HYDROGEOLOGIC FRAMEWORK OF U.S. MARINE CORPS BASE AT CAMP LEJEUNE, NORTH CAROLINA

By Alex P. Cardinell, Steven A. Berg, and Orville B. Lloyd, Jr.

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 93-4049

Prepared in cooperation with the

DEPARTMENT OF THE NAVY, U.S. MARINE CORPS

Raleigh, North Carolina

1993

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

For additional information,
write to:

District Chief
U.S. Geological Survey
3916 Sunset Ridge Road
Raleigh, North Carolina 27607

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED UNITS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
	Volume	
gallon (gal)	3.785	liter
million gallons (Mgal)	3,785	cubic meter
	Flow	
inch per hour (in/hr)	0.1094	meter per second
foot per second (ft/s)	0.3048	meter per second
foot per day (ft/d)	0.3048	meter per day
million gallons per day (Mgal/d)	0.04381	cubic meter per second
	Transmissivity	
cubic foot per day per square foot times foot of aquifer thickness $[(ft^3/d)/ft^2]ft$	0.0929	cubic meter per day per square meter times meter of aquifer thickness

***Sea level*:** In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviations used in this report:

ft/mi, foot per mile
in/yr, inch per year
mg/L, milligram per liter

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ABSTRACT

The hydrogeologic framework at Camp Lejeune consists of the surficial, Castle Hayne, Beaufort, and Peedee aquifers and intervening confining units. The Castle Hayne aquifer furnishes about 7 million gallons of water per day to Camp Lejeune, but the surficial, Beaufort, and Peedee aquifers, which contain freshwater in places, are not used for supply.

The Castle Hayne aquifer is composed of 60 to 90 percent sand and limestone with clay and silt beds, and ranges from 156 to 400 feet thick. Hydraulic conductivity of the aquifer ranges from 14 to 91 feet per day.

The Castle Hayne confining unit, which overlies the Castle Hayne aquifer, is composed of silt and sandy clay and averages 9 feet thick where present. This confining unit is incised by the New River and its tributaries, as well as some paleochannels.

The effects of pumping from the Castle Hayne aquifer have not significantly affected natural head gradients in the aquifer. However, the potential exists for lateral migration of saltwater where wells are located near streams or paleochannels that have incised the confining unit.

Except for one measurement of 960 milligrams per liter chloride in a water sample from the bottom of the Castle Hayne aquifer, dissolved-chloride concentrations in water samples from the Castle Hayne aquifer were less than 120 milligrams per liter. It is not known whether this occurrence of saltwater in the Castle Hayne aquifer is widespread or localized, but its presence indicates a potential for upward movement of saltwater beneath pumped wells.

INTRODUCTION

Camp Lejeune is a U.S. Marine Corps Base adjacent to and southeast of Jacksonville in Onslow County, North Carolina (fig. 1). It covers an approximate area of 164 mi^2, with almost 11 mi of its eastern boundary along the Atlantic Ocean. Camp Lejeune serves as a major Marine Corps training base for a number of missions, including amphibious warfare training. In 1988, Camp Lejeune had a population of more than 68,000 people, which included military personnel, dependents, and civilian workers.

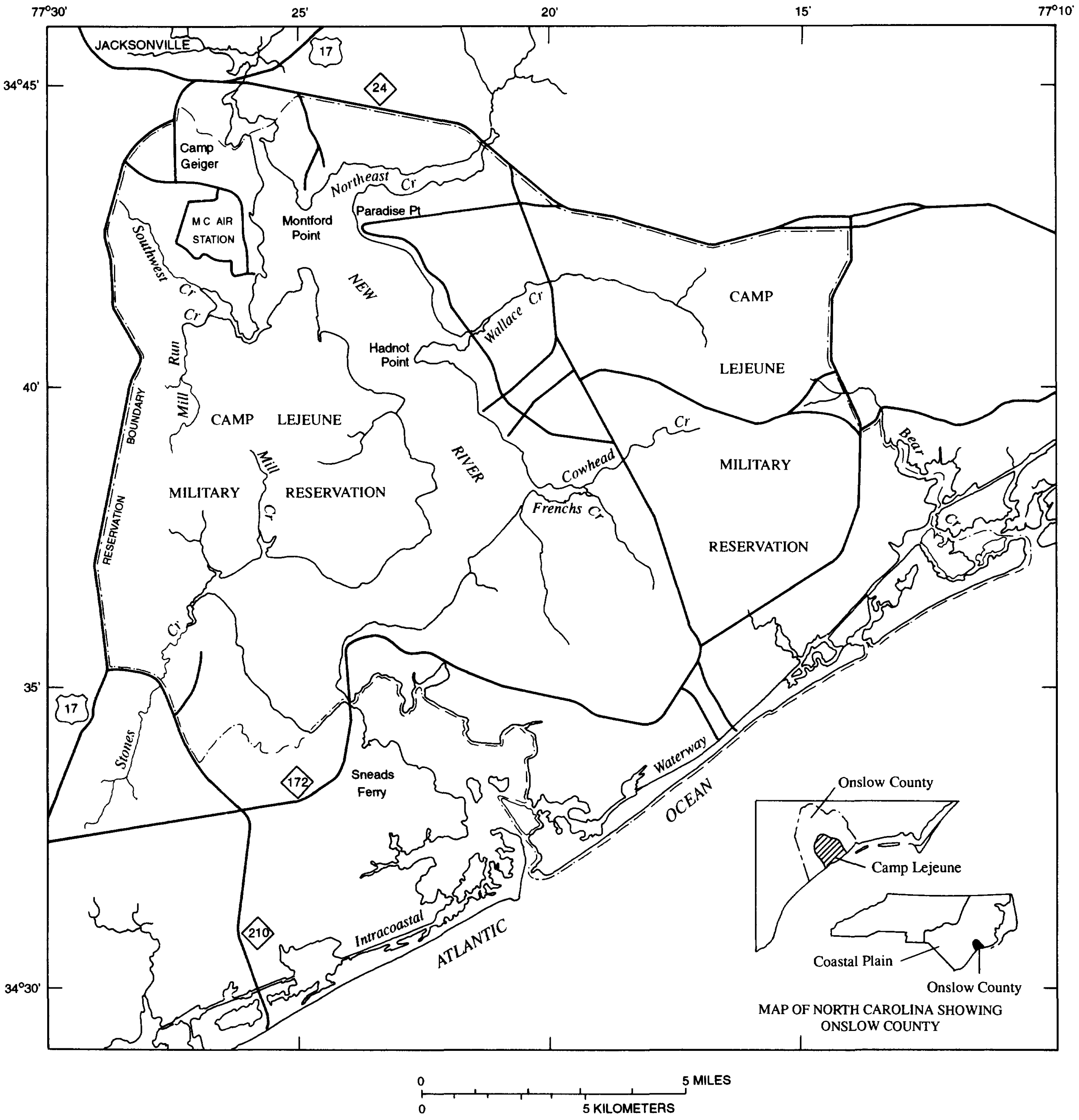


Figure 1.--Location of Camp Lejeune Marine Corps Base, North Carolina.

The Castle Hayne aquifer has supplied all of the freshwater to Camp Lejeune for its drinking water needs for 50 years. More than 100 water-supply wells have been constructed to accommodate the needs of increasing military and civilian populations. Ground-water withdrawals in this area have been among the largest in the State and in 1986 totaled about 7 Mgal/d (Harned and others, 1989).

Increasing growth in the population at Camp Lejeune is resulting in an increasing demand for water supply, but there is concern that large ground-water withdrawals from wells near the tidal reaches of the New River and its tributaries may cause saltwater to move laterally through shallow aquifers toward the Camp Lejeune water-supply wells. Pumping large amounts of ground water from wells open to the deeper aquifers could also cause vertical saltwater movement toward pumping wells from saltwater-bearing parts of these deeper aquifers.

Hazardous and toxic compounds are routinely used at Camp Lejeune, and in the past some of these compounds have been either dumped or spilled in various places on the Base. Because the Base is underlain by permeable surficial sediments, toxic compounds from these dump and spill sites have contaminated parts of the ground-water system (Putnam, 1983).

Camp Lejeune officials are concerned about contamination of ground-water supplies by wastes and saltwater, and need hydrologic information to determine the best management practices to accommodate increased development of ground-water resources and to protect the resource from contamination. To address this concern, in 1986 the U.S. Geological Survey, in cooperation with the U.S. Marine Corps, began a study of the hydrogeology of the Base. This investigation is the second of three planned phases of study to provide this information.

Purpose and Scope

This report describes the aquifers and confining units that constitute the hydrogeologic framework of the Camp Lejeune area and identifies conditions that might lead to surface and subsurface saltwater contamination of freshwater-bearing aquifers. Special emphasis is placed on the Castle Hayne aquifer, the major freshwater supply source for the Base.

From 1987 to 1989, geological, geophysical, and hydrologic data were collected and integrated with existing data from more than 180 wells. Nine test wells were constructed to obtain stratigraphic, lithologic, and hydrologic data. Borehole geophysical logs, driller's logs, and drill cuttings were examined, interpreted, and correlated to establish the lithology and stratigraphy of the freshwater-bearing aquifers and confining units.

Hydrogeologic sections and maps of the thickness and altitude of the tops of the aquifers were constructed to provide the basis for correlation and interpretation of the data. These define the framework consisting of the surficial, Castle Hayne, Beaufort, and Peedee aquifers and intervening confining units.

A seismic-reflection survey was conducted throughout the New River estuary and in a segment of the Intracoastal Waterway that passes through the study area. These data were used to determine the continuity of the hydrogeologic units beneath the estuary.

Water-level data were collected from research station wells of the North Carolina Department of Environment, Health, and Natural Resources (DEHNR), formerly known as the North Carolina Department of Natural Resources and Community Development (NRCD); from shallow wells constructed adjacent to U.S. Geological Survey (USGS) observation wells screened in the Castle Hayne aquifer; from other shallow observation wells; and from other deep observation and water-supply wells. These data were used to determine the distribution of hydraulic heads in the surficial, Castle Hayne, and deeper aquifers beneath Camp Lejeune, and to identify the degree of hydraulic separation of these aquifers.

Dissolved-chloride concentrations in ground water were used to determine the presence of saltwater in the aquifers. These data were either collected for this investigation or taken from earlier investigations.

Previous Investigations

LeGrand (1959) outlined production zones within the Castle Hayne aquifer at Camp Lejeune from test-well data. The North Carolina Department of Natural Resources and Community Development (1979) conducted a study of the ground-water quality on the northwestern boundary of Camp Lejeune. Harned and others (1989) made a preliminary assessment of the hydrogeologic setting at Camp Lejeune with emphasis on the Castle Hayne aquifer. Cardinell and others (1990) presented the results of a seismic-reflection profiling survey defining the continuity of hydrogeologic units beneath the New River and Intracoastal Waterway at Camp Lejeune.

The first regional study that included the Camp Lejeune area was by LeGrand (1960), who described the geology and ground water of Onslow County and eight other counties in southeastern North Carolina. LeGrand (1964) also outlined a hydrogeologic classification of the Coastal Plain based on concepts of ground-water recharge and discharge conditions. More recent regional studies include an investigation of the entire North Carolina Coastal Plain (Winner and Coble, 1989) and an investigation that focused on 14 counties in the Coastal Plain, including Onslow County (Winner and Lyke, 1986). None of these studies, however, presented a detailed hydrogeologic framework of the Castle Hayne and associated aquifers in the Onslow County-Camp Lejeune area.

The geologic character and depositional extent of the various geologic formations that compose the North Carolina Coastal Plain sediments are included in various regional geologic studies, such as Brown and others (1972), Dennison and Wheeler (1975), and Mixon and Pilkey (1976). Otte (1986) presented the depositional environment and extent of the Castle Hayne Formation in the Coastal Plain. Harris and others (1979) and Zullo and Harris (1979) discussed tectonic effects on Coastal Plain sediments near the study area.

Acknowledgments

Robert E. Alexander, the Environmental Engineer with Base Facilities at Camp Lejeune when this study began, served as principal liaison between the Marine Corps staff at Camp Lejeune and the U.S. Geological Survey. Thanks are extended to Stanley Miller of the Camp Lejeune Water Plants Department for his help in coordinating aquifer tests on the Base, and to Marine Corps Major Martin D. Hargas and George Turner of Base Operations for their help during the stratigraphic test-well drilling program. John G. Nickerson of the North Carolina Geological Survey helped construct several hydrogeologic sections.

HYDROGEOLOGIC SETTING

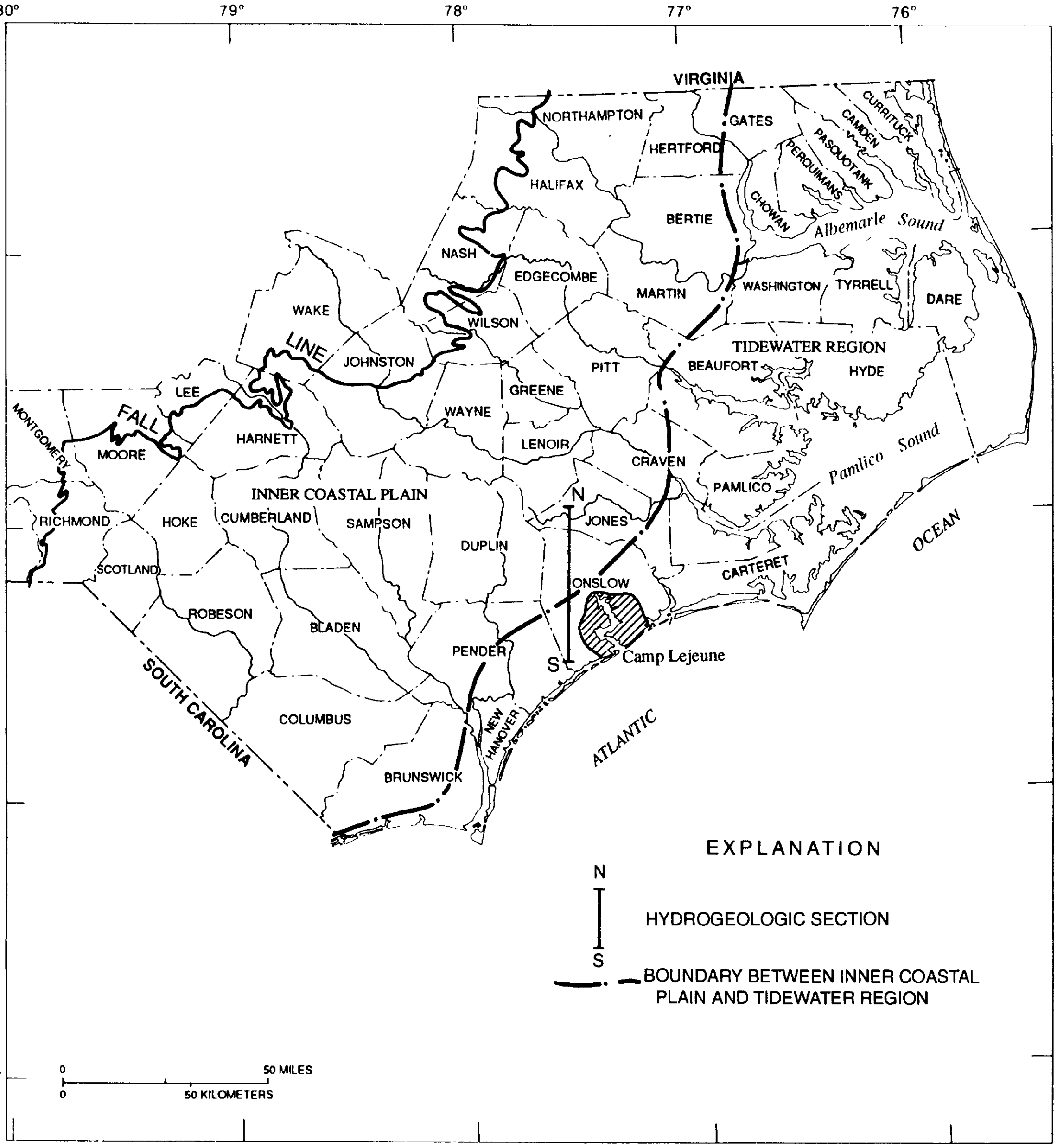
Camp Lejeune is in the Tidewater region of the Coastal Plain physiographic province (Stuckey, 1965), which contains a variety of coastal environments. The Tidewater region (fig. 2) is generally of low relief and swampy, with land surface altitudes ranging from sea level to 50 ft and averaging about 20 ft. Altitudes exceed 50 ft in only a few locations at Camp Lejeune. New River (fig. 1), a tidal estuary, bisects the Base and covers about 20 percent of the Base area. This saltwater estuary is shallow, with depths varying from 2 to 5 ft in most places.

The Camp Lejeune study area is located on an eastward-thickening wedge of sediment that consists of interbedded sands, silts, clays, calcareous clays, shell beds, sandstone, and limestone that were deposited in marine or near-shore environments (LeGrand, 1959; Winner and Coble, 1989). These sediments occur as layered, interfingering beds and lenses that dip and thicken southeastward from zero at the western boundary of the Coastal Plain Province (Fall Line, fig. 2) to more than 10,000 ft at the coast (Winner and Coble, 1989).

Ten aquifers consisting of permeable sand or limestone beds have been identified in the Coastal Plain of North Carolina by Winner and Coble (1989) and are shown in figure 3. These aquifers are separated by less permeable beds of clay and silt called confining units. In the Camp Lejeune area, seven of these aquifers and their associated confining units are present in the approximately 1,500-ft thick sedimentary sequence that overlies crystalline basement rocks (fig. 2). These aquifers are, from top to bottom, the surficial, Castle Hayne, Beaufort, Peedee, Black Creek, and upper and lower Cape Fear aquifers.

Recharge to the Coastal Plain aquifers occurs in interstream areas. Estimates of recharge to these aquifers range between 5 and 21 in. of rainfall yearly (Heath, 1980). Heath (1975) estimated recharge to the surficial, Yorktown, and Castle Hayne aquifers in the Albemarle-Pamlico Sound area was 0.5 inch per year (in/yr). Winner and Simmons (1977) estimated recharge to the Castle Hayne aquifer in Beaufort, Craven, and Pitt Counties to be about 0.8 in/yr.

Most ground water is naturally discharged from the Coastal Plain aquifer system by seepage into streams, swamps, and lakes. It is also discharged by evapotranspiration from the soil zone and by upward leakage through confining units to stream valleys, estuaries, and the ocean. Manmade ground-water discharge occurs when wells are pumped. Under



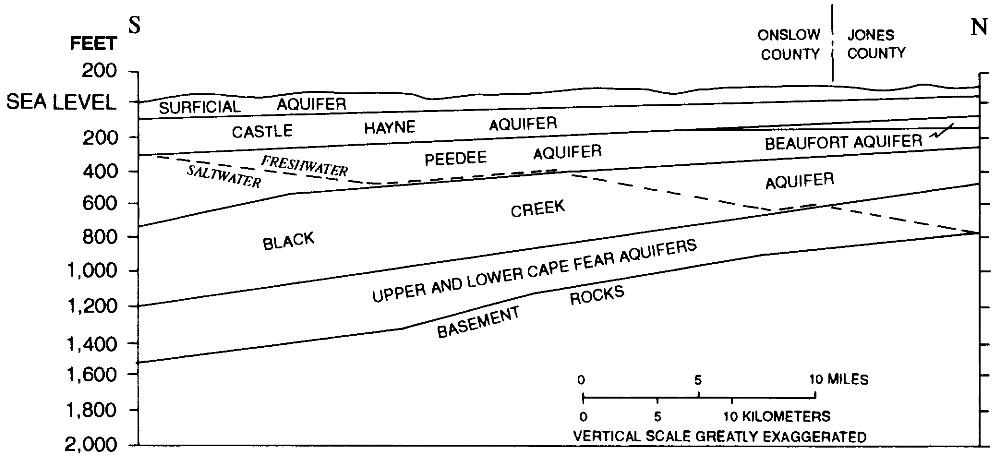


Figure 2.--Coastal Plain subdivisions and hydrogeologic section showing aquifers in Onslow County, North Carolina (modified from Harned and others, 1989).

GEOLOGIC UNITS			HYDROGEOLOGIC UNITS
SYSTEM	SERIES	FORMATION	AQUIFER AND CONFINING UNIT
Quaternary	Holocene Pleistocene	Undifferentiated	Surficial aquifer
Tertiary	Pliocene	Yorktown Formation [1]	Yorktown confining unit [1]
			Yorktown aquifer [1]
	Miocene	Eastover Formation [1]	Pungo River confining unit [1]
		Pungo River Formation [1]	Pungo River aquifer [1]
		Belgrade Formation [2]	Castle Hayne confining unit
	Oligocene	River Bend Formation	Castle Hayne aquifer
	Eocene	Castle Hayne Formation	Beaufort confining unit [3]
	Paleocene	Beaufort Formation	Beaufort aquifer
			Peedee confining unit
Cretaceous	Upper Cretaceous	Peedee Formation	Peedee aquifer
			Black Creek confining unit
		Black Creek and Middendorf Formations	Black Creek aquifer
			Upper Cape Fear confining unit
		Cape Fear Formation	Upper Cape Fear aquifer
			Lower Cape Fear confining unit
			Lower Cape Fear aquifer
	Lower Cretaceous	Unnamed deposits [1]	Lower Cretaceous confining unit [1]
			Lower Cretaceous aquifer [1]
Pre-Cretaceous basement rocks			

[1] Unit not identified at Camp Lejeune.
[2] Constitutes part of surficial aquifer and Castle Hayne confining unit at Camp Lejeune.
[3] Estimated to be restricted to deposits of Paleocene age at Camp Lejeune.

Figure 3.--Generalized relation between geologic and hydrogeologic units in the Coastal Plain of North Carolina (from Winner and Coble, 1989).

nonstressed (nonpumping) conditions, the amount of discharge from the aquifer system equals the recharge to it, and the amount discharged from shallow and deep aquifers is in proportion to their recharge. The bulk of ground-water discharge, other than that lost to evapotranspiration, provides the base flow of perennial streams. Within the Camp Lejeune area, a potentiometric-surface map of the Castle Hayne aquifer indicates the New River estuary is a principal area of ground-water discharge (Harned and others, 1989).

DELINEATION OF HYDROGEOLOGIC UNITS

Hydrogeologic units in the study area were delineated using geophysical methods (borehole geophysical logging and seismic-reflection profiling) and hydrologic and geochemical methods (measurement of water levels and delineation of saltwater distribution). The hydrogeologic units included in this study are the surficial aquifer, the Castle Hayne aquifer, the Beaufort aquifer, and the Peedee aquifer (fig. 3), which are the principal freshwater-bearing units in the study area.

Borehole Geophysical Logging

Borehole geophysical data included single-point resistance, spontaneous potential, and gamma-ray logs. Focused resistivity logs (long and short normal) were also used where they were available. One or more of these geophysical logs was available for interpretation at 109 wells or test holes at Camp Lejeune. Correlations of beds were made between wells as far as 10 mi.

Electrically resistive zones within the freshwater sections are generally identified as the more permeable sand or limestone units; where these units are areally extensive, they constitute aquifers. Less permeable beds are generally less resistive electrically and are identified as clay, silt, or indurated beds. Where these less resistive units are areally extensive, they may be considered as confining units. Sand or limestone beds that contain saltwater will also show a less resistive log signature and must be identified in conjunction with other log data.

Spontaneous potential logs measure a small voltage potential created at the boundary between beds of dissimilar rocks such as clay and sand. Potential signals are strongest where there is a sharp contrast in rock type at a bed boundary. These logs are best used to interpret the contact between beds.

Gamma-ray logs measure the natural radioactivity of the sediments. Higher radiation levels occur in clay and silt beds and in some beds containing certain phosphate minerals. These logs help distinguish between aquifers and confining units, and can also be used to trace marker beds containing phosphate minerals.

Variable drilling-mud characteristics, nonuniform hole conditions, and the use of different logging equipment or data scales resulted in variable geophysical log signatures. It was necessary at times to use lithologic logs and to examine well cuttings to help identify the sequence of beds between wells (fig. 4).

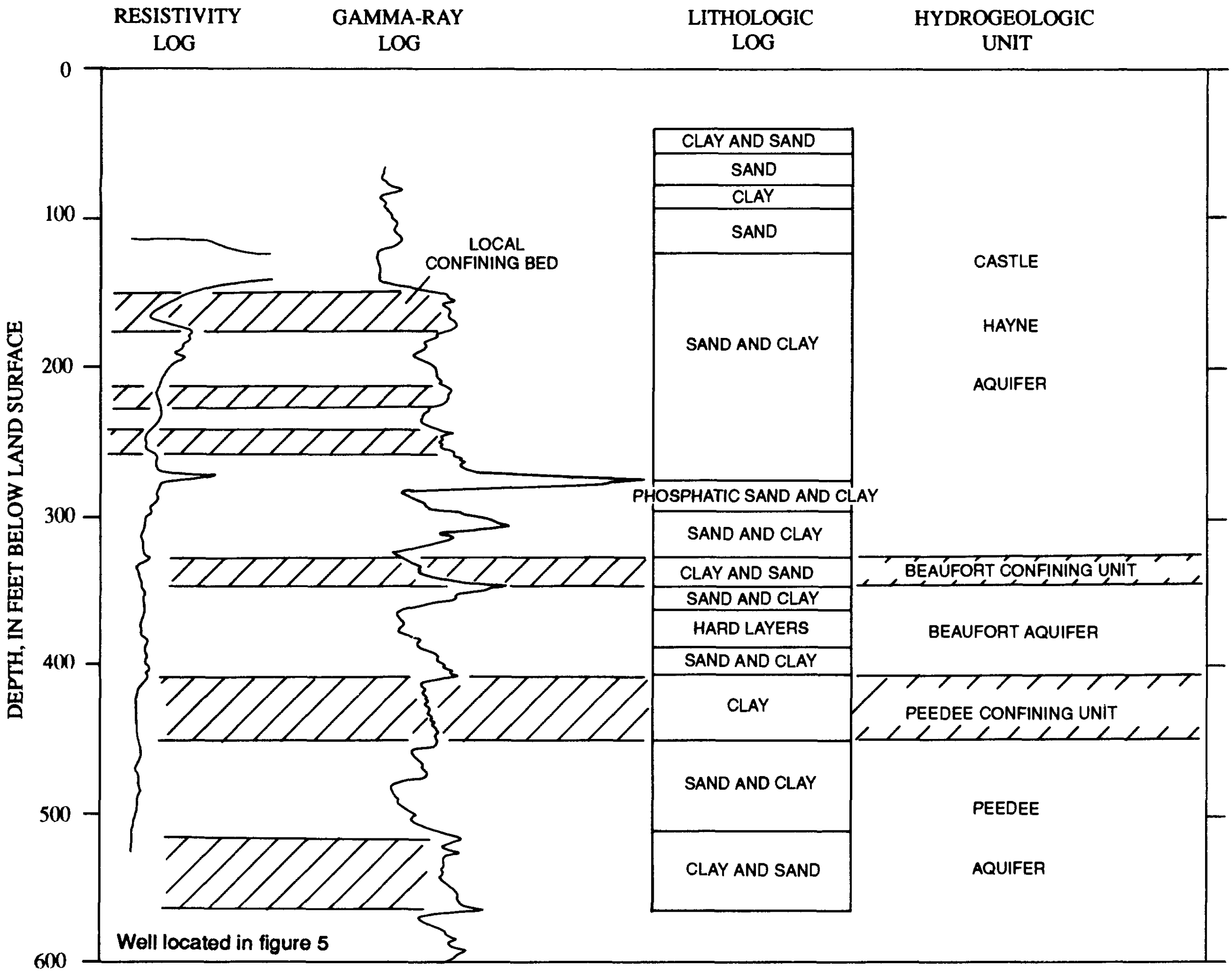


Figure 4.--Correlation of geophysical logs and lithologic log of well X24s2x at Hadnot Point, Camp Lejeune.

Seismic-Reflection Profiling

Borehole geophysical data were not available in the New River estuary, which includes about 20 percent of Camp Lejeune. However, seismic-reflection data were collected throughout this water body to establish the continuity of hydrogeologic units across the estuary. Data were collected for more than 100 mi of seismic profile lines across and along the New River estuary and along parts of the Intracoastal Waterway (fig. 5).

Acoustic penetration recorded by a seismic-reflection profile is measured in time units and can be correlated with borehole geophysical logs using a time-to-depth conversion. This conversion was accomplished with an acoustic-velocity log collected from well X24s2x at the

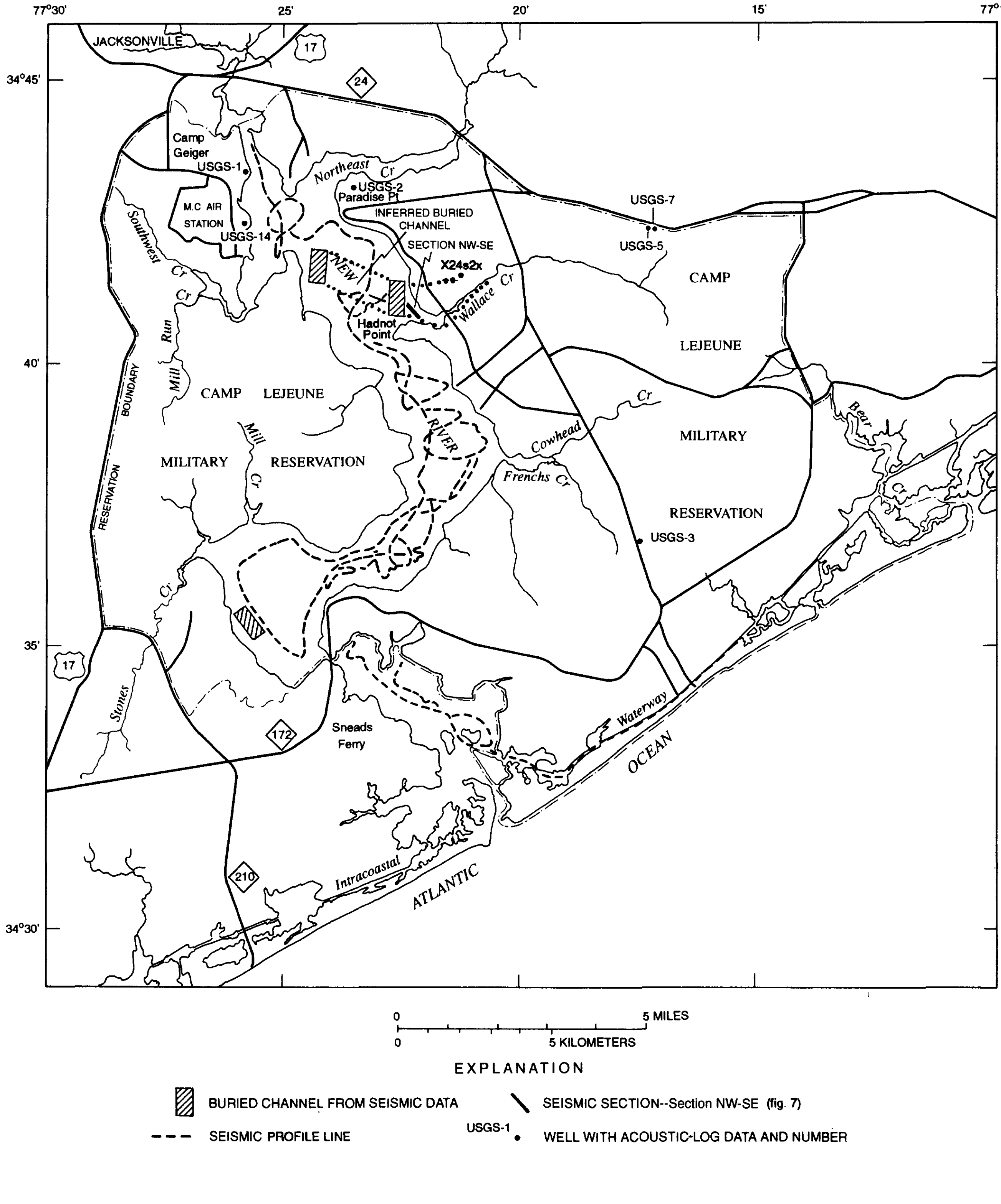


Figure 5.--Location of seismic profile lines, wells with acoustic-velocity logs, and buried channels.

Hadnot Point Research Station (fig. 6). Details of the correlation method are described in Cardinell and others (1990). An average sediment acoustic-velocity estimate of 6,000 ft/s, which closely matches the velocity curve for well X24s2x (fig. 6), was selected to convert the seismic travel time to depth in feet, and the seismic data were correlated with the borehole geophysical data. Within the study area, the seismic data also revealed the presence of buried and stacked paleostream channels within the Castle Hayne aquifer (fig. 7).

Water-Level Analysis

Water-level data were collected from the NRCD research station wells, from shallow (10-40 ft deep) wells throughout the study area, from observation wells screened in the upper part of the Castle Hayne aquifer that were placed adjacent to USGS stratigraphic tests (table 1), and from deeper wells screened in the Castle Hayne and other aquifers. Analyses of water-level data were based largely on data collected by Harned and others (1989) and supplemented by data collected during this investigation. Water-level data were used to assess the degree of hydraulic connection between aquifers, as well as hydraulic continuity within aquifers.

Saltwater Distribution

For purposes of this report, saltwater is defined as water containing a concentration of 250 milligrams per liter (mg/L), or more, of dissolved chloride. Dissolved-chloride concentrations in ground water were used to determine the distribution of saltwater in the surficial, Castle Hayne, and Beaufort aquifers, and to develop estimates of the depth to water with chloride concentrations of 250 mg/L or greater.

The chloride data base (table 2) consists of dissolved-chloride concentrations (1) in water from supply wells sampled by Base personnel during the last 30 years, (2) in water from NRCD research station wells, (3) in water from selected Base supply wells sampled by USGS personnel in 1987, and (4) in water from USGS observation wells (table 1). Because most wells at Camp Lejeune are not deeper than 200 ft and not deep enough to reach the saltwater-freshwater interface, data from Winner and Coble (1989) were used to estimate the position of the saltwater-freshwater interface in the deeper parts of the aquifer system.

HYDROGEOLOGIC FRAMEWORK OF CAMP LEJEUNE

This section contains descriptions of the lithology of the surficial, Castle Hayne, Beaufort, and Peedee aquifers, their areal extents, distribution of permeable material within each unit, properties of overlying confining units, relations with adjacent aquifers, and occurrence of saltwater. Well data from more than 180 wells were evaluated, and data from 81 wells were selected to construct hydrogeologic sections and maps of the aquifers and confining units to define the hydrogeologic framework of the Camp Lejeune study area. Locations of selected wells are shown in figure 8, and data from the wells are provided in table 3.

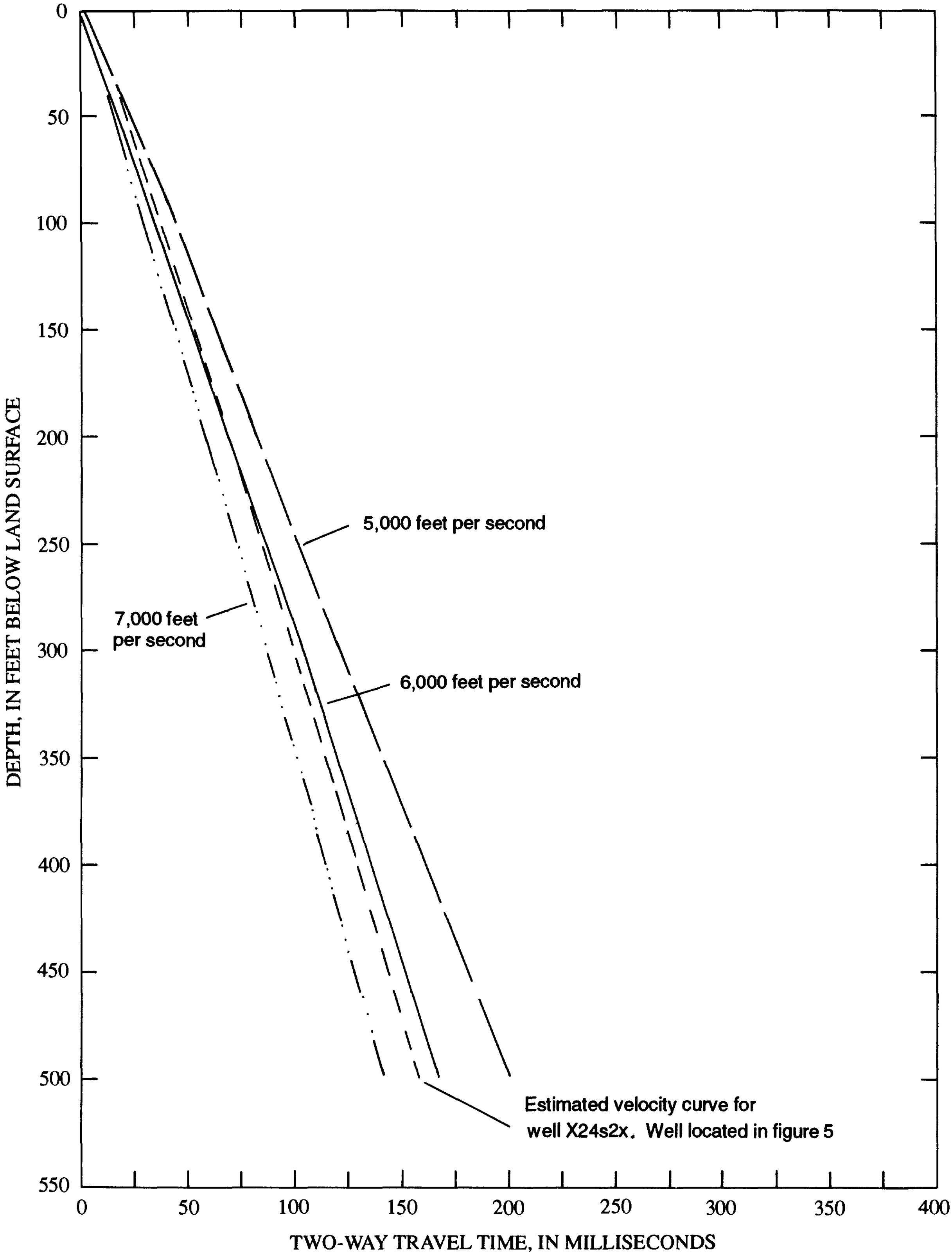


Figure 6.--Average acoustic-velocity curve for sediment at well X24s2x, Camp Lejeune, North Carolina (modified from Cardinell and others, 1990).

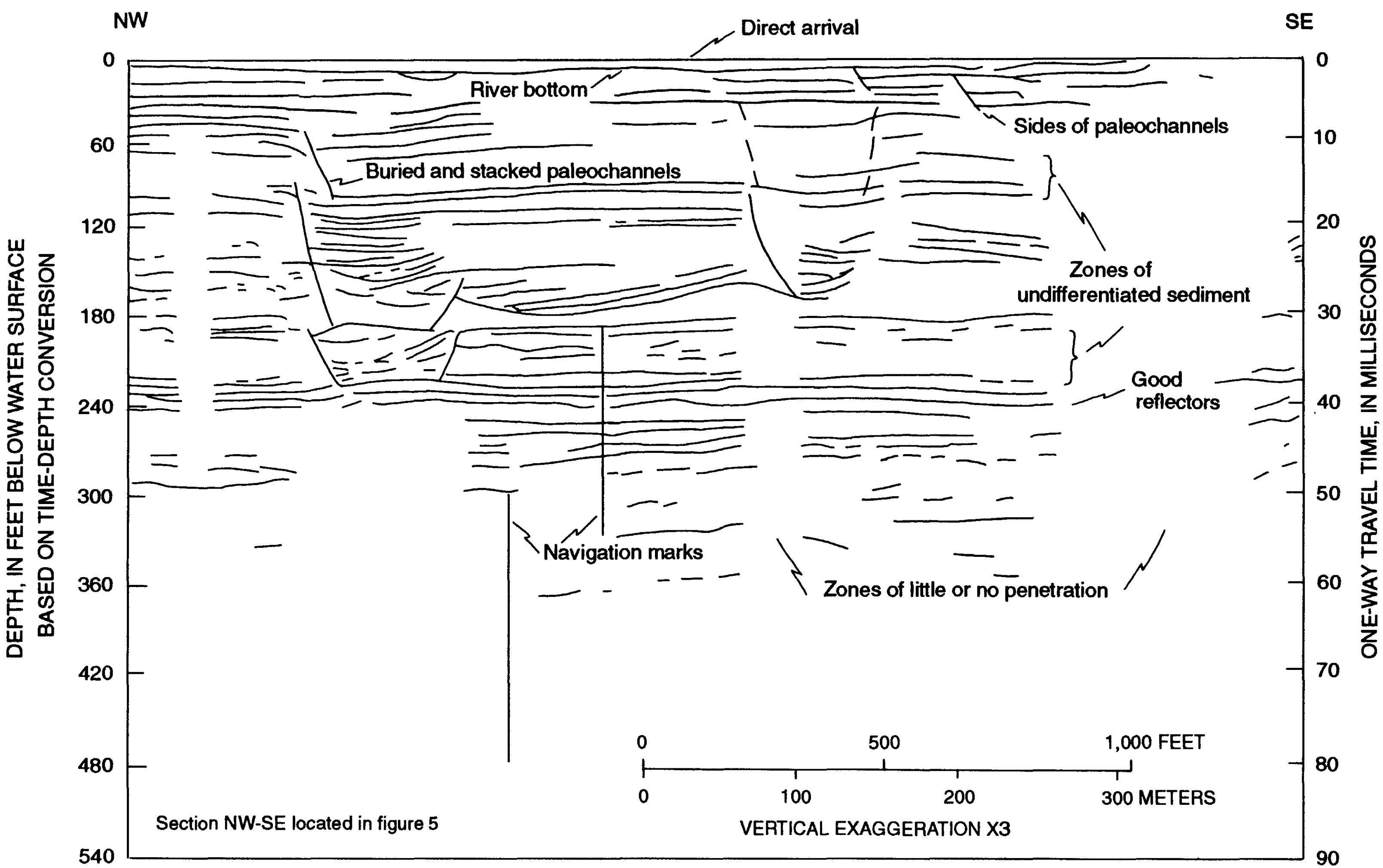


Figure 7.--Interpretation of seismic-reflection section NW-SE showing buried channels in the Castle Hayne aquifer near Hadnot Point at Camp Lejeune, North Carolina (modified from Cardinell and Berg, 1992).

Table 1.--*Data from U.S. Geological Survey stratigraphic tests and observation wells at Camp Lejeune, North Carolina*

[USGS, U.S. Geological Survey; ft, foot; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, no data; mg/L, milligram per liter]

Well number (fig. 8)	USGS identification number	Date drilled	Well depth (ft below land surface)	Screened interval (ft below land surface)	Altitude of land surface (ft)	Depth to water (ft)	Date of water-level measurement	Log data: Lithologic log depth (ft below surface)	Log data: Geophysical log depth (ft below surface)	Specific conductance (µS/cm) and date	Remarks
USGS-1	3443180772548	3-10-88	203	188-198	5	--	--	208	Caliper, electric, acoustic velocity-208; gamma, neutron-140	--	Sand in casing from 95 to 203 ft below land surface; well not used to measure water levels.
USGS-2	3443040772329	3-12-88	219	209-219	17	8.86	3-08-89	236	Gamma, electric, caliper, density acoustic velocity, neutron, gamma-232	1,030 on 3-1-89	None.
USGS-3	3436090771713	3-17-88	239	211-221	14	11.62	3-10-89	253	Electric, acoustic velocity, density-253; gamma, neutron-225	298 on 3-1-89	None.
USGS-4	3440370772519	3-07-88	204	142-152	28	16.63	3-02-89	232	Electric, gamma-232	802 on 3-2-89	Dissolved sodium, 110 mg/L; dissolved chloride, 120 mg/L. Sampled 3-2-89.
USGS-5	3442300771722	9-10-88	132.5	122.5-132.5	42.5	12.38	11-14-88	175	Electric, gamma-175; acoustic velocity-170	--	None.
USGS-6	3442030771820	3-16-88	220	210-220	33	15.78	3-08-89	253	Caliper, gamma, neutron-252	455 on 3-1-89	Dissolved chloride, 8.2 mg/L; dissolved sodium, 200 mg/L; alkalinity, 233 mg/L. Sampled 3-1-89.

Table 1.--*Data from U.S. Geological Survey stratigraphic tests and observation wells at Camp Lejeune, North Carolina*--**Continued**

[USGS, U.S. Geological Survey; ft, foot; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, no data; mg/L, milligram per liter]

								Log data			
Well number (fig. 8)	USGS identification number	Date drilled	Well depth (ft below land surface)	Screened interval (ft below land surface)	Altitude of land surface (ft)	Depth to water (ft)	Date of water-level measurement	Lithologic log depth (ft below surface)	Geophysical log depth (ft below surface)	Specific conductance (µS/cm) and date	Remarks
USGS-7	3442290771721	9-12-88	133.5	122.5-133.5	43.5	13.36	11-14-88	177	Electric-176; gamma-172; acoustic velocity-174	381 on 3-3-89	None.
USGS-8	3435200772406	9-08-88	212	202-212	26	23.25	3-07-89	238	Electric-110; gamma-233	3,910 on 3-2-89	Dissolved sodium, 170 mg/L; dissolved chloride, 960 mg/L; alkalinity, 343 mg/L. Sampled 3-2-89.
USGS-14	3442400772554	9-06-88	238	228-238	8	3.55	3-09-89	246	Gamma-240; acoustic velocity, electric-238	1,180 on 2-28-89	Dissolved sodium, 250 mg/L; dissolved chloride, 160 mg/L. Sampled 2-28-89.

Table 2.--*Chloride concentration in water from wells at Camp Lejeune, North Carolina*

[mg/L, milligram per liter; ft, foot; --, unknown]

Well number (fig. 8)	Total dissolved-chloride concentration (mg/L)	Year collected	Water sample depth below land surface (ft)	Remarks
BA-190	12	1978	--	
HP-621	8	1942	--	
HP-626	10	1957	--	
HP-628	9	1955	70	
	8	1984	70	Replaces HP-626.
	12	1984	120	Test interval.
	13	1984	140	Test interval.
	13	1987	--	
HP-629	11	1960	--	Replaces HP-621.
	10	1982	60	Test interval.
	7	1982	130	Test interval.
	8	1982	160	Test interval.
	10	1982	220	Test interval.
HP-639	10	1987	--	
HP-640	10	1987	--	
HP-643	12	1971	140	Test interval.
	12	1987	--	
HP-645	8	1971	95	
	15	1971	95	
	15	1987	--	
HP-647	56	1970	--	
HP-648	37	1971	115	Test interval.
	37	1971	250	Test interval.
	36	1987	--	
HP-649	6	1971	120	Test interval.
	11	1971	210	Test interval.
	14	1987	--	
HP-650	10	1971	80	Test interval.
	8	1971	120	Test interval.
	15	1987	--	
HP-699	12	1985	90	
	13	1989	--	

Table 2.--*Chloride concentration in water from wells at Camp Lejeune, North Carolina*--**Continued**

[mg/L, milligram per liter; ft, foot; --, unknown]

Well number (fig. 8)	Total dissolved-chloride concentration (mg/L)	Year collected	Water sample depth below land surface (ft)	Remarks
HP-703	12	1987	--	
HP-704	9	1987	--	
HP-705	51	1986	70	
	9	1987	--	
HP-706	29	1986	130	Test interval.
	20	1986	175	Test interval.
	10	1987	--	
HP-708	6	1985	90	
	10	1987	--	
MCAS-1254	11	1975	50	Test interval.
	72	1975	110	Test interval.
	77	1975	150	Test interval.
	86	1975	190	Test interval.
	100	1987	--	
RR-97	9	1979	60	Test interval.
	11	1979	110	Test interval.
	12	1979	290	Test interval.
	80	1987	--	
T-1	12	1959	63	Test interval.
	10	1959	325	Test interval.
T-2	10	1959	150	Test interval.
	8	1959	225	Test interval.
T-4	8	1959	180	Test interval.
	10	1959	240	Test interval.
T-5	10	1959	140	Test interval.
	12	1959	210	Test interval.
T-7	10	1959	140	Test interval.
	16	1959	210	Test interval.
T-12	8	1959	52	Test interval.
	48	1959	225	Test interval.
	340	1959	320	Test interval.
T-22	16	1959	150	
TC-201	13	1987	--	

Table 2.--*Chloride concentration in water from wells at Camp Lejeune, North Carolina*--Continued

[mg/L, milligram per liter; ft, foot; --, unknown]

Well number (fig. 8)	Total dissolved-chloride concentration (mg/L)	Year collected	Water sample depth below land surface (ft)	Remarks
TC-1251	31	1975	130	Test interval.
	38	1975	170	Test interval.
	30	1975	--	
TC-1255	50	1975	125	Test interval.
	80	1975	170	Test interval.
	66	1975	220	Test interval.
	78	1975	--	
TT-25	9	1980	--	
USGS-2	73	1988	219	
	73	1989	219	
USGS-3	7	1989	221	
USGS-4	120	1989	152	
USGS-6	8	1989	220	
USGS-8	960	1989	212	
USGS-14	160	1989	238	
X24s2x	80	1986	238	Test interval.
	730	1986	500	Test interval.
	3,359	1986	628	Test interval.
	3,839	1986	886	Test interval.
	5,658	1986	918	Test interval.
	13,896	1986	1,210	Test interval.
Y25q2	16	1982	350	Test interval.
	22	1982	450	Test interval.
	266	1982	540	Test interval.
	1,600	1982	880	Test interval.
	2,700	1982	1,000	Test interval.

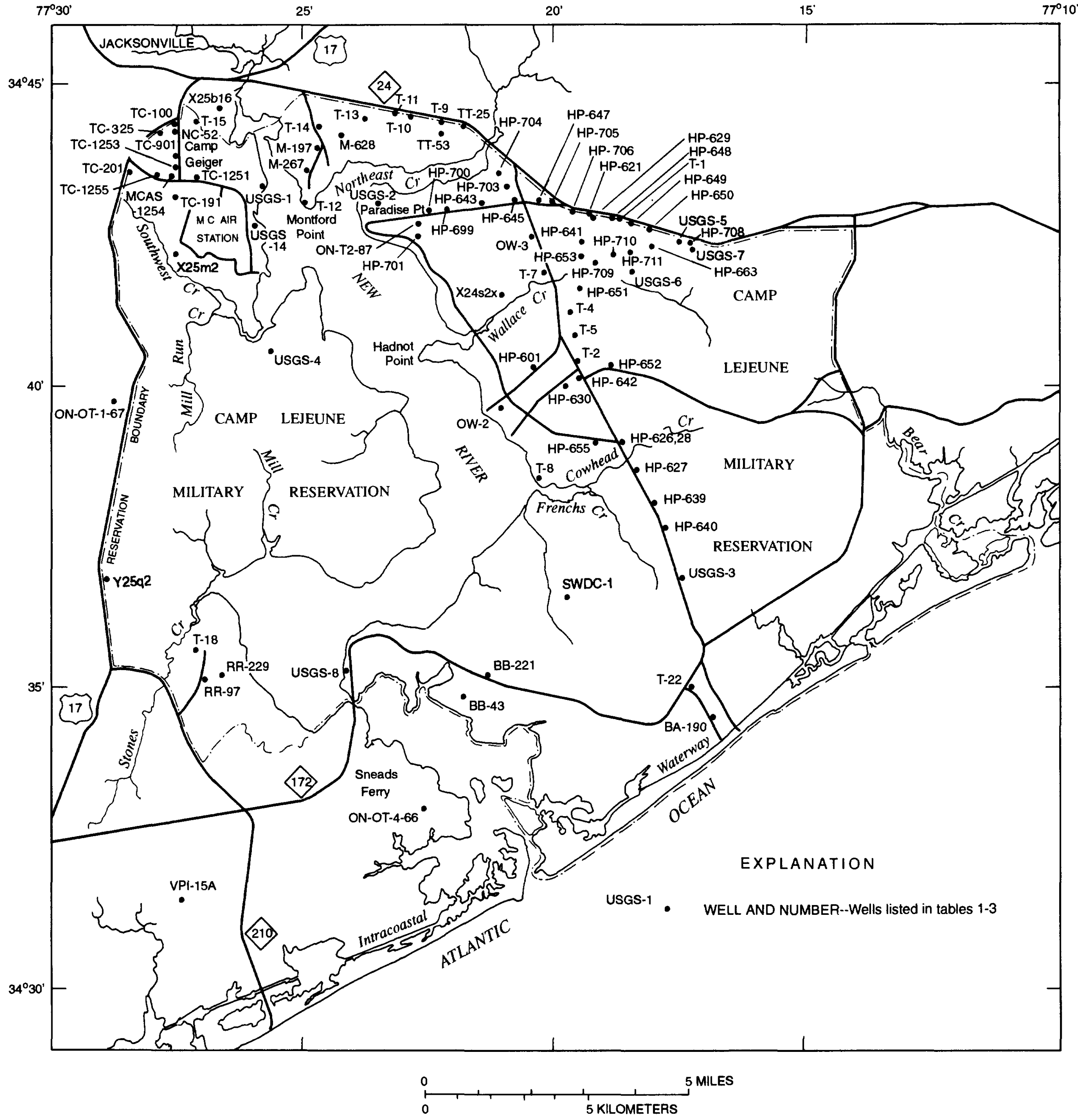


Figure 8.--Locations of selected wells at Camp Lejeune, North Carolina.

Table 3.--***Observed and estimated hydrogeologic data for selected wells at Camp Lejeune, North Carolina***

[Altitude: feet above or below (-) sea level; Data source: G, geophysical log; L, lithologic log; --, unknown; na, not applicable. Data deeper than total well depth are estimated values]

Well number (fig. 8)	Latitude	Longitude	Altitude of land surface (feet)	Total well depth (feet)	Data source	Surficial aquifer Thickness (feet)	Castle Hayne confining unit Altitude (feet)	Castle Hayne confining unit Thickness (feet)	Castle Hayne aquifer Altitude (feet)	Castle Hayne aquifer Thickness (feet)	Beaufort confining unit Altitude (feet)	Beaufort confining unit Thickness (feet)	Beaufort aquifer Altitude (feet)	Beaufort aquifer Thickness (feet)	Peedee confining unit Altitude (feet)	Peedee confining unit Thickness (feet)	Peedee aquifer Altitude (feet)	Percent of permeable material in Castle Hayne aquifer	Cross section reference (fig. 9)
BA-190	34°34'32"	77°16'51"	12	105	G	73	-61	7	-68	395	-463	22	-485	44	-529	26	-555	62	A-A', D-D'
BB-43	34°34'55"	77°21'48"	13	60	L	27	-14	15	-29	--	--	--	--	--	--	--	--	--	na
BB-221	34°35'22"	77°21'22"	40	200	G,L	40	0	22	-22	293	-315	20	-335	85	-420	--	--	--	na
HP-601	34°40'18"	77°20'20"	22	195	G,L	17	+5	17	-12	318	-330	13	-343	65	-408	40	-448	91	na
HP-627	34°38'37"	77°18'19"	31	163	--	29	+2	6	-4	394	-398	18	-416	46	-462	26	-488	83	A-A'
HP-628	34°39'04"	77°18'38"	26	200	G,L	18	+8	8	0	387	-387	20	-407	48	-455	27	-482	--	A-A'
HP-629	34°42'54"	77°19'12"	41	240	G	41	0	6	-6	348	-354	18	-372	45	-417	38	-455	83	B-B'
HP-630	34°40'03"	77°19'48"	26	176	G	14	+12	12	0	345	-345	21	-366	63	-429	27	-456	86	na
HP-639	34°38'05"	77°18'00"	23	176	G,L	30	-7	7	-14	392	-406	20	-426	48	-474	26	-500	89	A-A'
HP-640	34°37'38"	77°17'46"	30	176	G,L	44	-14	6	-20	390	-410	20	-430	45	-475	25	-500	89	na
HP-641	34°42'29"	77°19'22"	32	178	G	27	+5	9	-4	349	-353	13	-366	48	-414	38	-452	--	na
HP-642	34°40'10"	77°19'24"	29	210	G,L	15	+14	14	0	355	-355	18	-373	61	-434	34	-468	78	A-A'
HP-643	34°43'03"	77°21'18"	28	250	G,L	32	-4	9	-13	300	-313	16	-329	63	-392	40	-432	82	B-B'
HP-645	34°43'05"	77°20'43"	25	245	G,L	18	+7	5	+2	323	-321	18	-339	60	-397	40	-439	87	A-A', B-B'
HP-647	34°43'03"	77°20'17"	33	200	G,L	31	+2	6	-4	327	-331	16	-347	55	-402	40	-442	81	B-B'
HP-648	34°42'51"	77°18'48"	36	265	G,L	36	0	6	-6	358	-364	20	-384	37	-421	38	-459	77	B-B'
HP-649	34°42'44"	77°18'22"	37	284	G,L	38	-1	7	-8	360	-368	20	-388	38	-426	38	-464	88	B-B'
HP-650	34°42'39"	77°18'00"	38	179	G,L	31	+7	7	0	373	-373	21	-394	35	-429	38	-467	81	B-B'
HP-651	34°41'41"	77°19'27"	32	199	G,L	36	-4	9	-13	330	-343	12	-355	60	-415	33	-448	89	na
HP-652	34°40'19"	77°18'48"	30	183	G,L	36	-6	9	-15	360	-375	17	-392	55	-447	28	-475	--	na

Table 3.--*Observed and estimated hydrogeologic data for selected wells at Camp Lejeune, North Carolina*--**Continued**

[Altitude: feet above or below (-) sea level; Data source: G, geophysical log; L, lithologic log; --, unknown; na, not applicable. Data deeper than total well depth are estimated values]

Well number (fig. 8)	Latitude	Longitude	Altitude of land surface (feet)	Total well depth (feet)	Data source	Surficial aquifer Thickness (feet)	Castle Hayne confining unit Altitude (feet)	Castle Hayne confining unit Thickness (feet)	Castle Hayne aquifer Altitude (feet)	Castle Hayne aquifer Thickness (feet)	Beaufort confining unit Altitude (feet)	Beaufort confining unit Thickness (feet)	Beaufort aquifer Altitude (feet)	Beaufort aquifer Thickness (feet)	Peedee confining unit Altitude (feet)	Peedee confining unit Thickness (feet)	Peedee aquifer Altitude (feet)	Percent of permeable material in Castle Hayne aquifer	Cross section reference (fig. 9)
HP-653	34°42'10"	77°19'25"	32	270	G,L	32	0	10	-10	328	-338	19	-357	52	-409	44	-453	--	na
HP-655	34°39'08"	77°19'05"	26	145	G,L	17	+9	8	+1	380	-379	19	-398	50	-448	22	-470	81	na
HP-663	34°42'27"	77°17'58"	35	180	G,L	22	+13	12	+1	366	-365	20	-385	40	-425	45	-470	80	na
HP-699	34°43'00"	77°21'41"	23	124	G,L	34	-11	9	-20	272	-292	15	-307	70	-377	40	-417	--	B-B'
HP-700	34°43'00"	77°21'50"	20	130	G,L	32	-12	11	-23	274	-297	16	-313	68	-381	44	-425	80	B-B'
HP-701	34°42'33"	77°22'04"	24	110	G,L	40	-16	15	-31	200+	--	--	--	--	--	--	--	83	na
HP-703	34°43'33"	77°21'00"	31	34	--	26	+5	4	+1	330	-329	16	-345	58	-403	42	-445	--	A-A'
HP-704	34°43'49"	77°21'02"	26	124	G,L	21	+5	6	-1	356	-357	18	-375	56	-431	44	-475	66	A-A'
HP-705	34°43'06"	77°20'00"	34	160	G,L	33	+1	6	-5	334	-339	18	-357	50	-407	38	-445	86	B-B'
HP-706	34°42'58"	77°19'30"	41	176	G,L	41	0	6	-6	340	-346	17	-363	48	-411	38	-449	86	B-B'
HP-708	34°42'30"	77°17'21"	41	176	G,L	31	+10	8	+2	382	-380	20	-400	34	-434	42	-476	68	B-B'
HP-709	34°42'13"	77°18'59"	28	140	G,L	13	+15	9	+6	353	-347	19	-366	50	-416	42	-458	85	na
HP-710	34°42'11"	77°18'43"	32	140	G,L	16	+16	14	+2	353	-351	20	-371	46	-417	45	-462	83	na
HP-711	34°42'19"	77°18'23"	36	150	G,L	26	+10	16	-6	352	-358	19	-377	43	-420	44	-464	75	na
M-197	34°43'58"	77°24'38"	21	200	G,L	18	+3	4	-1	243	-244	19	-263	72	-335	34	-369	70	na
M-267	34°43'36"	77°24'51"	17	150	G,L	16	+1	3	-2	239	-241	20	-261	70	-331	35	-366	--	na
M-628	34°44'10"	77°24'17"	15	67	L	13	+2	8	-6	248	-254	21	-275	72	-347	38	-385	--	na
MCAS-1254	34°43'29"	77°27'36"	27	195	G	21	+6	6	0	168	-168	24	-192	88	-280	30	-310	--	B-B'
NC-52	34°44'18"	77°27'29"	17	70	L	4	+13	8	+5	170	-165	26	-191	88	-279	32	-311	--	na
ON-OT-1-67	34°39'36"	77°28'44"	62	1,400	G	--	--	--	--	--	-138	15	-153	73	-226	9	-235	--	C-C'

Table 3.--*Observed and estimated hydrogeologic data for selected wells at Camp Lejeune, North Carolina*--**Continued**

[Altitude: feet above or below (-) sea level; Data source: G, geophysical log; L, lithologic log; --, unknown; na, not applicable. Data deeper than total well depth are estimated values]

Well number (fig. 8)	Latitude	Longitude	Altitude of land surface (feet)	Total well depth (feet)	Data source	Surficial aquifer Thickness (feet)	Castle Hayne confining unit Altitude (feet)	Castle Hayne confining unit Thickness (feet)	Castle Hayne aquifer Altitude (feet)	Castle Hayne aquifer Thickness (feet)	Beaufort confining unit Altitude (feet)	Beaufort confining unit Thickness (feet)	Beaufort aquifer Altitude (feet)	Beaufort aquifer Thickness (feet)	Peedee confining unit Altitude (feet)	Peedee confining unit Thickness (feet)	Peedee aquifer Altitude (feet)	Percent of permeable material in Castle Hayne aquifer	Cross section reference (fig. 9)
ON-OT-4-66	34°33'00"	77°22'30"	30	1,681	G	30	0	15	-15	290	-305	25	-330	50	-380	45	-425	80	D-D'
ON-T2-87	34°42'41"	77°22'40"	20	260	G	31	-11	10	-21	272	-293	16	-309	71	-380	40	-420	--	na
OW-2	34°39'40"	77°20'59"	11	90	G	13	-2	5	-7	310	-317	20	-337	80	-417	36	-453	--	na
OW-3	34°42'28"	77°20'18"	23	75	G	3	+20	10	+10	334	-324	18	-342	59	-401	44	-445	--	A-A'
RR-97	34°35'12"	77°26'56"	56	200	G,L	29	+27	21	+6	235	-229	10	-239	29	-268	17	-285	81	C-C'
RR-229	34°35'17"	77°26'42"	31	253	G,L	10	+21	18	+3	225+	--	--	--	--	--	--	--	--	na
SWDC-1	34°37'02"	77°19'36"	30	56	L	50	-20	6	-26	--	--	--	--	--	--	--	--	--	na
T-1	34°42'49"	77°18'38"	30	477	G,L	30	0	6	-6	357	-363	21	-384	38	-422	38	-400	75	B-B'
T-2	34°40'26"	77°19'31"	29	240	G,L	17	+12	10	+2	352	-350	18	-368	66	-434	34	-468	68	A-A'
T-4	34°41'19"	77°19'31"	26	262	G,L	14	+12	8	+4	336	-332	18	-350	68	-418	40	-458	86	A-A'
T-5	34°40'55"	77°19'29"	15	232	G,L	19	-4	16	-20	316	-336	16	-352	70	-422	40	-462	79	A-A'
T-7	34°42'00"	77°20'07"	26	225	G,L	16	+10	0	0	325	-325	17	-342	60	-402	44	-446	--	A-A'
T-8	34°39'20"	77°19'50"	20	500	G,L	19	+1	13	-12	352	-364	15	-379	60	-439	18	-458	--	na
T-9	34°44'27"	77°22'09"	28	177	G,L	24	+4	9	-5	339	-344	26	-370	56	-426	46	-472	70	na
T-10	34°44'34"	77°22'51"	25	250	G,L	11	+14	10	+4	323	-319	24	-343	58	-401	52	-453	67	na
T11	34°44'36"	77°23'13"	25	202	G,L	27	-2	7	-9	290	-299	22	-321	62	-383	40	-423	65	na
T-12	34°43'03"	77°24'59"	6	352	G,L	16	-10	5	-15	222	-237	19	-256	70	-326	32	-358	80	B-B'
T-13	34°44'24"	77°23'46"	19	250	G,L	13	+6	6	0	282	-282	21	-303	66	-369	42	-411	77	na
T-14	34°44'18"	77°24'42"	20	200	G,L	11	+9	4	+5	253	-248	18	-266	76	-342	38	-380	70	na
T-15	34°44'25"	77°27'07"	15	477	G,L	3	+12	7	+5	180	-175	22	-197	86	-283	34	-317	69	na

Table 3.--*Observed and estimated hydrogeologic data for selected wells at Camp Lejeune, North Carolina*--Continued

[Altitude: feet above or below (-) sea level; Data source: G, geophysical log; L, lithologic log; --, unknown; na, not applicable. Data deeper than total well depth are estimated values]

Well number (fig. 8)	Latitude	Longitude	Altitude of land surface (feet)	Total well depth (feet)	Data source	Surficial aquifer: Thickness (feet)	Castle Hayne confining unit: Altitude (feet)	Castle Hayne confining unit: Thickness (feet)	Castle Hayne aquifer: Altitude (feet)	Castle Hayne aquifer: Thickness (feet)	Beaufort confining unit: Altitude (feet)	Beaufort confining unit: Thickness (feet)	Beaufort aquifer: Altitude (feet)	Beaufort aquifer: Thickness (feet)	Peedee confining unit: Altitude (feet)	Peedee confining unit: Thickness (feet)	Peedee aquifer: Altitude (feet)	Percent of permeable material in Castle Hayne aquifer	Cross section reference (fig. 9)
T-18	34°35'37"	77°27'05"	52	302	G,L	19	+33	26	+7	221	-214	8	-222	29	-252	29	-280	84	na
T-22	34°35'01"	77°17'20"	23	161	G,L	67	-44	12	-56	388	-444	22	-466	44	-510	27	-537	62	A-A'
TC-100	34°44'28"	77°27'29"	20	67	G	5	+15	10	+5	--	--	--	--	--	--	--	--	--	na
TC-191	34°43'07"	77°27'29"	26	180	G,L	26	0	3	-3	164	-167	--	--	--	-291	28	-319	72	na
TC-201	34°43'28"	77°28'31"	33	68	L	18	+15	7	+8	158	-150	24	-174	90	-264	30	-294	--	B-B'
TC-325	34°44'12"	77°27'55"	21	200?	G,L	11	+10	6	+4	156	-152	30	-182	86	-268	30	-298	68	na
TC-901	34°43'45"	77°27'27"	21	77	G,L	15	+6	5	+1	160	--	--	--	--	--	--	--	--	na
TC-1251	34°43'29"	77°27'10"	20	240	G	20	0	7	-7	180	-187	21	-208	86	-294	32	-326	72	B-B'
TC-1253	34°43'37"	77°27'29"	22	250	G	18	+4	4	0	162	-162	38	-200	90	-290	31	-321	81	na
TC-1255	34°43'29"	77°27'54"	31	251	G,L	23	+8	6	+2	168	-166	22	-188	84	-272	28	-300	76	B-B'
TT-25	34°44'19"	77°21'43"	31	200	G,L	21	+10	4	+6	364	-358	28	-386	48	-434	46	-480	71	A-A'
TT-53	34°44'14"	77°22'12"	24	90	G	17	+7	7	0	--	--	--	--	--	--	--	--	--	na
USGS-1	34°43'18"	77°25'48"	5	208	G,L	11	-6	6	-12	204	-216	18	-234	76	-310	32	-342	--	B-B'
USGS-2	34°43'04"	77°23'29"	17	236	G,L	19	-2	9	-11	256	-267	17	-284	72	-356	36	-392	59	na
USGS-3	34°36'09"	77°17'13"	41	253	G,L	61	-20	6	-26	400	-426	20	-446	44	-490	26	-516	62	A-A'
USGS-4	34°40'37"	77°25'19"	28	232	G,L	17	+11	6	+5	213	-208	13	-221	67	-288	30	-318	67	na
USGS-14	34°42'40"	77°25'54"	8	246	G,L	8	0	4	-4	202	-206	19	-225	13+	--	--	--	--	na
VPI-15A	34°31'30"	77°27'23"	26	1,575	G	20	+6	22	-16	228	-244	12	-256	48	-304	25	-329	96	C-C', D-D'
X24s2x	34°41'39"	77°21'04"	23	1,526	G,L	14	+9	10	-1	308	-309	16	-325	68	-393	44	-437	77	na
X25m2	34°42'18"	77°27'34"	15	156	G	24	-9	6	-15	164	-179	--	--	--	--	--	--	--	na
X25b16	34°44'35"	77°26'40"	15	185	G	6	+9	6	+3	195	-192	20	-212	88	-300	34	-334	--	na
Y25q2	34°36'41"	77°29'01"	67	1,355	G,L	32	+35	25	+10	203	-193	16	-209	25	-234	31	-265	92	D-D'

Four hydrogeologic sections were constructed to show the correlation of the aquifers and confining units at Camp Lejeune (plate 1, in pocket). Location of the sections and the wells used to construct them are shown in figure 9. Because most of the wells in the study area are less than 250 ft deep, aquifer correlations below this depth were made from several key deep wells and from seismic-reflection data, and were correlated with all hydrogeologic sections. The seismic data also provided aquifer depth and trend information in areas where no well data were available. The altitude of the tops of the Castle Hayne, Beaufort, and Peedee aquifers, thicknesses of the Castle Hayne and Beaufort aquifers, and the thickness of the confining unit for the Castle Hayne aquifer are interpreted primarily from the hydrogeologic sections.

Surficial Aquifer

The surficial aquifer consists of interfingering beds of sand, clay, sandy clay, and silt of Quarternary and Miocene age (fig. 3) that contain some peat and shells. Sand beds of the Belgrade Formation of Miocene age that may occur in the area are considered part of the surficial aquifer. The clay, sandy clay, and silt beds that occur in the surficial aquifer are thin and discontinuous, and have limited lateral continuity. Some of these discontinuous beds tend to have a more pronounced log signature in well logs east of the New River (plate 1). The surficial aquifer immediately overlies the Castle Hayne confining unit.

The thickness of the surficial aquifer ranges from 0 to 73 ft and averages nearly 25 ft over most of the study area (plate 1). The aquifer is generally thickest in the interstream divide areas and presumed absent where it is cut by the New River and its tributaries. The greatest observed thickness of the surficial aquifer occurs in the southeastern part of Camp Lejeune along section A-A' (plate 1), and may be part of a former beach ridge in this area. At well USGS-3, a 10-15 ft thick interbedded sand and peat sequence occurs between 25 and 40 ft below land surface in the surficial aquifer (plate 1). This unit likely represents more recent channel or lagoonal fill than the buried channels that occur in the Castle Hayne aquifer. The surficial aquifer is less than 10 ft thick in the northwestern part of Camp Lejeune in the Camp Geiger area as observed in well NC-52, for example (table 3). The New River, Northeast Creek, Wallace Creek, Cowhead Creek, Stones Creek, and Mill Creek are presumed to cut through the surficial aquifer in the Camp Lejeune area, although the heads of smaller streams may not completely incise the aquifer.

According to Winner and Coble (1989), the surficial aquifer is composed of more than 90 percent sand in the eastern part of the Base and 70-90 percent sand in the western part of the Base. The general lithology of the surficial aquifer and the absence of any thick, continuous clay beds are indications of good vertical conductivity within the aquifer. Tant and others (1974) indicate that the soils in the study area have good infiltration capacity and are classified as well-drained to very well-drained sandy soil and sandy loam with vertical saturated permeabilities of 2-20 in/hr in the Camp Lejeune area. The estimated lateral hydraulic conductivity of the surficial aquifer in the Camp Lejeune area is 50 ft/d (Winner and Coble, 1989) and is based on a general composition of fine sand mixed with some silt and clay.

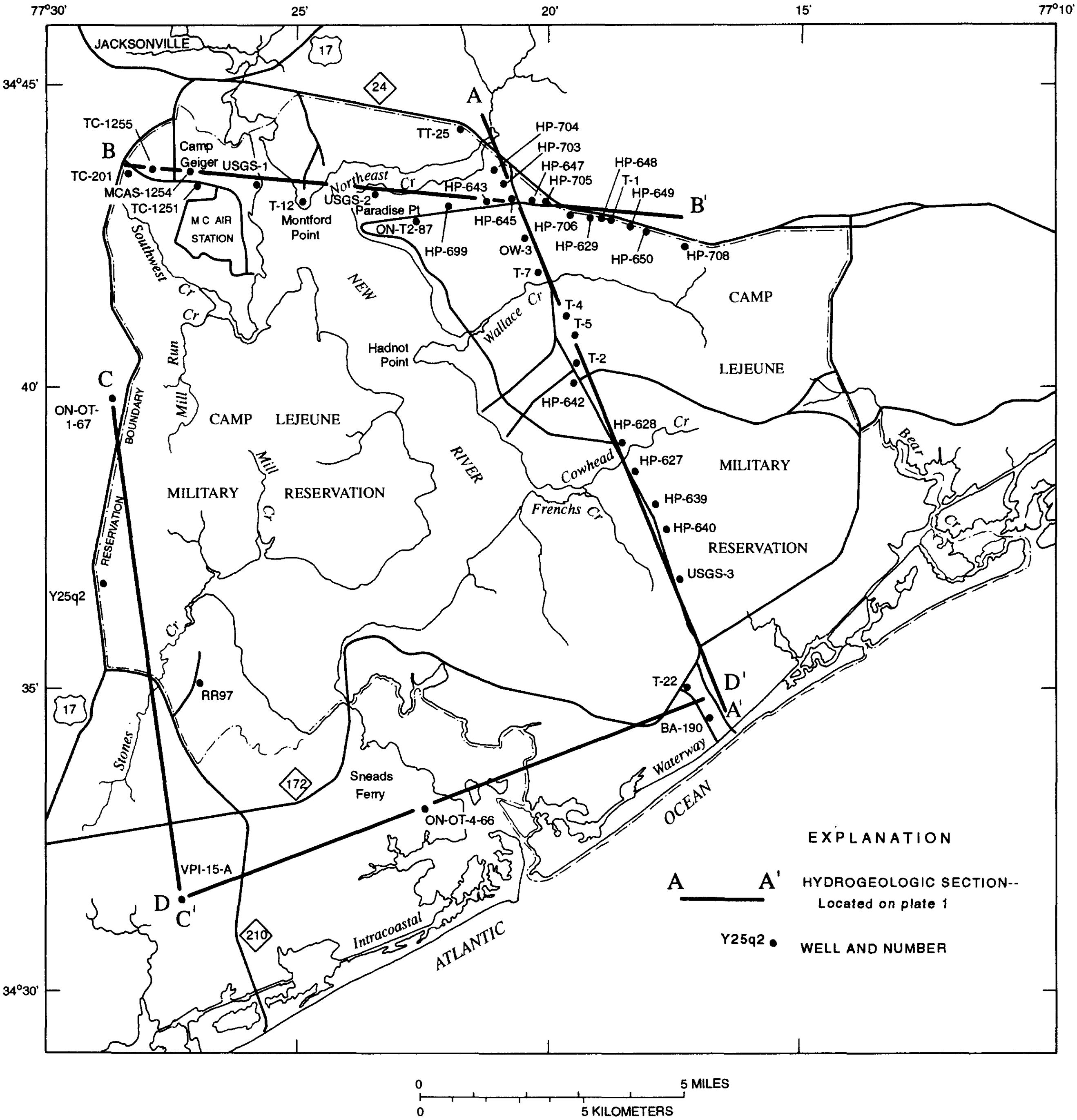


Figure 9.--Locations of hydrogeologic sections at Camp Lejeune, North Carolina.

Recharge to the surficial aquifer is by rainfall. Most of this recharge is discharged to local streams, but some recharge reaches the underlying Castle Hayne aquifer through the Castle Hayne confining unit.

Saltwater has not been detected in wells open to the surficial aquifer at Camp Lejeune. Because the heads of some tidal streams may have only partially cut into the surficial aquifer, the question is raised that the aquifer may contain saltwater at these places. However, because these streams are also lines of discharge for the surficial aquifer, the presence of saltwater in the aquifer is likely only a transient problem during storm surges and is not considered to pose a serious contamination problem.

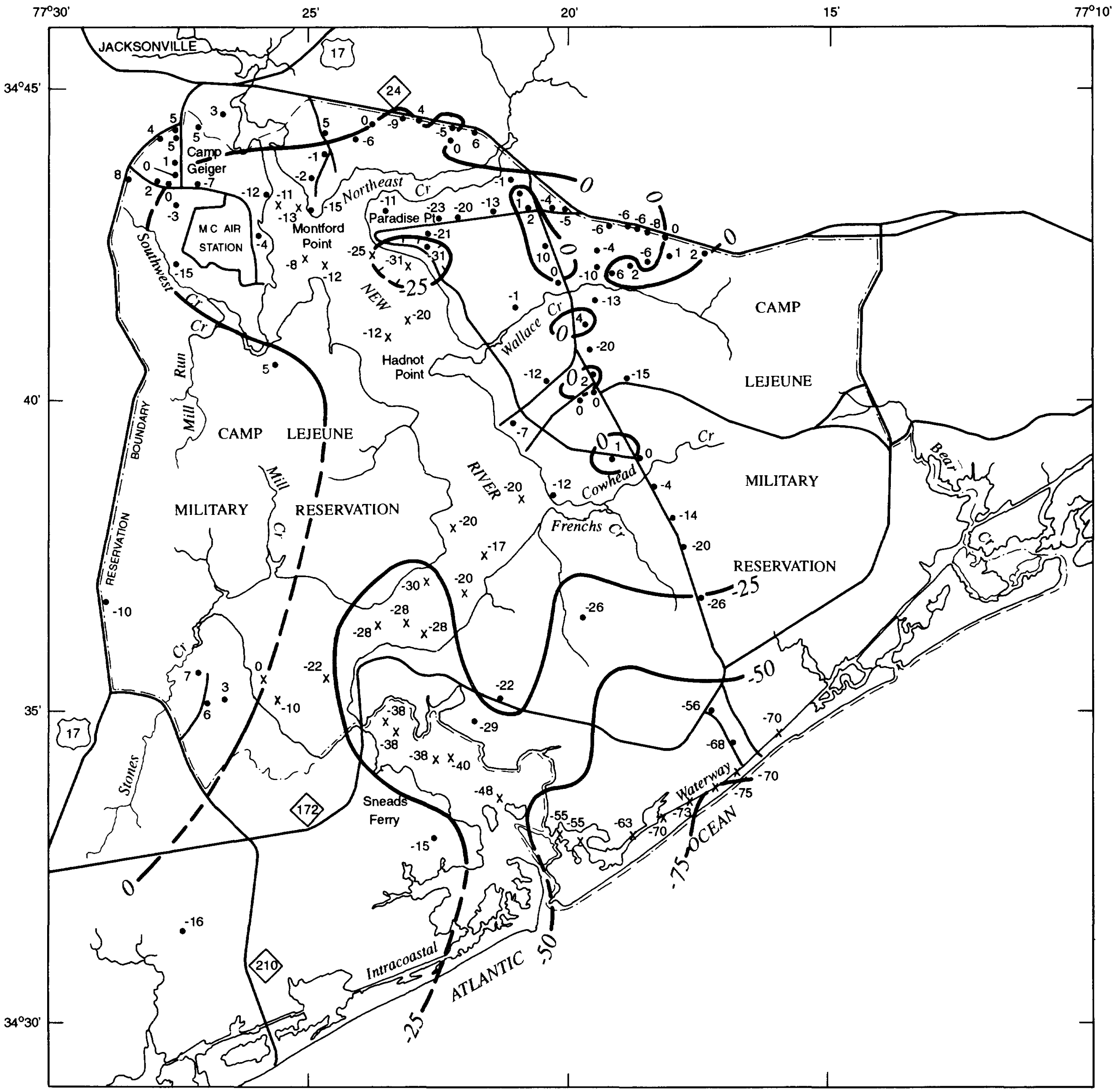
Castle Hayne Aquifer

The Castle Hayne aquifer at Camp Lejeune includes the Castle Hayne Formation of Eocene age and some lower beds of the River Bend Formation of Oligocene age (fig. 3). The Castle Hayne aquifer primarily consists of beds of sand, shell rock, and limestone (Winner and Coble, 1989). Clay, silt, silty and sandy clay, and indurated limestone beds also occur within the aquifer. The upper part of the aquifer consists primarily of calcareous sand with some continuous and discontinuous thin (10-15 ft) clay and silt beds. The calcareous sand becomes progressively more limy with depth. The lower part of the aquifer consists of consolidated or poorly consolidated limestone and sandy limestone interbedded with clay and sand. There is a sequence of one or more indurated limestone marker beds near the bottom of the Castle Hayne aquifer that have distinctive log signatures (plate 1). The sediments below these marker beds are mostly sand and sandy clay, and typically increase in silt and clay content near the base of the aquifer. The base of the Castle Hayne aquifer is the top of a regionally continuous clay designated as the Beaufort confining unit.

The top of the Castle Hayne aquifer ranges from 10 ft above sea level at wells OW-3 and Y25q2 to 68 ft below sea level at well BA-190 (table 3), and is estimated to be more than 70 ft below sea level along the Intracoastal Waterway east of the New River (fig. 10). In the northern and northwestern parts of Camp Lejeune, the top of the aquifer is irregular with 10-20 ft of local relief occurring over short distances. In the area southeast of the New River, however, the top of the aquifer is more regular and slopes southeastward at about 10 feet per mile (ft/mi).

The observed thickness of the Castle Hayne aquifer ranges from 156 ft in well TC-325 to 400 ft in well USGS-3 (table 3). The aquifer is thinnest in the area of Camp Geiger in the northwest corner of the Base, and thickest in the eastern quarter of the Base. Although the slope of the top of the Castle Hayne aquifer trends southeastward, the aquifer thickens in an easterly direction (fig. 11) and may be 500 ft thick or more along Bear Creek at the eastern boundary of the Base.

The Castle Hayne aquifer averages 80 percent permeable material (sand and limestone) in the North Carolina Coastal Plain (Winner and Coble, 1989). At Camp Lejeune, estimates of the amounts of permeable material in the Castle Hayne aquifer, derived from well logs, range from 59 to 96 percent (table 3), and average about 76 percent. There is a general trend



0 5 MILES

0 5 KILOMETERS

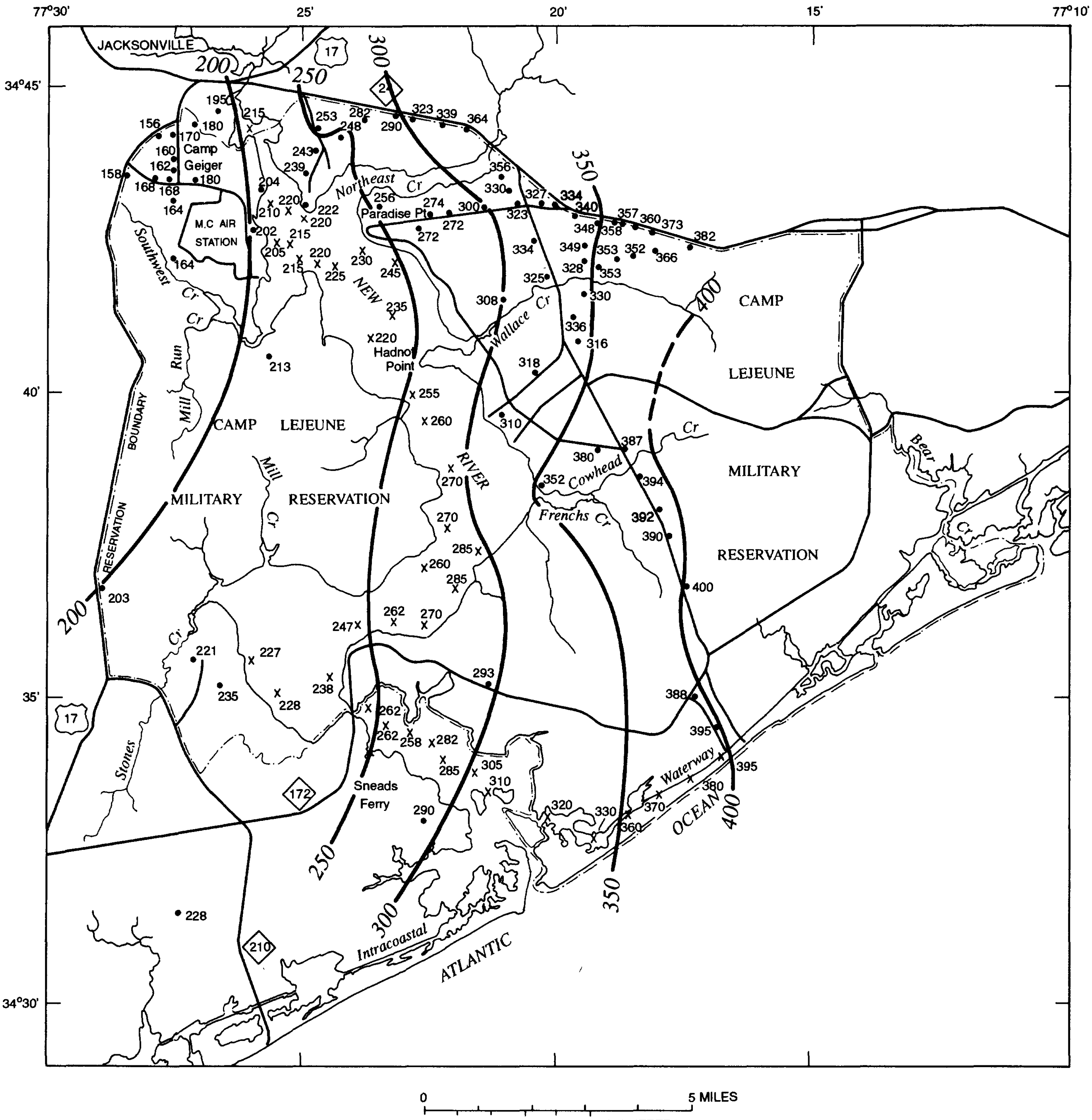
EXPLANATION

—-25— STRUCTURE CONTOUR--Shows altitude of top of Castle Hayne aquifer. Dashed where approximately located. Contour interval 25 feet. Hachured to indicate depression in top of aquifer. Datum is sea level

•-15 WELL--Number is altitude of top of Castle Hayne aquifer in feet above or below (-) sea level

-38 X NAVIGATION FIX POINT ALONG SEISMIC PROFILE LINE (FIG. 5) --Number is estimated altitude of top of Castle Hayne aquifer in feet below (-) sea level

Figure 10.--Altitude of the top of the Castle Hayne aquifer at Camp Lejeune, North Carolina.



EXPLANATION

—200— LINE OF EQUAL THICKNESS OF CASTLE HAYNE AQUIFER--Dashed where approximately located. Interval 50 feet

• 160 WELL--Number is thickness of Castle Hayne aquifer in feet

210 X NAVIGATION FIX POINT ALONG SEISMIC PROFILE LINE (FIG. 5)--Number is estimated thickness of Castle Hayne aquifer in feet

Figure 11.--Thickness of the Castle Hayne aquifer at Camp Lejeune, North Carolina.

for the amount of permeable material in the aquifer to decrease from west to east across Camp Lejeune (fig. 12). Because the aquifer also thickens in that direction, the decrease in percentage of sand and limestone is attributed to an increase in clay and silt in the aquifer in that direction (section A-A′, plate 1). In the northern part of Camp Lejeune, the percentages of permeable material in the Castle Hayne aquifer vary widely over relatively short distances and show no discernible trend.

Estimates of the hydraulic properties of the Castle Hayne aquifer from a few studies at Camp Lejeune are available. Results from these studies show that transmissivity values range from 820 to 24,500 $[(ft^3/d)/ft^2]ft$; hydraulic conductivities range from 14 to 91 ft/d; and storage coefficients range from 0.0002 to 0.001 (table 4), which indicate wide local variation of these properties. Using an average hydraulic conductivity of 65 ft/d for the Castle Hayne aquifer determined by Winner and Coble (1989), and using ranges of aquifer thickness determined in this study (table 3), transmissivity estimates range from 10,140 to 26,000 $[(ft^3/d)/ft^2]ft$ (table 4).

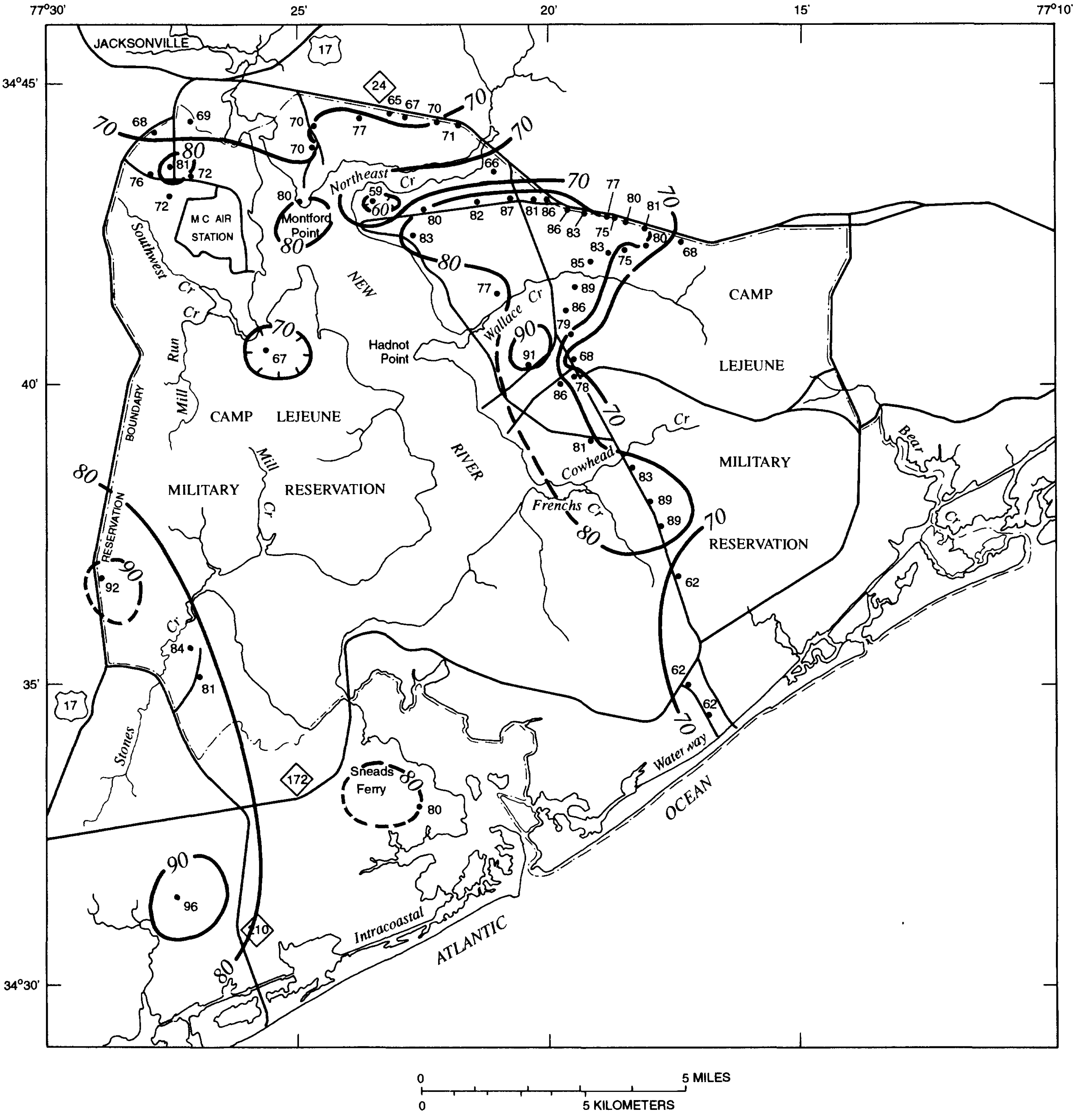
Castle Hayne Confining Unit

The Castle Hayne confining unit overlies the Castle Hayne aquifer and is composed of clay, silt, and sandy clay beds. These beds form a unit across Camp Lejeune that may be represented by one or more geological units, such as (1) Quaternary or Miocene deposits at the bottom of the surficial aquifer, (2) uppermost beds of the River Bend Formation, or (3) uppermost beds of the Castle Hayne Formation. In general, the Castle Hayne confining unit at Camp Lejeune may be characterized as a group of less permeable beds at the top of the Castle Hayne aquifer that have been partly eroded or incised in places.

The thickness of the Castle Hayne confining unit ranges from 0 to 26 ft (table 3), and averages about 9 ft where present. There is no discernible trend in the thickness of the confining unit at Camp Lejeune, although it is more than 20 ft thick only in the southern and southwestern parts of the Base (fig. 13); the unit may also be thicker in the eastern part of the Base, where the Castle Hayne aquifer shows a thickening (fig. 11).

The Castle Hayne confining unit is incised by the New River and its major tributaries as interpreted from seismic-reflection profiles. Although Cardinell and others (1990) correlated older clay units across the New River, no continuous clay beds above the Castle Hayne aquifer were discerned from the seismic record in the estuary. Moreover, the presence of buried paleochannels (fig. 7) in post-Castle Hayne sediments provides evidence of the removal in the estuary of some, if not most, of the sediments originally deposited above the Castle Hayne aquifer.

The vertical hydraulic conductivity of the Castle Hayne confining unit was estimated to range from 0.0014 to 0.41 ft/d (table 4). These values are comparable to those determined by Morris and Johnson (1967) for the vertical hydraulic conductivities of silt; thus, this confining unit may only be partly effective in retarding the vertical movement of ground water between the surficial and Castle Hayne aquifers.



EXPLANATION

—80— LINE OF EQUAL SAND AND LIMESTONE PERCENT IN CASTLE HAYNE AQUIFER--Dashed where approximately located. Hachured to indicate values less than surrounding area. Interval 10 percent

•80 WELL--Number is sand and limestone percent in Castle Hayne aquifer

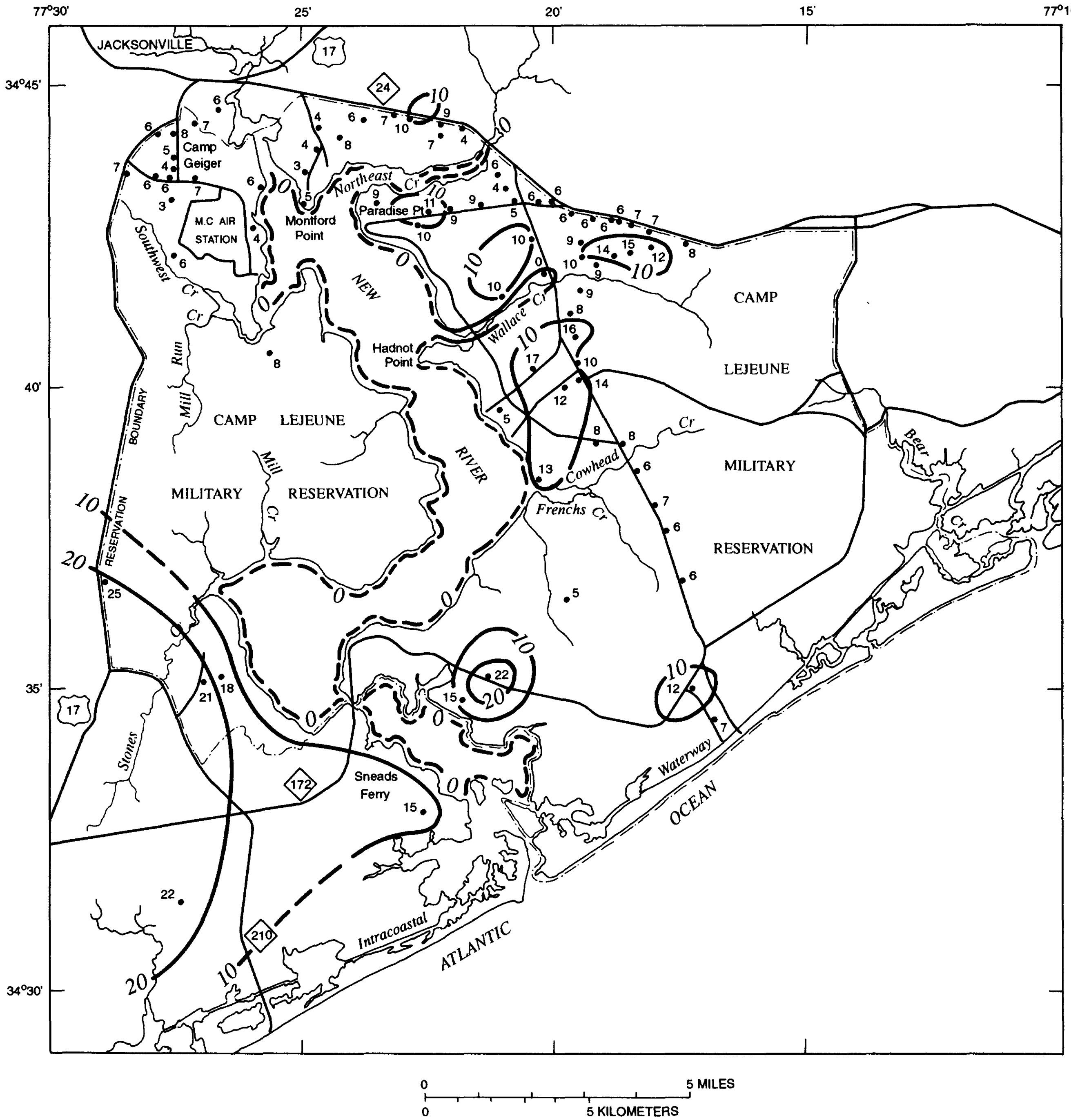
Figure 12.--Percentage of sand and limestone in the Castle Hayne aquifer at Camp Lejeune, North Carolina.

Table 4.--*Estimates of Castle Hayne aquifer and confining-unit hydraulic properties at Camp Lejeune, North Carolina*

[USGS, U.S. Geological Survey; ESE, Inc., Environmental Science and Engineering, Incorporated; DEHNR, North Carolina Department of Environment, Health, and Natural Resources; RASA, U.S. Geological Survey Regional Aquifer Systems Analysis program; --- no data]

Hydraulic properties	USGS phase I study[1]	USGS aquifer test[2]	ESE, Inc.[3]	DEHNR aquifer test[4]	RASA estimate[5]
Aquifer transmissivity (cubic foot per day per square foot times foot of aquifer thickness)	4,300 to 24,500 average 9,500	1,140 to 1,325	820 to 1,740 average 1,280	900	10,140 to 26,000
Aquifer hydraulic conductivity (foot per day)	14 to 82 average 35	20 to 60	---	18 to 91 average 54	45 to 80 average 65
Aquifer storage coefficient (dimensionless)	---	0.0002 to 0.00022	0.0005 to 0.001 average 0.0008	0.0019	---
Confining-unit vertical hydraulic conductivity (foot per day)	---	0.03 to 0.41	0.0014 to 0.051 average 0.0035	---	---

[1]Analysis of specific capacity data from Harned and others (1989).
[2]Aquifer test at well HP-708.
[3]Aquifer test at Hadnot Point well HP-462 from Environmental Sciences and Engineering, Inc. (1988).
[4]Unpublished aquifer test data at well X24s2x, from DEHNR well records (1985).
[5]Transmissivities based on range of aquifer thickness (table 3) and average hydraulic conductivity from Winner and Coble (1989).



EXPLANATION

—— 10 —— LINE OF EQUAL THICKNESS OF CASTLE HAYNE CONFINING UNIT--Dashed where approximately located. Interval 10 feet

10 • WELL--Number is thickness of Castle Hayne confining unit

Figure 13.--Thickness of the Castle Hayne confining unit at Camp Lejeune, North Carolina.

Relation With Other Aquifers

The Castle Hayne aquifer is overlain by the surficial aquifer and Castle Hayne confining unit, except where these units have been eroded. The Castle Hayne aquifer is either exposed in some of the tidal streams or partly covered by channel deposits or other river sediments. The Castle Hayne is not known to crop out subaerially at Camp Lejeune. The Beaufort confining unit and aquifer underlie the Castle Hayne aquifer throughout the Camp Lejeune area (plate 1).

The surficial aquifer supplies the primary recharge to the Castle Hayne aquifer. Although most of the rainfall recharge to the surficial aquifer discharges to the local streams, a relatively small amount infiltrates through the Castle Hayne confining unit to the Castle Hayne aquifer. According to Harned and others (1989), recharge to the Castle Hayne aquifer occurs in the interstream areas of Camp Lejeune where the water level in the Castle Hayne is 5 or more feet above sea level. This is where water levels in the surficial aquifer are generally 2-6 ft higher than those in the Castle Hayne aquifer.

There is some evidence to indicate a potential for ground water to move upward from the Beaufort aquifer, through the Beaufort confining unit, and recharge the Castle Hayne aquifer from below. Data from unpublished DEHNR records show that a temporary well completed in the Beaufort aquifer at well Y25q2 had a water level about 2 ft higher than a similar temporary well in the overlying Castle Hayne aquifer.

Water-level maps generated by Harned and others (1989) show ground-water naturally discharges from the Castle Hayne aquifer into the New River and major tributaries. Superimposed on this natural discharge is the manmade discharge (pumpage) from the Castle Hayne aquifer of about 7 Mgal/d. The maps from Harned and others (1989) indicate that this pumpage had no effect on the overall natural discharge regime, and that drawdown caused by pumping extends only a short distance from the pumping well. Because some channels of the New River and its tributaries cut through the Castle Hayne confining unit in places and may be hydraulically connected with the Castle Hayne aquifer, any reversal of the natural head gradient caused by pumping from the Castle Hayne aquifer near these streams could establish the potential for the movement of saltwater from the estuarine streams into the Castle Hayne aquifer.

Buried paleostream channels in the Castle Hayne aquifer have been indicated by seismic-reflection profiling (fig. 5). The buried channels near Hadnot Point are defined by gently upward-curving strong bottom reflectors and truncated side reflections (fig. 7). Variable reflection intensities within the paleostream channels indicate a nonhomogeneous channel fill; however, the type of fill is unknown. The fill deposits might be fluvial gravels, sands, silts, and clays or they could be deltaic beach sands, lagoonal deposits, peat, or shell hash.

Buried paleostream channels are also interpreted from log data based on the presence of significant amounts of organic material in samples. Hydrogeologic section A-A′ (plate 1) shows two possible buried channels at well T-7 near Wallace Creek and at well USGS-3. A 40-ft zone containing organic-rich silt and black clay with traces of wood was reported in the driller's log from well T-7. It is possible that Wallace Creek traces an older submerged and covered paleochannel. At well USGS-3, a 25-ft bed of sandy peat was also designated as a buried channel.

These buried paleostream channels may have some hydrogeologic significance. Should the normal discharge head gradient in the Castle Hayne aquifer toward the estuary become reversed due to pumping as outlined above, the potential would exist for lateral migration of saltwater along the paleostream channels that connect with the estuary. However, this potential would depend on the type of channel fill present; silt and clay channel fill would greatly retard the movement of saltwater, for example. Additional data are needed to (1) locate the landward extent of buried paleochannels and (2) determine the types of sediment contained in them.

Occurrence of Saltwater

Water containing dissolved-chloride concentration of more than 250 mg/L has not been observed in the Castle Hayne aquifer at Camp Lejeune, except for one measurement of 960 mg/L chloride in water from near the bottom of the aquifer at well USGS-8 in the southern part of the Base (table 2). All other water samples contained dissolved-chloride concentrations less than 120 mg/L, but most of the wells sampled were 200 ft deep or less. Because of the lack of data, there may be some undiscovered places where the lower part of the Castle Hayne aquifer contains saltwater, especially in the southern part of the Base. Winner and Coble (1989) also reported saltwater was not present in the Castle Hayne aquifer in the Camp Lejeune area, but as their investigation covered the entire Coastal Plain, it did not account for local occurrences of saltwater that appears to be the case at well USGS-8 (fig. 8).

Because saltwater may be present at the bottom of the Castle Hayne aquifer in some places beneath Camp Lejeune, the potential exists for saltwater contamination of wells pumping from this aquifer. Vertical movement of saltwater could occur in response to lowered head in the aquifer directly beneath a pumping well. An indication of this situation would be a gradual increase in the chloride concentration in the water from the well.

The presence and effectiveness of local confining units in the Castle Hayne aquifer to retard vertical flow and the pumping rate of the well are the determining factors in this type of contamination problem. Ground-water models of several types are used to address this problem and other questions about movement of water in aquifers. Models may also be used to indicate optimal well locations and pumping rates to minimize effects of lateral or vertical saltwater encroachment.

Beaufort Aquifer

The Beaufort aquifer underlies the Beaufort confining unit and the Castle Hayne aquifer and is composed primarily of sediments of the Beaufort Formation of Paleocene age (fig. 3). These deposits consist of fine to medium glauconitic sand, clayey sand, and clay beds of marine origin, with a few thin (3-6 ft) shell and limestone beds. The Beaufort

Formation lies unconformably on rocks of Cretaceous age (Lloyd, 1968). As with other hydrogeologic units, the Beaufort aquifer is not necessarily restricted to a single formation and may include permeable beds of older Cretaceous formations that are in hydraulic connection with the Beaufort aquifer. The bottom of the Beaufort aquifer is defined as the top of the Peedee confining unit.

The interpretation of the top of the Beaufort aquifer at Camp Lejeune was primarily based on the logs for 16 test holes that reached the unit, 9 of which are shown on plate 1. Observed altitudes of the top of the aquifer range from 153 ft below sea level at well ON-OT-1-67 to 368 ft below sea level at well HP-649; the top of the aquifer is estimated to be 485 ft below sea level at well BA-190. A number of estimates for the top of the Beaufort aquifer were also made from seismic-reflection data. The top of the aquifer dips east-southeastward across the Base at an average rate of about 25 ft/mi (fig. 14), and based on this rate, likely exceeds 600 ft below sea level in the extreme eastern part of Camp Lejeune.

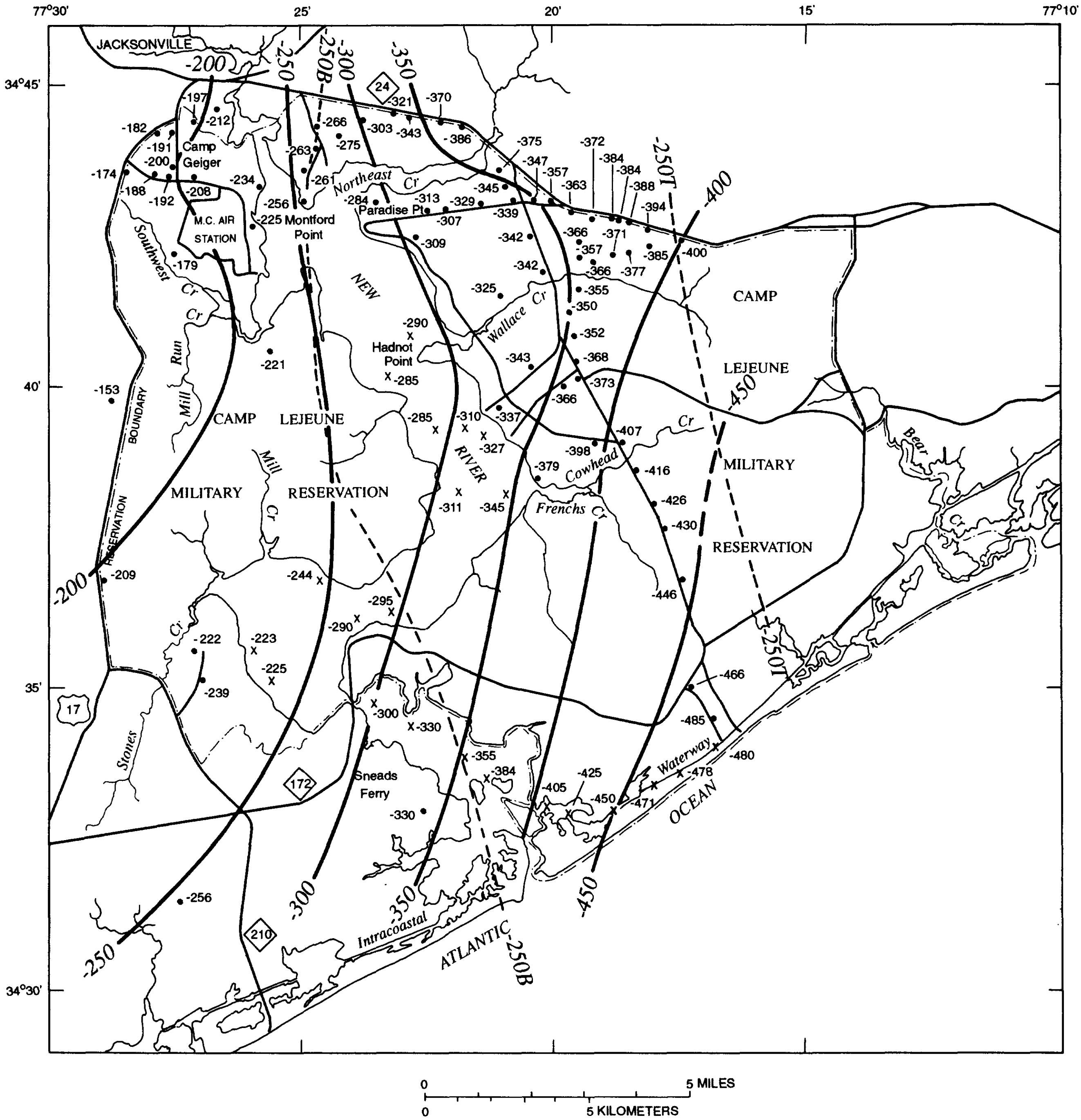
The thickness of the Beaufort aquifer was measured in 11 test holes that were drilled through the unit, and ranges from 25 ft at well Y25q2 to 86 ft at well T-15. According to Winner and Coble (1989), Camp Lejeune is located near the limit of the Beaufort aquifer, and the aquifer thins and pinches out west and northwest of the Base. However, the aquifer is estimated to be 90 ft thick, or more, in the northwestern corner of the Base near Camp Geiger (fig. 15). The estimated average thickness of the Beaufort aquifer is about 60 ft. The aquifer is thickest in a broad area over the New River estuary and in the northwestern part of Camp Lejeune (fig. 15).

Winner and Coble (1989) estimated that the percentage of permeable material in the Beaufort aquifer in the Camp Lejeune area ranges from 70 to 90 percent, with 80 percent or more occurring in the western part of the Base. They also noted that this aquifer contains a greater percentage of sand where it is a single sand unit. The Beaufort aquifer is composed of a single sand bed at each of the test holes, except at well T-1 where two beds are recognized (B-B′, plate 1).

There are no aquifer tests available for the Beaufort aquifer at Camp Lejeune with which to determine hydraulic properties of the aquifer. Model-derived transmissivity values for the Beaufort aquifer developed by Giese and others (1991) for the Camp Lejeune area ranged from less than 500 to more than 1,000 $[(ft^3/d)/ft^2]ft$. Winner and Coble (1989) estimated that the hydraulic conductivity for the Beaufort aquifer along its western margin was no more than 25 ft/d. Using this estimated hydraulic conductivity value and the observed thicknesses of the Beaufort aquifer at the Base, transmissivity of the Beaufort aquifer is estimated to range from 625 to 2,250 $[(ft^3/d)/ft^2]ft$ at Camp Lejeune.

Beaufort Confining Unit

The Beaufort confining unit overlies the Beaufort aquifer and consists of clay, silt, and sandy clay of the uppermost sediments of the Beaufort Formation, and also likely includes lowermost clay and silt beds of the overlying Castle Hayne Formation (fig. 3). In only a few places is this confining unit composed of a distinct clay; most of the available logs show this interval to be silty or sandy clay beds (plate 1).



EXPLANATION

—— -250 —— STRUCTURE CONTOUR--Shows altitude of top of Beaufort aquifer. Dashed where approximately located. Contour interval 50 feet. Datum is sea level

- - - - - -250T LINE OF EQUAL 250 MILLIGRAMS PER LITER CHLORIDE CONCENTRATION AT TOP OF BEAUFORT AQUIFER - From Winner and Coble, 1989

- - - -250B LINE OF EQUAL 250 MILLIGRAMS PER LITER CHLORIDE CONCENTRATION AT BOTTOM OF BEAUFORT AQUIFER--From Winner and Coble, 1989

-225 • WELL--Number is altitude of top of Beaufort aquifer in feet below (-) sea level

-330 X NAVIGATION FIX POINT ALONG SEISMIC PROFILE LINE (FIG. 5)--Number is estimated altitude of top of Beaufort aquifer in feet below (-) sea level

Figure 14.--Altitude of the top of the Beaufort aquifer at Camp Lejeune, North Carolina.

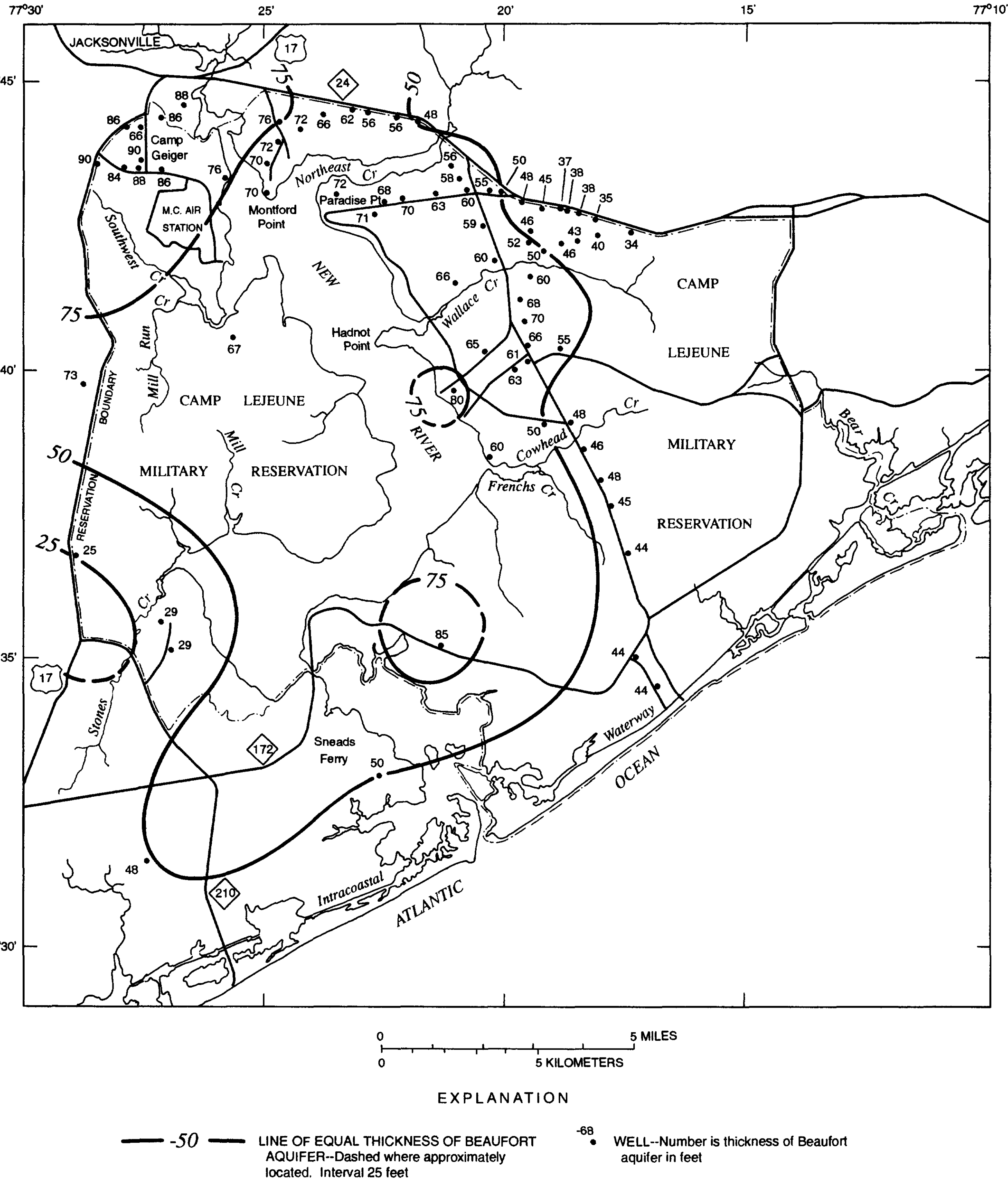


Figure 15.--Thickness of the Beaufort aquifer at Camp Lejeune, North Carolina.

The observed thickness of the Beaufort confining unit ranges from 8 ft at well T-18 to 38 ft at well TC-1253. The average thickness of the confining unit from observed and estimated values is about 19 ft (table 3). The thickness of the Beaufort confining unit was not mapped.

The general silty character of the Beaufort confining unit is similar to that of the Castle Hayne confining unit. Although the deeper unit is slightly thicker and is not known to be discontinuous, it also is likely to be only partly effective in retarding the vertical exchange of ground water between the Beaufort and Castle Hayne aquifers. The vertical hydraulic conductivity of the Beaufort confining unit is probably in the same range as that given for the Castle Hayne confining unit.

Relation With Other Aquifers

The Beaufort aquifer and confining unit are overlain by the Castle Hayne aquifer and underlain by the Peedee aquifer and confining unit throughout the study area. Within the area of Camp Lejeune, Giese and others (1991, fig. 113) show simulated recharge to the Beaufort aquifer from the Castle Hayne aquifer in the higher interstream areas of the Base. They also show that the Beaufort aquifer receives upward recharge from the Peedee aquifer in the stream valleys and other areas of the Base. At well Y25q2, a measured water level in a temporary well in the Peedee aquifer was about 0.1 ft higher than the water level in a similar temporary well in the Beaufort aquifer (unpublished DEHNR well records, 1985).

Because there are no pumping wells withdrawing water from the Beaufort aquifer in the area of Camp Lejeune, recharge to the Beaufort aquifer is balanced by discharge from it. This discharge takes place through the Beaufort confining unit and moves into the overlying Castle Hayne aquifer. Most of the upward discharge takes place beneath the streams and estuaries of the Base.

Occurrence of Saltwater

The interpretation of the presence of saltwater in the Beaufort aquifer is primarily based on a map by Winner and Coble (1989) that shows a transition from freshwater to saltwater in the Beaufort aquifer beneath Camp Lejeune. This transition zone is about 6 to 8 mi wide and extends nearly north-south through the middle of the Base (fig. 14). The aquifer entirely contains freshwater to the west of the transition zone and entirely contains saltwater to the east of the zone. Within the transition zone, the aquifer contains freshwater and saltwater, generally with the freshwater occurring on top of the denser saltwater. The position of the estimated 250 mg/L line of equal chloride concentration in the Beaufort aquifer is also shown on the hydrogeologic sections (plate 1).

A water sample from a test interval at a depth of 450 ft in the Beaufort aquifer at well Y25q2 west of the transition zone contained a chloride concentration of 22 mg/L (table 2). At well T-12, in the transition zone, a sample of water from a depth of 320 ft near the bottom of the Beaufort aquifer (plate 1) contained 340 mg/L chloride.

Peedee Aquifer

The Peedee aquifer underlies the Peedee confining unit and the Beaufort aquifer, and is composed primarily of sand of the Peedee Formation of Cretaceous age (fig. 3), which is interbedded with clay and silt. A few thin beds of calcareous sandstone and impure limestone also are interlayered with sand in some places. In the Camp Lejeune area, the top of the Peedee aquifer ranges from 235 ft below sea level at well ON-OT-1-67 to 437 ft below sea level at well X24s2x; the top is estimated to be 555 ft below sea level at well BA-190 (plate 1). The top of the Peedee aquifer slopes eastward at a rate of about 23 ft/mi (fig. 16), and Lyke and Winner (1990) report the thickness of the aquifer to range from 102 to 255 ft at the Base.

Peedee Confining Unit

The Peedee confining unit is composed of beds of clay, silt, and sandy clay that form the uppermost units of the Peedee Formation. In some places, the confining unit may also include lowermost beds of the Beaufort Formation (fig. 3). The altitude of the top of the confining unit ranges from 226 ft below sea level at well ON-OT-1-67 to 393 ft below sea level at well X24s2x. The top of the confining unit is estimated to be 529 ft below sea level at well BA-190. The observed thickness of the Peedee confining unit at Camp Lejeune ranges from 9 to 45 ft, and the average of observed and estimated thicknesses given in table 3 is about 35 ft.

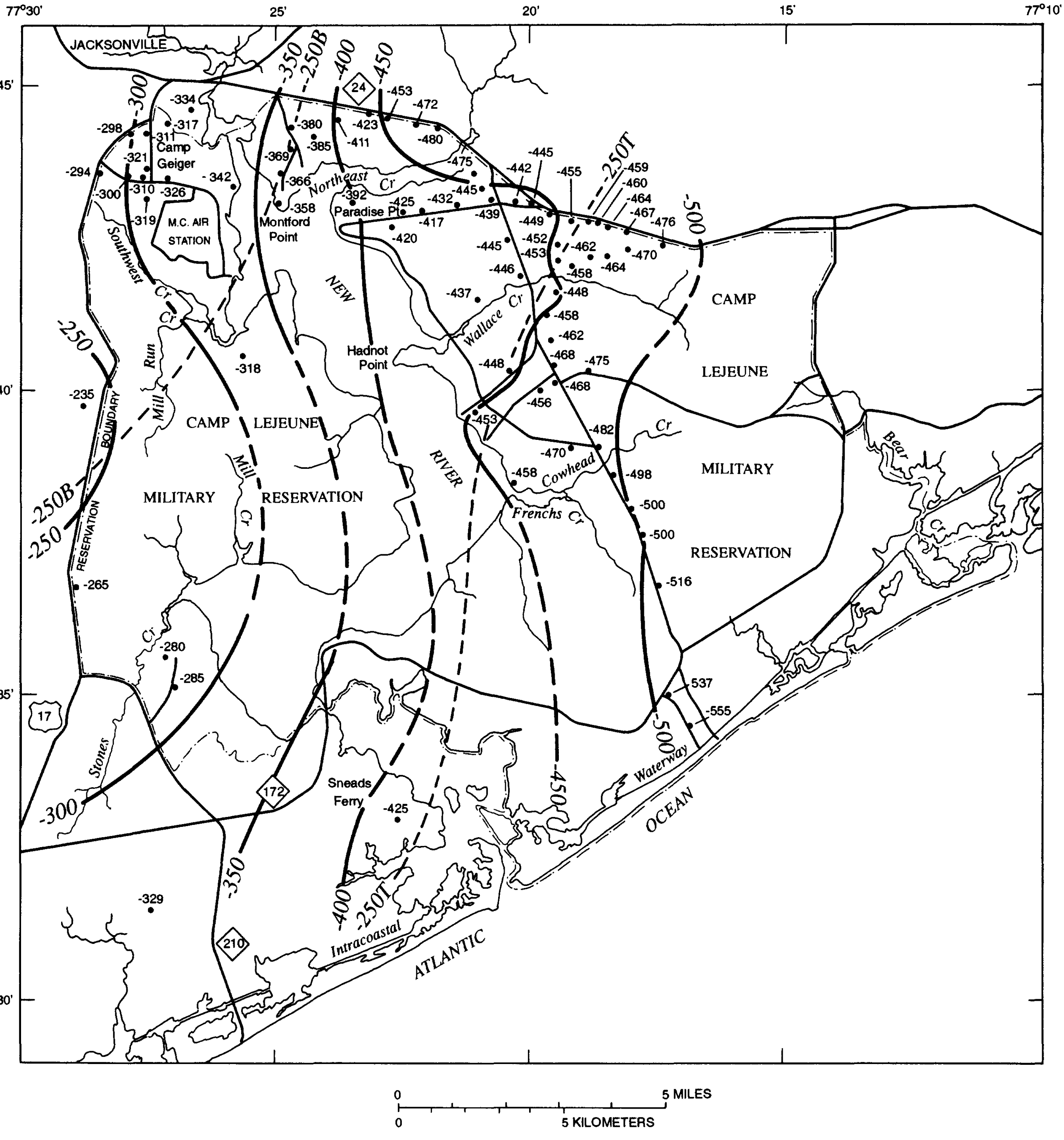
Relation With Other Aquifers

Recharge to the Peedee aquifer is mostly from overlying units north and northwest of Camp Lejeune (Giese and others, 1991, fig. 114). Discharge from the aquifer takes place as a general upward movement of ground water from the aquifer throughout the coastal area of Onslow County, including Camp Lejeune. As discussed earlier in this report, an observed water level in the Peedee aquifer was slightly higher than the water level in the overlying Beaufort aquifer.

Although Camp Lejeune does not pump water from the Peedee aquifer, north of the Base the City of Jacksonville and Onslow County water systems maintain well fields that withdraw water from the aquifer. In 1986, nearly 1 Mgal/d was pumped from the Peedee aquifer by these systems. Up to this time, pumpage from the Peedee aquifer has resulted in a total decline of about 20 ft in the water level in this aquifer in the northern area of Camp Lejeune (Lyke and Brockman, 1990). The principal effect of this pumping is to reduce the upward discharge potential from the Peedee aquifer to the Beaufort aquifer at Camp Lejeune.

Occurrence of Saltwater

The full thickness of the Peedee aquifer contains freshwater only in the northwest part of Camp Lejeune in the vicinity of Camp Geiger. This assessment is based on the study by Winner and Coble (1989) that shows a saltwater transition zone in the Peedee aquifer across



EXPLANATION

-250 STRUCTURE CONTOUR--Shows altitude of top of Peedee aquifer. Dashed where approximately located. Contour interval 50 feet. Datum is sea level

-250B LINE OF EQUAL 250 MILLIGRAMS PER LITER CHLORIDE CONCENTRATION AT BOTTOM OF PEEDEE AQUIFER--From Winner and Coble, 1989

-250T LINE OF EQUAL 250 MILLIGRAMS PER LITER CHLORIDE CONCENTRATION AT TOP OF PEEDEE AQUIFER--From Winner and Coble, 1989

-235 • WELL--Number is altitude of top of Peedee aquifer in feet below (-) sea level

Figure 16.--Altitude of the top of the Peedee aquifer at Camp Lejeune, North Carolina.

most of the western half of the Base, and is depicted on figure 16. This zone is about 6 to 8 mi wide in which the percentage of saltwater in the aquifer increases west to east.

Samples of water from test intervals in the Peedee aquifer at well Y25q2 contained chloride concentrations ranging from 266 to 1,600 mg/L, and a sample of water from a test interval at well X24s2x contained 730 mg/L chloride concentration (table 2). Both these well sites are in the transition zone near its western limit.

SUMMARY

The U.S. Marine Corps Base at Camp Lejeune is located along the New River and adjacent to the Atlantic Ocean in Onslow County, North Carolina. Increasing growth in population at Camp Lejeune has resulted in an increased demand for water supply. Concerns about the potential for contamination of ground-water supplies by hazardous wastes generated on the Base and the need for information to determine the best management practices to minimize the threat of contamination and to assure a continuing supply of freshwater for the Base prompted initiation of a study of the hydrogeology of Camp Lejeune.

Camp Lejeune is in the Tidewater region of the Coastal Plain and is on an eastward-thickening wedge of unconsolidated or partly consolidated beds of sand, silt, clay, calcareous clay, shells, and limestone that is about 1,500 ft thick at the Base. Aquifers that occur beneath the Base include the surficial, Castle Hayne, Beaufort, Peedee, Black Creek, and upper and lower Cape Fear. Between each of these aquifers is a confining unit of clay and silt of varying thickness that serves to retard the movement of water between the aquifers. Although the surficial, Castle Hayne, Beaufort, and Peedee aquifers contain freshwater, only the Castle Hayne is used by Camp Lejeune as a water supply. The principal focus of this report in on the Castle Hayne and the other freshwater-bearing aquifers.

Hydrogeologic units at Camp Lejeune were mapped using borehole geophysical logs and seismic-reflection profiling in the New River. Acoustic-velocity logs from Camp Lejeune wells were used to convert seismic travel times to depths.

Water-level data were used to assess the degree of hydraulic connection between aquifers and the hydraulic continuity within aquifers. Water-quality data consisted largely of chloride concentrations, which were used to establish the position of the saltwater-freshwater interface in the deeper parts of the aquifer system.

The surficial aquifer at Camp Lejeune is the uppermost aquifer and consists of sand, clay, sandy clay, and silt beds of Quaternary and Miocene age. This aquifer ranges from 0 to 73 ft thick and is composed of 70 to 90 percent sand. The surficial aquifer is generally thickest in interstream areas of the Base and is absent where cut by the New River and its tributaries. Based on a general composition of fine sand mixed with some silt and clay, the hydraulic conductivity of the surficial aquifer is estimated to be about 50 ft/d.

Recharge to the surficial aquifer is by rainfall, but most of this water is discharged to local streams. Some recharge reaches the underlying Castle Hayne aquifer through the Castle Hayne confining unit. Saltwater has not been detected in the surficial aquifer.

The Castle Hayne aquifer is composed of sand, shell rock, and limestone of the River Bend Formation of Oligocene age and the Castle Hayne Formation of Eocene age. The top of this unit ranges from 10 ft above to 68 ft below sea level, and east of New River, slopes southeastward about 10 ft/mi. The observed thickness of the Castle Hayne aquifer ranges from 156 to 400 ft, but may be more than 500 ft thick at the eastern boundary of the Base.

The amount of permeable material (sand and limestone) in the Castle Hayne aquifer ranges from less than 60 percent to more than 90 percent. Estimates of the hydraulic conductivity of the Castle Hayne aquifer at Camp Lejeune range from 14 to 91 ft/d, a wide local variation.

The Castle Hayne confining unit overlies the Castle Hayne aquifer and is composed of beds of clay, silt, and sandy clay. This unit averages about 9 ft thick where it is present and ranges from 0 to 26 ft in thickness. The confining unit is incised by the New River and its tributaries, and seismic data also show the presence of paleochannels which have cut through the confining unit.

Recharge to the Castle Hayne aquifer is mostly by downward percolation from the surficial aquifer in interstream areas on the Base. Water-level data indicate there is also the potential for water in the underlying Beaufort aquifer to move upward into the Castle Hayne aquifer.

Ground water naturally discharges from the Castle Hayne aquifer beneath New River and its tributaries. Manmade discharge consists of about 7 Mgal/d pumpage from wells to supply Camp Lejeune. Water-level maps from an earlier study show that this pumpage has no effect on the overall natural discharge regime in the Castle Hayne aquifer. Pumping effects extend only short distances from wells pumping from this aquifer. However, because the Castle Hayne confining unit is missing in places beneath streams, any reversal of natural head gradient caused by pumping from the Castle Hayne aquifer near these streams may establish a potential for the movement of saltwater from these estuarine streams into the aquifer. Paleostream channels linking the Castle Hayne aquifer with the estuary may also provide a hydraulic conduit for lateral migration of saltwater in a similar fashion depending on the type of channel fill present.

Water containing dissolved-chloride concentration of more than 120 mg/L has not been observed in the Castle Hayne aquifer, except for one measurement of 960 mg/L in water taken from the lower part of the aquifer. Whether or not this is a localized occurrence of saltwater in the aquifer is not known. Thus, a potential exists for the upward movement of saltwater from the bottom of the Castle Hayne aquifer toward the intake of a pumping well at a higher level in the aquifer.

The Beaufort aquifer underlies the Castle Hayne aquifer and is separated from it by the Beaufort confining unit. This aquifer is composed of fine to medium glauconitic sand, clayey sand, silt, sand, and shell and limestone beds. The top of the Beaufort aquifer ranges from 153 to 368 ft below sea level, and averages about 60 ft thick. Sand constitutes 70 to 90 percent of the aquifer with an estimated hydraulic conductivity of 25 ft/d. The Beaufort confining unit consists of clay, silt, and sandy clay beds averaging nearly 20 ft thick.

Freshwater occurs in the Beaufort aquifer in the western quarter of Camp Lejeune. East and south of the New River there is a transition zone where water in the aquifer progressively becomes salty from bottom to top in an easterly direction. In this transition zone, a water sample from the bottom of the Beaufort aquifer contained 340 mg/L chloride.

The Peedee aquifer underlies the Beaufort aquifer at depths ranging from 235 to 437 ft below sea level. The Peedee confining unit separates the two aquifers. The Peedee aquifer is composed mostly of sand interlayered with clay and silt beds. The top of the aquifer slopes eastward at a rate of about 23 ft/mi, and the thickness of the Peedee aquifer ranges from 102 to 255 ft at Camp Lejeune, as reported in an earlier study. The clay and silt beds that form the Peedee confining unit range from 9 to 45 ft thick.

Freshwater in the Peedee aquifer occurs only in the northwestern part of Camp Lejeune. East and southeast of this area, water in the aquifer increases in salt content from bottom to top. In the freshwater-saltwater transition zone, a sample of water near the bottom of the Peedee aquifer contained 1,600 mg/L chloride.

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