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Ground-Water Resources of the Camp Lejeune Marine Corps Base--Water-Use Data, A Preliminary Geohydrologic Framework, And Water-Level Data

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OPEN-FILE REPORT

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DRAFT

Ground-water Resources of the Camp Lejeune Marine Corps Base--Water-Use Data, A Preliminary Geohydrologic Framework, And Water-Level Data

By Douglas Harned, Orville Lloyd, Rick Treece, and Gerad Bales

DRAFT

CONTENTS

TABLES

ILLUSTRATIONS

INTERNATIONAL SYSTEM UNITS

The following factors may be used to convert the U.S. customary units published in this report to the International System of Units. (SI).

Multiply U.S. Customary unit	By	To obtain SI (metric) unit
	Length	
inches (in)	25.4	millimeters (mm)
feet (ft)	.3048	meters (m)
miles (mi)	1.609	kilometers (km)
	Area	
square feet (ft^2)	.0929	square meters (m^2)
square miles (mi^2)	2.590	square kilometers (km^2)
	Volume	
Cubic feet (ft^3)	0.02832	cubic meters (m^3)
	Flow	
cubic feet per second (ft^3/s)	.02832	cubic meters per second (m^3/s)
gallons per minute (gal/min)	0.00379	cubic meters per minute (m^3/min)
	Velocity	
feet per day (ft/day)	.3048	meters per day (m/day)
	Mass	
pounds (lb avoirdupois)	.4536	kilograms (kg)

RELATION OF UNITS OF HYDRAULIC CONDUCTIVITY AND TRANSMISSIVITY

A, Hydraulic conductivity (K)

Feet per day (ft/day)	Meters per day (m/day)	Gallons per day per square foot (gal/day ft^2)
ONE	0.305	7.48
3.28	ONE	24.5
.134	.041	ONE

B, Transmissivity (T)

Square feet per day (ft^2/day)	Square meters per day (m^2/day)	Gallons per day per foot (gal/day ft)
ONE	0.0929	7.48
10.76	ONE	80.5
.134	.0124	ONE

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ABSTRACT

In the first year of a four-year study of the ground-water resources of the Camp Lejeune Marine Corps Base, available water-use data has been reviewed, a description of the hydrologic system has been initiated, a water level monitoring network has been installed, and two water-level surveys have been made. The objectives of this study are: to describe the ground-water resources of the Marine Corps Base at Camp Lejeune North Carolina, and environs and to construct a ground-water flow model that will be used to evaluate alternative ground-water use and management practices. This is a three-phased study: the first phase is examination of available data, the second phase is collection of additional data and construction of new observation wells, and the third phase is modeling. This report describes the results of the first phase of study.

Water use by the Base has grown from around 4 million gallons a day in 1941 to around 8 million gallons a day currently. In recent years water demand has not increased substantially, however, the pumping scheme and treatment by the 8 water plants on the Base has changed. Current expansion of the Holcomb Boulevard treatment plant has coincided with the discontinuation of many supply wells in the Hadnot Point system.

The Castle Hayne aquifer is the principal water-suppy source for the Base. The aquifer is made up of a series of sand and limestone beds that underlie the area to a depth of 300 feet. The upper aquifer appears to be

hydraulically connected to the New River. The dip of the beds n the Camp Lejeune area is to the southeast at 19 degrees with a strike of north 79 degrees east.

Clay beds make up only about 15-25 percent of the section, indicating that the water supply aquifer is only partially confined. In the Air Station area there is evidence that a possible fault may have breeched clay layers causing saltwater contamination.

Well-acceptance tests indicate a mean specific capacity of 8.8 gallons per minute per foot of drawdown. Transmissivity values estimated using specific capacities give a mean confined value of 19,400 and an unconfined value of 15,100 (gals/d)/ft.

Contour maps of water levels for both of the water level surveys show that the regional water-level contours tend to follow surface contours. The New River is a mjor discharge area for the water-supply aquifer. A seasonal water-level variation of 1-3 feet is evident.

The hydraulic gradient outside of pumping areas is 5-15 feet per mile. Near pumping wells the gradient increases, averaging 150-200 feet per mile. Water moves at a rate of about 2-3 feet per day outside of pumping areas, and around 35-40 feet per day around pumping wells.

INTRODUCTION

This is the first report of a four-year study of the ground-water resources of Camp Lejeune Marine Corps Base covering the results of the first year, and first phase of the study. This is a three phased study: the first phase is the examination of available data, the second phase is the collection of additional data and construction of new observation wells, and the third phase is modeling.

Camp Lejeune Marine Corps Base is located southeast of the city of Jacksonville in Onslow County, North Carolina. The Base is bounded on the north by N.C. Highway 24, the east by N.C. Highway 172 and Bear Creek, the southeast by the Atlantic Ocean, the southwest by the New River and an irregular line that roughly parallels N.C. Highway 172, and on the west by U.S. Highway 17 (see fig. 1).

Camp Lejeune plays an essential role in training many Marine Corps men and women for jobs that are necessary to preserve our national security. The Base is the only military training center in the eastern United States where joint amphibious training exercises can be carried out with all branches of the Armed Services. A plentiful and good-quality water supply is vital for Camp Lejeune to carry out its mission and to maintain the operational readiness of the Fleet Marine Forces. Because it would be very difficult to impound large supplies of fresh water on the surface of the land in the area, Camp Lejeune relies on large amounts of ground water for water supply.

Since Camp Lejeune was first opened in the late 1930's, water supply has been derived from wells that tap freshwater-bearing aquifers (sands and limestone) which occur between land surface and about 300 feet below land surface. Clay and silty clay confining beds are interlayered with the aquifer material but are generally thin and discontinuous beneath the Base. Salty water occurs in the deep sand aquifers that underlie the area and in the shallow aquifer material adjacent to the Atlantic Ocean and tidal reaches of the New River and its tributaries.

Over the years, more than 100 wells have been drilled and operated to satisfy increasing demands for water as the Base's functions and population grew. At present, ground-water withdrawals rank among the largest in the State and are estimated at 7.5 million gallons per day. The Base presently supports a population of about 100,000.

An increase in the amount of waste generated by Base operations has accompanied the growth of the Base. As a result, significant amounts of wastes containing hazardous and toxic organic compounds have been disposed of or spilled on the Base. Most of the disposal and spill sites are directly underlain by sand and lack natural or synthetic barriers to prevent the wastes from moving downward into the ground-water system. Consequently, some wastes have infiltrated to the water table and have contaminated some ground water in the shallow and supply aquifers. Many of the waste-disposal and spill sites are near water-supply wells. The use of a number of supply wells has been discontinued recently because organic compounds have been detected in the well water.

Ground-water withdrawals from wells that are near the tidal reaches of the New River and its tributaries may cause salty water in these drainage-ways to move into and through the shallow aquifers toward the pumping wells. It is also possible that salty water could be drawn upward from deeper parts of the aquifer system by wells pumping large amounts of ground water from the deep sand aquifers or the lower parts of the sand and limestone aquifer.

Purpose and Scope

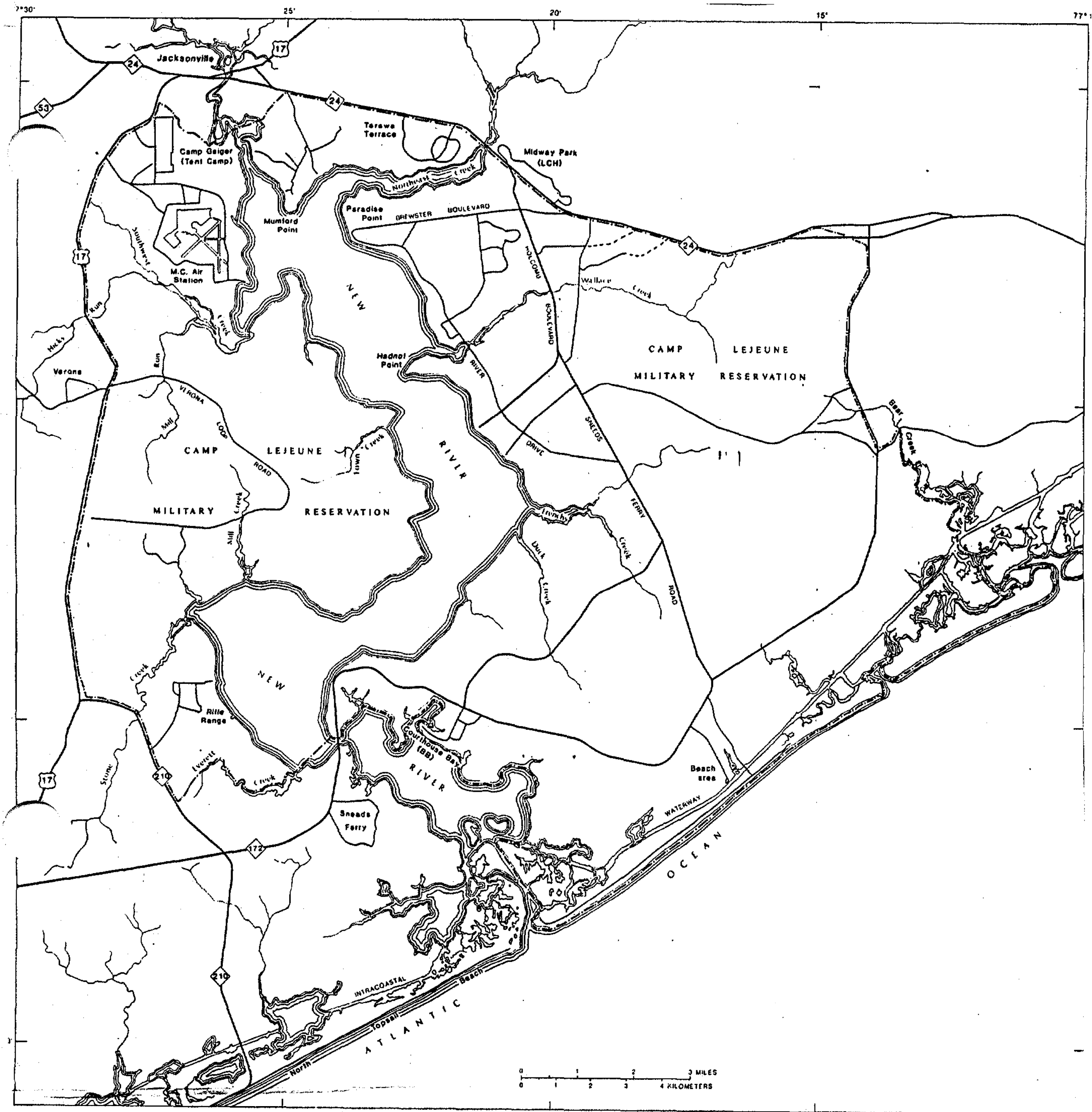
Growing water-supply needs coupled with the threat of present and future contamination of existing wells (by disposed wastes or salty water) has prompted the Marine Corps to request the U.S. Geological Survey to study the geohydrology of the Base and environs and determine ground-water use and management practices that will reduce the chances of further contamination and help assure that future water-supply needs are met.

The objective of the study is to describe the ground-water resources of the Base and environs and to construct an appropriate ground-water flow model. The flow model will be used to evaluate alternative ground-water use and management practices that will reduce chances for further contamination and help assure that future water-supply needs are met.

The objective of this report is to describe results of the first year of study. Results of this phase of study include an evaluation of water-use data, a preliminary description of the geohydrology of the base, establishment of the initial components of the ground-water level monitoring network, and instrumentation of a basin to measure groundwater recharge.

The study area includes the Marine Corps Base and environs (figure 1). The data analysis for this report focuses on the developed areas of the Base, including Hadnot Point, the Marine Corps Air Station, and Tarawa Terrace, because the bulk of the available data is from these areas.

The available ground-water data that were reviewed for this report included well records maintained by the Utilities Division on the Base, records from the files of the North Carolina Department of Natural Resources and Community Development (NRCD), and records from U.S. Geological Survey



Base taken from, Defense Mapping Agency Hydrographic Center; *Camp Lejeune Special Map*, 1:50,000.

Figure 1.--Camp Lejeune Marine Corps Base study area.

(USGS) files. These data include: borehole geophysical logs, water-level measurements, well-construction descriptions, lithologic descriptions of well cuttings, and water-use information. The well-record data from these sources spans the entire record of well-drilling for water supply from the early 1940's to the present. Data for a water quality survey of October 1986 of the Base water-supply wells was obtained from Environmental Science and Engineering Inc. Borehole geophysical logs for the test well drilled in 1986 by NRCD for the Hadnot Point Research Station of the NRCD ground-water monitoring program have also been used in this analysis.

Two special surveys of ground-water levels from all accessible wells were made for this study. The first survey was run in October of 1986 during a period of relatively low water levels. The second survey was run in April 1987 during a period of relatively high water levels.

Six water-level recorders currently (April, 1987) make up the water-level monitoring network at Camp Lejeune. The water-level recorders were established in June and July 1986. A stream gage and a rain gage were installed in June 1986. A tide gage was established in August 1986. Data from these stations are reviewed in this report.

Acknowledgments

Robert Alexander, of Staff Facilities at Camp Lejeune, served as the principal liaison between staff on the Marine Base, the U.S. Geological Survey, and Environmental Sciences and Engineering Inc. Mack Frazelle and Junior Johnson of Camp Lejeune Utilities helped provide access to well-record data.

Richard Shiver, of the North Carolina Department of Natural Resources and Community Development Wilimington Office, provided well records and geophysical logs, and coordinated the well-drilling for the Hadnot Point Research Station wells.

Mike Geden, of Environmental Sciences and Engineering, provided water-quality data established for the current Navy Assessment and Control of Installation Pollutants (NACIP) study at the Base for the water-supply wells, and allowed access to shallow monitor wells.

Eben Frankenburg helped in the construction of the geohydrologic cross sections and interpretive mapping. Orville B. Lloyd and Alex Cardinell reviewed the borehole geophysical logs and traced hydrologic units in the cross sections.

Orville B. Lloyd wrote much of the introduction. Rick Treece analyzed the water-use data, and wrote the water-use section. Jerad Bales wrote the hydrologic budget section.

Steve Howe, Gerald Strickland, Alex Cardinell, Lloyd Edwards, and Rick Treece all helped with the study field work. Gerry Idler ran the borehole geophysical logs for 18 wells on the Base.

Technical reviews of this report were received from Eben Frankenburg and Orville B. Lloyd.

STUDY DESIGN

Study Elements

The principal elements of the study design include determining: (1) the lateral extent, thickness, and hydraulic characteristics of aquifers and confining beds, (2) the potentiometric surfaces of the aquifers, (3) the amounts of ground-water recharge and discharge, (4) the quality of freshwater contained by the aquifers and the relationship between the freshwater and saltwater in the aquifers, and building (6) a deterministic flow model of the ground-water system of the Base. This is a three-phased study: the first phase is the examination of available data, the second phase is collection of additional data including construction of new observation wells, and the third phase is modeling.

Geohydrologic framework--The depth, thickness, and lateral extent of the aquifers and confining beds will be determined and mapped from a study of geophysical and lithologic logs made from existing wells and new wells constructed for the study.

A major part of the study can be implemented with data that is either presently available or can be collected from existing wells. However, some new test drilling will be needed to better define the geohydrologic framework, the factors that control ground-water movement through the framework, and the ground-water quality.

The drilling and sampling of the NACIP program will describe and define the nature and extent of ground-water contamination from hazardous-waste sites on the Base. Therefore, drilling done for the USGS study will be located away from the hazardous-waste sites to reduce the expense of required and special drilling and safety procedures.

Ground-water movement through the geohydrologic framework--Data from geophysical and lithologic logs will be used in conjunction with aquifer-test data to determine and map the water transmitting and storage capabilities (hydraulic conductivity, storage coefficient and porosity, respectively) of the aquifers and confining beds. Aquifer tests will be designed so that aquifer anisotropy, if it exists, can be determined. In addition, water-level data collected from existing and new wells will be used to determine and map the potentiometric surfaces of the aquifers. The water-level data indicate the hydraulic gradient throughout the aquifer systems. The hydraulic gradient, hydraulic conductivity, storage coefficient and porosity are needed to determine the direction and rate of ground-water movement in the area.

Water-resources budget--Data on precipitation, evapotranspiration, runoff, water levels and water use will be collected, compiled and analyzed to estimate ground-water recharge and discharge in the area.

Quality of ground water--Water samples will be collected from existing and new wells and analyzed for major ion concentrations (including chloride), and organic compounds, heavy metals, and other chemicals associated with work and waste disposal at the Base. The water-quality data will be used to identify, quantify, and determine the source of chemical constituents in the fresh ground water and to help determine the position of the freshwater-saltwater interface in the Base area. Quality assurance will be coordinated with the USGS Denver laboratory.

Water-level and water-quality data obtained from more than 50 wells drilled during the second phase of the NACIP program at the Base (Putnam , 1983) will be used in conjunction with data collected during the USGS study. The NACIP data will help define the hydrology and any potential and existing water-quality problems. The wells drilled for the NACIP program are designed to test the ground-water quality to a depth of about 30 feet below the water table and are located adjacent to 22 waste-disposal or spill sites at the Base. Analyses of soil, rock, and water samples collected from these wells are being used to confirm whether or not the shallow ground-water and aquifer material have been contaminated. Confirmation of contamination in the shallow part of the ground-water system will provide an alert to potential contamination in the deeper supply aquifer.

Drilling of an additional four to six observation wells (50 to 100 feet deep) will be needed to investigate the position of the freshwater-saltwater interface and its relation to supply-well pumping.

Ground-water flow model--The compiled and analyzed data will be used to construct and calibrate a fine-grid, finite-difference ground-water flow model. The model will be the basic tool with which to analyze the effects of alternative ground-water supply development scenarios for the Base. The model will extend beyond the boundaries of the Base and include most or all of Onslow County. The model boundaries will coincide with natural hydrogeologic boundaries or will parallel the regional ground-water flow lines as defined by the Regional Aquifer Systems Analysis Model (J. L. Eimers, U.S. Geological Survey, written commun., 1987). The freshwater/saltwater interface, which extends from the Atlantic Ocean on the southeast landward beneath the Base, will be a no-flow boundary. This inter face is defined as the estimated location of water with a 10,000 mg/L chloride concentration. The water table will be a free surface.

Work Plan

The objective of Phase 1 of the study (April 1986-April 1987) was to collect, compile and analyze available data on water use, geohydrology, water levels in aquifers and prepare a report that describes the available data and new data needs. Specific work tasks included:

1) Compile all available ground-water data from USGS, State, and Camp Lejeune files for the area, including water-level, water-quality, water-use, and well-log data. Construct a computer data set of these data that will facilitate future statistical analysis.
2) Develop preliminary maps and other information products describing the geohydrologic framework beneath the base and adjacent areas in Onslow County.
3) Map potentiometric surfaces of the water-supply aquifer from water-level measurements made primarily in existing wells.

The information from work tasks 1, 2, and 3 were used to make a preliminary assessment of the geohydrologic framework beneath Camp Lejeune. This assessment will be reviewed in Phase 2a to determine the location and number of new wells to be drilled. This report is a discussion of the results of the Phase 1 study.

Phase 2 will extend over a two-year period and will be devoted to test drilling and the collection and analysis of additional water quality, hydrogeologic, and aquifer hydraulic-parameter data. The work tasks associated with the drilling, testing, and analysis of new well data will be divided into two subphases, 2a and 2b. Phase 2a will be a drilling phase and Phase 2b will be a testing and data-analysis phase.

Specific work tasks of Phase 2a (April 1987-April 1988) include:

1) Review available geologic, hydrologic, and chemical data and determine exact location and number of test wells to be drilled.
2) Prepare drilling specifications, distribute specifications for bids, and award contract.
3) Drill test wells and collect data needed to determine and verify the physical and chemical characteristics of the aquifer and confining-bed materials and fluids that overlie and occur within the deep, limestone water-supply aquifer.
4) Prepare report on the results of Phase 2a investigations.

Specific work tasks for Phase 2b (April 1988- April 1989) include:

1) Complete drilling, sampling, and hydraulic tests of test wells.
2) Complete geophysical logging of new and existing wells. Analyze logs.
3) Conduct aquifer tests on new and existing wells to determine hydraulic properties of aquifer unit(s) and confining beds.
4) Based on new findings, refine and edit the preliminary assessment of the geohydrologic framework that was developed during Phase 1.
5) Prepare a report that describes the refined geohydrologic framework.

In Phase 3 (April 1989- April 1990) the analysis of data collected in Phases 1 and 2a-b will allow modeling of the system. Specific work tasks for Phase 3 include:

1) Construct a finite-difference ground-water flow model of the hydrogeologic system in and around Camp Lejeune based on the data and interpretations that resulted from investigations during Phases 1 and 2.
2) Determine a grid system for area and discretize appropriate maps of aquifer and confining-bed characteristics (such as structure tops, thicknesses, hydraulic conductivity, potentiometric surfaces, etc.).
3) Determine boundary conditions.
4) Develop a steady-state digital model for unstressed (pre-pumping) conditions in the area.
5) Evaluate different ground-water pumpage and development schemes to determine which alternatives will reduce the chances for contamination of the water-supply aquifer (optimization analysis).
6) Prepare report on the results of Phase 3 investigations.

The ground-water flow model will be a management aid that can be used to guide site selection for new wells through prediction of water-level drawdowns that will occur in response to planned pumping rates at potential well sites, and to evaluate water-level drawdowns at existing production wells through prediction of drawdowns that would occur in response to alternative pumping schedules. The potential benefits to be gained from model studies are less well interference, lower pumping costs, and reduced chance for contamination of the water supply.

physical characteristics of each treatment plant with the plant capacities, etc.

The amount of water used has increased with time and increased service population. Over the years, more than 100 wells have been drilled to supply water to the base for drinking and other base operations. Since World War II, the base has grown from a service population of 3,000 to the present service population of about ~~100,000~~ 63,000. The population increase and water demand began to level-off in the early 1960's. The population of the base has remained relatively constant over the past two decades, therefore, water demands have not risen substantially. Most of the problems related to water supply of the base appear to be of a water quality and availability nature instead of due to increased pumping rate.

Reliable historical water-pumpage data are scarce and virtually nonexistent prior to 1970. The internal structure of the utilities operations and the lack of State regulatory authority on the base are limiting factors in locating and acquiring historical data, and establishing water-use trends and projections. Apparently, valuable records may have been destroyed or discarded as a result of the filing procedures of the base.

The largest change over the past decade has not been so much an increase in water demands, but an alteration of pumping scheme. Figure 2 shows that pumping rates have decreased in the Hadnot Point area and increased especially in the Holcomb Boulevard system (figure 3). This is partially due to the current expansion of the Holcomb Blvd. treatment facility and the discontinuation of many supply wells in the Hadnot Point system. Table 2 shows amount of raw water treated for the period from 1975 through 1986. The amount of raw water treated at each individual treatment plant from 1975 through 1986 are presented in figures 4 - 8. The amount

WATER-USE DATA

Since the establishment of Camp Lejeune, the sole source of its water supply has been from wells. Initially, there were no treatment facilities, so raw water was consumed without treatment. In 1941, the Hadnot Point Water Treatment System was placed in operation with 21 wells on line. The total pumping capacity of the plant was 7.30 Mgal/day and the maximum amount delivered to the plant in 1942 was 4.80 Mgal/day. The Hadnot Point Water System served the main part of the base including the regimental area, post troops area, industrial area, Naval Hospital, Paradise Point housing, Midway Park housing project, and the Camp Lejeune schools. The Hadnot Point System served the entire base except for some untreated water withdrawn from wells scattered at locations on the periphery of the base until the early 1950's when a private firm built the treatment facility at Tarawa Terrace. In the mid 1950's water treatment plants were constructed at Onslow Beach and Montford Point, and the Tarawa Terrace plant was taken over by the U.S. Government. In the 1960's, water-treatment facilities were added at the Rifle Range area and Courthouse Bay. In 1971, the Holcomb Boulevard Treatment Plant was built with a designed plant capacity of 2.0 Mgal/day. The Holcomb Blvd. Plant is presently being expanded to a total plant capacity of 5.0 Mgal/day and much of the water demands have already been shifted from the Hadnot Point plant to Holcomb Blvd. Table 1 gives the

Table 1. Physical characteristics of each water-treatment plant.

Physical Characteristics of Water Treatment Plants
Camp Lejeune Marine Base - March, 1987

PLANT	Plant Capacity (Mgal/day)	Number of Wells	Population Served
Hadnot Point	5.900	35	32,134
Holcomb Blvd.	2.304	8	8,139
Tarawa Terrace	1.152	6	6,196
Montford Point	0.522	8	2,962
MCAS	4.081	26	10,315
Rifle Range	0.648	4	348
Courthouse Bay	0.864	5	3,091
Onslow Beach	0.250	2	248

Table 2. Water use for Camp Lejeune Military Base Water Systems, in million gallons per day.

YEAR/PLANT	HADNOT POINT	HOLCOMB BLVD	TARAWA TERRACE	MONTFORD POINT	MCAS	RIFLE RANGE	COURTHSE BAY	ONSLOW BEACH	CAMP GEIGER	CGA-5	YEARLY TOTAL
1975	3.39	0.71	0.83	0.42	0.48	0.31	0.36	0.11	0.51	0.02	7.14
1976	3.75	0.78	0.85	0.42	0.41	0.34	0.34	0.12	0.48	0.02	7.51
1977	3.69	0.92	0.86	0.44	0.76	0.28	0.37	0.12	0.16	0.02	7.62
1978	3.71	1.12	0.90	0.42	1.17	0.25	0.41	0.09	0.00	0.02	8.09
1979	3.42	1.05	0.83	0.36	1.20	0.25	0.40	0.09	0.00	0.00	7.60
1980	3.46	1.04	0.78	0.25	1.13	0.20	0.41	0.10	0.00	0.00	7.37
1981	3.37	1.17	0.88	0.31	1.07	0.25	0.45	0.14	0.00	0.00	7.64
1982	3.43	1.23	0.98	0.28	1.02	0.24	0.46	0.12	0.00	0.00	7.76
1983	3.21	1.26	0.94	0.32	1.01	0.26	0.43	0.10	0.00	0.00	7.53
1984	3.54	1.22	0.85	0.33	0.93	0.26	0.51	0.11	0.00	0.00	7.75
1985	3.23	1.26	0.83	0.44	0.96	0.29	0.49	0.14	0.00	0.00	7.64
1986	3.00	1.23	0.90	0.43	0.76	0.24	0.57	0.11	0.00	0.00	7.24

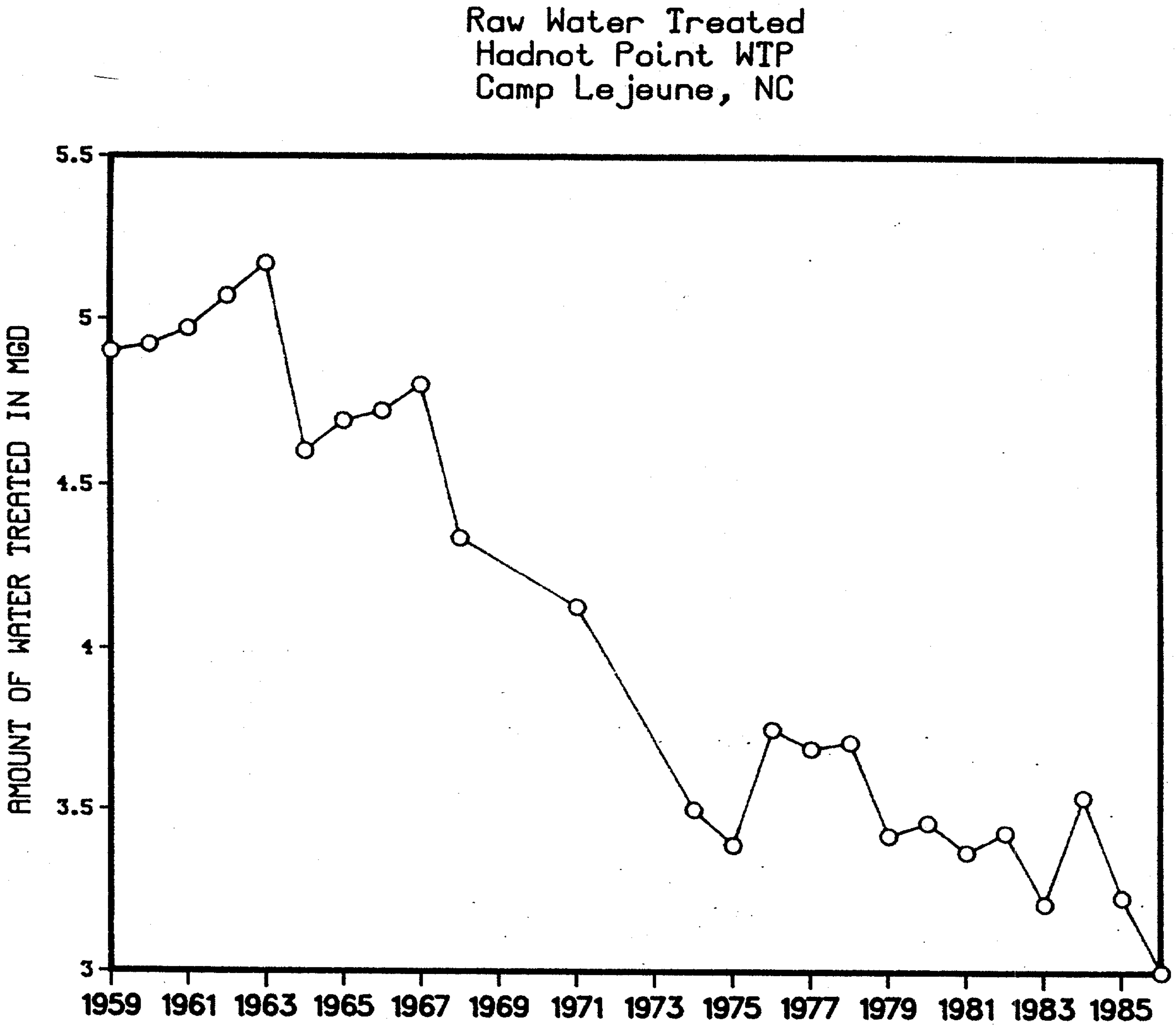


Figure 2. Raw water treated by the Hadnot Point Water Treatment Plant, from 1959 to 1986.

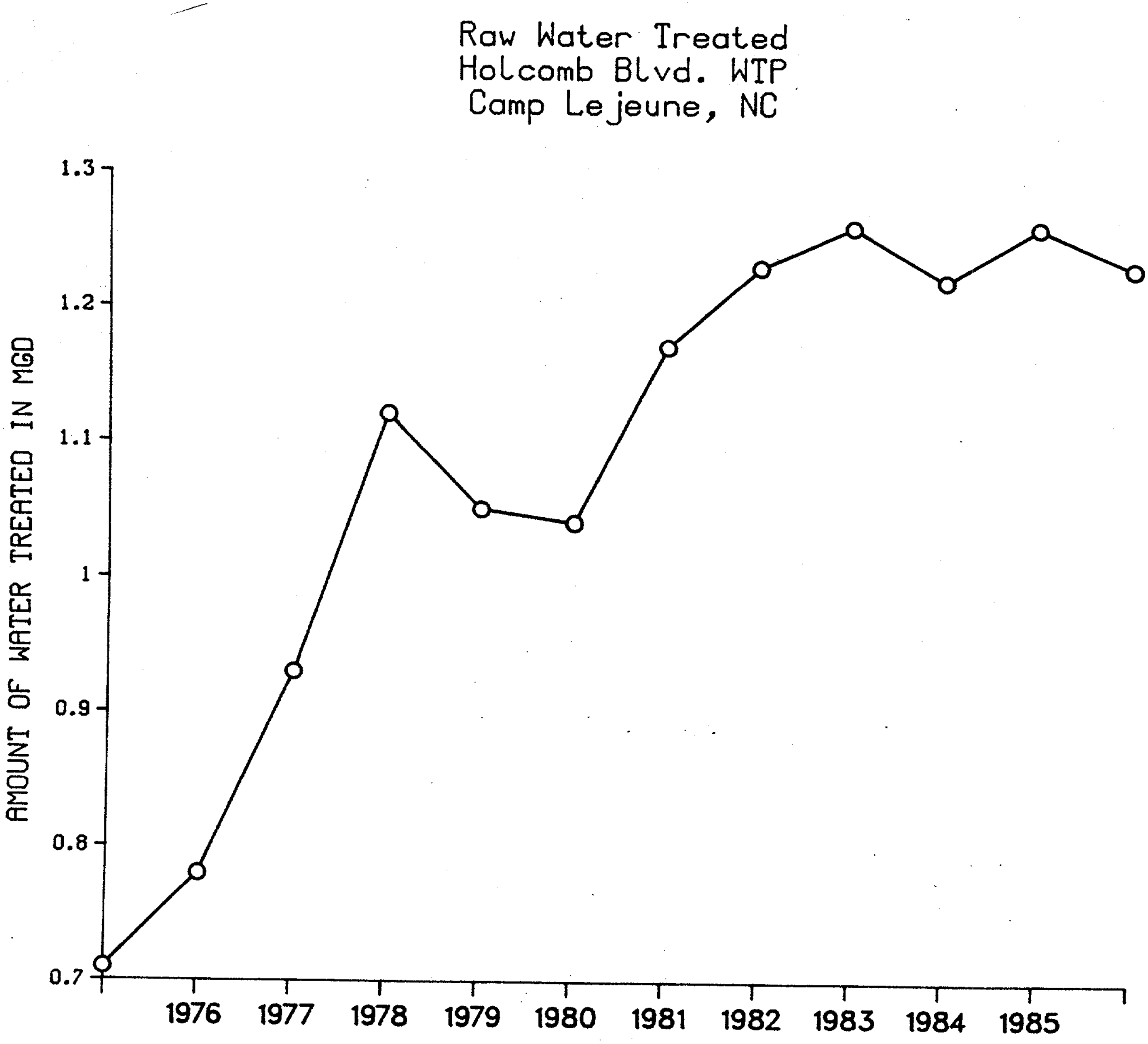


Figure 3. Raw water treated by the Holcolmb Boulevard Water Treatment Plant, from 1975 to 1986.

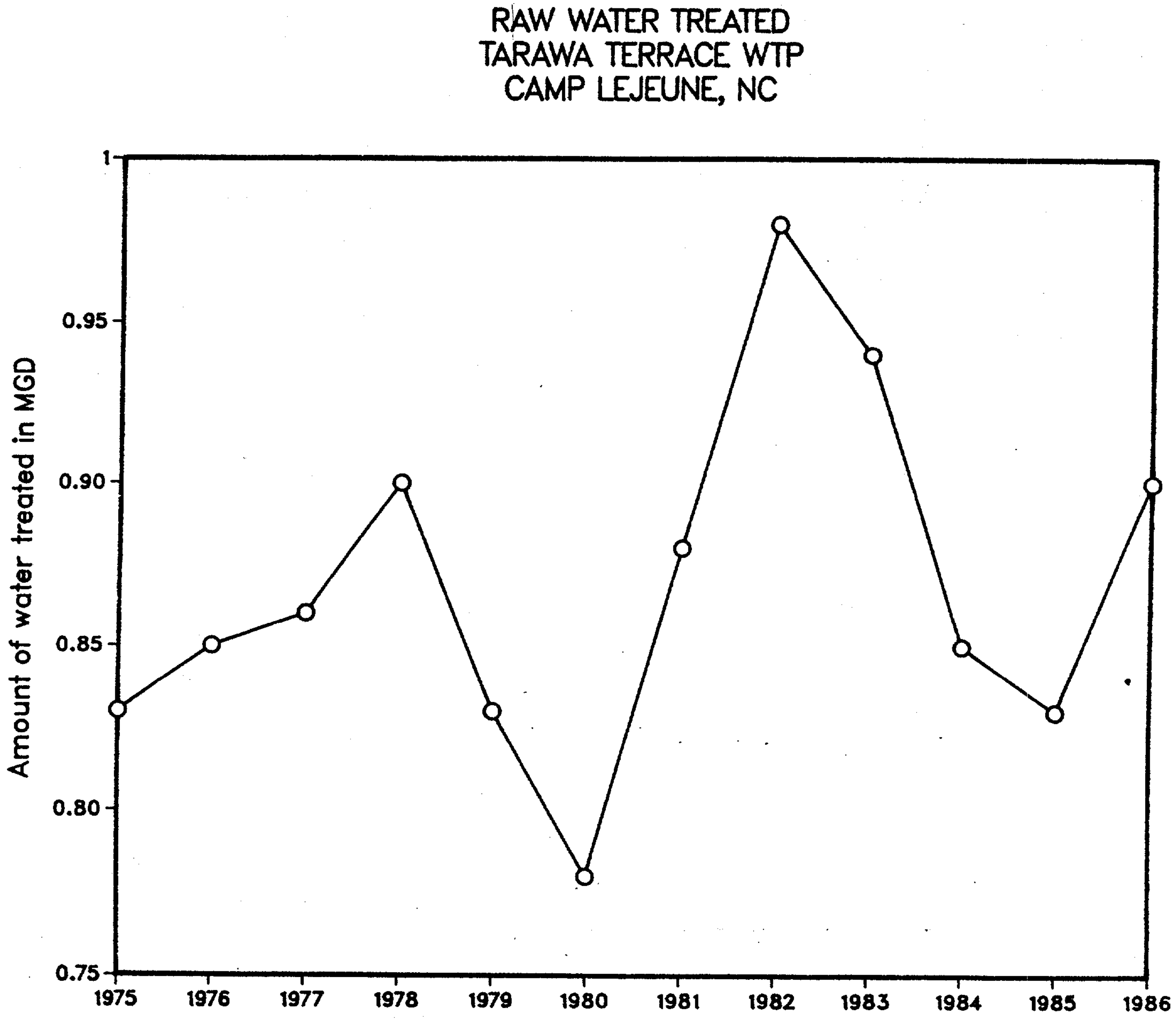


Figure 4. Raw water treated by the Tarawa Terrace Water Treatment Plant, from 1975 to 1986.

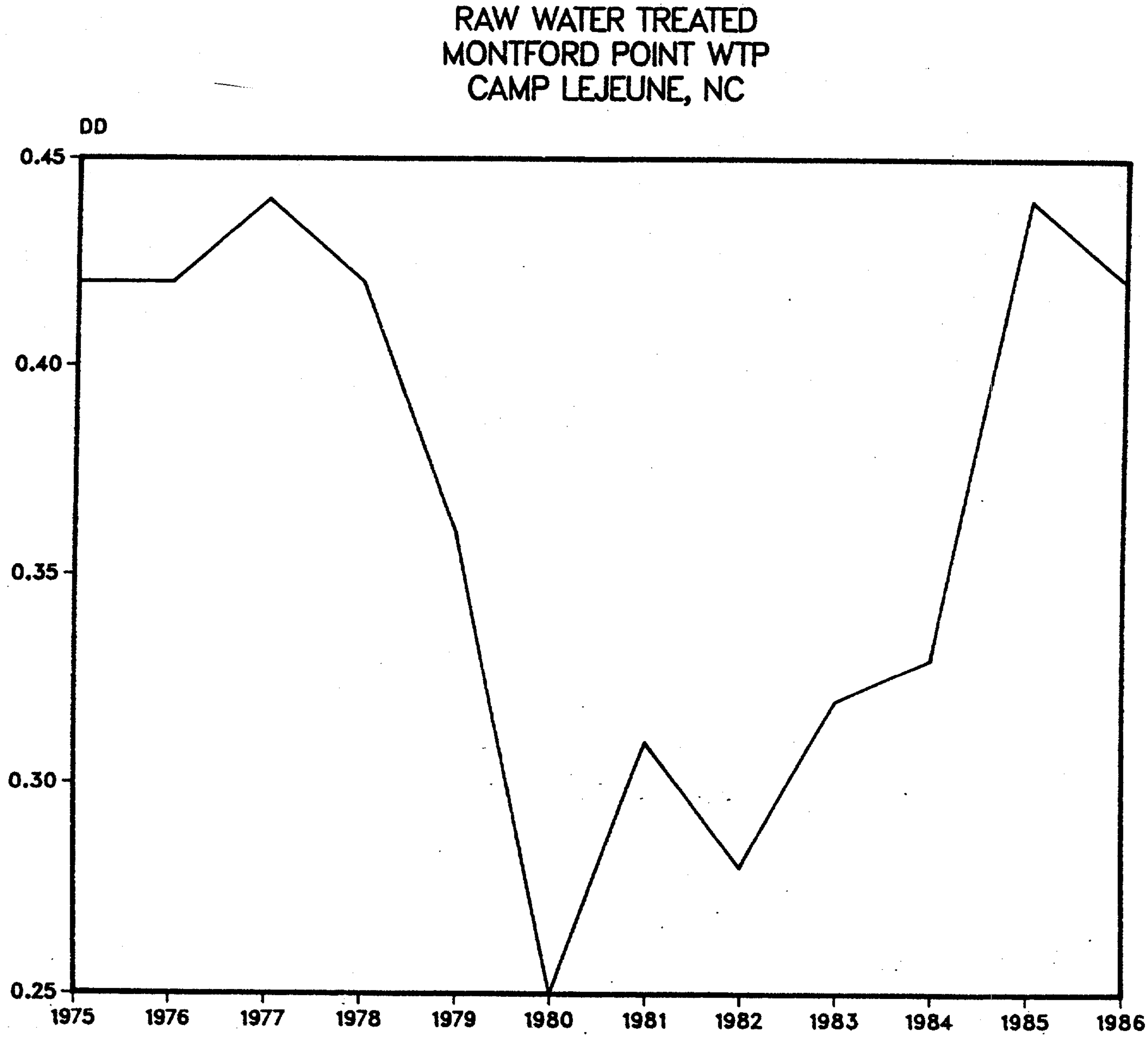


Figure 5. Raw water treated by the Monford Point Water Treatment Plant, from 1975-1986.

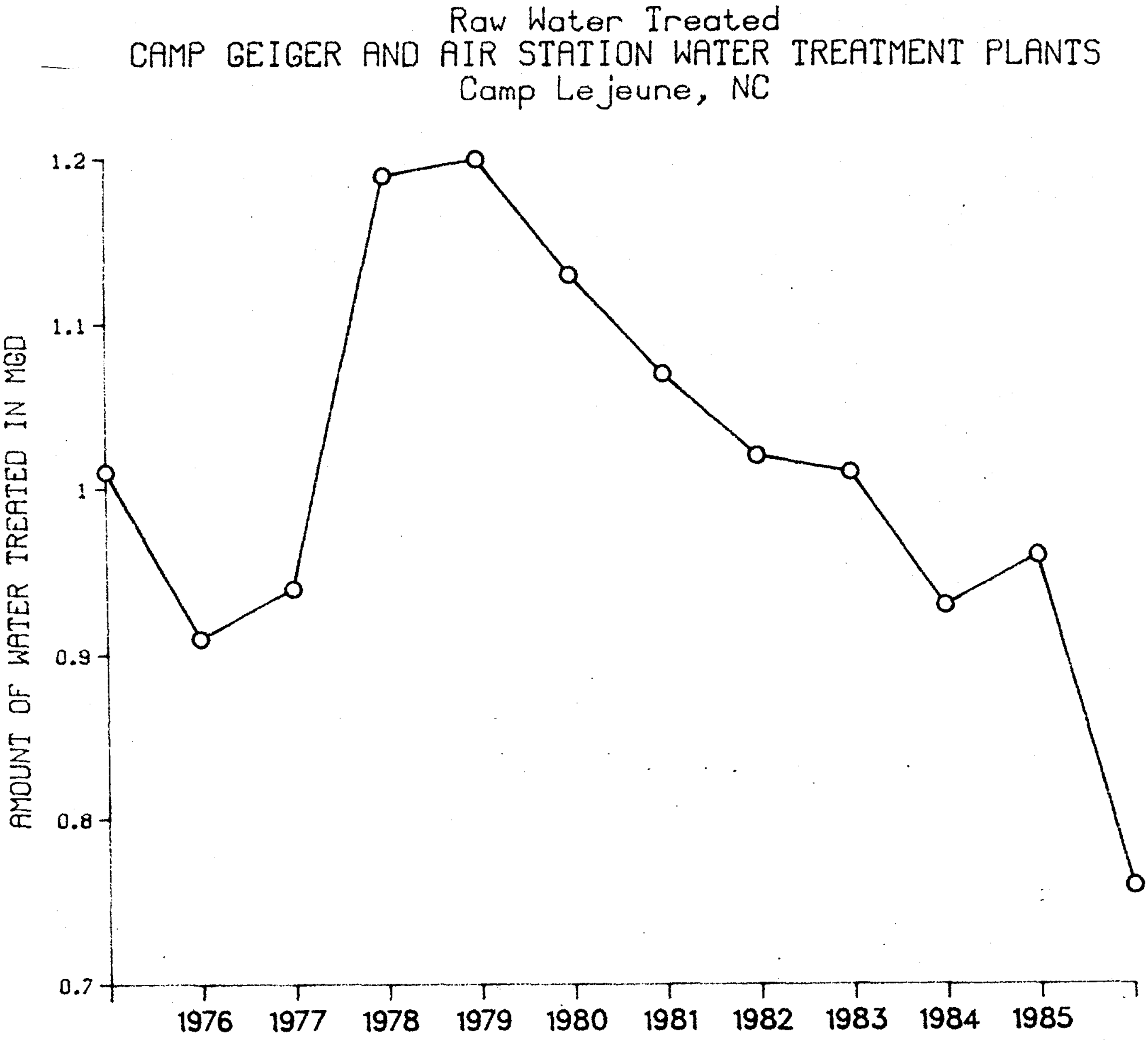


Figure 6. Raw water treated by the Camp Geiger and Air Station Water Treatment Plants, from 1975 to 1986.

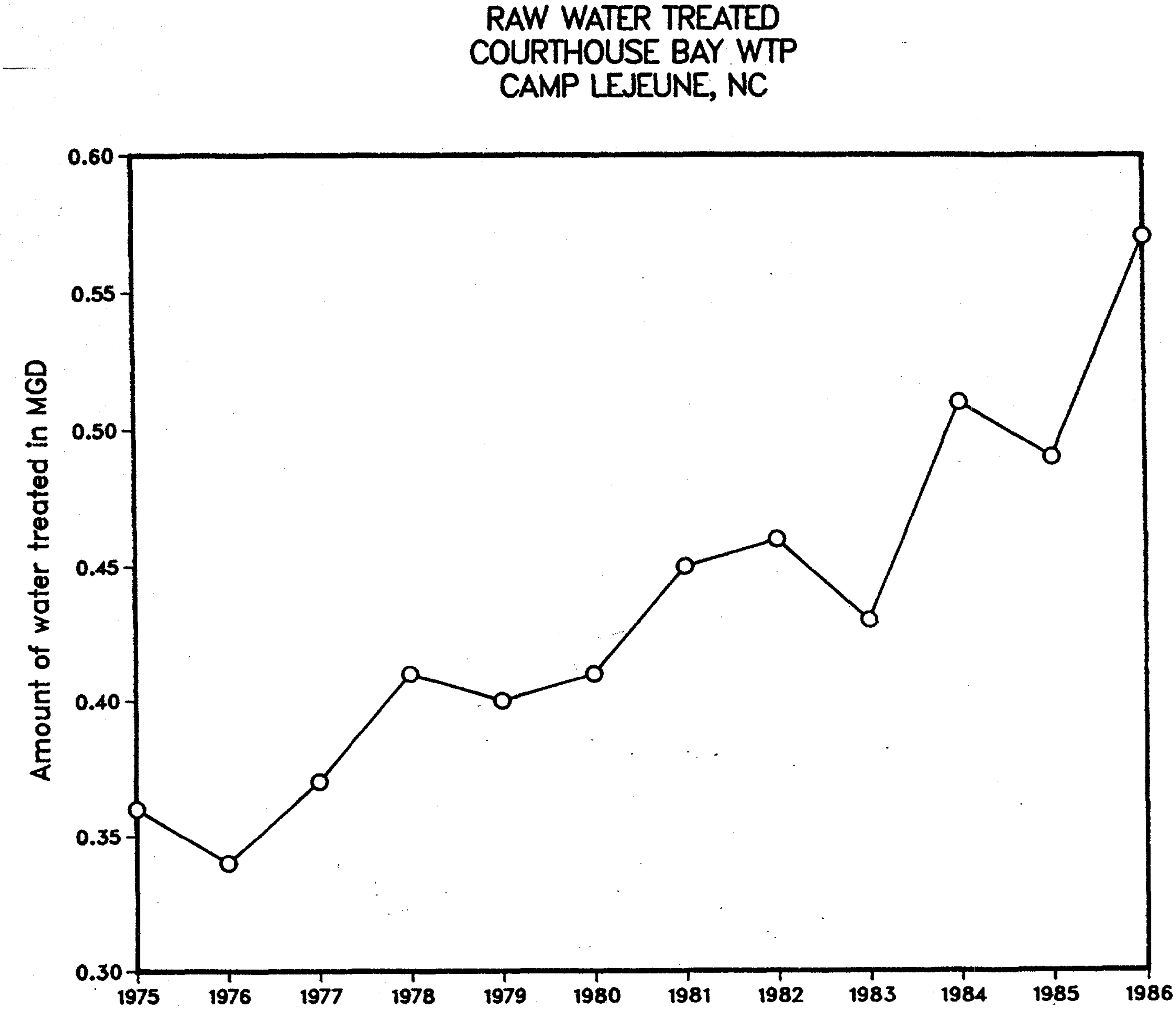


Figure 7. Raw water treated at the Courthouse Bay Water Treatment Plant, from 1975 to 1986.

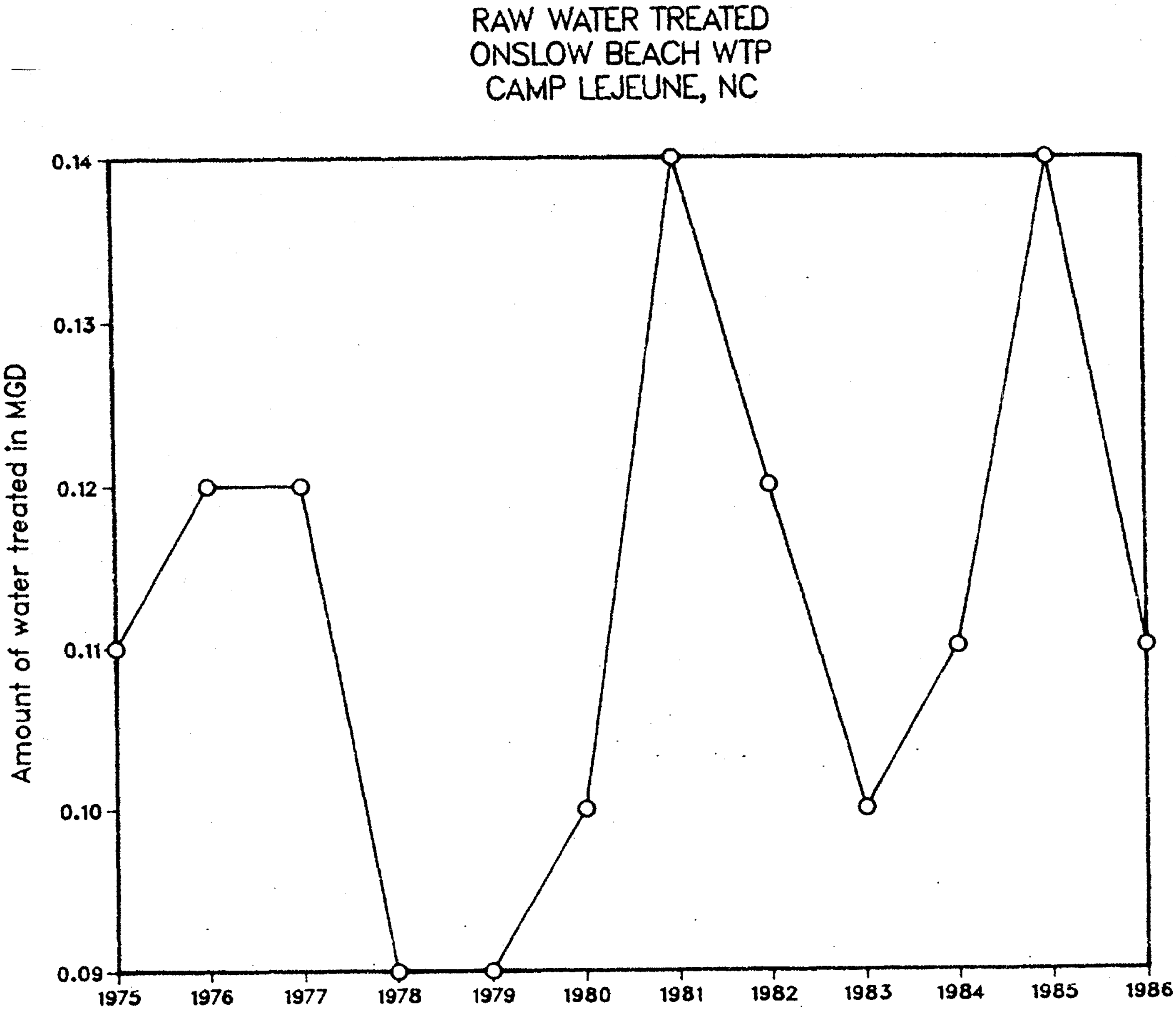


Figure 8. Raw water treated at the Onslow Beach Water Treatment Plant, from 1975 to 1986.

of water treated by the individual water-treatment plants is relational to the pumpage rate of the well fields. The amount of raw water treated in 1975 totalled 7.14 Mgal/day for the nine water systems that were in operation (Fig. 9). The Camp Geiger WTP was discontinued in 1977 and the supply wells in that system were interconnected with the Air Station system. In 1986, the amount of raw water treated totalled 7.23 Mgal/day for the eight treatment plants currently in operation. The data indicate that there has not been a substantial change in the amount of water treated in the past 12 years. There is season variation, as shown on figure 10, with the summer showing the greatest water use and the winter the least. Unfortunately, there are no reliable data on water withdrawals from individual wells. Well data on pumping capacity, yield of a well, and time of pumpage can be used to estimate withdrawals of an individual well. This method was beyond the initial scope of this project, but could be incorporated in future studies.

An indication of the water withdrawals from a well centroid can be derived from the data on treated water that is metered at each treatment facility. Obviously, there are some conveyance losses from the transport of water from the well to the treatment facility; moreover, it is difficult to quantify withdrawals from the source of supply. Conveyance losses are directly related to the efficiency of the system and the condition of the distribution lines. A leak-detection analysis is required to accurately determine the efficiency of the system. Most water-supply systems have an average conveyance loss of between 15- 20 % of the water withdrawals.

Per-capita water use ranges from 552 gallons at Onslow Beach to 86 gallons at Hadnot Point. The average per-capita use for the entire base is 106 gallons. Per-capita water use is calculated as the total of the water supplied divided by the population served and is usually used to compare

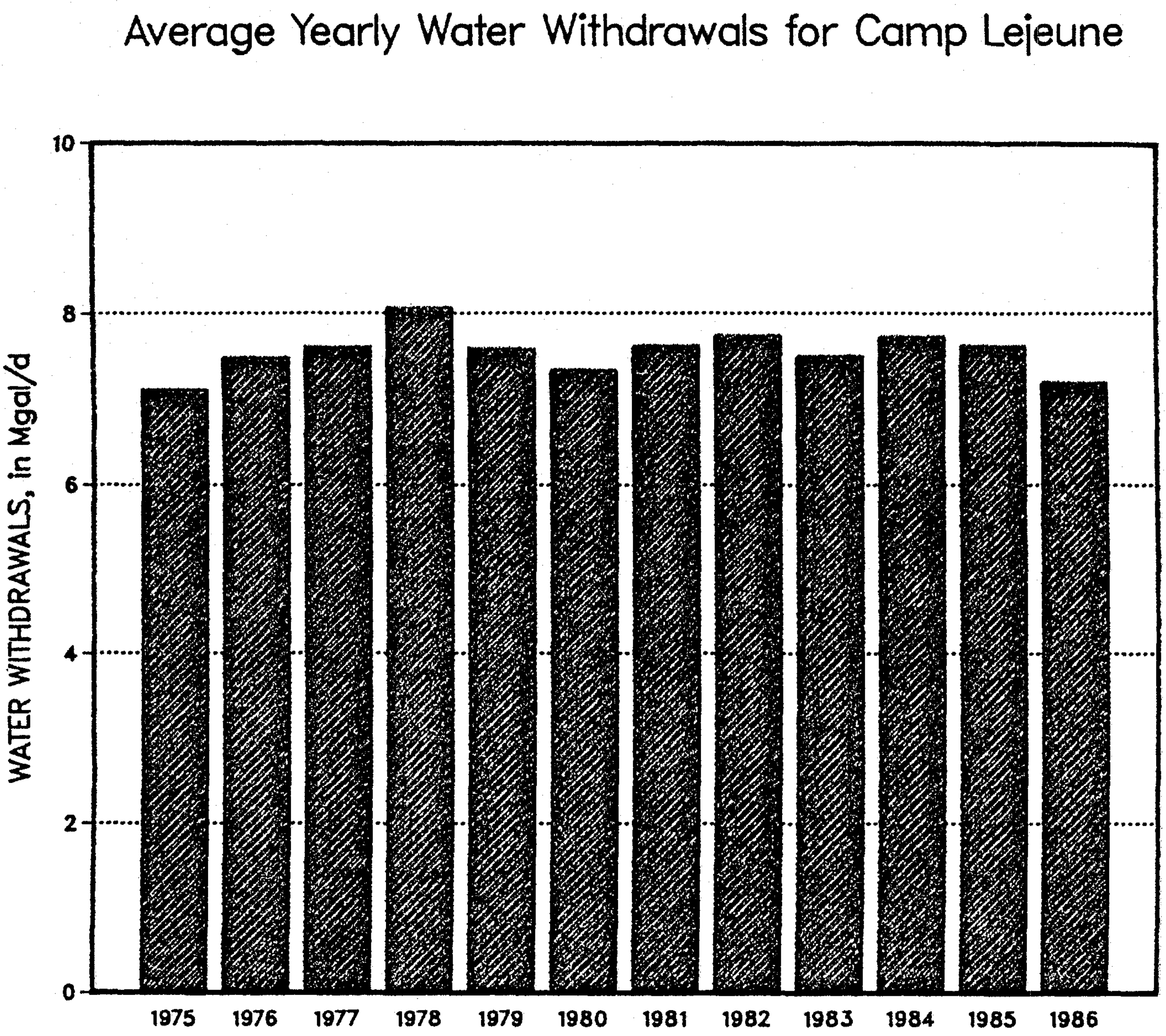


Figure 9. Average yearly water withdrawals for Camp Lejeune.

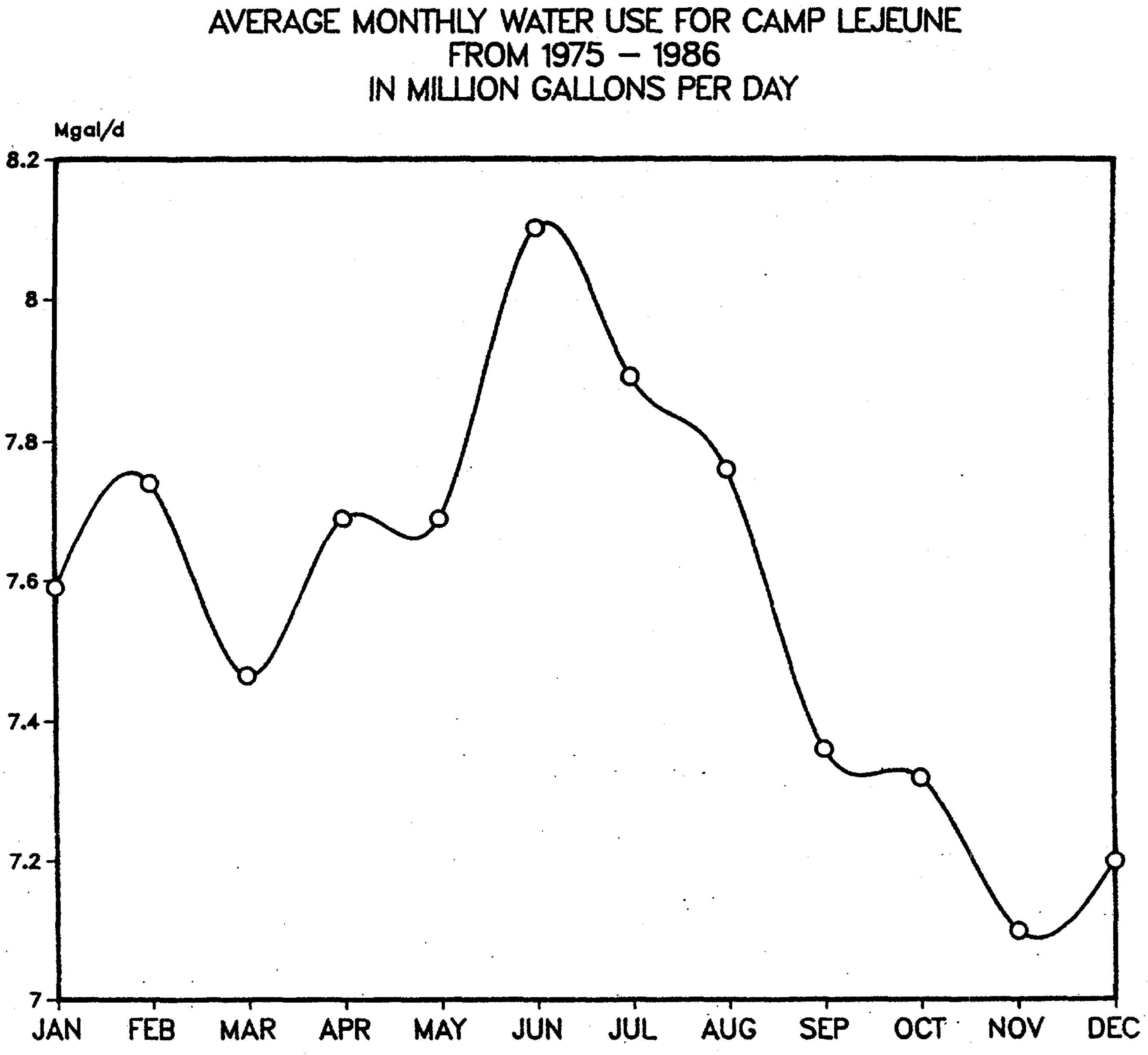


Figure 10. Average monthly water use for Camp Lejeune from 1975 to 1986.

gross pumpage from different systems (Winner and Lyke, 1986). The higher values at some areas are due to the type of water-use activities in that area. Hadnot Point W.S. serves the bulk of the industrial/commercial users on the main past of the base. The Marine Corp Air Station system also serves industrial type users. The Onslow Beach system serves recreational users to a large extent; while the other five systems serve residential users almost exclusively, which explains the low per-capita use values for those systems. Because Camp Lejeune is a federal military installation, the billing and accounting structures are set quite differently from other public-supply systems; therefore, they can not provide records that show accurate water distribution. They have users categorized as "reimbursable" or "non-reimbursable" users, and unfortunately, the "non-reimbursable" users constitute the majority of the users.

GEOHYDROLOGIC FRAMEWORK

Camp Lejeune is underlain by interbedded sands, clays, calcareous clays, shell beds, sandstone, and limestone (LeGrand, 1959). These sediments are layered in interfingering beds and lenses that gently slope toward the coast. In the Camp Lejeune area, the sediments are around 1500 feet thick and overlie igneous and metamorphic basement rocks. These sediments were deposited in ocean or near-ocean environments. A generalized cross section of the Coastal Plain sediment is shown in figure 11.

The principal water-supply aquifer for the Base is the series of sand and limestone beds that underlie the area to a depth of around 200 feet. This series of layers is generally referred to as the Castle Hayne Aquifer. The Castle Hayne Aquifer is the most productive aquifer in North Carolina, and is a critical water-supply source for the southern coast and east central Coastal Plain. The area of the Coastal Plain that uses the Castle Hayne Aquifer for water supply is shown in figure 11. Onslow County, and Camp Lejeune lie well within the area of the aquifer that contains fresh water, although the proximity of saltwater in deeper layers just below the aquifer and on the surface in the New River Estuary is of concern in managing water withdrawals from the aquifer. The freshwater and saltwater zones of the Castle Hayne Aquifer are shown in figure 11.

In order to understand the geology and hydrology of the Castle Hayne Aquifer in the Camp Lejeune area it is necessary to describe the physical

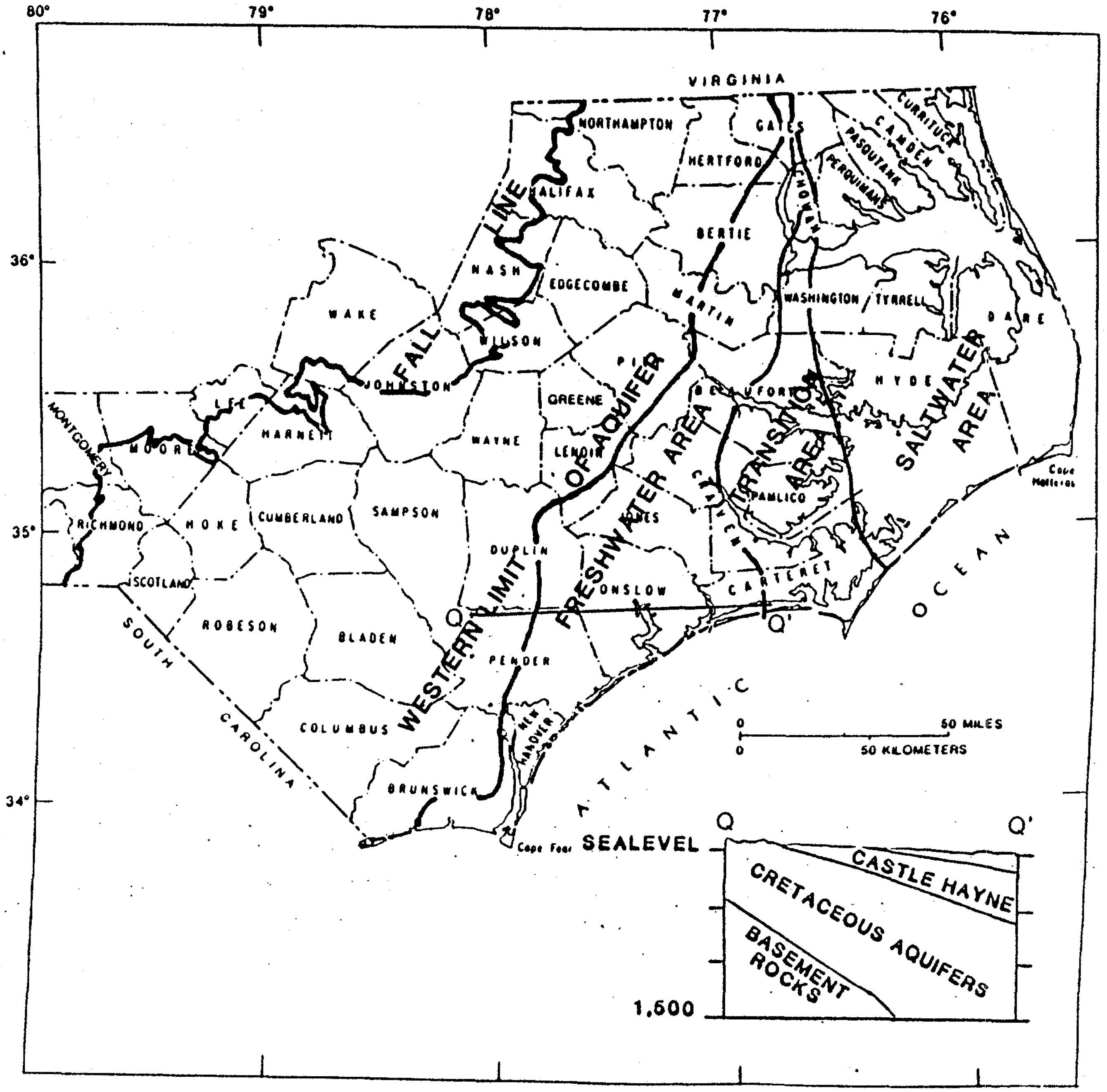


Figure 11. Freshwater and saltwater (250 mg/L chloride) areas in the Castle Hayne aquifer, and a simplified cross section of the Coastal Plain.

system in the best possible manner. The description of the system, referred to here as the geohydrologic framework, provides the foundation for an understanding of the flow system, and is the physical basis for the mathematical model to be used to mimic the way the natural system works.

The construction of a geohydrologic framework, or a descriptive conceptual model of the ground-water flow network and its relation to geology and stratigraphy, is a four step process. First, a review of existing geohydrologic studies for the area provides the foundation for more detailed analysis. Second, all available borehole geophysical-log data for the area are obtained, well-location data are mapped, well-drilling and construction data are compiled, and lithologic information is compiled. Cross sections are drawn that include the best geophysical-log data, lithologic data, well-construction data, and water-quality indicators such as chloride ion concentrations, and conductivity. Third, layers which have a regional extent are traced on the cross sections. The layers are identified with careful examination of the geophysical logs and related data. Fourth, interpretations from the cross sections are mapped, areas where more data are needed are identified, and a plan for collecting the new data is made.

Previous Studies

Previous work by LeGrand (1959) involved an examination of well data, the drilling of 22 test wells, and recommendations for future drilling of water-supply wells. LeGrand obtained geophysical logs for the test wells to help identify the best zone to pump, however, he did not trace the zones areally. LeGrand's geologic descriptions and data provide a solid foundation for more a detailed look at the water-supply aquifer system.

A study by the North Carolina Department of Natural Resources and Community Development of the groundwater quality for the Georgetown Community located near the northwest border of Camp Lejeune, gives a careful analysis of geohydrology in a small area including 64 wells. Information from this study is useful in linking data between Camp Gieger and Mumford Point.

Two ongoing multi-county Geological Survey modeling studies provide the basic structure for the Camp Lejeune framework and proposed model. The Regional Aquifer Systems Analysis (RASA) study (Winner and Coble, USGS, written commun. ,1987) produced a general geohydrologic framework for the entire Coastal Plain of North Carolina, and a flow model of the ground-water system. The Central Coastal Plain (CCP) study (Lyke and Winner, USGS, written commun., 1987) is a similar large-scale study focusing on a 14 county area of the Coastal Plain of North Carolina including Onslow County. The CCP study has refined the framework developed for the RASA study, and will also produce a flow model.

Available Data

Borehole geophysical logs, lithologic data, well-construction data, and pumping-test data were obtained from Camp Lejeune, NRCD, and USGS files. Data is available for over 180 well locations. These data are the raw material of the framework analysis.

The mean pumping rate for Camp Lejeune wells for which data was available was 179 gallons per minute ranging from 88 gpm to 350 gpm (N=85, SD= 61). The mean pumping rates vary regionaly, with Mumford Point and Camp Geiger wells showing the lowest rates of around 130 gpm and Hadnot Point wells showing the highest rates of around 195 gpm.

The locations of the screened intervals used in the water supply wells gives an indication of which layers are water bearing. A contour map of the depth to the top of the upper most screen is shown in figure 12, and a map of the depth of the lower most screen is shown in figure 13. These maps give a rough idea of the location in the subsurface of the top and the bottom of the water-supply aquifer on the base. As is apparent from the maps the screened zones are spread out over 20-150 feet, giving a good measure that the water-supply aquifer is at least this thick. The mean thickness of the screened zone of the water-supply wells on the base is 84 feet (N= 68, SD= 44).

In the Hadnot Point area it appears from these maps that the water-supply aquifer is closest to land surface under the New River, and in fact probably is directly connected to the New River. On the map in figure 12 the uppermost screens on the west side of the river are probably not set in the

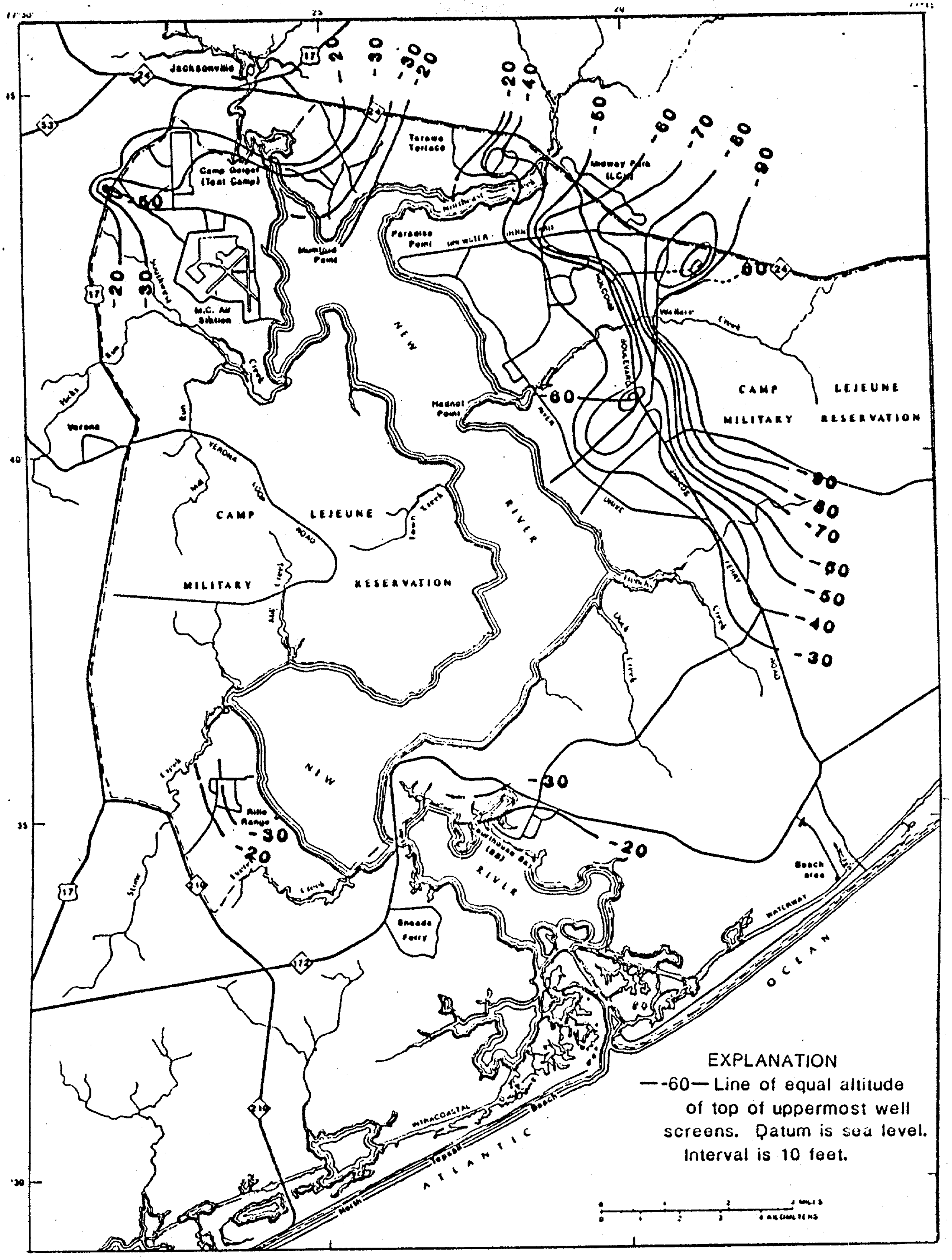
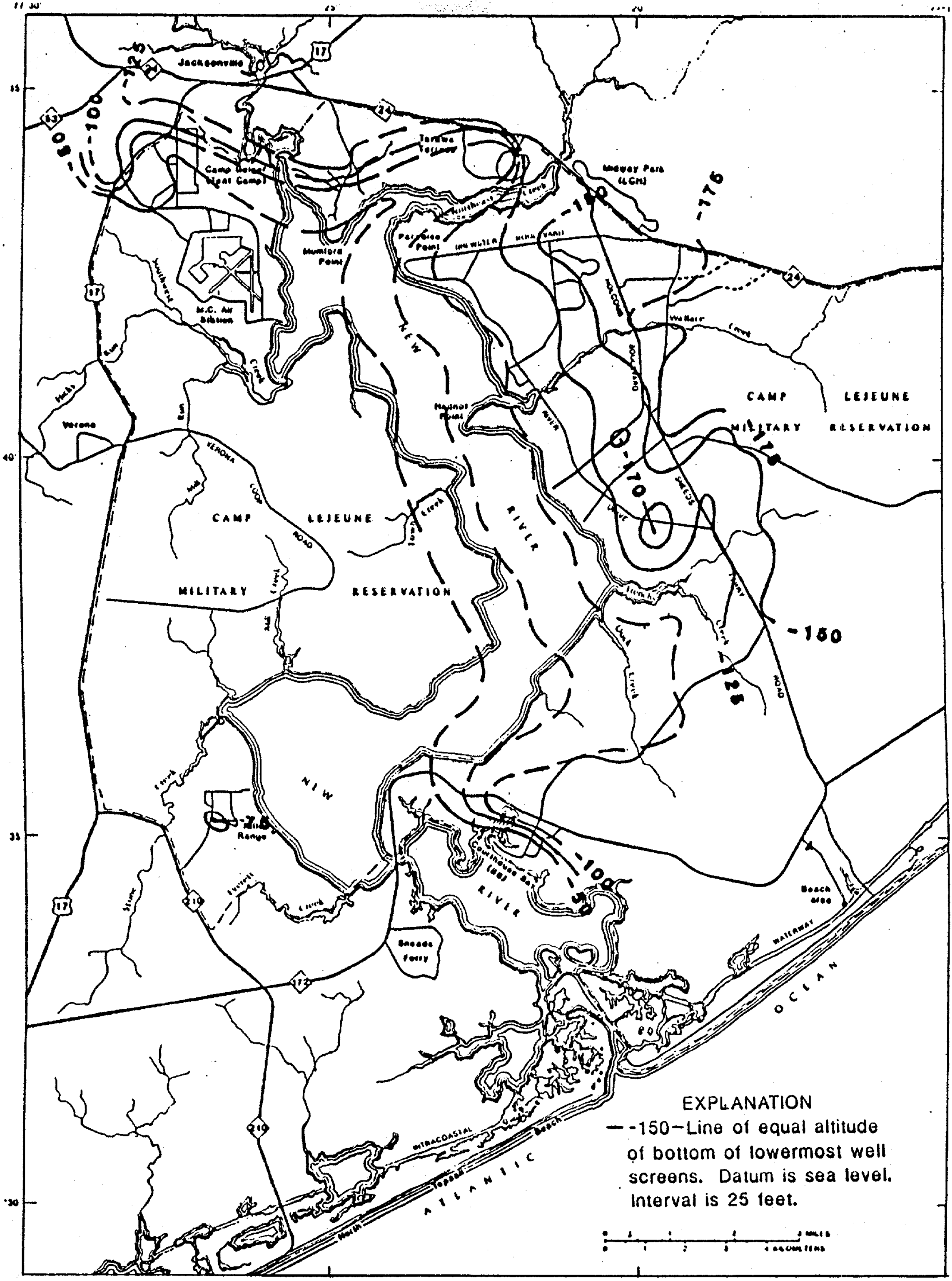


Figure 12. Lines of equal altitude of the top of the uppermost well screens.



Base taken from Defense Mapping Agency Hydrographic Center

Figure 13. Lines of equal altitude of the bottom of the lowermost well screens.

equivalent layers of the east side, because the layers first screened on the east side apparently meet the surface in the New River. Some anomalies apparent in the map of the lowermost screen elevations are due to the fact that most all the wells do not completely penetrate the full thickness of the water-supply aquifer.

Specific conductance, a measure of the ability of water to carry an electric current, gives an approximate expression of the amount of ionic material dissolved in water. Specific conductance was measured in the Camp Lejeune water-supply wells during a water sampling survey by Environmental Science and Engineering Inc. (ESE) during October and November 1986. The specific conductance values from this survey are plotted on the map shown in figure 14. In general, the specific conductance values measured in the Marine Corps Air Station area are considerably higher than those found in the Hadnot Point area. Tarawa Terrace, Mumford Point, the Rifle Range and Courthouse Bay all had specific conductance values higher than Hadnot Point, but lower in general than those measured in the Air Station area. A few wells show very high levels, probably due to saltwater contamination. The source of this contamination is a subject for future study.

Well-acceptance tests used to confirm well yields were obtained from Camp Lejeune files and reviewed. These tests provide water-level drawdown data over time under one or more controlled rates of pumping. The ratio of the pumping rate (Q) and the drawdown (s) is referred to as the specific capacity. Specific capacity is generally reported in units of yield per unit of drawdown such as gallons per minute per foot. The mean specific capacity for all the available well tests was 8.8 gallons per minute per foot of drawdown (N=42, SD=10.5) ranging from 2.3 to 61.5 gallons per minute per foot of drawdown. In the Hadnot Point area the specific capacity is 6.0

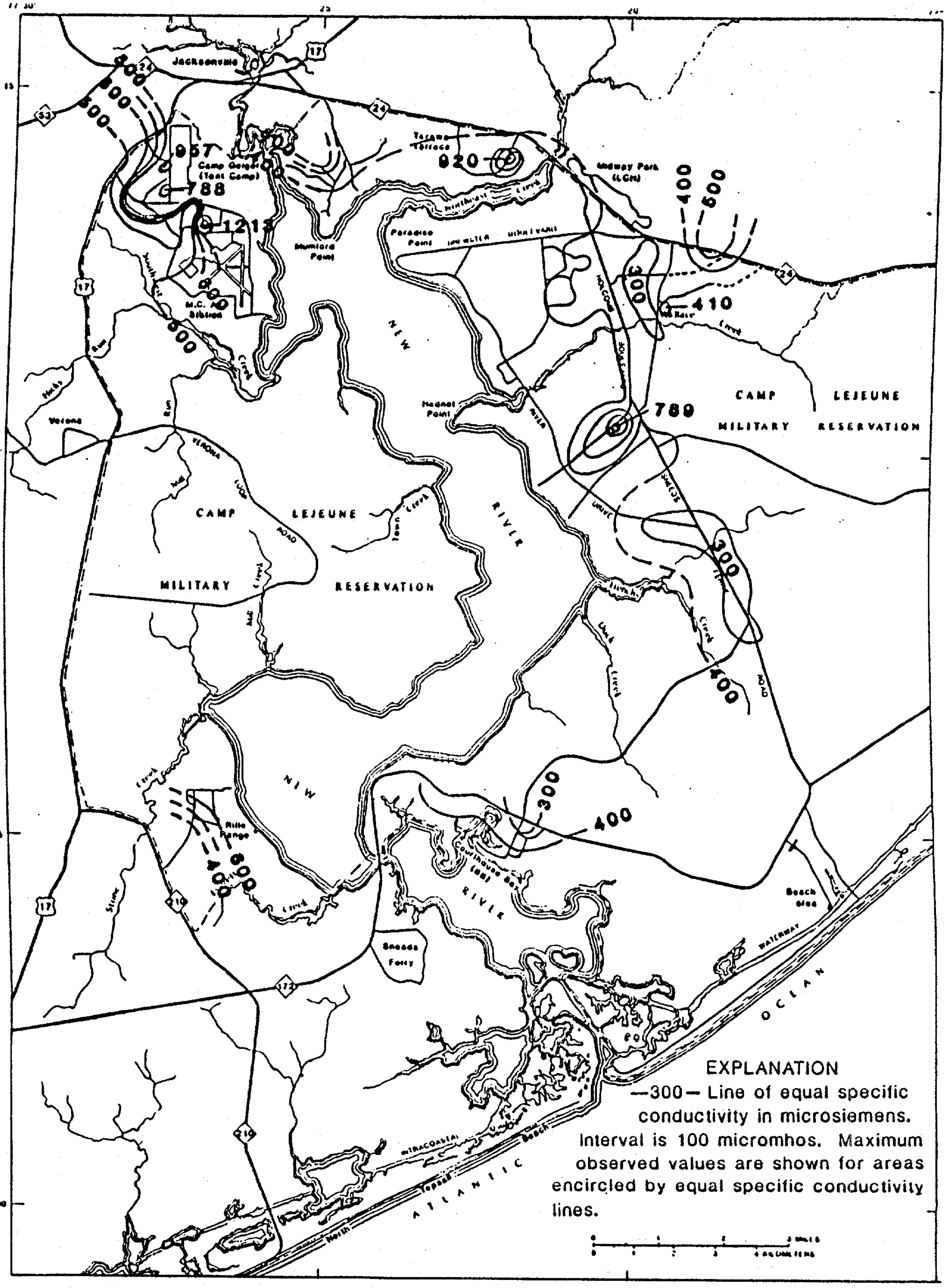


Figure 14. Lines of equal specific conductivity.

gallons per minute per foot of drawdown (N=29, SD=3.0) ranging from 2.3 to 15.8 gallons per minute per foot of drawdown. Regional patterns in specific capacity are not apparent enough to allow contouring or generalization at this time.

The total water-level drawdown is the combined drawdown in the aquifer and the drawdown caused by turbulent flow in the well itself. The drawdown generated by turbulent flow in the well, termed well loss, may be a result of blockage of the well screens by aquifer material, or blockage by iron bacteria. The relatively low specific capacities measured in wells at Camp Lejeune indicate low well efficiency, or a low ratio of tested specific capacity to the specific capacity that could be calculated using only the drawdown in the aquifer. Additional well testing will need to be done to investigate the reasons for the low specific capacities.

A simple estimation procedure outlined by Driscoll (1986) gives an approximation of well transmissivity values from measured specific capacities. The transmissivity of an aquifer is a measure of the capacity of an aquifer to transmit water. Transmissivity is calculated as:

$$T = K\ b$$

Where T is transmissivity, K is hydraulic conductivity, and b is the aquifer thickness. Hydraulic conductivity is a hydraulic constant that is a function of the nature of the water-bearing openings in the rock and the water flowing through those openings.

To estimate transmissivity values from specific capacity (Driscoll, 1986) Jacob's modified nonequilibrium equation (Cooper and Jacob, 1946):

$$s = \frac{264\,Q}{T} \log \frac{0.3\,T\,t}{r^2\,S}$$

is rearranged to obtain specific capacity:

$$\frac{Q}{s} = \frac{T}{264 \log \frac{0.3Tt}{r^2\,S}}$$

where:

s = drawdown in the well, in feet

Q = yield of the well, in gallons per minute

t= time of pumping, in days

r = radius of the well, in feet

S = storage coefficient of the aquifer (dimensionless) --defined as the volume of water that an aquifer discharges or takes into storage for a unit surface area and change in water level. This coefficient is a function of the hydraulics of the aquifer, and varies depending on the compression of the aquifer which is in turn related to the degree of confinement of the aquifer, that is, the degree of separation of the aquifer from surface recharge.

To use this equation to estimate transmissivity, probable values for variables in the log function can be assumed:

t = 1 day

r = 0.375 feet (mean well diameter of 51 Camp Lejeune wells)

T = 112,500 gallons per day per foot (transmissivity value for Camp Lejeune from areal maps by Winner and Coble, USGS, written commun., 1987)
S = 0.001 for a confined aquifer, and
0.075 for an unconfined aquifer (Driscoll, 1986)

Given these assumptions the confined transmissivity is given by:

$$T = \frac{Q\ 2212}{s}$$

and the unconfined transmissivity is given by:

$$T = \frac{Q\ 1717}{s}$$

Using the specific capacity values determined from the well-acceptance tests the mean confined transmissivity estimate for the Base is 19,400 gallons per day per foot (N=42, SD=23,200) ranging from 5,100 to 136,000 gallons per day per foot. The mean confined transmissivity estimate for the Hadnot Point area is 13,400 gallons per day per foot (N=29, SD=6,600) ranging from 5,100 to 35,000 gallons per day per foot. The mean unconfined transmissivity estimate for the base is 15,100 gallons per day per foot (N= 42, SD=23,200) ranging from 5,100 to 105,500 gallons per day per foot. The mean unconfined transmissivity estimate for the Hadnot Point area is 10,400 gallons per day per foot (N= 29, SD=5,100) ranging from 4,000 to 27,100 gallons per day per foot.

An estimate of hydraulic conductivity can be obtained by dividing the transmissivity by the thickness of the water-supply aquifer. Using the thickness of the screen zone as a measure of the water-supply aquifer thickness, the hydraulic conductivity using the confined transmissivity is 2100 gallons per day per square foot (N= 20, SD= 3700) ranging from 250 to 17,000 gallons per day per square foot. The estimated hydraulic conductivity using the unconfined transmissivity is 1600 gallons per day per square foot (N= 20, SD= 2900) ranging from 200 to 13,000 gallons per day per square foot. These values compare favorably to hydraulic conductivities reported by Heath (1980) of 2300 (gal/day)/ft2 for Castle Hayne limestone and 1500 (gal/day)/ft2 for coarse sand. As with the transmissivity estimates calculations of hydraulic conductivity from specific capacity are subject to error. If some of the water-level drawdown in the well is due to well inefficiency, then these calculations would yield values lower than what may be the true aquifer values. Further well testing is required to confirm these estimates.

Borehole Geophysical Logs

The geophysical well log is an important tool that can be used to help determine the character and thickness of the layers penetrated by individual wells (Heath, 1980). The most common type of log is the electric log. In an electric log, measurements of spontaneous potential (SP) and resistivity (R) of the penetrated beds are made. Spontaneous potential is the voltage difference that occurs between a reference electrode on the surface and the natural potential of an electrode as it is moved in the well. Resistivity of the layers is measured with a probe containing induction coils that send a current through the formation layers as the probe is moved up ordown the well. Receiver coils in turn measure the resistance of the layers to the induced current. A continuous graph of the SP and resistivity with depth is the usual method of recording the response. An example of an idealized electric log and its interpretation is shown in figure 15.

The Gamma-ray log is another type of geophysical log that is quite useful especially in identifying clay layers. Gamma-ray logs are made by sending a sensor up or down a well which measures the natural rate of emission of gamma rays by radioactive elements contained within the rock or sediment layers. In general, clays contain a greater concentration of radioactive elements than sands and therefore emit more gamma rays. The relative rates of gamma ray emission are graphed with well depth, and used to help define the location of clay confining layers. An idealized gamma ray log and its interpretation is shown in figure 15.

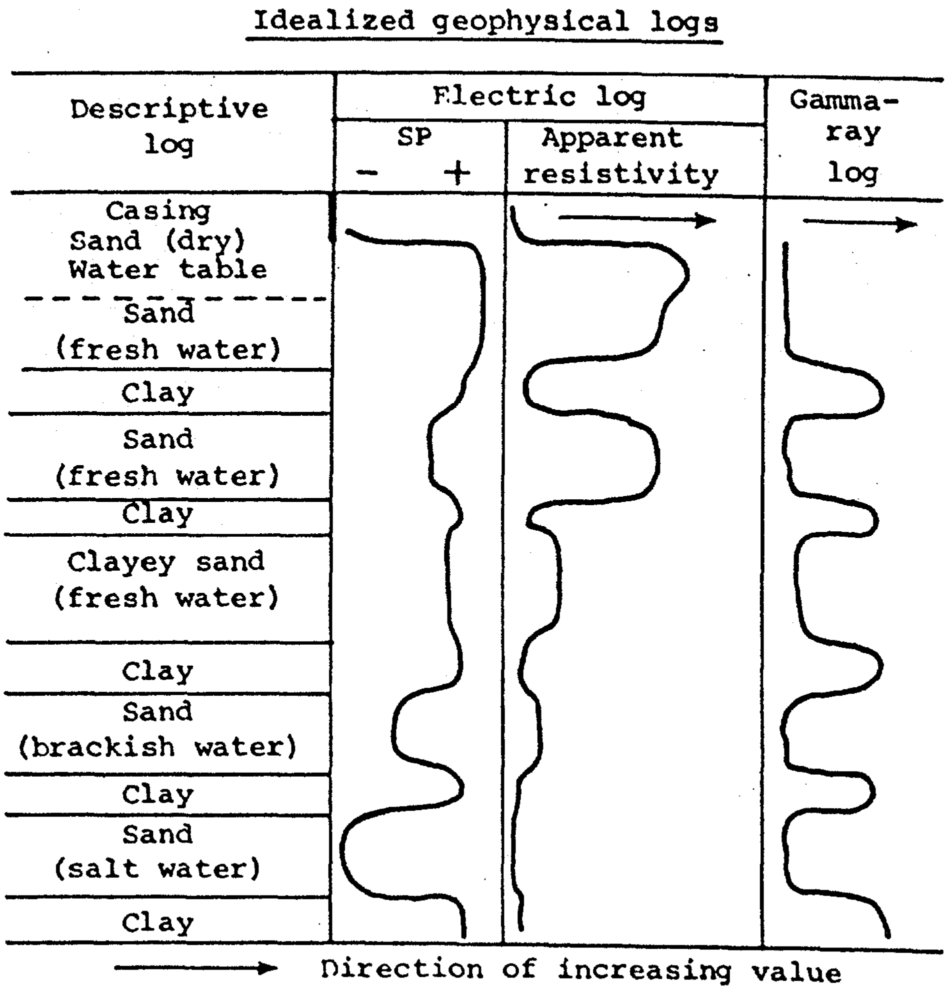


Figure 15. Idealized geophysical logs and their interpretation (after Heath, 1980).

A map showing the well locations where geophysical or lithologic logs are available is shown in Figure 16. There are a considerable number of logs available for the developed areas of the base. The average depth of water-supply wells on the base is 200 feet, therefore, geophysical logs of these wells can only be used to identify geohydrology through that part of the aquifer system that is used for the principal water supply. However, there are a few deep wells (T8, VPI-15, VPI-15a, RR-97, Y25Q2, OT-22, and ON-OT-1-67) that can be used to trace the deeper layers. Borehole geophysical logs of 16 accessible open wells on the Base and two new observation wells were run by the USGS for this study.

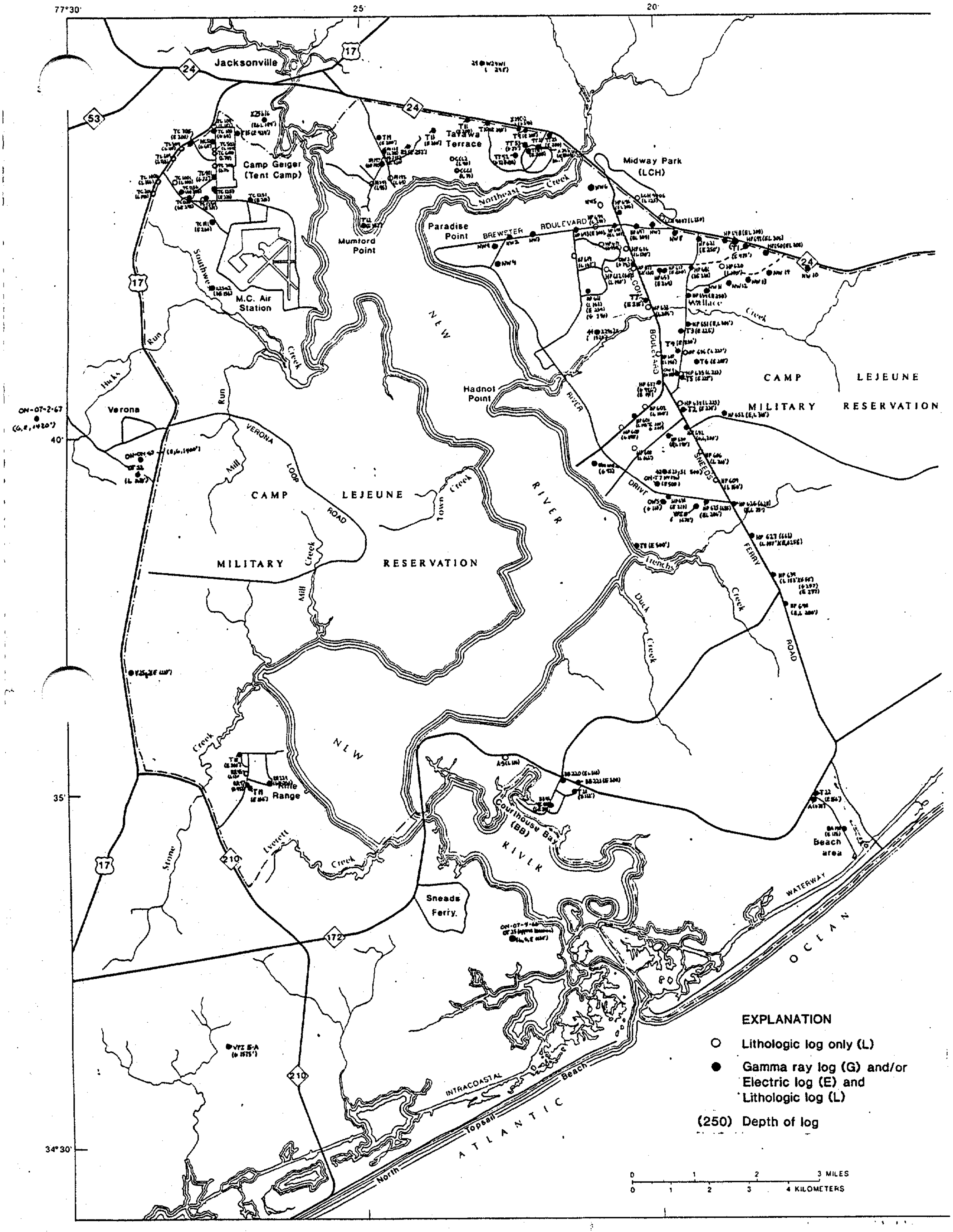


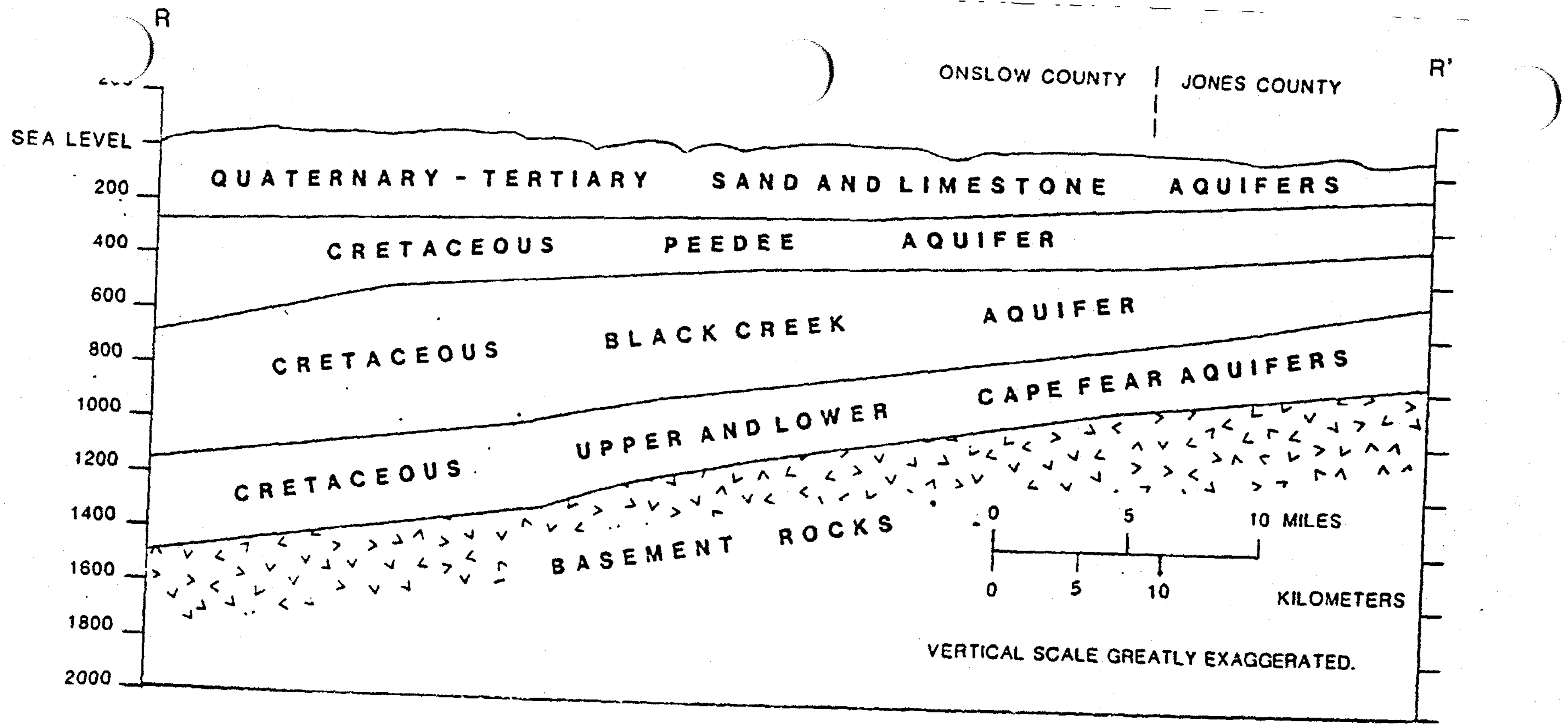
Figure 16. Locations of available borehole geophysical logs.

Cross Sections

One of the initial steps in construction of a geohydrologic framework is the drawing of cross sections. The cross sections are useful in identifying the nature and continuity of aquifer and confining layers, and help define areas that require additional study.

The framework analysis of the Central Coastal Plain (CCP) study by Lyke and Winner (USGS, written commun., 1987) provides the foundation for the framework construction for the Camp Lejeune area. A generalized cross section developed for the CCP study that runs through Onslow County and part of Jones County is shown in figure 17. This cross section shows the major aquifers underlying Onslow County: the Quaternary-Tertiary sand and limestone aquifers which include the Castle Hayne which is the primary water-supply aquifer for Camp Lejeune, the Cretaceous Peedee aquifer which is the primary water-supply for Jacksonville, the Cretaceous Black Creek aquifer, and the Cretaceous Cape Fear Aquifers.

Three cross sections have been drawn as part of the Phase I Study. The locations of these cross sections, labeled A-A’, B-B’, and C-C’, are shown on figure 18. Cross section A-A’ starts at Tarawa Terrace, and runs through the Hadnot Point area along Sneeds Ferry Road to Onslow Beach. Cross section B-B’ starts at Camp Geiger, runs through the Marine Corps Air Station, Mumford Point, Paradise Point, along Brewster Boulevard and then to Route 24. Cross section C-C’ starts at the NRCD Hadnot Point Research Station, and runs along Wallace Creek up to Route 24. All three sections use the best available well data and geophysical logs. The majority of the logs



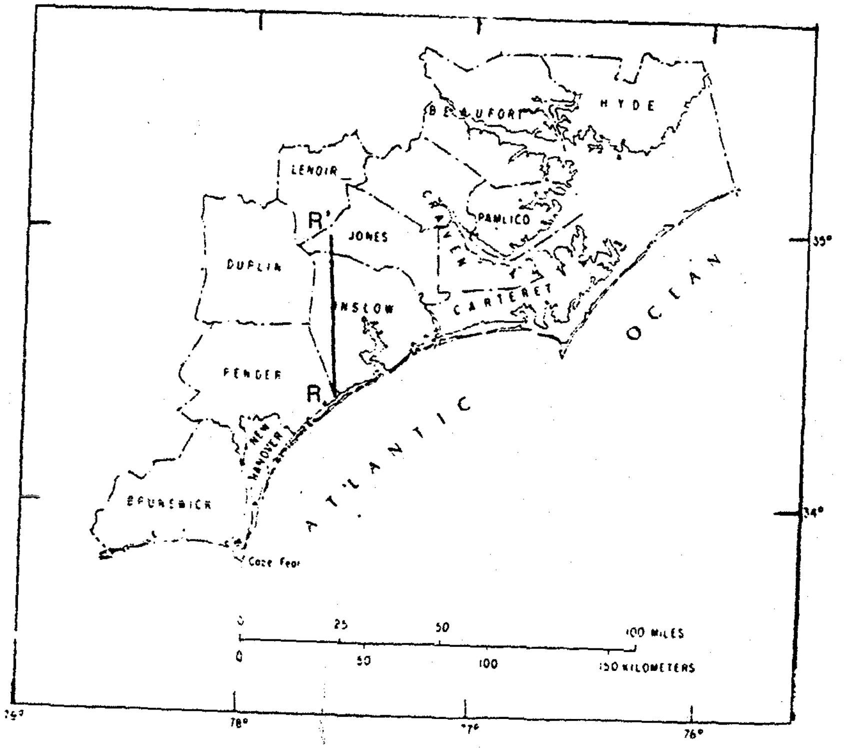


Figure 17. A generalized geohydrologic cross section through part of Jones and Onslow Counties, North Carolina (Bill Lyke, USGS, written commun., 1987).

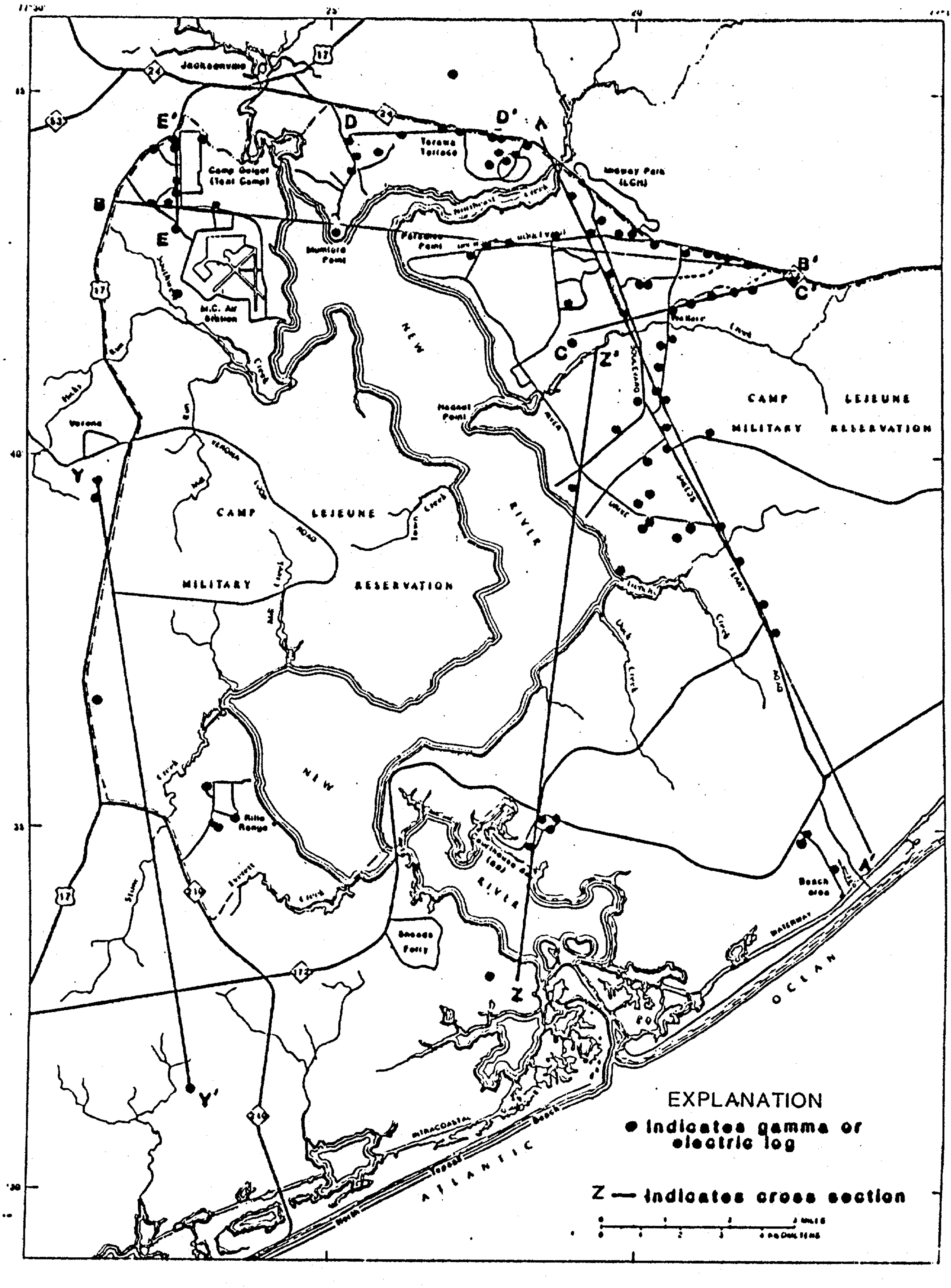


Figure 18. Locations of cross sections drawn for the Phase I study, and sections proposed for the Phase II study.

used are 200-250 feet deep, which corresponds to the usual depth of the water supply wells on the Base. Therefore, the cross sections that could be developed for this area are of the uppermost 300 feet only.

Cross section A-A' is shown in figure 19. In this cross section, and those to follow, the predominant clay beds, which represent confining layers, have been shaded gray, while the sand and limestone beds, which are the water-bearing layers, are unshaded. Section A-A' shows beds that dip gently to the southeast towards the Ocean. The most striking characteristic of clay beds in this section is their thinness. Overall, only about 15 percent of the first 200 feet is readily identifable as clay. Although the cross sections trace continuous clay beds along the full length of the section, these beds thin and thicken from well to well, and are not likely to be present in all areas. In addition, the clays probably allow considerable leakage of water through them. Therefore, from this cross section the Castle Hayne aquifer in this area is at best only partially confined.

A chronostratigraphic rock unit is defined as a body of rock deposited over a definable period of time. A comparison of the logs making up the A-A' cross section and the chronostratigraphic units reported by Brown and others (1972) indicates that Post Miocene (~ <5 million years old) sediments cover Late Miocene (6 million years old) and Oligocene (~35 million years old) sediments as indicated in figure 19. The top of the Oligocene rocks corresponds to the Regional Aquifer Systems Analysis study aquifer 7, or in general, the Castle Hayne aquifer.

Cross-section B-B' is shown in figure 20. The layers shown on B-B' dip gently to the east. Once again, the traceable clay units are relatively thin, ranging from around 24 percent of the section in the Marine Corps Air

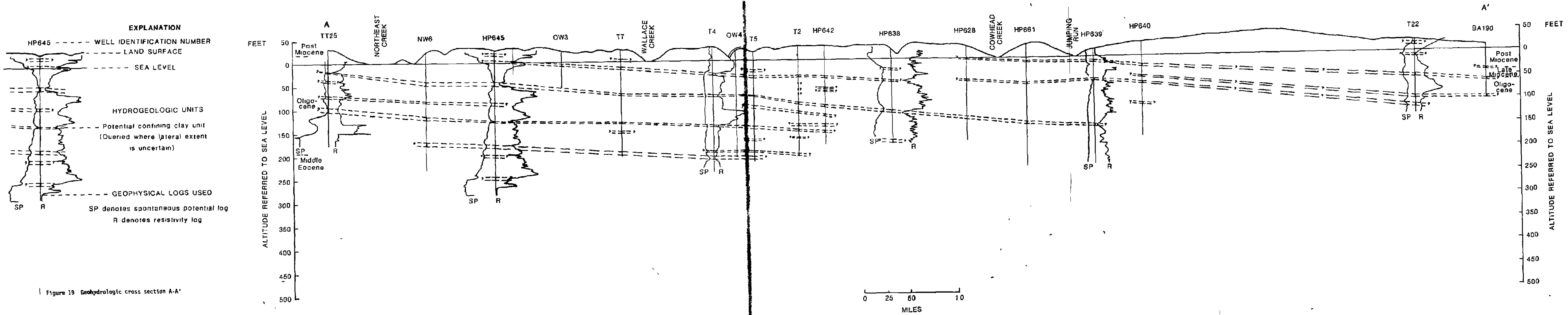


Figure 19 Geohydrologic cross section A-A'

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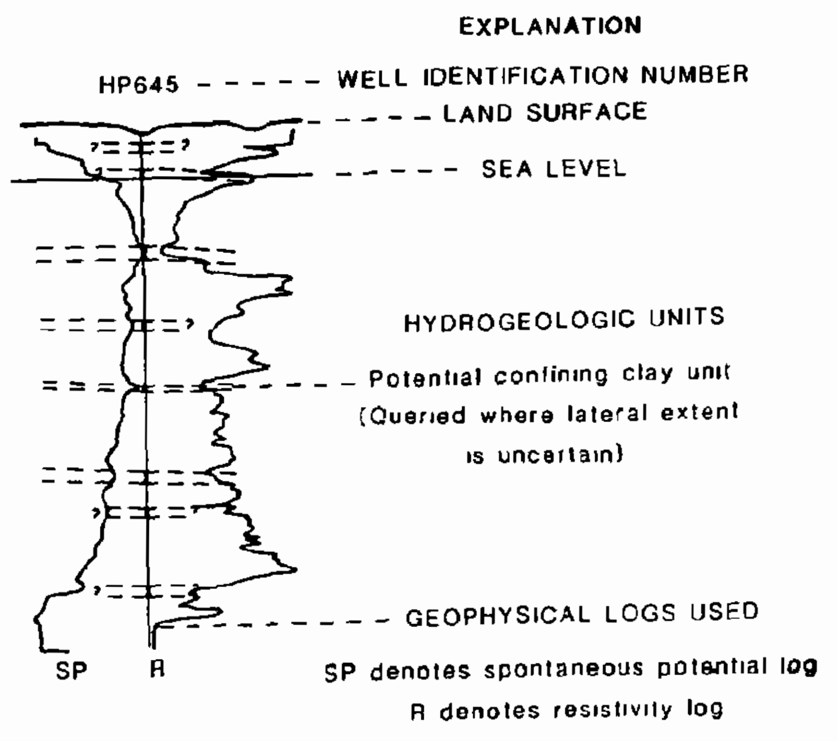

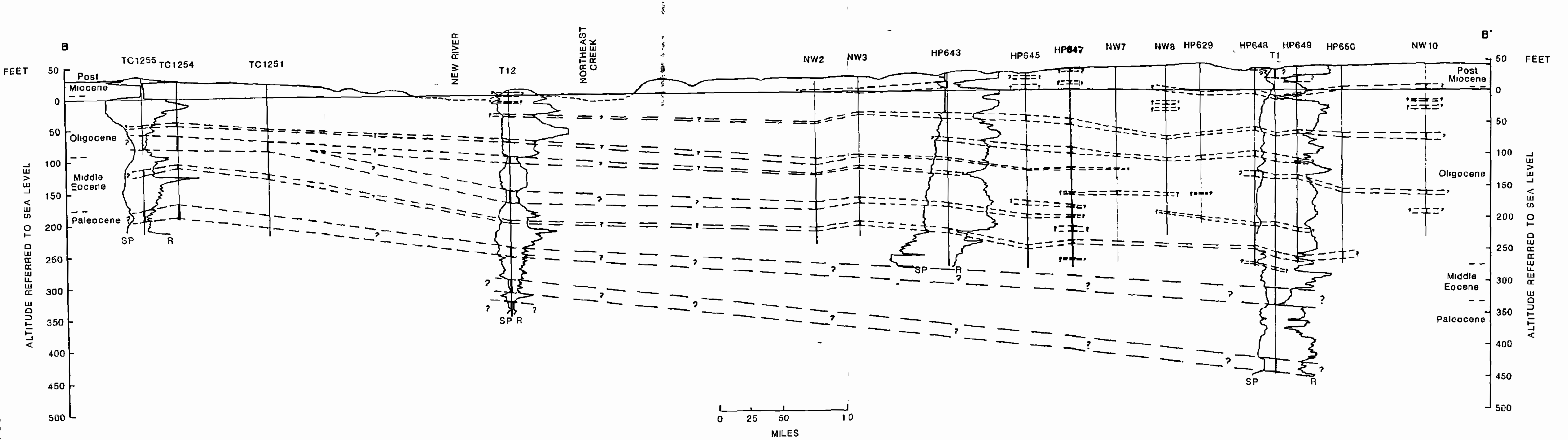

Figure 20 Geohydrologic cross section B-B'

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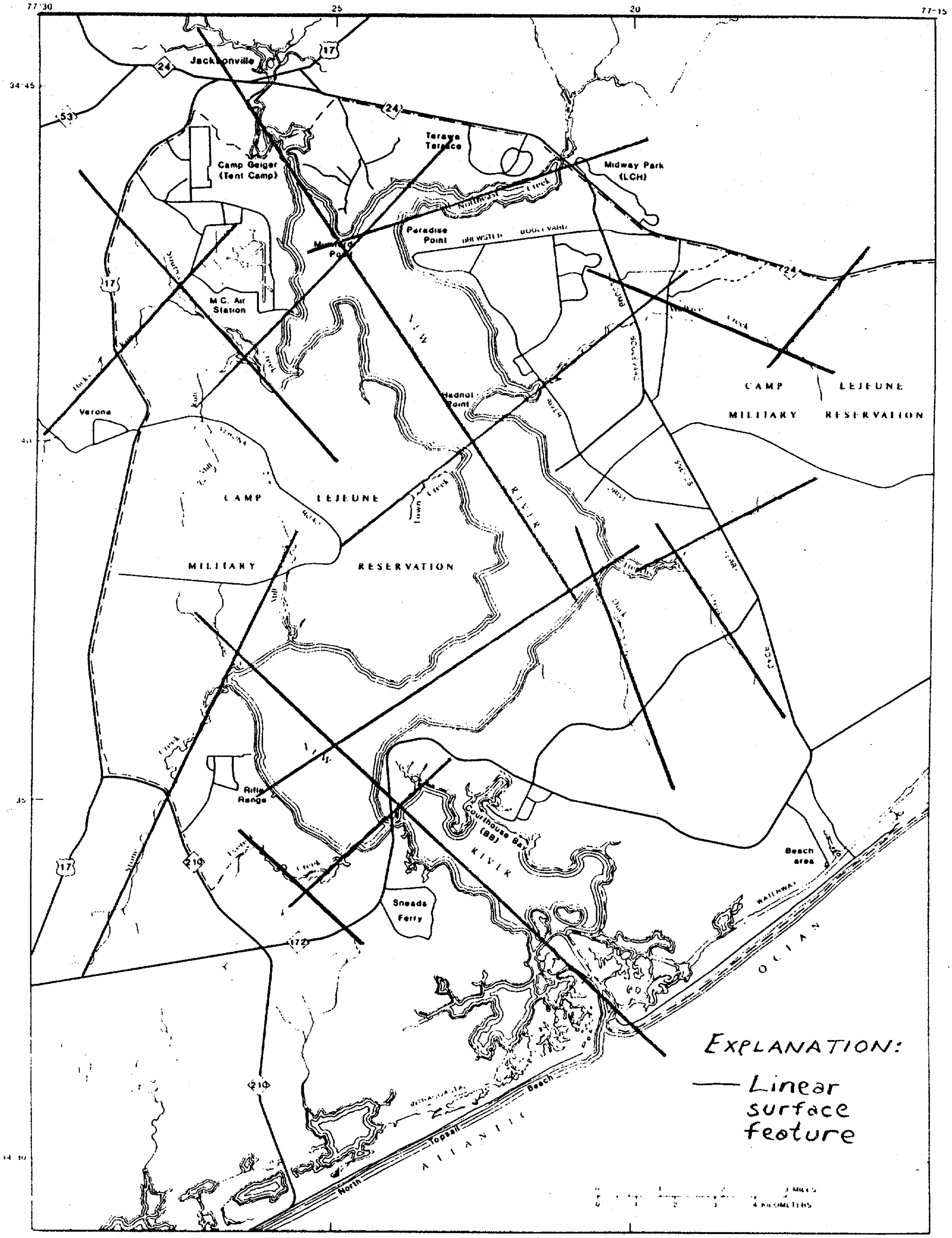
Base area to less than 20 percent in the area around Brewster Boulevard and Route 24. As was apparent from A-A', the aquifer system seems only partially confined, and is therefore readily open to recharge from the surface as well as contamination. Logically, the deeper beds in the section will show greater confinement as greater total thickness of clay separates the deeper flow system from the surface.

The Post Miocene deposits are thinner in section B-B' than those indicated to the south along section A-A'. It appears that the Oligocene sediments, including the Castle Hayne aquifer, connects directly to the bottom of the New River.

On the western side of cross-section B-B' below Stick Creek the section thins and it appears that two clay units merge into one that underlies the Air Station. The reason for this is unclear. However, one hypothesis to explain this interpretation is the existence of a fault paralleling the New River in this area. This hypothesis is bolstered by the observation of an apparent regional regularity of linear orientation of surface features such as streams. A map of the Camp Lejeune area showing some of the linear elements is presented in figure 21. This hypothesis may be relevant to the study of the water resources of the Air Station area, because a fault beneath the New River, in combination with erosion of the updip part of the sediments, may have breached clay layers that serve elsewhere to keep salt water from the New River out of the water-supply aquifer. Testing this hypothesis, by drilling test holes and using surface geophysical techniques is proposed for the second phase of study.

Cross section C-C' is shown in figure 22. The clay layers in this section show very little dip indicating that it runs nearly perpendicular to the direction that the beds slope. Overall, the three cross sections show



Base taken from Defense Mapping Agency Hydrographic Center, Camp Lejeune Special Map, 1:50,000

Figure 21. Surface linears possibly related to subsurface structure in the Camp Lejeune area.

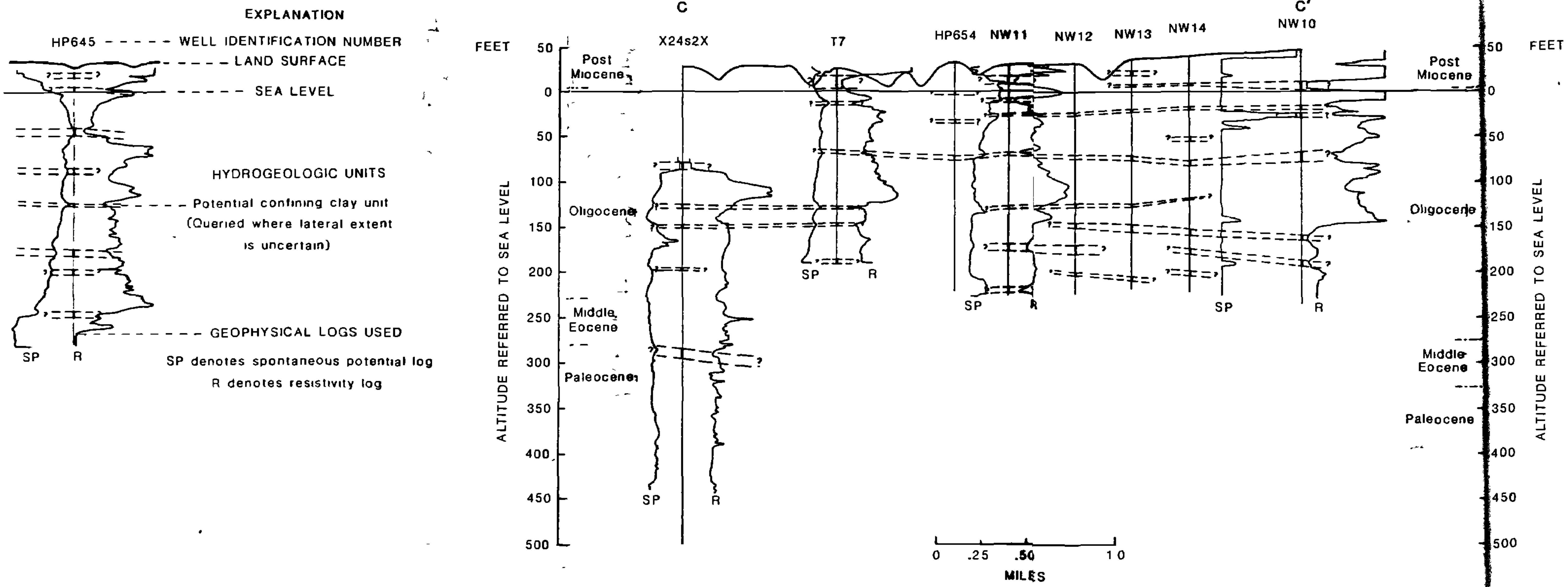


Figure 22 Geohydrologic cross section C-C'.

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the regional direction of dip to be southeast at a slope of 10 feet per mile. Like section A-A' the discernable clay beds make up only about 15 percent of the total thickness of the uppermost 250 feet of sediments. Once again this is an indicator of only partial confinement of the water-supply aquifer from the surface.

The Post Miocene deposits near the surface have been nearly cut though in several places by tributaries to Wallace Creek. The top of the Oligocene sediments is found near to sea level on section C-C'.

Using selected depths to some of the clay beds traced on all three cross sections, the dip and the strike of the beds can be calculated. The dip is the direction and amount that the beds are sloping, and the strike is the axis of the dip. The dip of the beds in the Camp Lejeune area is to the southeast at 19 degrees with a strike of north 79 degrees east.

Further Study-- Additional cross sections E-E', D-D' and deep (1000 feet) sections Y-Y', and Z-Z' shown in figure 18 are proposed for the second phase of study. These new sections will be constructed using available geophysical logs.

New wells drilled along the western end of B-B' near the Air Station and on Paradise Point will test the hypothesis that there is a fault running beneath the New River. A well on A-A' between HP-640 and T-22 is needed to fill the gap in geophysical information between Hadnot Point and the Beach Area. Finally, a wells drilled along the Camp Lejeune--Cherry Point Railroad to the northeast of the Base and wells drilled along Wallace Creek will allow the examination of a potentially important new areas of water supply.

Surface geophysical techniques may provide additional information that will help interpretation of the hydrogeologic framework. A sub-bottom profiler, a seismic geophysical tool used in water, will be used to collect seismic profiles along transects in the New River. Seismic profiles along the New River could be used to locate faults, define geological structure, and tie together the data interpretations of cross sections B-B' and Z-Z'.

GROUND-WATER LEVEL DATA PROGRAM

Measurement of ground water levels is an essential step in defining the ground-water flow system. It is important to know the variation that occurs within the aquifer due to climatic effects (such as rainfall variation and barometric variation), and the tidal cycle. Long-term record of water levels is required to assess regional trends caused by pumpage. Areal surveys of water levels are required to map the potentiometric head for the different parts of the aquifer system. These water levels in turn allow the calculation of hydraulic gradient, which is needed to calculate the relative velocity of flow, and the regional direction of water flow. Finally, a record of water levels over time is required to calibrate the flow model.

Network Concepts

Water levels vary in aquifers as a function of natural conditions or manmade stresses (Winner, 1981). A water-level monitoring network needs to include the measurement of variation from both sources.

In the hydrologic cycle rainfall enters the ground in recharge areas, infiltrates down through the surficial soil layers and the unsaturated zone until it reaches the saturated zone. In the saturated zone water moves towards the direction of lowest hydraulic pressure, moving through the system towards discharge areas where it is eventually discharged to the surface. An illustration showing generalized movement of water through a typical Coastal Plain system is shown in figure 23. In the Coastal Plain of North Carolina where the sediments include beds that serve to impede flow, the hydraulic head in confined aquifers will show a different pattern of variation over time than that for unconfined aquifers. The water level in unconfined aquifers represents the water table which is defined as the top of the zone of saturation. Shallow water-table wells show a strong variation in water level with season, and with rainfall. In the winter the shallow system receives more recharge than in the summer when much of the water evaporates or transpirates in plants before it can move deeper into the ground. Therefore, shallow water levels are generally highest in the winter months and lowest in late spring, summer and early fall. Some seasonal variation is also common in a confined aquifer, but, the water-

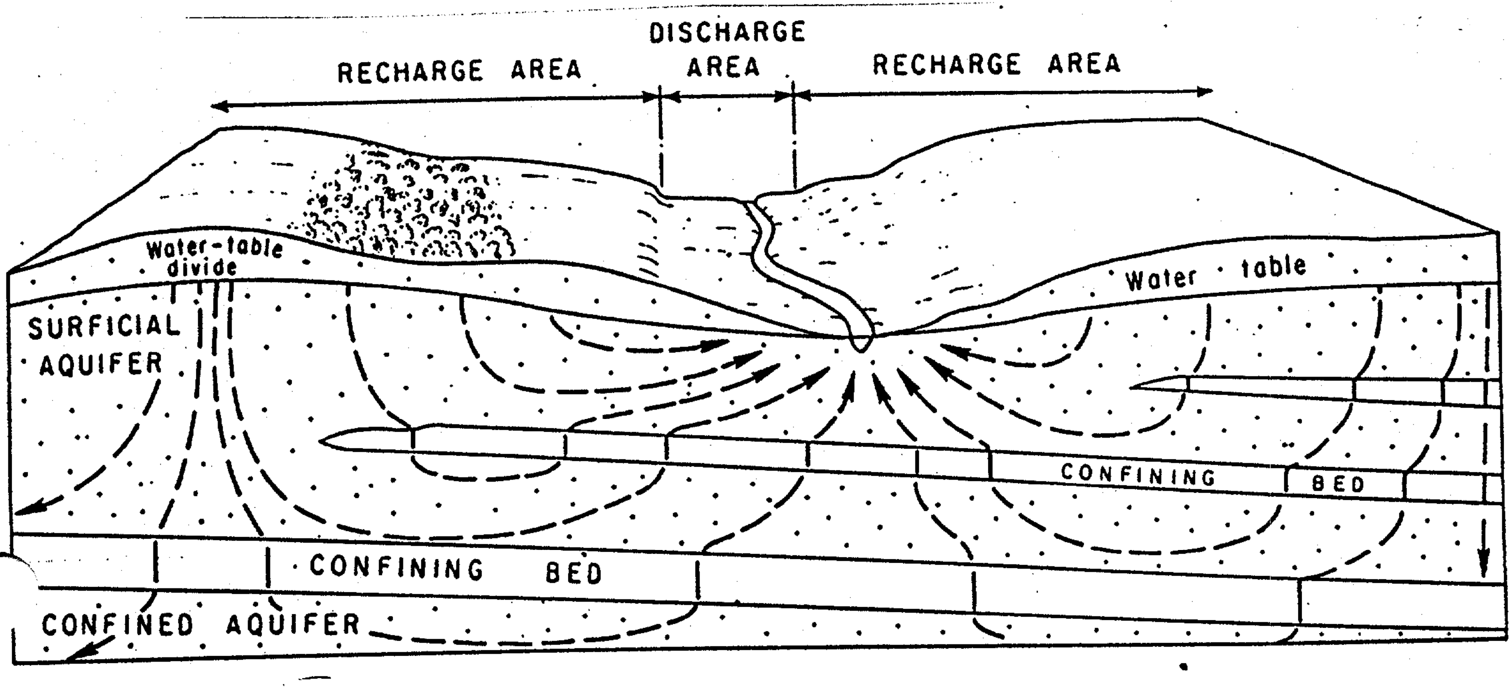


Figure 23. Movement of water through a ground-water system of unconfined and confined aquifers-- a typical Coastal Plain situation (from Winner, 1981).

level changes tend to be slower and over a smaller range than for water-table wells. Tidal and barometric changes also effect water levels. Tidal effects are observed in both confined and unconfined aquifers. Barometric effects are generally more evident in confined aquifers than in unconfined aquifers (Todd,1959). An increase in atmospheric pressure results in a decline in water level.

The principal ways that man causes changes in the ground-water flow system include pumpage, stream channelization, and covering recharge areas with impervious buildings and pavement. The most significant of these is pumpage.

Water levels in the aquifer around a pumping well form a cone of depression around the well. The extent of the cone is largely a function of how long a well is pumped and the hydraulic conductivity of the surrounding aquifer. The longer a well is pumped the larger the cone becomes up until a new equilibrium is reached between recharge and discharge. The cones are widespread and shallow in highly transmissive aquifers, and less widespread and deep in less transmissive aquifers. Pumpage effects may show up as rapid fluctuations due to pumping schedules of nearby wells, or as a long term and generalized decline due to regional withdrawals from the aquifer.

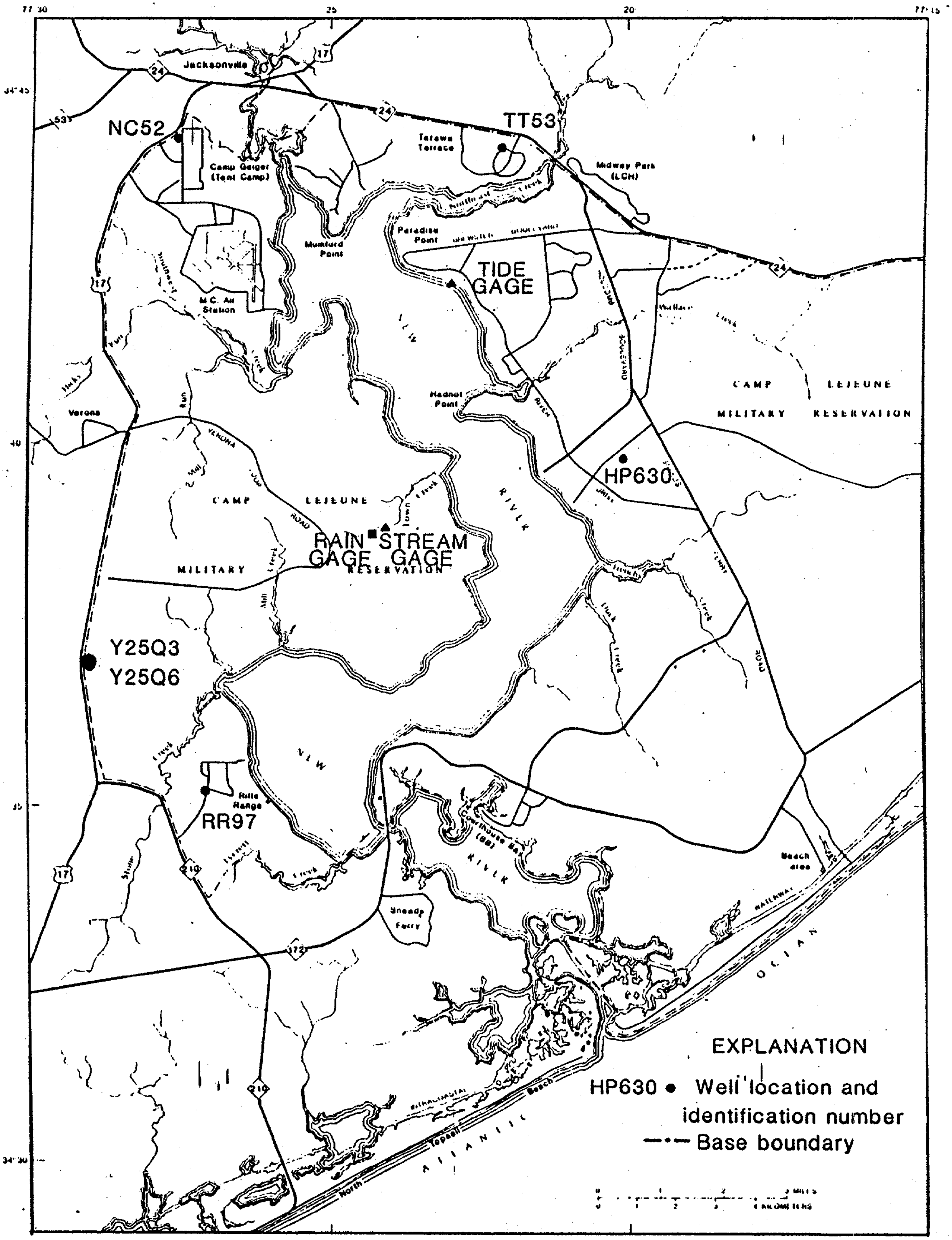
A network designed to measure both natural and man-induced variation in water levels in the Camp Lejeune area requires observation wells in both the unconfined and partially confined aquifers. It requires measurement of tidal and barometric effects. Finally, both long-term regional trends and effects of individual pumping wells need to be identified.

Water-Level Monitoring Network

The ground-water level monitoring network for Camp Lejeune that was installed during the first phase of study is made up of 6 wells. The locations of these stations are shown on figure 24. Wells NC-52, TT-53, and Y25Q6 are all shallow wells screened in zones down to 70 feet deep. Wells HP-630, and Y25Q3 are screened in the Castle Hayne Aquifer. Well Hp-630 is screened at 60-160 feet and Y25Q3 is screened at 150-240 feet. Well RR-97 is screened 385-425 feet which is below the aquifer used for water supply on the Base. All of the monitor wells are instrumented with an automatic digital recorder set to make hourly water-level measurements. In addition to the monitor wells a tide gage was installed on the Bachelor Officer Quarters pier (see figure 24), and recording barometers were used during the two water-level surveys.

The shallow wells NC-52, and Y25Q6 show similar hydrographs. The hydrograph for NC-52 is shown on figure 25 and for Y25Q6 on figure 26. Both Hydrographs show considerable variation in water levels due to variation in recharge from rainfall. Some seasonality is evident in both wells. The relatively low water levels of late summer were followed by much higher levels in August due to unusually wet weather. The low water levels in September and October were followed by higher levels in the winter months as decreased evapotranspiration allowed more rainfall to reach the subsurface. The change in water level due to seasonal variation is around 3 feet.

The hydrograph of well TT-53 (figure 27) shows considerable variation in water level which in this case appears to be a result of both climatic



Base taken from Defense Mapping Agency Hydrographic Center, Camp Lejeune Special Map, 1:50,000

Figure 24. Locations of monitoring stations at Camp Lejeune.

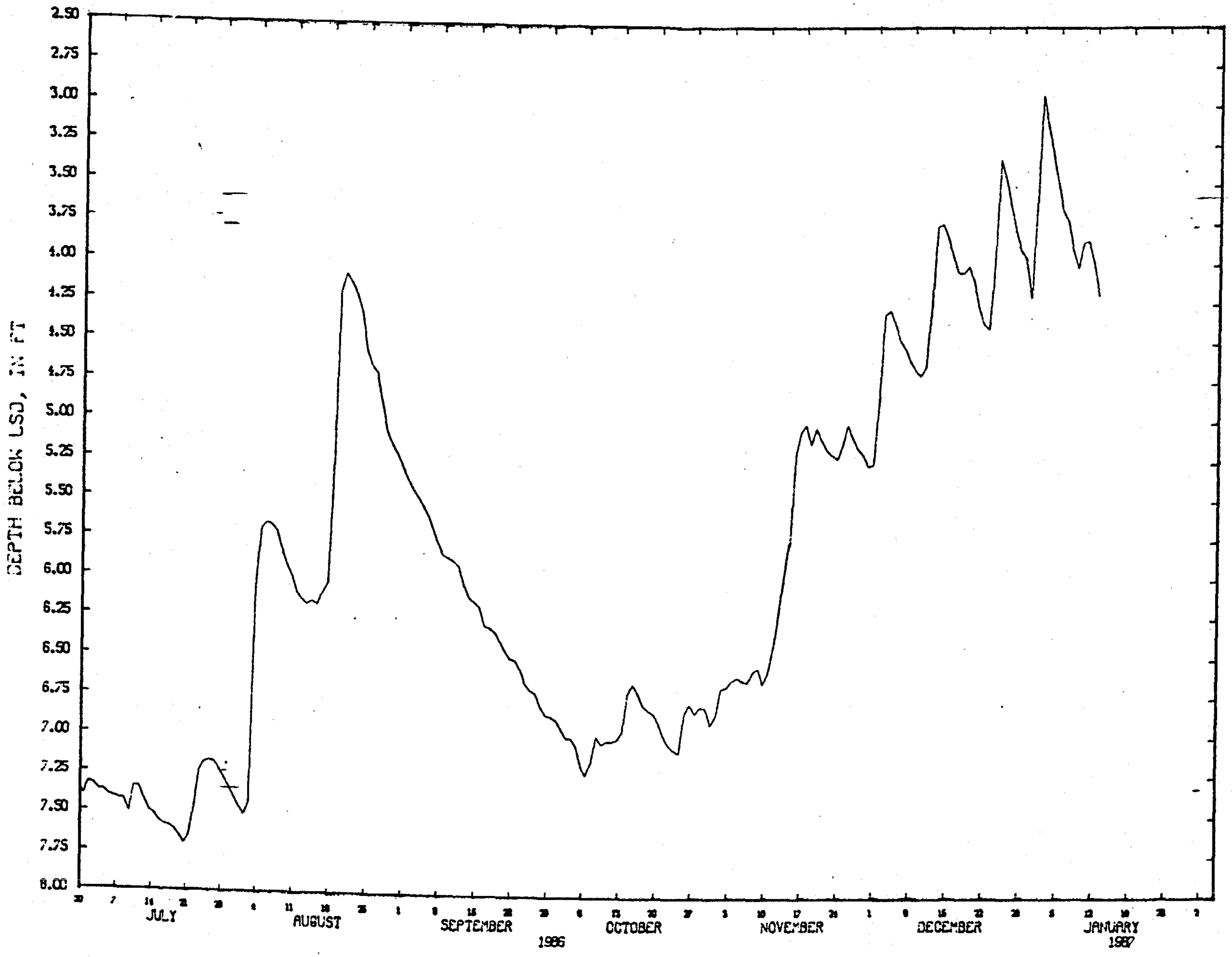


Figure 25. Hydrograph for well NC-52, for the period of July 1986 through January 1987.

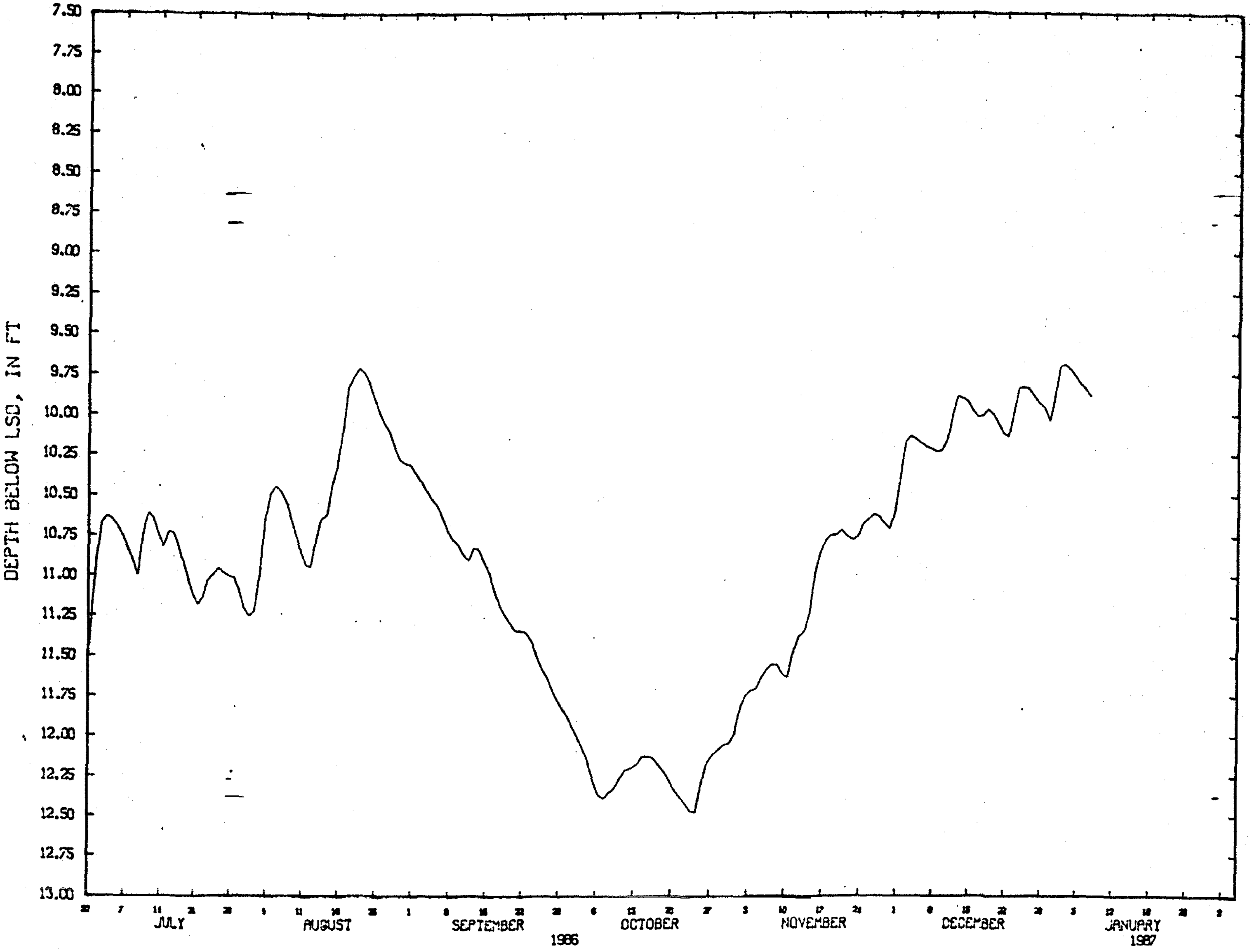


Figure 26. Hydrograph for well Y25Q6, for the period of July 1986 through January 1987.

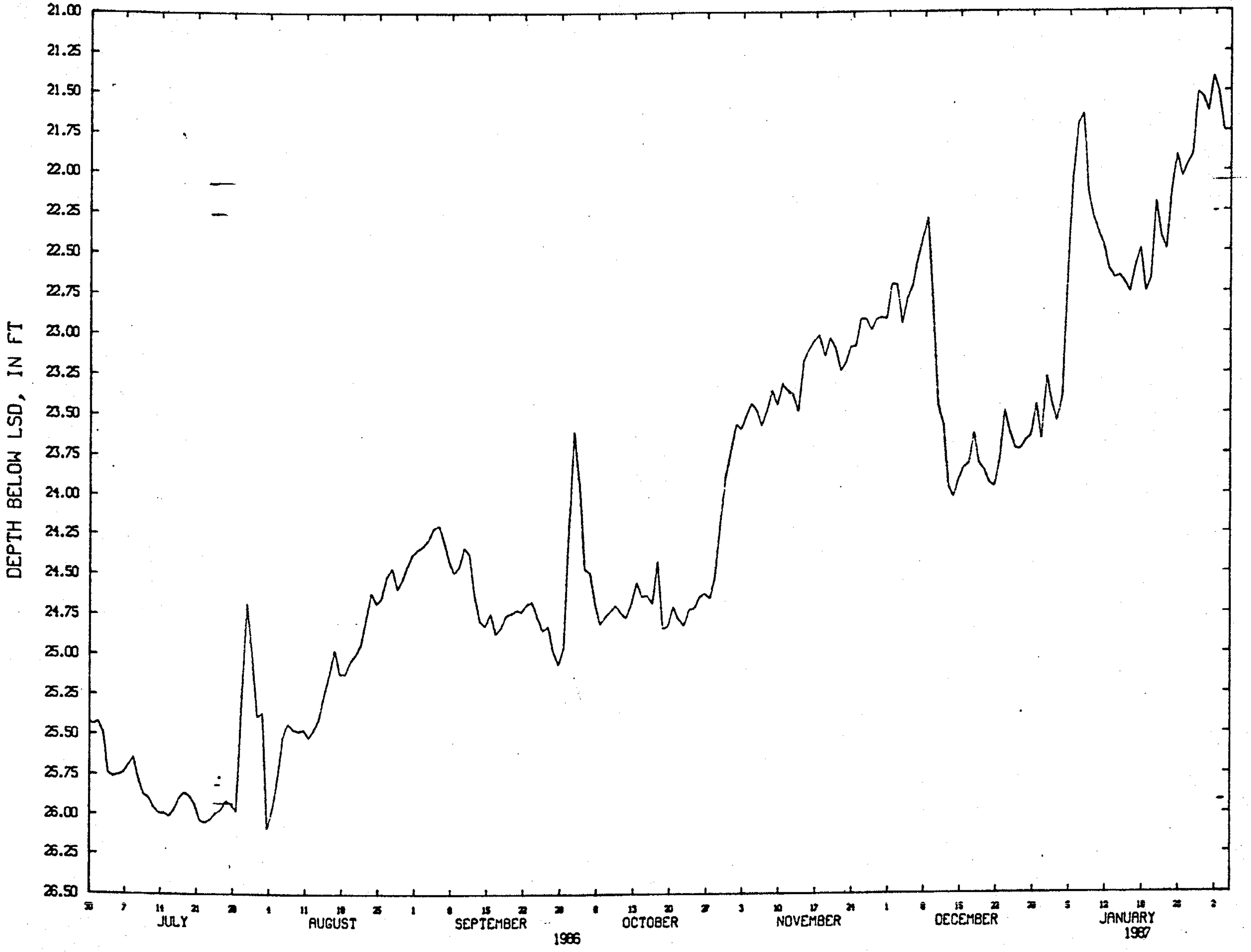


Figure 27. Hydrograph for well TT-53, for the period of July 1986 through January 1987.

variation and pumpage. In particular, the month of December, 1986 appears to show lower water levels probably due to pumpage. The amount of change in water level due to pumpage is around 1-2 feet. Seasonality is also apparent with the water-levels of the late summer months being lower than those of the winter months.

Wells HP-630 and Y25Q3, which are screened in the Castle Hayne aquifer, show similar hydrographs. The hydrograph for well HP-630 is shown in figure 28, and the hydrograph for well Y25Q3 is shown in figure 29. The seasonal response is evident, but less short-term variation is seen. The hydrographs for these wells indicate a much greater degree of confinement than for wells NC-52, Y25Q6, and TT-53. The amount of change in water level due to seasonal variation is around 1.5 feet. Well HP-630 also shows what appears to be variation due to pumpage although much less dramatic than that for TT-53.

Well RR-97 (figure 30), which is screened below the Castle Hayne aquifer, shows less seasonal variation than even the subdued pattern of well Y25Q3. This is an indication of greater relative confinement from the surface.

The general relationships of the hydrographs of the wells can be seen clearly when they are all plotted together as on figure 31. The similarity of the seasonal responses of wells NC-52 and Y25Q6, the similarity of the hydrographs of wells HP-630 and Y25Q3, and the effect of pumpage in well TT-53 is evident this figure.

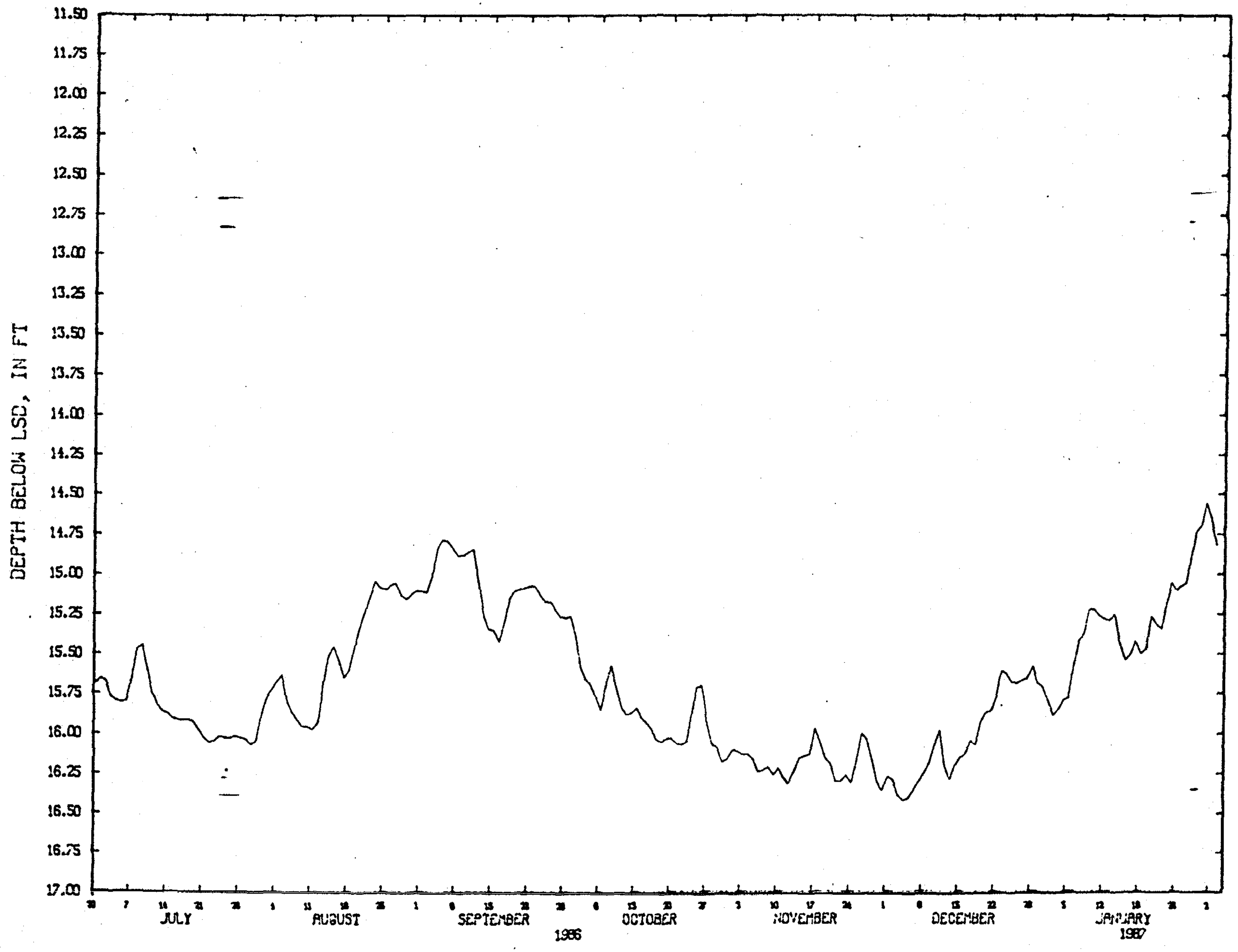


Figure 28. Hydrograph for well HP-630, for the period of July 1986 through January 1987.

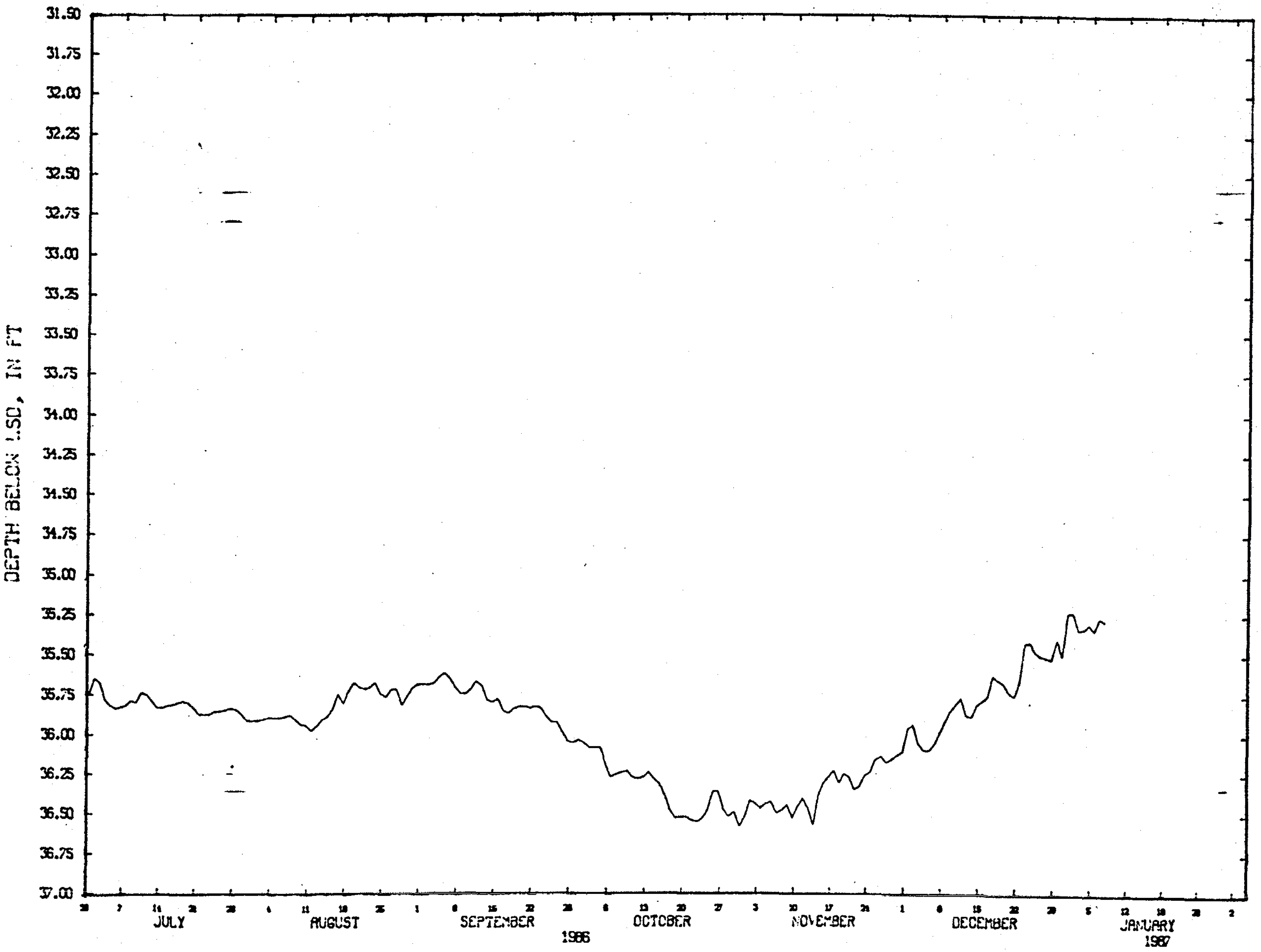


Figure 29. Hydrograph for well Y25Q3, for the period of July 1986 through January 1987.

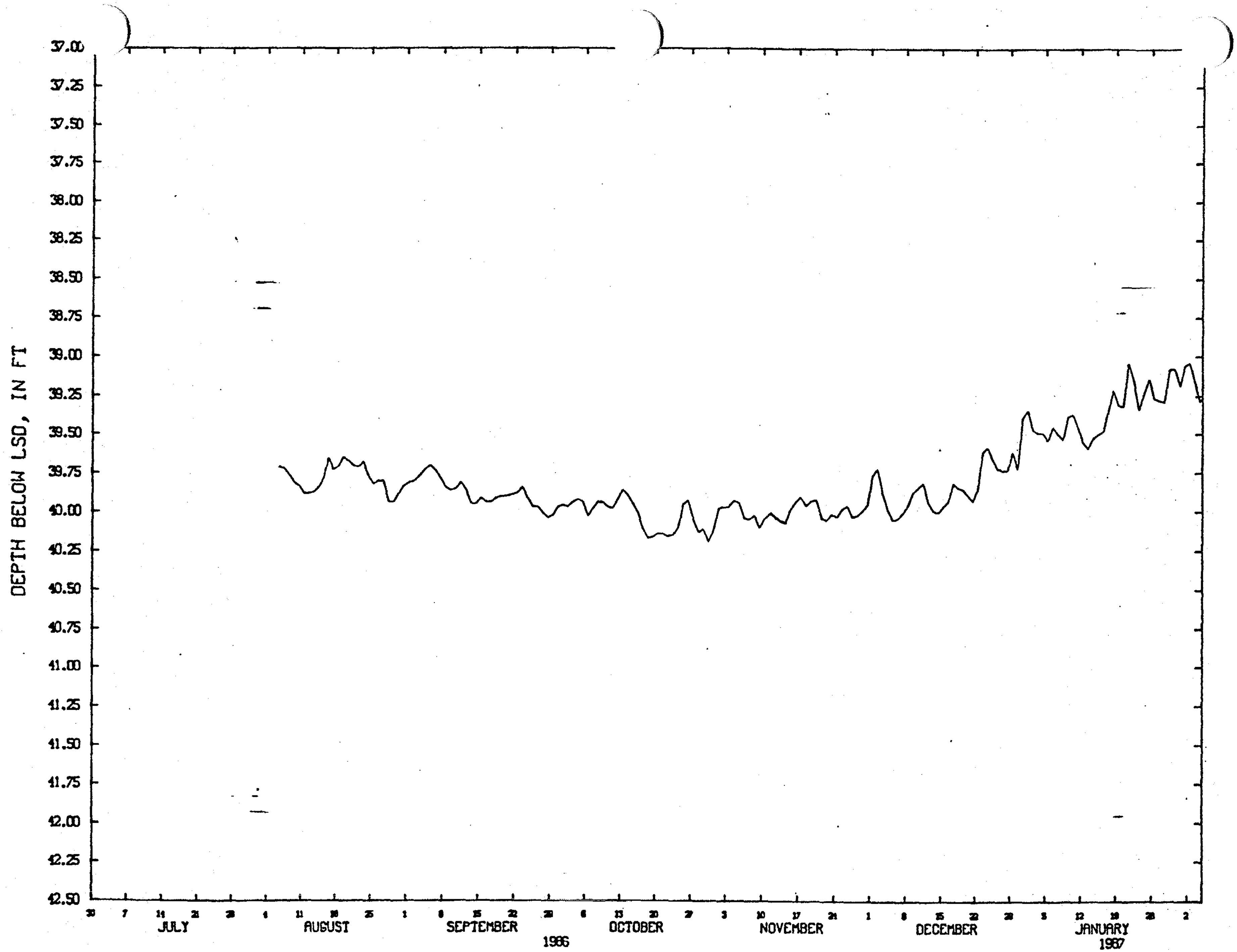


Figure 30. Hydrograph for well RR-97, for the period of August 1986 through January 1987.

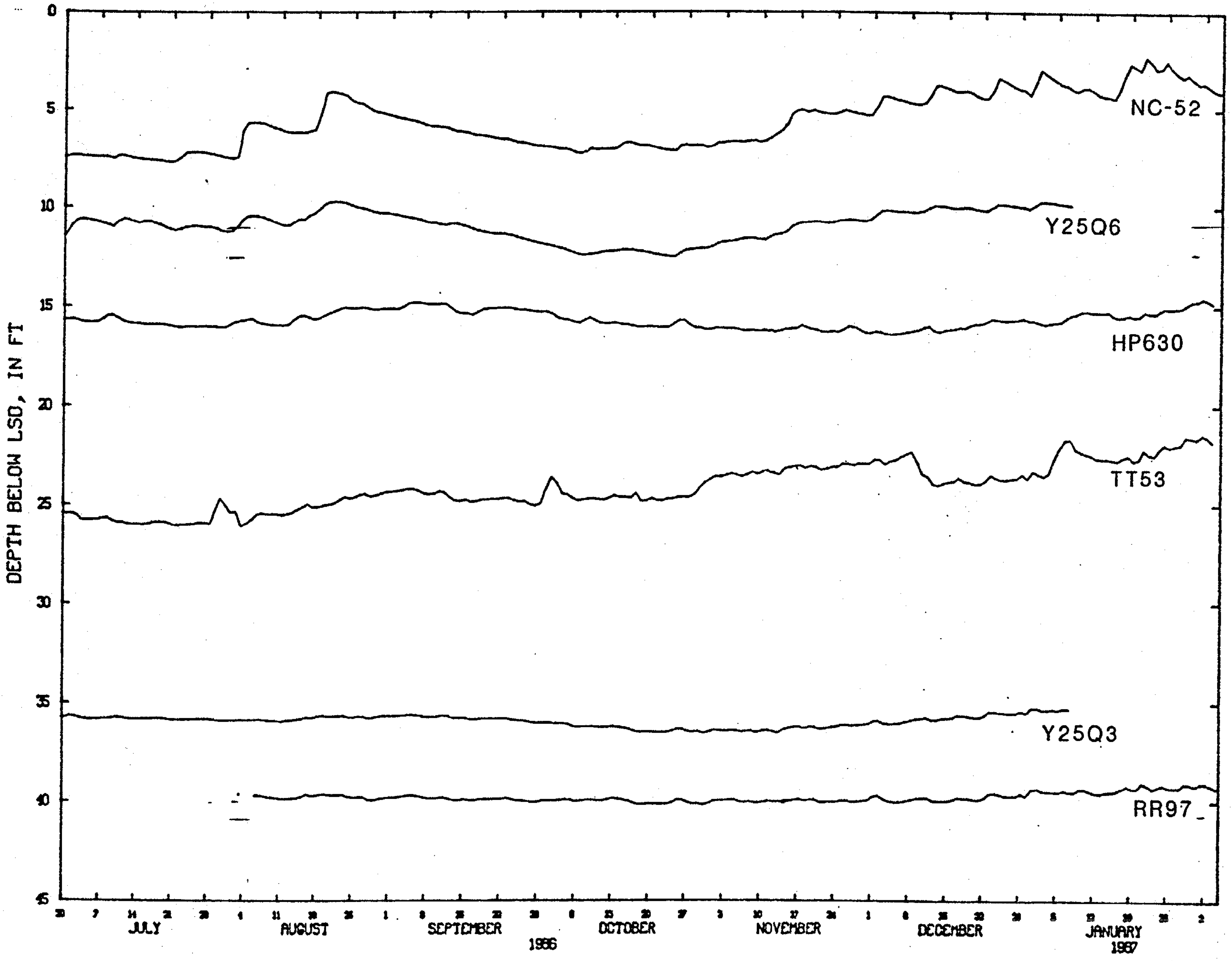


Figure 31. Hydrographs for wells NC-52, Y25Q6, HP-630, TT-53, Y25Q3, and RR-97 for the peroid of July 1986 through January 1987.

Water-Level Surveys

Water-level surveys of the Base water-supply aquifer were run during the week of October 19-25, 1986, and from April 7-10, 1987. The October survey was an effort to measure water levels during the seasonal low period, and the April survey was intended to measure water levels during the seasonal high period.

An examination of the hydrographs of the monitor wells for the October period show little short-term climatic effects for the wells screened in the Castle Hayne (HP-630 and Y25Q3). The hydrographs for wells HP-630 and Y25Q3 for this period are very similar (figure 32). This lack of variation is contrasted by the decline seen in water levels in the shallow wells NC-52 and Y25Q6 for the same period. The hydrograph for well NC-52 is shown in figure 33. Stability in water level is desirable during a water-level survey. Fortunately, during the October survey the only variation apparent in the Castle Hayne wells is minor, and probably due to barometric and tidal effects. Barometric variation is a possible explanation for the short-term changes seen in the water levels for well NC-52 shown in figure 33. A trace of the barometric pressure (uncalibrated) for this period is shown on figure 34. A comparison of the two graphs shows that most peaks in water levels correspond to dips in air pressure. A comparison of barometric variation and water levels for the April survey was not possible at the time of writing of this report.

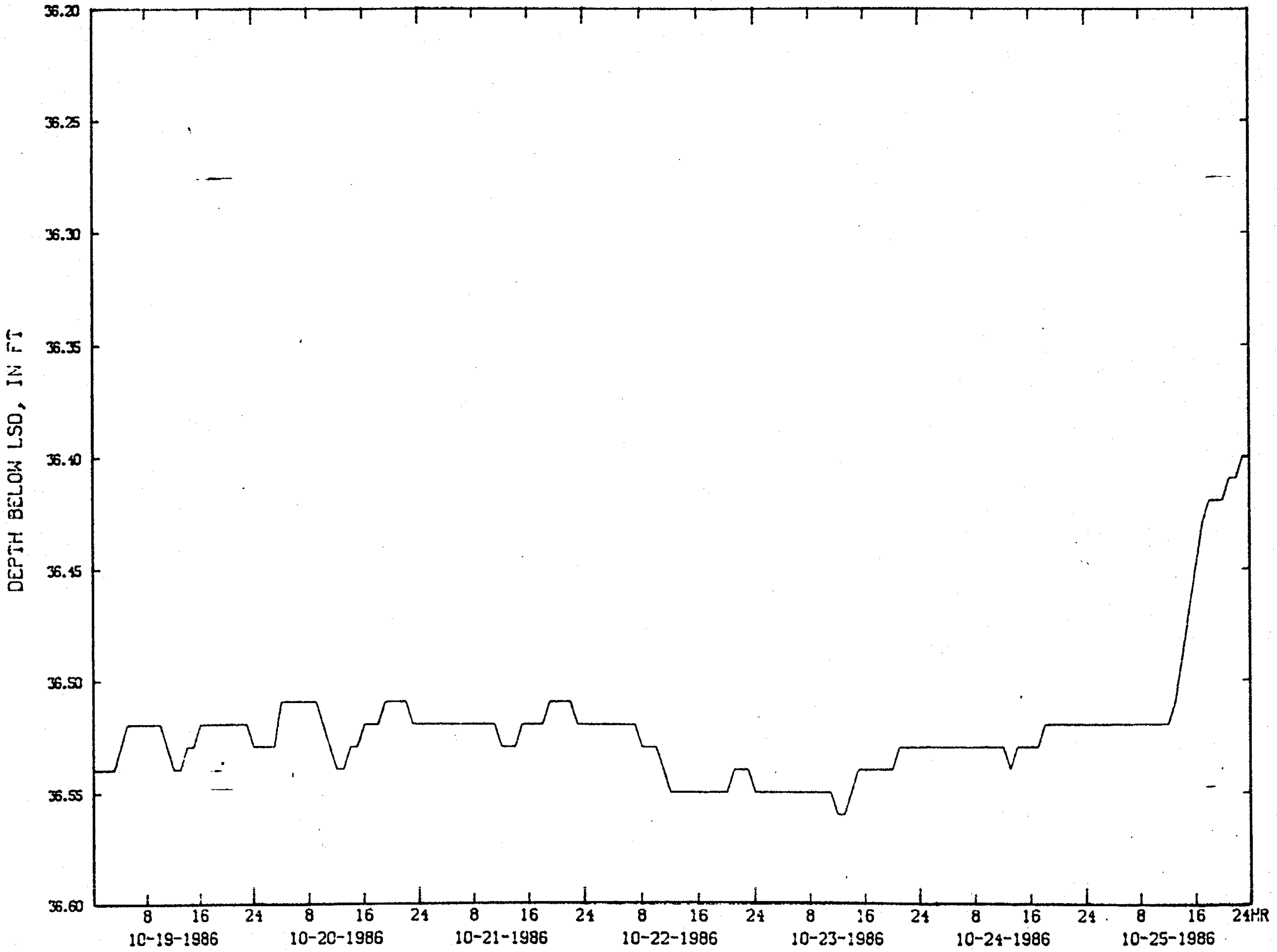


Figure 32. Hydrograph for well Y25Q3, for the period of October 19, 1986 through October 25, 1986.

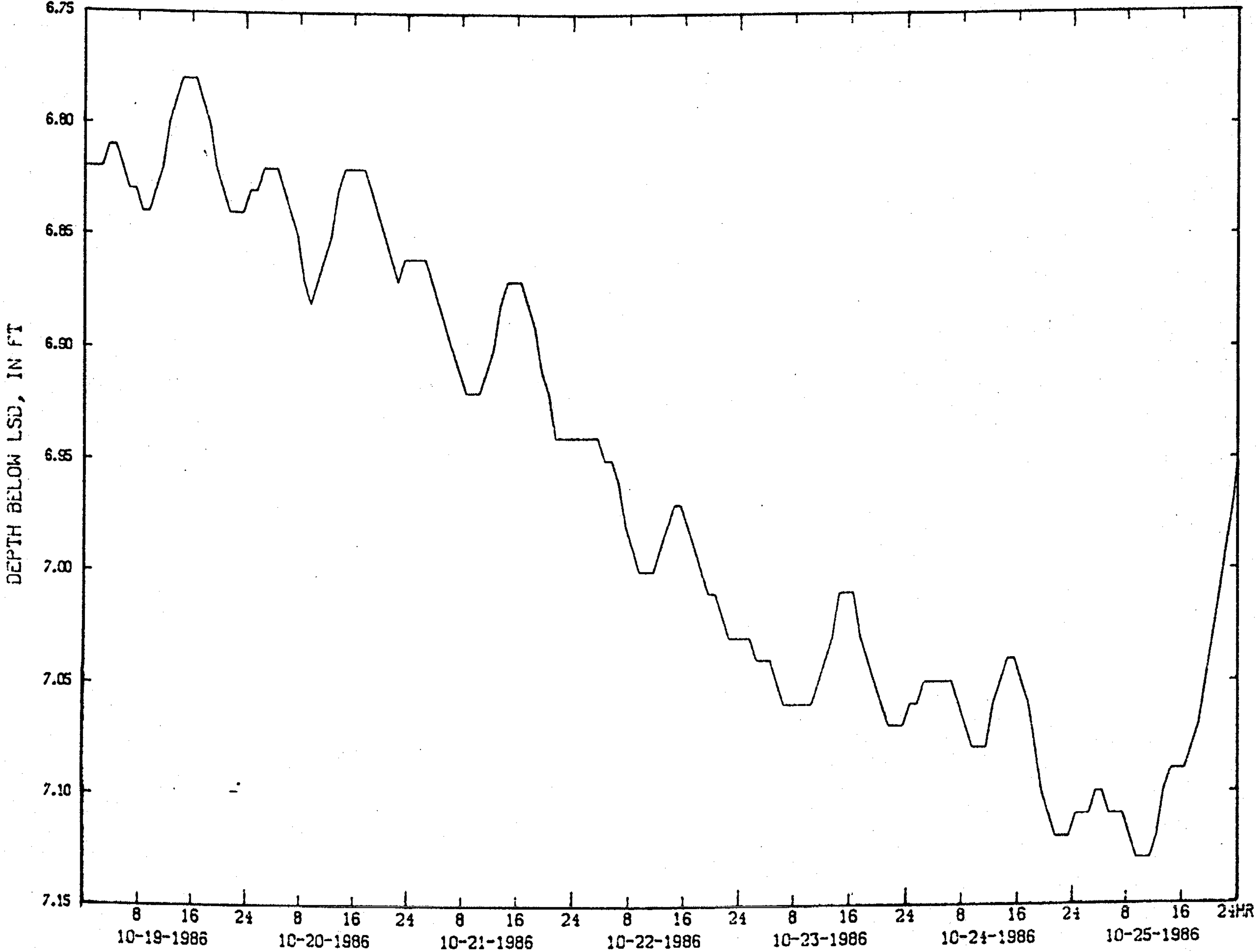


Figure 33. Hydrograph for well NC-52, for the period of October 19, 1986 through October 25, 1986.

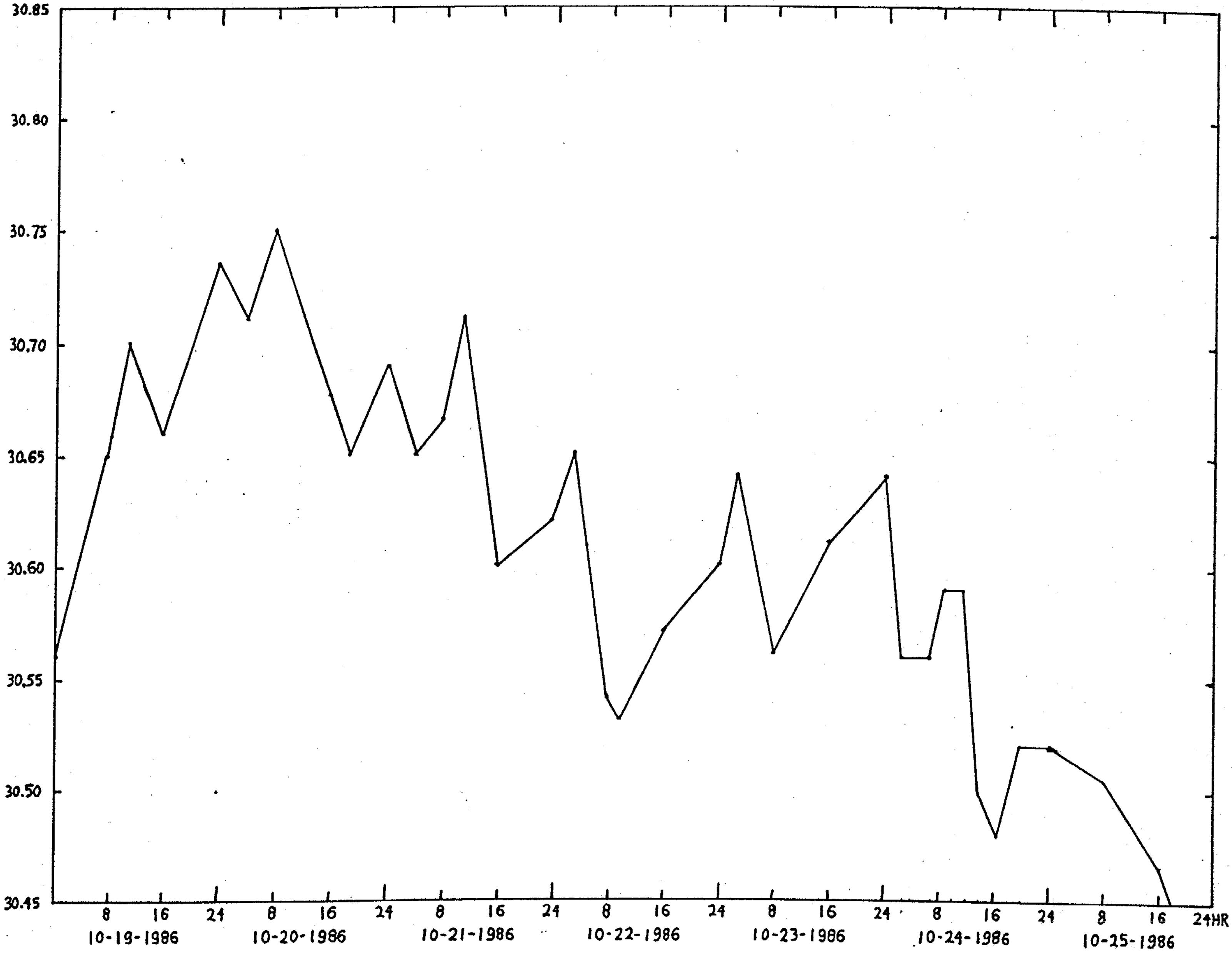


Figure 34. Barograph from well site TT-53, for the period of October 19, 1986 through October 25, 1986.

The water-level surveys included all the available nonpumping wells in the water-supply aquifer on the Base. For the October survey 127 wells were measured, and in the April survey 120 wells were measured. Pumping levels were not measured, however, estimated pumping levels for the wells were obtained from the available records. The water-level measurements were made using steel surveying tapes and the measuring points were marked and recorded. Because of the paucity of confining material and the multiple-screen nature of most of the wells,all the measured water levels have been initially plotted together and considered to be representative of the potentiometric surface in the water supply aquifer.

A generalized contour map of the water levels measured during the October survey is shown in figure 35 and for the April survey in figure 36. A comparison of the two periods indicates that, as expected, water levels measured in April following the winter recharge period are higher than water levels measured in October at the end of the growing season.

There are several important generalizations about the flow system that can be made from examination of the water level maps. First, the regional contours tend to follow land surface contours. Second, the flow lines that can be drawn from these water-level contours indicate that flow in the regional ground-water system for the Castle Hayne aquifer is towards surface streams and the New River. The flow lines, which are drawn as perpendiculars to the water-level contours, are shown in figures 35 and 36. Finally, the pumping centers, which appear as concentric rings of contours on the maps (figures 35 and 36), are relatively small in areal extent that there appears to be little interference between wells.

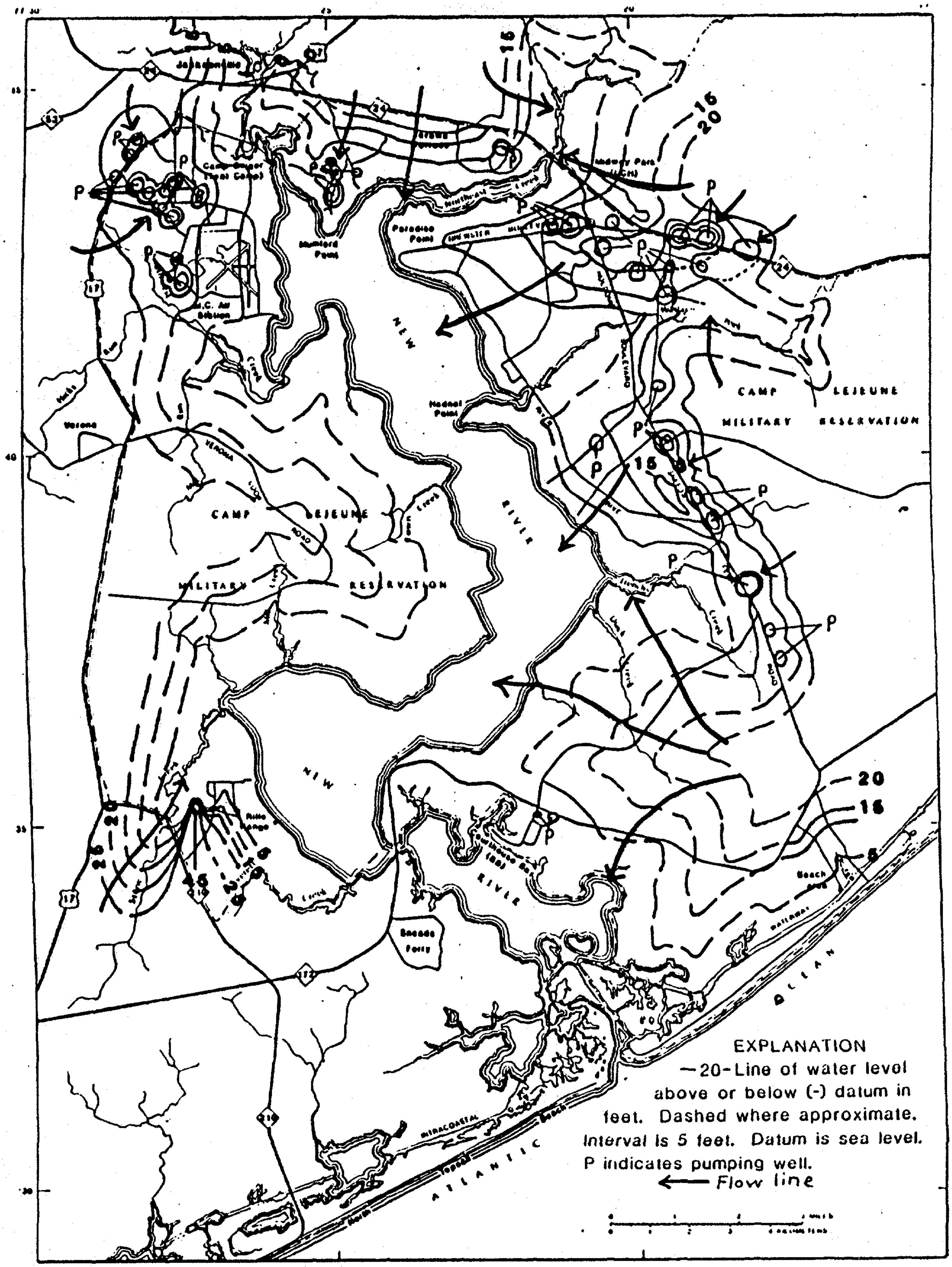
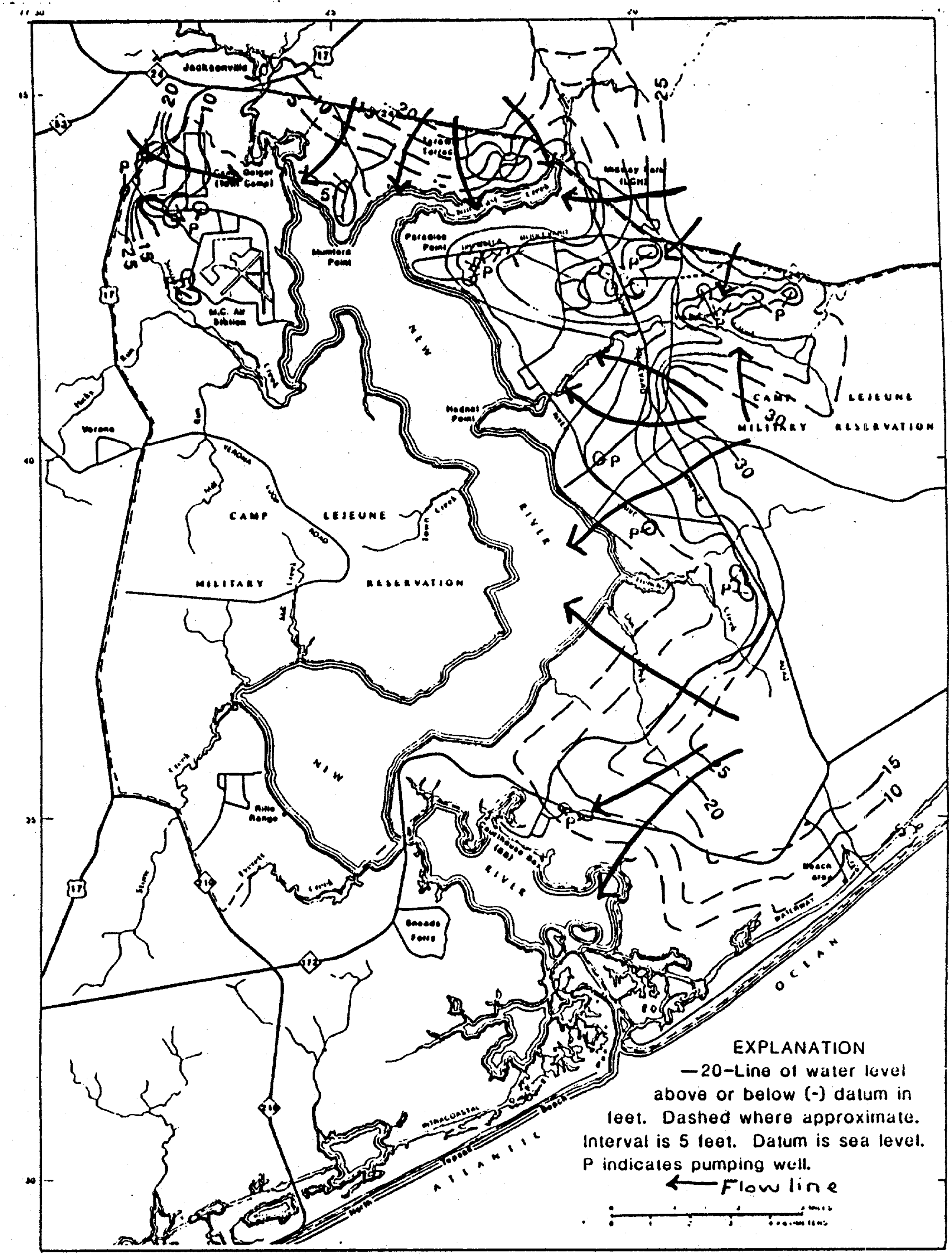


Figure 35. Water levels in the water-supply aquifer for Camp Lejeune, measured from October 20-23, 1986.



EXPLANATION
—20—Line of water level above or below (-) datum in feet. Dashed where approximate. Interval is 5 feet. Datum is sea level.
P indicates pumping well.
←— Flow line

Figure 36. Water levels in the water-supply aquifer for Camp Lejeune, measured from April 4-7, 1987.

Ground-Water Velocity

Ground water moves in the direction of decreasing total head as represented by water level in a well. The rate at which the water moves depends largely on the slope of the underground water surface, called the hydraulic gradient. Hydraulic gradients vary locally, depending on the geohydrology, and the proximity to a pumping well. Hydraulic gradients can be calculated for the Camp Lejeune area using water-level data of the type used to generate the maps of figures 35 and 36. In general, for the Camp Lejeune area the hydraulic gradient for areas unaffected by pumping ranges from 5 to 15 feet per mile. In the cone of depression of pumping wells the hydraulic gradients are much greater ranging from 150 to 200 feet per mile.

Given a measure of hydraulic gradient and of hydraulic conductivity ground-water velocity can be estimated using the following equation:

$$v = \frac{K\,dh}{n\,dl}$$

Where: v = velocity, in feet per day

n = Porosity (estimated to be 0.20 percent for the Castle Hayne by Heath, 1980)

K = hydraulic conductivity, in gallons per day per square foot/ 7.5 (conversion to feet per day), and

dh/dl = hydraulic gradient.

Using the estimates of hydraulic conductivity derived earlier (see Available Data section) and a common range of hydraulic gradients, the ground-water velocity for the Camp Lejeune area is around 2-3 feet per day. Near pumping wells, where the hydraulic gradient is quite steep, the ground water can move at approximately 35-45 feet per day.

HYDROLOGIC BUDGET

Concepts

Application of a numerical ground-water model requires the specification of conditions at the boundaries of the region under study. In this case, boundary conditions are required at land surface, at the lower boundary of the computational domain, and at the lateral boundaries of the study area. The lower boundary is defined in this study by an impermeable formation so that no flow occurs across the boundary. Lateral boundaries which correspond to rivers are defined by a constant hydraulic head. The flow of water across other lateral boundaries will be determined from the results of the RASA study of the North Carolina Coastal Plain (Eimers, USGS, personal commun., 1987). This section describes procedures used to determine the boundary condition at the land surface.

The surface boundary condition describes the recharge to the uppermost aquifer. Under steady state conditions, recharge is equal to the discharge of the aquifer, including discharge to surface streams and pumping. Hence, long-term recharge, and thus the surface boundary condition, may be determined from a hydrologic budget of the system.

A hydrologic budget is a statement of the balance between total water gains and losses in a drainage basin for a given period of time. The hydrologic budget for a basin in which there is no import or export of water may be expressed quantitatively as:

$$RF = Q + ET + \Delta SM + \Delta GW_s$$

where RF = rainfall,

Q = streamflow,

ET = evapotranspiration,

ΔSM = change in soil moisture, and

ΔGW_s = change in ground-water storage.

Streamflow, Q, consists of surface runoff, RO, and ground-water discharge, GW_d, or baseflow. Each of the terms in the above equation may be expressed as a rate or a volume.

In this study, rainfall (RF) and streamflow (Q) are being measured at a representative site within Camp Lejeune (see figure 24). Rainfall data are also available from other nearby rain gages to check for areal variations in rainfall. Evapotranspiration (ET) will be estimated from National Weather Service records at nearby Hofmann Forest. Over the long-term, soil moisture may be assumed to be fairly constant so that $\Delta SM = 0$. Because steady state conditions have been assumed, there is also no long-term change in the amount of water stored in the ground-water system and $\Delta GW_s = 0$. Surface runoff volumes may be delineated from ground-water discharge by applying hydrograph separation techniques to the streamflow record, thus providing an estimate of the surface boundary condition, or recharge, needed for the ground-water model.

Instrumentation

A 0.9 sq mi basin located near the geographic center of the study area was instrumented to obtain measurements of rainfall and streamflow. A photograph of the rain gage, which provides readings of continuous rainfall amounts is shown in figure 37. Streamflow is measured at the site on Town Creek shown in figure 24.

The streamflow measurement station consists of a continuous stage recorder. Discharge measurements will be made at the site to relate stage to flow rate. The weir (figure 38) was installed to provide a stable section for measurement of stage and discharge. Although there were no indications at the site, backwater from culverts located just downstream from the discharge measurement site could affect the quality of information obtained during high flow events.

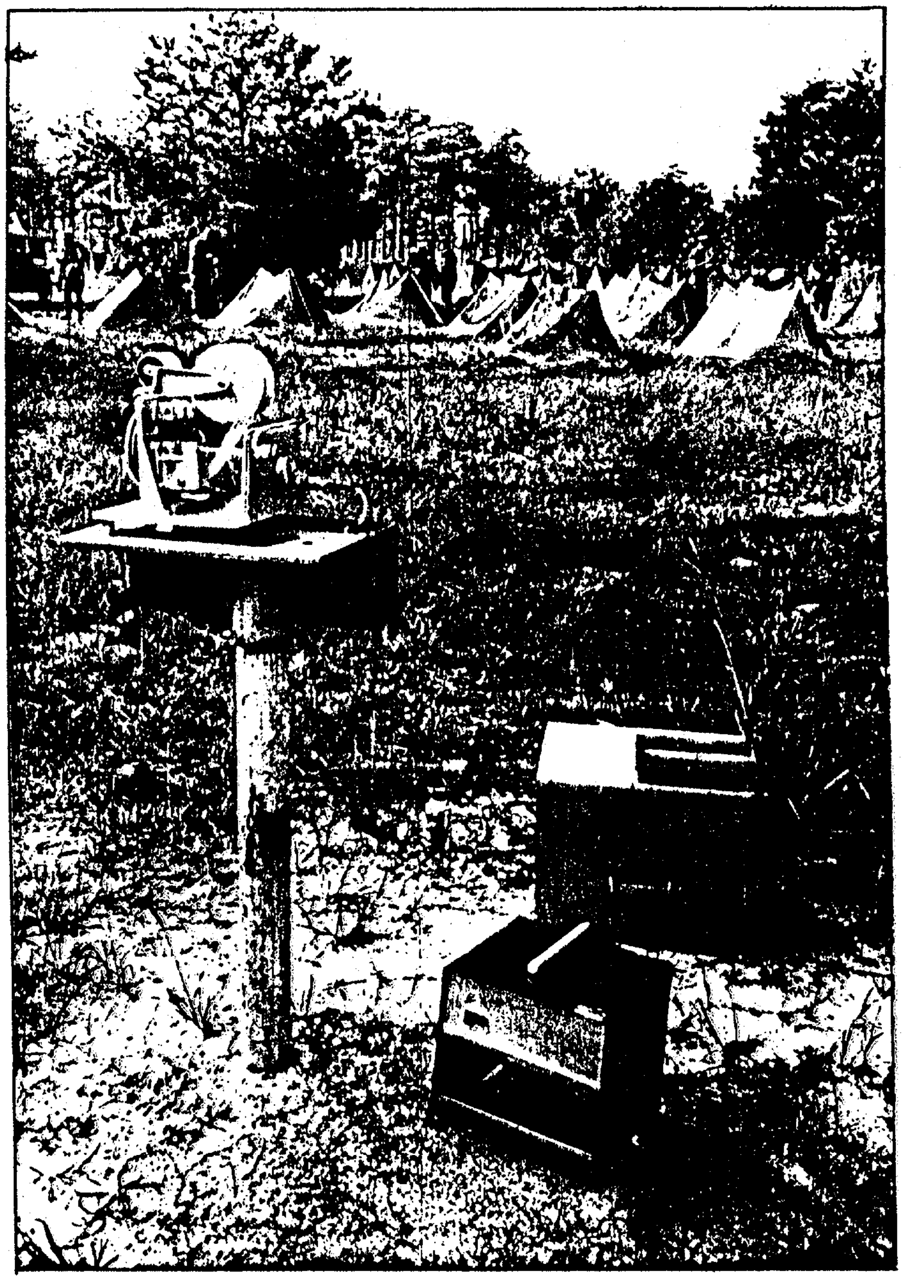


Figure 37. Raingage in the Town Creek basin Camp Lejeune, N.C.

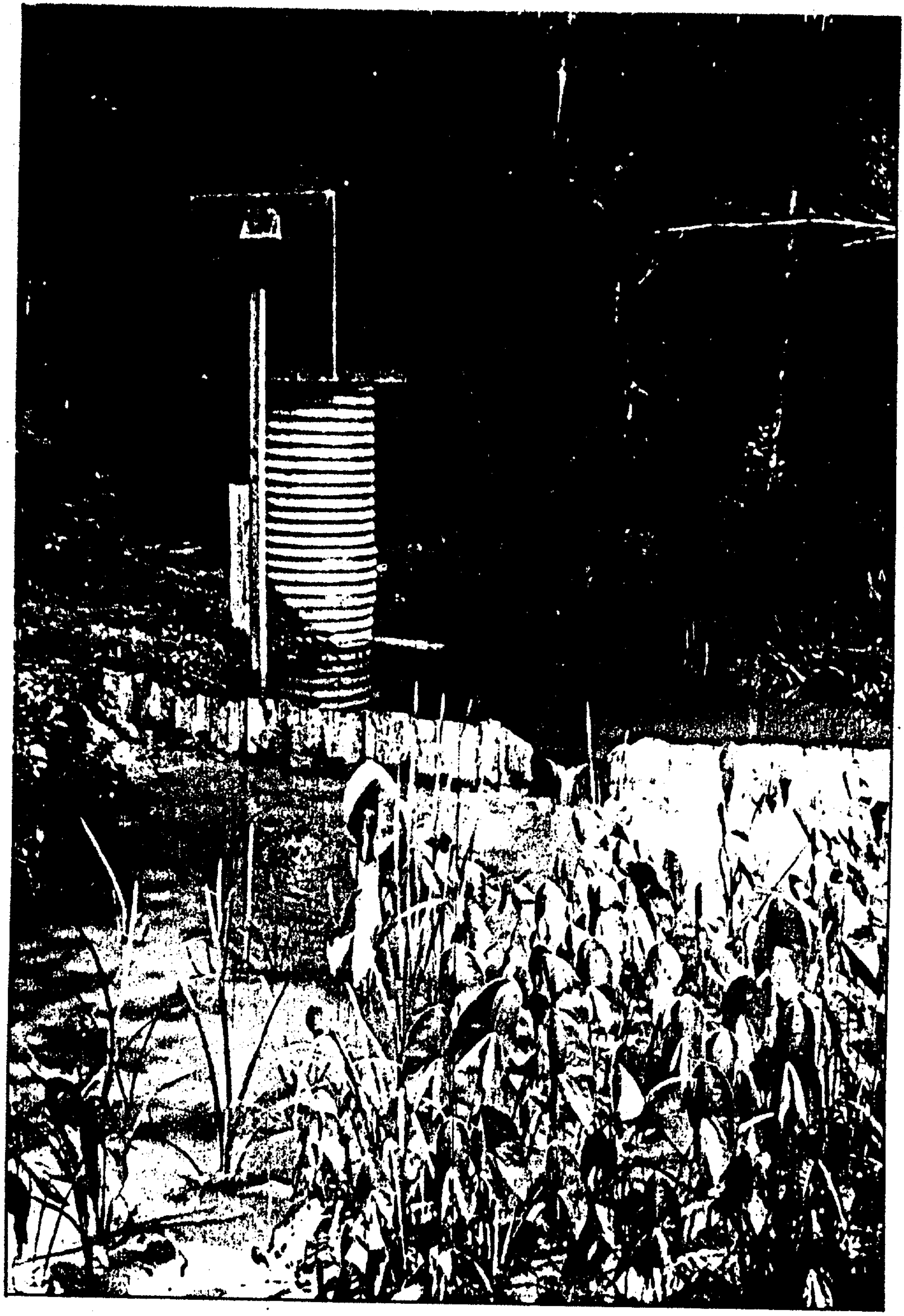


Figure 38. Streamgage on Town Creek, Camp Lejeune, N.C.

SUMMARY

In the first year of a four-year study of the ground-water resources of the Camp Lejeune Marine Corps Base, available data on water use has been reviewed, a preliminary geohydrologic framework has been constructed, a water-level monitoring network has been installed, and water-level surveys have been made. The objective of the overall study is to provide a detailed description of the ground-water resources of the Base that will allow construction of a ground-water flow model, and guide future ground-water development.

This is a three-phased study: the first phase, for which this report is a summary, was the examination of available data; the second phase, which is scheduled to take two years, is the collection of additional data andconstruction of new observation wells; and the third phase and final year of the study is modeling. The principal elements of the study include the construction of a geohydrologic description of the ground-water system, and development of an understanding of the ground-water movement through the geohydrologic framework, measurement of the water-resources budget to obtain an assesment of ground-water recharge, a review of available and collection of new water-quality data, and construction of a ground-water flow model.

Water use by the Base has grown from around 4 million gallons a day in 1941 to around 8 million gallons a day currently. In recent years water demand has not increased substantially, however, the pumping scheme and treatment by the 8 water plants on the Base has changed. Current expansion of the Holcomb Boulevard treatment plant has coincided with the discontinuation of many supply wells in the Hadnot Point system.

The principal water-supply aquifer for the base is the Castle Hayne aquifer which is made up of a series of sand and limestone beds that underlie the area to a depth that ranges from about 200 to 300 feet. The sands and limestone are interbedded with thin clay layers that provide only limited confinement to the deeper zones of the aquifer.

The process of construction of a geohydrologic framework is a four step process: first, existing studies are reviewed, second, well data and geophysical data are compiled and cross sections are constructed using thesedata, third, layers that have regional extent are traced, and fourth, the interpretations from the cross sections are mapped and areas where further data are needed are identified. In this report, the preliminary three steps of the process are underway, and some new data needs have been identified.

Two previous studies by the USGS provide the basic structure for the Camp Lejeune framework. In particular the Central Coastal Plain study (Lyke and Winner, written commun., 1987) which focuses on a 14 county area including Onslow County, provides information about the layers below those used for water supply by the Base.

Data for over 180 well locations were obtained from Camp Lejeune, NRCD, and USGS files. The file data includes well-screen data, water-quality data, well-acceptance test data, and borehole geophysical logs. The screened zones in wells on the base range from 20-150 feet of the total well depth with a mean thickness of 84 feet. Maps of the screened intervals indicate that the water-supply aquifer is probably directly connected to the New River. A specific conductance survey of Base well water made by ESE shows high values indicating probable saltwater contamination in the Marine Corps Air Station area.

Well-acceptance tests indicate a mean specific capacity of 8.8 gallonsper minute per foot of drawdown for all wells tested. Transmissivity values estimated from the specific-capacity values give a mean confined transmissivity of 19,400 gallons per day per foot and a mean unconfined transmissivity of 15,100 gallons per day per foot for the base. Using the total thickness of the screened zone to represent aquifer thickness hydraulic conductivity can be estimated from transmissivity. The mean estimated hydraulic conductivity for the confined case is 2100 gallons per day per square foot, and for the unconfined case is 1600 gallons per day per square foot.

Three cross sections have been drawn as part of the Phase I study using the best available well logs and some new logs run for this study. The sections show that the beds dip gently to the southeast towards the Ocean. Only 15-24 percent of the first 200 to 250 feet of sediment can be readily classified as clay beds. Consequently, the cross sections show that the Castle Hayne Aquifer is only partially confined. It also appears that the Castle Hayne Aquifer connects directly to the bottom of the New River.

In the Air Station area there is evidence from the cross sections and surface linear features, such as the orientation of strem reaches, that there may be a fault paralleling the New River. This evidence suggests the hypothesis that saltwater contamination in the area may be related to breaching of confining layers under the New River. This hypothesis must be tested with further data collection. New observation wells drilled near the shore of the New River in the Air Station area will help identify the source of saltwater contamination. Also, additional wells are proposed to fill data gaps in existing cross sections, and make new sections possible.

The ground-water level monitoring network installed on the Base consists of 6 wells. Three of these wells are shallow; screened in zones down to 70 feet deep. Two of the wells are screened in, and one well is screened below the Castle Hayne aquifer. A seasonal variation in water level is evident in all of the wells. The summer to winter difference ranges from 3 feet in the shallow wells down to 1-2 feet in the deeper wells. The reduced seasonal effect is an indication of greater confinement at depth. Water-level variation due to pumpage is also evident in two of the wells.

Water level surveys of the Base water-supply aquifer were run during October 19-25, 1986, and during April 7-10, 1987. The October survey provided a measure of water levels during a period when one would expect low water levels, and the April survey provided data for a period when high water levels would be expected. Contour maps of the water levels for each survey show that the regional water-level contours tend to follow surface topography. The regional flow of ground water is towards surface streams and the New River. Pumping centers are relatively small in areal extent to the point that there seems to be little interference by one well on another.

The general areal hydraulic gradient outside of areas affected by pumping is 5-15 feet per mile. The hydraulic gradient is quite steep near pumping wells, averaging 150-200 feet per mile. Using the estimates of hydraulic conductivity and a common range of hydraulic gradients the hydraulic velocity outside of areas affected by pumping is calculated to range from 2-3 feet per day. Near pumping wells the hydraulic velocity is more on the order of 35-45 feet per day.

An assessment of the hydrologic budget, to allow an estimate of groundwater recharge, is required for the model of the system. A small basin located near the geographic center of the Base was instrumented with a streamgage and a raingage. The groundwater component of streamflow measured at this station will be calculated, providing an estimate of ground-water recharge.

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GEOLOGICAL SURVEY
Water Resources Division
P.O. Box 2857
Raleigh, NC 27602

May 7, 1987

Mr. Robert E. Alexander
Environmental Engineer, Facilities
United States Marine Corps
Marine Corps Base
Camp Lejeune, North Carolina 28542-5001

Dear Bob,

Enclosed is a draft copy of the Phase I report. This version of the report will now be submitted to USGS review, which will include an outside review by Rick Shiver. I expect the review process to take 3-6 months. When the report is then prepared for final publication, the illustrations will be redrafted in publication format, and the maps will probably be reproduced at a larger size.

I hope to hear from you soon about Phase II plans. Until then, it is still full speed ahead.

Sincerely,

Doug

Douglas A. Harned
Hydrologist

Enclosure

DAH/kh