other laboratories conducting the same tests;

2. Failure to maintain data quality assurance records which shall include information on instrument calibration and maintenance, sample collection and analysis times, and test results for duplicate, spiked and split or reference samples.

(e) When any of the conditions described in paragraph (d) are not corrected within 30 calendar days from the date of notification by the department, the permittee shall be subject to revocation of the permit pursuant to Section 403.087(6), Florida Statutes.

(f) The submission of fraudulent data to the department by any person may subject such person to the imposition of criminal and civil penalties pursuant to Section 403.161(1)(c), Florida Statutes.

(2) Waste treatment facilities shall be provided with safe access points for obtaining representative influent and effluent samples which are required by this Chapter.

Specific Authority: 403.061(7), F.S.
Law Implemented: 403.101, 403.061(15), F.S., Section 8, Chapter 75-22 (Laws of Florida, 1975).
History: New 1-1-75, Amended 6-10-76.

17-19.05 Sampling Schedules, Parameters.

(1) The minimum schedule for sampling and parameters to be sampled, for wastewater treatment plants is as specified in Figure 17-19.05 #3.

(2) Sampling times for grab samples and sampling periods for composition samples may be specified by the department for the purpose of obtaining representative samples.

Specific Authority: 403.061(7), F.S.
Law Implemented: 403.101, 403.061(15), F.S., Section 8, Chapter 75-22 (Laws of Florida, 1975).
History: New 1-1-75, Amended 6-10-76.

17-19.06 Sampling Points.

(1) Samples of both the influent and effluent are required for BOD and suspended solids tests. Effluent samples only are required for all other tests.

(2) Plant influent samples shall be collected so that they do not contain digester supernatant or returned activated sludge, or any other plant process recycled waters.

(3) All effluent analyses shall be performed on samples collected immediately before discharge to surface or groundwaters.

(4) The minimum requirements for sampling locations, parameters, frequencies and compositing specifications required in this section of Chapter 17, Florida Administrative Code, may be modified by the Secretary or the Secretary's designee on a case by case basis, depending upon local requirements for assessment and maintenance of water quality. Where such modification has been made, a written report, signed by the Secretary or the Secretary's designee, describing the modification and its technical justification shall be filed and available for public inspection at the Department's Tallahassee, district and subdistrict offices.

Specific Authority: 403.061(7), F.S.
Law Implemented: 403.101, 403.061(15), F.S., Section 8, Chapter 75-22 (Laws of Florida, 1975).
History: New 1-1-75, Amended 6-10-76.

17-19.07 Monitoring Wells.

(1) In addition to the samples required elsewhere in this Chapter, wastewater treatment facilities which are designed so that some or all of their treated or untreated wastes may enter subsurface waters, shall be provided with the minimum number of monitoring wells necessary to assess the effects of this waste upon subsurface waters. The locations and characteristics of these monitoring wells shall be approved by the Secretary or the Secretary's designee.

The basis for such determination of the location and characteristics of such monitoring wells shall be made in writing, filed, and available for public inspection in the department's Tallahassee, district and subdistrict offices.

Monitoring wells shall be tested according to the schedule shown in Figure 17-19.07 #4.

Specific Authority: 403.061(7), F.S.
Law Implemented: 403.061(15), F.S.
History: New 1-1-75, Amended 6-10-76.

17-19.08 Existing Permit Monitoring Requirements. In lieu of complying with the monitoring requirements contained in this Chapter, owners of domestic wastewater treatment plants who hold currently valid department operation permits issued prior to the effective date of this rule which set forth specific monitoring requirements may continue to comply with such requirements until the expiration of such permits. This provision shall not apply to the monitoring requirements specified in National Pollutant Discharge Elimination System Permits issued by the U.S. Environmental Protection Agency pursuant to the Water Pollution Control Act Amendments of 1972.

Specific Authority: 403.061(7), F.S.
Law Implemented: 403.101, 403.061(15), F.S.
History: New 1-1-75, Amended 6-10-76.

Figure 17-19.03 #1

STATE OF FLORIDA DEPARTMENT OF ENVIRONMENTAL REGULATION
DOMESTIC WASTEWATER TREATMENT PLANT MONTHLY OPERATING REPORT

(1) GMS # ___________ Month ____________ Year ______

____

Signature of Lead Operator in Charge Date

I certify that I am familiar with the information contained in this report and that to the best of my knowledge and belief such information is true, complete, and accurate.

(2) PLANT NAME: ______________________________

(3) PLANT ADDRESS: ______________________________

(4) CITY: ______________ (5) COUNTY: ____________ PHONE NO. ____________

(6) PERMIT NUMBER (7) AVG FLOW MGD (8) DESIGN FLOW MGD (9) TYPE

__________ ___.___ ___.___ ___

(10) MAX FLOW (MGD) (11) POP SERVED (12) FECAL COLIFORM SAMPLE METHOD
[ ] Membrane Filter
[ ] Most Probable Number

___.___ __________

(13) INDUSTRIAL CONTRIBUTION (14) % FLOW (15) BOD (mg/l) (16) TSS (mg/l)
Ind Flow MGD BOD lb/d TSS lb/d INFIL EFFLUENT EFFLUENT

___.___ ______ ______ ______ ______ ______

(17) pH (18) TOTAL N mg/l (19) AMMONIA mg/l (20) NITRITE + NITRATE mg/l (21) TOTAL P mg/l (22) ORTHO P mg/l (23) CHLOR RESID ppm

___ ___ ___ ___ ___ ___ ___

(24) BOD (mg/l) (25) DO (mg/l) (26) EFFLUENT
UPSTREAM DNSTREAM TIME/DATE OF SAMPLE UPSTREAM DNSTREAM PARAMETER VALUE (UNITS)

___.___ ___.___ ______/______ ___.___ ___.___ ______ ______ ______

(27) TYPE SAMPLE(S) (28) TYPE EFFL DISPOSAL

______________ ______________

(29) PLANT STAFFING

LEAD OPERATOR SHIFT 1 (Day) SHIFT 2 (Evening) SHIFT 3 (Night)

DER Form 17-1.205(7) Effective November 30, 1982 ____________

(30)

	FLOW (mgd)	CHLORINE RESIDUAL (ppm)	BOD EFFLUENT (mg/l)	TSS EFFLUENT (mg/l)	pH EFFLUENT (0.1)	TOTAL N (mg/l)	TOTAL P (mg/l)	FECAL COLIFORM (no/100 ml)
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								
31								
TOT								
AVG								

Page 1 of 2

Figure 17-19.03 #1 Continued

INSTRUCTIONS

(1) GMS No: This number should be obtained from the District Office issuing the permit and will remain the same through out the life of the facility.

(2) Enter Name of Plant (e.g., Main Street Plant No. 4).

(3)-(5) Plant Location.

(6) Your Current Permit Number.

(7) Average Monthly flow in MGD recorded to three significant figures as average from Item (30).

(8) Design flow in MGD as permitted (e.g., 1,100,000 gpd, enter 1,100).

(9) One digit and one letter code to indicate type of plant and its size. The number from 1 to 4 indicates type of treatment; its letter, A to D indicates plant size.

Level	Type of Plant	Plant Size MGD			
		A	B	C	D
1	AWT	3+	0.5 up to 3.0	0.002 up to 0.5	none
2	Activated Sludge/ Contact Stab.	5+	1.0 up to 5.0	0.002 up to 1.0	none
3	Extended Air	8+	2.0 up to 8.0	0.025 up to 2.0	0.002 up to 0.025
4	Trickling Filter	10+	3.0 up to 10.0	0.025 up to 3.0	0.002 up to 0.025

(10) Maximum flow in MGD that occurred during any one day of the month as indicated in Item 30.

(11) Population Served - Enter the population served by this facility. This may be computed by multiplying the number of connections times the local average of persons per connection.

(13) Industrial Contribution - This line will be completed by those facilities who have industries contributing more than 50,000 gpd each or which have a flow equal to or greater than 5% of the Design flow (Item 8 above).

Industrial Flow - Enter amount of Average Monthly Flow in MGD of the Industrial Waste contributed.

BOD_5 - Enter Average Monthly BOD in lb/d of the Industrial Waste Influent.

TSS - Enter Average Monthly TSS in lb/d of the Industrial Waste Influent.

(14) % Flow Infiltration - Enter the percentage of the Average Monthly flow attributed to infiltration. (Best estimate)

(15) Average Monthly BOD_5 as recorded in Item 30.

(16) Average Monthly TSS as recorded in Item 30.

NOTE: For Items 15 and 16 BOD_5 and TSS Analyses for effluent will be performed on samples taken after Chlorination but before discharging to surface or ground waters.

(17) Average Monthly pH of effluent to nearest 0.1

(19) - (22) Nutrient Analysis as required by permit.

(23) Min. Chlorine Residual (ppm to nearest 0.1) as recorded in Item 30.

(24) - (25) Where required, report Monthly Average Stream BOD_5 and dissolved Oxygen (DO). If so, enter data as required in mg/l.

(26) This space is provided for those facilities which may have additional reporting requirements.

(27) Enter type of sample(s) taken for analysis (e.g., Grab, 8 hr., etc.) as required by Fla. Admin. Code Rule 17-19.

(28) Enter type of effluent disposal (e.g., Surface Waters, Spray Irrigation, Drainfield, EVAP/PERC Pond).

(29) Enter Operator Class A,B,C or D and certification number. The lead operator is usually in charge of the day shift. For plant staffing, list the operator who will have responsibility for the plant or shift for the majority of the time. For example, in shift rotations, the operator who will cover that shift most of the time throughout the year. NOTE: This form must be signed by the lead operator as defined in Rule 17-16.02(5).

(30) Record parameters as directed by Florida Administrative Code Rule 17-19 or the permit. Record units as indicated on the form (e.g., MGD, mg/l, ppm, etc.)

DER Form 17-1.205(7) Effective November 30, 1982

Figure 17-19.04 #2
References to Approved Sampling and Testing Procedures (*)

No.	Storet Code	Parameter		Reporting Units	References: Standards Methods	ASTM	EPA Methods
1	00310	BOD_5: Biochemical Oxygen Demand-5 day, 20°c		mg/l as O_2	p.489	—	—
2	00530	TSS: Total suspended (non-filterable) solids		mg/l	p.537	--	p.268
3	50053	FLOW: Flow through a treatment plant; monthly average		mgd	see rule text		
4a	31616	FECAL COLI: fecal coliform: membrane filter		/100 ml	p.684	--	--
4b	31615	FECAL COLI: fecal coliform: MPN method		/100 ml	p.669	--	--
5	50060	Cl_2-TOT: Chlorine, total residual		mg/l as Cl_2	p.382	p.223	p.35
6	00400	pH: Hydrogen ion activity	a	pH units	p.500	p.248	p.239
7	50064	Cl_2-FREE: Chlorine, free available		mg/l as Cl_2	p.112		
8	00630	NO_2+NO_3: Nitrite plus nitrate	b	mg/l as N	p.458 p.461	p.124	p.201 p.197 p.215 p.207
9	00605	ORG-N: Organic Nitrogen (TKN minus NH_3-N)	c	mg/l as N	p.468 p. 469		p.175 p.182
10	00610	NH_3-N: Ammonia Nitrogen		mg/l as N			p.159 p.168
	70507	ORTHO-P: Ortho-phosphate		mg/l as P	p.532	p.42	p.249 p.256
12	00665	TOTAL-P: Phosphorus, total	d	mg/l as P	p.526 p.532	p.42	p.249 p.256
13	00680	TCC: Total Organic Carbon		mg/l as C	p.257	p.702	p.236
14	00340	COD: Chemical Oxygen Demand		mg/l	p.495	p.219	p.20
15	00940	Cl: Chloride		mg/l as Cl	p.96 p.97	p.23 p.21	p.29 p.31
16	70300	TDS: Total dissolved (filterable) solids		mg/l	--	--	p.266

* Approved quality control procedures are contained in "Handbook for Analytical Quality Control in Water and Wastewater Laboratories." This publication is available from the U.S. Environmental Protection Agency, Office of Technology Transfer, Cincinnati, Ohio 45268.

(a) pH paper may be used by non-NPDES permittees of less than 100,000 gpd design capacity.
(b) Combined or sum of separate determinations.
(c) Kjeldahl digestion after ammonia distillation.
(d) Persulfate digestion result including ortho-phosphate.

PBS&J
POST BUCKLEY SCHUH & JERNIGAN, INC

CLIENT: NORTH FORT MYERS UTILITY INCORPORATED

PROJECT: TEST / INJECTION WELL DRAWINGS

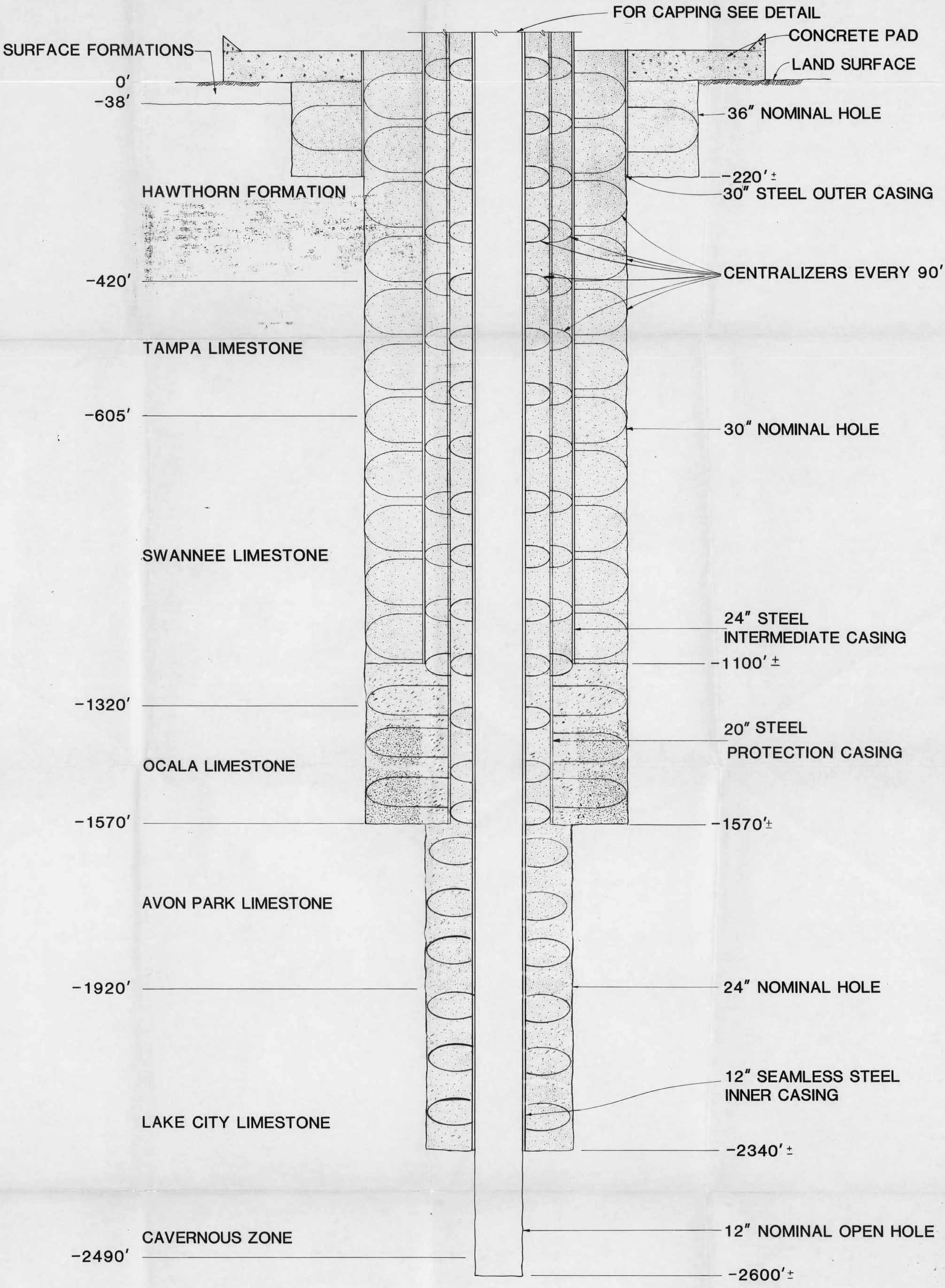
TASK:

ORIGINAL: FEB 2, 1987
REVISIONS:
1. JULY 16, 1987
2. JULY 31, 1987

FLORIDA P.E. 12577
NOT VALID FOR CONSTRUCTION UNLESS SIGNED IN THIS BLOCK

JOB NO. 08-07380
DRAWN J.M.C. & A.C.
DESIGNED PIT
CHECKED CURTIS
QC PIT

SHEET C-2



OLDSMAR LIMESTONE

NOTE:
ALL GROUTING IS TO BE TYPE II CEMENT
GROUT (SULFUR RESISTANT) FLORIDA CLASS H

NOT TO SCALE