DARE COUNTY-WIDE HYDROGEOLOGICAL STUDY AND GROUNDWATER RESOURCE EVALUATION

Prepared for:

The Dare County Water Production Department
600 Mustian Street
Kill Devil Hills, NC 27948

May 1998

By:

Missimer International, Inc.
8140 College Parkway, Suite 202
Fort Myers, FL 33919

Project Number
FH7-571

Wm. Scott Manahan
Project Manager

W. Kirk Martin, P.G.
North Carolina Registered
Professional Geologist #1112

Weixing Guo, Ph.D.
Computer Modeling Specialist

FH7-571.5

MISSIMER INTERNATIONAL INC.

May 28, 1998

Mr. Bob Oreskovich
Dare County Water Department
600 Mustian Street
Kill Devil Hills, NC 27948

Re: Dare County-Wide Study Final Report

Dear Bob:

We are pleased to submit 20 copies of the report entitled "Dare County-Wide Hydrogeological Study and Groundwater Resource Evaluation." The report documents the methods and results of aquifer exploration and testing and provides a conceptual plan for meeting projected public water supply demands to the year 2020.

We appreciate having the opportunity to conduct this study for the county and are available to assist with implementation of report recommendations. Please contact me if you have any questions or comments regarding the report.

Yours sincerely,

W. Kirk Martin, P.G.
North Carolina Registered
Professional Geologist #1112

Wm. Scott Manahan
Project Manager

WKM/WSM/lk

FH7-571.5

8140 College Parkway, Suite 202
Fort Myers, Florida 33919
(941) 432-9494
FAX (941) 432-9453

TABLE OF CONTENTS

TABLE OF CONTENTS - Continued:

LIST OF FIGURES

LIST OF FIGURES - Continued:

LIST OF FIGURES - Continued:

Figure	Description	Page

LIST OF TABLES

EXECUTIVE SUMMARY

The Dare County Water Department supplies potable water to the residents of eastern Dare County where the increasing demand for potable water stems from population growth. The Dare County Commission recognized the need to increase the supply capacity of the County water system, and authorized this study to evaluate the groundwater resources available in eastern Dare County for public supply purposes. Surface-water sources were considered to be economically prohibitive because of the higher treatment cost associated with using reverse osmosis technology for these waters and their variable water quality.

The County currently has four water treatment facilities to supply its five separate water distribution systems. The combined capacity of these treatment plants is 11 MGD. Raw water supplies to these facilities are provided by wellfields tapping the water-table, Principal, and Mid-Yorktown aquifers. The 1.5 MGD Fresh Pond treatment facility owned by the Town of Nags Head is the only surface-water source utilized on the Outer Banks.

Since projections indicate a peak potable water demand in the county of 21 MGD by the year 2020, expansion of existing water sources and/or development of new water supply sources is needed to meet potable demands. The purposes of this investigation were: to evaluate existing water supply sources and determine the feasibility of increasing the supply capacity of these sources, identify and evaluate potential new water supply sources, and to present a plan for increasing the water supply capability of the county water system. The investigation included a review and compilation of existing data and information regarding groundwater resources available in eastern Dare County, test well construction, aquifer testing, water quality sampling and analyses, and evaluation of impacts associated with groundwater development by using computer model simulations.

Results of the investigation indicate that sufficient groundwater resources are available to meet the County's projected potable water demands through the year 2020. The water-table, Principal, and Mid-Yorktown aquifers will continue to be utilized as raw water sources. A summary of the plan for increasing the supply capacity of the county water system is as follows:

- Expand the Kill Devil Hills reverse osmosis plant to a produced water capacity of 8.0 MGD. Nine additional production wells should be installed in an alignment extending south from the existing wellfield to supply the raw water necessary for plant expansion.

- Construct a reverse osmosis plant and wellfield at Duck. The plant capacity should be 1.0 MGD with the capability for expansion to 2.0 MGD. Two production wells tapping the Principal aquifer will be required to meet the initial raw water supply needs of the plant.

- Expand the Rodanthe reverse osmosis plant and wellfield to a produced water capacity of 2.0 MGD when necessary to meet increased demands. One or two additional production wells will be required to supply the plant.

- Proceed with expansion and upgrades to the Dare Hatteras Water System currently underway or in final design stages. The proposed improvements to the water system will be adequate to meet the potable water demands of southern Hatteras Island.

- Possibly expand the Skyco water plant and wellfield to a peak capacity of 7.0 MGD. Expansion of this facility should only be implemented if the community of Wanchese is connected to the public water supply system and if additional hydrogeologic investigation prove the viability of additional withdrawals. Drawdowns caused by the wellfield expansion will be mitigated to some extent by the reduction in domestic well pumpage.

- Investigate the feasibility of utilizing aquifer storage and recovery (ASR) technology as a water management technique. The use of ASR may be effective in increasing the efficiency of existing water treatment plant operations. Capital cost savings may be realized by using the technology to design proposed new water supply facilities, and expand existing facilities to meet average rather than peak demands.

1.0 CONCLUSIONS AND RECOMMENDATIONS

A hydrogeological study and evaluation of the groundwater resources in Dare County was conducted to determine the availability of groundwater resources suitable for use as public water-supply sources. Existing supply sources were evaluated and potential new water supply sources were identified. The conclusions and recommendations presented below are based on the results of the study.

1.1 Conclusions

- Total existing water system capacity is 11 MGD, while the projected peak potable water demand for the Dare County Water Department in the year 2020 is estimated to be 21 MGD. Based on the study results, adequate groundwater resources are available in eastern Dare County to meet projected increases in potable water demand to the year 2020.

- Groundwater resources in eastern Dare County were evaluated to a depth of approximately 400 feet as part of a hydrogeologic study of raw water supplies available to meet potable demands within the county water system. The three major aquifers most feasible for use are the water-table aquifer, the Principal or upper Yorktown aquifer, and the Mid-Yorktown aquifer.

- A new groundwater supply source was located at Duck. The Principal aquifer was identified in a test well completed between the depths of 100 and 160 feet below land surface. The transmissivity of the aquifer is estimated to be approximately 70,000 gpd/ft, indicating it has the potential for development as a public water supply source with a capacity of 2 MGD or greater. Water quality within the aquifer is brackish and reverse osmosis will be required to treat the water to potable standards.

- A high quality groundwater source was found at Kill Devil Hills. The Principal aquifer was encountered between the depths of 200 and 280 feet in a test well constructed during this investigation. The dissolved chloride concentrations of water samples obtained from this well ranged from 280 to 300 mg/l indicating the salinity of this zone is low. The transmissivity of the aquifer determined from pump testing was 5900 gpd/ft. Individual well yields will be limited to 200 gpm or less.

- Viable groundwater supply sources were found at Mann's Harbor. The Principal aquifer and Mid-Yorktown aquifer were tested at Mann's Harbor as part of this investigation. Both aquifers exhibited high yield characteristics at this site. Water quality in the Principal aquifer is very good with a low level of dissolved solids. Water in the Mid-Yorktown aquifer is more mineralized but still of relatively good quality. Both aquifers have the potential for development as public water supply sources.

- Groundwater quality is highly variable in eastern Dare County ranging from fresh to sea water depending upon location and depth. Volumes of freshwater adequate for public supply purposes are stored within the water-table and Principal aquifers on the Dare County mainland and Roanoke Island. Primarily brackish water, which would require desalination, is available in amounts suitable for public supply purposes on the Outer Banks. A lense of freshwater exists on the barrier islands which is used for domestic supply and irrigation purposes throughout the Outer Banks and is also the current source of supply for the Dare Hatteras Water System.

- The Kill Devil Hill facility can be expanded to 8 MGD over a 20-year period. Existing hydraulic and solute transport models of the Kill Devil Hills reverse osmosis plant wellfield were used to estimate drawdowns and future changes in raw water quality that may result due to pumpage. The solute model results indicate that the average TDS concentration from the Kill Devil Hills wellfield may increase from the current level of approximately 4000 mg/l to 6000 mg/l in the year 2020. A maximum aquifer drawdown of approximately 17 feet near the center of the wellfield is anticipated based on the modeling results.

- Results of the hydrogeologic data analyses and modeling conducted indicate that expansion of the Rodanthe R.O. plant to a capacity of 2.0 MGD is feasible.

- Data analyses and modeling results indicate that expansion of the Skyco water treatment plant and wellfield to a capacity of 7.0 MGD may be feasible. Expansion of the Skyco facility is contingent upon the community of Wanchese connecting to the public water supply systems. Also, a more detailed hydrogeologic analysis will be required to assess the potential for saline-water intrusion.

- Water system improvements currently underway and/or in final design stages for the Dare Hatteras Water System will be adequate to meet projected demands of 3.0 MGD for that system.

1.2 Recommendations

- The Kill Devil Hills R.O. plant and raw water supply wellfield should be expanded to a final produced water capacity of 8.0 MGD over the next 20 years. The expansion should be accomplished in 1.0 MGD increments as needed based on demands. A total of nine additional Mid-Yorktown aquifer R.O. supply wells should be constructed to meet the demand. A minimum of two test wells should be constructed in the proposed wellfield alignment to assess water quality and aquifer yield conditions prior to final production well and pipeline construction.

- Two to four wells tapping the Principal aquifer in Kill Devil Hills should be installed for blending with the reverse osmosis permeate, because the lower salinity levels in the Principal aquifer will allow the plant operators to increase blend ratios and reduce plant operation costs. Additional testing to fully evaluate long-term yield and quality of the aquifer should be conducted prior to production well construction.

- Consideration should be given to construction of a small reverse osmosis plant and wellfield in Duck, because of the discovery of a new, relatively low salinity groundwater supply. The facility would increase the amount of potable water supply and provide an additional interconnect to improve overall system reliability. Additional testing to fully evaluate the aquifer yield potential and water quality of the source aquifer should be conducted prior to plant construction.

- Based on the availability of brackish water from the Mid-Yorktown aquifer, the reverse osmosis plant and wellfield in Rodanthe may be expanded when necessary to meet demands. Some additional production wells should be constructed to increase the plant produced water capacity to 2.0 MGD. Solute transport modeling of the aquifer system should be conducted to estimate future water quality changes and determine the location, number, and pumping rate for the new production wells.

- The Skyco water treatment plant and wellfield on Roanoke Island should be expanded by the installation of three additional production wells, only if certain criteria are met. Wellfield expansion is recommended only if necessary to meet demands and if the community of Wanchese is connected to the county water supply system and if future, detailed hydrogeologic analysis indicates that saline-water intrusion will not be a problem. Limiting production from the Skyco plant or improvements to the treatment method may be required due to proposed changes to the federal trihalomethane (THM) standard.

- The groundwater monitoring conducted by the County water department staff should continue in order to provide valuable information regarding water levels and water quality conditions at the county wellfields. The data should be reviewed periodically and any trends noted for potential incorporation into the wellfield management plan.

- Since water demands show large seasonal fluctuations, the feasibility of using Aquifer Storage and Recovery (ASR) technology for water management purposes should be investigated. This concept involves storing large volumes of water underground during periods of low demand and then recovering the water to meet peak season demands. This could reduce long-term potable water supply costs to the consumer.

2.0 INTRODUCTION

2.1 Background

The Dare County Water Department produces potable water to supply the citizens on the Outer Banks of North Carolina. Public water supply first became available on the Outer Banks in 1964 when surface-water pumped from the Fresh Pond was used to supply the towns of Kill Devil Hills and Nags Head. The Fresh Pond treatment plant owned by the town of Nags Head is now utilized to meet only peak summer demands and is capable of producing up to 1.5 MGD of water for limited periods of time. In 1979, a wellfield and water treatment plant were built on Roanoke Island at Skyco to increase the amount of water available to the public supply system. The Skyco water plant is capable of producing over 5.0 MGD and is supplied by 10 production wells that tap the upper Yorktown or Principal aquifer. The raw water supplied to the Skyco plant is fresh and a conventional ion exchange process is used to treat the water. A reverse osmosis (R.O.) plant and raw water supply wellfield were constructed in Kill Devil Hills and placed into operation during August of 1989 to further increase the supply of potable water. Brackish water supplied by 10 production wells is the source of water for the R.O. plant which has a current finished water production capacity of 3.0 MGD.

The combined maximum water production capacity of the three public supply sources is 9.5 MGD. The three supply sources are interconnected and collectively form the Dare Regional Water Supply System (DRWSS). The DRWSS supplies water to the towns of Kill Devil Hills, Nags Head, and Manteo for wholesale purchase and subsequent distribution within their respective water systems. Dare County also operates a distribution system that is supplied by the DRWSS and serves the residents of Kitty Hawk, Southern Shores, Duck, Collington, and customers on Roanoke Island outside of the Manteo town limits.

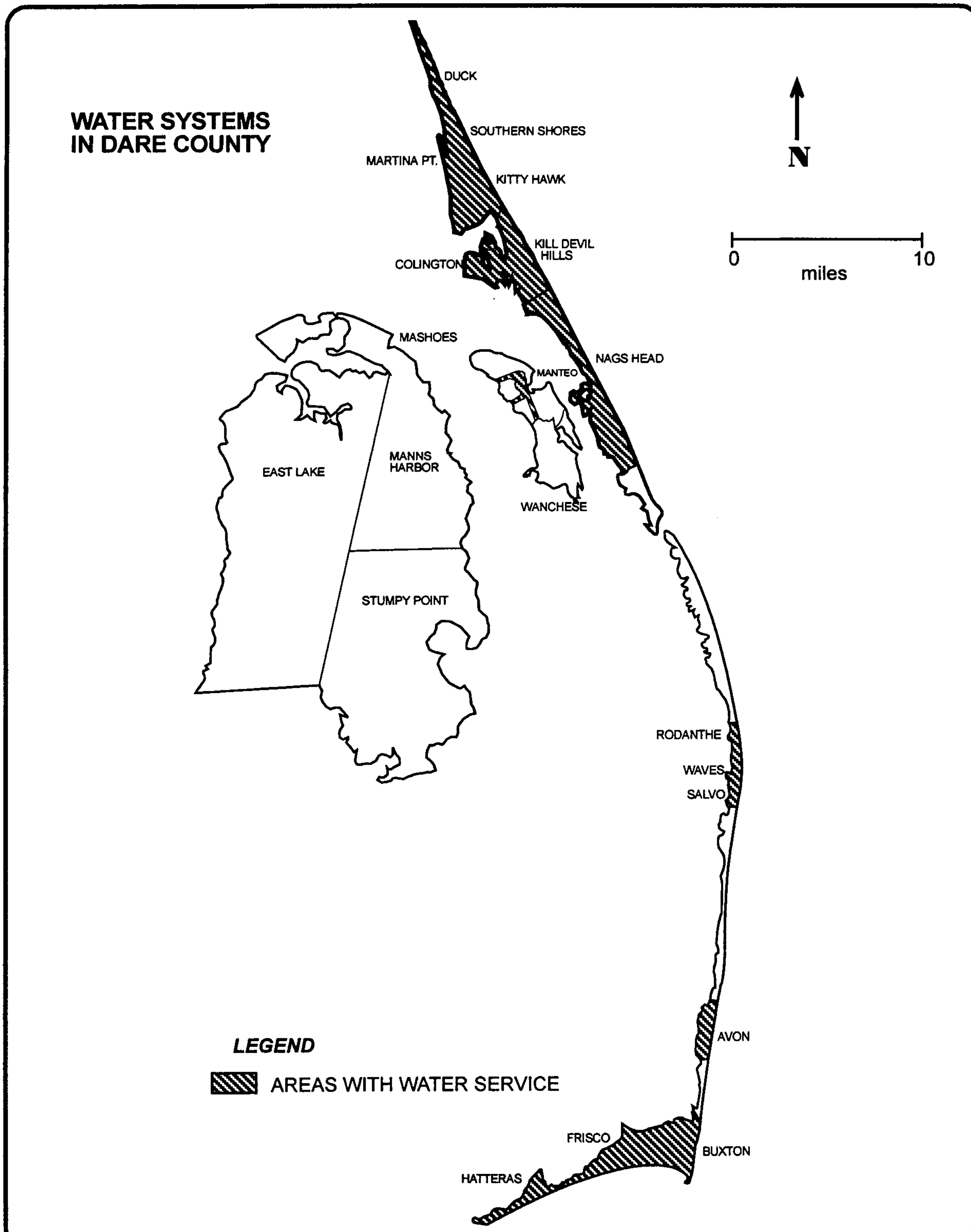
A separate water supply system including wellfield, reverse osmosis plant, and distribution piping was constructed in Rodanthe and placed into operation during March of 1996. This system has a production capacity of 1.0 MGD and is supplied with brackish water pumped from 2 wells that tap the Mid-Yorktown aquifer. The communities of Rodanthe, Waves, and Salvo (RWS) are served by this plant. The RWS water system is currently not interconnected with any other water system.

Potable water supply for the communities of Avon, Buxton, Frisco, and Hatteras Village on the southern end of Hatteras Island is obtained from a shallow wellfield that taps the water-table aquifer. The wellfield and water treatment plant were originally constructed and operated by the Cape Hatteras Water Association. The Dare County Water Department acquired the assets of the Cape Hatteras Water Association and assumed operation of its facilities during July of 1997. Raw water is obtained from a large number (greater than 30) of low yield wells and the plant has a capacity of approximately 2.0 MGD. Expansion of this facility is currently in the design stage to include a 2.1 MGD reverse osmosis plant to treat brackish water and a 0.9 MGD anion exchange treatment system for water from the shallow aquifer. Brackish water will be obtained from a wellfield consisting of 4 wells tapping the Mid-Yorktown aquifer. Distribution system improvements are currently underway as part of the water system expansion. The Dare Hatteras Water System is not interconnected with any other water system at this time.

A map of Dare County showing the areas served by the Dare County Water Department is provided as Figure 2-1. The combined capacity of the water plants operated by the Dare County Water Department is currently 11 MGD. A summary of the existing water supply sources and their respective capacities is provided in Table 2.1-1. Expansion of some existing facilities and/or construction of new water treatment facilities will be required to meet future increases in potable water demands.

2.2 Purpose and Scope

Expansion of the facilities that supply potable water to the residents of Dare County is necessary to meet projected increases in the demand for potable water. A county-wide hydrogeological study and groundwater resource evaluation was authorized by the Dare County Board of Commissioners in September, 1997. The purpose of this study is to identify and evaluate the



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	Pr. No. FH7-571 **DWG No.**WDC-1**Date:** 5/17/98	

FIGURE 2 - 1. MAP SHOWING AREAS OF DARE COUNTY CURRENTLY SERVED BY THE DARE COUNTY WATER DEPARTMENT.

TABLE 2.1-1 SUMMARY OF EXISTING WATER SUPPLY SOURCES AND CAPACITIES

Facility	Water Source	Produced Water Capacity (MGD)
Fresh Pond (Nags Head)	Surface Water	1.5*
Skyco Water Plant	Principal Aquifer	>5.0
Kill Devil Hills R.O. Plant	Mid-Yorktown Aquier	3.0**
Rodanthe R.O. Plant	Mid-Yorktown Aquifer	1.0**
Cape Hatteras Water Plant	Water-Table Aquifer	2.0
	Total =	11.0 MGD

*The Fresh Pond capacity is not included in the total because this facility is owned by the town of Nags Head and is only used on an intermittent basis.

**The reverse osmosis plants operate with a recovery efficiency of approximately 75%. The raw water supply requirements for these plants is approximately 33% greater than the produced water capacity.

supply potential of fresh and brackish groundwater resources available in coastal and mainland Dare County for public supply use.

The primary objectives of the project were to evaluate existing water supply sources and determine the feasibility of expanding these sources and to identify and evaluate potential new water supply sources. A work scope was developed to achieve the project objectives. The initial task was to compile and review available data. Information evaluated in the review included: historic pumpage data from each of the county water department wellfields; water level and water quality data from the county monitor well network; reports prepared previously by consultants, the county, and other government agencies; population and water demand projections and other pertinent demographic information. Areas where additional data were needed to complete the groundwater resource evaluation were identified during the data compilation and review.

The second general task was to conduct test drilling to obtain water quality and preliminary aquifer yield data to help evaluate potential new sources of water. A total of four new test wells were constructed at three separate test sites. Lithologic analyses, geophysical logging, pump testing, and water quality sampling and analyses were conducted at each site. Data collected during the investigation were analyzed to assess the potential for expanding existing supply sources and developing new water supply sources. Computer model simulations were used to estimate the impacts associated with proposed pumpage from new wellfields and increased withdrawal amounts from existing facilities. This report was prepared to document the methods and procedures utilized during the investigation and the results obtained. Recommendations for meeting future potable water supply needs are included in the report. Brief descriptions of the approach taken at each of the project study areas are presented in the following subsection of this report.

2.3 Project Approach

2.3.1 Kill Devil Hills

Expansion of the Kill Devil Hills reverse osmosis (R.O.) plant and raw water supply wellfield is considered the most likely scenario for a large scale increase in potable water supply for the county water department. The R.O. plant currently has three 1.0 MGD reverse osmosis skids and was designed to accommodate five additional skids for a total plant capacity of 8.0 MGD. Previously, proposed wellfield expansion scenarios only considered the installation of additional wells from the Fresh Pond area south toward Nags Head. A decision was made to construct a test well north of the existing alignment. The test well was constructed to provide information on water quality and potential production well yield to assess the feasibility of wellfield expansion to the north. The project approach at Kill Devil Hills also included utilizing previously developed aquifer hydraulic and solute transport computer models to evaluate drawdown impacts and water quality changes that might occur with time caused by various wellfield expansion scenarios.

2.3.2 Duck

Because hydrogeologic data in the Duck area is very limited, construction of a test well was included in the work scope at this location. The approach at Duck was to drill a test hole, complete a well in the most promising zone, conduct pump tests and water quality sampling, and make a preliminary evaluation of the water supply potential of any units identified. Development of a hydraulic computer model to estimate drawdowns that might result due to large scale pumpage was also included.

2.3.3 Roanoke Island

The Skyco water plant on Roanoke Island has the largest production capacity of the water treatment facilities operated by the Dare County Water Department. The feasibility of expanding the Skyco plant and raw water supply wellfield was investigated as part of this study. The work scope at this site included reviewing historic pumpage, water quality, and monitor well data as well as existing reports on the area. A hydraulic computer model was developed to assess the drawdown impacts associated with increased pumpage and wellfield expansion.

2.3.4 Rodanthe, Waves, and Salvo

The Rodanthe, Waves, and Salvo (RWS) water system is supplied by a reverse osmosis plant located in Rodanthe. This plant has a capacity of 1.0 MGD and was designed to accommodate an expansion up to 2.0 MGD. The work scope for the RWS system was intended to determine the feasibility of increasing raw water supply to the plant when expansion of the facility becomes necessary. A hydraulic computer model of the aquifer system was developed to determine the drawdown impacts associated with increased pumpage.

2.3.5 Dare Hatteras Water System

Expansion of the Dare County Hatteras Water System is currently in the final design stage. Distribution system improvements and construction of a new reverse osmosis plant are scheduled for completion in the fall of 1999. The project approach for this area was to summarize the proposed water system improvements in the context of the County-wide study. In addition, a final modeling scenario for the proposed brackish water wellfield to include actual production well locations was included in the work scope.

2.3.6 Mainland Dare County

The communities of Mann's Harbor and Stumpy Point on Mainland Dare County are not served by a public water supply system. A water supply feasibility study for Stumpy Point was recently completed for the County by Hobbs, Upchurch & Associates, P.A. The work scope for this part of the County-wide study was therefore focused on Mann's Harbor. The project approach at Mann's Harbor included a review of available data to determine target supply zones, test well construction to evaluate water quality and yield characteristics of the selected zones, and computer modeling to assess the drawdown impacts that might result due to pumpage.

3.0 POTABLE WATER DEMANDS

3.1 Past Water Use

DRWSS

Water supplied to the Kill Devil Hills, Nags Head, and Dare County water systems is produced by the Dare Regional Water Supply System (DRWSS). This water is produced primarily at the Kill Devil Hills R.O. plant and the Skyco ion exchange plant. Fresh Pond is used as a water source occasionally to meet peak demands in the summer. Graphs showing historic average and maximum daily water production from both plants and the DRWSS over the last three fiscal years are provided as Figures 3-1 and 3-2, respectively. The ratio of peak demands to average day demands exceeds 2:1 due to the large influx of visitors in the summer. The fiscal year extends from July through June of the following year. The data sets presented in the figures begin in June of 1994 and end in July of 1997. Analysis of the data indicate that average and maximum day demands from the DRWSS have remained relatively constant during this time period. The maximum amount of water produced at the R.O. plant has consistently averaged approximately 3.0 MGD which is the current treatment capacity of the plant. The demand for water from the DRWSS is anticipated to increase significantly over the next two decades as the population of the county increases. Demand projections for the DRWSS and other plants operated by the county are provided in the following subsection of this report.

RWS

The reverse osmosis plant that supplies potable water to the communities of Rodanthe, Waves, and Salvo was placed into operation during March of 1996. Average daily raw water pumpage data from the wellfield that supplies the plant are shown on Figure 3-3. Peak production for both 1996 and 1997 occurred in the month of July and was less than 0.4 MGD. The RWS plant is capable of producing 1.0 MGD of potable water and operates with a recovery efficiency of 75%.

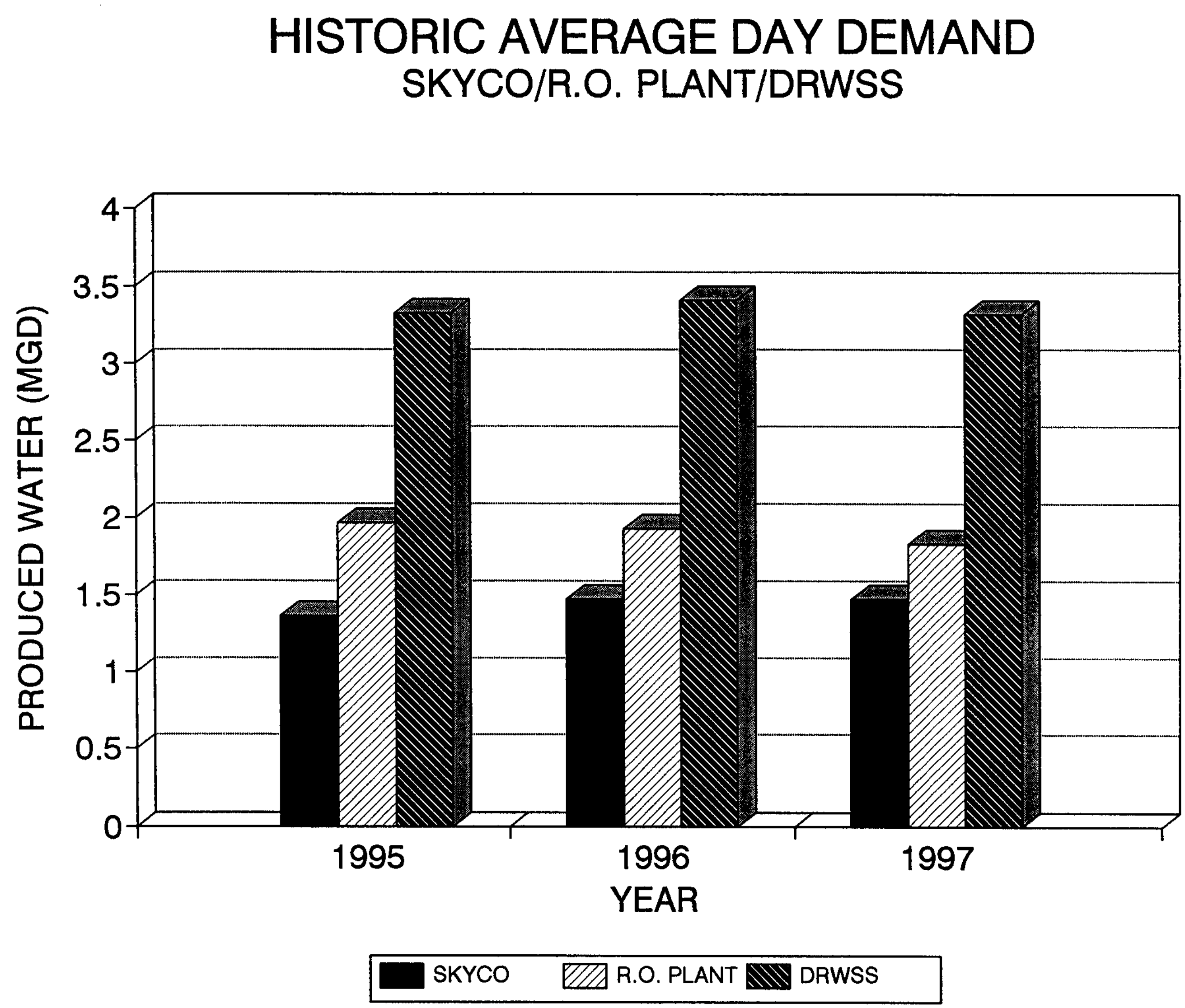

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FIGURE 3-1. GRAPH SHOWING THE AMOUNT OF WATER PRODUCED AT THE SKYCO PLANT AND KDH R.O. PLANT AND DISTRIBUTED BY THE DRWSS

HISTORIC MAXIMUM DAY DEMAND
SKYCO/R.O. PLANT/DRWSS

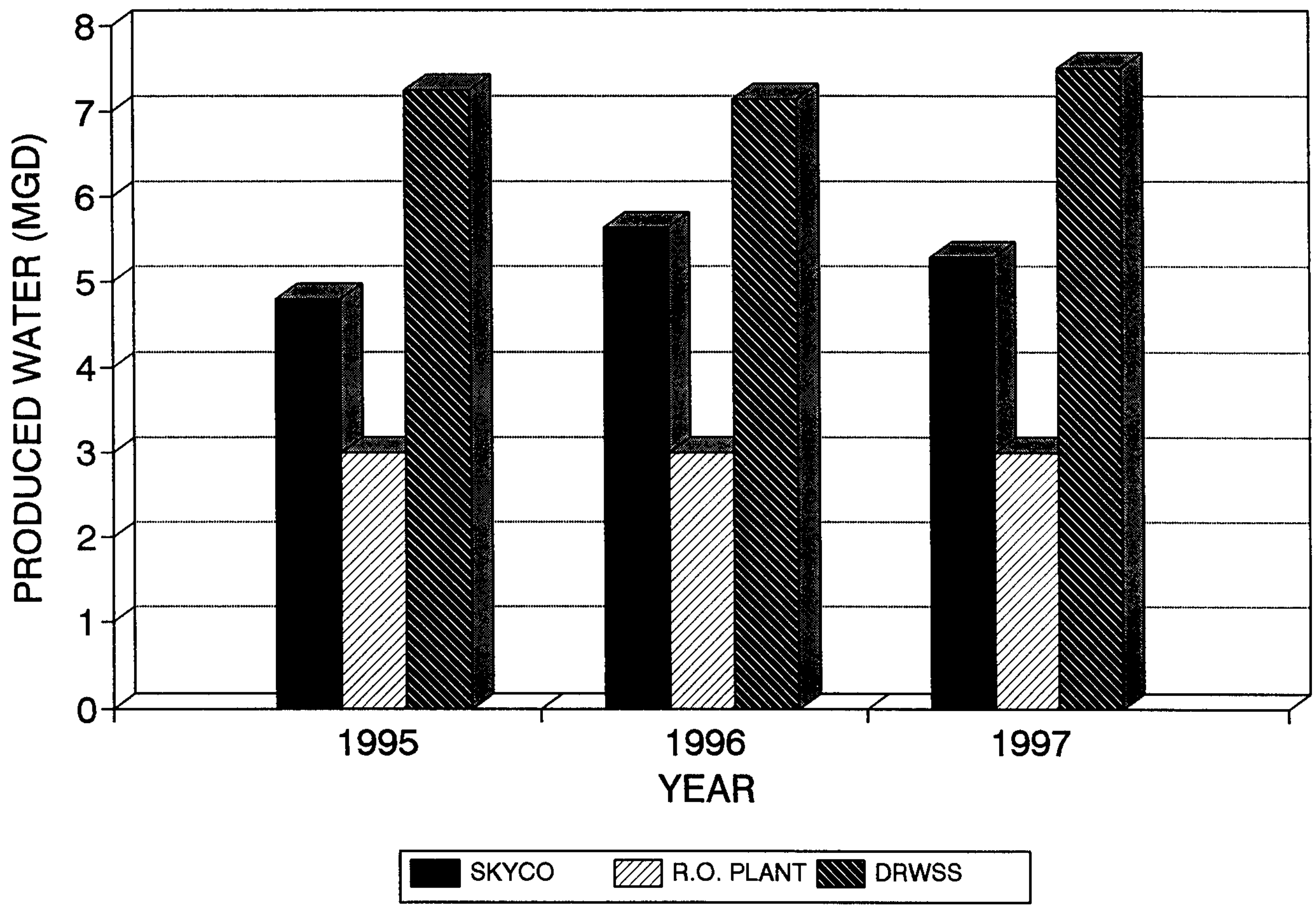

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FIGURE 3-2. GRAPH SHOWING PEAK WATER PRODUCTION AT THE SKYCO PLANT AND KDH R.O. PLANT AND DISTRIBUTED BY THE DRWSS

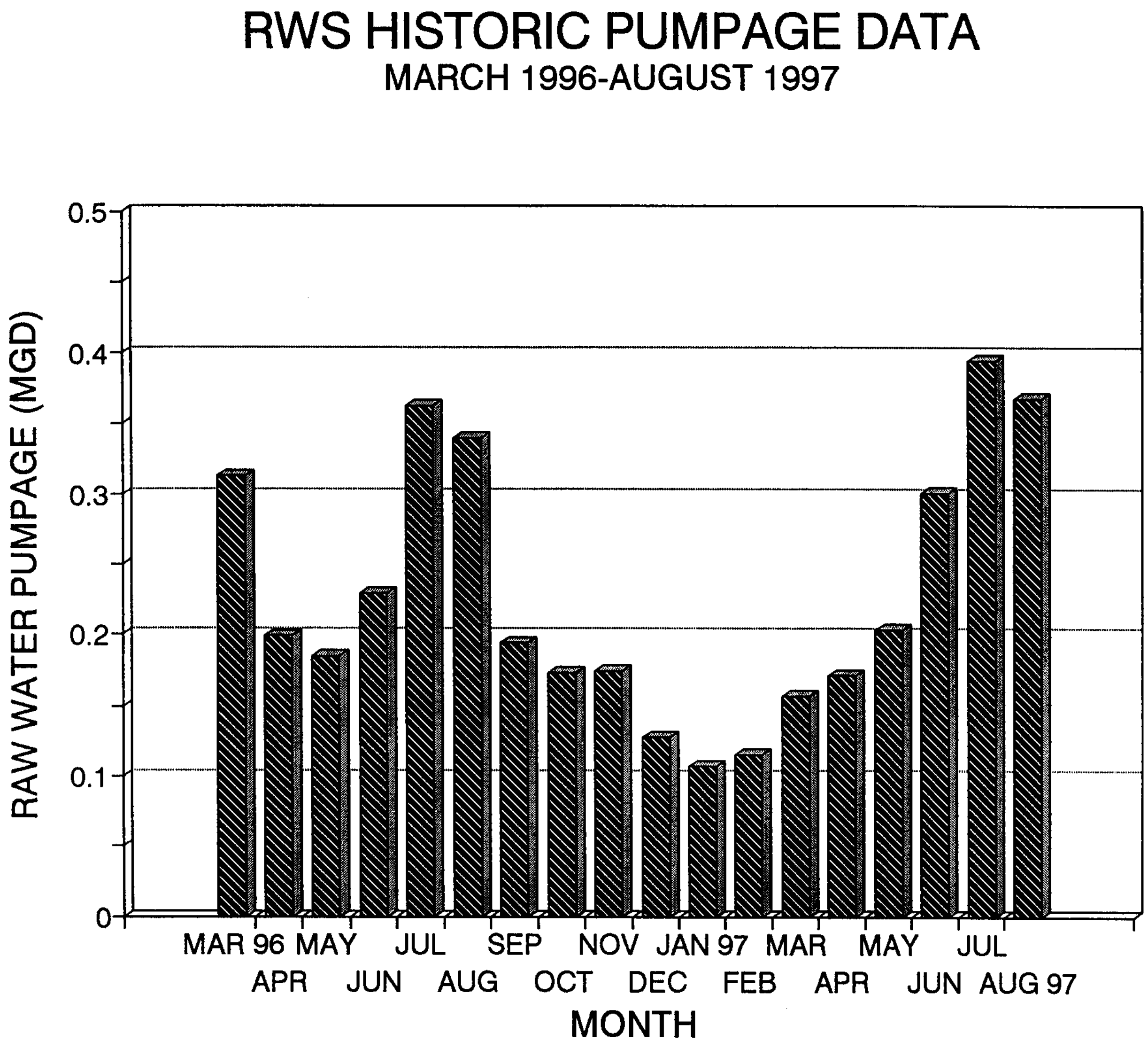

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FIGURE 3-3. GRAPH SHOWING RAW WATER PUMPAGE AT THE RWS R.O. PLANT FROM MARCH 1996 TO AUGUST 1997

Hatteras Water System

Potable water for the communities of Avon, Buxton, Frisco and Hatteras Village on Hatteras Island is currently obtained from a shallow wellfield that taps the water-table aquifer. Historic raw water average daily pumpage data for the wellfield that supplies the water plant is presented in Figure 3-4. Peak average daily production occurs in the summer months and reached a high of 1.265 MGD during July of 1997 which is close to the maximum plant capacity. The capacity of the Hatteras water system to produce potable water will be increased by the construction of a reverse osmosis plant at the site of the existing water plant. Design of the reverse osmosis plant is currently underway and the facility is scheduled for completion in the fall of 1999.

Other Areas

Residents in the communities of Mann's Harbor, Stumpy Point, Wanchese, and other unincorporated areas of the county rely on individual wells for water supply. No data are available on the amount of water used for domestic supply although it is estimated to be significant as less than 60% of the county population is served by a public water supply system.

3.2 Projected Demands

DRWSS

The communities served by the DRWSS experience large seasonal fluctuations in water demand. Peak water usage typically occurs in July or August during the height of tourist season. The ratio of peak to average day demand exceeds 2:1. It is very difficult to accurately project water use demands when factors such as weather and economic conditions can influence the number of people served significantly. The demand projections used in this analysis were provided by the Dare County planning department based on state population estimates. Estimated average and maximum daily water use demands for the DRWSS are presented in Figure 3-5. A range of estimates is provided because of the inherent uncertainty in the projections. The maximum anticipated water use demand in the year 2020 from the DRWSS is approximately 16.0 MGD. Average day demands may range from approximately 6.0 to 8.0 MGD.

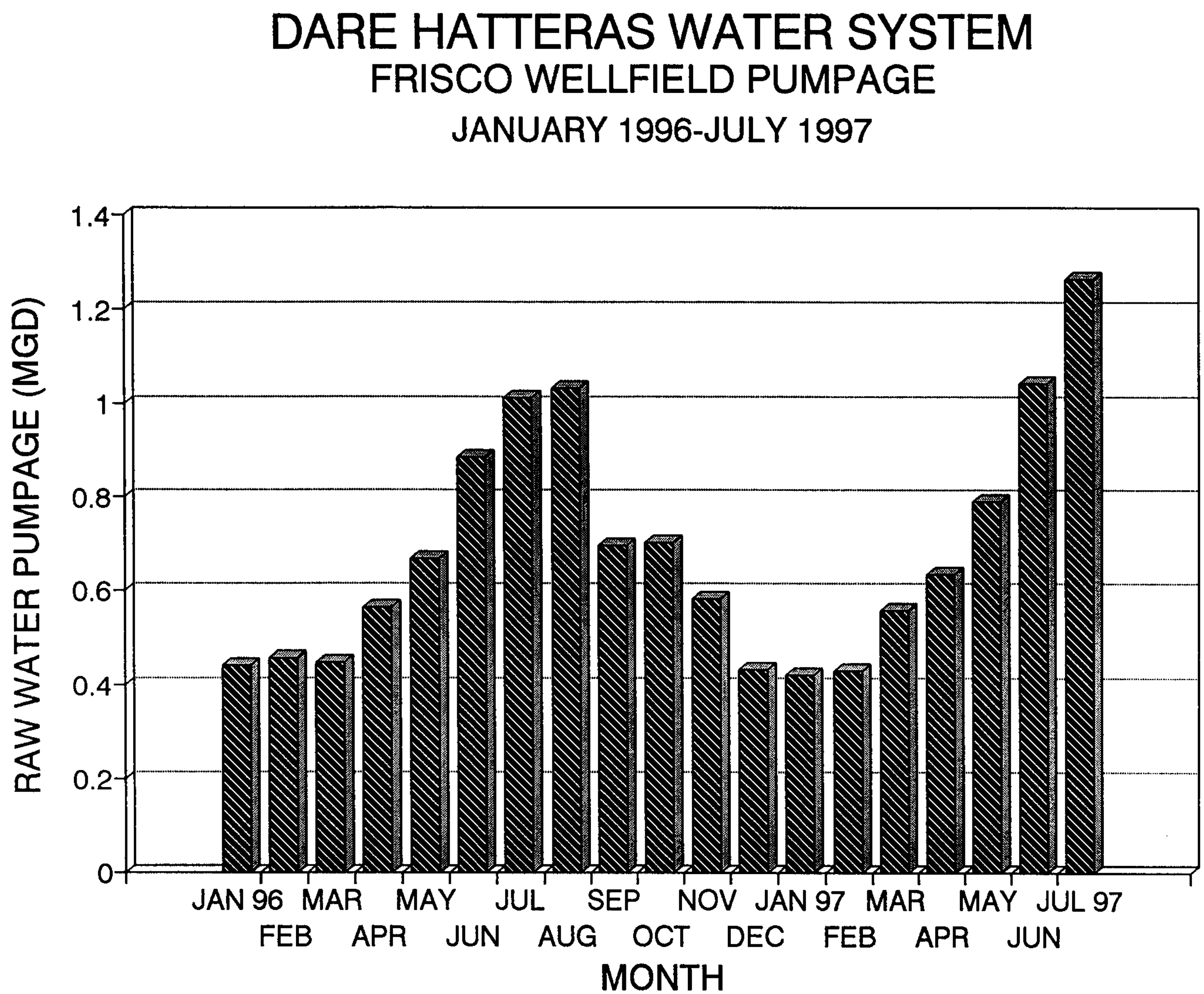

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FIGURE 3-4. GRAPH SHOWING RAW WATER PUMPAGE AT THE FRISCO WELLFIELD FROM JANUARY 1996 TO JULY 1997

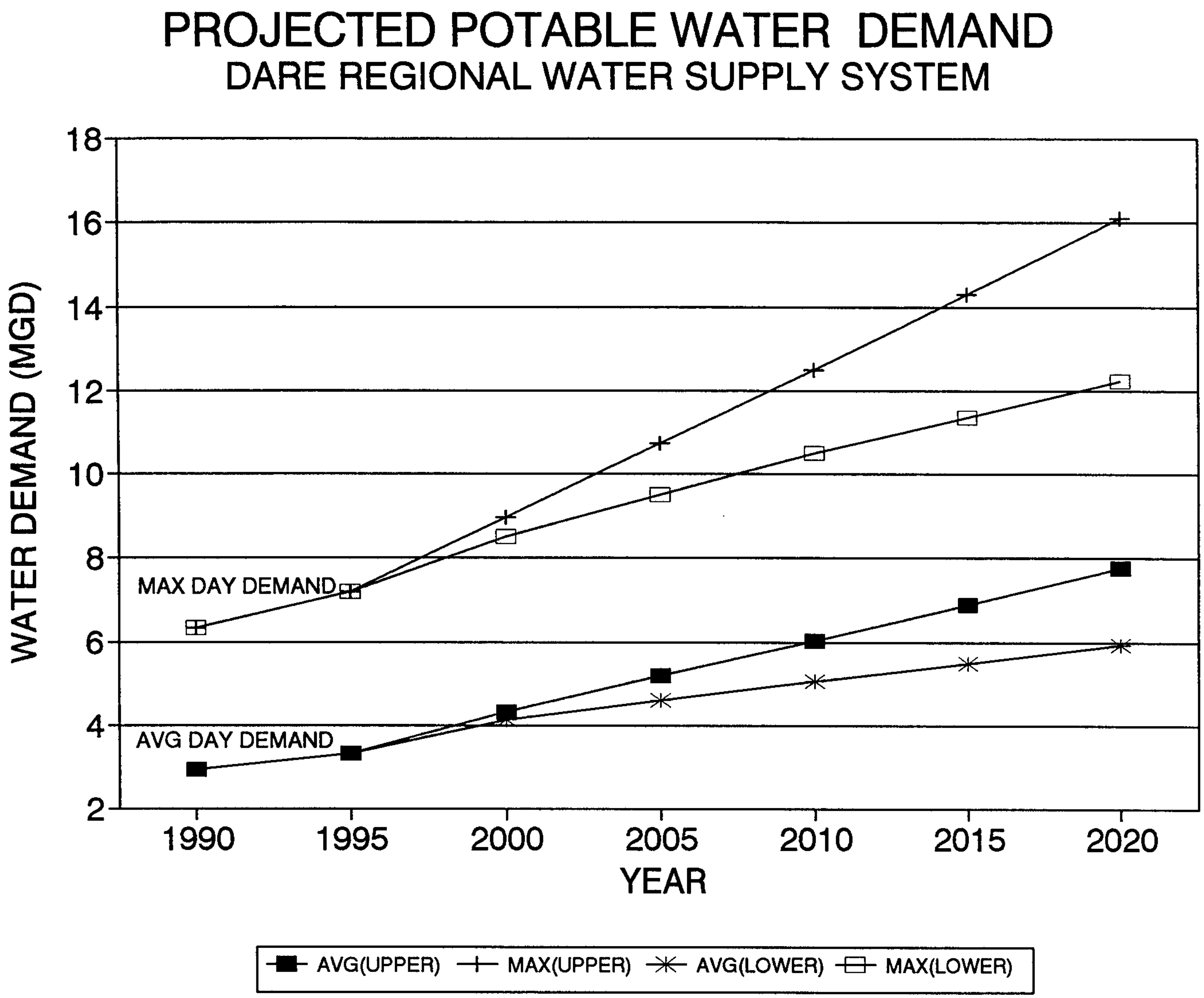

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FIGURE 3-5. GRAPH SHOWING PROJECTED POTABLE WATER DEMANDS FOR THE DRWSS TO THE YEAR 2020

RWS

Water use demand projections for the communities of Rodanthe, Waves, and Salvo were again determined by using information provided by the Dare County planning department. Peak season average daily water use demands are estimated to range from a low of 0.6 MGD to as high as 2.0 MGD in the year 2020. The wide range in demand estimates is again due to uncertainties in future growth rates and the amount of seasonal visitors.

Hatteras Water System

Water use demand projections for the Dare Hatteras water system were determined based on projections by the Cape Hatteras Water Association. A graph showing estimated average and peak daily demands is provided as Figure 3-6. A maximum daily demand of 3.0 MGD from the Hatteras waster system is anticipated in the year 2020. A summary of the projected demands for each of the above water supply systems is provided in Table 3.2-1.

Other Areas

Demand projections for the communities of Mann's Harbor, Stumpy Point, and Wanchese were made based on an estimated daily per capita water use rate of 150 gpd. Detailed population projections for these communities and other unincorporated areas within the county were not available from the county planning department. Best estimates of future populations in unincorporated Dare County were used with the assumed per capita use rate (150 gpd/person) to calculate projected demands. The average daily water use in these areas in the year 2020 is estimated to range from 2.0 to 3.0 MGD. Peak demands are estimated at 4.0 to 5.0 MGD.

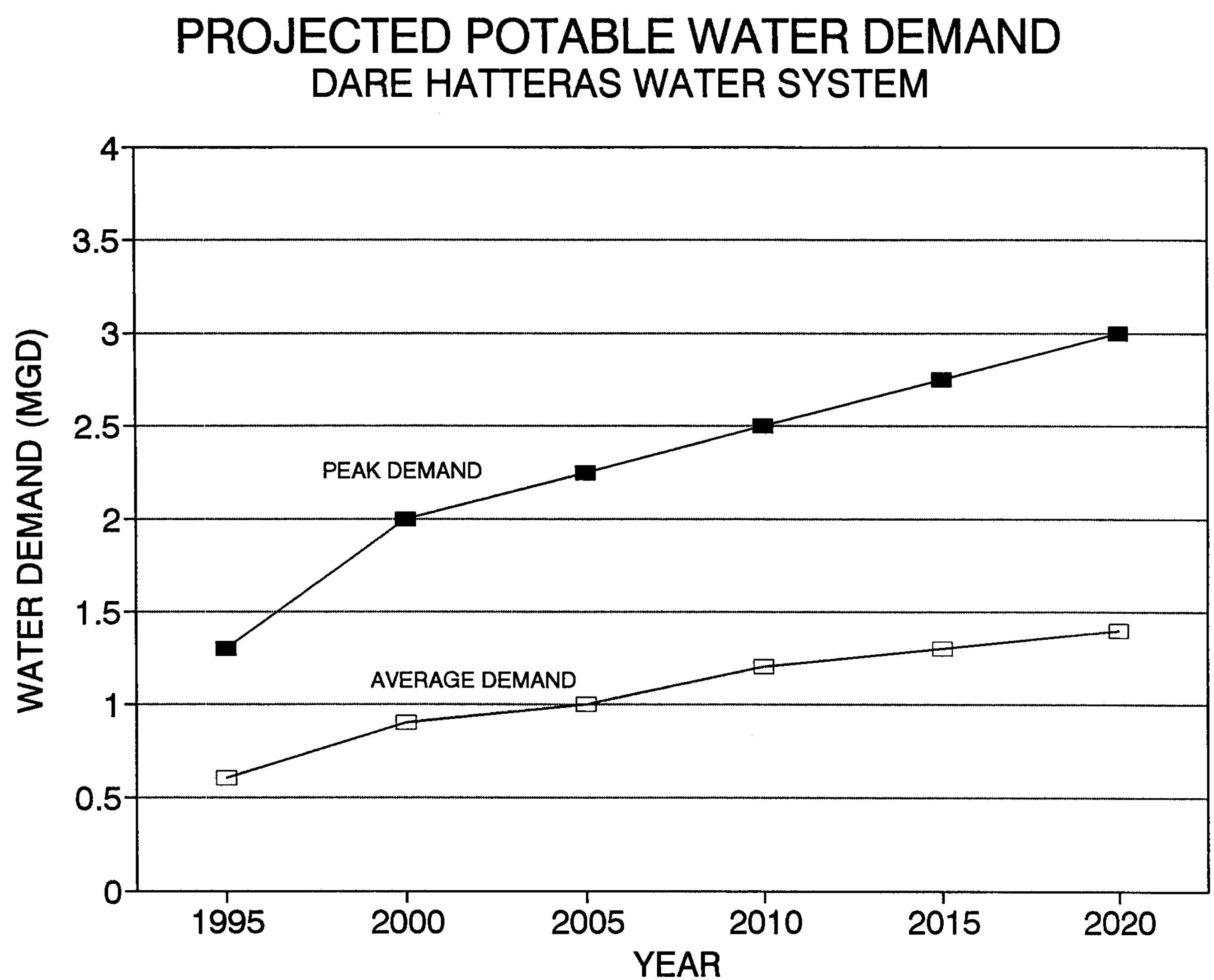

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FIGURE 3-6. GRAPH SHOWING ESTIMATED AVERAGE AND PEAK WATER DEMANDS FOR THE DARE HATTERAS WATER SYSTEM

TABLE 3.2-1 SUMMARY OF DARE COUNTY WATER DEPARTMENT WATER SUPPLY SYSTEM CAPACITIES AND PROJECTED DEMANDS

Water Supply System	Current Capacity (MGD)	Projected Peak Demand Year 2020 (MGD)
Dare Regional Water Supply System	8.0	16.0
Rodanthe, Waves, and Salvo	1.0	2.0
Hatteras Water System	2.0	3.0
TOTAL	**11.0**	**21.0**

4.0 METHODS OF INVESTIGATION

4.1 Data Compilation and Review

The initial task of the county-wide hydrogeological study was to collect and review existing data regarding the availability of groundwater resources for public supply purposes in Dare County. A number of water-supply studies have been conducted over the past 30 years in the county. Previous evaluations were typically limited to localized investigations at individual communities. The purpose of this data compilation and review was to determine what information was available and also areas where additional data are needed to properly evaluate groundwater resource availability in the County as a whole.

A relatively large amount of data were available in the Kill Devil Hills, Skyco, and Frisco areas because public supply wellfields have been in operation at these locations for many years. Considerably less information was available for the Duck and Mainland Dare County areas. Results of the data review indicated where additional data were needed and influenced the selected test well locations and the target intervals.

Dare County staff provided much of the information needed for the review including monitor well water level and water quality data, water plant production figures, and water use demand projections. Government agencies including the North Carolina Department of Environment, Health and Natural Resources (DEHNR), the United States Geological Survey (USGS), and the North Carolina Geological Survey provided reports, geophysical logs, and other pertinent data and information. Reports prepared by private consultants, including Missimer International were also utilized. A partial list of references is provided in this report.

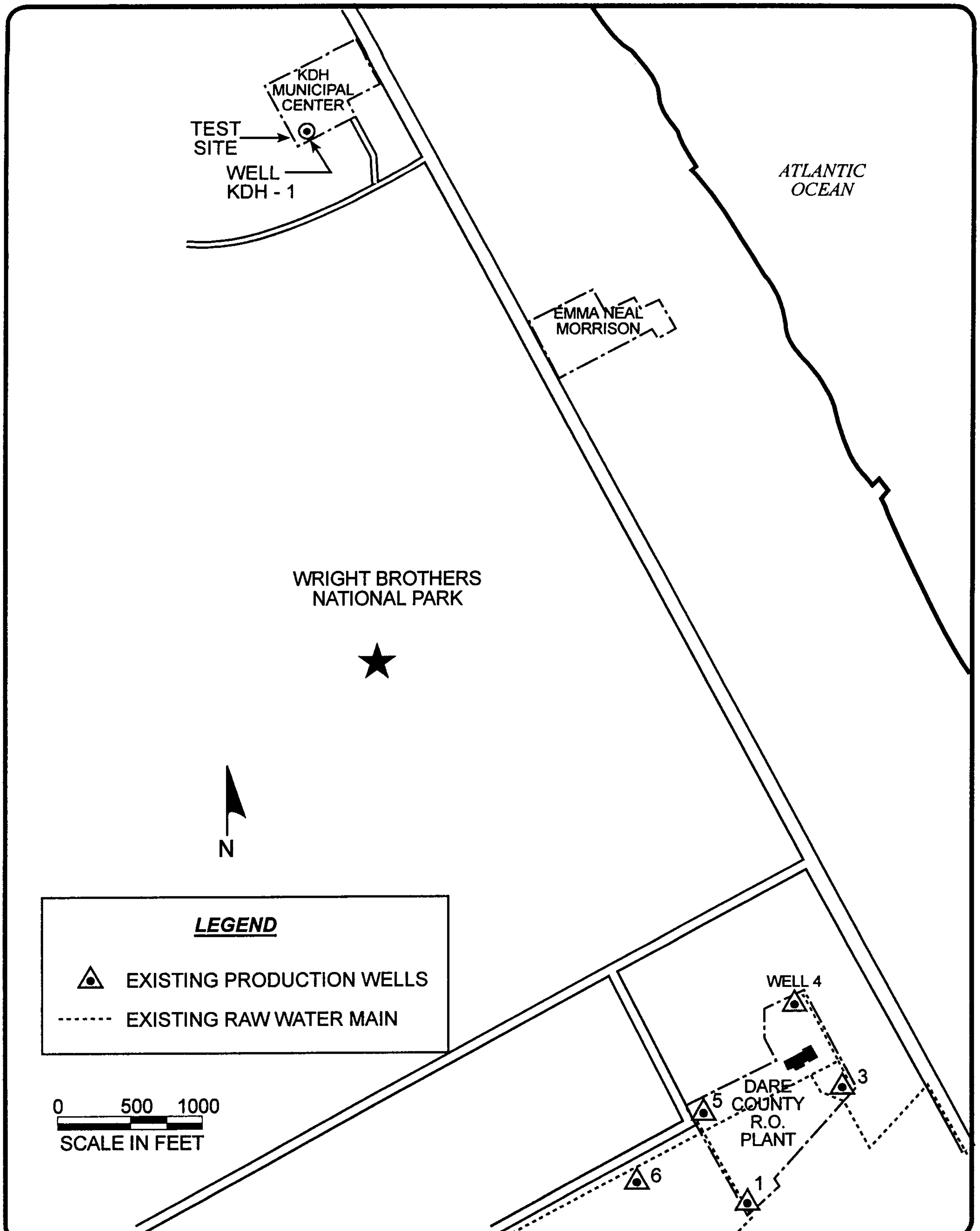
4.2 Well Construction and Testing

A total of four test wells were installed at three different locations for the county-wide hydrogeological study. A pair of test wells was installed at the Mann's Harbor test site and a single well was constructed at each of the Kill Devil Hills and Duck test sites. Skipper's Well Drilling from Leland, North Carolina, was subcontracted to construct and test the wells. Missimer International, Inc. (MI) staff provided on-site supervision during drilling and collected formation samples for lithologic analyses. At each site a test hole was drilled using the mud rotary method to a depth of 400 feet below land surface and geophysical logs were run. The on-site hydrogeologist selected screen intervals and determined final well design based on analysis of the drill cuttings and geophysical logs. Copies of the geologist's logs and geophysical logs are included in the appendix. Brief descriptions of the drilling and testing activities conducted at each site are provided below.

4.2.1 Kill Devil Hills

The Kill Devil Hills test well (KDH-1) was constructed behind the EMS station near the Kill Devil Hills elevated water storage tank. The test site is at the Kill Devil Hills Municipal Center approximately 1.5 miles north of the reverse osmosis plant as shown on Figure 4-1. The purpose of this well was to determine the feasibility of extending the existing alignment of raw water supply wells to the north. Previously, all proposed wellfield expansion scenarios considered expansion of the alignment to the south from the fresh pond area towards Nags Head.

Drilling commenced on the morning of March 24, 1998 and a nominal 9-inch diameter hole was advanced to a depth of 400 feet below land surface. Two permeable sand units beneath the surficial aquifer were encountered in the test hole between the approximate depths of 200-280 feet and 320-400 feet below land surface, respectively. The upper sand corresponds to what has historically been termed the Principal or upper Yorktown aquifer. The lower sand unit occurs within the Mid-Yorktown aquifer which is the zone tapped by the 10 existing raw water supply wells that feed the Kill Devil Hills reverse osmosis plant. At the test site, the lower unit was comprised primarily of very fine to fine grained sand and thus did not appear to be highly productive. The upper sand unit was chosen for further evaluation.



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Pr. Name: DARE COUNTY-WIDE STUDY

Pr. No. FH7-571 **DWG No.** KDH-1 **Date:** 5/17/98

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FIGURE 4-1. MAP SHOWING LOCATIONS OF THE REVERSE OSMOSIS PLANT AND TEST WELL KDH-1 IN KILL DEVIL HILLS.

A well string consisting of 80 feet of 4-inch diameter, 0.025-inch slotted Schedule 80 PVC pipe followed by 200 feet of Schedule 40 PVC casing was placed in the borehole. A blank section of pipe five feet long was placed below the screen to act as a sump. Construction details for well KDH-1 and the other test wells installed for this investigation are summarized in Table 4.2-1. A coarse sand gravel pack (Morie #2) was placed around the screen through a tremie pipe to a height of 10 feet above the screen and the well was then developed with compressed air. The well was developed for approximately six hours and subsequently grouted with neat cement from the top of the gravel pack to land surface. A schematic diagram of the well is provided as Figure 4-2.

A 5-hp electric submersible pump was placed in the well with the intake set at approximately 80 feet below surface for testing purposes. The well was pumped at three separate rates ranging from 50 to 90 gpm. Drawdown in the well was measured with a pressure transducer coupled to an electronic data logger. Results of the step drawdown test are summarized in Table 4.2-2. A specific capacity value of less than 2.0 gpm/ft was determined at a pumping rate of 90 gpm indicating the yield potential of this unit is relatively low. An additional test was conducted by pumping well KDH-1 at a constant rate of 90 gpm for approximately 22 hours. Drawdown in the well was measured at closely spaced time intervals and a semi-log plot of drawdown vs. time was constructed for analysis purposes (Figure 4-3).

The method developed by Jacob (1952) was used to analyze the data. A straight-line segment is selected from the semi-log plots and the change in drawdown over one log cycle is determined and substituted into equation (1) to determine the aquifer transmissivity.

$$T = \frac{264Q}{\Delta s} \qquad (1)$$

where,

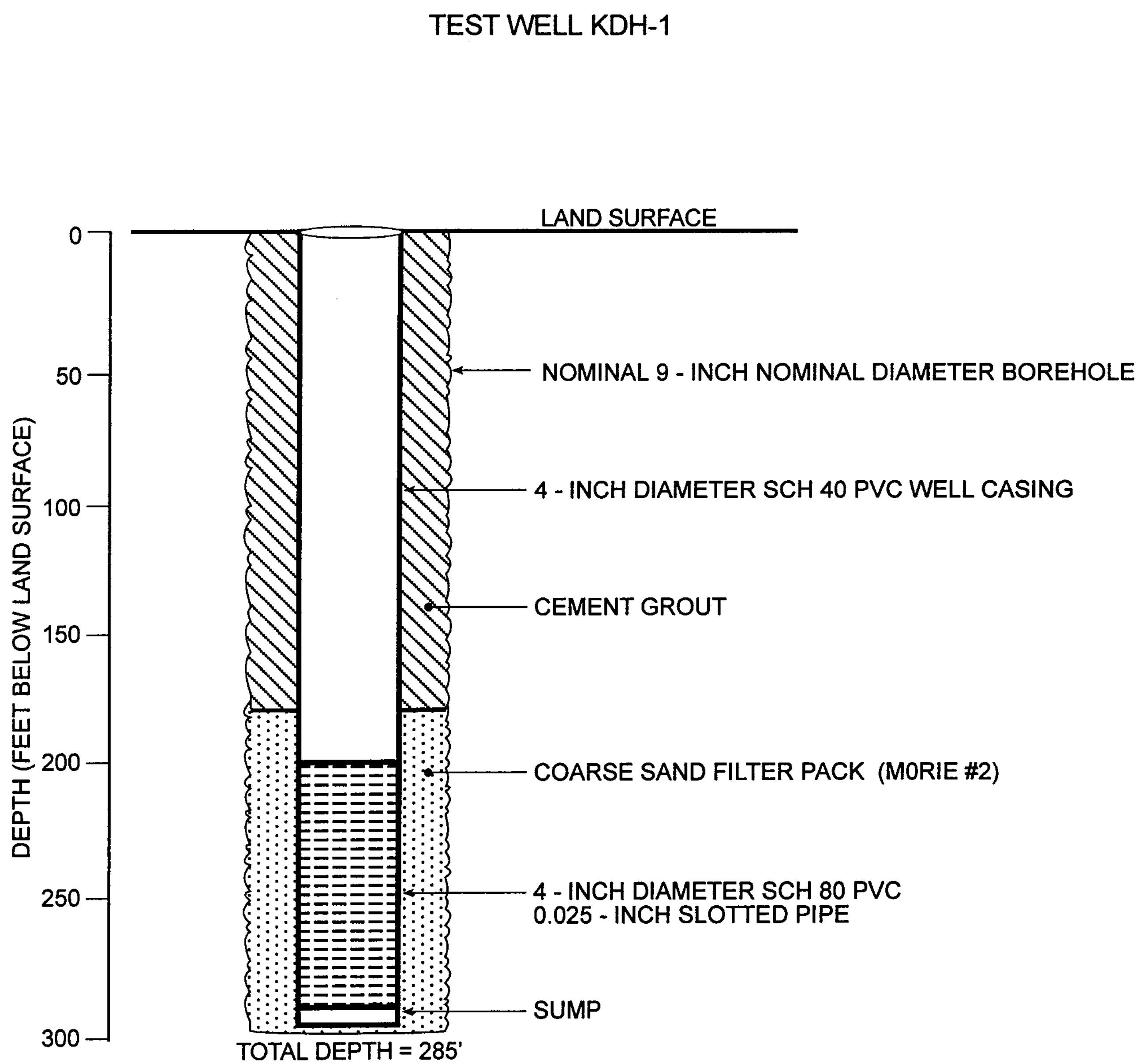
T = transmissivity (gpd/ft)
Q = pumping rate (gpm)
Δs = head difference between log cycles (feet)

TABLE 4.2-1

DARE COUNTY-WIDE STUDY
TEST WELL CONSTRUCTION DETAILS

Well	Total Depth (Feet)	Casing Depth (Feet)	Screened Interval (Feet)	Aquifer
KDH-1	285	200	200-280 5' sump	Principal (upper Yorktown)
DUCK-1	180	100	100-160 20' sump	Principal (upper Yorktown)
MANN (SHALLOW)	197	135	135-195 2' sump	Principal (upper Yorktown)
MANN (DEEP)	356	250	250-350 6' sump	Mid-Yorktown

*All of the test wells were constructed with 4-inch diameter Schedule 40 PVC casings. The screened sections consist of 4-inch diameter Schedule 80 PVC pipe with 0.025-inch slots. Morie #2 coarse sand was used as the filter pack material.



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	Pr. No. FH7-571 **DWG No.** DH3-2 **Date:** 5/12/98	

FIGURE 4 - 2. SCHEMATIC DIAGRAM SHOWING CONSTRUCTION DETAILS OF TEST WELL KDH - 1.

TABLE 4.2-2

DARE COUNTY-WIDE STUDY
STEP DRAWDOWN TEST - WELL KDH-1

Test Date: 3/26/98
Recorded By: Scott Manahan
Static Water Level: 18.57 Ft. Below Measuring Point (BMP)*

Pumping Rate (GPM)	**Time (Minutes)**	**Pumping Water Level (Ft. BMP)**	**Drawdown (Feet)**	**Specific Capacity (GPM/Ft)**
50	5	38.79	20.22	
	10	39.69	21.12	
	20	40.38	21.81	
	30	40.74	22.17	
	40	40.90	22.33	
	50	40.85	22.28	
	60	41.16	22.59	2.2
75	5	55.14	36.57	
	10	55.36	36.79	
	20	55.73	37.16	
	30	56.06	37.49	
	40	56.33	37.76	
	50	56.63	38.06	
	60	56.92	38.35	2.0
90	5	61.55	42.98	
	10	62.26	43.69	
	20	63.13	44.56	
	30	63.68	45.11	
	40	64.00	45.43	
	50	64.75	46.18	
	60	65.67	47.10	1.9

*Measuring point is top of casing approximately 3.5 feet above land surface.

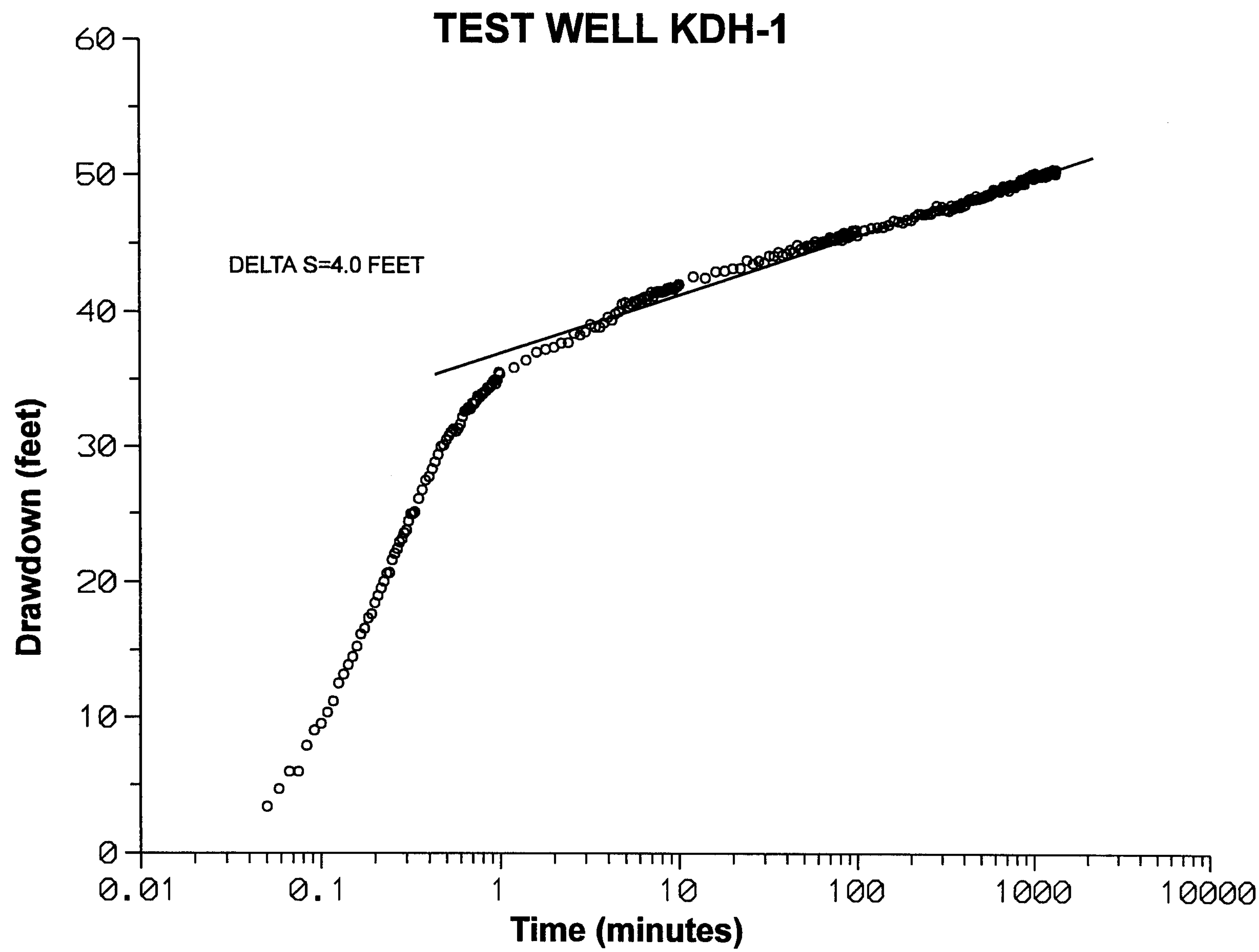

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FIGURE 4-3 . Semi-Log graph showing drawdown in test well KDH-1 while pumping the well at 90 gpm.

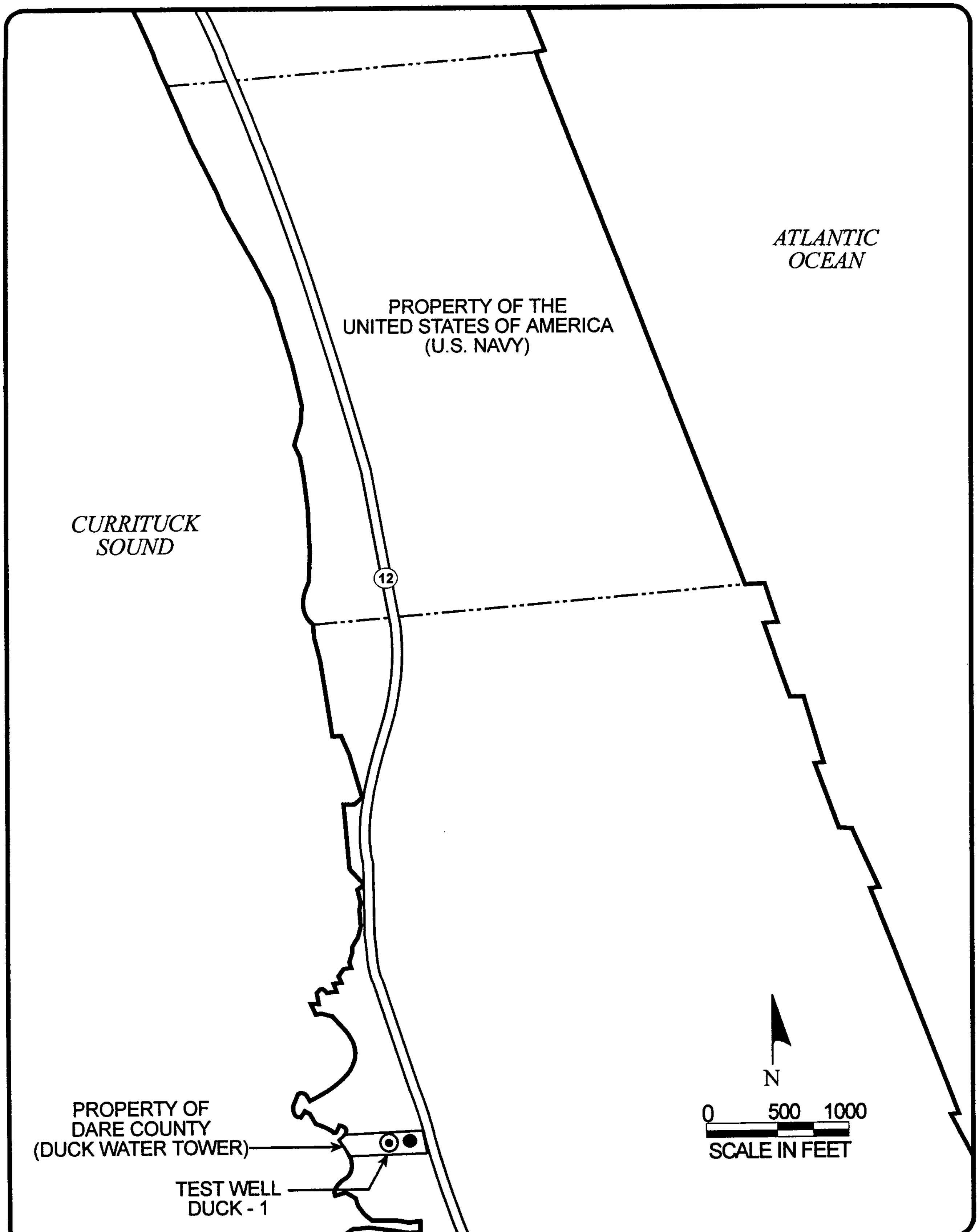
A transmissivity value of 5900 gpd/ft was calculated from the data obtained during testing indicating that the yield potential of this zone is relatively low.

4.2.2 Duck

The Duck test well (Duck-1) was constructed behind the elevated water storage tank in Duck at the location shown in Figure 4-4. Previous test drilling conducted in 1972 by the state of North Carolina, north of Kitty Hawk, indicated that low yield and poor water quality conditions could be expected in this area. Test well Duck-1 was constructed to determine if any groundwater sources were available at the test site that were suitable for public supply purposes.

The drilling and testing procedures were very similar to those utilized during the construction of the Kill Devil Hills test well. A borehole was advanced to a depth of 400 feet below land surface on March 31, 1998 and geophysical logs were conducted. A zone consisting of coarse quartz sand and gravel between the depths of 100 and 160 feet below land surface was the only unit encountered that appeared capable of yielding large volumes of water.

Well Duck-1 was constructed with 60 feet of 4-inch diameter PVC screen followed by 100 feet of 4-inch diameter Schedule 40 PVC well casing to land surface. A blank section of pipe 20 feet long was placed below the screen as a sump. The well was gravel packed, developed with air and grouted with neat cement. A schematic diagram of the well is provided as Figure 4-5. A 5-hp submersible test pump was placed in the well and used to conduct a 3-stage step drawdown test and a constant rate test. The step drawdown test results are summarized in Table 4.2-3. A semi-log plot of the constant rate test which was conducted at 100 gpm is included as Figure 4-6. The method developed by Jacob (1952) was again used to analyze the time and drawdown data collected during the pump test. A transmissivity value of 70,000 gpd/ft was determined indicating this zone has a potentially high productive capacity. It is likely that a large diameter, properly designed and constructed well could produce water at a rate of several hundred gallons per minute at this location.



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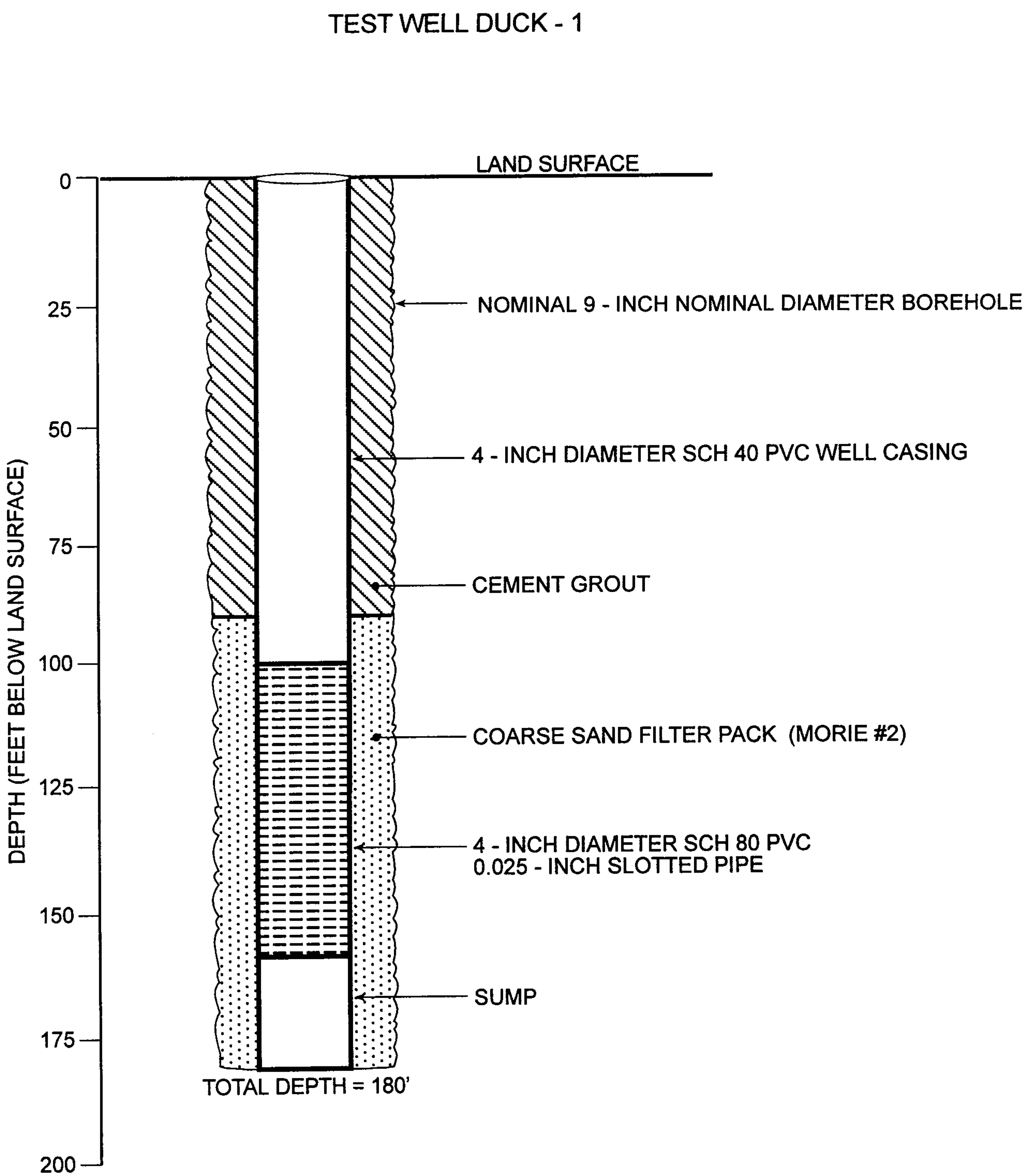
Pr. Name: DARE COUNTY-WIDE STUDY	
Pr. No. FH7-571 **DWG No.**WDC-1 **Date:** 5/17/98	

Groundwater and Environmental Services

FIGURE 4 - 4. SITE MAP SHOWING LOCATIONS OF THE DUCK WATER TOWER AND TEST WELL DUCK - 1.



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Pr. Name: Dare County-Wide Study
Pr. No. FH7-571 **DWG No.** DH3-2 **Date:** 5/11/98

Groundwater and Environmental Services

FIGURE 4 - 5. SCHEMATIC DIAGRAM SHOWING CONSTRUCTION DETAILS OF TEST WELL DUCK - 1.

TABLE 4.2-3

DARE COUNTY-WIDE STUDY
STEP DRAWDOWN TEST - WELL DUCK-1

Test Date: 4/2/98
Recorded By: Scott Manahan
Static Water Level: 2.71 Ft. Below Measuring Point (BMP)*

Pumping Rate (GPM)	Time (Minutes)	Pumping Water Level (Ft. BMP)	Drawdown (Feet)	Specific Capacity (GPM/Ft)
60	5	9.92	7.21	
	10	9.86	7.15	
	20	9.39	6.68	
	30	9.75	7.04	
	40	9.99	7.28	
	50	9.70	6.99	
	60	9.89	7.18	8.3
80	5	14.42	11.71	
	10	13.93	11.22	
	20	14.40	11.69	
	30	13.80	11.09	
	40	13.88	11.17	
	50	14.06	11.35	
	60	13.96	11.25	6.8
100	5	18.98	16.27	
	10	19.14	16.43	
	20	19.19	16.48	
	30	18.71	16.00	
	40	19.26	16.55	
	50	19.19	16.48	
	60	19.44	16.73	6.0

*Measuring point is top of casing approximately 2.8 feet above land surface.

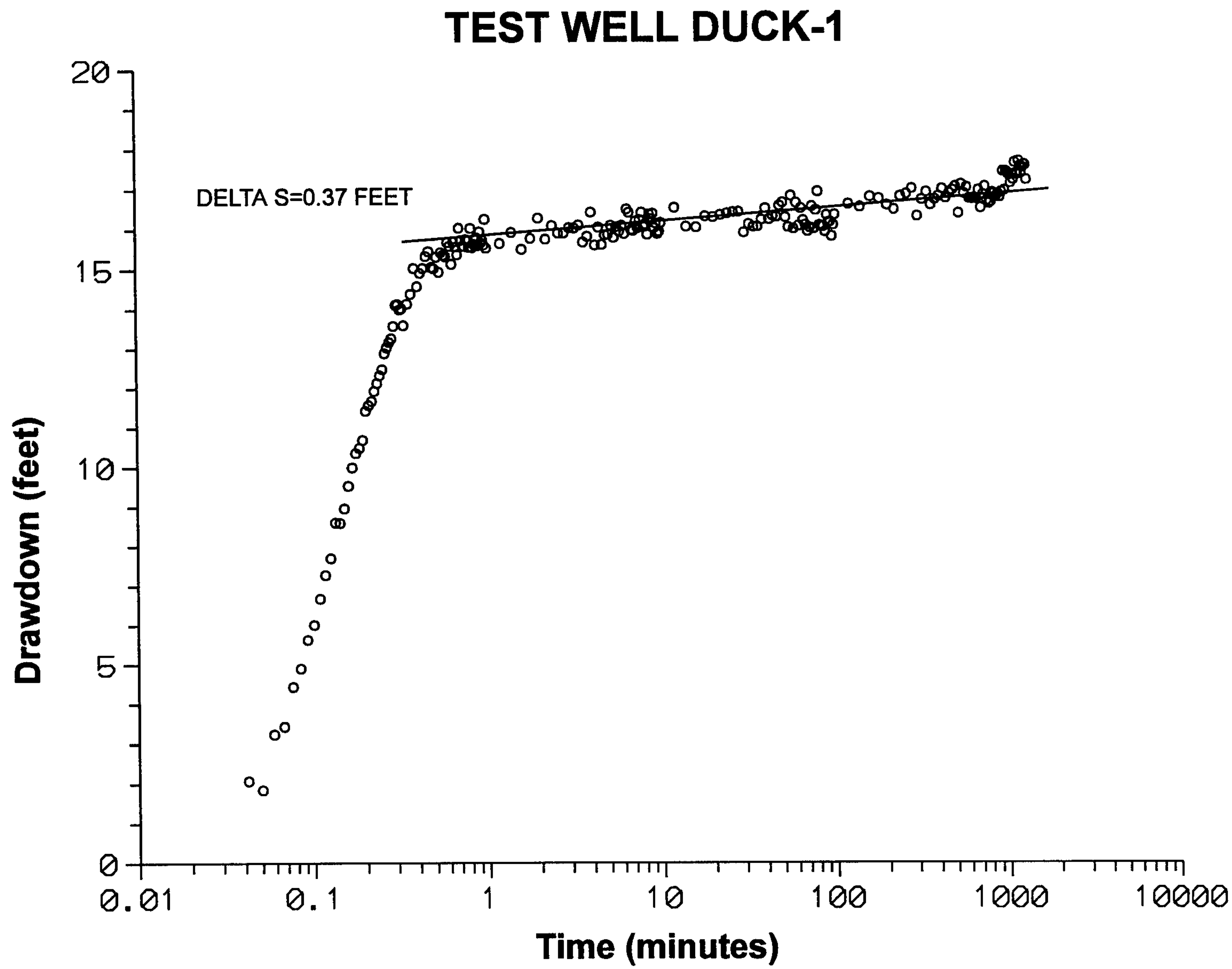

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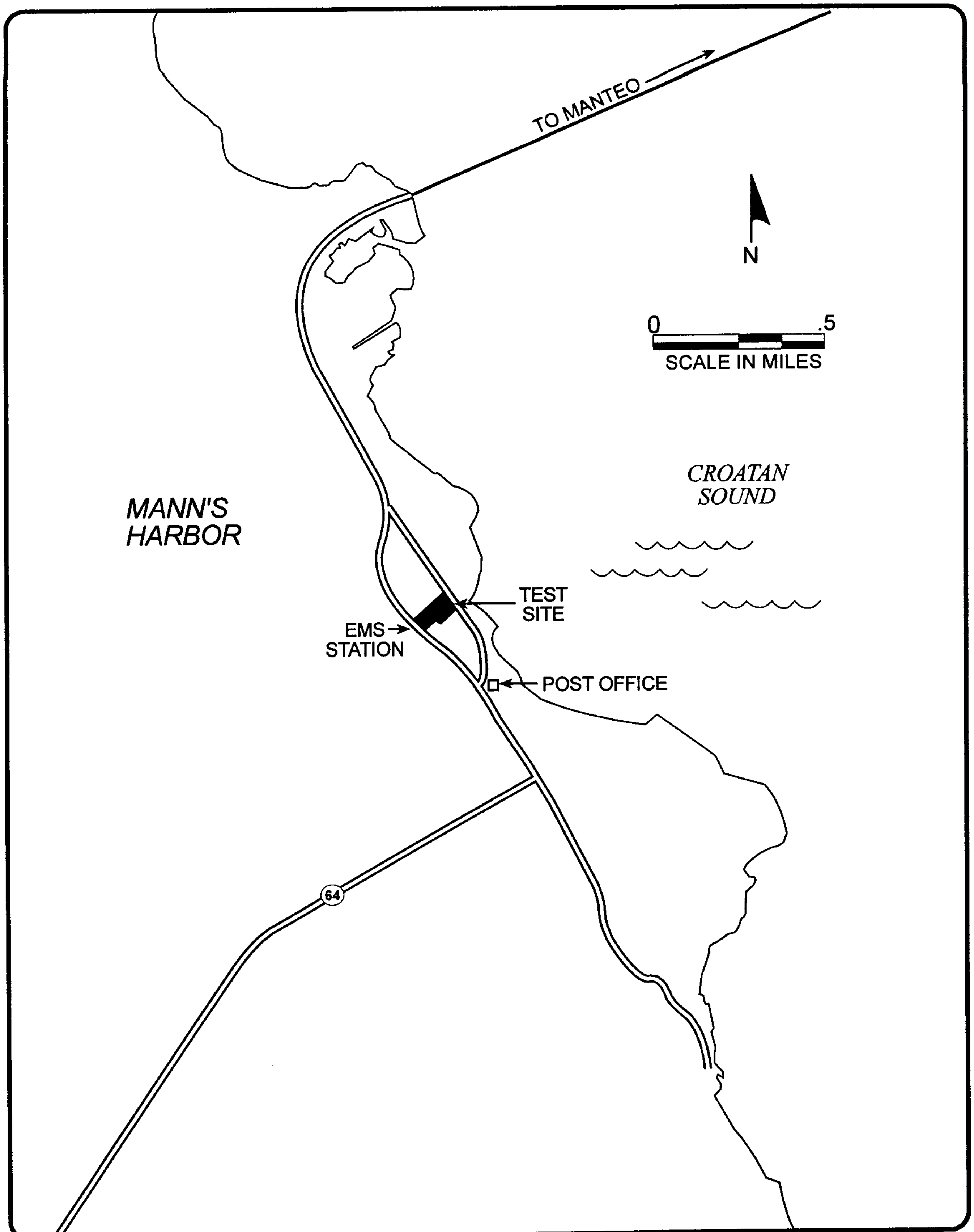
FIGURE 4-6 . Semi-Log graph showing drawdown in test well DUCK-1 while pumping the well at 100 gpm.

4.2.3 Mann's Harbor

Test drilling at Mann's Harbor was conducted on property owned by Dare County behind the EMS station at the location shown on Figure 4-7. Two zones were tested at this site. Previous testing conducted by the state in this area indicated that a freshwater zone suitable for public supply development might be encountered between the depth range from 100 to 200 feet below land surface and that a brackish water aquifer might be present below 250 feet. The test wells constructed at Mann's Harbor were installed to update and confirm the previous test results and to evaluate the feasibility of developing a source of water suitable for public supply purposes.

Drilling of the test hole at the Mann's Harbor test site began on the morning of April 6, 1998 and was completed late that evening at a depth of 400 feet below land surface. Geophysical logs were conducted and confirmed the presence of two permeable zones within the tested interval. The upper sand unit was encountered between the depths of approximately 130 and 200 feet below land surface. The lower sand unit was encountered at approximately 245 feet below land surface and was separated from the upper sand by a clay layer. The lower sand unit is approximately 100 feet thick and begins as an unconsolidated sand that grades into a soft to moderately hard sandstone in the bottom 50 feet of the interval. Two wells were completed to test the water quality and yield characteristics of both the upper and lower sand units.

The deeper zone well (Mann-Deep) was constructed by placing a 4-inch diameter screened section 100 feet long in the borehole followed by 250 feet of 4-inch diameter Schedule 40 PVC well casing to land surface. A section of blank pipe six feet long was placed at the bottom of the screen as a sump. The well was gravel packed, developed, and grouted in a manner similar to the other test wells. The shallow zone test well (Mann-Shallow) was constructed with screen from 135 feet to 195 feet below land surface approximately 20 feet east of the deep well. This well was completed, developed, and grouted in the same manner as the deeper zone well. A schematic diagram showing construction details of the wells is provided as Figure 4-8.



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Pr. No. FH7-571	**DWG No.** MH-1 **Date:** 5/17/98

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FIGURE 4-7. MAP SHOWING THE TEST SITE LOCATION IN MANN'S HARBOR.

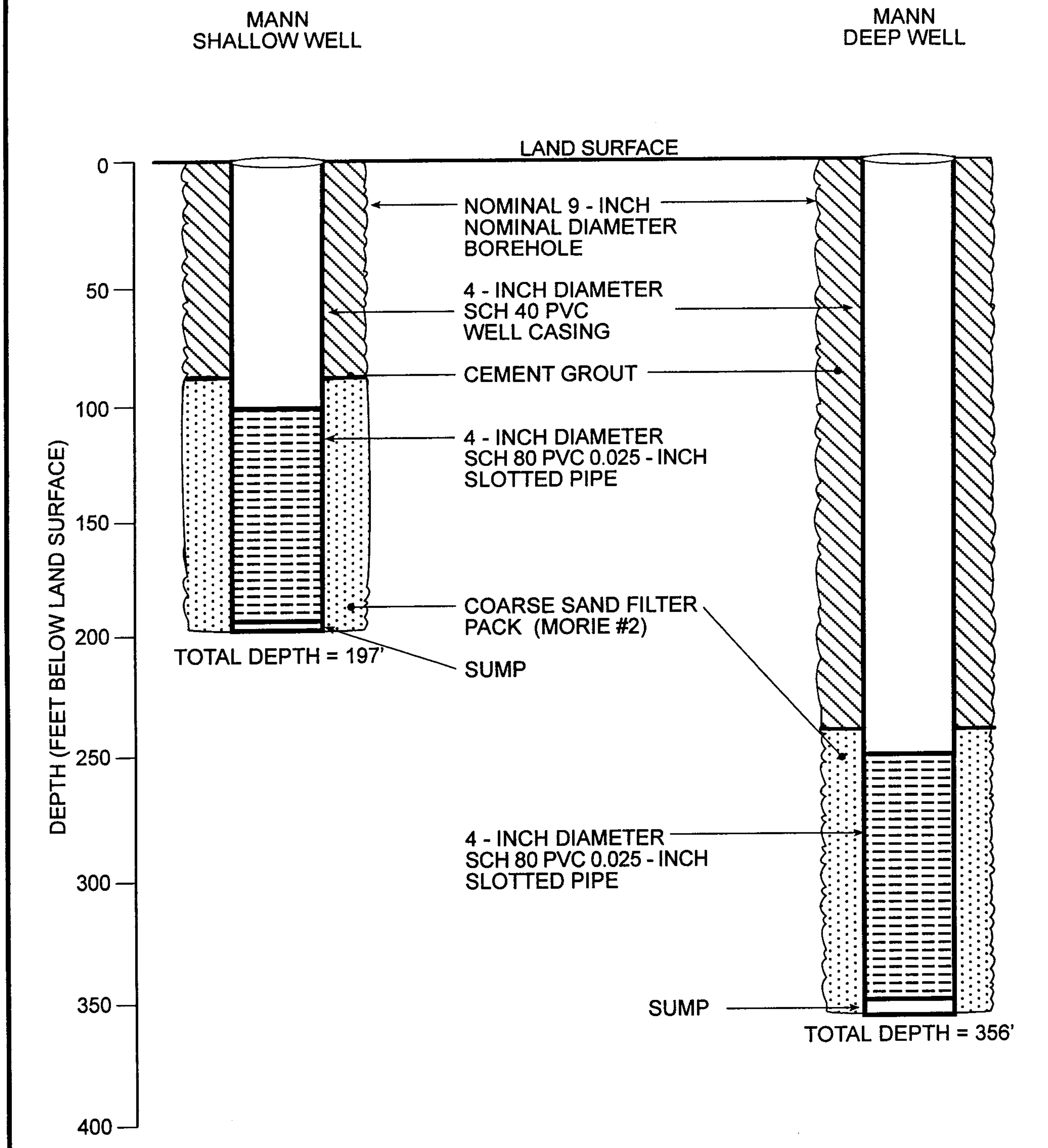

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FIGURE 4 - 8. SCHEMATIC DIAGRAM SHOWING CONSTRUCTION DETAILS OF THE DEEP AND SHALLOW TEST WELLS AT MANNS HARBOR

Step drawdown and constant rate tests were conducted on both wells. The step drawdown test results are summarized in Tables 4.2-4 and 4.2-5. Semi-log plots of drawdown vs. time data for both wells are provided as Figures 4-9 and 4-10. Transmissivity values calculated for the shallow and deep zones are 51,000 gpd/ft and 73,000 gpd/ft, respectively. The transmissivity of 51,000 gpd/ft calculated for the shallow zone is consistent with the value of 50,000 gpd/ft estimated previously for this zone at Mann's Harbor by the state of North Carolina. The test results indicate that both units have the ability to yield large volumes of water suitable for public supply purposes. However, water quality conditions varied significantly between the two zones. The water quality sampling methods utilized during the investigation and the analyses results obtained are discussed in the following subsection of this report. A summary of the transmissivity values calculated at each of the test sites is provided in Table 4.2-6.

4.3 Water Quality Sampling and Analyses

Water samples were obtained from all of the test wells installed as part of the county-wide hydrogeological investigation. A similar sampling procedure was used for each test well. Samples were taken from the pump discharge during step drawdown and constant rate pump testing. The samples were analyzed for dissolved chloride concentration by the Dare County water department staff. Additional samples were obtained near the end of constant rate testing after the well had been pumped at rates ranging from 90 to 100 gpm for approximately 24 hours. Detailed analyses of these samples were conducted by Dare County staff and also by Savannah Laboratories in Tampa, Florida. Analytical reports prepared by Dare County staff and Savannah Laboratories are included in the appendix. Water quality conditions at each test site are described in the following subsections of this report.

4.3.1 Kill Devil Hills

The analyses results indicate that the zone tapped by well KDH-1 is relatively fresh with a dissolved chloride concentration of approximately 290 mg/l. By comparison, the average dissolved chloride concentration of the raw water from the production wells that supply the

TABLE 4.2-4

DARE COUNTY-WIDE STUDY
STEP DRAWDOWN TEST - WELL MANN DEEP

Test Date: 4/8/98
Recorded By: Scott Manahan
Static Water Level: 9.86 Ft. Below Measuring Point (BMP)*

Pumping Rate (GPM)	Time (Minutes)	Pumping Water Level (Ft. BMP)	Drawdown (Feet)	Specific Capacity (GPM/Ft)
70	5	21.57	11.71	
	10	21.23	11.37	
	20	21.57	11.71	
	30	21.68	11.82	
	40	21.81	11.95	
	50	20.96	11.10	
	60	21.80	11.94	5.9
85	5	25.31	15.45	
	10	25.66	15.80	
	20	26.07	16.21	
	30	25.82	15.96	
	40	26.08	16.22	
	50	25.71	15.85	
	60	26.17	16.31	5.2
97	5	30.03	20.17	
	10	30.12	20.26	
	20	30.26	20.40	
	30	30.33	20.47	
	40	30.34	20.48	
	50	30.34	20.48	
	60	30.19	20.33	4.7

*Measuring point is top of casing approximately 2.7 feet above land surface.

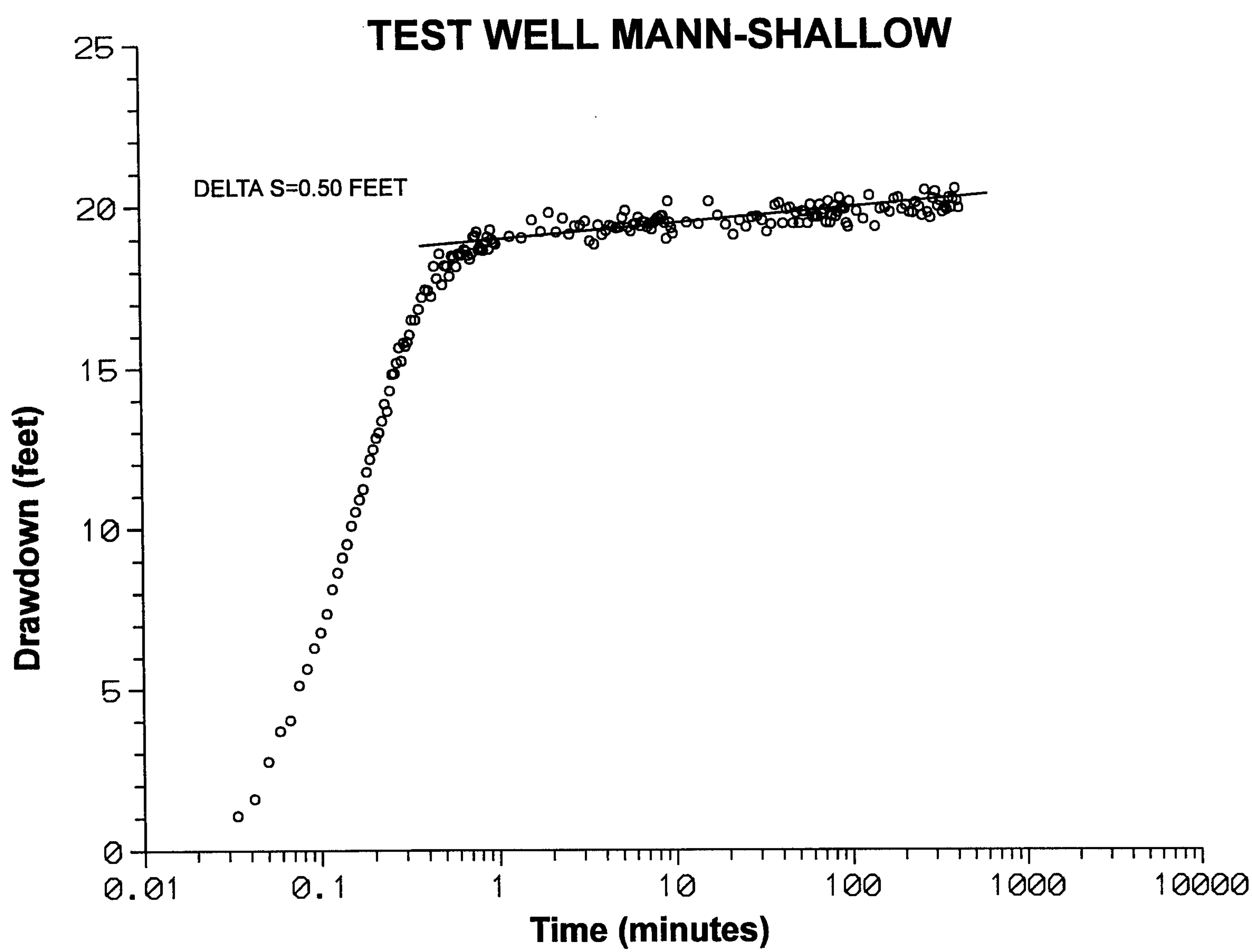
TABLE 4.2-5

DARE COUNTY-WIDE STUDY
STEP DRAWDOWN TEST - WELL MANN SHALLOW

Test Date: 4/11/98
Recorded By: Scott Manahan
Static Water Level: 7.30 Ft. Below Measuring Point (BMP)*

Pumping Rate (GPM)	Time (Minutes)	Pumping Water Level (Ft. BMP)	Drawdown (Feet)	Specific Capacity (GPM/Ft)
60	5	16.09	8.79	
	10	16.13	8.83	
	20	16.40	9.10	
	30	16.11	8.81	
	40	16.28	8.98	
	50	16.07	8.77	
	60	16.61	9.31	6.4
75	5	20.28	12.98	
	10	20.52	13.22	
	20	19.90	12.60	
	30	20.19	12.89	
	40	20.37	13.07	
	50	20.37	13.07	
	60	20.28	12.98	5.7
97	5	27.03	19.73	
	10	27.15	19.85	
	20	27.12	19.82	
	30	27.11	19.81	
	40	27.01	19.71	
	50	27.26	19.96	
	60	26.94	19.64	4.9

*Measuring point is top of casing approximately 3.2 feet above land surface.



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	Pr.No. FH7-571 DWG No.	Date: 4/20/98 Rev.No. 1	

FIGURE 4-9 . Semi-Log graph showing drawdown in test well MANN-SHALLOW while pumping the well at 97 gpm.

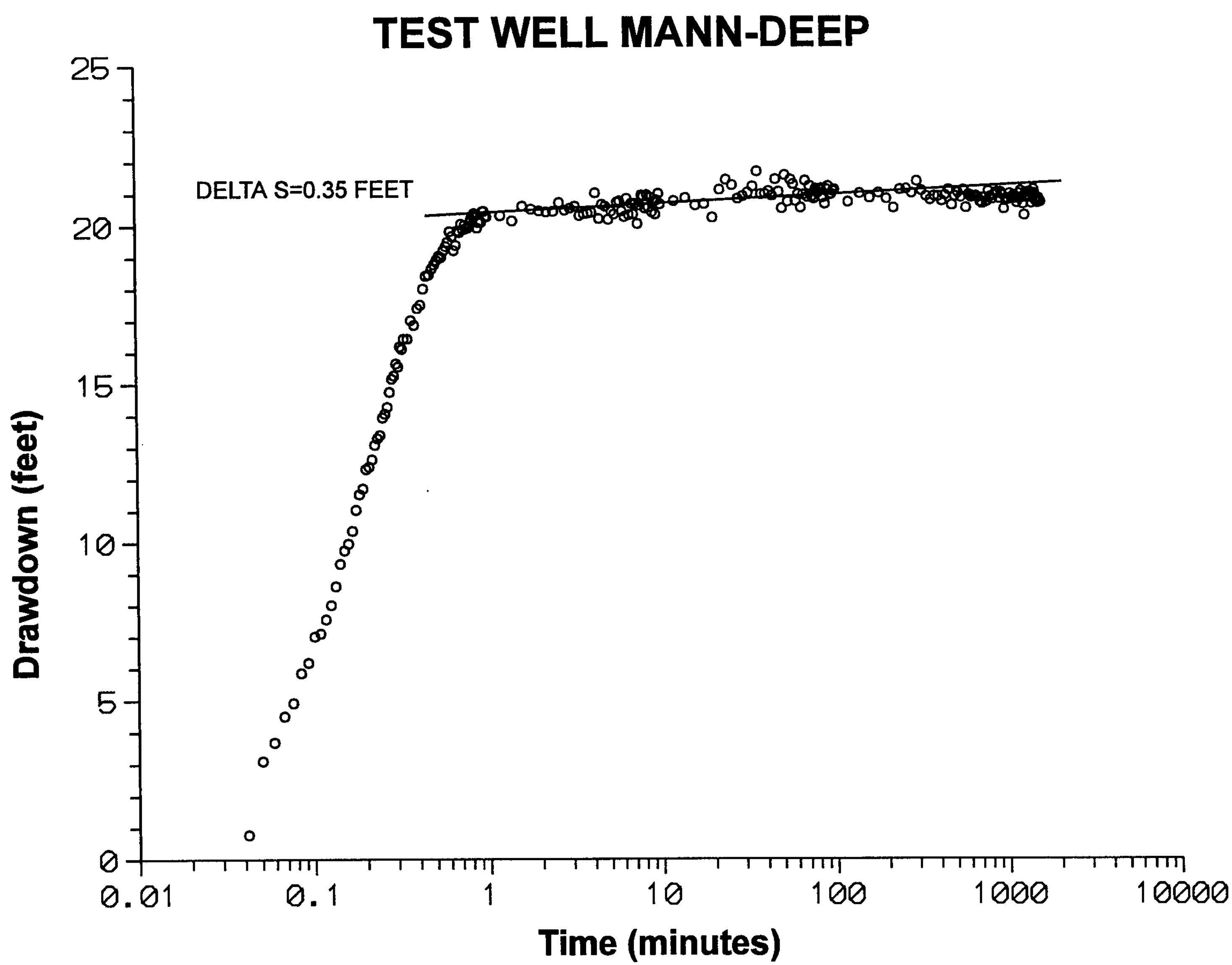

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FIGURE 4-10 . Semi-Log graph showing drawdown in test well MANN-DEEP while pumping the well at 97 gpm.

TABLE 4.2-6

DARE COUNTY-WIDE STUDY
SUMMARY OF TRANSMISSIVITY VALUES

Test Site	Transmissivity (GPD/FT)	Interval Tested (Feet BLS)	Aquifer
Kill Devil Hills	5,900	200-280	Principal (upper Yorktown)
Duck	70,000	100-160	Principal (upper Yorktown)
Mann's Harbor (Shallow Zone)	51,000	135-195	Principal (upper Yorktown)
Mann's Harbor (Deep Zone)	73,000	250-350	Mid-Yorktown

reverse osmosis plant is approximately 2500 mg/l. The relatively low salinity conditions found in the Kill Devil Hills test well indicates this Principal/upper Yorktown aquifer zone may be useful as a source of blend water for the reverse osmosis plant. A blend ratio of approximately 10% to 15% is currently used at the plant. It may be possible to increase the blend ratio to 20% or 25% by utilizing blend water with a lower salinity. However, it should be noted that analyses to evaluate the long-term stability of water quality in this zone under the influence of pumping have not been conducted.

The water quality within the Principal/upper Yorktown aquifer unit may have already been affected by wellfield pumpage from the underlying Mid-Yorktown aquifer. Samples obtained from a test well in Kill Devil Hills in 1972 installed by the state of North Carolina had dissolved chloride concentrations that ranged from 133 to 140 m/l in the depth interval from 228 to 266 feet below land surface. Pumpage induced leakage may have caused water quality changes in the overlying upper Yorktown aquifer. Water from the upper Yorktown aquifer may also require limited treatment for color removal prior to blending as a value of 31 color units was recorded for the sample obtained from well KDH-1. In spite of the potential problems noted above, the upper Yorktown aquifer may be a very good source of blend water for the reverse osmosis plant and its use for this purpose should be investigated further. The transmissivity of the zone is low so individual well yields would likely be limited to 200 gpm or less.

4.3.2 Duck

The water quality analyses results from test well Duck-1 indicate brackish conditions with a total dissolved solids concentration of 2200 mg/l. This quality water is slightly more saline than the average water quality obtained from the Kill Devil Hills reverse osmosis plant wellfield when it was placed into operation in 1989. The water obtained from test well Duck-1 appears to be suitable for low pressure reverse osmosis treatment. A thick sequence of very low permeability clay is present below the productive sand unit at the Duck test site. Additional testing to determine the lateral extent of this sand unit and further evaluate water quality and yield characteristics of the aquifer would be required prior to development of the source for public water supply purposes.

4.3.3 Mann's Harbor

The chemical analyses indicate that water quality in the upper sand unit, which is referred to as the Principal or upper Yorktown aquifer, is very good. The water is fresh and low in iron content and meets most of the state drinking water standards. Water from this aquifer would be suitable for public supply purposes with minimal treatment. Treatment for hardness using conventional or membrane softening methods would likely result in a finished water that meets state and federal drinking water standards. The use of an anion exchange resin to reduce trihalomethane (THM) formation potential may be necessary.

Water samples were obtained from several domestic wells in Mann's Harbor and subsequently analyzed for dissolved chloride concentration and iron content. All of the samples had low iron and chloride concentrations. It is likely that most domestic wells in the area tap the Principal aquifer or the shallow surficial aquifer. The Principal (upper Yorktown) aquifer exhibits very good water quality conditions and appears to be a viable source of water for public supply purposes.

Water samples obtained from test well Mann-Deep which taps the Mid-Yorktown aquifer were more mineralized than the samples obtained from the overlying upper Yorktown aquifer. However, the water quality was relatively good with a low dissolved iron concentration and a dissolved chloride concentration that falls below the state maximum contaminant level. The total dissolved solids and total hardness concentrations exceed the state recommended maximum for drinking water. It is likely that a membrane softening type treatment method would yield a product water that meets all of the applicable drinking water standards. However, the long-term stability of water quality in the Mid-Yorktown aquifer at Mann's Harbor might be affected by large scale pumpage. A water sample obtained from a test well drilled by the state of North Carolina in 1972 from the depth interval between 332 and 342 feet below land surface had a dissolved chloride concentration of 1510 mg/l. It is possible that water within the aquifer is density stratified with freshwater occurring near the top of the unit and brackish water present in the lower part of the unit. A test program designed to fully evaluate the aquifer yield potential and water quality with depth would be required prior to full scale development of the Mid-Yorktown aquifer as a public water supply for the community of Mann's Harbor.

4.3.4 Water Quality Summary

Water quality conditions varied significantly in samples obtained from the test wells installed for this investigation. As expected, better water quality was found in the wells constructed on mainland Dare County because of the closer proximity to the aquifer recharge area. However, water with suitable quality for development as a public supply source or to supplement an existing source was encountered in each of the test wells. A table that summarizes the water quality conditions determined during the test program is provided below.

TABLE 4.2-7

DARE COUNTY-WIDE STUDY
SUMMARY OF WATER QUALITY ANALYSES RESULTS

Well (Depth Interval)	Dissolved Chloride Concentration (mg/l)	Total Dissolved Solids (mg/l)	Iron (mg/l)	Color (color units)	Potential Use	Minimum Treatment Requirement
KDH-1 (200'-280')	290	840	0.021	31	Blend for R.O. permeate	Anion exchange for color removal
Duck-1 (100'-160')	1500	2500	1.12	12	Public supply source	Low pressure reverse osmosis
Mann Shallow (135'-195')	30	300	0.036	7	Public supply source	Conventional or membrane softening
Mann Deep (250'-350')	240	710	0.165	14	Public supply source	Membrane softening
Drinking Water Standard	250	500	0.300	15	N/A	N/A

*Anlayses results presented in this table provided by Dare County Water Department

5.0 HYDROGEOLOGY

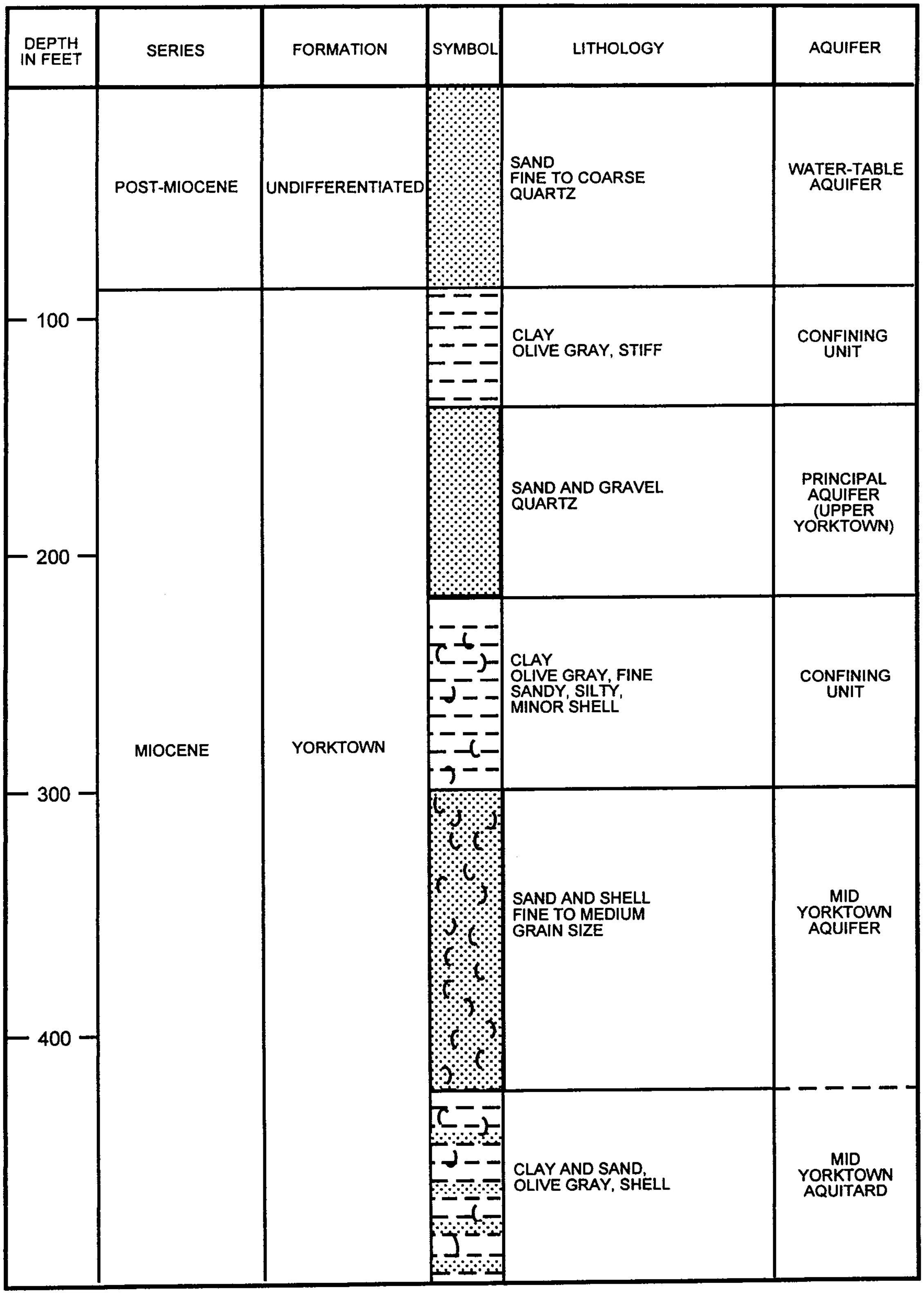
5.1 Geology

Hydrogeologic investigations in Dare County have been conducted by the North Carolina Department of Environment, Health, and Natural Resources, Division of Water Resources, the U.S. Geological Survey, and various consultants including Missimer International, Inc. The geologic descriptions provided herein are based on information obtained while drilling test wells for previous investigations at each of the wellfields operated by the Dare County Water Department. In addition, four test wells were constructed as part of this investigation to obtain further information on the hydrogeologic conditions in eastern Dare County. A generalized stratigraphic column showing the relative positions of the aquifers and confining units in the county is provided as Figure 5-1.

The uppermost and youngest strata encountered consist of undifferentiated marine and non-marine clastic sediments of post-Miocene age. The primary constituents include fine to coarse grained quartz sand with common shell beds and minor amounts of interbedded clay and fine grained phosphorite sand. Permeable sediments within these deposits form the water-table aquifer which is up to 100 feet thick or more in the study area. The water-table aquifer is currently the source of water for the Dare Hatteras water system and it is used throughout the county for domestic supply and irrigation purposes.

The Yorktown Formation of Miocene age underlies the surficial sand deposits. The formation consists of beds of fine to coarse grained sand and dense clay units with sandy limestone and sandstone layers also present in some locations. Thickness of the formation can exceed 500 feet in eastern Dare County. The Yorktown Formation is described in more detail below beginning with the upper confining beds.

The upper Yorktown Formation confining beds in the study area consist of olive-gray marine clays with interbedded fine sand, shell, and phosphate material. Thickness of the confining unit



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Pr. No. FH7-571 **DWG No.STR1** **Date:** 5/21/98

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FIGURE 5 - 1. GENERALIZED STRATIGRAPHIC COLUMN SHOWING THE RELATIVE POSITIONS OF AQUIFERS AND CONFINING UNITS IN EASTERN DARE COUNTY.

ranges from less than 50 feet to approximately 150 feet in the study area. These beds have a very low hydraulic conductivity and provide confinement between the surficial sands and the underlying Principal (upper Yorktown) aquifer.

Beneath the upper Yorktown confining beds is a unit of fine to very coarse grained sand and gravel with minor amounts of shell and clay interbedded. The Principal or upper Yorktown aquifer occurs within this unit which ranges from a thickness of 100 feet or more in some locations to very thin or absent in southern Dare County. The Principal aquifer is the unit tapped by the Skyco wellfield and is also the source of water to many domestic wells on Roanoke Island and the Dare County mainland.

A low permeability dense marine clay layer that contains minor amounts of silt, sand, and shell lies beneath the Principal aquifer and separates it from the underlying Mid-Yorktown aquifer. The thickness of this unit is variable ranging from approximately 30 and 45 feet in Mann's Harbor and Kill Devil Hills, respectively, to over 200 feet in Duck.

The Mid-Yorktown aquifer lies beneath the Yorktown Formation confining beds in eastern Dare County. In most areas, the aquifer consists primarily of medium to fine grain quartz sand with occasional shell, phosphatic material, and coarse sand layers. However, a limestone facies was encountered in test wells drilled near Frisco in southern Dare County. The limestone unit at Frisco is a relatively well consolidated, dark gray, biogenic, skeletal limestone with well developed secondary porosity (Missimer International, Inc., 1998). In addition, sandstone facies were encountered within this unit in test wells drilled at Mann's Harbor and Rodanthe. The Mid-Yorktown aquifer was not encountered in the test well constructed at Duck to a depth of 400 feet. Where present, the aquifer generally attains a thickness of 100 feet or more. The Mid-Yorktown aquifer is the source of water for the two reverse osmosis plants currently operated by the county and is the proposed source of water for the reverse osmosis plant that will be constructed to supply the Dare Hatteras water system. Low permeability sediments within the Mid-Yorktown aquitard separates the Mid-Yorktown aquifer from underlying units. A north-south hydrogeologic cross-section showing the depths at which the various aquifers and confining units are encountered in eastern Dare County is provided as Figure 5-2. The geologic cross-section line is shown on Figure 5-3.

5.2 Aquifer Hydraulic Characteristics

Water-Table Aquifer

The water-table aquifer is the uppermost water bearing unit in the study area and is by definition unconfined or in direct contact with atmospheric pressure. This aquifer is currently the source of public water supply on Southern Hatteras Island which is the only location where detailed testing of the aquifer has been conducted in the study area. The transmissivity of the aquifer in the Buxton woods area of Hatteras Island is estimated to range between 20,000 and 40,000 gpd/ft based on testing conducted there (Burkett, 1996). Transmissivity is a term that indicates the ease at which water flows through the aquifer and is equal to the product of the aquifer hydraulic conductivity (permeability) times the saturated aquifer thickness. Transmissivity values are often expressed in the units of gallons per day per foot which indicates the amount of water that will flow through a vertical strip of the aquifer one foot wide with a hydraulic gradient of one. Transmissivity of the aquifer in other areas is likely to range from less than 5000 gpd/ft up to 50,000 gpd/ft depending upon the aquifer thickness, grain size of the sand, and the relative amounts of interbedded clay and shell. The specific yield may range from 0.10 to 0.25. Recharge to the aquifer is by direct infiltration of precipitation. Discharge occurs through pumpage, evaporation, transpiration, and outflow to surface-water bodies. Water levels vary based on local topography, hydraulic conductivity, pumpage, and precipitation amounts and are typically within five feet or less of land surface.

Principal Aquifer

The hydraulic characteristic of the Principal aquifer vary considerably across eastern Dare County. In Kill Devil Hills the aquifer is comprised primarily of fine to medium grained sand with interbedded clay and shell layers. The transmissivity of the aquifer in Kill Devil Hills is relatively low and estimated to be approximately 5900 gpd/ft based on a single well test conducted as part of this investigation. Recently conducted pump tests at Mann's Harbor and

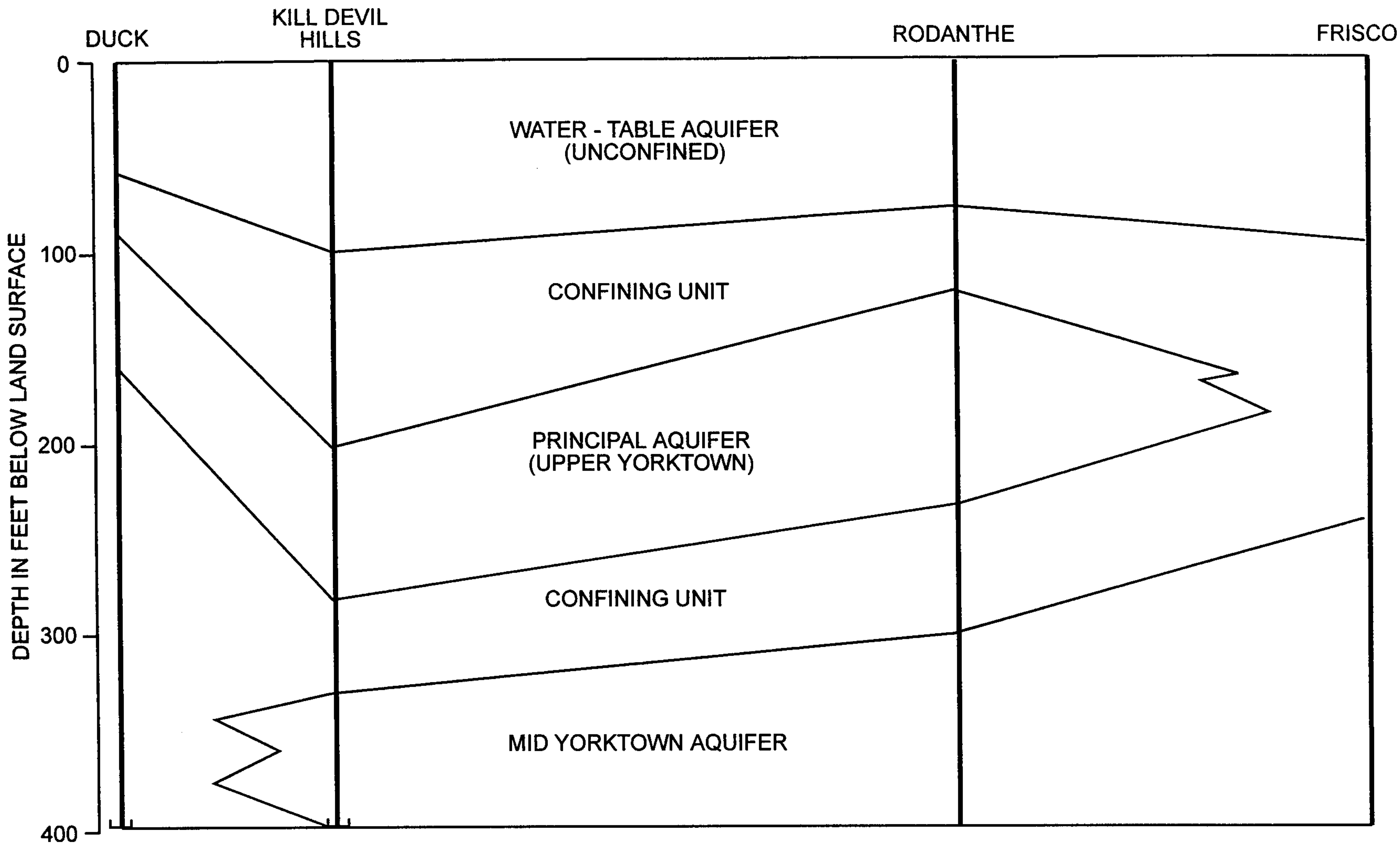

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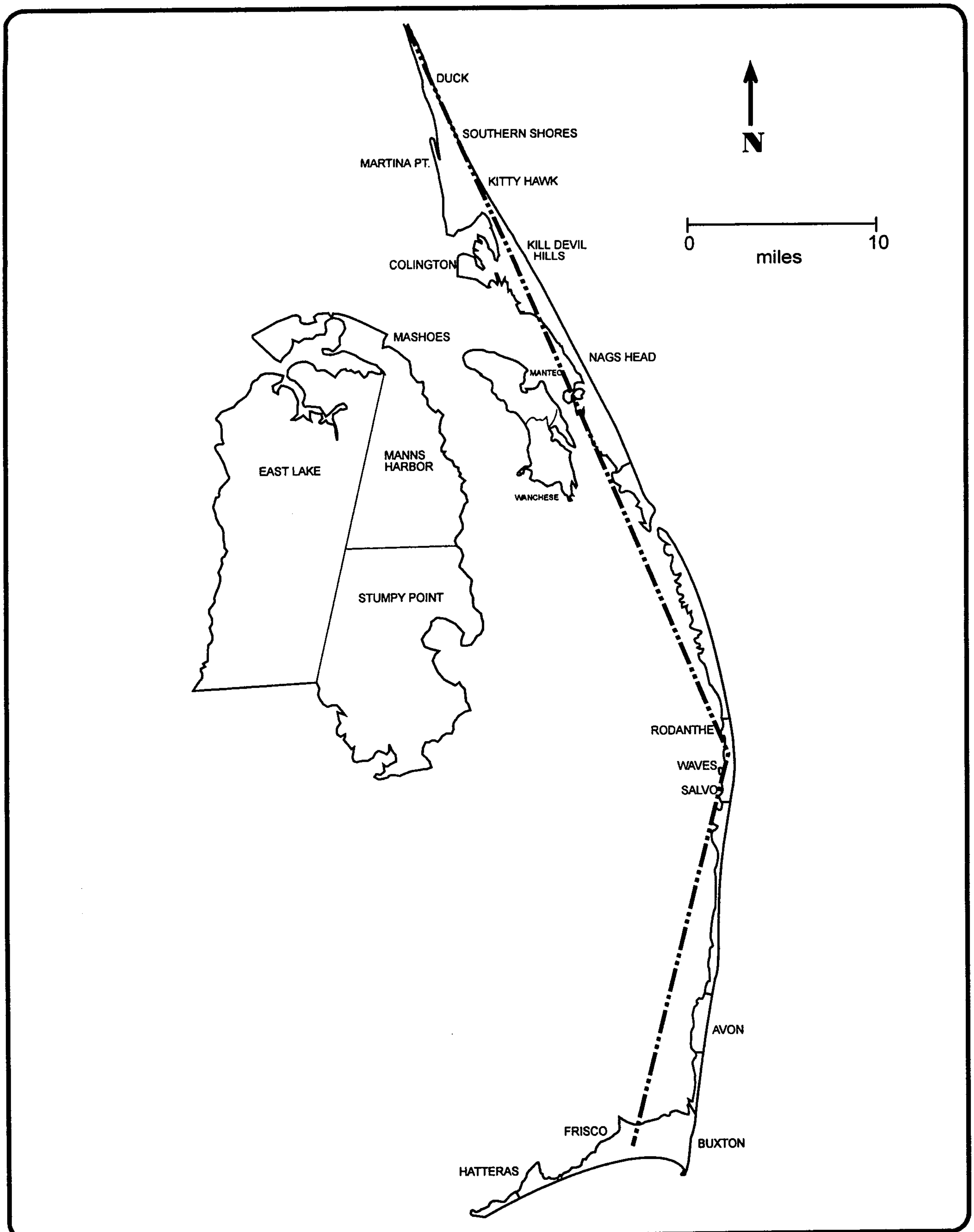
FIGURE 5 - 2. NORTH - SOUTH HYDROGEOLOGIC CROSS-SECTION OF THE OUTER BANKS FROM DUCK TO FRISCO.



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Pr. No. FH7-571 **DWG No.**WDC-1**Date:** 5/21/98

Groundwater and Environmental Services

FIGURE 5 - 3. LINE OF NORTH - SOUTH HYDROGEOLOGIC CROSS SECTION IN DARE COUNTY.

Duck yielded transmissivity values for the Principal aquifer of approximately 50,000 and 70,000 gpd/ft, respectively. Coarse sand and gravel units were present within the aquifer at these test sites. A transmissivity value of 60,000 gpd/ft was estimated for the aquifer by the state based on a pump test conducted in 1972 near the Skyco wellfield site on Roanoke Island. Recharge to the aquifer in eastern Dare County is thought to occur primarily by vertical leakage through the overlying confining unit and from lateral inflow from inland areas. Discharge from the aquifer occurs from well pumpage and lateral flow to the sea. Water levels in the aquifer are generally above mean sea level and within 5 or 10 feet of land surface. The exception occurs near centers of pumpage where drawdown effects can result in water levels of over 20 feet below land surface. A water level of 24 feet below land surface was recorded in August of 1993 in monitor well J303 which was installed by the DEHNR adjacent to the Skyco wellfield.

Mid-Yorktown Aquifer

The transmissivity of the Mid-Yorktown aquifer in eastern Dare County is also variable but typically exceeds 50,000 gpd/ft (Missimer & Associates, 1992). The lithologic characteristics of the aquifer vary considerably across the county. Higher transmissivity values occur where fossiliferous, high permeability, limestone units are present in the aquifer and lower transmissivities are noted where fine to medium grained sand is the primary aquifer constituent. Aquifer tests have been conducted on the Mid-Yorktown aquifer at Kill Devil Hills, Rodanthe, Mann's Harbor, and in Frisco. Transmissivity values range from approximately 45,000 gpd/ft up to 290,000 gpd/ft based on the test results. Transmissivity values for the Mid-Yorktown aquifer in eastern Dare County are summarized in Table 5.2-1. Recharge to the aquifer occurs on the mainland west of the Outer Banks, primarily from direct rainfall infiltration where the Yorktown Formation crops out at land surface. In addition, brackish water recharge occurs where the Albermarle and Pamlico Sounds intersect the recharge area of the Mid-Yorktown aquifer. During pumpage, additional recharge is induced by vertical leakage through overlying and underlying confining units. Discharge from the aquifer occurs from lateral flow to the sea and well pumpage. Water levels in the aquifer are typically above mean sea level and within 10 feet of land surface but are significantly lower near centers of pumpage. At the Kill Devil Hills wellfield water levels in the aquifer are currently 20 to 25 feet below land surface compared to

TABLE 5.2-1 MEASURED TRANSMISSIVITY VALUES FOR THE MID-YORKTOWN AQUIFER DARE COUNTY, NORTH CAROLINA

Location	**Transmissivity (gpd/ft)**	**Aquifer Use**
Kill Devil Hills	64,000 - 160,000	R.O. Feedwater
Rodanthe	45,000 - 89,000	R.O. Feedwater
Mann's Harbor	73,000	Not Used
Frisco	230,000 - 290,000	R.O. Feedwater (proposed)

approximately 10 feet below land surface before the wellfield was placed into operation. Recent measurements from monitor wells tapping the Mid-Yorktown aquifer near the Frisco water plant showed water levels were near land surface or approximately 5 feet above mean sea level. Water levels measured in the test wells completed at Mann's Harbor showed the potentiometric surface of the Principal aquifer was approximately 3 feet higher than that of the underlying Mid-Yorktown aquifer indicating that some potential recharge to the Mid-Yorktown aquifer may occur due to vertical leakage from the Principal aquifer.

5.3 Water Quality

Water-Table Aquifer

Water quality in the surficial or water-table aquifer is highly variable depending upon location and depth. On the mainland, generally freshwater conditions are present while on the barrier islands only a lense of freshwater floating on denser seawater occurs. The depth to which freshwater is present on the islands depends on the proximity of saline surface-water bodies, topography, and climatic conditions. A relatively thick freshwater lense occurs on southern Hatteras Island between Buxton and Frisco because the island is over 2 miles wide in this area and receives substantial recharge from precipitation. Freshwater occurs to a depth of approximately 100 feet at the Frisco wellfield which currently uses the water-table aquifer as the source of supply. Water from this wellfield has relatively high levels of color, dissolved iron, and organics and requires extensive treatment to meet potable standards. Lower levels of dissolved iron, color, and organic constituents are present in the lower part of the aquifer and the County is in the process of replacing shallower wells screened between 30 and 50 feet below land surface with wells screened from 60 to 70 feet. The water-table aquifer is used for domestic supply and irrigation purposes throughout Dare County. Most of these wells are shallow since saline water can occur at depths of 20 feet below land surface or less in some areas.

Principal Aquifer

Water quality in the Principal or upper Yorktown aquifer is also highly variable in eastern Dare County. Freshwater occurs at Mann's Harbor and on Roanoke Island where this aquifer is tapped by the Skyco wellfield. On the Outer Banks water quality within the aquifer ranges from slightly brackish to near seawater. The test well recently completed as part of this study at Kill Devil Hills within the Principal aquifer had a dissolved chloride concentration of 290 mg/l. At Rodanthe, dissolved chloride concentrations in samples obtained from test well TW-2 which taps the Principal aquifer average approximately 17,000 mg/l. A dissolved chloride concentration of 1500 mg/l was measured in samples obtained from the test well recently completed in this aquifer at Duck indicating the Principal aquifer may be a viable source of raw water for reverse osmosis treatment at this location.

Mid-Yorktown Aquifer

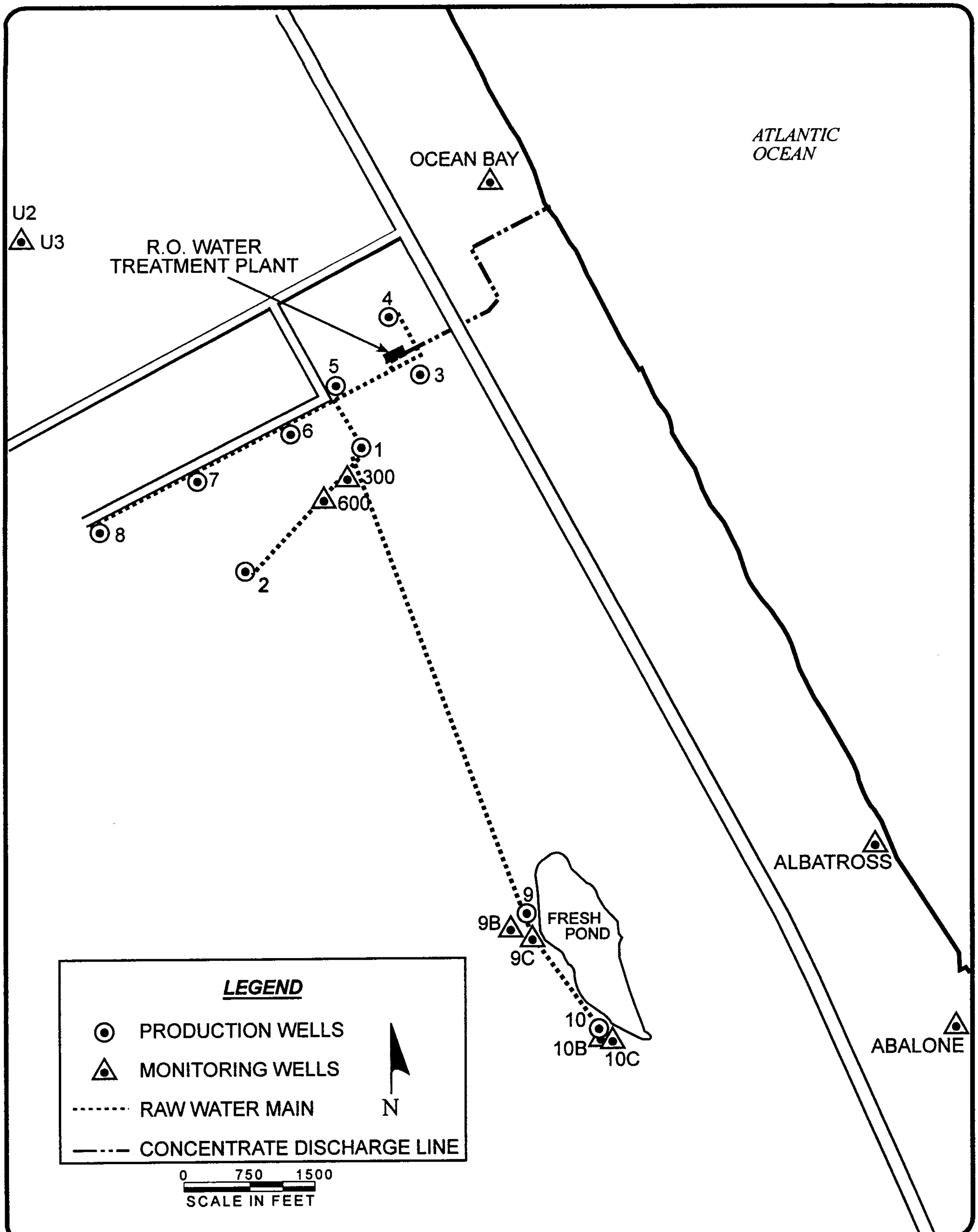
Brackish water occurs within the Mid-Yorktown aquifer throughout most of the study area. Again, water quality is highly variable depending upon the location in the county. A dissolved chloride concentration of 240 mg/l and TDS concentration of 710 mg/l were measured in a sample obtained from the Mid-Yorktown aquifer test well recently constructed in Mann's Harbor. Water within the Mid-Yorktown aquifer is significantly more saline on the Outer Banks. The production wells that supply the reverse osmosis plant at Kill Devil Hills tap the Mid-Yorktown aquifer and currently have an average dissolved chloride concentration of approximately 2500 mg/l. The dissolved chloride concentration from the production wells has approximately doubled since the wellfield was placed into operation in 1989. The increase in dissolved chloride concentrations is attributed to recharge from the lower part of the aquifer or next lower aquifer. Monitor wells completed at varying depths show that salinity levels increase with depth due to density stratification. At Rodanthe, the dissolved chloride concentration of samples obtained from the Mid-Yorktown aquifer production wells average approximately 500 mg/l, but values ranging from 3700 mg/l to over 10,000 mg/l were recorded for samples obtained from the Mid-Yorktown aquifer test wells constructed near Frisco. The variation in water quality within the aquifer is likely related to the relative proximities of tidal saline surface-water bodies and aquifer recharge areas. Density stratification within the aquifer also occurs at Rodanthe and Frisco based on deep monitor well data from these locations.

6.0 WATER SUPPLY EVALUATIONS AND MODELING

Computer model simulations were used to evaluate the impacts associated with water-supply development at each of the study areas considered. In each case, a hydraulic flow model was used to estimate the amount of drawdown that might occur due to pumpage for public supply purposes. At Kill Devil Hills, hydraulic and solute transport computer models of the aquifer system developed previously were used to assess drawdown impacts and water quality changes that might occur due to expansion of the reverse osmosis plant and wellfield. Descriptions of the water-supply evaluations conducted at each area are provided in the following subsections of this report.

6.1 Kill Devil Hills

The reverse osmosis plant at Kill Devil Hills has been in operation since August of 1989 and is supplied by a wellfield that taps the Mid-Yorktown aquifer between the approximate depths of 320 and 420 feet below land surface. Initially, eight wells constructed on the Baum Tract near the R.O. plant were used for raw water supply. The average total dissolved solids (TDS) concentration of the raw water obtained from the wellfield increased by approximately 50% from roughly 2000 mg/l to 3000 mg/l in the first two years of plant operation. A study of the aquifer system was authorized by the Dare County Commission to determine the cause of the relatively rapid water quality degradation. Hydraulic and solute transport computer models were developed to simulate the aquifer response to pumpage and estimate future changes in water quality. A detailed description of how the models were constructed and used for predictive purposes is provided in the report entitled "Investigation and Predictive Modeling of Water Quality Changes Within the Yorktown Aquifer, Dare County, North Carolina" (Missimer & Associates, Inc., 1992). The primary conclusion of the study was that excessive drawdown in the aquifer at the Baum Tract wellfield was inducing adverse water quality changes. A recommendation was made to construct two additional production wells south of the Baum Tract to spread the pumpage over a larger area. Production wells #9 and #10 were constructed and placed into operation in 1994. Locations of the existing production wells are shown on Figure 6-1.



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Pr. No. FH7-571 **DWG No.**WDC-1 **Date:** 5/17/98

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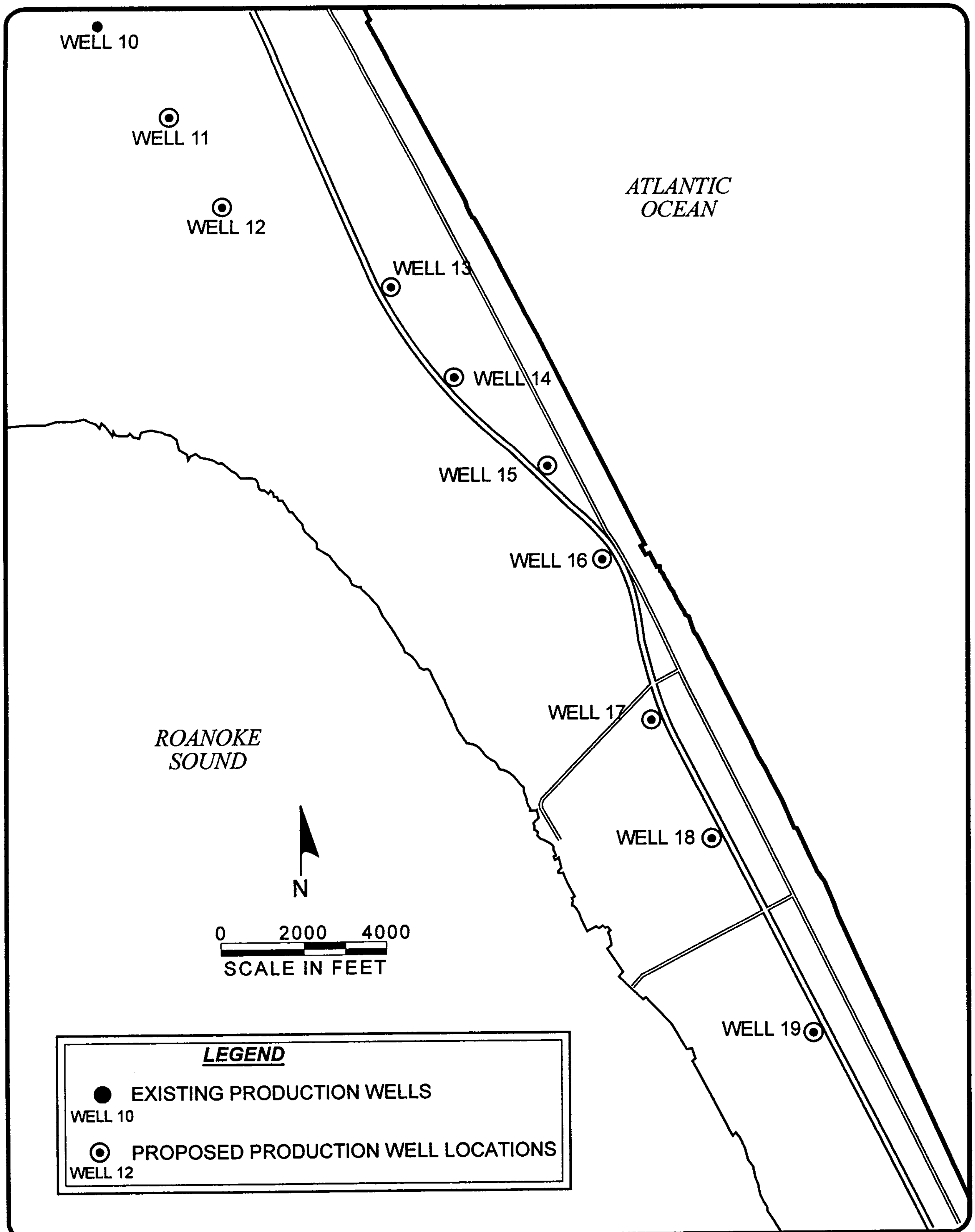
FIGURE 6 - 1. MAP SHOWING LOCATIONS OF KILL DEVIL HILLS R.O. PLANT AND EXISTING PRODUCTION AND MONITOR WELLS.

Installation of the two additional supply wells was successful in reducing the rate of water quality change. The water quality changes predicted by the solute model developed for the study agree closely with actual water quality data collected by the water plant operators over the past several years indicating the model was well calibrated and useful for predicting future water quality changes. The existing computer models were therefore used to estimate drawdowns and water quality changes that may occur due to increased pumpage from the wellfield.

The modeling scenario considered for this study included adding two new production wells in the year 2000 to increase the finished water capacity of the R.O. plant by approximately 1.0 MGD. Additional well pairs were added at 5 year increments in the years 2005, 2010, and three wells were added in the year 2015. The final scenario included a total of 19 wells pumping at a combined maximum raw water pumping rate (June, July, August) of 10.34 MGD. Peak pumpage from the original eight wells is limited to a maximum of 3.5 MGD. The final average pumping rate was 6.84 MGD which is consistent with the current peak to average pumping ratio at this facility of approximately 1.5:1. Well locations were selected based on proposed sites provided by Dare County staff at the locations shown on Figure 6-2. The model was run to the year 2020. Predicted average raw water quality to be expected from the wellfield from the present to the year 2020 is shown on Figure 6-3. This curve is the high range of the prediction averaged over the seasonal variation. A sensitivity analysis would provide a slightly greater range of values. The data shown through 1997 are real. The predictions begin after 1997.

Simulated drawdowns in the Mid-Yorktown aquifer at years 2000, 2010, and 2020 are presented in Figures 6-4 through 6-6. The simulation results indicate that an average raw water TDS of approximately 6000 mg/l can be expected in the year 2020 after the wellfield has been expanded by the addition of nine wells and the produced water capacity of the plant is increased to 8.0 MGD. A maximum drawdown of 17 feet near the center of the wellfield is predicted. The modeling results indicate that expansion of the wellfield and R.O. plant is feasible with acceptable water quality changes and source aquifer drawdowns. It should be noted that the modeling scenarios were conducted based on available data and that the amount of water quality data available for the Mid-Yorktown aquifer south of Kill Devil Hills is limited. Construction of test



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Pr. No. FH7-571 **DWG No.** WDC-1 **Date:** 5/17/98

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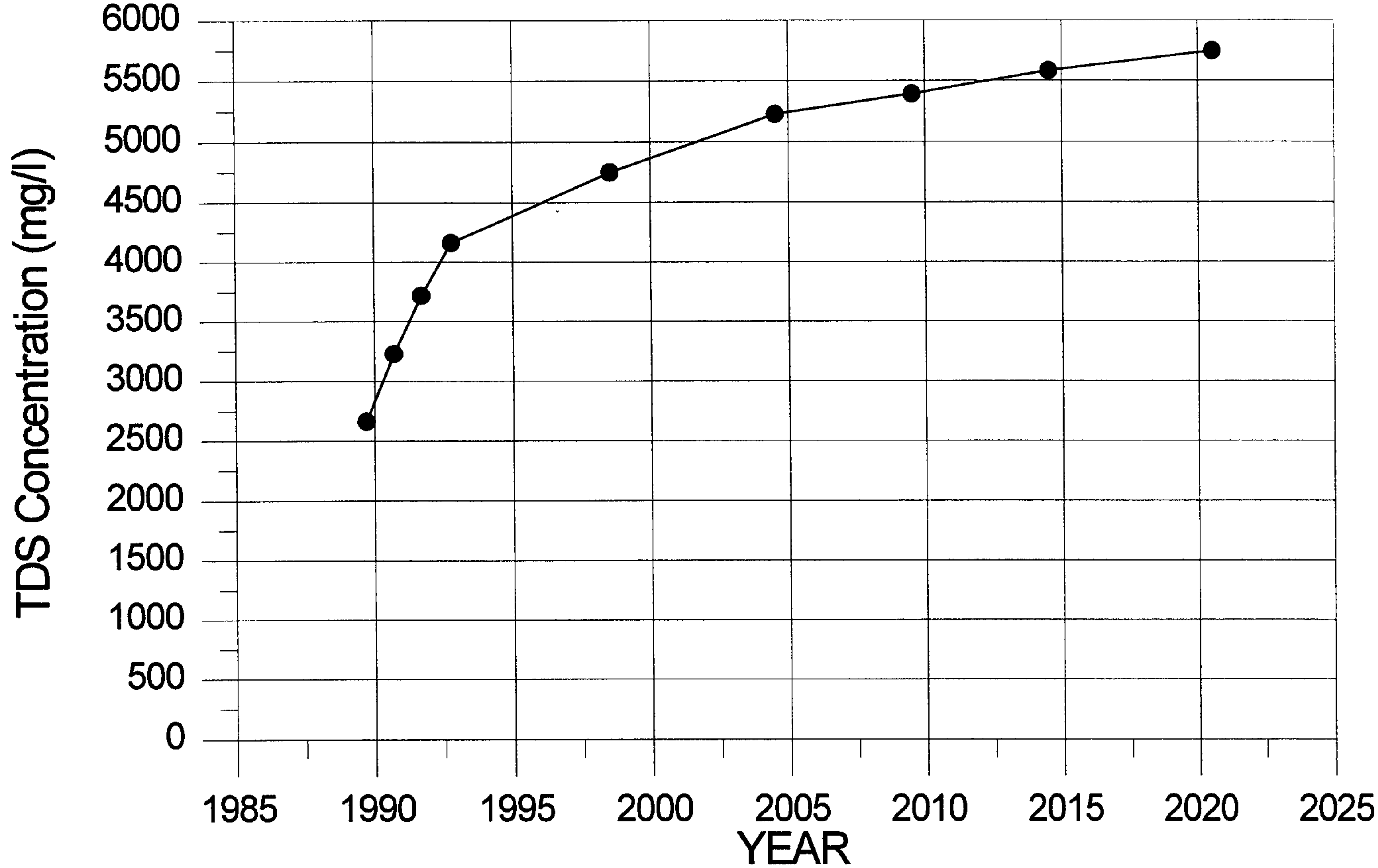
FIGURE 6 - 2. PROPOSED NEW PRODUCTION WELL LOCATIONS FOR THE KILL DEVIL HILLS R.O. PLANT.



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Pr.No.FH7-571 Date: 05/22/1998

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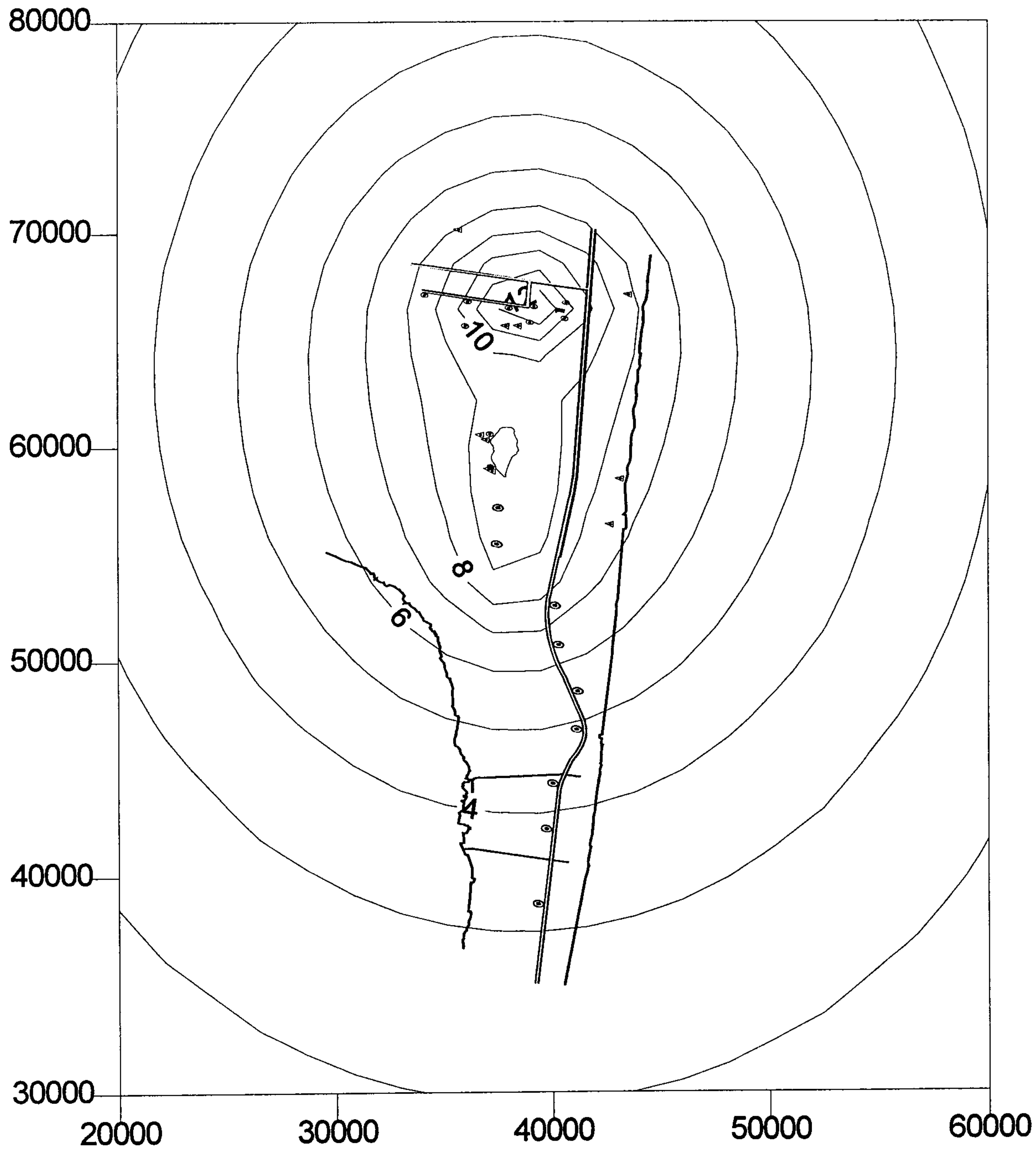
FIGURE 6-3. MODEL PREDICTED AVERAGE KDH WELL-FIELD RAW WATER QUALITY FROM 1989 TO 2020.



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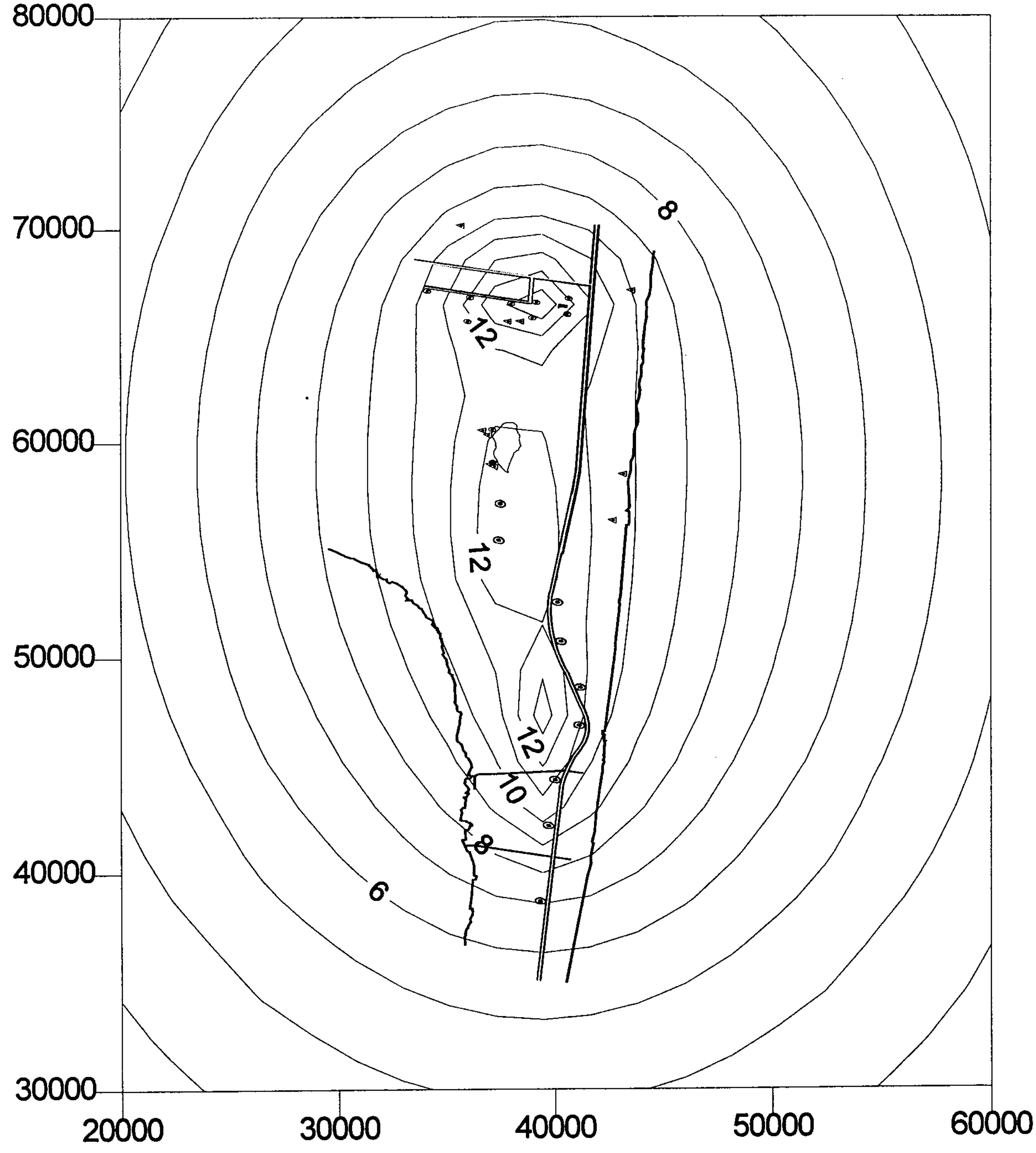
Pr.No. FH7-571 Date: 05/22/1998

Groundwater and Environmental Services

FIGURE 6-4. SIMULATED PEAK DRAWDOWN (FT) IN THE MID-YORKTOWN AQUIFER - YEAR 2000 at KDH WELLFIELD.



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Pr.No.FH7-571 Date: 05/22/1998

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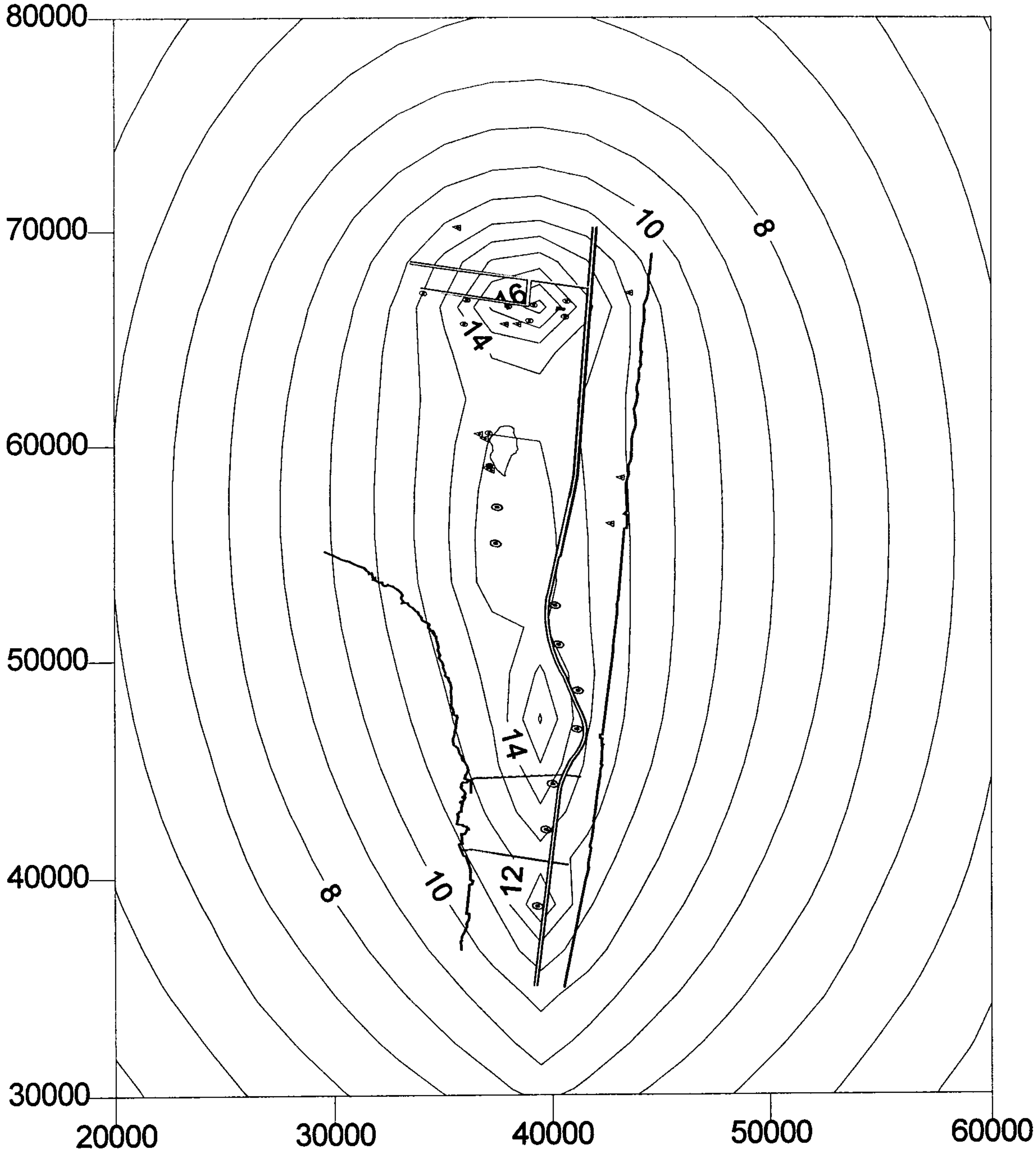
FIGURE 6-5. SIMULATED PEAK DRAWDOWN (FT) IN THE MID-YORKTOWN AQUIFER - YEAR 2010 at KDH WELLFIELD.



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Pr.No.FH7-571 Date: 05/22/1998

Groundwater and Environmental Services

FIGURE 6-6. SIMULATED PEAK DRAWDOWN (FT) IN THE MID-YORKTOWN AQUIFER - YEAR 2020 at KDH WELLFIELD.

wells near the middle and terminus of the proposed extended wellfield alignment is recommended to evaluate water-quality conditions and aquifer yield potential at these locations prior to the installation of new production wells and pipeline infrastructure. As more information becomes available, the solute transport (water quality) model should be revised.

6.2 Duck

Results of test drilling conducted at Duck indicate that large scale pumpage for public water supply purposes may be feasible at this location. A high permeability sand and gravel unit was encountered between the depths of 100 and 160 feet below land surface in test well Duck-1. Pump test results indicate the transmissivity of this zone is approximately 70,000 gpd/ft. Water quality analyses results indicate the water may be suitable for low pressure reverse osmosis treatment.

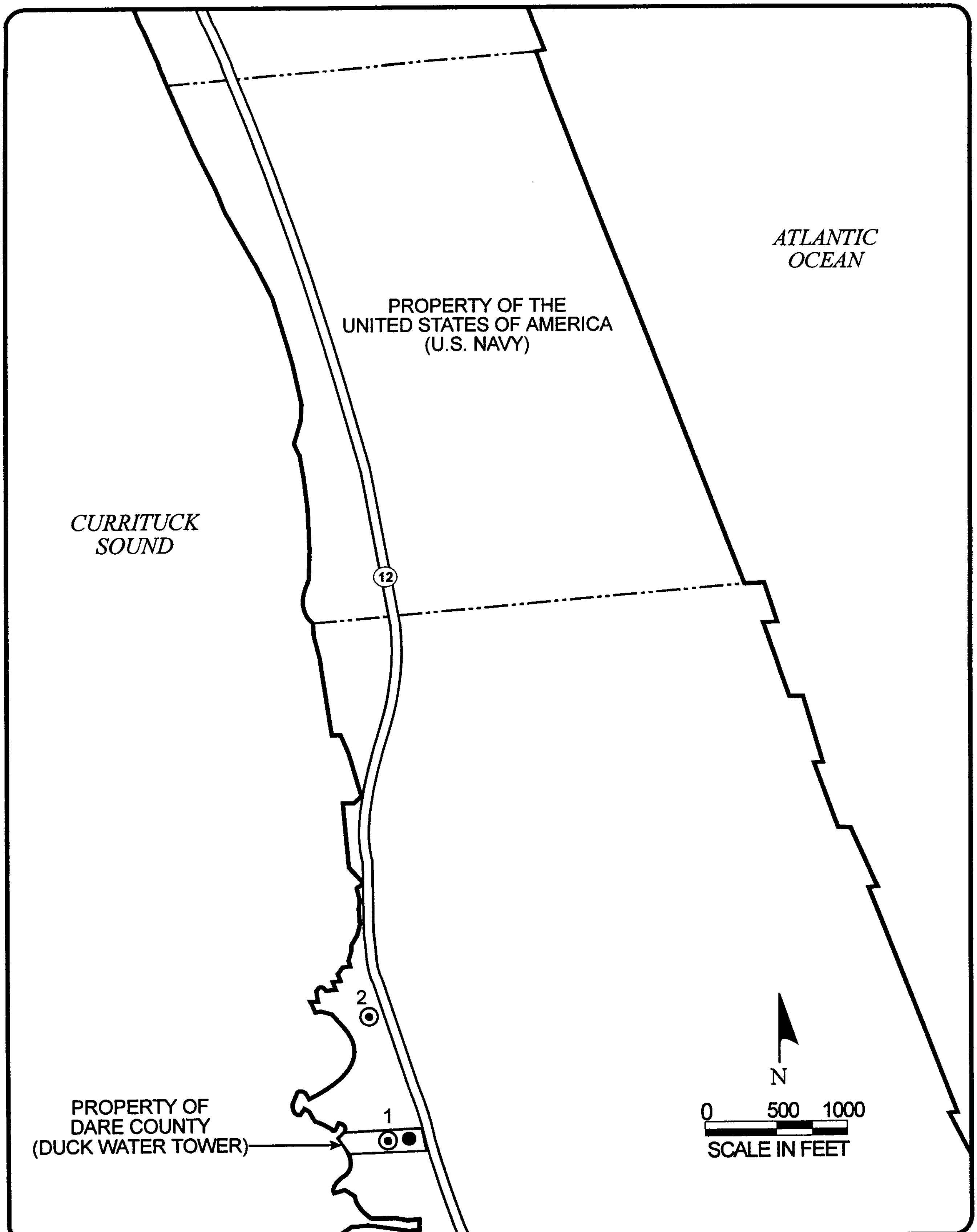
A three-dimensional hydraulic flow model of the site was developed using the U.S. Geological Survey finite difference code MODFLOW (McDonald and Harbaugh, 1988). A three layer representation was used to correspond to the observed hydrostratigraphic units identified during test drilling. The aquifer parameters used in the model are summarized in Table 6.2-1. A variably spaced model grid configuration was utilized with small grid spacing near well cells for higher resolution and large spacing away from the area of interest. The grid used for this modeling effort included 68 rows and 68 columns. The lateral boundaries of the model were set far from the well cells to minimize boundary effects on the model results. Constant head cells were placed at the perimeter of the model and a no-flow boundary is used to represent the thick clay layer lying below the aquifer. The model was used to simulate two wells pumping at 500 gpm each spaced 1000 feet apart for a period of 90 days with no recharge. Potential well locations are shown on Figure 6-7. A maximum drawdown of approximately 12 feet in the aquifer near a production well can be expected based on the model results. Model simulated drawdowns in the aquifer are shown on Figure 6-8.

TABLE 6.2-1 SUMMARY OF AQUIFER PARAMETERS USED FOR MODELING PURPOSES AT DUCK

Layer	Lithology	Thickness (feet)	Horizontal Hydraulic Conductivity* (feet/day)	Storage Coefficient
1	Sand and shell	55	49.0	0.20**
2	Clay	35	0.1	1×10^{-5}
3	Sand and gravel	70	134.0	2×10^{-5}

*An anisotropy ratio of 10:1 for horizontal hydraulic conductivity to vertical hydraulic conductivity was used for each layer.

**Specific Yield



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Pr. No. FH7-571 DWG No.WDC-1 Date: 5/17/98

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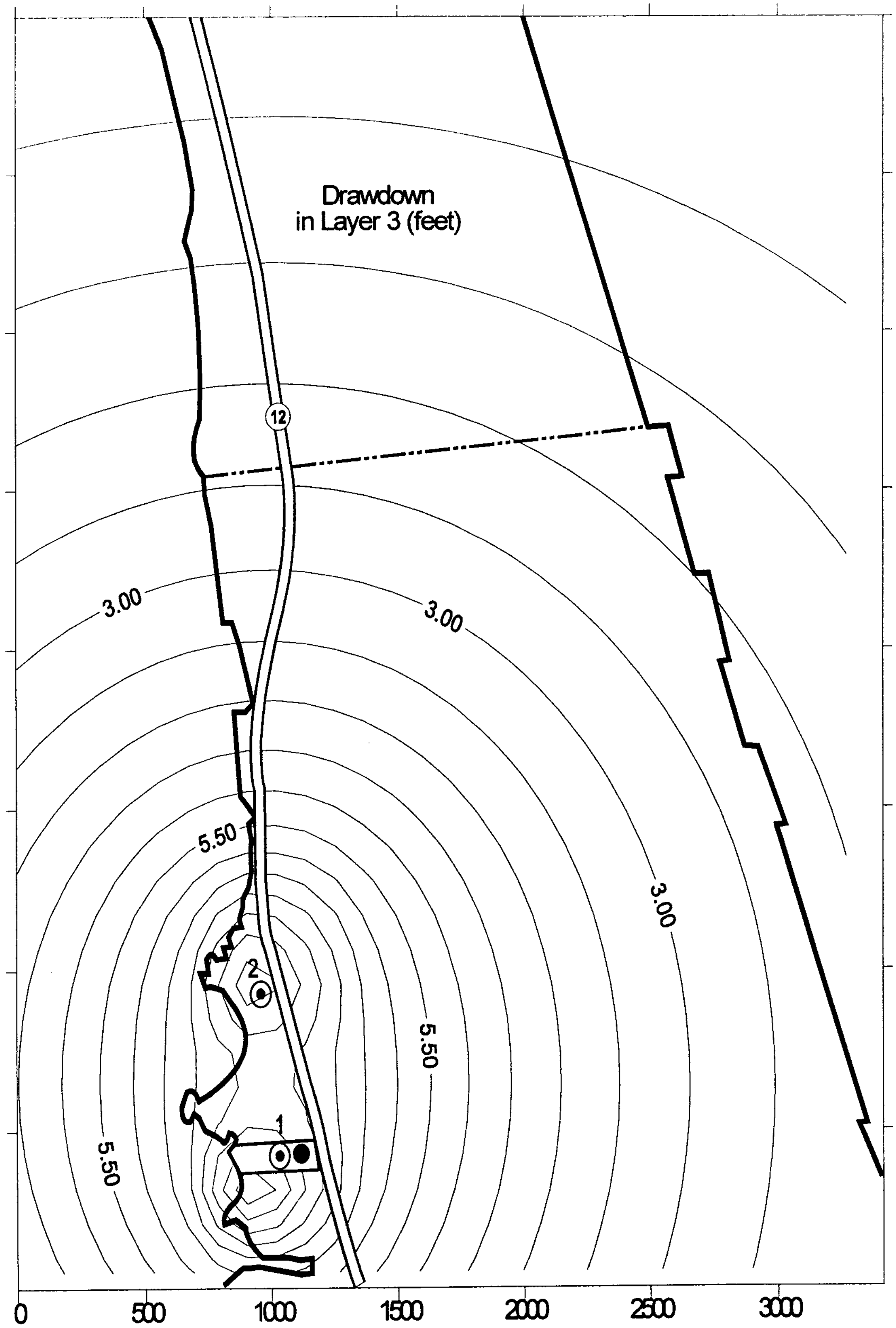
FIGURE 6 - 7. SITE MAP SHOWING POTENTIAL PRODUCTION WELL LOCATIONS AT DUCK.



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DWG No. 571-6.8 Rev. No.

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FIGURE 6-8. Model simulated drawdown from two wells pumping at 500 gpm each for 90 days without recharge.

Preliminary test drilling and modeling efforts completed at Duck indicate that development of a source of water for public supply purposes there is feasible. The modeling scenario considered a raw water pumping rate of 1000 gpm which is adequate to supply a reverse osmosis plant with a finished water capacity of 1.0 MGD assuming a recovery efficiency of approximately 70%. A facility very similar to the reverse osmosis plant at Rodanthe could be constructed at Duck with an initial capacity of 1.0 MGD and the ability for expansion to 2.0 MGD. Product water could be piped directly into the existing distribution system. The costs for reverse osmosis plant and wellfield construction would likely be similar to the costs for the Rodanthe plant and wells. It should be noted that the feasibility analysis presented above is very preliminary in nature and based on aquifer yield and water quality results from a single test well. Additional test drilling, aquifer performance testing and solute transport modeling are recommended prior to the design and construction of a wellfield and treatment plant in Duck.

6.3 Roanoke Island

The Skyco water treatment plant on Roanoke Island has the highest water production capacity of the water treatment facilities operated by the Dare County Water Department. This facility has been in operation since 1979 and currently produces an annual average of approximately 1.5 MGD of potable water. During the summer months, average daily production increases to approximately 3.0 MGD and peak production from the plant can exceed 5.0 MGD. Water quality in the production wells has remained stable since the plant was put into operation which indicates that the safe yield of the aquifer has likely not been exceeded by the current withdrawal amounts. The feasibility of increasing the capacity of the Skyco wellfield and water plant was investigated as part of this study.

In addition to providing feedwater to the Skyco water plant, the Principal aquifer supplies many domestic wells in the Wanchese area. The County received numerous reports of domestic well pump problems due to low ground water levels from the residents of Wanchese during the 1980s and 1990s. The County replaced wells and pumps for many residents of Wanchese to alleviate these problems. The feasibility of expanding the Skyco wellfield is contingent upon the residents of Wanchese connecting to the County water system.

The additional drawdown that would result due to expansion of the wellfield was estimated by constructing a three-dimensional hydraulic flow model of the aquifer system. The MODFLOW code was utilized and a three layer representation of the aquifer system was developed. Aquifer parameters used in the model are summarized in Table 6.3-1. A transmissivity value of 60,000 gpd/ft was used for the Principal aquifer based on values reported for this unit on southern Roanoke Island by the state of North Carolina (Peek, 1972). A variably spaced grid consisting of 54 rows and 54 columns was used. Lateral boundaries of the model were placed far from the well cells to reduce boundary effects. Constant head boundaries were used at the perimeter of the model and a no flow boundary forms the bottom of the model. The model was used to simulate pumpage from the existing 10 wells with 3 additional wells extending southeast from production well #4 with spacings of approximately 1500 feet. Existing and proposed well locations are shown on Figure 6-9. A combined pumpage rate of 5.5 MGD from the wellfield for 90 days without recharge was considered. This rate is approximately 2.0 MGD greater than the average summer time pumpage over the last 3 years. A maximum drawdown of approximately 13 feet in the aquifer near the production wells can be expected based on the model results. Simulated drawdowns in the aquifer are shown on Figure 6-10. The increase in pumpage due to expansion of the wellfield could result in up to 5 additional feet of drawdown to residential wells in Wanchese during the summer season. This additional drawdown might cause well withdrawal problems for residents with shallow well centrifugal pumps. It should be noted that prior to expansion of the wellfield, a more detailed model effort should be completed including evaluating the potential for long-term water quality changes.

6.4 Rodanthe, Waves, and Salvo

The reverse osmosis plant and wellfield that supply the RWS water system currently has an installed production capacity of 1.0 MGD. The capacity of the water system is adequate to meet current and projected demands. However, population growth rates are difficult to predict

TABLE 6.3-1 SUMMARY OF AQUIFER PARAMETERS USED FOR MODELING PURPOSES AT ROANOKE ISLAND

Layer	Lithology	Thickness (feet)	Horizontal Hydraulic Conductivity* (feet/day)	Storage Coefficient
1	Sand and shell	80	80.0	0.20**
2	Clay	60	0.2	1×10^{-5}
3	Sand and gravel	90	90.0	5×10^{-5}

*An anisotropy ratio of 10:1 for horizontal hydraulic conductivity to vertical hydraulic conductivity was used for each layer.

**Specific Yield

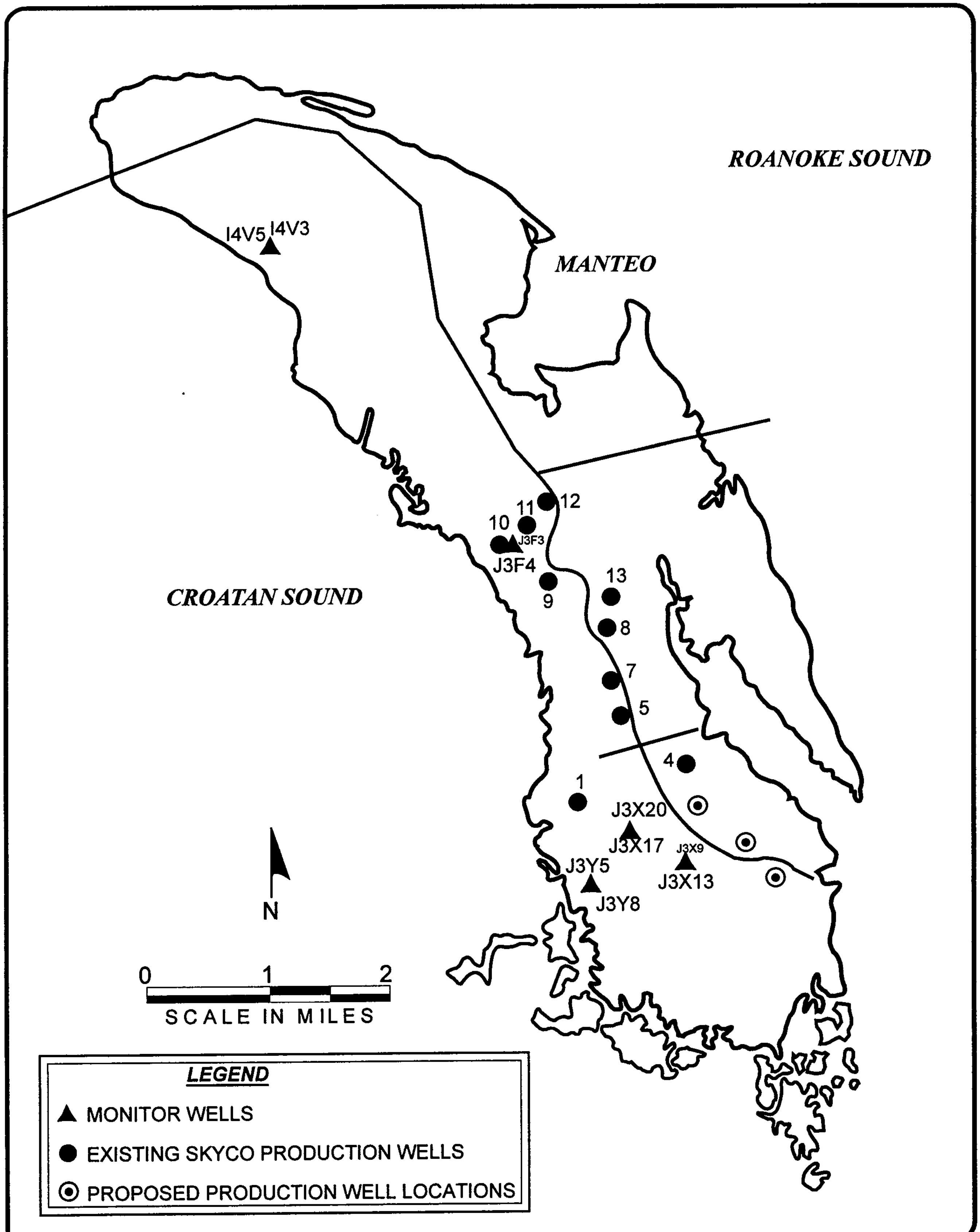

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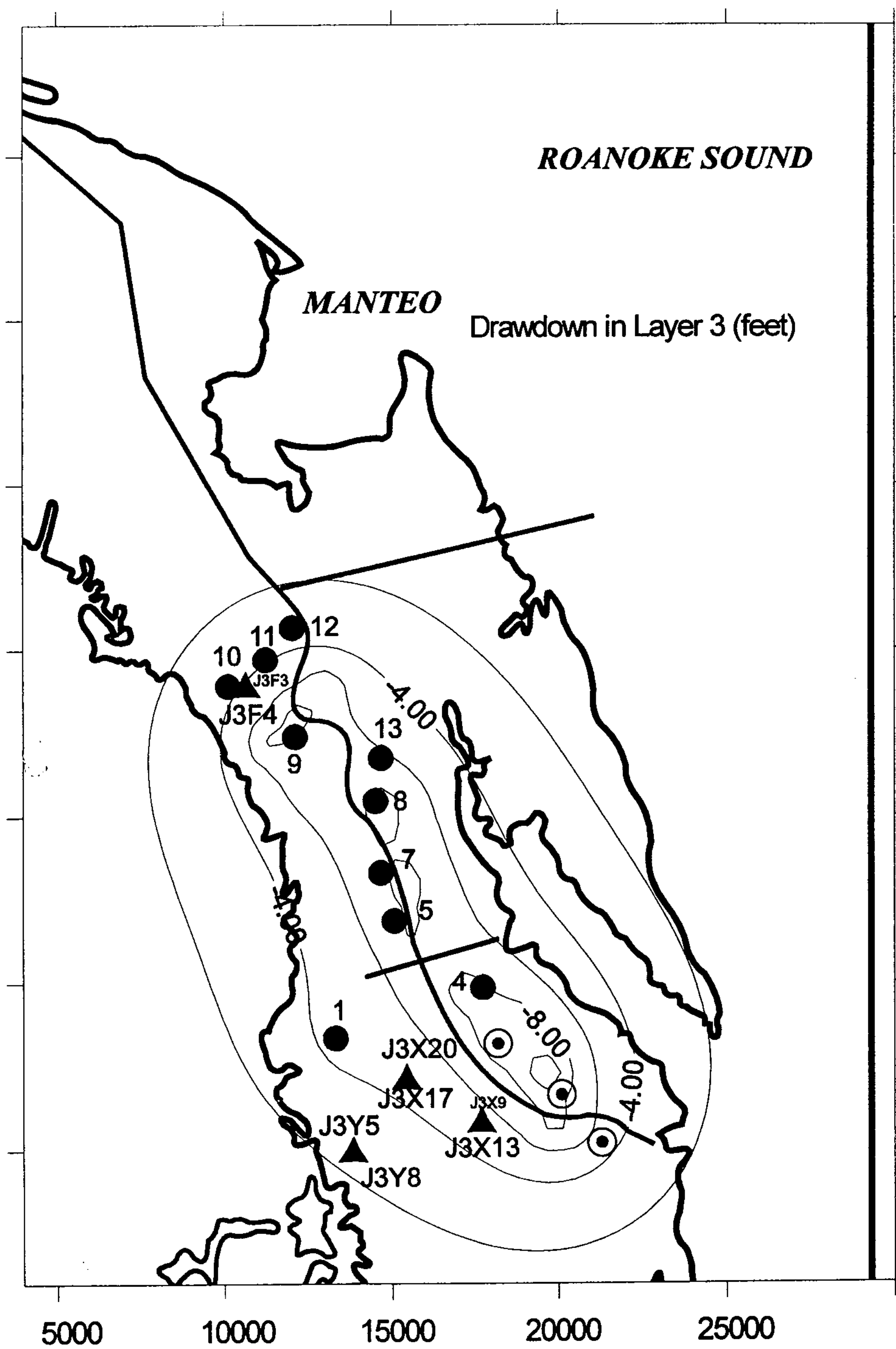
FIGURE 6 - 9. SITE MAP SHOWING LOCATIONS OF EXISTING AND PROPOSED PRODUCTION WELLS ON ROANOKE ISLAND.



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Pr. No.	FH7-571	Date:	May 1998
DWG No.	571-6.10	Rev. No.	

GROUNDWATER AND ENVIRONMENTAL SERVICES

FIGURE 6-10. Model simulated drawdown from thirteen wells pumping at a combined rate of 5.5 MGD for 90 days without recharge.

accurately and expansion of the RWS facility may be required if future demands exceed current projections. The piping and layout of the RWS plant was designed to accommodate expansion up to a maximum capacity of 2.0 MGD of finished water. An analysis was undertaken to determine the feasibility of increasing wellfield pumpage to provide sufficient raw water to meet the expanded plant demands. A raw water supply of 2.7 MGD would be required at plant buildout assuming a plant recovery efficiency of 75%.

A three-dimensional, multi-layer, hydraulic flow model of the aquifer system was developed with the MODFLOW computer code. The model layers correspond to hydrostratigraphic units identified during drilling of test wells and production wells at the site. Aquifer parameters used in the model are summarized in Table 6-4.1. A variably spaced grid consisting of 58 columns and 58 rows was used for the simulation. Constant head cells were placed at the perimeter of the model distant from the well cells to reduce boundary effects on the model results. The model simulates three wells spaced 2000 feet apart pumping at 620 gpm each for a combined production rate of 2.7 MGD for 90 days without recharge. Locations of the existing production wells at Rodanthe are shown on Figure 6-11. An additional production well could be constructed 2000 feet south of well #2 for the proposed wellfield expansion. Approximately 22 feet of drawdown in the aquifer near a production well may be expected based on the model results. Simulated drawdowns in the Mid-Yorktown aquifer due to this withdrawal amount are shown in Figure 6-12.

Expansion of the RWS wellfield to a raw water pumping capacity of 2.7 MGD is feasible with the addition of one well. The existing production wells have a high productive capacity and are capable of producing at the model simulated pumping rates. The model utilized addresses drawdown impacts only and does not consider the potential for water quality changes that may result due to increased pumpage. Water quality has remained stable since the wellfield was placed into operation approximately two years ago. Water quality conditions should continue to be monitored and solute transport modeling of the aquifer system should be conducted prior to expansion of the reverse osmosis plant and wellfield.

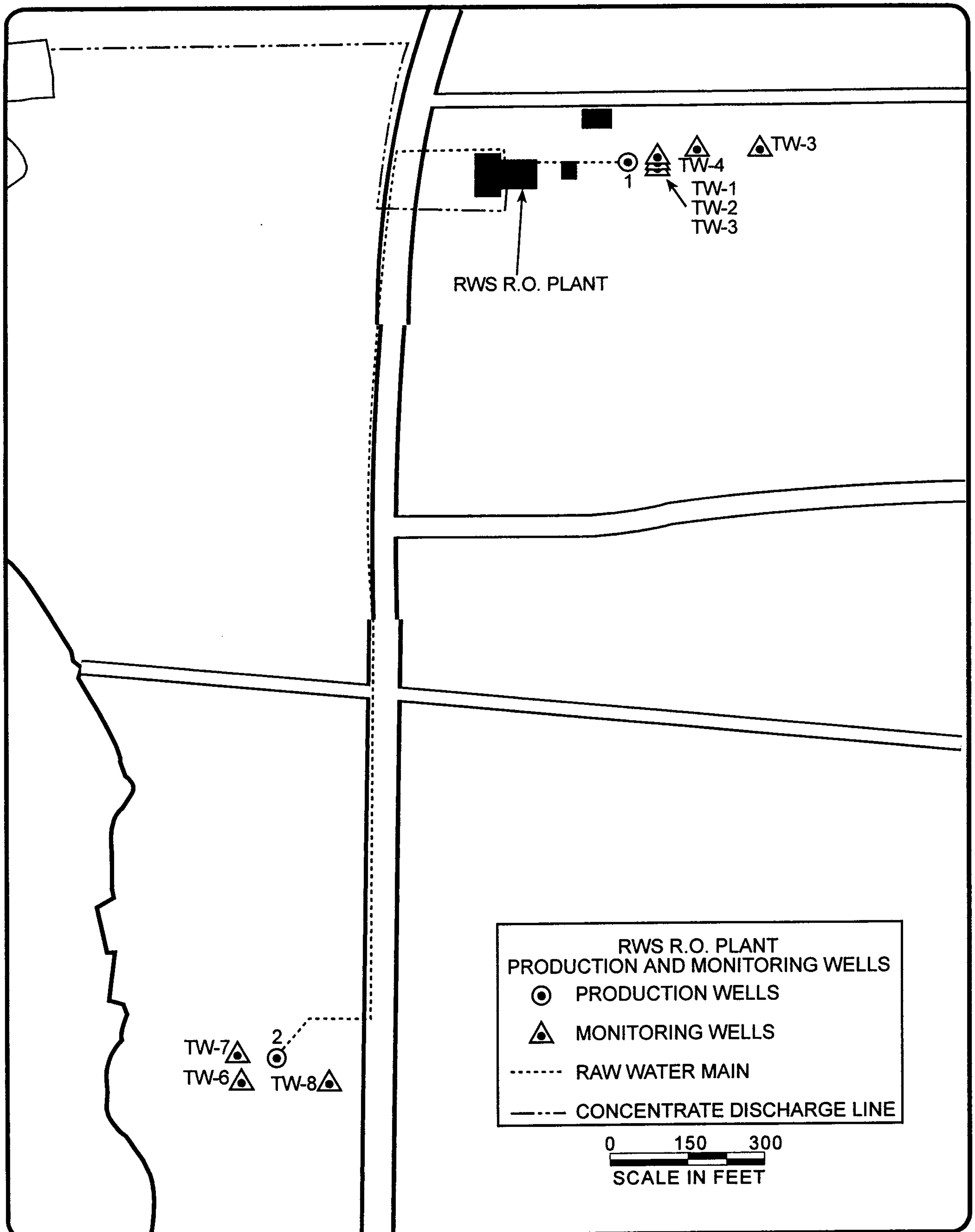
TABLE 6.4-1

SUMMARY OF AQUIFER PARAMETERS
USED FOR MODELING PURPOSES AT RODANTHE

Layer	Lithology	Thickness (feet)	Horizontal Hydraulic Conductivity* (feet/day)	Storage Coefficient
1	Sand and shell	100	27.0	0.20**
2	Clay	40	0.1	1×10^{-5}
3	Sand and gravel	90	74.0	2.5×10^{-4}
4	Clay	60	0.3	1×10^{-5}
5	Sand and shell	100	66.0	2.5×10^{-4}

*An anisotropy ratio of 10:1 for horizontal hydraulic conductivity to vertical hydraulic conductivity was used for each layer.

**Specific Yield



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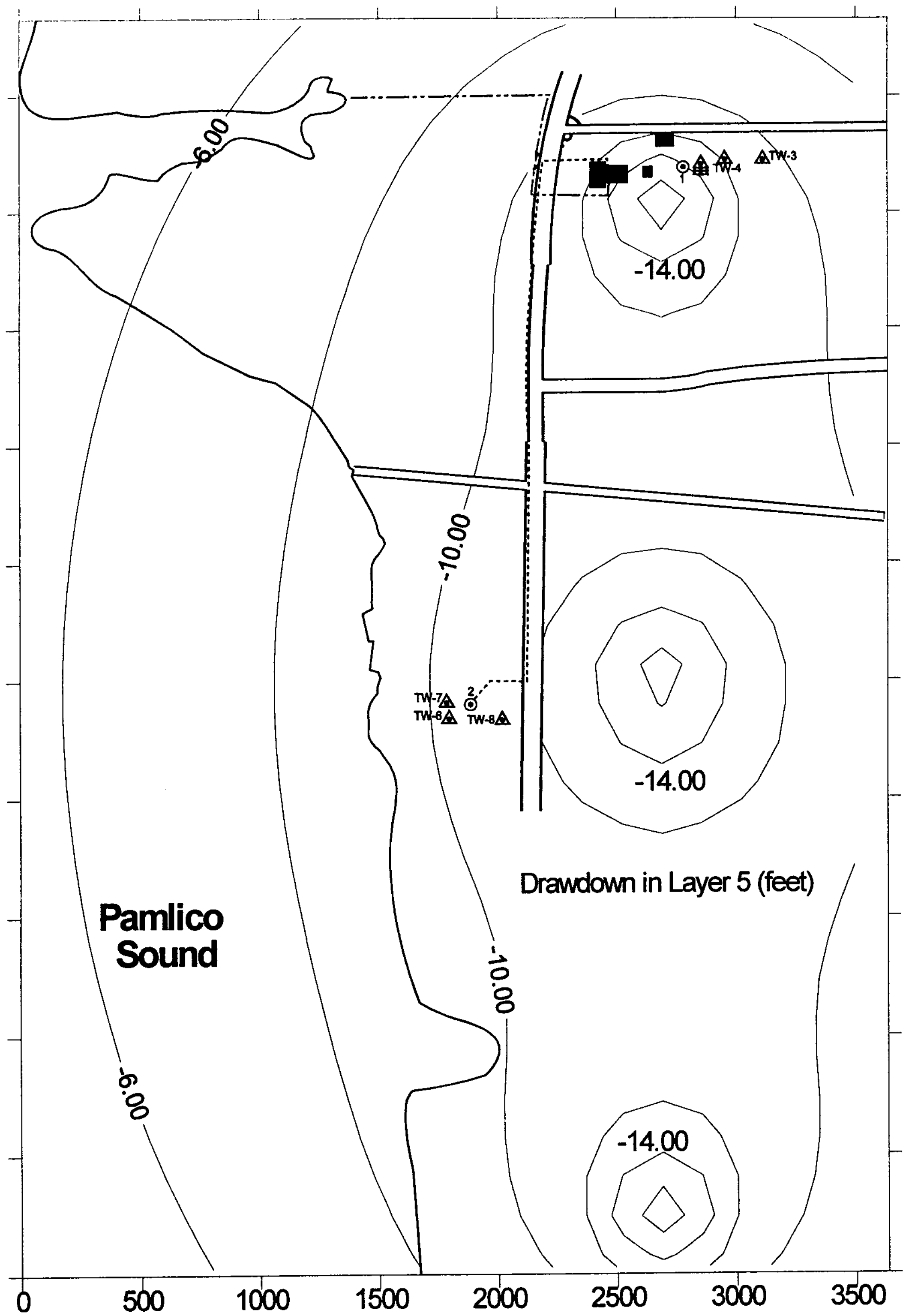
Pr. No. FH7-571 **DWG No.**WDC-1**Date:** 5/17/98

Groundwater and Environmental Services

FIGURE 6 - 11. SITE MAP SHOWING LOCATIONS OF EXISTING PRODUCTION AND MONITOR WELLS IN RODANTHE.



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Pr. Name:	Dare County-wide study		
Pr. No.	FH7-571	Date:	May 1998
DWG No.	571-6.10	Rev. No.	

GROUNDWATER
AND
ENVIRONMENTAL SERVICES

FIGURE 6-12. Model simulated drawdown from three wells pumping at 620 gpm each for a combined rate of 2.7 MGD for 90 days without recharge.

6.5 Dare Hatteras Water System

The Dare Hatteras water system is currently undergoing a large scale expansion. Elements of the expansion include: construction of a 2.1 MGD reverse osmosis plant and wellfield, upgrading the existing wellfield and treatment system, and distribution system improvements. The distribution system improvements and upgrading of the shallow aquifer wellfield are currently underway. The new reverse osmosis plant and upgrading of the existing treatment system are currently in the final design phase. The entire project is scheduled for completion in the fall of 1999.

Descriptions of the hydraulic and solute transport computer models that were used to evaluate proposed reverse osmosis wellfield design scenarios are included in the report entitled "Dare County Water Production Department, Cape Hatteras Reverse Osmosis Wellfield Study, Dare County, North Carolina" (Missimer International, Inc., 1998). Based on the analyses conducted it was concluded that the Mid-Yorktown aquifer is a viable long-term source of feedwater supply for the proposed reverse osmosis plant. Additional information regarding the proposed improvements to the Dare Hatteras water system is available in the preliminary design reports for the water system prepared by AEPI/Rostek, Inc., and Hobbs, Upchurch & Associates, P.A.

6.6 Mainland Dare County

The communities of Mann's Harbor and Stumpy Point on mainland Dare County are not currently served by a public water supply system. A water-supply feasibility study for the community of Stumpy Point was completed for Dare County in March of 1998 (Hobbs, Upchurch, 1998). Results of the Stumpy Point study indicate that development of a public water supply there is feasible. Results of test drilling conducted at Mann's Harbor indicate that development of a public water supply there is also feasible. Two aquifers, the Principal aquifer and the Mid-Yorktown aquifer, both exhibit adequate yield potential for large scale pumpage. Water quality is very good in the Principal aquifer and meets most of the state recommended drinking water standards. The quality of the water in the Mid-Yorktown aquifer is relatively good and it is likely that this water could be economically treated to potable standards.

A three-dimensional hydraulic flow model of the aquifer system at Mann's Harbor was developed to assess the potential drawdown impacts of pumpage for a public water supply facility. A five layer model was utilized with the Principal aquifer represented by layer 3 and the Mid-Yorktown aquifer included as layer 5. Transmissivity values for the aquifer layers were determined based on the results of pumping tests conducted on the wells constructed as part of this investigation. Hydraulic characteristics for the other model layers were estimated based on available data and our interpretation of the geologic sequence beneath the site. Aquifer parameters used in the model are summarized in Table 6.6-1. The variably spaced grid used for model simulations is shown on Figure 6-13. Constant head cells were placed at the perimeter of the model distant from the well cells. The bottom of the model is represented by a no-flow boundary. Pumpage from each aquifer was simulated in separate model runs. The model runs were used to simulate two wells pumping at 100 gpm each with a spacing of 400 feet for a period of 90 days with no recharge. The total withdrawal rate in each case was 0.29 MGD which exceeds the anticipated demand for this community. Estimated drawdowns due to pumpage in each aquifer are presented in Figures 6-14 and 6-15. Inspection of the figures indicates that relatively small drawdowns can be expected regardless of which aquifer is used for withdrawal purposes. Maximum simulated drawdowns of approximately 3.5 and 3.0 feet occur near the production wells due to the projected pumpage.

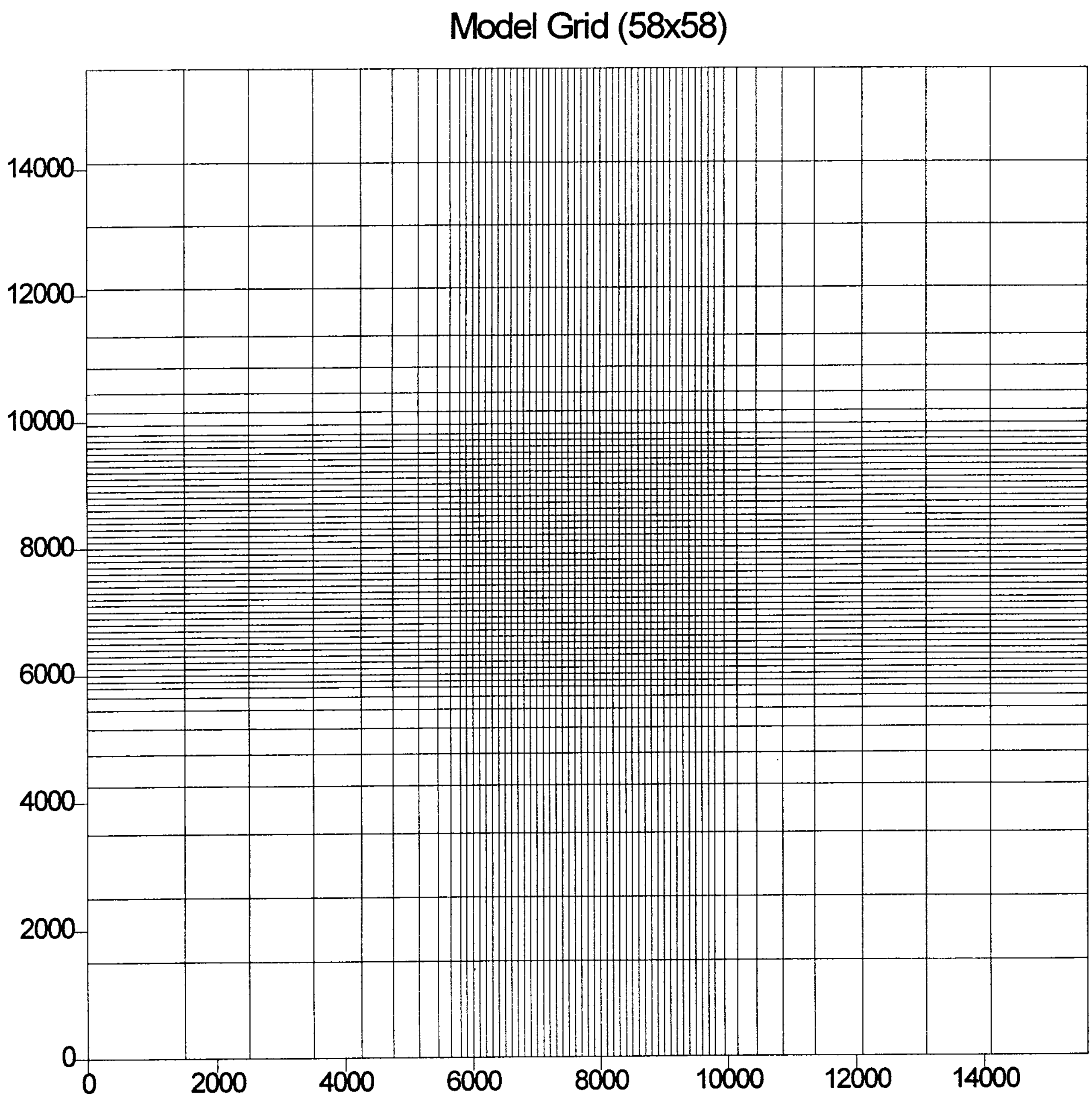
The preliminary test drilling and modeling efforts conducted at Mann's Harbor indicate that the development of a source of water for public supply purposes for the community is feasible. Two aquifers capable of yielding large amounts of water are available. The Principal aquifer is considered more favorable for development because the water within this aquifer is of better quality than the underlying Mid-Yorktown aquifer. Under the influence of pumpage, groundwater quality is likely to remain more stable in the Principal aquifer than in the Mid-Yorktown aquifer. Further testing to fully evaluate the aquifer characteristics and long term supply potential of the

TABLE 6.6-1 SUMMARY OF AQUIFER PARAMETERS USED FOR MODELING PURPOSES AT MANN'S HARBOR

Layer	Lithology	Thickness (feet)	Horizontal Hydraulic Conductivity* (feet/day)	Storage Coefficient
1	Sand and shell	60	33.0	0.2**
2	Clay	70	0.2	1×10^{-5}
3	Sand and gravel	70	95.0	5×10^{-5}
4	Clay	40	0.3	1×10^{-5}
5	Sand and sandstone	110	85.0	5×10^{-5}

*An anisotropy ratio of 10:1 for horizontal hydraulic conductivity to vertical hydraulic conductivity was used for each layer.

**Specific Yield



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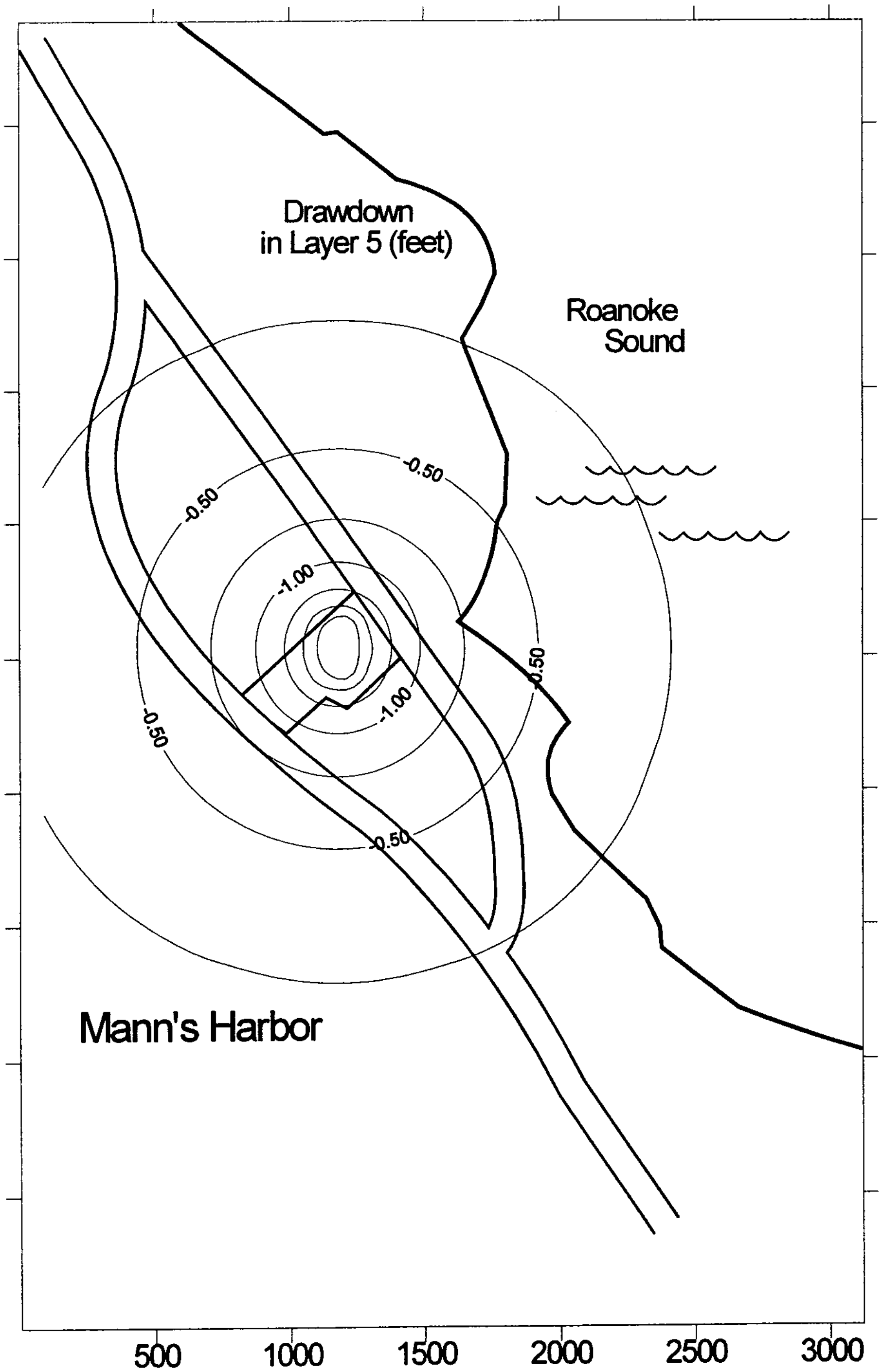
Pr. Name:	Dare County-wide study		
Pr. No.	FH7-571	Date:	May 1998
DWG No.	571-6.13	Rev. No.	

GROUNDWATER
AND
ENVIRONMENTAL SERVICES

FIGURE 6-13. Variably spaced model grid used for the Manns Harbor simulation



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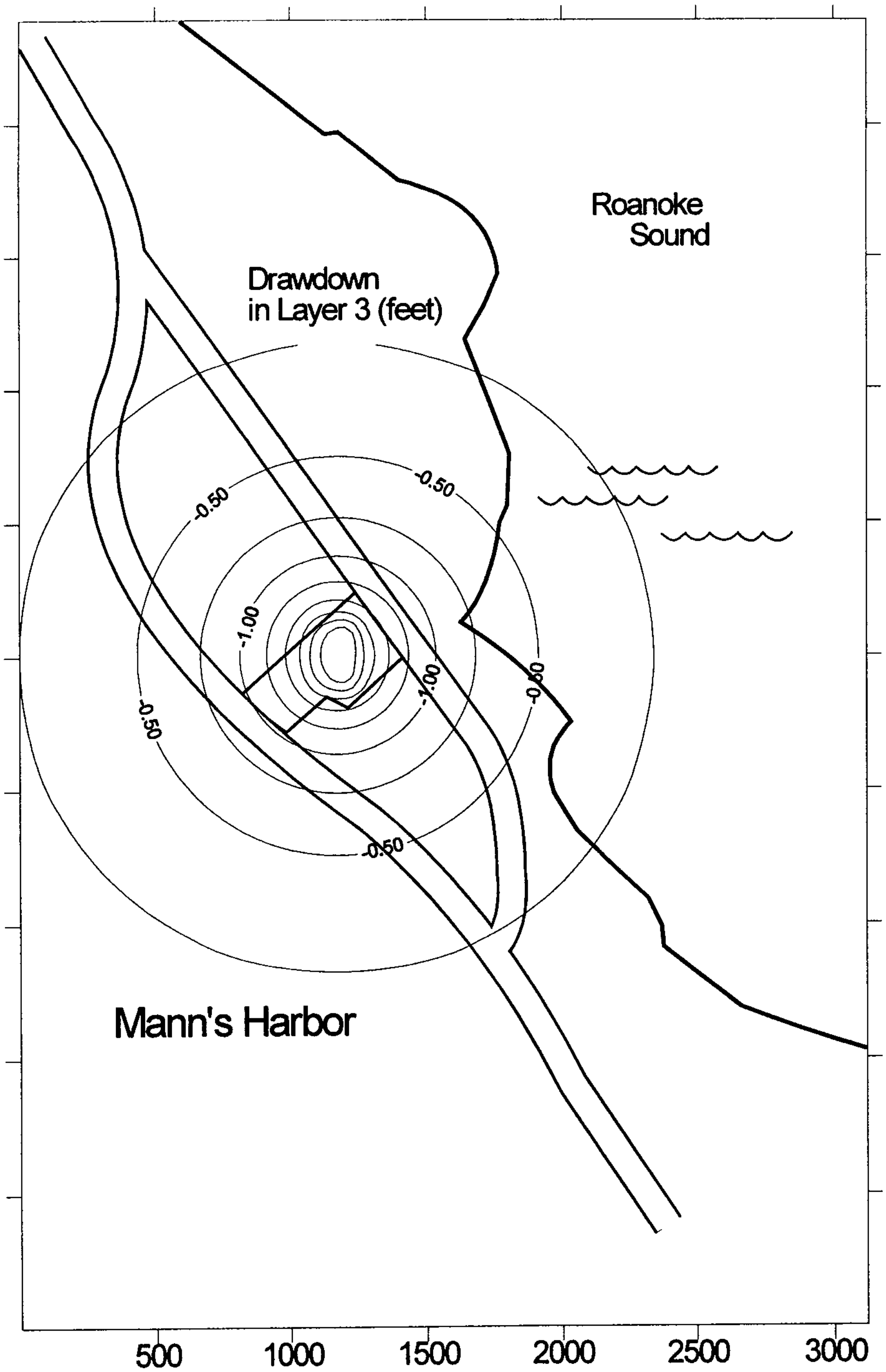
Pr. No.	FH7-571	Date:	May 1998
DWG No.	571-6.14	Rev. No.	

GROUNDWATER
AND
ENVIRONMENTAL SERVICES

FIGURE 6-14. Model simulated drawdown from two wells pumping at 100 gpm each from the Mid Yorktown Aquifer for a combined rate of 0.29 MGD for 90 days without recharge



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Pr. No.	FH7-571	Date:	May 1998
DWG No.	571-6.15	Rev. No.	

GROUNDWATER
AND
ENVIRONMENTAL SERVICES

FIGURE 6-15. Model simulated drawdown from two wells pumping at 100 gpm each from the Principal Aquifer for a combined rate of 0.29 MGD for 90 days without recharge proposed water source is recommended prior to the design and construction of a public water supply system in Mann's Harbor.

7.0 WATER SUPPLY PLAN

7.1 Introduction

The Dare County Water Department needs to expand its potable water-supply capacity to meet increasing demands. The construction of water treatment plants, production wells, and distribution system improvements are complex tasks that require detailed engineering work, cost evaluations, legal review, and administrative analyses. The water supply plan presented herein is conceptual in nature in that exact locations, costs, and plans for proposed infrastructure improvements are not specified. Instead, a general plan to meet the growing demand for water is presented that includes recommendations for expansion of existing facilities and also identifies potential locations for new water supply infrastructure. In addition, areas are identified where further data acquisition and analyses are needed. The timing of proposed water system improvements will depend on the growth rate of the area and will be based on potable water demands. The water supply plan is separated into four sections that include the three main water supply systems currently operated by Dare County plus the mainland population center. Each of these sections are described in more detail below.

7.2 Dare Regional Water Supply System (DRWSS)

The DRWSS is the largest supplier of potable water on the Outer Banks and supplies customers from Duck to Nags Head and parts of Roanoke Island. The three water treatment facilities that supply the DRWSS currently have a combined finished water production capacity of approximately 9.5 MGD. Water demand projections indicate that peak demands from this system may reach 16.0 MGD or more by the year 2020. Recommendations for increasing the water supply capacity of the DRWSS follow.

Expansion of the reverse osmosis plant and wellfield at Kill Devil Hills is considered the most likely scenario for large scale increases in potable water supply. The plant currently has a production capacity of 3.0 MGD and was designed for ultimate expansion up to 8.0 MGD. The feasibility of expanding the wellfield and increasing raw water withdrawals was evaluated and is viable. Additional wells and treatment equipment should be added as needed based on demands until the plant is built out to a capacity of 8.0 MGD. Consideration should also be given to constructing two or more wells tapping the Principal aquifer north of the R.O. plant. This lower salinity water might be used for blending purposes with the reverse osmosis permeate. Increasing the blend ratio will reduce plant operation costs and may delay the need for new R.O. raw water supply wells.

The construction of a new reverse osmosis plant and wellfield at Duck should also be considered. The plant and wellfield would be very similar to the Rodanthe plant with an initial installed capacity of 1.0 MGD and the ability for expansion to 2.0 MGD. The capital costs for construction of the facilities could be expected to be similar to those at Rodanthe except that construction of a distribution system would not be required. Water from the plant could be piped directly into the existing distribution system. It should be noted that land acquisition costs may be significantly higher at Duck than in Rodanthe. Having a water source interconnect at the north end of the DRWSS distribution system at Duck would help to increase the overall system reliability in the event of a hurricane or major transmission main break. Detailed testing of the source aquifer at Duck should be conducted prior to the construction of any new water supply infrastructure. In addition, the ability to obtain a permit for disposal of the concentrate generated by the plant should be investigated as the overall project feasibility is contingent upon having a method for concentrate disposal.

Expansion of the water plant and wellfield at Skyco on Roanoke Island is feasible. The construction of three additional supply wells and plant improvements would increase the production capacity of this facility by approximately 2.0 MGD to 7.0 MGD. Connection of the residents of Wanchese to the county water supply system would be required to avoid domestic well problems caused by seasonal drawdown effects. Blending of water from the Skyco plant and R.O. plant results in a mix with an acceptable trihalomethane (THM) formation potential. Proposed changes in the federal drinking water standard for THM concentrations may ultimately limit production from the Skyco plant or necessitate improvements to the treatment process utilized at the plant.

The Fresh Pond treatment facility should be maintained as a source of supply to meet peak demands. The peak water supply capability of the DRWSS would be increased to a total of 18.5 MGD if all of the above system improvements were implemented. This amount exceeds the maximum projected demand for the system. The Dare County Water Department should implement improvements to the DRWSS from the options presented above as needed based on potable water demands. Decisions regarding which option to select should be based on a number of factors including: estimated capital and operation costs, permitting feasibility, ability to meet current and proposed drinking water standards, and consideration of system reliability. Expansion of the Kill Devil Hills reverse osmosis plant and wellfield and installation of low salinity blend wells tapping the Principal aquifer are recommended as the initial options to increase potable water supply to the DRWSS.

7.3 Rodanthe, Waves, and Salvo

The RWS water system has an installed capacity of 1.0 MGD which is adequate to meet current and projected demands for the area served by the system. The water plant was designed to accommodate expansion to a produced water capacity of 2.0 MGD. Modeling results indicate the Mid-Yorktown aquifer is capable of yielding the required raw water supply. The plant expansion could be accomplished in two phases as needed based on demands. An additional 0.5 MGD reverse osmosis skid could be installed to increase the plant capacity to 1.5 MGD. The pumping rate of the two production wells could be increased to meet the additional raw water demand. The second phase of expansion would include the installation of another 0.5 MGD reverse osmosis skid and one new production well. The new production well should be placed approximately 2000 feet south of existing production well #2. Water quality data from the production and monitor wells should be reviewed carefully prior to any water system expansions. It may be necessary to revise the plan to include a fourth production well if unacceptable water quality degradation occurs.

7.4 Dare Hatteras Water System

Expansion of the Dare Hatteras water system is currently underway. The Phase I water system improvements will include construction of a reverse osmosis plant with a produced water capacity of 1.4 MGD and upgrading the shallow well treatment system to include a 0.6 MGD anion exchange process. Phase II improvements will include an additional 0.7 MGD of reverse osmosis supply and 0.3 MGD of anion exchange capacity. The final total produced water capacity of the system will be 3.0 MGD. Phase I is scheduled for completion during the fall of 1999. The Phase II water system improvements will be implemented when needed to meet potable water demands. At buildout the Dare Hatteras water system will be capable of meeting projected demands for southern Hatteras Island to the year 2020.

7.5 Mainland Dare County

A water supply feasibility study was recently completed by Hobbs, Upchurch and Associates for the community of Stumpy Point on the Dare County mainland. A recommendation to pursue implementation of a water system for Stumpy Point was made based on the results of the study. The proposed water system at Stumpy Point includes two 65 gpm supply wells, a small reverse osmosis plant, and distribution system with storage facilities. Applications for loans and grants to fund the proposed system have been submitted to the appropriate agencies.

The results of drilling and testing completed at Mann's Harbor indicate that development of a source of water for public supply purposes there is also feasible. A small treatment plant and distribution system similar to that proposed for Stumpy Point could be installed at Mann's Harbor. Groundwater quality at Mann's Harbor is much better than at Stumpy Point so reverse osmosis treatment would not be required. Conventional or membrane softening treatment of water from the Principal aquifer would likely result in a produced water that meets state recommended drinking water standards. Operation and maintenance costs are typically less for conventional and membrane softening systems than for reverse osmosis systems. Domestic wells in Mann's Harbor currently tap the water-table and Principal aquifers and the water quality is generally good. Residents of Mann's Harbor may be reluctant to connect to a public water supply system because of the associated expense and the fact that their wells currently produce relatively good quality water. The primary benefits of constructing a public water supply system at Mann's Harbor would be fire protection which is currently unavailable and the water would meet all drinking water standards.

Remote areas of mainland Dare County and the Outer Banks will continue to be served by domestic wells. It is not technically or economically feasible to supply potable water to every home in the county. The impacts of domestic well pumpage are minimal because pumping rates are low and the locations are widespread.

7.6 Alternative Water Supplies

The Dare County Water Department experiences extreme seasonal fluctuations in potable water demands due to the large number of tourists that visit the area each summer. Ground storage and elevated storage tanks within the potable water distribution system do not have sufficient capacity to handle major seasonal changes in peak day demand. The water supply facilities operated by the county have been designed to meet the peak summer water demands. As a result, a large excess water supply capacity is available during much of the year.

Aquifer Storage and Recovery (ASR) is a relatively new concept to improve the management of potable water systems. The basic concept of ASR is to treat water to potable standards during periods of low demand and inject the water into an underground aquifer. During periods of high demand, the water is recovered and pumped back into the water distribution system. The aquifer system in an ASR system is used as a giant, natural storage tank. By effective use of the ASR concept, water treatment facilities can be sized and operated closer to average day demands. Considerable cost savings can be realized by the overall more efficient operation of the treatment plants.

The suitability of an aquifer to function as a storage zone is dependent on a number of hydrogeologic factors. These factors affect the abilities of the zone to both receive injected water and to return the water to the user in the approximate quality at which it was injected. The aquifer characteristics that affect the performance of an ASR system most significantly are transmissivity and leakance. Transmissivity is a measure of an aquifers ability to receive and yield water in response to pressure changes. The leakance coefficient is a measure of how well the aquifer is confined from other aquifers by its upper and lower confining beds. Ideally, an aquifer utilized for ASR purposes would have a moderate transmissivity and low leakance.

After treatment and injection of the water, some mixing of the native water and stored water will occur, and the recovered water will usually contain some increased concentrations of natural groundwater constituents. At the beginning of the recovery process, the water quality is very near that of the injected water. However, as the water is recovered, with time, the water quality tends to approach that of the native water. The first recovery period generally shows significant deterioration in quality; however, after each cycle, the recovery efficiency improves. Ultimately, recovery efficiencies of 80 to 90% may be attained depending upon the geologic setting and operational factors such as storage volume and retention time.

ASR wells are regulated by Underground Injection Control (UIC) rules promulgated by the United States Environmental Protection Agency. A significant amount of drilling and testing is required to insure the proposed injection and recovery activities will not adversely affect underground sources of drinking water. State requirements for well construction and operation of public water systems must also be met. The use of ASR as a water management tool is growing in Florida and several western states. This technology has not been utilized in the state of North Carolina, however, its use should be considered by Dare County.

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APPENDICES

GEOLOGIST'S LOGS OF TEST WELLS

DARE COUNTY WIDE HYDROGEOLOGICAL STUDY
GEOLOGIST'S LOG OF TEST WELL KDH-1

Depth (feet)	Description
0-10	Sand, grayish-brown (5Y 3/2), fine to medium grained, subangular, minor organics.
10-20	Sand, grayish-brown (5Y 3/2) to medium gray (N5), fine to medium grained, subangular, minor organics.
20-40	Sand, light gray (N7) to medium gray (N5), fine, well sorted, subangular, minor shell fragments.
40-50	Sand, medium gray (N5) to grayish-brown (5Y 3/2), fine, well sorted, subangular, minor shell fragments.
50-70	Sand, medium gray (N5), fine to coarse grained, poorly sorted, subangular to subrounded, common shell fragments.
70-80	Sand, light olive-gray (5Y 5/2), medium to coarse grained, subangular to rounded, moderately sorted, minor phosphate grains, trace shell fragments.
80-90	Sand, as above, some fluid loss.
90-100	Sand, light olive-gray (5Y 5/2), medium to coarse grained, moderately sorted, subangular to rounded, minor phosphate, shell, and gray clay interbedded.
100-113	Clay, medium gray (N5) to light olive-gray (5Y 6/1), soft, sticky, phosphatic, minor sand interbedded.
113-150	Interbedded sand and clay layers. Sand is light gray (N7) to medium dark gray (N4), fine to coarse grained, subangular to rounded, occasional phosphate grains. Clay is medium dark gray (N4), soft, sticky.
150-200	Clay, dark gray (N3) to olive-gray (5Y 4/1), soft, sticky, fine sand, shell and silt interbedded, finely phosphatic.
200-225	Sand, light gray (N7) to light olive-gray (5Y 6/1), fine to coarse (mostly medium grain), moderately sorted, common shell fragments, occasional phosphatic clay interbedded. Some fluid loss.
225-250	Shell, multicolored, common fine to coarse grained sand interbedded, occasional sandy phosphatic clay interbedded. Some fluid loss.
250-280	Sand and shell, as above. Some fluid loss.
280-325	Clay, light olive-gray (5Y 6/1), stiff, sandy, phosphatic shell interbedded.
325-350	Sand, dark gray (N3), fine, subangular, minor shell, phosphatic, minor clay interbedded.
350-400	Sand, dark gray (N3), very fine to fine, moderately well sorted, compacted, subangular, occasional shell fragments, minor clay.

DARE COUNTY-WIDE HYDROGEOLOGICAL STUDY
GEOLOGIST'S LOG OF TEST WELL DUCK-1

Depth (feet)	Description
0-7	Peat, dark brown, soft, sandy, abundant organics.
7-13	Sand, medium gray (N5), fine, well sorted, subangular, minor shell.
13-46	Sand, as above with abundant shell interbedded.
46-55	Sand, medium gray (N5), fine to medium grained, moderately well sorted, subangular, common shell, common gray clay interbedded.
55-90	Clay, olive gray (5Y 4/2), soft, sticky, cohesive, occasional shell.
90-100	Sand, medium gray (N5), fine grained, well sorted, common olive gray clay interbedded.
100-125	Sand, quartz, clear to light gray (N7), medium to very coarse and pebble sizes, poorly sorted, subrounded to well rounded, high apparent porosity and permeability, minor shell. Some fluid loss.
125-150	Sand and gravel, multicolored, very coarse grained to large pebble sizes, moderate sorting, subrounded to well rounded, high apparent porosity and permeability, minor shell, minor clay. Some fluid loss.
150-160	Sand, multicolored, medium to very coarse grained, poorly sorted, subrounded to rounded, minor shell, minor clay.
160-175	Clay, olive gray (5Y 4/1), soft, sticky, cohesive, minor sand and shell.
175-210	Clay, as above.
210-225	Clay, olive gray (5Y 4/1), soft, sticky, cohesive, finely phosphatic, occasional fragments, trace sand.
225-250	Clay, olive gray (5Y 4/1), soft, sticky, cohesive, finely phosphatic, common shell fragments, minor sand. Hard lense at 237 feet.
250-275	Clay, greenish gray (5G 6/1), soft, sticky, occasional shell fragments.
275-300	Clay, as above.
300-325	Clay, light olive gray (5Y 6/1), soft, sticky, silty, minor shell.
325-375	Clay, as above.
375-400	Clay, light olive gray (5Y 6/1) to greenish gray (5G 6/1), soft, sticky, silty, finely phosphatic, trace shell.

DARE COUNTY-WIDE HYDROGEOLOGICAL STUDY
GEOLOGIST'S LOG OF TEST WELL MANN-DEEP

Depth (feet)	Description
0-8	Sand, moderate brown (5YR 4/4), fine, well sorted, subangular, minor yellow clayey sand interbedded, minor organics.
8-15	Sand, dark yellowish brown (10YR 4/2), fine to medium, subangular to subrounded, trace clay.
15-21	Clay, dark gray (N3), sandy, cohesive.
21-26	Sand, quartz, translucent, coarse to pebble sizes, well rounded.
26-32	Clay, medium gray (N5), soft, silty, sand interbedded.
32-44	Sand, quartz, translucent, coarse to pebble sizes, rounded, gray clay layers interbedded. Some fluid loss.
44-50	Shell, very pale orange (10YR 8/2), common fine to medium grained sand interbedded, occasional gray clay. Some fluid loss.
50-65	Interbedded shell, sand, and clay as above. Clay content increasing with depth.
65-90	Clay, medium bluish gray (5B 5/1), sandy, cohesive, common shell.
90-95	Sand, translucent to white (N9), medium to coarse, rounded, abundant bluish gray clay.
95-105	Clay, medium bluish gray (5B 5/1), sandy, occasional shell.
105-130	Clay, light olive gray (5Y 6/1), sandy, fine sand layers interbedded, minor shell.
130-150	Sand, multicolored, medium to very coarse grained and pebble sizes, subrounded to well rounded, minor shell and clay.
150-175	Sand, as above becoming coarser with depth. Common large pebble sizes.
175-195	Sand, as above.
195-213	Sand, multicolored, quartz, medium to coarse, common gray clay interbedded.
213-225	Clay, medium gray (N5) to olive gray (5Y 6/1), soft, sticky, finely phosphatic, minor sand.
225-239	Clay, as above.
239-250	Sand, light gray (N7) to medium gray (N5), medium grained, well sorted, subangular to subrounded, occasional shell and clay interbedded.

DARE COUNTY-WIDE HYDROGEOLOGICAL STUDY
GEOLOGIST'S LOG OF TEST WELL MANN-DEEP
- CONTINUED -

Depth (feet)	Description
250-275	Sand, quartz, multicolored and medium gray (N5), fine to coarse grained, poorly sorted, common shell, minor clay. Some fluid loss.
275-300	Sand, as above.
300-325	Sandstone, medium dark gray (N4), medium grained, soft to medium hard, friable, poor to moderately well indurated, minor coarse sand interbedded.
325-355	Sandstone, as above.
355-360	Clay, medium gray (N5), phosphatic, sticky, occasional coarse sand interbedded.
360-400	Clay, grayish olive (10Y 4/2), soft, sticky, silty, minor shell and coarse quartz sand.

WATER QUALITY ANALYSES

LOG NO: B8-30897
Received: 31 MAR 98
Reported: 16 APR 98

Mr. Scott Manahan
Missimer International, Inc.
8140 College Parkway, Suite 202
Fort Myers, FL 33919

Project: Dare Co. Wide Study/FH7-571
Sampled By: Client
Code: 093480416

REPORT OF RESULTS

LOG NO	SAMPLE DESCRIPTION , LIQUID SAMPLES	DATE/ TIME SAMPLED
30897-1	KDH-1	03-27-98

PARAMETER	30897-1
Fluoride	
Fluoride, mg/l	0.26
Date Analyzed	04.02.98
Alkalinity	
Alkalinity (to pH 4.5) as CaCO3, mg/l	350
Date Analyzed	04.01.98
Bicarbonate Alkalinity as CaCO3	
Bicarbonate Alkalinity as CaCO3, mg/l	330
Date Analyzed	04.01.98
Sulfate as SO4 (375.4)	
Sulfate as SO4, mg/l	5.6
Date Analyzed	04.03.98
Chloride (325.3)	
Chloride, mg/l	280
Date Analyzed	04.06.98
Total Dissolved Solids	
Total Dissolved Solids, mg/l	600
Date Analyzed	04.02.98
Copper (6010)	
Copper, mg/l	<0.025
Preparation Date	04.02.98
Date Analyzed	04.06.98
Iron (6010)	
Iron, mg/l	<0.050
Preparation Date	04.02.98
Date Analyzed	04.06.98

SL SAVANNAH LABORATORIES
& ENVIRONMENTAL SERVICES, INC.

6712 Benjamin Road • Suite 100 • Tampa, FL 33634 • (813) 885-7427 • Fax (813) 885-7049

LOG NO: B8-30897
Received: 31 MAR 98
Reported: 16 APR 98

Mr. Scott Manahan
Missimer International, Inc.
8140 College Parkway, Suite 202
Fort Myers, FL 33919

Project: Dare Co. Wide Study/FH7-571
Sampled By: Client
Code: 111080416

REPORT OF RESULTS

LOG NO	SAMPLE DESCRIPTION , LIQUID SAMPLES	DATE/ TIME SAMPLED
30897-1	KDH-1	03-27-98

PARAMETER	30897-1
Manganese (6010)	
Manganese, mg/l	<0.010
Preparation Date	04.02.98
Date Analyzed	04.06.98
Zinc (6010)	
Zinc, mg/l	<0.020
Preparation Date	04.02.98
Date Analyzed	04.06.98
Nickel (6010)	
Nickel, mg/l	<0.040
Preparation Date	04.02.98
Date Analyzed	04.06.98
Boron	
Boron, mg/l	0.78
Preparation Date	04.02.98
Date Analyzed	04.06.98
Hardness as CaCO3	
Hardness as CaCO3, mg/l	31
Noncarbonate Hardness as CaCO3	
Hardness as CaCO3, mg/l	<5.0
Silica as SiO2 (6010)	
Silica as SiO2, mg/l	12
Preparation Date	04.02.98
Date Analyzed	04.06.98
Bromide	
Bromide, mg/l	2.0
Date Analyzed	04.02.98

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Fort Myers, FL 33919

Project: Dare Co. Wide Study/FH7-571
Sampled By: Client
Code: 093480416

REPORT OF RESULTS

LOG NO	SAMPLE DESCRIPTION , LIQUID SAMPLES	DATE/ TIME SAMPLED
30897-1	KDH-1	03-27-98

PARAMETER	30897-1
Strontium (6010)	
Strontium, mg/l	0.16
Preparation Date	04.02.98
Date Analyzed	04.06.98
Sulfide (376.2)	
Sulfide , mg/l	<0.10
Preparation Date	04.02.98
Date Analyzed	04.02.98

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LOG NO: B8-30897
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Reported: 16 APR 98

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Fort Myers, FL 33919

Project: Dare Co. Wide Study/FH7-571
Sampled By: Client
Code: 093480416

REPORT OF RESULTS

LOG NO	SAMPLE DESCRIPTION , QC REPORT FOR LIQUID SAMPLES	DATE/ TIME SAMPLED
30897-2	Method Blank	
30897-3	Accuracy (%Rec)	
30897-4	Precision (%RPD)	

PARAMETER	30897-2	30897-3	30897-4
Fluoride			
Fluoride, mg/l	<0.20	99 %	1.0 %
Date Analyzed	04.02.98	04.02.98	---
Alkalinity			
Alkalinity (to pH 4.5) as CaCO3, mg/l	<1.0	97 %	0 %
Date Analyzed	04.01.98	04.01.98	---
Bicarbonate Alkalinity as CaCO3			
Bicarbonate Alkalinity as CaCO3, mg/l	<1.0	97 %	0 %
Date Analyzed	04.01.98	04.01.98	---
Sulfate as SO4 (375.4)			
Sulfate as SO4, mg/l	<5.0	106 %	4.6 %
Date Analyzed	04.03.98	04.03.98	---
Chloride (325.3)			
Chloride, mg/l	<1.0	102 %	0.98 %
Date Analyzed	04.06.98	04.06.98	---
Total Dissolved Solids			
Total Dissolved Solids, mg/l	<5.0	98 %	1.9 %
Date Analyzed	04.02.98	04.02.98	---
Copper (6010)			
Copper, mg/l	<0.025	100 %	3.0 %
Preparation Date	04.02.98	04.02.98	---
Date Analyzed	04.06.98	04.06.98	---
Iron (6010)			
Iron, mg/l	<0.050	100 %	0 %
Preparation Date	04.02.98	04.02.98	---
Date Analyzed	04.06.98	04.06.98	---

SL SAVANNAH LABORATORIES
& ENVIRONMENTAL SERVICES, INC.

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LOG NO: B8-30897
Received: 31 MAR 98
Reported: 16 APR 98

Mr. Scott Manahan
Missimer International, Inc.
8140 College Parkway, Suite 202
Fort Myers, FL 33919

Project: Dare Co. Wide Study/FH7-571
Sampled By: Client
Code: 111080416

REPORT OF RESULTS

LOG NO	SAMPLE DESCRIPTION , QC REPORT FOR LIQUID SAMPLES	DATE/ TIME SAMPLED
30897-2	Method Blank	
30897-3	Accuracy (%Rec)	
30897-4	Precision (%RPD)	

PARAMETER	30897-2	30897-3	30897-4
Manganese (6010)			
Manganese, mg/l	<0.010	98 %	0 %
Preparation Date	04.02.98	04.02.98	---
Date Analyzed	04.06.98	04.06.98	---
Zinc (6010)			
Zinc, mg/l	<0.020	99 %	0 %
Preparation Date	04.02.98	04.02.98	---
Date Analyzed	04.06.98	04.06.98	---
Nickel (6010)			
Nickel, mg/l	<0.040	101 %	0 %
Preparation Date	04.02.98	04.02.98	---
Date Analyzed	04.06.98	04.06.98	---
Boron			
Boron, mg/l	<0.050	92 %	0 %
Preparation Date	04.02.98	04.02.98	---
Date Analyzed	04.06.98	04.06.98	---
Silica as SiO2 (6010)			
Silica as SiO2, mg/l	<0.50	88 %	1.1 %
Preparation Date	04.02.98	04.02.98	---
Date Analyzed	04.06.98	04.06.98	---
Bromide			
Bromide, mg/l	<2.0	104 %	0.96 %
Date Analyzed	04.02.98	04.02.98	---

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& ENVIRONMENTAL SERVICES, INC.

6712 Benjamin Road • Suite 100 • Tampa, FL 33634 • (813) 885-7427 • Fax (813) 885-7049

LOG NO: B8-30897
Received: 31 MAR 98
Reported: 16 APR 98

Mr. Scott Manahan
Missimer International, Inc.
8140 College Parkway, Suite 202
Fort Myers, FL 33919

Project: Dare Co. Wide Study/FH7-571
Sampled By: Client
Code: 111080416

REPORT OF RESULTS

LOG NO	SAMPLE DESCRIPTION , QC REPORT FOR LIQUID SAMPLES	DATE/ TIME SAMPLED
30897-2	Method Blank	
30897-3	Accuracy (%Rec)	
30897-4	Precision (%RPD)	

PARAMETER	30897-2	30897-3	30897-4
Strontium (6010)			
Strontium, mg/l	<0.010	98 %	0 %
Preparation Date	04.02.98	04.02.98	---
Date Analyzed	04.06.98	04.06.98	---
Sulfide (376.2)			
Sulfide , mg/l	<0.10	92 %	2.2 %
Preparation Date	04.02.98	04.02.98	---
Date Analyzed	04.02.98	04.02.98	---

Methods: EPA SW-846
EPA 600/4-79-020
HRS Certification #'s: 84385, E84282, 87279, E87052, 87357, E87089

Michael F. Valder, Project Manager

Serial Number 10[illegible]72

SL SAVANNAH LABORATORIES & ENVIRONMENTAL SERVICES, INC.

ANALYSIS REQUEST AND CHAIN OF CUSTODY RECORD

☐ 5102 LaRoche Avenue, Savannah, GA 31404	Phone: (912) 354-7858	Fax: (912) 352-0165
☐ 2846 Industrial Plaza Drive, Tallahassee, FL 32301	Phone: (904) 878-3994	Fax: (904) 878-9504
☐ 414 SW 12th Avenue, Deerfield Beach, FL 33442	Phone: (954) 421-7400	Fax: (954) 421-2584
☐ 900 Lakeside Drive, Mobile, AL 36693	Phone: (334) 666-6633	Fax: (334) 666-6696
☐ 6712 Benjamin Road, Suite 100, Tampa, FL 33634	Phone: (813) 885-7427	Fax: (813) 885-7049
☐ 100 Alpha Drive, Suite 110, Destrehan, LA 70047	Phone: (504) 764-1100	Fax: (504) 725-1163

PROJECT REFERENCE: Dare County Wide Study
PROJECT NO.: FH7-571
P.O. NUMBER:
PROJECT LOC. (State): NC
SAMPLER(s) NAME: Scott Manahan
PHONE: (941) 432-9494
FAX: (941) 432-9453
CLIENT NAME: Missimer International
CLIENT PROJECT MANAGER: Scott Manahan
CLIENT ADDRESS (CITY, STATE, ZIP): 8140 College Parkway Suite 202 Fort Myers, FL 33919

PAGE 1 OF 1

☐ STANDARD REPORT DELIVERY
☐ EXPEDITED REPORT DELIVERY (surcharge)
Date Due:

MATRIX TYPE: AQUEOUS (WATER) / SOLID OR SEMISOLID / AIR / NONAQUEOUS LIQUID (oil, solvent, etc)

REQUIRED ANALYSES — NUMBER OF CONTAINERS SUBMITTED

SAMPLE DATE	SAMPLE TIME	SL NO.	SAMPLE IDENTIFICATION	AQUEOUS (WATER)	SOLID OR SEMISOLID	AIR	NONAQUEOUS LIQUID	Inorganics (N/A)	metals (HNO_3)	H2S (2NOAc)	Silica & SC (HNO_3)	Br (N/A)					REMARKS
3/27/98			KDH-1					2	2	2	2	2					

RELINQUISHED BY: (SIGNATURE)	DATE	TIME	RELINQUISHED BY: (SIGNATURE)	DATE	TIME	RELINQUISHED BY: (SIGNATURE)	DATE	TIME
[signature]	3-25-98	1605	William J. Manahan [signature]	3/27/98	14:00			

RECEIVED BY: (SIGNATURE)	DATE	TIME	RECEIVED BY: (SIGNATURE)	DATE	TIME	RECEIVED BY: (SIGNATURE)	DATE	TIME

LABORATORY USE ONLY

RECEIVED FOR LABORATORY BY: (SIGNATURE)	DATE	TIME	CUSTODY INTACT	CUSTODY SEAL NO.	SL LOG NO.	LABORATORY REMARKS
[signature]	3-31-98	1445	☑ YES ☐ NO		B830897	22° Cooler Temp.

ORIGINAL

SL *SAVANNAH LABORATORIES*
& ENVIRONMENTAL SERVICES, INC.

6712 Benjamin Road • Suite 100 • Tampa, FL 33634 • (813) 885-7427 • Fax (813) 885-7049

LOG NO: B8-30965
Received: 07 APR 98
Reported: 16 APR 98

Mr. Scott Manahan
Missimer International, Inc.
8140 College Parkway, Suite 202
Fort Myers, FL 33919

Project: Dare Co. Wide Study/FH7-571
Sampled By: Client
Code: 094680416

REPORT OF RESULTS

LOG NO	SAMPLE DESCRIPTION , LIQUID SAMPLES	DATE/ TIME SAMPLED
30965-1	DUCK-1	04-03-98/1030

PARAMETER	30965-1
Fluoride	
Fluoride, mg/l	0.17
Date Analyzed	04.10.98
Alkalinity	
Alkalinity (to pH 4.5) as CaCO3, mg/l	200
Date Analyzed	04.14.98
Bicarbonate Alkalinity as CaCO3	
Bicarbonate Alkalinity as CaCO3, mg/l	200
Date Analyzed	04.14.98
Sulfate as SO4 (375.4)	
Sulfate as SO4, mg/l	<5.0
Date Analyzed	04.13.98
Chloride (325.3)	
Chloride, mg/l	1500
Date Analyzed	04.09.98
Total Dissolved Solids	
Total Dissolved Solids, mg/l	2200
Date Analyzed	04.07.98
Copper (6010)	
Copper, mg/l	<0.025
Preparation Date	04.09.98
Date Analyzed	04.14.98
Iron (6010)	
Iron, mg/l	1.6
Preparation Date	04.09.98
Date Analyzed	04.14.98

SL SAVANNAH LABORATORIES
& ENVIRONMENTAL SERVICES, INC.

6712 Benjamin Road • Suite 100 • Tampa, FL 33634 • (813) 885-7427 • Fax (813) 885-7049

LOG NO: B8-30965
Received: 07 APR 98
Reported: 16 APR 98

Mr. Scott Manahan
Missimer International, Inc.
8140 College Parkway, Suite 202
Fort Myers, FL 33919

Project: Dare Co. Wide Study/FH7-571
Sampled By: Client
Code: 111380416

REPORT OF RESULTS

LOG NO	SAMPLE DESCRIPTION , LIQUID SAMPLES	DATE/ TIME SAMPLED
30965-1	DUCK-1	04-03-98/1030

PARAMETER	30965-1
Manganese (6010)	
Manganese, mg/l	0.45
Preparation Date	04.09.98
Date Analyzed	04.14.98
Zinc (6010)	
Zinc, mg/l	<0.020
Preparation Date	04.09.98
Date Analyzed	04.14.98
Nickel (6010)	
Nickel, mg/l	<0.040
Preparation Date	04.09.98
Date Analyzed	04.14.98
Boron	
Boron, mg/l	0.34
Preparation Date	04.09.98
Date Analyzed	04.14.98
Hardness as CaCO3	
Hardness as CaCO3, mg/l	810
Noncarbonate Hardness as CaCO3	
Hardness as CaCO3, mg/l	610
Silica as SiO2 (6010)	
Silica as SiO2, mg/l	25
Preparation Date	04.15.98
Date Analyzed	04.15.98
Bromide	
Bromide, mg/l	7.0
Date Analyzed	04.10.98

SL SAVANNAH LABORATORIES
& ENVIRONMENTAL SERVICES, INC.

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Mr. Scott Manahan
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8140 College Parkway, Suite 202
Fort Myers, FL 33919

Project: Dare Co. Wide Study/FH7-571
Sampled By: Client
Code: 094680416

REPORT OF RESULTS

LOG NO	SAMPLE DESCRIPTION , LIQUID SAMPLES	DATE/ TIME SAMPLED
30965-1	DUCK-1	04-03-98/1030

PARAMETER	30965-1
Strontium (6010)	
Strontium, mg/l	1.6
Preparation Date	04.09.98
Date Analyzed	04.14.98
Sulfide (376.1)	
Sulfide, mg/l	<1.0
Preparation Date	04.10.98
Date Analyzed	04.10.98

SL SAVANNAH LABORATORIES
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Project: Dare Co. Wide Study/FH7-571
Sampled By: Client
Code: 111380416

REPORT OF RESULTS

LOG NO	SAMPLE DESCRIPTION , QC REPORT FOR LIQUID SAMPLES	DATE/ TIME SAMPLED
30965-2	Method Blank	
30965-3	Accuracy (%Rec)	
30965-4	Precision (%RPD)	

PARAMETER	30965-2	30965-3	30965-4
Fluoride			
Fluoride, mg/l	<0.20	100 %	1.2 %
Date Analyzed	04.10.98	04.10.98	---
Alkalinity			
Alkalinity (to pH 4.5) as CaCO3, mg/l	<1.0	97 %	0 %
Date Analyzed	04.14.98	04.14.98	---
Bicarbonate Alkalinity as CaCO3			
Bicarbonate Alkalinity as CaCO3, mg/l	<1.0	97 %	0 %
Date Analyzed	04.14.98	04.14.98	---
Sulfate as SO4 (375.4)			
Sulfate as SO4, mg/l	<5.0	107 %	4.7 %
Date Analyzed	04.13.98	04.13.98	---
Chloride (325.3)			
Chloride, mg/l	<1.0	100 %	0.70 %
Date Analyzed	04.09.98	04.09.98	---
Total Dissolved Solids			
Total Dissolved Solids, mg/l	<5.0	101 %	0.80 %
Date Analyzed	04.07.98	04.07.98	---
Copper (6010)			
Copper, mg/l	<0.025	106 %	0.94 %
Preparation Date	04.09.98	04.09.98	---
Date Analyzed	04.14.98	04.14.98	---
Iron (6010)			
Iron, mg/l	<0.050	106 %	6.4 %
Preparation Date	04.09.98	04.09.98	---
Date Analyzed	04.14.98	04.14.98	---

SL *SAVANNAH LABORATORIES*
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LOG NO: B8-30965
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8140 College Parkway, Suite 202
Fort Myers, FL 33919

Project: Dare Co. Wide Study/FH7-571
Sampled By: Client
Code: 111380416

REPORT OF RESULTS

LOG NO	SAMPLE DESCRIPTION , QC REPORT FOR LIQUID SAMPLES	DATE/ TIME SAMPLED
30965-2	Method Blank	
30965-3	Accuracy (%Rec)	
30965-4	Precision (%RPD)	

PARAMETER	30965-2	30965-3	30965-4
Manganese (6010)			
Manganese, mg/l	<0.010	104 %	0.95 %
Preparation Date	04.09.98	04.09.98	---
Date Analyzed	04.14.98	04.14.98	---
Zinc (6010)			
Zinc, mg/l	<0.020	106 %	0.94 %
Preparation Date	04.09.98	04.09.98	---
Date Analyzed	04.14.98	04.14.98	---
Nickel (6010)			
Nickel, mg/l	<0.040	105 %	0.95 %
Preparation Date	04.09.98	04.09.98	---
Date Analyzed	04.14.98	04.14.98	---
Boron			
Boron, mg/l	<0.050	106 %	0.95 %
Preparation Date	04.09.98	04.09.98	---
Date Analyzed	04.14.98	04.14.98	---
Silica as SiO2 (6010)			
Silica as SiO2, mg/l	<0.50	90 %	1.1 %
Preparation Date	04.15.98	04.15.98	---
Date Analyzed	04.15.98	04.15.98	---
Bromide			
Bromide, mg/l	<2.0	100 %	1.0 %
Date Analyzed	04.10.98	04.10.98	---

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& ENVIRONMENTAL SERVICES, INC.

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LOG NO: B8-30965
Received: 07 APR 98
Reported: 16 APR 98

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Missimer International, Inc.
8140 College Parkway, Suite 202
Fort Myers, FL 33919

Project: Dare Co. Wide Study/FH7-571
Sampled By: Client
Code: 111380416

REPORT OF RESULTS

LOG NO	SAMPLE DESCRIPTION , QC REPORT FOR LIQUID SAMPLES	DATE/ TIME SAMPLED
30965-2	Method Blank	
30965-3	Accuracy (%Rec)	
30965-4	Precision (%RPD)	

PARAMETER	30965-2	30965-3	30965-4
Strontium (6010)			
Strontium, mg/l	<0.010	106 %	0.94 %
Preparation Date	04.09.98	04.09.98	---
Date Analyzed	04.14.98	04.14.98	---
Sulfide (376.1)			
Sulfide, mg/l	<1.0	90 %	4.3 %
Preparation Date	04.10.98	04.10.98	---
Date Analyzed	04.10.98	04.10.98	---

Methods: EPA SW-846
EPA 600/4-79-020
HRS Certification #'s: 84385, E84282, 87279, E87052, 87357, E87089

Michael F. Valder, Project Manager

S[redacted]umb[redacted]10[redacted]19[redacted]

SL SAVANNAH LABORATORIES
& ENVIRONMENTAL SERVICES, INC.

ANALYSIS REQUEST AND CHAIN OF CUSTODY RECORD

☐ 5102 LaRoche Avenue, Savannah, GA 31404 Phone: (912) 354-7858 Fax: (912) 352-0165
☐ 2846 Industrial Plaza Drive, Tallahassee, FL 32301 Phone: (904) 878-3994 Fax: (904) 878-9504
☐ 414 SW 12th Avenue, Deerfield Beach, FL 33442 Phone: (954) 421-7400 Fax: (954) 421-2584
☐ 900 Lakeside Drive, Mobile, AL 36693 Phone: (334) 666-6633 Fax: (334) 666-6696
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☐ 100 Alpha Drive, Suite 110, Destrehan, LA 70047 Phone: (504) 764-1100 Fax: (504) 725-1163

PROJECT REFERENCE: Dare County wide study
PROJECT NO.: FH7-571
P.O. NUMBER:
PROJECT LOC. (State): NC
SAMPLER(s) NAME: Scott Manahan
PHONE: (941) 432-9494
FAX: 432-9453
CLIENT NAME: Dare County, NC
CLIENT PROJECT MANAGER: Bob Oreskovich
CLIENT ADDRESS (CITY, STATE, ZIP): 600 Mustian street, Kill Devil Hills, NC 27948

MATRIX TYPE: AQUEOUS (WATER) / SOLID OR SEMISOLID / AIR / NONAQUEOUS LIQUID (oil, solvent, etc)

REQUIRED ANALYSES: Inorganics, Metals, H_2S, Silica B Sr, Br

PAGE ___ OF ___

☐ STANDARD REPORT DELIVERY
☐ EXPEDITED REPORT DELIVERY (surcharge)
Date Due

SAMPLE DATE	SAMPLE TIME	SL NO.	SAMPLE IDENTIFICATION	AQUEOUS (WATER)	SOLID OR SEMISOLID	AIR	NONAQUEOUS LIQUID	Inorganics	Metals	H_2S	Silica B Sr	Br	REMARKS
4/3/98	10:15 am to 10:30 am		DUCK-1	X				2	2	2	2	2	

(NUMBER OF CONTAINERS SUBMITTED)

RELINQUISHED BY: (SIGNATURE)	DATE	TIME	RELINQUISHED BY: (SIGNATURE)	DATE	TIME	RELINQUISHED BY: (SIGNATURE)	DATE	TIME
[signature]	3-30-98	1700	William A. Manahan [signature]	4/3/98	11:05 am			
RECEIVED BY: (SIGNATURE)	**DATE**	**TIME**	**RECEIVED BY: (SIGNATURE)**	**DATE**	**TIME**	**RECEIVED BY: (SIGNATURE)**	**DATE**	**TIME**
			Chris Wells [signature]	4-7-98	1415			

LABORATORY USE ONLY

RECEIVED FOR LABORATORY BY: (SIGNATURE)	DATE	TIME	CUSTODY INTACT	CUSTODY SEAL NO.	SL LOG NO.	LABORATORY REMARKS:
Chris Wells [signature]	4-7-98	1412	☑ YES ☐ NO		B830965	

ORIGINAL

SL SAVANNAH LABORATORIES
& ENVIRONMENTAL SERVICES, INC.

6712 Benjamin Road • Suite 100 • Tampa, FL 33634 • (813) 885-7427 • Fax (813) 885-7049

LOG NO: B8-31038
Received: 16 APR 98
Reported: 23 APR 98

Mr. Scott Manahan
Missimer International, Inc.
8140 College Parkway, Suite 202
Fort Myers, FL 33919

Project: Dare Co. Wide Study/FH7-571
Sampled By: Client
Code: 171480423

REPORT OF RESULTS

LOG NO	SAMPLE DESCRIPTION , LIQUID SAMPLES	DATE/ TIME SAMPLED
31038-1	MANN-SHALLOW	04-13-98/1530

PARAMETER	31038-1
Fluoride	
Fluoride, mg/l	<0.20
Date Analyzed	04.21.98
Alkalinity	
Alkalinity (to pH 4.5) as CaCO3, mg/l	270
Date Analyzed	04.17.98
Bicarbonate Alkalinity as CaCO3	
Bicarbonate Alkalinity as CaCO3, mg/l	270
Date Analyzed	04.17.98
Sulfate as SO4 (375.4)	
Sulfate as SO4, mg/l	<5.0
Date Analyzed	04.21.98
Chloride (325.3)	
Chloride, mg/l	27
Total Dissolved Solids	
Total Dissolved Solids, mg/l	360
Date Analyzed	04.16.98
Copper (6010)	
Copper, mg/l	<0.025
Preparation Date	04.20.98
Date Analyzed	04.22.98
Iron (6010)	
Iron, mg/l	<0.050
Preparation Date	04.20.98
Date Analyzed	04.22.98

SL SAVANNAH LABORATORIES
& ENVIRONMENTAL SERVICES, INC.

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LOG NO: B8-31038
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Project: Dare Co. Wide Study/FH7-571
Sampled By: Client
Code: 171480423

REPORT OF RESULTS

LOG NO	SAMPLE DESCRIPTION , LIQUID SAMPLES	DATE/ TIME SAMPLED
31038-1	MANN-SHALLOW	04-13-98/1530

PARAMETER	31038-1
Manganese (6010)	
Manganese, mg/l	0.054
Preparation Date	04.20.98
Date Analyzed	04.22.98
Zinc (6010)	
Zinc, mg/l	<0.020
Preparation Date	04.20.98
Date Analyzed	04.22.98
Nickel (6010)	
Nickel, mg/l	<0.040
Preparation Date	04.20.98
Date Analyzed	04.22.98
Boron	
Boron, mg/l	0.089
Preparation Date	04.20.98
Date Analyzed	04.22.98
Hardness as CaCO3 (6010)	
Hardness as CaCO3, mg/l	170
Preparation Date	04.20.98
Date Analyzed	04.22.98
Noncarbonate Hardness as CaCO3	
Hardness as CaCO3, mg/l	<5.0
Silica as SiO2 (6010)	
Silica as SiO2, mg/l	19
Preparation Date	04.20.98
Date Analyzed	04.20.98

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8140 College Parkway, Suite 202
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Project: Dare Co. Wide Study/FH7-571
Sampled By: Client
Code: 171480423

REPORT OF RESULTS

LOG NO	SAMPLE DESCRIPTION , LIQUID SAMPLES	DATE/ TIME SAMPLED
31038-1	MANN-SHALLOW	04-13-98/1530

PARAMETER	31038-1
Bromide	
Bromide, mg/l	<2.0
Date Analyzed	04.20.98
Strontium (6010)	
Strontium, mg/l	0.51
Preparation Date	04.20.98
Date Analyzed	04.22.98
Sulfide (376.1)	
Sulfide, mg/l	<1.0
Preparation Date	04.20.98
Date Analyzed	04.20.98

SL ***SAVANNAH LABORATORIES***
& ENVIRONMENTAL SERVICES, INC.

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LOG NO: B8-31038
Received: 16 APR 98
Reported: 23 APR 98

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Missimer International, Inc.
8140 College Parkway, Suite 202
Fort Myers, FL 33919

Project: Dare Co. Wide Study/FH7-571
Sampled By: Client
Code: 171480423

REPORT OF RESULTS

LOG NO	SAMPLE DESCRIPTION , QC REPORT FOR LIQUID SAMPLES
31038-2	Method Blank
31038-3	Accuracy (%Rec)
31038-4	Precision (%RPD)

PARAMETER	31038-2	31038-3	31038-4
Fluoride			
Fluoride, mg/l	<0.20	106 %	1.7 %
Date Analyzed	04.21.98	04.21.98	---
Alkalinity			
Alkalinity (to pH 4.5) as CaCO3, mg/l	<1.0	97 %	0 %
Date Analyzed	04.17.98	04.17.98	---
Bicarbonate Alkalinity as CaCO3			
Bicarbonate Alkalinity as CaCO3, mg/l	<1.0	97 %	0 %
Date Analyzed	04.17.98	04.17.98	---
Sulfate as SO4 (375.4)			
Sulfate as SO4, mg/l	<5.0	92 %	0 %
Date Analyzed	04.21.98	04.21.98	---
Chloride (325.3)			
Chloride, mg/l	<1.0	97 %	5.2 %
Date Analyzed	04.20.98	04.20.98	---
Total Dissolved Solids			
Total Dissolved Solids, mg/l	<5.0	100 %	1.3 %
Date Analyzed	04.16.98	04.16.98	---
Copper (6010)			
Copper, mg/l	<0.025	101 %	0 %
Preparation Date	04.20.98	04.20.98	---
Date Analyzed	04.22.98	04.22.98	---
Iron (6010)			
Iron, mg/l	<0.050	100 %	0 %
Preparation Date	04.20.98	04.20.98	---
Date Analyzed	04.22.98	04.22.98	---

SL SAVANNAH LABORATORIES
& ENVIRONMENTAL SERVICES, INC.

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LOG NO: B8-31038
Received: 16 APR 98
Reported: 23 APR 98

Mr. Scott Manahan
Missimer International, Inc.
8140 College Parkway, Suite 202
Fort Myers, FL 33919

Project: Dare Co. Wide Study/FH7-571
Sampled By: Client
Code: 171480423

REPORT OF RESULTS

LOG NO	SAMPLE DESCRIPTION , QC REPORT FOR LIQUID SAMPLES
31038-2	Method Blank
31038-3	Accuracy (%Rec)
31038-4	Precision (%RPD)

PARAMETER	31038-2	31038-3	31038-4
Manganese (6010)			
Manganese, mg/l	<0.010	100 %	1.0 %
Preparation Date	04.20.98	04.20.98	---
Date Analyzed	04.22.98	04.22.98	---
Zinc (6010)			
Zinc, mg/l	<0.020	99 %	0 %
Preparation Date	04.20.98	04.20.98	---
Date Analyzed	04.22.98	04.22.98	---
Nickel (6010)			
Nickel, mg/l	<0.040	101 %	2.0 %
Preparation Date	04.20.98	04.20.98	---
Date Analyzed	04.22.98	04.22.98	---
Boron			
Boron, mg/l	<0.050	94 %	0 %
Preparation Date	04.20.98	04.20.98	---
Date Analyzed	04.22.98	04.22.98	---
Hardness as CaCO3 (6010)			
Hardness as CaCO3, mg/l	<3.3	---	---
Preparation Date	04.20.98	---	---
Date Analyzed	04.22.98	---	---
Silica as SiO2 (6010)			
Silica as SiO2, mg/l	<0.50	96 %	3.1 %
Preparation Date	04.20.98	04.20.98	---
Date Analyzed	04.20.98	04.20.98	---

SL SAVANNAH LABORATORIES & ENVIRONMENTAL SERVICES, INC.

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Project: Dare Co. Wide Study/FH7-571
Sampled By: Client
Code: 171480423

REPORT OF RESULTS

LOG NO	SAMPLE DESCRIPTION , QC REPORT FOR LIQUID SAMPLES
31038-2	Method Blank
31038-3	Accuracy (%Rec)
31038-4	Precision (%RPD)

PARAMETER	31038-2	31038-3	31038-4
Bromide			
Bromide, mg/l	<2.0	102 %	0 %
Date Analyzed	04.20.98	04.20.98	---
Strontium (6010)			
Strontium, mg/l	<0.010	98 %	1.0 %
Preparation Date	04.20.98	04.20.98	---
Date Analyzed	04.22.98	04.22.98	---
Sulfide (376.1)			
Sulfide, mg/l	<1.0	87 %	1.1 %
Preparation Date	04.20.98	04.20.98	---
Date Analyzed	04.20.98	04.20.98	---

Methods: EPA SW-846
EPA 600/4-79-020
HRS Certification #'s: 84385, E84282, 87279, E87052, 87357, E87089

Michael F. Valder, Project Manager

SAVANNAH LABORATORIES
& ENVIRONMENTAL SERVICES, INC.

6712 Benjamin Road • Suite 100 • Tampa, FL 33634 • (813) 885-7427 • Fax (813) 885-7049

LOG NO: B8-31021
Received: 14 APR 98
Reported: 22 APR 98

Mr. Scott Manahan
Missimer International, Inc.
8140 College Parkway, Suite 202
Fort Myers, FL 33919

Project: Dare Co. Wide Study/FH7-571
Sampled By: Client
Code: 161980422

REPORT OF RESULTS

LOG NO	SAMPLE DESCRIPTION , LIQUID SAMPLES	DATE/ TIME SAMPLED
31021-1	MANN-DEEP	04-09-98/1500

PARAMETER	31021-1
Fluoride	
Fluoride, mg/l	0.35
Date Analyzed	04.17.98
Alkalinity	
Alkalinity (to pH 4.5) as CaCO3, mg/l	330
Date Analyzed	04.14.98
Bicarbonate Alkalinity as CaCO3	
Bicarbonate Alkalinity as CaCO3, mg/l	330
Date Analyzed	04.14.98
Sulfate as SO4 (375.4)	
Sulfate as SO4, mg/l	<5.0
Date Analyzed	04.14.98
Chloride (325.3)	
Chloride, mg/l	230
Date Analyzed	04.15.98
Total Dissolved Solids	
Total Dissolved Solids, mg/l	740
Date Analyzed	04.16.98
Copper (6010)	
Copper, mg/l	<0.025
Preparation Date	04.16.98
Date Analyzed	04.17.98
Iron (6010)	
Iron, mg/l	0.16
Preparation Date	04.21.98
Date Analyzed	04.21.98

SL SAVANNAH LABORATORIES
& ENVIRONMENTAL SERVICES, INC.

6712 Benjamin Road • Suite 100 • Tampa, FL 33634 • (813) 885-7427 • Fax (813) 885-7049

LOG NO: B8-31021
Received: 14 APR 98
Reported: 22 APR 98

Mr. Scott Manahan
Missimer International, Inc.
8140 College Parkway, Suite 202
Fort Myers, FL 33919

Project: Dare Co. Wide Study/FH7-571
Sampled By: Client
Code: 161980422

REPORT OF RESULTS

LOG NO	SAMPLE DESCRIPTION , LIQUID SAMPLES	DATE/ TIME SAMPLED
31021-1	MANN-DEEP	04-09-98/1500

PARAMETER	31021-1
Manganese (6010)	
Manganese, mg/l	0.018
Preparation Date	04.16.98
Date Analyzed	04.17.98
Zinc (6010)	
Zinc, mg/l	<0.020
Preparation Date	04.16.98
Date Analyzed	04.17.98
Nickel (6010)	
Nickel, mg/l	<0.040
Preparation Date	04.16.98
Date Analyzed	04.17.98
Boron	
Boron, mg/l	0.72
Preparation Date	04.16.98
Date Analyzed	04.17.98
Hardness as CaCO3 (6010)	
Hardness as CaCO3, mg/l	140
Preparation Date	04.21.98
Date Analyzed	04.22.98
Noncarbonate Hardness as CaCO3	
Hardness as CaCO3, mg/l	<5.0
Silica as SiO2 (6010)	
Silica as SiO2, mg/l	23
Preparation Date	04.16.98
Date Analyzed	04.20.98

LOG NO: B8-31021
Received: 14 APR 98
Reported: 22 APR 98

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8140 College Parkway, Suite 202
Fort Myers, FL 33919

Project: Dare Co. Wide Study/FH7-571
Sampled By: Client
Code: 161980422

REPORT OF RESULTS

LOG NO	SAMPLE DESCRIPTION , LIQUID SAMPLES	DATE/ TIME SAMPLED
31021-1	MANN-DEEP	04-09-98/1500

PARAMETER	31021-1
Bromide	
Bromide, mg/l	2.0
Date Analyzed	04.20.98
Strontium (6010)	
Strontium, mg/l	1.2
Preparation Date	04.16.98
Date Analyzed	04.20.98
Sulfide (376.1)	
Sulfide, mg/l	<1.0
Preparation Date	04.16.98
Date Analyzed	04.16.98

SL SAVANNAH LABORATORIES
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Code: 161980422

REPORT OF RESULTS

LOG NO	SAMPLE DESCRIPTION , QC REPORT FOR LIQUID SAMPLES	DATE/ TIME SAMPLED
31021-2	Method Blank	
31021-3	Accuracy (%Rec)	
31021-4	Precision (%RPD)	

PARAMETER	31021-2	31021-3	31021-4
Fluoride			
Fluoride, mg/l	<0.20	106 %	1.7 %
Date Analyzed	04.17.98	04.21.98	---
Alkalinity			
Alkalinity (to pH 4.5) as CaCO3, mg/l	<1.0	97 %	0 %
Date Analyzed	04.14.98	04.14.98	---
Bicarbonate Alkalinity as CaCO3			
Bicarbonate Alkalinity as CaCO3, mg/l	<1.0	97 %	0 %
Date Analyzed	04.14.98	04.14.98	---
Sulfate as SO4 (375.4)			
Sulfate as SO4, mg/l	<5.0	90 %	90 %
Date Analyzed	04.14.98	04.14.98	---
Chloride (325.3)			
Chloride, mg/l	<1.0	101 %	0 %
Date Analyzed	04.15.98	04.15.98	---
Total Dissolved Solids			
Total Dissolved Solids, mg/l	<5.0	100 %	1.3 %
Date Analyzed	04.16.98	04.16.98	---
Copper (6010)			
Copper, mg/l	<0.025	102 %	0 %
Preparation Date	04.16.98	04.16.98	---
Date Analyzed	04.17.98	04.17.98	---
Iron (6010)			
Iron, mg/l	<0.050	98 %	4.1 %
Preparation Date	04.21.98	04.21.98	---
Date Analyzed	04.21.98	04.21.98	---

SL SAVANNAH LABORATORIES
& ENVIRONMENTAL SERVICES, INC.

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Sampled By: Client
Code: 161980422

REPORT OF RESULTS

LOG NO	SAMPLE DESCRIPTION , QC REPORT FOR LIQUID SAMPLES	DATE/ TIME SAMPLED
31021-2	Method Blank	
31021-3	Accuracy (%Rec)	
31021-4	Precision (%RPD)	

PARAMETER	31021-2	31021-3	31021-4
Manganese (6010)			
Manganese, mg/l	<0.010	102 %	0.99 %
Preparation Date	04.16.98	04.16.98	---
Date Analyzed	04.17.98	04.17.98	---
Zinc (6010)			
Zinc, mg/l	<0.020	102 %	0.99 %
Preparation Date	04.16.98	04.16.98	---
Date Analyzed	04.17.98	04.17.98	---
Nickel (6010)			
Nickel, mg/l	<0.040	100 %	1.0 %
Preparation Date	04.16.98	04.16.98	---
Date Analyzed	04.17.98	04.17.98	---
Boron			
Boron, mg/l	<0.050	94 %	1.1 %
Preparation Date	04.16.98	04.16.98	---
Date Analyzed	04.17.98	04.17.98	---
Hardness as CaCO3 (6010)			
Hardness as CaCO3, mg/l	<3.3	---	---
Preparation Date	04.21.98	---	---
Date Analyzed	04.22.98	---	---
Silica as SiO2 (6010)			
Silica as SiO2, mg/l	<0.50	97 %	2.1 %
Preparation Date	04.16.98	04.16.98	---
Date Analyzed	04.20.98	04.20.98	---

SL **SAVANNAH LABORATORIES**
& ENVIRONMENTAL SERVICES, INC.

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8140 College Parkway, Suite 202
Fort Myers, FL 33919

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Sampled By: Client
Code: 161980422

REPORT OF RESULTS

LOG NO	SAMPLE DESCRIPTION , QC REPORT FOR LIQUID SAMPLES	DATE/ TIME SAMPLED
31021-2	Method Blank	
31021-3	Accuracy (%Rec)	
31021-4	Precision (%RPD)	

PARAMETER	31021-2	31021-3	31021-4
Bromide			
Bromide, mg/l	<2.0	102 %	0 %
Date Analyzed	04.20.98	04.20.98	---
Strontium (6010)			
Strontium, mg/l	<0.010	96 %	1.0 %
Preparation Date	04.16.98	04.16.98	---
Date Analyzed	04.20.98	04.20.98	---
Sulfide (376.1)			
Sulfide, mg/l	<1.0	89 %	1.1 %
Preparation Date	04.16.98	04.16.98	---
Date Analyzed	04.16.98	04.16.98	---

Methods: EPA SW-846
EPA 600/4-79-020
HRS Certification #'s: 84385, E84282, 87279, E87052, 87357, E87089

Michael F. Valder, Project Manager

[redacted]3[redacted]02[redacted] S[redacted]umb[redacted]10[redacted]19[redacted]

SL SAVANNAH LABORATORIES
& ENVIRONMENTAL SERVICES, INC.

☐ 5102 LaRoche Avenue, Savannah, GA 31404 Phone: (912) 354-7858 Fax: (912) 352-0165
☐ 2846 Industrial Plaza Drive, Tallahassee, FL 32301 Phone: (904) 878-3994 Fax: (904) 878-9504
☐ 414 SW 12th Avenue, Deerfield Beach, FL 33442 Phone: (954) 421-7400 Fax: (954) 421-2584
☐ 900 Lakeside Drive, Mobile, AL 36693 Phone: (334) 666-6633 Fax: (334) 666-6696
☐ 6712 Benjamin Road, Suite 100, Tampa, FL 33634 Phone: (813) 885-7427 Fax: (813) 885-7049
☐ 100 Alpha Drive, Suite 110, Destrehan, LA 70047 Phone: (504) 764-1100 Fax: (504) 725-1163

ANALYSIS REQUEST AND CHAIN OF CUSTODY RECORD

ORIGINAL

PROJECT REFERENCE: Dare County Wide
PROJECT NO.: FH7-571
P.O. NUMBER:
PROJECT LOC. (State):
SAMPLER(s) NAME: Scott Marahan
PHONE: (941) 432-9494
FAX: (941) 432-9453
CLIENT NAME: Missimer International
CLIENT PROJECT MANAGER: Scott Marahan
CLIENT ADDRESS (CITY, STATE, ZIP): 8140 College Parkway, Suite 202, Fort Myers, FL 33914

MATRIX TYPE: AQUEOUS (WATER) / SOLID OR SEMISOLID / AIR / NONAQUEOUS LIQUID (oil, solvent, etc)

REQUIRED ANALYSES

PAGE OF

☐ STANDARD REPORT DELIVERY
☐ EXPEDITED REPORT DELIVERY (surcharge)
Date Due

SAMPLE DATE	SAMPLE TIME	SL NO.	SAMPLE IDENTIFICATION	AQUEOUS (WATER)	SOLID OR SEMISOLID	AIR	NONAQUEOUS LIQUID	NUMBER OF CONTAINERS SUBMITTED	REMARKS

RELINQUISHED BY: (SIGNATURE)	DATE	TIME	RELINQUISHED BY: (SIGNATURE)	DATE	TIME	RELINQUISHED BY: (SIGNATURE)	DATE	TIME
[signature]	4/6/98	1115	William S. [signature]	4/9/98	4:30pm			
RECEIVED BY: (SIGNATURE)	**DATE**	**TIME**	**RECEIVED BY: (SIGNATURE)**	**DATE**	**TIME**	**RECEIVED BY: (SIGNATURE)**	**DATE**	**TIME**
			[signature]	4-14-98	0945			

LABORATORY USE ONLY

RECEIVED FOR LABORATORY BY: (SIGNATURE)	DATE	TIME	CUSTODY INTACT	CUSTODY SEAL NO.	SL LOG NO.	LABORATORY REMARKS:
[signature]	4-14-98	1049	☒ YES ☐ NO		B831021	

DARE COUNTY, NORTH CAROLINA

Date Sample Drawn: 3-27-98
By Whom: LA, NC, AB

Location: KDH Test Well

Certificate of Analysis or Test

	KDH Test Well	Max Contaminant Level
P - Alkalinity as $CaCO_3$, mg/l	0	N/A
Total Alkalinity $CaCO_3$, mg/l	330	N/A
Bicarbonate as HCO_3, mg/l	402	N/A
Carbonate as CO_3, mg/l	0	N/A
Hydroxide as OH, mg/l	0	N/A
Total Hardness as $CaCO_3$, mg/l	40	150.0 *
Calcium Hardness as $CaCO_3$, mg/l	8	N/A
Magnesium as $CaCO_3$, mg/l	32	N/A
Calcium as Ca, mg/l	3.2	60.0 *
Color, C.U. (Color Units)	31	15.0 ●
Silica as SiO_2, mg/l	4.4	N/A
Conductivity as μmhos/cm	1630	N/A
Iron, Fe, mg/l	.021	0.30●
Potassium, K, mg/l	18.52	N/A
Copper, Cu, μg/l	< 70 μg/l	1,300 μg/l ☆
Manganese, Mn, mg/l	0.005	.05●
Phosphate as PO_4, mg/l	1.66	5.0 *
Chloride as Cl^-, mg/l	300	250.0 *
Fluoride as F, mg/l	.46	4.0 *
Nitrate as NO_3, mg/l	.264	10.0●
Zinc as Zn, mg/l	.103	5.0 ●
Chlorine (free Cl_2), mg/l	0	0.2 ✱
Lead as Pb, μg/l	< 5 μg/l	15 μg/l ☆
Corrosiveness	----	N/A
pH	7.48	6.5—8.5 *
pHs	----	N/A
Turbidity, N.T.U.	.22	1.0 ●
Total Suspended Solids, mg/l	.3	N/A
Total Dissolved Solids, mg/l	840	500.0 *
Sulfate as SO_4, mg/l	2.24	250.0 *
Sodium as Na, mg/l (est.)	----	250.0 ●
Sulfide as S, mg/l	0	N/A

* Recommended State Maximums ✱ Mandatory State Minimum ●Mandatory State Maximums ☆ - Action Level N/A Not available - No limit
mg/l = Parts per million μg/l = Parts per billion

COUNTY OF DARE

KILL DEVIL HILLS. NORTH CAROLINA 27948

600 MUSTIAN
PHONE (919) 47

Dare County Water System
Water Sample Analysis

DUCK TEST WELL

Parameter		State Max / Min
Total Hardness (mg/l as $CaCO_n$	320	150
Iron (mg/l as Fe)	1.12	0.3
Chloride (mg/l as CL)	~~[illegible]~~ 1500	250
Fluoride (mg/l as F)	.30	4.0
Color	12	15
pH	7.38	6.5 - 8.5
Turbidity, NTU	10.25	1.0
Total Dissolved Solids (mg/l)	2500	500
Free Chlorine Residual (mg/l)	Ø	not less than 0.2
Total Chlorine Residual (mg/l)	Ø	N/A
Bacteriological Results		
* Fluoride is now being added to the water as of August 13, 1991.		

Name: Scott Manahan Phone #:

Address:

Date Sample Taken: 4-3-98 Sample Drawn Location: Duck Moniter well

Date Analysis Completed: 4-3-98 Operator: AB

Date Bacteriological Completed: / Operator: /

* SMALL BOTTLE
CHLORIDES 1850 AB

DARE COUNTY, NORTH CAROLINA

Date Sample Drawn:
By Whom: LA, OL, DH Date Analysis Completed:
Wells running:
Water Treatment Plant: Manns Harbour Well (Deep Zone) 250'-350'

Certificate of Analysis or Test

	Well Water Raw	Finished Water Quality	Distributed Water Quality	Max Contaminant Level
P - Alkalinity as $CaCO_3$, mg/l	0			N/A
Total Alkalinity $CaCO_3$, mg/l	286			N/A
Bicarbonate as HCO_3, mg/l	348.7			N/A
Carbonate as CO_3, mg/l	6			N/A
Hydroxide as OH, mg/l	0			N/A
Total Hardness as $CaCO_3$, mg/l	168			150.0 •
Calcium Hardness as $CaCO_3$, mg/l	120			N/A
Magnesium as $CaCO_3$, mg/l	48			N/A
Calcium as Ca, mg/l	48			60.0 •
Color, C.U. (Color Units)	14			15.0 ●
Silica as SiO_2, mg/l	22.7			N/A
Conductivity as μmhos/cm	1380			N/A
Iron, Fe, mg/l	.165			0.30 ●
Potassium, K, mg/l	2X 31.83			N/A
Copper, Cu, μg/l	< 70 μg/l	< 70 μg/l	< 70 μg/l	1,300 μg/l ☆
Manganese, Mn, mg/l	.033			.05 ●
Phosphate as PO_4, mg/l	.381			5.0 •
Chloride as Cl^-, mg/l	240			250.0 •
Fluoride as F, mg/l	.45			4.0 •
Nitrate as NO_3, mg/l	.352			10.0 ●
Zinc as Zn, mg/l	.736			5.0 ●
Chlorine (free Cl_2), mg/l	.02			0.2 *
Lead as Pb, μg/l	< 5 μg/l	< 5 μg/l	< 5 μg/l	15 μg/l ☆
Corrosiveness	-0.02			N/A
pH	7.6			6.5—8.5 •
pHs	7.82			N/A
Turbidity, N.T.U.	.38			1.0 ●
Total Suspended Solids, mg/l	.2			N/A
Total Dissolved Solids, mg/l	710			500.0 •
Sulfate as SO_4, mg/l	4.4			250.0 •
Sodium as Na, mg/l (est.)	124.69			250.0 ●
Sulfide as S, mg/l	0			N/A

• Recommended State Maximums * Mandatory State Minimum ● Mandatory State Maximums ☆ - Action Level N/A Not available - No limit
mg/l = Parts per million μg/l = Parts per billion

DARE COUNTY, NORTH CAROLINA

Date Sample Drawn: 4-13-98 Date Analysis Completed: 4-1-98
By Whom: GL, CP
Wells running:
Water Treatment Plant: R.O. Plant

Certificate of Analysis for Test

MANNS HARBOR SHALLOW

	[redacted]	Finished Water Quality	Distributed Water Quality	Max Contaminant Level
P - Alkalinity as $CaCO_3$, mg/l	0			N/A
Total Alkalinity $CaCO_3$, mg/l	250			N/A
Bicarbonate as HCO_3, mg/l	304.87			N/A
Carbonate as CO_3, mg/l	0			N/A
Hydroxide as OH, mg/l	0			N/A
Total Hardness as $CaCO_3$, mg/l	90432			150.0 *
Calcium Hardness as $CaCO_3$, mg/l	170			N/A
Magnesium as $CaCO_3$, mg/l	262			N/A
Calcium as Ca, mg/l	68			60.0 *
Color, C.U. (Color Units)	7			15.0 ✸
Silica as SiO_2, mg/l	18.8			N/A
Conductivity as μmhos/cm	630			N/A
Iron, Fe, mg/l	.036			0.30✸
Potassium, K, mg/l	28			N/A
Copper, Cu, μg/l	< 70 μg/l	< 70 μg/l	< 70 μg/l	1,300 μg/l ☆
Manganese, Mn, mg/l	.078			.05✸
Phosphate as PO_4, mg/l	.227			5.0 *
Chloride as Cl^-, mg/l	30			250.0 *
Fluoride as F, mg/l	.14			4.0 *
Nitrate as NO_3, mg/l	.308			10.0✸
Zinc as Zn, mg/l	.016			5.0 ✸
Chlorine (free Cl_2), mg/l	.09			0.2 ✱
Lead as Pb, μg/l	< 5 μg/l	< 5 μg/l	< 5 μg/l	15 μg/l ☆
Corrosiveness	~~[illegible]~~	.44		N/A
pH	7.83			6.5–8.5 *
pHs	~~7.48~~	7.39		N/A
Turbidity, N.T.U.	.18			1.0 ✸
Total Suspended Solids, mg/l	.2			N/A
Total Dissolved Solids, mg/l	330			500.0 *
Sulfate as SO_4, mg/l	4.92			250.0 *
Sodium as Na, mg/l (est.) ✱—	451.86	✱		250.0 ✸
Sulfide as S, mg/l	0			N/A

* Recommended State Maximums ✱ Mandatory State Minimum ✸Mandatory State Maximums ☆ - Action Level N/A Not available - No limit
mg/l = Parts per million μg/l = Parts per billion

GEOPHYSICAL LOGS

(C:\MANN\GR.GB5) MANNS HARBOUR 4/6/98

Gamma
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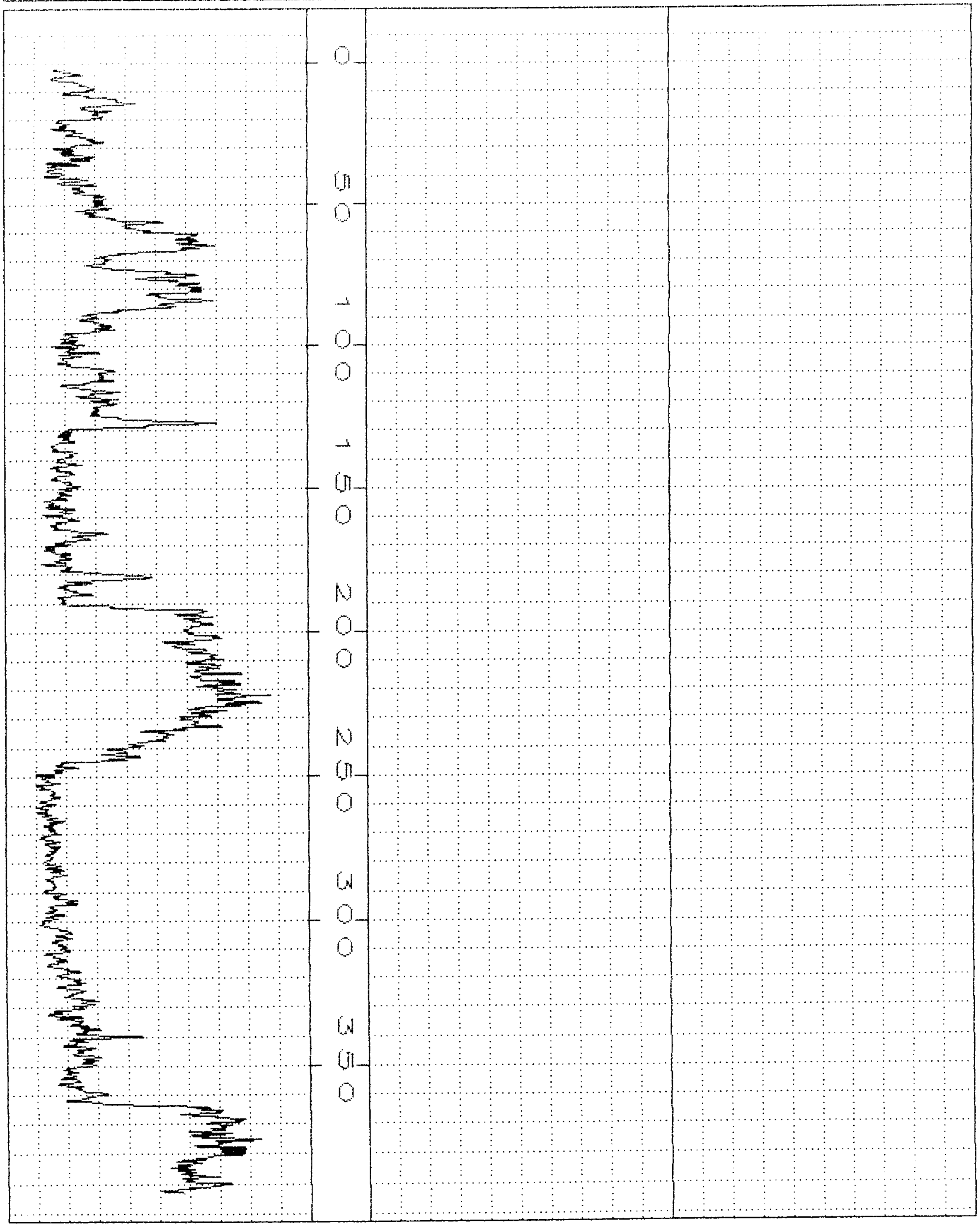

Gamma
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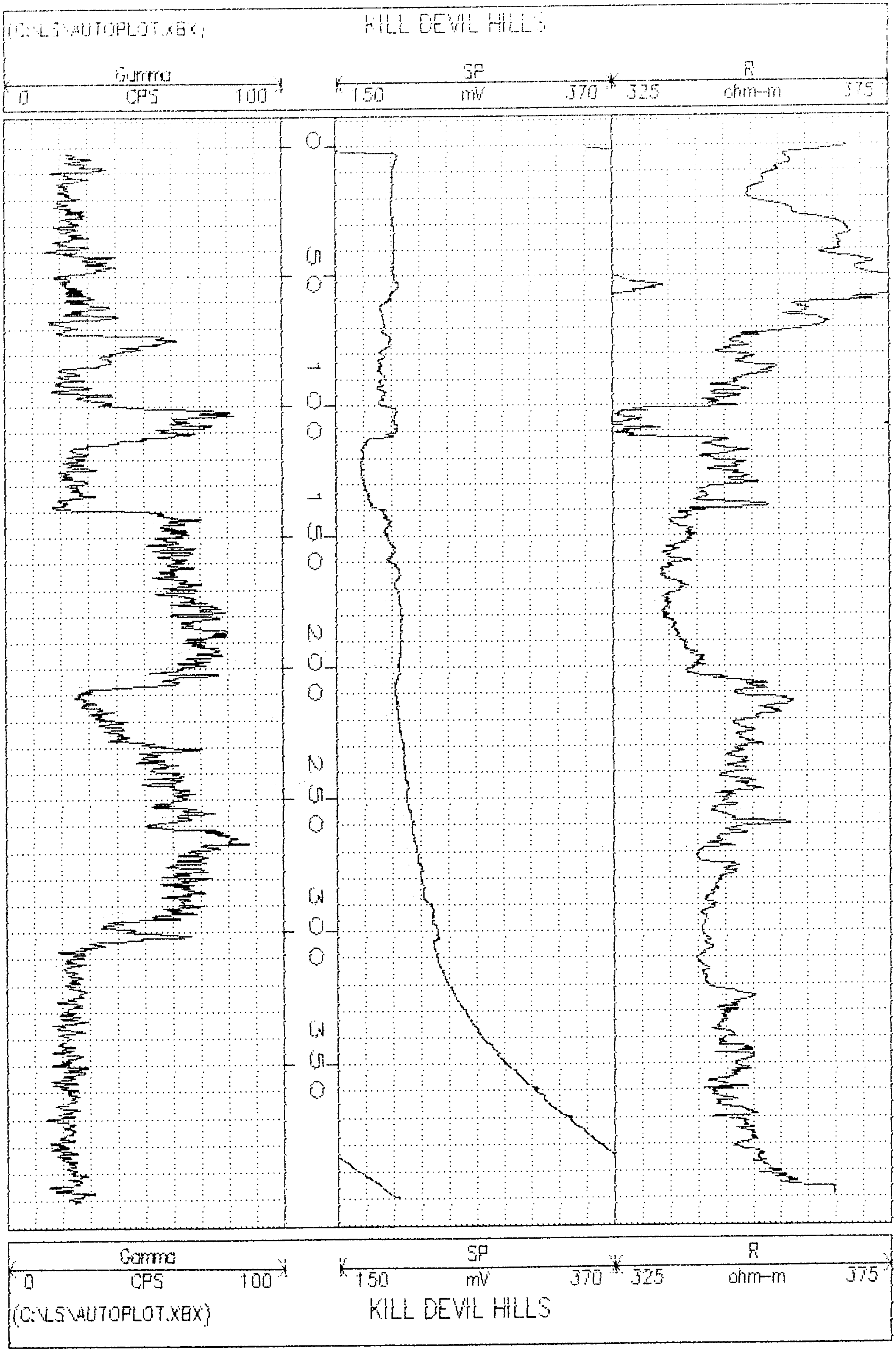
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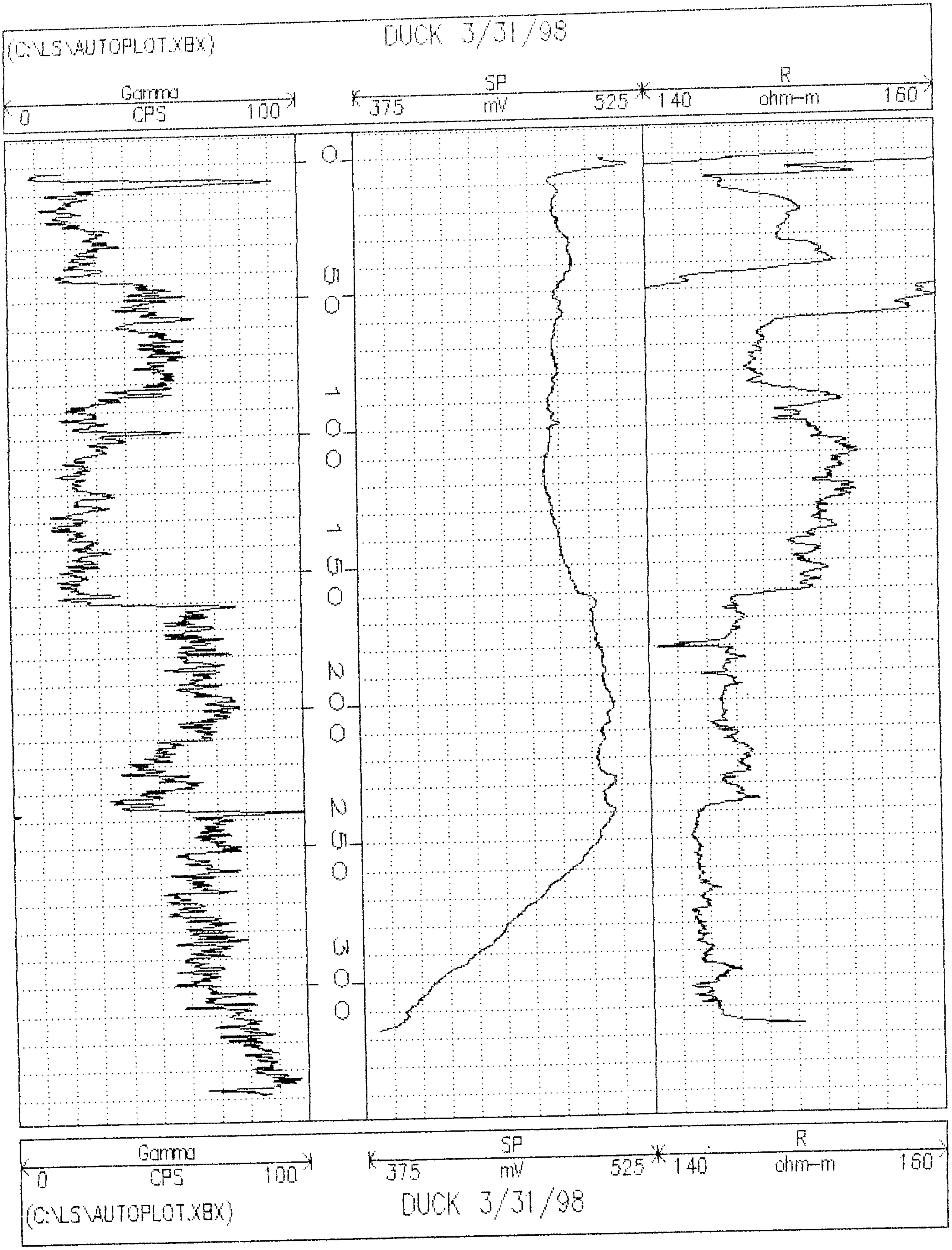

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DUCK 3/31/98
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DUCK 3/31/98