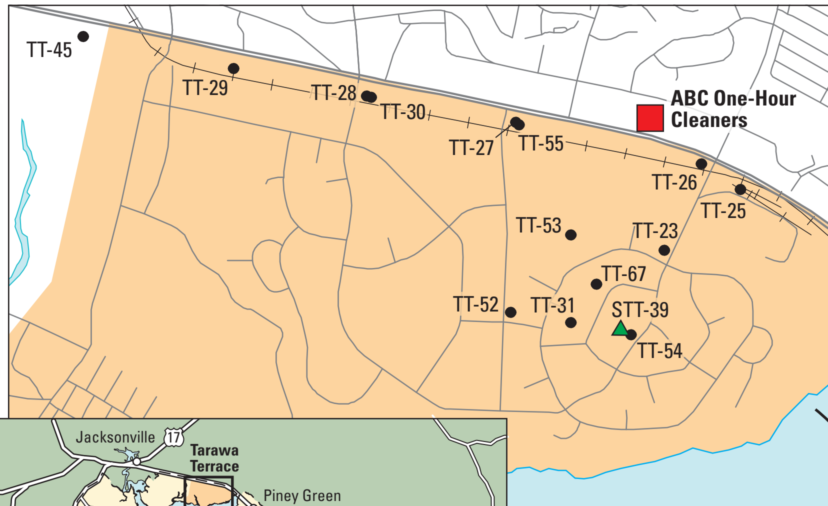
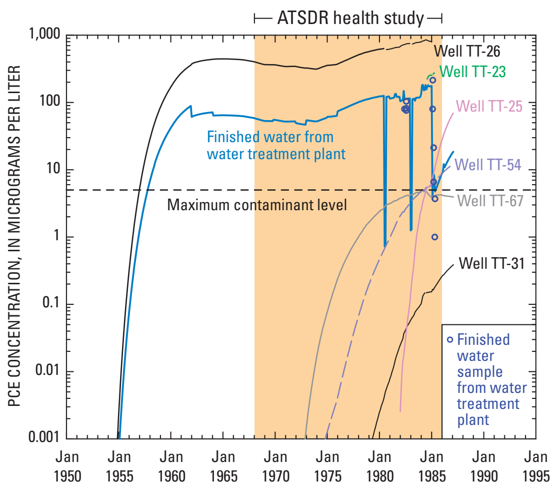
Analyses of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water at Tarawa Terrace and Vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina: Historical Reconstruction and Present-Day Conditions

Chapter B: Geohydrologic Framework of the Castle Hayne Aquifer System





DEPARTMENT OF HEALTH & HUMAN SERVICES · USA

ATSDR
AGENCY FOR TOXIC SUBSTANCES AND DISEASE REGISTRY

Atlanta, Georgia–September 2007

Front cover: Historical reconstruction process using data, information sources, and water-modeling techniques to estimate historical exposures

Maps: U.S. Marine Corps Base Camp Lejeune, North Carolina; Tarawa Terrace area showing historical water-supply wells and site of ABC One-Hour Cleaners

Photographs on left: Ground storage tank STT-39 and four high-lift pumps used to deliver finished water from tank STT-39 to Tarawa Terrace water-distribution system

Photograph on right: Equipment used to measure flow and pressure at a hydrant during field test of the present-day (2004) water-distribution system

Graph: Reconstructed historical concentrations of tetrachloroethylene (PCE) at selected water-supply wells and in finished water at Tarawa Terrace water treatment plant

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By Robert E. Faye

Agency for Toxic Substances and Disease Registry
U.S. Department of Health and Human Services
Atlanta, Georgia

September 2007

ATSDR
AGENCY FOR TOXIC SUBSTANCES
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Foreword

The Agency for Toxic Substances and Disease Registry (ATSDR), an agency of the U.S. Department of Health and Human Services, is conducting an epidemiological study to evaluate whether in utero and infant (up to 1 year of age) exposures to volatile organic compounds in contaminated drinking water at U.S. Marine Corps Base Camp Lejeune, North Carolina, were associated with specific birth defects and childhood cancers. The study includes births occurring during the period 1968–1985 to women who were pregnant while they resided in family housing at the base. During 2004, the study protocol received approval from the Centers for Disease Control and Prevention Institutional Review Board and the U.S. Office of Management and Budget.

Historical exposure data needed for the epidemiological case-control study are limited. To obtain estimates of historical exposure, ATSDR is using water-modeling techniques and the process of historical reconstruction. These methods are used to quantify concentrations of particular contaminants in finished water and to compute the level and duration of human exposure to contaminated drinking water.

Final interpretive results for Tarawa Terrace and vicinity—based on information gathering, data interpretations, and water-modeling analyses—are presented as a series of ATSDR reports. These reports provide comprehensive descriptions of information, data analyses and interpretations, and modeling results used to reconstruct historical contaminant levels in drinking water at Tarawa Terrace and vicinity. Each topical subject within the water-modeling analysis and historical reconstruction process is assigned a chapter letter. Specific topics for each chapter report are listed below:

- **Chapter A**: Summary of Findings
- **Chapter B**: Geohydrologic Framework of the Castle Hayne Aquifer System
- **Chapter C**: Simulation of Groundwater Flow
- **Chapter D**: Properties and Degradation Pathways of Common Organic Compounds in Groundwater
- **Chapter E**: Occurrence of Contaminants in Groundwater
- **Chapter F**: Simulation of the Fate and Transport of Tetrachloroethylene (PCE) in Groundwater
- **Chapter G**: Simulation of Three-Dimensional Multispecies, Multiphase Mass Transport of Tetrachloroethylene (PCE) and Associated Degradation By-Products
- **Chapter H**: Effect of Groundwater Pumping Schedule Variation on Arrival of Tetrachloroethylene (PCE) at Water-Supply Wells and the Water Treatment Plant
- **Chapter I**: Parameter Sensitivity, Uncertainty, and Variability Associated with Model Simulations of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water
- **Chapter J**: Field Tests, Data Analyses, and Simulation of the Distribution of Drinking Water
- **Chapter K**: Supplemental Information

An electronic version of this report, *Chapter B: Geohydrologic Framework of the Castle Hayne Aquifer System*, and its supporting information and data will be made available on the ATSDR Camp Lejeune Web site at *http://www.atsdr.cdc.gov/sites/lejeune/index.html.* Readers interested solely in a summary of this report or any of the other reports should refer to *Chapter A: Summary of Findings* that also is available at the ATSDR Web site.

Contents

Figures

Tables

Conversion Factors

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Volume	
million gallons (MG)	3,785	cubic meter (m^3)
	Flow rate	
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
million gallons per day (MGD)	3,785	cubic meters per day (m^3/d)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Glossary and Abbreviations

DCE	1,1-DCE	1,1-dichloroethylene or 1,1-dichloroethene
	1,2-DCE	1,2-dichloroethylene or 1,2-dichloroethene
	1,2-cDCE	*cis*-1,2-dichloroethylene or *cis*-1,2-dichloroethene
	1,2-tDCE	*trans*-1,2-dichloroethylene or *trans*-1,2-dichloroethene

PCE tetrachloroethene, tetrachloroethylene, 1,1,2,2-tetrachloroethylene, or perchloroethylene; also known as PERC® or PERK®

TCE 1,1,2-trichloroethene, 1,1,2-trichloroethylene, or trichloroethylene

Analyses of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water at Tarawa Terrace and Vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina: Historical Reconstruction and Present-Day Conditions

Chapter B: Geohydrologic Framework of the Castle Hayne Aquifer System

By Robert E. Faye[1]

Abstract

Two of three water-distribution systems that have historically supplied drinking water to family housing at U.S. Marine Corps Base Camp Lejeune, North Carolina, were contaminated with volatile organic compounds (VOCs). Tarawa Terrace was contaminated mostly with tetrachloroethylene, and Hadnot Point was contaminated mostly with trichloroethylene. Because scientific data relating to the harmful effects of VOCs on a child or fetus are limited, the Agency for Toxic Substances and Disease Registry (ATSDR), an agency of the U.S. Department of Health and Human Services, is conducting an epidemiological study to evaluate potential associations between in utero and infant (up to 1 year of age) exposures to VOCs in contaminated drinking water at Camp Lejeune and specific birth defects and childhood cancers. The study includes births occurring during the period 1968–1985 to women who were pregnant while they resided in family housing at Camp Lejeune. Because limited measurements of contaminant and exposure data are available to support the epidemiological study, ATSDR is using modeling techniques to reconstruct historical conditions of groundwater flow, contaminant fate and transport, and the distribution of drinking water contaminated with VOCs delivered to family housing areas. This report, Chapter B, provides detailed analyses and interpretations of well and geohydrologic data used to develop the geohydrologic framework of the Castle Hayne aquifer system at Tarawa Terrace and vicinity.

Background

U.S. Marine Corps Base Camp Lejeune, North Carolina, is located in the Coastal Plain of North Carolina, in Onslow County, southeast of the City of Jacksonville and about 70 miles northeast of the City of Wilmington, North Carolina. The major cultural and geographic features of Camp Lejeune are shown in Figure B1 and on Plate 1. A major focus of this investigation is the water-supply and distribution network at Tarawa Terrace, a noncommissioned officers' housing area located near the northwest corner of the base (Plate 1). Tarawa Terrace was constructed during 1951 and was subdivided into housing areas I and II. Areas I and II originally contained a total of 1,846 housing units described as single, duplex, and multiplex, and accommodated a resident population of about 6,000 persons. (Sheet 3 of 18, Map of Tarawa Terrace II Quarters, June 30, 1961; Sheet 7 of 34, Tarawa Terrace I Quarters, July 31, 1984). The general area of Tarawa Terrace is bordered on the east by Northeast Creek, to the south by New River and Northeast Creek, and generally to the west and north by drainage boundaries of these streams.

Groundwater is the source of contaminants that occurred in the water-distribution system at Tarawa Terrace and was supplied to the distribution system via water-supply wells. Contamination of groundwater by a halogenated hydrocarbon, tetrachloroethylene (PCE), was first detected in water supplies at Tarawa Terrace during 1982 (Written communication, Grainger Laboratories, August 10, 1982). The source of contamination was later determined to be ABC One-Hour Cleaners, located on North Carolina Highway 24 (SR 24) and west and slightly north of several Tarawa Terrace water-supply wells (Shiver 1985, Figure 4). Production at supply wells TT-26 and TT-23 was terminated during February 1985 because of contamination by PCE and related degradation products, trichloroethylene (TCE), and dichloroethene (DCE).

Historical reconstruction characteristically includes the application of simulation tools, such as models, to re-create or represent past conditions. At Camp Lejeune, historical reconstruction methods include linking materials mass balance (mixing) and water-distribution system models to groundwater fate and transport models. Groundwater fate and transport

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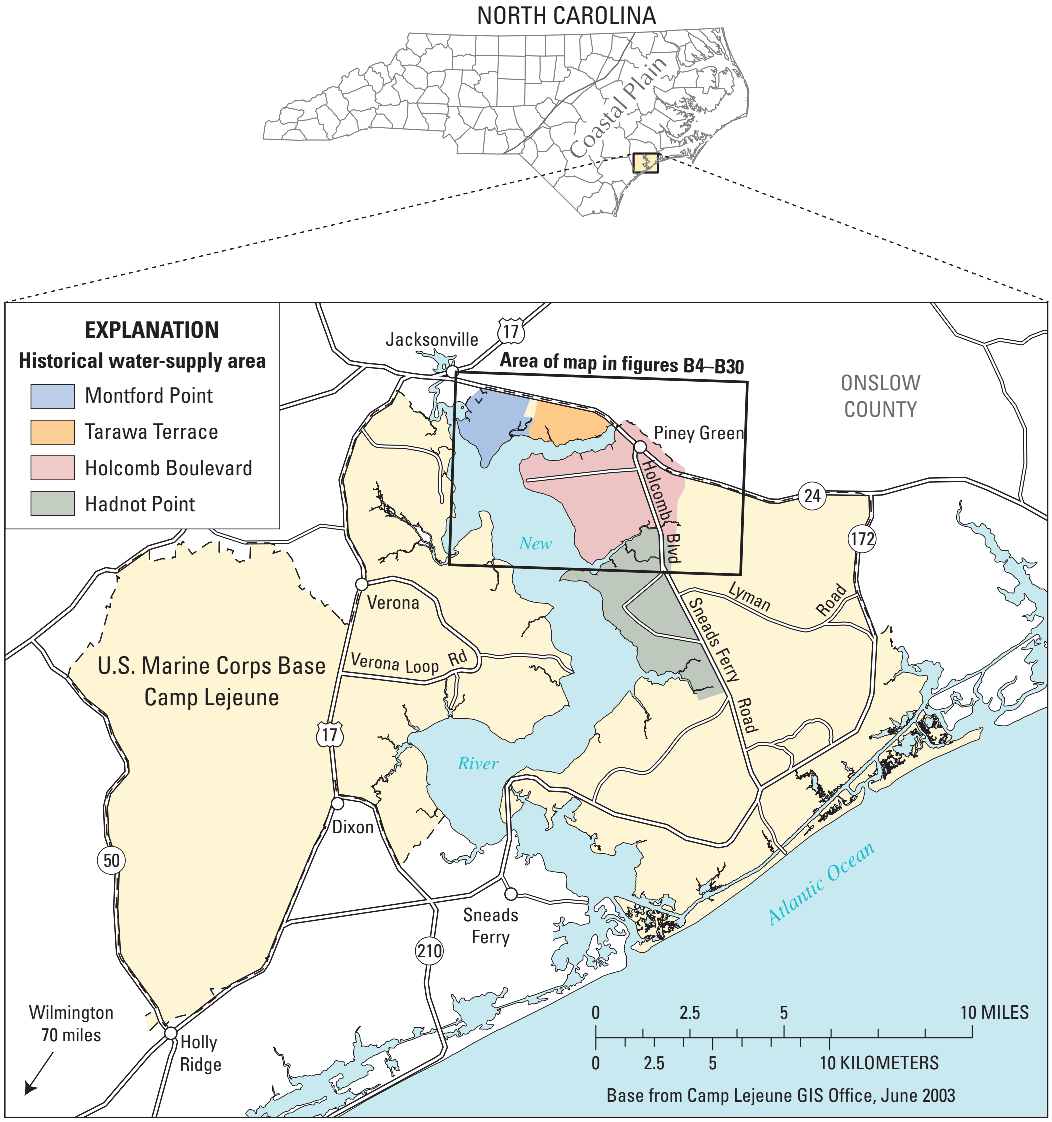


Figure B1. Cultural and geographic features of U.S. Marine Corps Base Camp Lejeune, North Carolina.

models are based to a large degree on groundwater-flow velocities or specific discharges simulated by a groundwater-flow model. The groundwater-flow model is characterized by the vertical and spatial distribution of aquifers and confining units and their related hydraulic characteristics, such as hydraulic conductivity and specific storage. The unified assemblage of hydraulic characteristics and the related geologic, hydraulic and hydrologic elements that characterize vertically contiguous aquifers and confining units is termed in this report a geohydrologic framework. An aquifer system is defined herein as comprised of two or more water-bearing units separated at least locally by confining units that impede the vertical movement of groundwater but do not greatly affect the hydraulic continuity of the system (Poland et al. 1972). The Castle Hayne aquifer system described in this report generally comprises the "Castle Hayne aquifer" of Harned et al. (1989) and Cardinell et al. (1993) and the Castle Hayne Formation and so-called "limestone unit" of LeGrand (1959).

Purpose of Study

This study seeks to describe and quantify the geometry, hydraulic characteristics, and potentiometric levels of the aquifers and confining units that comprise the Castle Hayne aquifer system and overlying water-bearing units in the vicinity of Tarawa Terrace, Marine Corps Base Camp Lejeune. The study area generally includes those parts of Marine Corps Base Camp Lejeune between New River and Northeast Creek and between Wallace and Northeast Creeks (Plate 1). Unit geometry is described in terms of the altitude at the top of contiguous units and unit thickness. Hydraulic characteristics of aquifer units are described in terms of horizontal hydraulic conductivity. Potentiometric levels are represented by contour maps of water levels measured at wells. Potentiometric gradients defined by these water-level contours generally correspond to directions of groundwater flow.

Previous Investigations

Investigations of groundwater supplies in the area that would later become Marine Corps Base Camp Lejeune were conducted by David C. Thompson of the U.S. Geological Survey during April 1941 and reported to the Navy Department by memorandum (Thompson 1941). Thompson's report briefly described the results of test well drilling in the vicinities of Paradise Point and Hadnot Point (Plate 1) and concluded that the best sources of groundwater were the limestone rocks and related coquina rocks of the Castle Hayne Formation.

LeGrand (1959) evaluated the contemporary water supply at Camp Lejeune east of New River and constructed 22 test wells to depths ranging from about 200 to 500 feet (ft). Detailed construction and lithologic data were collected at most test sites along with geophysical logs, water-level, and water-quality data. Boreholes T-9 to T-14 were constructed at or near Tarawa Terrace and provided the first detailed description of the Castle Hayne aquifer system in that part of Camp Lejeune. Electric logs obtained during this investigation were instrumental in identifying the geohydrologic units that comprise the Castle Hayne aquifer system throughout the eastern part of Camp Lejeune.

Shiver (1985) summarized the results of investigations of contaminated groundwater in two Tarawa Terrace supply wells and in three test wells north of Tarawa Terrace, located to identify the source of PCE contamination. Well-construction, water-level, and lithologic data were included in the report along with concentrations of selected contaminant constituents. The source of contamination was identified as the ABC One-Hour Cleaners, located west and slightly north of Tarawa Terrace supply wells TT-25 and TT-26 at 2127 Lejeune Boulevard (SR 24) (Plate 1).

Harned et al. (1989) conducted a comprehensive and detailed review of groundwater data and conditions throughout Camp Lejeune during 1986 and 1987. Water-level measurements were obtained at almost all supply and other observation wells. Continuous water-level data at several supply and observation wells were published in the form of hydrographs for several months during 1986 and 1987. Construction and well-capacity test data also were reported for many wells. Annual water-use as an average in millions of gallons per day (MGD) was reported for seven Camp Lejeune water treatment plants (WTPs), including Tarawa Terrace, for the period 1975–1987. Existing borehole geophysical logs and drillers' logs were assembled, and additional geophysical logs were collected at test wells and where existing wells were accessible. Published well data refer to the period 1941–1986, when most of the supply wells were constructed at Camp Lejeune. Significantly, three "hydrogeologic" sections were constructed generally from east to west and north to south across Camp Lejeune east of the New River. These sections subdivide the "Castle Hayne aquifer" into several distinct aquifers and confining units based on the correlation of generally continuous clays. The vertical sequence of sediments represented on each section extends generally from land surface to the base of the Castle Hayne aquifer system. Correlation of units from site to site was based largely on borehole electric-log signatures. Borehole electric logs, well capacity and pump test data, well-location maps, and water-level data collected by Harned et al. (1989) provided the bases for much of the geohydrologic framework described herein.

Cardinell et al. (1993) used much of the borehole data collected previously by Harned et al. (1989) to extend "hydrogeologic" sections west of the New River and south to the coastal margin of Camp Lejeune. Highly generalized maps showing the altitude at the top and base of the "Castle Hayne aquifer" also were constructed for the entire Marine Corps Base Camp Lejeune area. Seismic-reflection or surface resistivity data were collected and analyzed and used to estimate the base of the "Castle Hayne aquifer" at several points within Tarawa Terrace.

Roy F. Weston, Inc. (1992, 1994) conducted detailed investigations of groundwater contamination at and in the vicinity of ABC One-Hour Cleaners including the drilling, construction, and sampling of 25 monitor wells open to the "surficial aquifer" and "Castle Hayne aquifer" and 25 soil borings, which sampled the unsaturated zone in the immediate vicinity of ABC One-Hour Cleaners (Roy F. Weston, Inc. 1992, 1994). Several monitor wells were located within and immediately adjacent to Tarawa Terrace and proximate to several Tarawa Terrace supply wells, as well as north and west of ABC One-Hour Cleaners. Borehole logs of the monitor wells and concentrations of contaminant constituents in samples from these wells provided detailed descriptions of the lithology of the "surficial aquifer" and the distribution of contaminants within the "surficial aquifer." In addition, hydrocone samples were obtained at various depths at 47 locations mostly in the immediate vicinity of ABC One-Hour Cleaners and between Lejeune Boulevard (SR 24) and the Tarawa Terrace housing area. Concentrations of PCE at hydrocone locations ranged from not detected to 30,000 micrograms per liter (µg/L). Aquifer tests were conducted in conjunction with several monitor wells. Corresponding values of horizontal hydraulic conductivity ranged from about 10 to 30 feet per day (ft/d) for the "surficial aquifer." Storativity ranged from magnitude 10^{-4} to 10^{-3}. Contemporaneous water-level data collected at paired monitor wells open, respectively, to the "surficial aquifer" and "Castle Hayne aquifer" indicated little or no difference in head between the aquifers. Where a vertical hydraulic gradient was noted, the gradient was generally downward.

Baker Environmental, Inc. (1998) constructed a digital groundwater-flow model of the entire Camp Lejeune area to evaluate water-level changes and related effects of groundwater pumping at several groundwater remediation project sites (Baker Environmental 1998). The model was vertically subdivided into five layers corresponding to a "surficial unit," a "Castle Hayne confining unit," an "Upper Castle Hayne aquifer," a "Castle Hayne fractured limestone unit," and a "Lower Castle Hayne aquifer." These framework components generally correspond to the subdivisions described in sections published in Harned et al. (1989) and Cardinell et al. (1993). Recharge to the water table was simulated at a rate of 11 inches per year.

In addition to the investigations cited previously, more than 20 reports describing the site investigation and removal of underground storage tanks provided water-level and borehole lithologic data at many sites at Tarawa Terrace. These data generally correspond only to the "surficial aquifer," but several reports provided data for the "Castle Hayne aquifer" as well. Results of these investigations and related site data are summarized in Faye and Green (2007).

In the southern part of Tarawa Terrace just north of the shore line with New River, several reports describe the results of comprehensive and areally extensive investigations of groundwater hydrocarbon contamination caused by leaking underground storage tanks. Monitor well data here are similar to those reported in the vicinity of ABC One-Hour Cleaners indicating little or no difference in head between the "surficial aquifer" and "Castle Hayne aquifer." Similarly, aquifer-test results indicate that horizontal hydraulic conductivites of the "surficial aquifer" range from 1 to about 10 ft/d (Law Engineering, Inc. 1994a, b, 1995a, b; Richard Catlin & Associates, Inc. 1994a, b, 1995a, b).

Methods of Study

Borehole geophysical logs, particularly single-point electric logs, were used as aids to determine the lithology and variations in lithology with depth at well sites throughout the study area (Figure B2). Permeable units such as sands and limestone saturated with freshwater (less than 5,000 milligrams per liter of total dissolved solids) generally correspond to zones of high electrical resistivity and are commonly open to screened intervals in wells and understood to be water bearing. Conversely, poorly permeable zones, such as clays and marls, correspond to zones of high electrical conductivity and low resistivity and are commonly understood to yield little or no water to wells. Using these relations as guidelines in conjunction with descriptions of rocks and sediments noted on drillers' logs and borehole logs, vertically contiguous and dissimilar lithologic units were identified at well and borehole sites as aquifers and confining units. The altitude of the contact between identified aquifers and confining units were recorded at each site for each unit (Tables B3–B14).

[2] Kriging: A regression technique used in geostatistics to approximate or interpolate field data

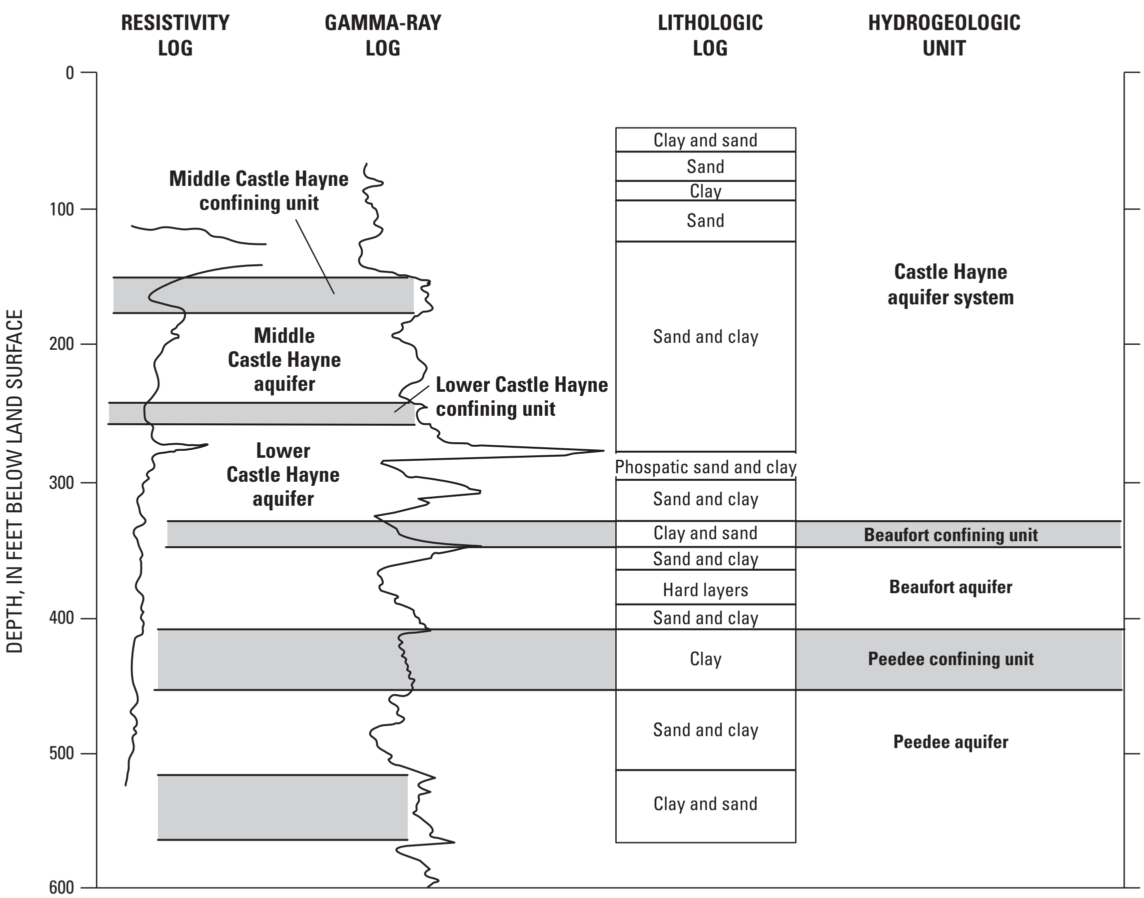


Figure B2. Correlation of geophysical logs and lithologic log, borehole X24S2a, U.S. Marine Corps Base Camp Lejeune, North Carolina (modified from Cardinell et al. 1993, Figure 4).

Correlation of units from well site to well site or borehole site within the study area was accomplished by comparing similar lithologies and electric log signatures and generally conforming to corresponding selections noted on the "hydrogeologic" sections of Harned et al. (1989) and Cardinell et al. (1993) (Figure B3, this report). The altitude at the top of selected units was then distributed spatially as point data and interpolated to the remainder of the study area using a method of Kriging[2]. Similar methods were used to map the thickness of selected units, potentiometric levels, and horizontal hydraulic conductivity (Figs. B4–B30). Point data used to map unit thickness were the differences in altitude between a unit top and bottom at a single site. For most units, the number of point data used to map a surface was greater than the number used to map thickness, because electric or borehole logs did not penetrate the entire thickness of a unit at every site. Accordingly, a direct comparison of unit altitude and thickness at a specific site may not exactly correspond to the mapped altitude shown for a vertically adjacent site, particularly when such comparisons are made using thickness and surface maps of the deeply buried units such as the Middle and Lower Castle Hayne aquifers and confining units. Such differences are generally less than two contour intervals as shown on the respective surface maps. Regardless of vertical placement, contours of unit top or thickness shown on all hydrogeologic unit maps should be considered estimated or approximate and subject to change, as additional relevant data become available. Coordinate locations of Hadnot Point water-supply wells used in this series of reports were current at the time of analysis and may differ slightly from updated coordinate locations published in subsequent reports.

Horizontal hydraulic conductivity at several locations was determined entirely from well acceptance and capacity test data, which most frequently was derived from step-drawdown tests. Step-drawdown tests typically record drawdown over time at a single well during several changes in well discharge rate. Several tests were distance-drawdown or single-well aquifer tests. Distance-drawdown tests use a single pumping well discharging at a constant rate and several observation wells located at different radial distances from the pumping well. Once a static drawdown condition is achieved in each observation well, water levels are measured in the observation and pumping wells and, along with discharge rate and radial distances, are recorded as test results. Single-well tests record drawdown over time during a period of constant well discharge. Transmissivity was computed as a result of each aquifer test regardless of test method. Horizontal hydraulic conductivity was calculated by dividing transmissivity by the assigned aquifer thickness or, where thickness was unknown, by the total open interval of the well. All methods of aquifer-test analysis used in this study were based on confined aquifer conditions. Analysis of step-drawdown data was based largely on the method described by Rorabaugh (1953) with modifications and additions suggested by Earlougher (1977) and Lee (1982). Distance-drawdown analyses are principally graphical and were based on methods described by Weissman et al. (1977). Single-well test data related to a constant discharge rate were analyzed using the method described by Cooper and Jacob (1946). Tests where water levels were recorded in one or more observation wells during pumping at a distal well were analyzed using the Hantush Leaky Aquifer method (Hantush and Jacob 1955). All data analyses, regardless of test methods, used computer codes written for the public domain by Halford and Kuniansky (2002). The extrapolation of horizontal hydraulic conductivity point data to the entire study area was accomplished by interpolation based on Kriging methodology. Contour maps of horizontal hydraulic conductivity are intended to represent general trends and changes in conductivity at a base-wide scale and may not accurately represent highly specific, local conditions such as test results at a single well.

Geologic Framework

Geologic units of interest to this study are those that occur at or near land surface and extend to a depth generally recognized as the base of the Castle Hayne Formation. The lithostratigraphic top of the Castle Hayne Formation has not been definitively identified. In the northern part of Tarawa Terrace, borehole logs collected in conjunction with the drilling of monitor wells by Roy F. Weston, Inc. (1992, 1994) variously identify the top of the Castle Hayne Formation, "Castle Hayne Limestone," or the "Castle Hayne aquifer" at or near the top of the first occurrence of limestone or shell limestone, at an approximate depth ranging from 60 to 70 ft at most sites but ranging in depth to about 90 ft at one location. Overlying this limestone or fossiliferous rock is a dark gray silty clay, silt, or sandy silt that ranges in thickness from about 5 to 15 ft. This clay is also identified as a "lean" and sandy clay. For this study, the top of this clay or sandy silt is assigned as the top of the Castle Hayne Formation. Borehole and other drillers' and geophysical logs in the remainder of the study area do not identify the top of the Castle Hayne Formation. Also, the first occurrence of limestone or fossiliferous rocks cannot always be used as an approximate indicator of the Castle Hayne Formation because similar rocks occur in progressively higher (younger) sediments to the south and southeast of Tarawa Terrace. However, the clay noted previously at the assigned top of the Castle Hayne Formation is a well-recognized, generally persistent, geohydrologic unit that occurs throughout most of the study area (Harned et al., 1989, Sections A–A', B–B', and C–C'; Cardinell et al., 1993, Sections A–A' and B–B') and is designated herein the Local confining unit (Figure B3, this report). Consequently, contours of constant altitude at the top of the Local confining unit are considered to also approximate the top of the Castle Hayne Formation. As shown in Figure B15, the top of the Castle Hayne Formation occurs in the northern part of and west of Tarawa Terrace at altitudes ranging from about –20 to –30 ft (Table B8), and dips to the east-southeast at a generally uniform rate to the vicinity of Wallace Creek, where the altitude at the top of the unit at one location is less than –110 ft.

The base of the Castle Hayne Formation is reported by Harned et al. (1989) and Cardinell et al. (1993) to occur

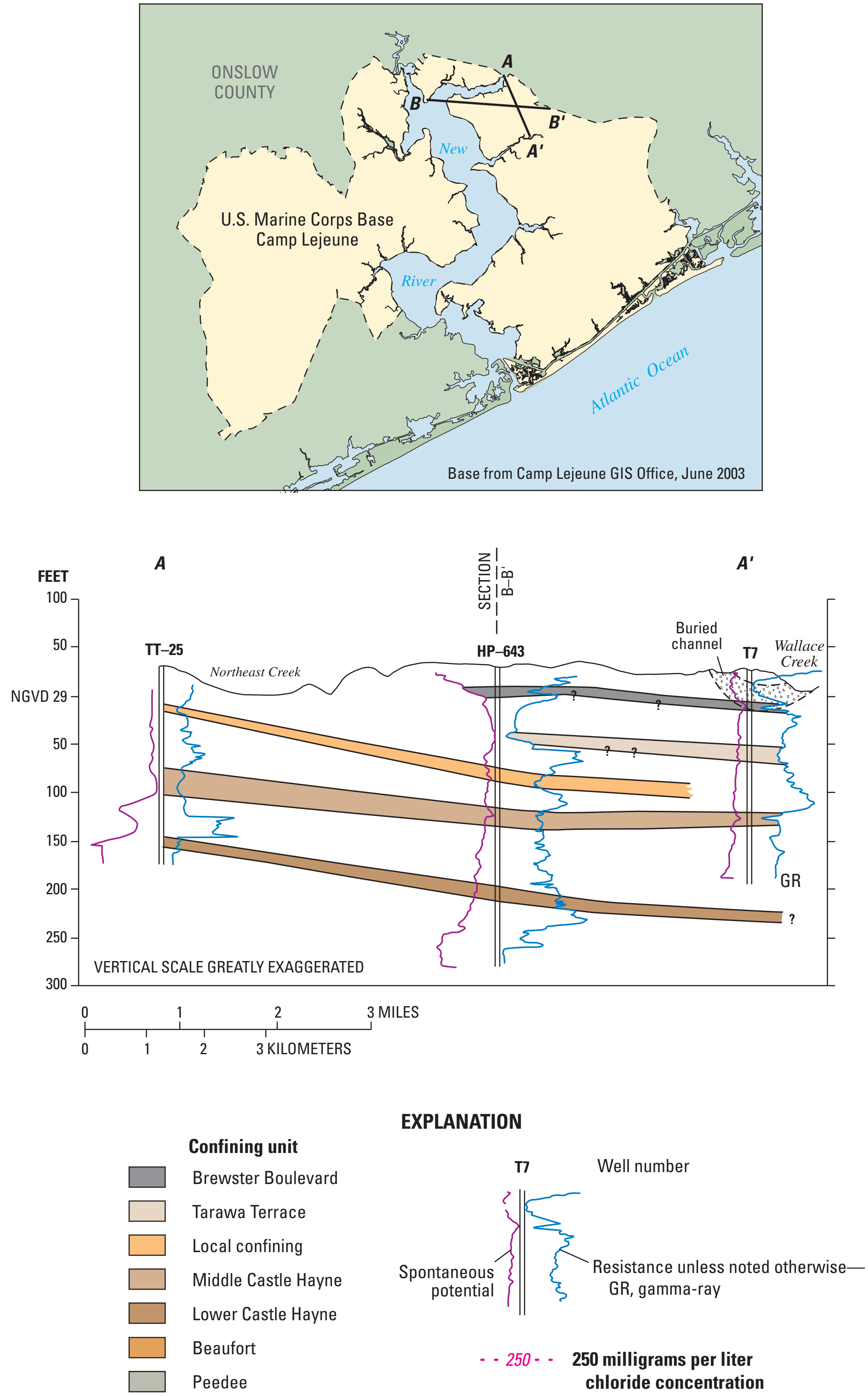


Figure B3. Hydrogeologic sections A–A' and B–B' (modified from Cardinell et al. 1993, Plate 1).

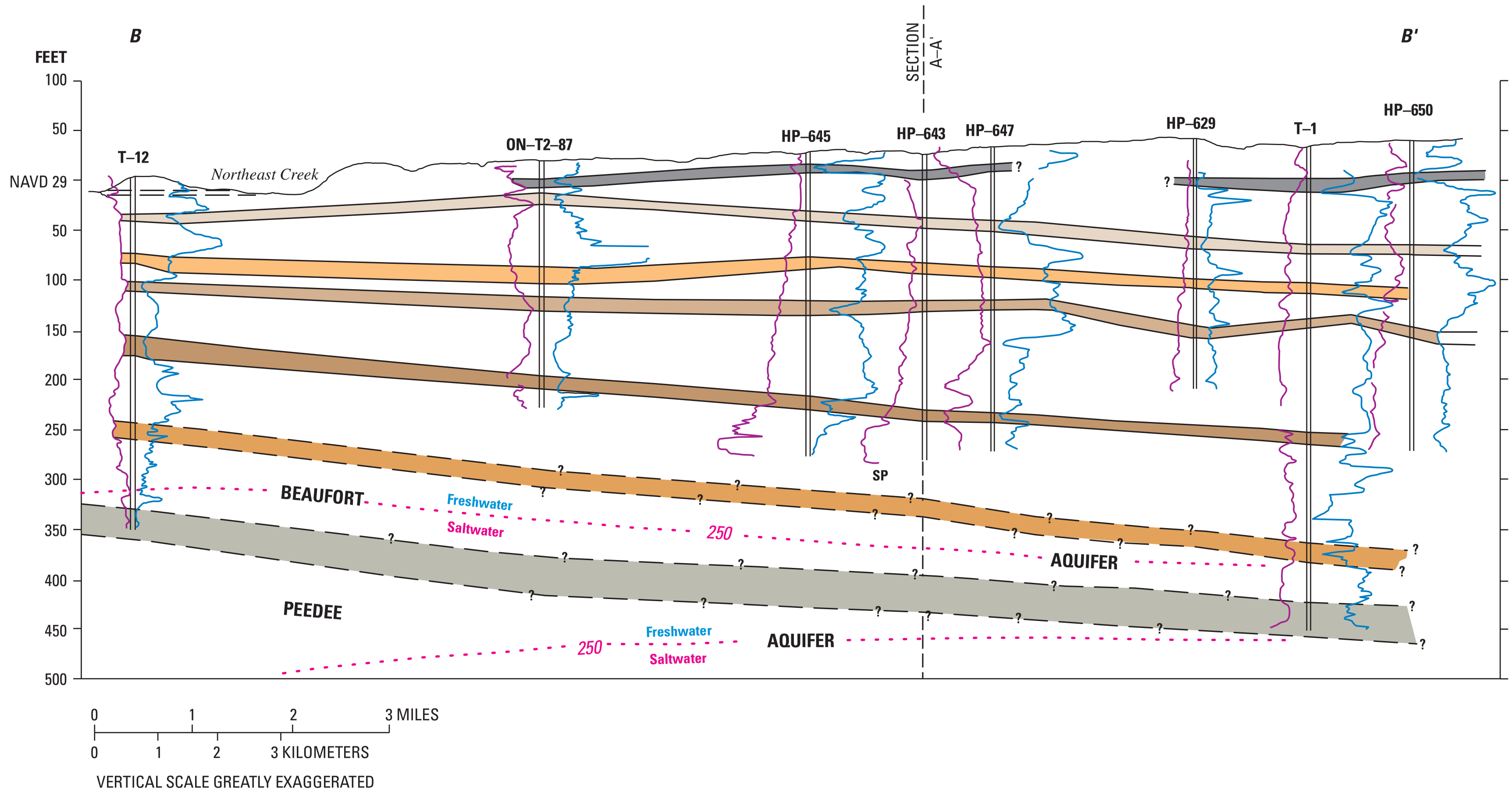
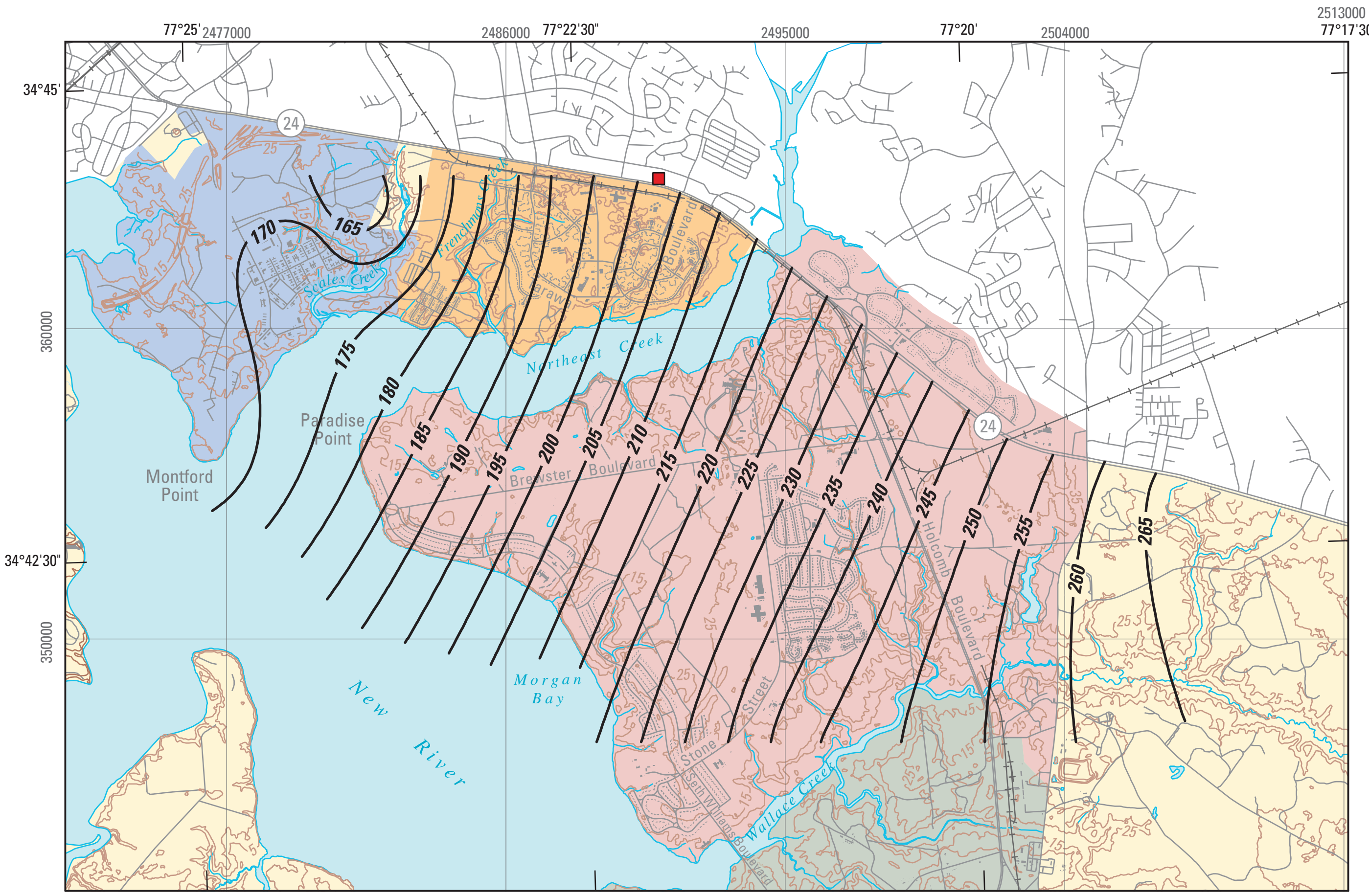


Figure B3. Hydrogeologic sections A–A' and B–B' (modified from Cardinell et al. 1993, Plate 1).—Continued



Base from U.S. Marine Corps and U.S. Geological Survey digital data files
Map coordinates are North Carolina State Plane coordinates
North American Datum of 1983

0 1 2 MILES
0 1 2 KILOMETERS

EXPLANATION

Historical water-supply areas of Camp Lejeune Military Reservation

- Montford Point
- Tarawa Terrace
- Holcomb Boulevard
- Hadnot Point

Other areas of Camp Lejeune Military Reservation

— *235* — **Line of equal thickness of Castle Hayne Formation**—Interval 5 feet

— *25* — **Topographic contour**—Interval 10 feet

ABC One-Hour Cleaners

Figure B4. Thickness of the Castle Hayne Formation, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

at the top of the Beaufort Formation, which is described as capped by a relatively thick unit of clay, silt, and sandy clay. This clay is named in this report the Beaufort confining unit, following similar usage by Harned et al. (1989) and Cardinell et al. (1993), and is a recognizable unit in logs of deep wells at Camp Lejeune (Figure B3). The top of the Beaufort confining unit occurs at about altitude –220 ft in the northern and western parts of the study area and dips gradually to the south and southeast to an altitude of about –360 ft in the vicinity of the headwaters of Wallace Creek (Figure B27). Comparing the maps that show the approximate top and base of the Castle Hayne Formation (Figures B15 and B27), the thickness of the Castle Hayne Formation is shown to range from about 170 ft in the vicinity and west of Tarawa Terrace to about 265 ft near the headwaters of Wallace Creek (Figure B4).

In general, the Castle Hayne Formation at Camp Lejeune consists primarily of silty and clayey sand and sandy limestone with interbedded deposits of clay and sandy clay. The sand is fine, often gray in color, and frequently fossiliferous. LeGrand (1959) indicates a “tendency toward layering” with respect to the alternating (with depth) beds of predominantly sandy or clayey sediments. Much of the limestone is shell limestone, also called “shell hash,” “shellrock,” or “coquina” in drillers’ logs. Legrand (1959) states that “at Hadnot Point, Tarawa Terrace, and Montford Point the shellrock to a depth of about 250 feet is rather thin and is subordinate in quantity to sand.” Results of this study support LeGrand’s conclusion. Several of the clay deposits appear to be continuous and areally extensive (Harned et al., 1989, Sections A–A', B–B', and C–C'; Cardinell et al., 1993, Sections A–A' and B–B') and range in thickness from about 10 ft to more than 30 ft. Lensoidal clays probably occur frequently. The occurrence of limestone is probably also discontinuous, particularly in the vicinity of Tarawa Terrace. Carbonate units of the Castle Hayne Formation at Camp Lejeune are marine and were likely deposited in near shore environments. Associated clastic units are probably beach deposits or were formed in deltaic or other near shore transitional environments.

Harned et al. (1989) and Cardinell et al. (1993) assign an Eocene undifferentiated age to the Castle Hayne Formation, and this age is assigned as well in this report. Similarly, they assign a Paleocene age to the Beaufort Formation at Camp Lejeune and this age is adopted as well for this study (Table B1).

Sediments that occur between land surface and the top of the Castle Hayne Formation are variously referred to as the River Bend Formation of Oligocene age and Belgrade Formation of early Miocene age (Cardinell et al. 1993; Harned et al. 1989) (Table B1). These sediments consist largely of fine to medium, silty, gray and white sand interbedded with clay, sandy clay, and silt. Clays and sands are frequently fossiliferous, particularly at depths greater than 30 ft. The base of these units conforms to the top of the Castle Hayne Formation (Figure B15) and dips uniformly to the south and southeast. Unit thickness is zero at land surface and increases southeastwardly to about 140 ft in the vicinity of the headwaters of Wallace Creek.

Table B1. Generalized relation between Quaternary and Tertiary age geologic and hydrogeologic units at Marine Corps Base Camp Lejeune, North Carolina (modified from Harned et al. 1989 and Cardinell et al. 1993).

System	GEOLOGIC UNITS		HYDROGEOLOGIC UNITS
	Series	Formation	Aquifer and confining unit
Quaternary	Holocene Pleistocene	Undifferentiated	Undifferentiated
Tertiary	Pliocene	Absent	Absent
	Miocene	Absent	Absent
		Belgrade Formation	Brewster Boulevard aquifer Brewster Boulevard confining unit Tarawa Terrace aquifer Tarawa Terrace confining unit
	Oligocene	River Bend Formation	Upper Castle Hayne aquifer–River Bend unit
	Eocene	Castle Hayne Formation	Local confining unit
			Upper Castle Hayne aquifer–Lower unit
			Middle Castle Hayne confining unit
			Middle Castle Hayne aquifer
			Lower Castle Hayne confining unit
			Lower Castle Hayne aquifer
	Paleocene	Beaufort Formation	Beaufort confining unit[1]

[1]Occurs at top of Beaufort Formation

Geohydrologic Framework

Eleven aquifers and confining units that occur between land surface and the top of the Beaufort Formation at Camp Lejeune were identified and named after local cultural features where the units were first identified or as subdivisions of the Castle Hayne Formation. From shallowest to deepest these units are the Brewster Boulevard aquifer, Brewster Boulevard confining unit, Tarawa Terrace aquifer, Tarawa Terrace confining unit, Upper Castle Hayne aquifer–River Bend unit, Local confining unit, Upper Castle Hayne aquifer–Lower unit, Middle Castle Hayne confining unit, Middle Castle Hayne aquifer, Lower Castle Hayne confining unit, Lower Castle Hayne aquifer, and Beaufort confining unit (Table B2). The top of the Beaufort confining unit is considered to be the base of groundwater flow of interest to this study. The River Bend unit of the Upper Castle Hayne aquifer is so named to conform to the upper part of the Castle Hayne aquifer as described by Cardinell et al. (1993). As defined for this study, the River Bend unit probably includes sediments of the Castle Hayne Formation only at the base, if at all. The Local confining unit separates the River Bend unit and the Lower unit of the Upper Castle Hayne aquifer and conforms in areal extent and thickness to the clay or sandy clay described previously as the lithostratigraphic top of the Castle Hayne Formation (Figure B15). The Upper Castle aquifer–River Bend unit is the uppermost unit of the Castle Hayne aquifer aystem, as defined for this study. The Lower Castle Hayne aquifer is the basal unit of the Castle Hayne aquifer aystem.

Most geohydrologic unit surfaces trend to the south and southeast and increase in thickness in the same directions. The tops of most units are characterized by a moderate to high degree of irregularity at one or several locations. Such irregularities are manifest on maps as hatched areas or areas of closed contours where surface altitudes are lower or higher than altitudes interpolated for adjacent areas. Unit tops as shown likely represent eroded surfaces that at one or several times were exposed to the effects of erosion, weathering, dissolution, and similar agencies. Accordingly, surface irregularities may represent relict stream channels or hill tops. Where a unit is largely limestone in composition, surface irregularities possibly represent the remnants of a karst terrain characterized by sinkholes or similar enlarged solution or fracture features. A generalized correlation of geologic and geohydrologic units at Marine Corps Base Camp Lejeune is shown in Table B1.

Table B2. Geohydrologic units and unit thickness at Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[Units are listed from youngest to oldest; N/A, not applicable]

Geohydrologic unit	Thickness range, in feet
Brewster Boulevard aquifer	10 to 40
Brewster Boulevard confining unit	0 to 30
Tarawa Terrace aquifer	10 to 50
Tarawa Terrace confining unit	10 to 40
Castle Hayne aquifer system	
Upper Castle Hayne aquifer–River Bend unit	10 to 60
Local confining unit	5 to 20
Upper Castle Hayne aquifer–Lower unit	5 to 50
Middle Castle Hayne confining unit	10 to 30
Middle Castle Hayne aquifer	30 to 120
Lower Castle Hayne confining unit	20 to 35
Lower Castle Hayne aquifer	40 to 90
Beaufort confining unit	N/A

Brewster Boulevard Aquifer

Brewster Boulevard is the west-east trending road that extends from Paradise Point to Holcomb Boulevard (Figure B5). The Brewster Boulevard aquifer and confining unit occur only southeast of Northeast Creek. Thin sands or clays equivalent to this unit may occur at land surface in the Tarawa Terrace and Montford Point areas but were undifferentiated for this study. Sediments of the aquifer unit occur at or near land surface in the vicinity of Brewster Boulevard and are comprised largely of fine-grained frequently brown and white sand. Similar lithologies were also observed in the vicinity of borehole T-1, north and east of Wallace Creek, and adjacent to SR 24. The surface of the Brewster Boulevard aquifer declines to the south and southwest and generally ranges in altitude from about 29 ft in the vicinity of Brewster Boulevard to near sea level in the southwestern part of the study area (Table B3). Unit thickness generally increases west to east from a minimum of about 14 ft near Northeast Creek to about 38 ft near SR 24 and the eastern limit of the study area (Figure B6).

Table B3. Altitude at the top of the Brewster Boulevard aquifer, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[NGVD 29, National Geodetic Vertical Datum of 1929]

Site name[1]	Location coordinates[2]		Unit altitude, in feet above NGVD 29
	East	North	
HP-643	2494346	356083	29
HP-645	2497333	356430	27
HP-646	2497870	357826	28
HP-649	2508630	354860	18
HP-663	2510881	352712	28
HP-698	2492410	355870	23
HP-699	2490430	355560	23
HP-700	2485200	355270	20
HP-706	2502990	355940	24
HP-708	2514450	353090	27
HP-709	2505650	351270	8
ON-T2-87	2487495	353877	21
S190A	2487640	353870	20
T-1	2507870	355030	14
T-7	2500628	349685	2

[1]See Plate 1 for location

[2]Location coordinates are North Carolina State Plane coordinates, North American Datum of 1983

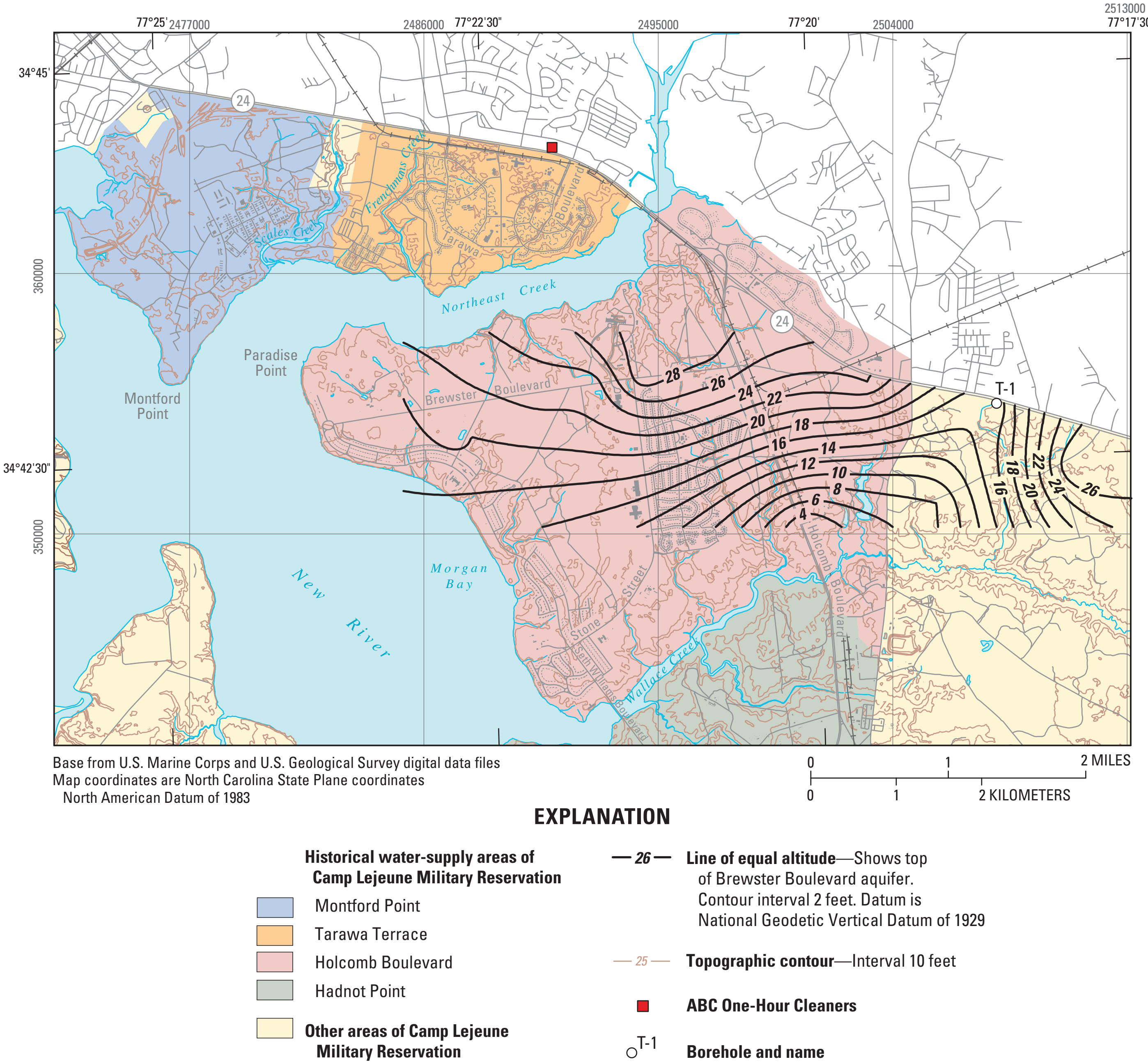


Figure B5. Altitude at the top of the Brewster Boulevard aquifer, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

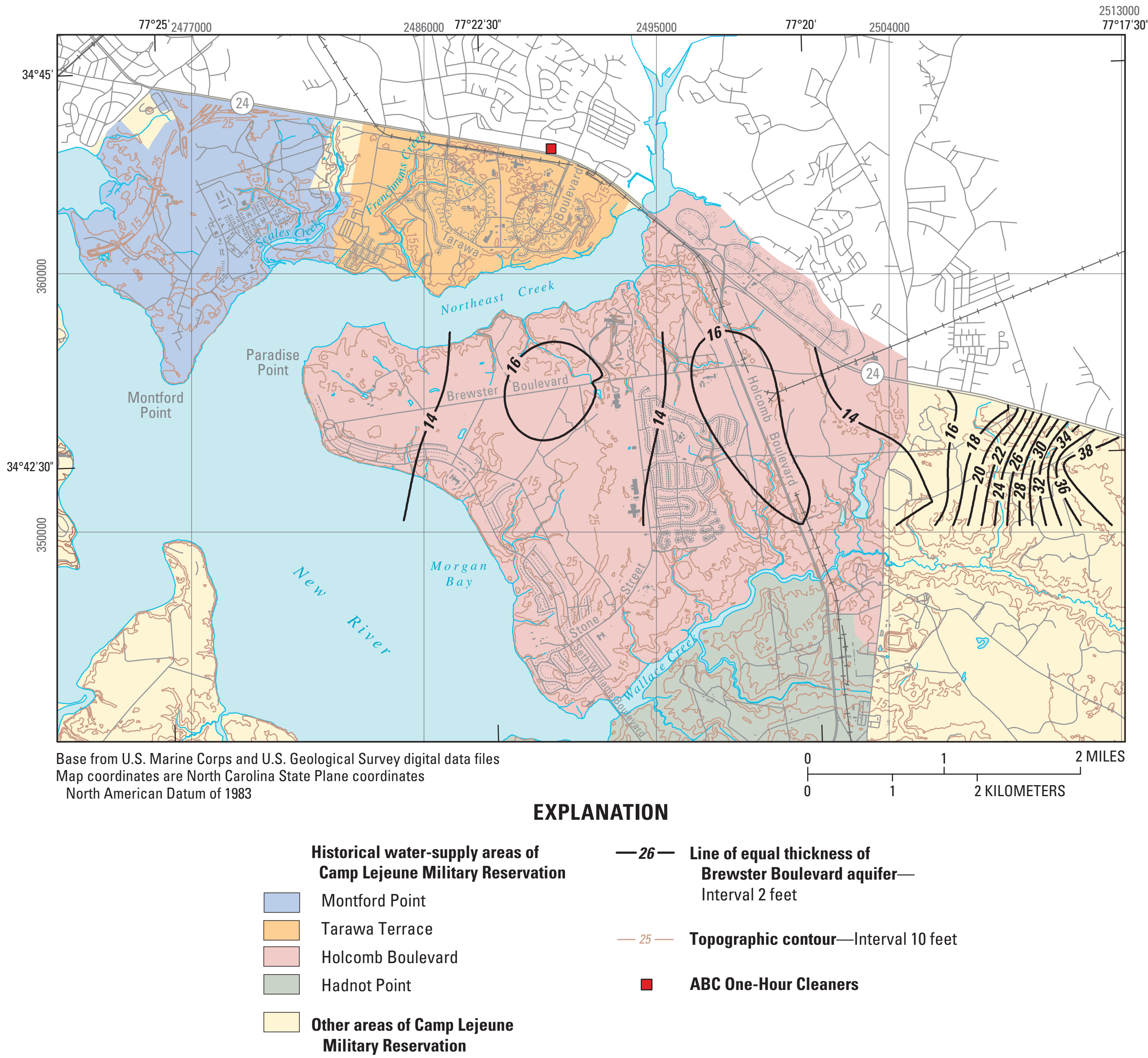


Figure B6. Thickness of the Brewster Boulevard aquifer, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Brewster Boulevard Confining Unit

The surface of the Brewster Boulevard confining unit trends generally southeast from a maximum altitude of about 8 ft in the vicinity of Brewster Boulevard to an altitude of about –16 ft north of the headwaters of Wallace Creek (Table B4, Figure B7). The lithology of the Brewster Boulevard confining unit is described variously as a white or blue clay in the vicinity of Brewster Boulevard and a blue to black clay in the vicinity of Wallace Creek and borehole T-7. Elsewhere, the unit is undifferentiated in drillers' descriptions. Thickness of the Brewster Boulevard confining unit varies minimally throughout the study area from about 9 ft along Brewster Boulevard to about 17 ft north of Wallace Creek near SR 24 (Figure B8). Contours of equal thickness are somewhat irregular, without a discernable trend.

Comparison of altitudes at the top of the "Castle Hayne confining unit" described by Cardinell et al. (1993, Table 3, Sections A–A' and B–B') at 19 well sites to corresponding altitudes identified for this study as the top of the Brewster Boulevard confining unit indicates a high degree of correspondence at 6 sites and substantial disagreement at 13 sites. Disagreement appears random and extends throughout most of the area of occurrence of the Brewster Boulevard confining unit. Such comparisons not withstanding, some agreement between the unit described as the "Castle Hayne confining unit" by Cardinell et al. (1993) and the geohydrologic unit described herein as the Brewster Boulevard confining unit clearly exists within the assigned area of the unit. Because Cardinell et al. (1993) assign all sediments above the "Castle Hayne confining unit" to the "surficial aquifer," by definition, some correspondence also exists between their "surficial aquifer" and the geohydrologic unit described herein as the Brewster Boulevard aquifer.

Table B4. Altitude at the top of the Brewster Boulevard confining unit, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[NGVD 29, National Geodetic Vertical Datum of 1929; –, below NGVD 29]

Site name[1]	Location coordinates[2]		Unit altitude, in feet above or below NGVD 29
	East	North	
HP-621 (old)	2504784	355315	11
HP-621 (new)	2505510	354290	4
HP-641	2504106	353016	–4
HP-643	2494346	356083	13
HP-645	2497333	356430	17
HP-646	2497870	357826	16
HP-648	2506809	355200	9
HP-649	2508630	354860	0
HP-650	2510615	354300	9
HP-651	2503790	348090	–13
HP-663	2510881	352712	–11
HP-698	2492410	355870	7
HP-699	2490430	355560	6
HP-700	2485200	355270	8
HP-706	2502990	355940	8
HP-708	2514450	353090	–13
HP-709	2505650	351270	–6
HP-711	2509200	352130	–10
LCH-4009	2499585	358589	9
ON-T2-87	2487495	353878	5
S190A	2487640	353870	5
T-1	2507870	355030	–3
T-7	2500628	349685	–10

[1]See Plate 1 for location

[2]Location coordinates are North Carolina State Plane coordinates, North American Datum of 1983

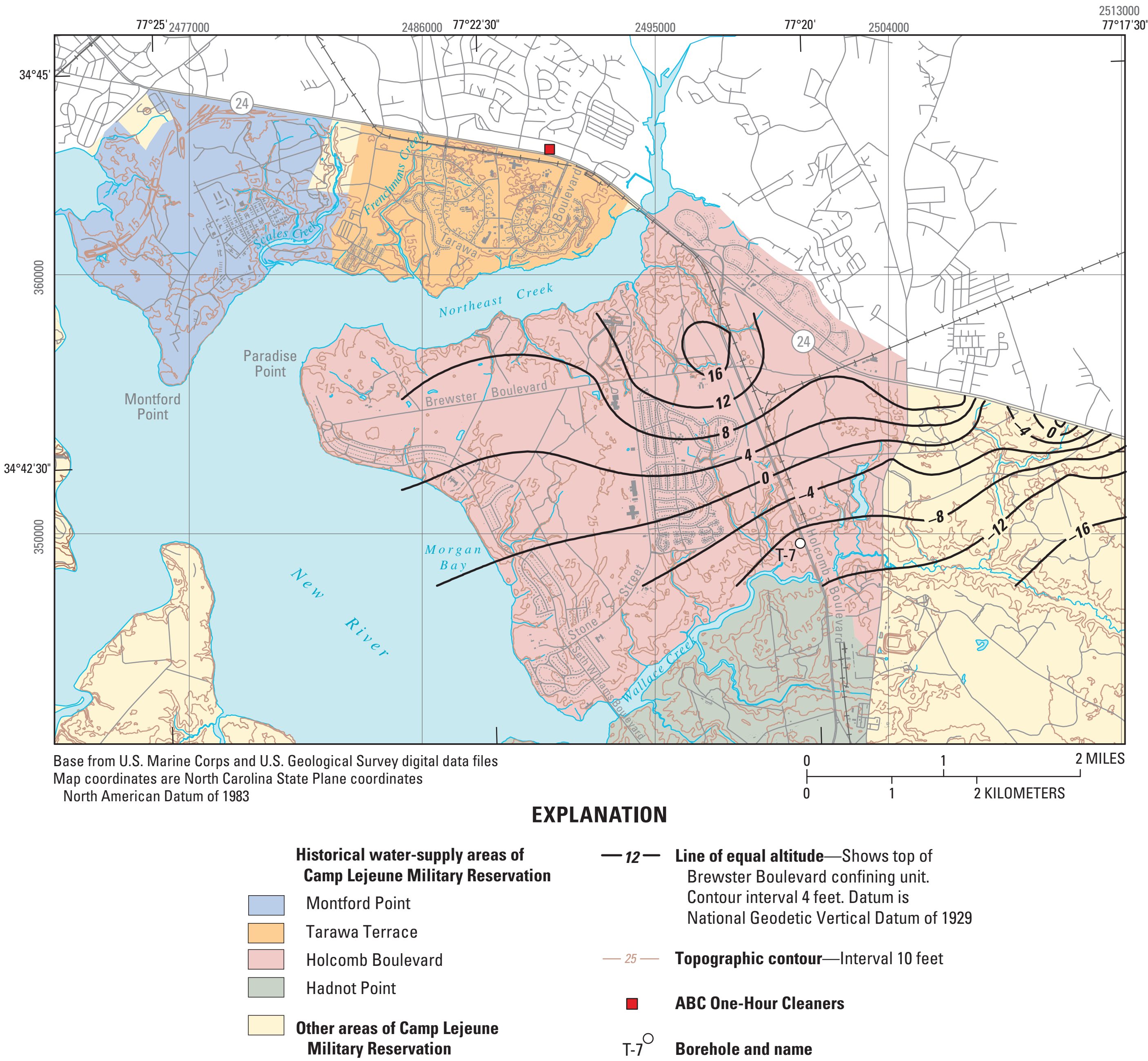
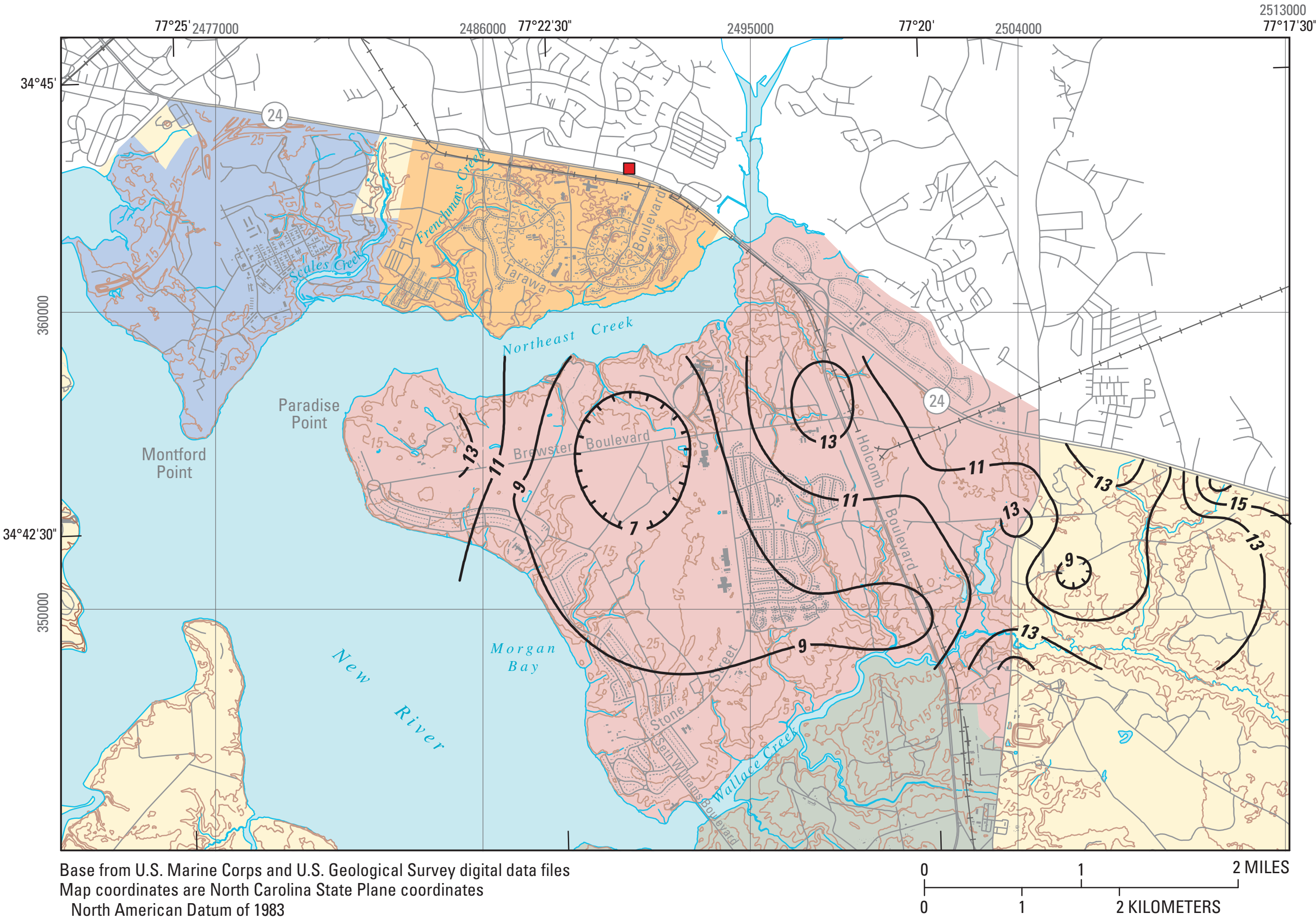


Figure B7. Altitude at the top of the Brewster Boulevard confining unit, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.



EXPLANATION

Historical water-supply areas of Camp Lejeune Military Reservation

- Montford Point
- Tarawa Terrace
- Holcomb Boulevard
- Hadnot Point

Other areas of Camp Lejeune Military Reservation

13 **Line of equal thickness of Brewster Boulevard confining unit**—Interval 2 feet. Hachures indicate depression

25 **Topographic contour**—Interval 10 feet

ABC One-Hour Cleaners

Figure B8. Thickness of the Brewster Boulevard confining unit, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.