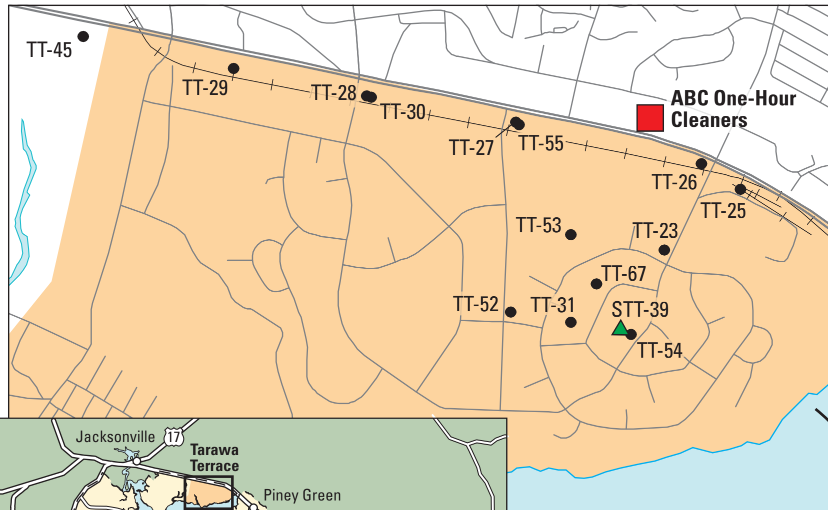
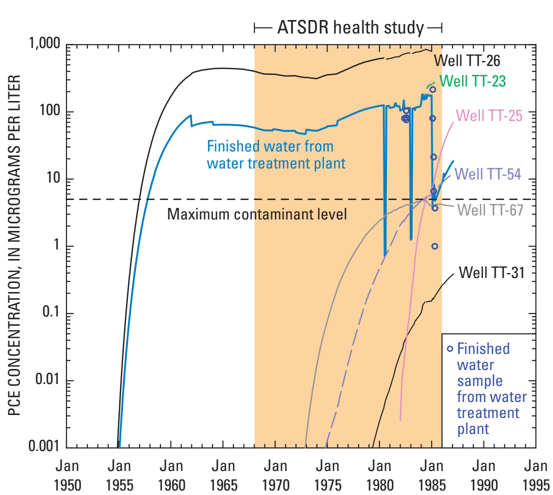
Analyses of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water at Tarawa Terrace and Vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina: Historical Reconstruction and Present-Day Conditions

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

Author

Robert E. Faye, MSCE, PE
Civil Engineer/Hydrologist
Robert E. Faye and Associates, Inc.
Consultant to Eastern Research Group, Inc.
Lexington, Massachusetts

For additional information write to:

Project Officer
Exposure-Dose Reconstruction Project
Division of Health Assessment and Consultation
Agency for Toxic Substances and Disease Registry
1600 Clifton Road, Mail Stop E-32
Atlanta, Georgia 30333

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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

[1] Consultant to Eastern Research Group, Inc., Lexington, Massachusetts.

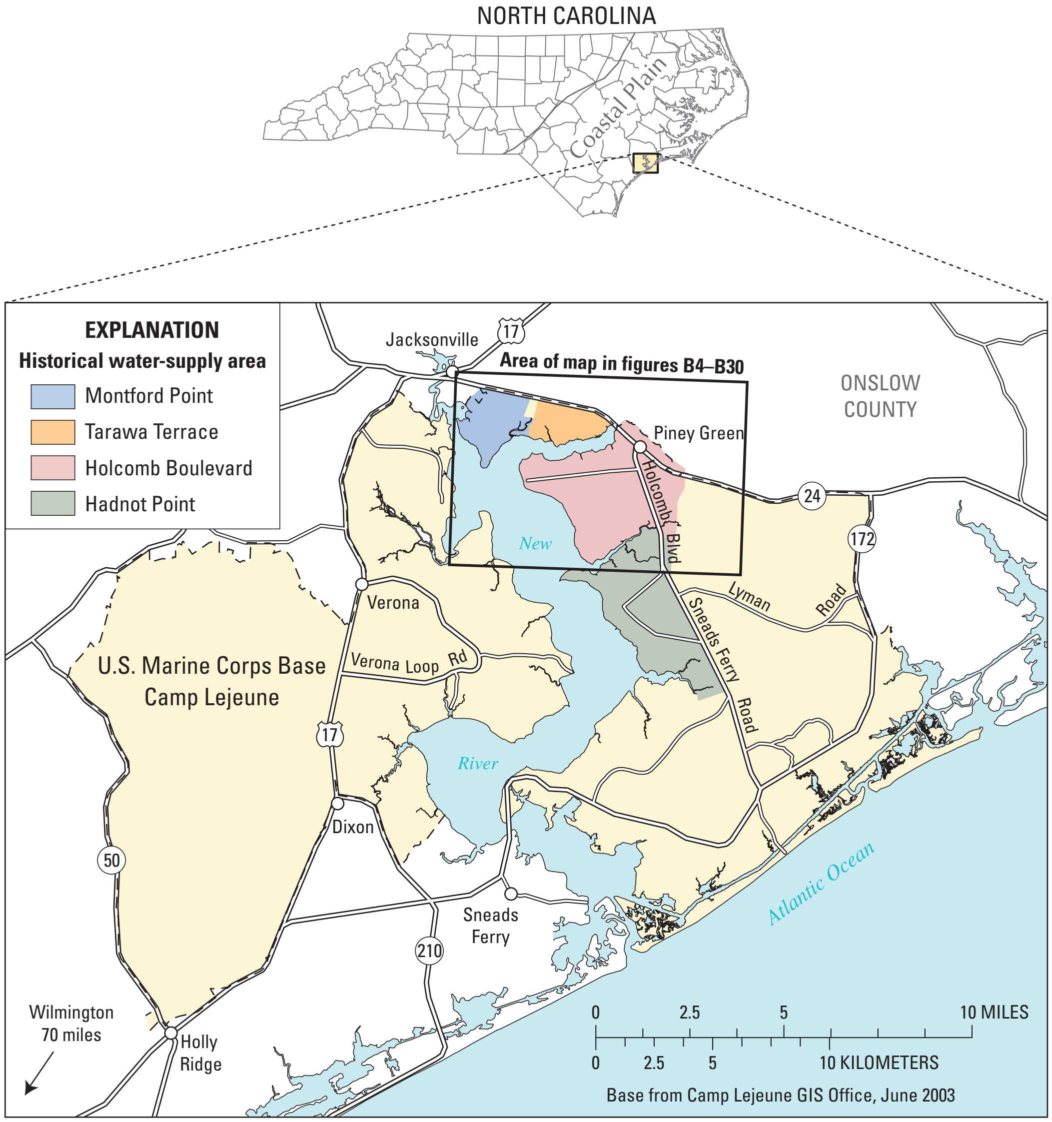


Figure B1. Cultural and geographic features of U.S. Marine Corps Base Camp Lejeune, North Carolina.

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

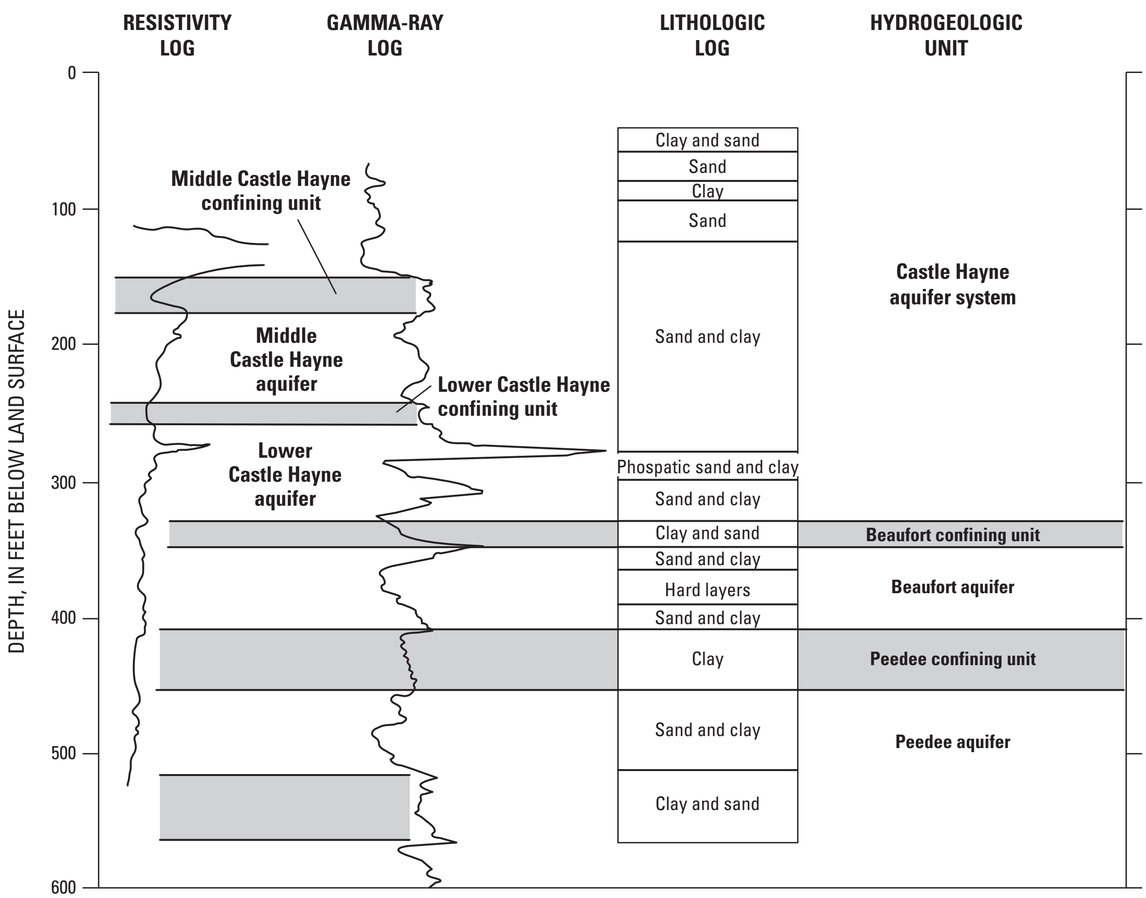


Figure B2. Correlation of geophysical logs and lithologic log, borehole X24S2a, U.S. Marine Corps Base Camp Lejeune, North Carolina (modified from Cardinell et al. 1993, Figure 4).

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

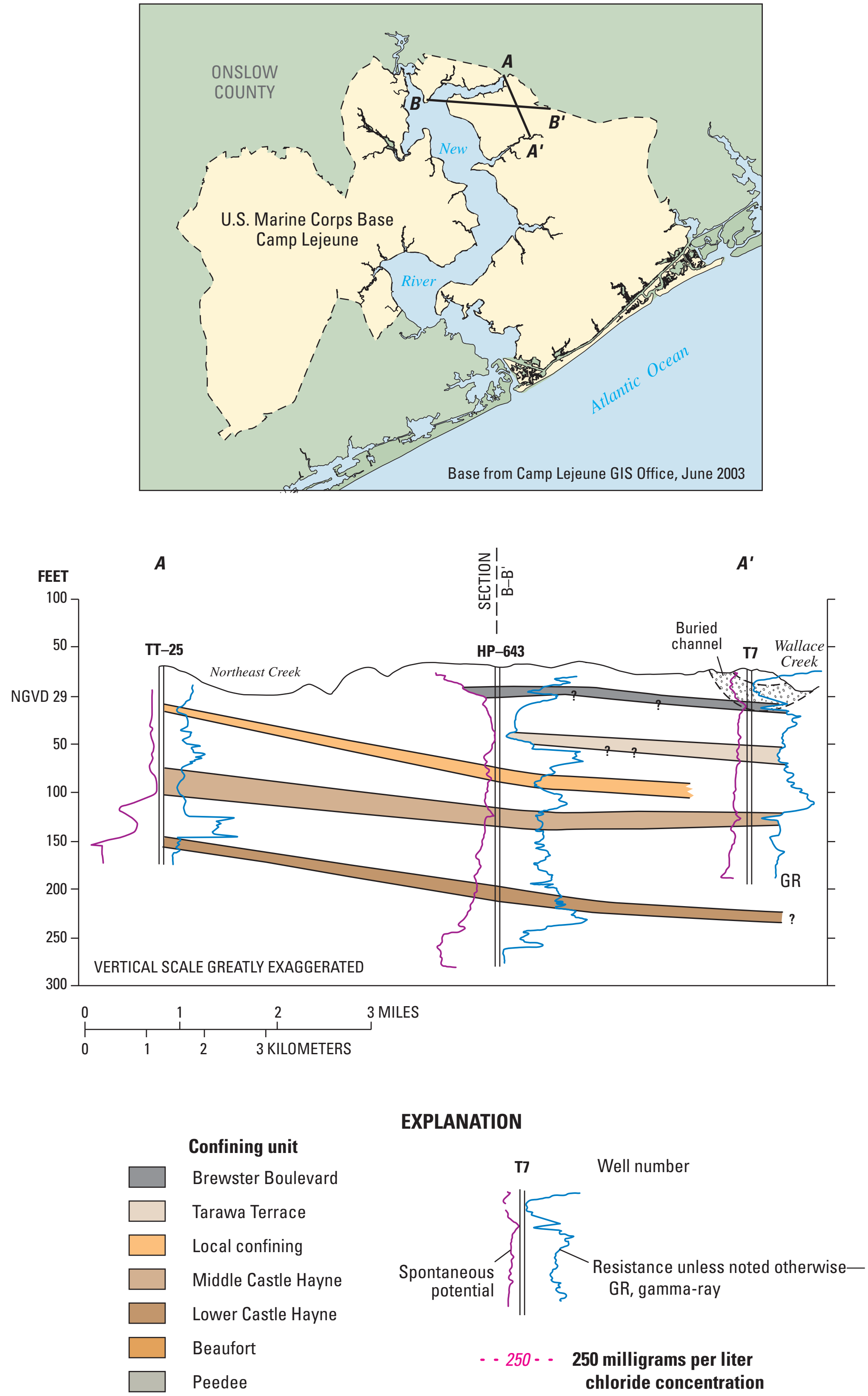


Figure B3. Hydrogeologic sections A–A' and B–B' (modified from Cardinell et al. 1993, Plate 1).

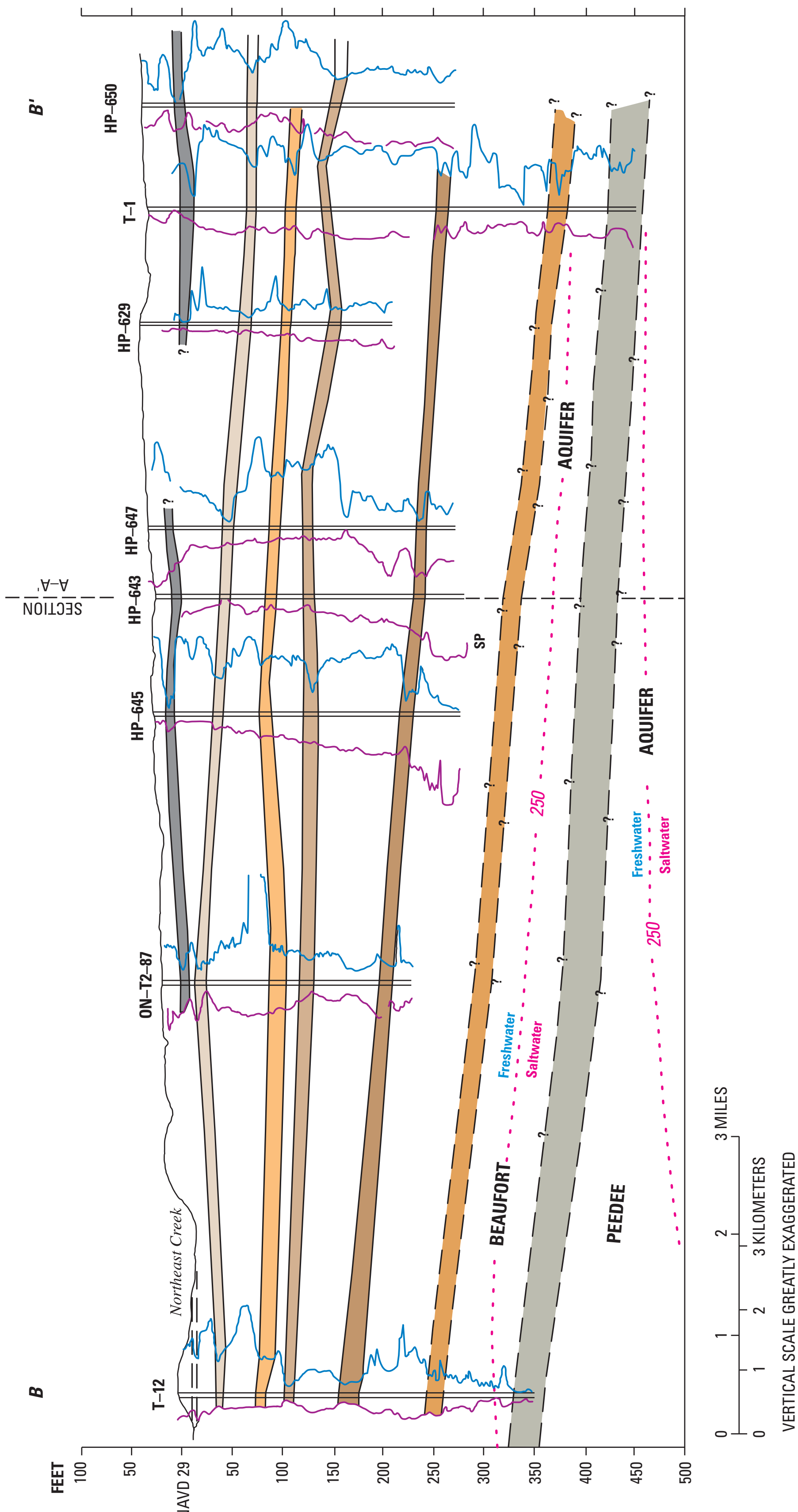


Figure B3. Hydrogeologic sections A–A' and B–B' (modified from Cardinell et al. 1993, Plate 1).—Continued

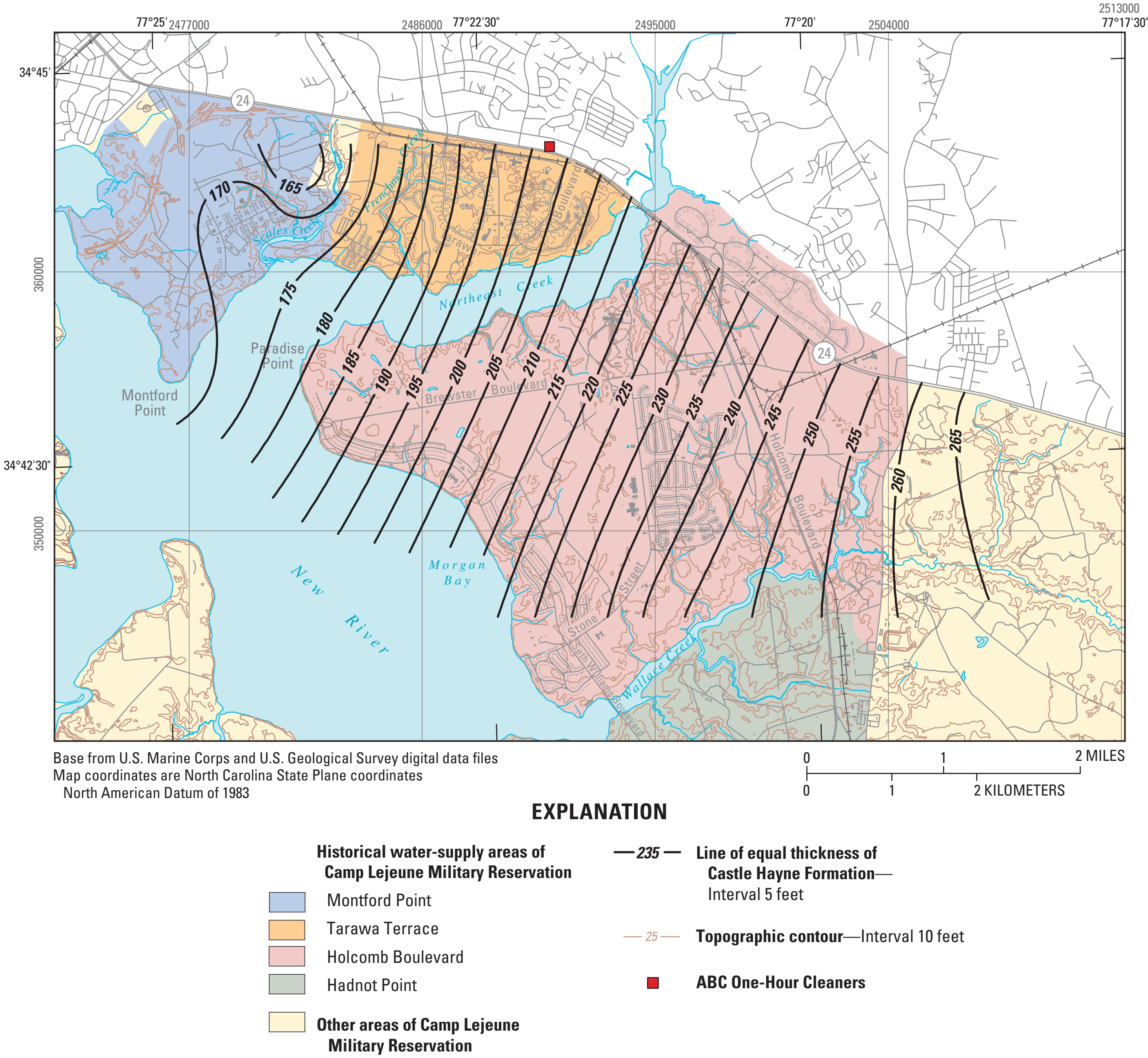


Figure B4. Thickness of the Castle Hayne Formation, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

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

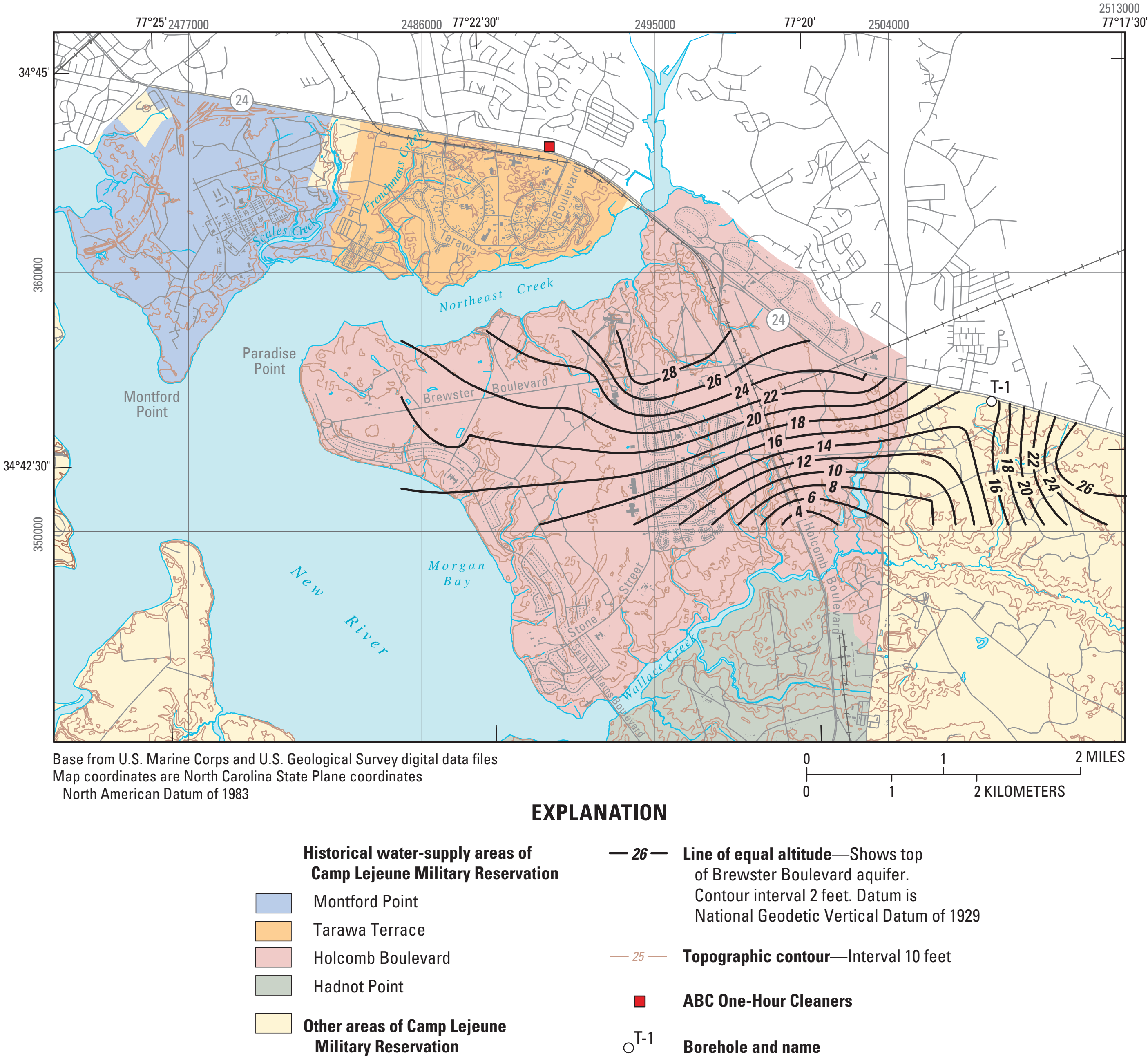


Figure B5. Altitude at the top of the Brewster Boulevard aquifer, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

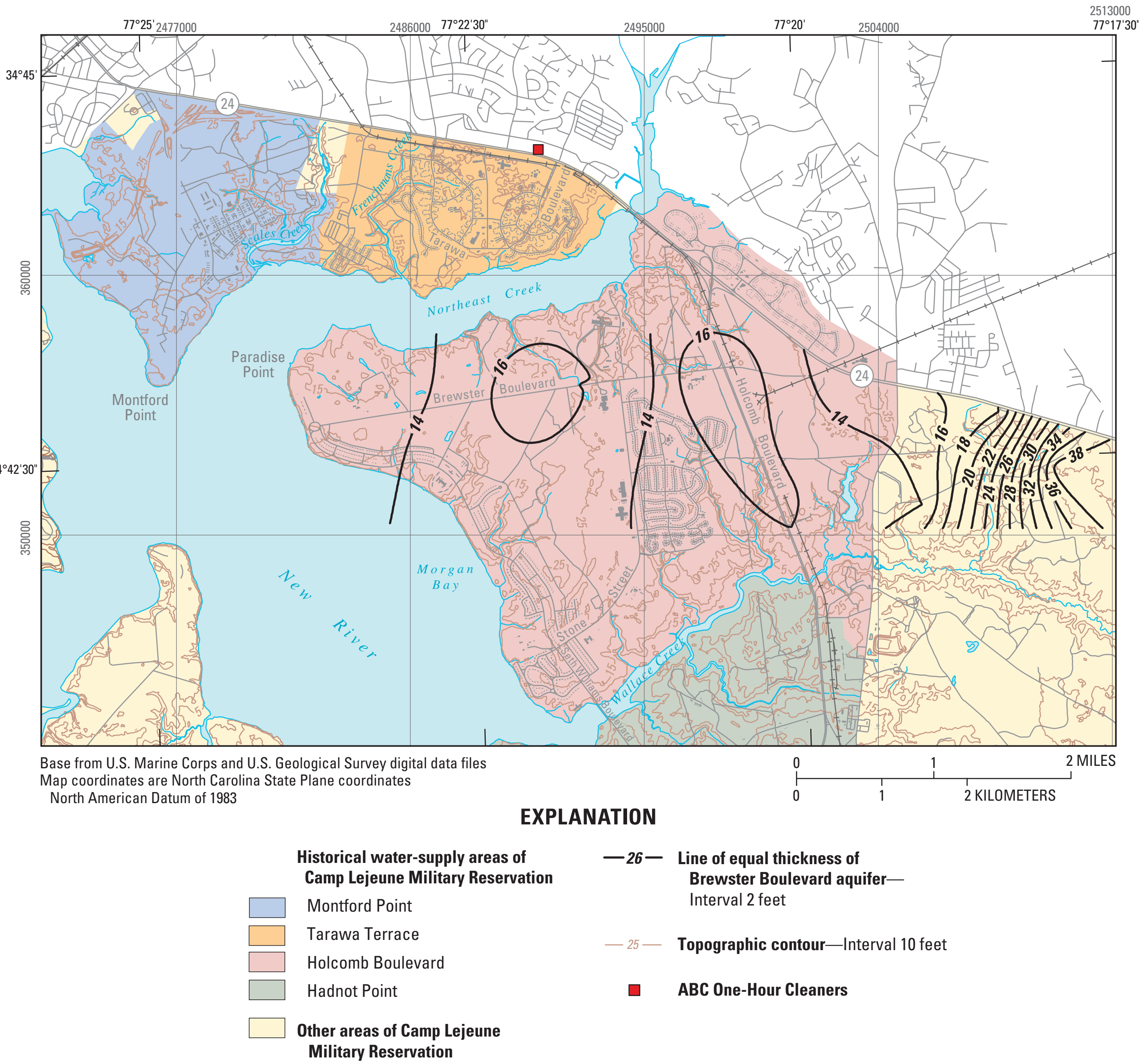


Figure B6. Thickness of the Brewster Boulevard aquifer, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

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

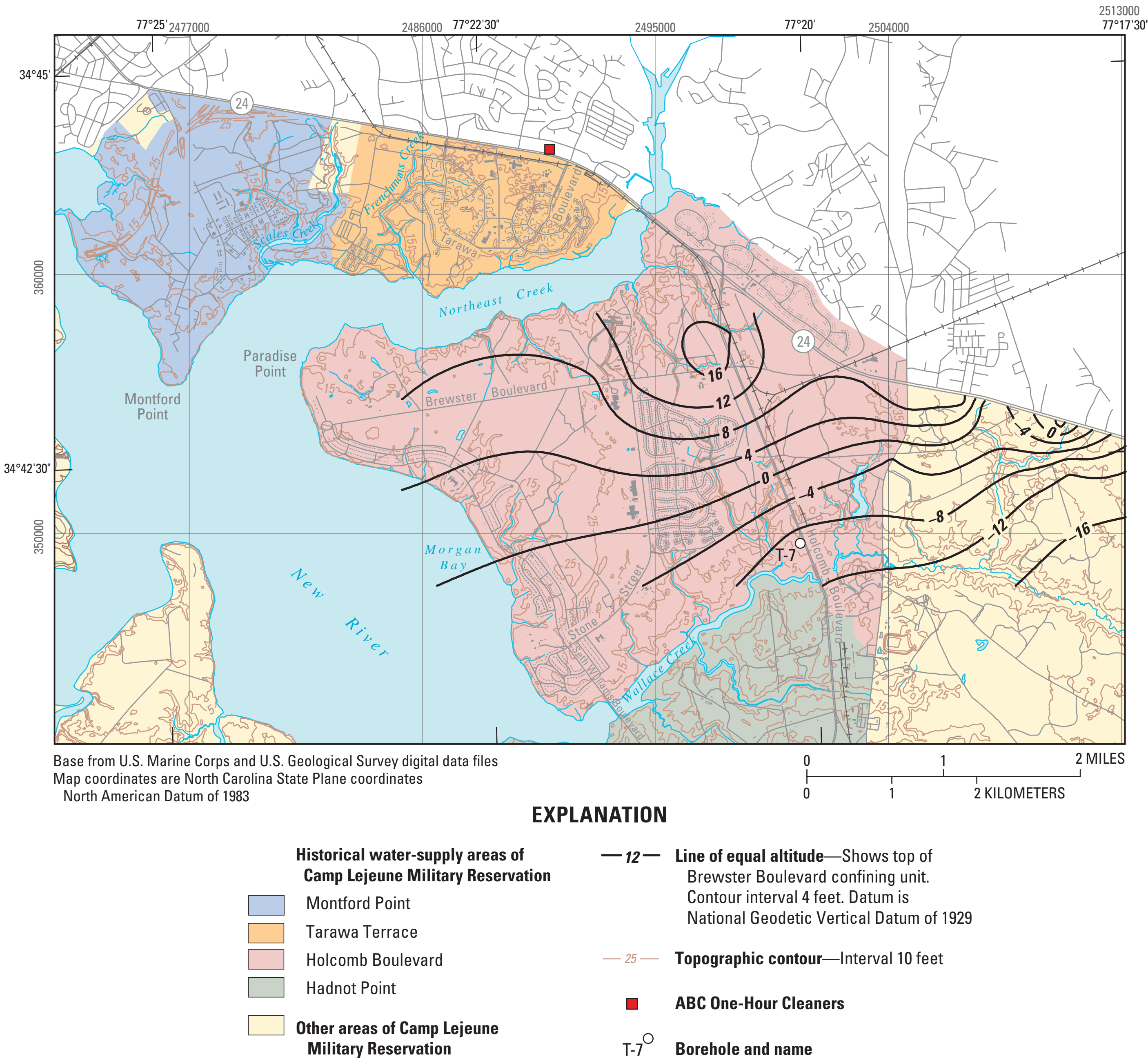
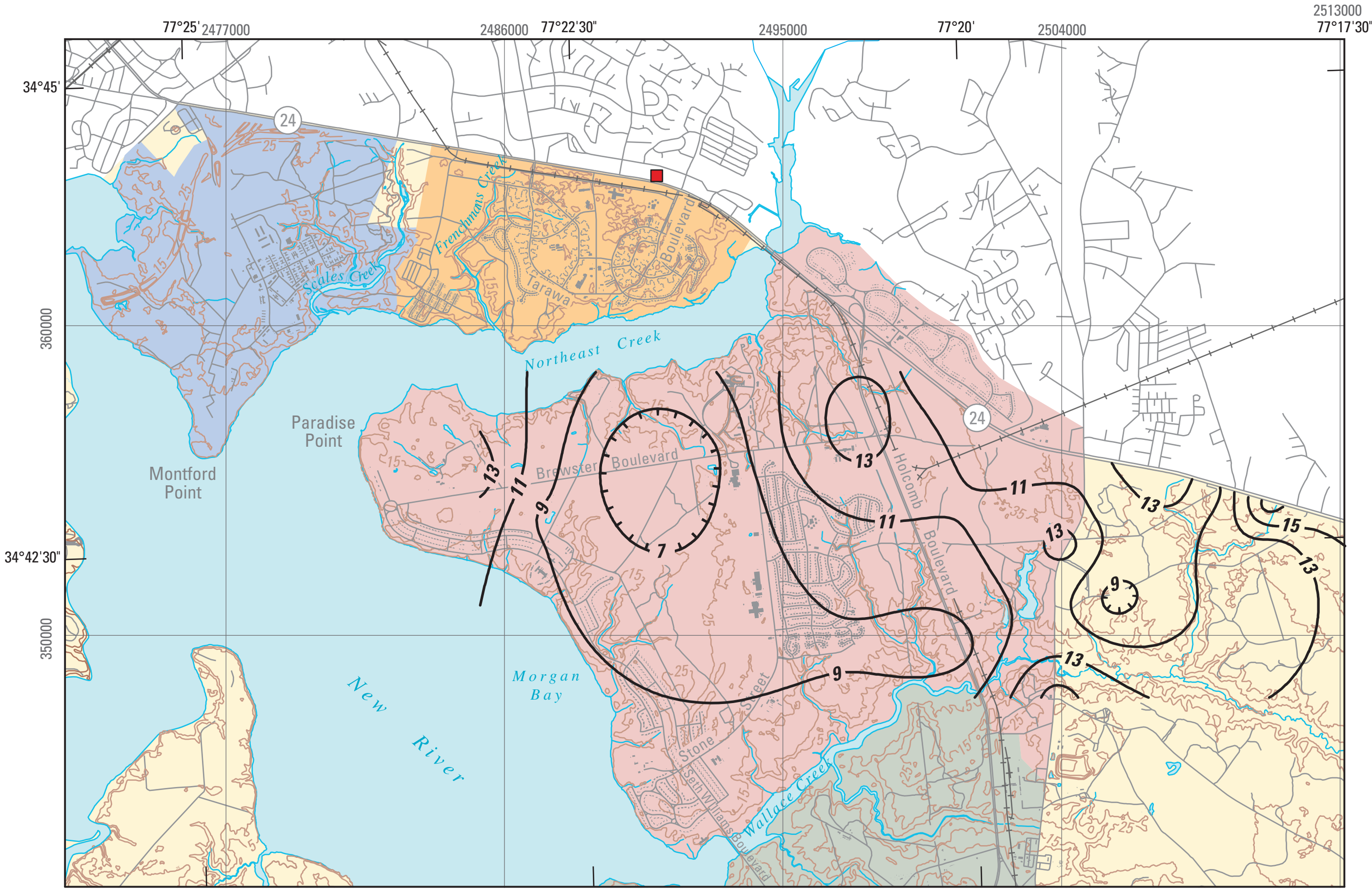


Figure B7. Altitude at the top of the Brewster Boulevard confining unit, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.



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

—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.

Tarawa Terrace Aquifer

Contours of equal altitude at the top of the Tarawa Terrace aquifer are shown in Figure B9. This aquifer occurs at or near land surface north of Tarawa Terrace at about altitude 25 ft. Minimum altitude is about –30 ft near the southeastern limit of the study area and north of the headwaters of Wallace Creek (Table B5). Surface altitudes decline at a generally uniform rate northwest to southeast. Altitudes in the vicinity of Tarawa Terrace and Montford Point also decline to the south and southeast toward Northeast Creek. Borehole logs completed by Roy F. Weston, Inc. (1992, 1994) indicate the lithology of the Tarawa Terrace aquifer in the northern part of Tarawa Terrace and vicinity is a fine-grained, gray silty sand containing thin beds and lenses of frequently sandy silt and clay. In the southern part of Tarawa Terrace, the aquifer is a mix of tan, gray and white-colored, well-sorted, medium-grained sand, reportedly of "moderately high permeability" (borehole logs completed by Richard Catlin & Associates, Inc. 1995a). At Montford Point, in the vicinity of well M-267 and borehole T-12, the Tarawa Terrace aquifer is a fine- to medium-grained tan or gray silty sand, possibly also containing thin lenses or beds of clay. Similar lithologies occur in the vicinity of Brewster Boulevard where the Tarawa Terrace aquifer is composed of a fine white sand at wells HP-699 and HP-704. Southeast of Brewster Boulevard the Tarawa Terrace aquifer is composed of light gray to white medium-grained, fossiliferous sand (borehole T-7). At borehole T-1, near the southeastern limit of the study area, lithology at the top of the aquifer is shell limestone that grades with depth into a fine- to medium-grained sand.

Northeast Creek and New River in the vicinity of Tarawa Terrace and Montford Point are incised into the upper part of the Tarawa Terrace aquifer. Consequently, contours shown on Figure B9 that cross these streams and their larger tributaries in these areas represent relict rather than contemporary structure. The downstream channel of Wallace Creek also may be incised within the uppermost part of the Tarawa Terrace aquifer and contours shown at the top of the aquifer in this area also may represent relict rather than modern conditions.

The Tarawa Terrace aquifer as defined herein is equivalent to the uppermost part of the "surficial aquifer" described by Roy F. Weston, Inc. (1992, 1994) during investigations of groundwater contamination at ABC One-Hour Cleaners north and west of Tarawa Terrace. Similarly, the "surficial aquifer" described by Law Engineering, Inc. (1994a, b, 1995a, b), Richard Catlin & Associates, Inc. (1995a), and other investigations of groundwater in the vicinity of underground fuel storage tanks at Tarawa Terrace corresponds largely to the Upper Castle Hayne aquifer–River Bend unit and the lowermost part of the Tarawa Terrace aquifer of this study.

Thickness of the Tarawa Terrace aquifer is least, about 11 ft, in the immediate vicinity of Tarawa Terrace and near Brewster Boulevard and Paradise Point (Figure B10). Thickness generally increases from the northern part of Tarawa Terrace to the west and southeast to a maximum of about 50 ft near the intersection of SR 24 and the unnamed road that extends east of Brewster Boulevard. Thickness increases rapidly from about 12 to 30 ft westward between Tarawa Terrace and Montford Point and from 20 to about 50 ft southeast of Northeast Creek.

Table B5. Altitude at the top of the Tarawa Terrace aquifer, 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] East	Location coordinates[2] North	Unit altitude, in feet above or below NGVD 29
HP-611 (old)	2495393	350856	–9
HP-612 (old)	2497144	352386	–6
HP-613	2499335	352969	–11
HP-621 (new)	2505510	354290	–14
HP-629 (new)	2504800	355152	–10
HP-641	2504106	353016	–18
HP-643	2494346	356083	1
HP-645	2497333	356430	3
HP-646	2497870	357826	2
HP-648	2506809	355200	–3
HP-649	2508630	354860	–9
HP-650	2510615	354300	–9
HP-651	2503790	348090	–29
HP-663	2510881	352712	–22
HP-698	2492410	355870	1
HP-699	2490430	355560	1
HP-700	2488520	355270	–6
HP-701	2487690	353540	–10
HP-703	2496450	358140	6
HP-706	2502990	355940	–2
HP-708	2514450	353090	–29
HP-709	2505650	351270	–14
HP-711	2509200	352130	–22
LCH-4006	2499585	358589	0
M-244	2475713	361306	20
M-267	2476609	359232	17
M-628	2479434	362735	14
ON-T2-87	2487495	353878	–3
S190A	2487640	353870	–4
T-1	2507870	355030	–15
T-7	2500628	349685	–18
T-9	2490489	364648	29
T-10	2487680	364960	25
T-11	2485278	365352	23
T-12	2476550	355830	6
T-13	2481170	363930	22
T-14	2476788	364170	25
TT-25	2491984	364042	19
TT-52	2489060	362321	25

[1]See Plate 1 for location

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

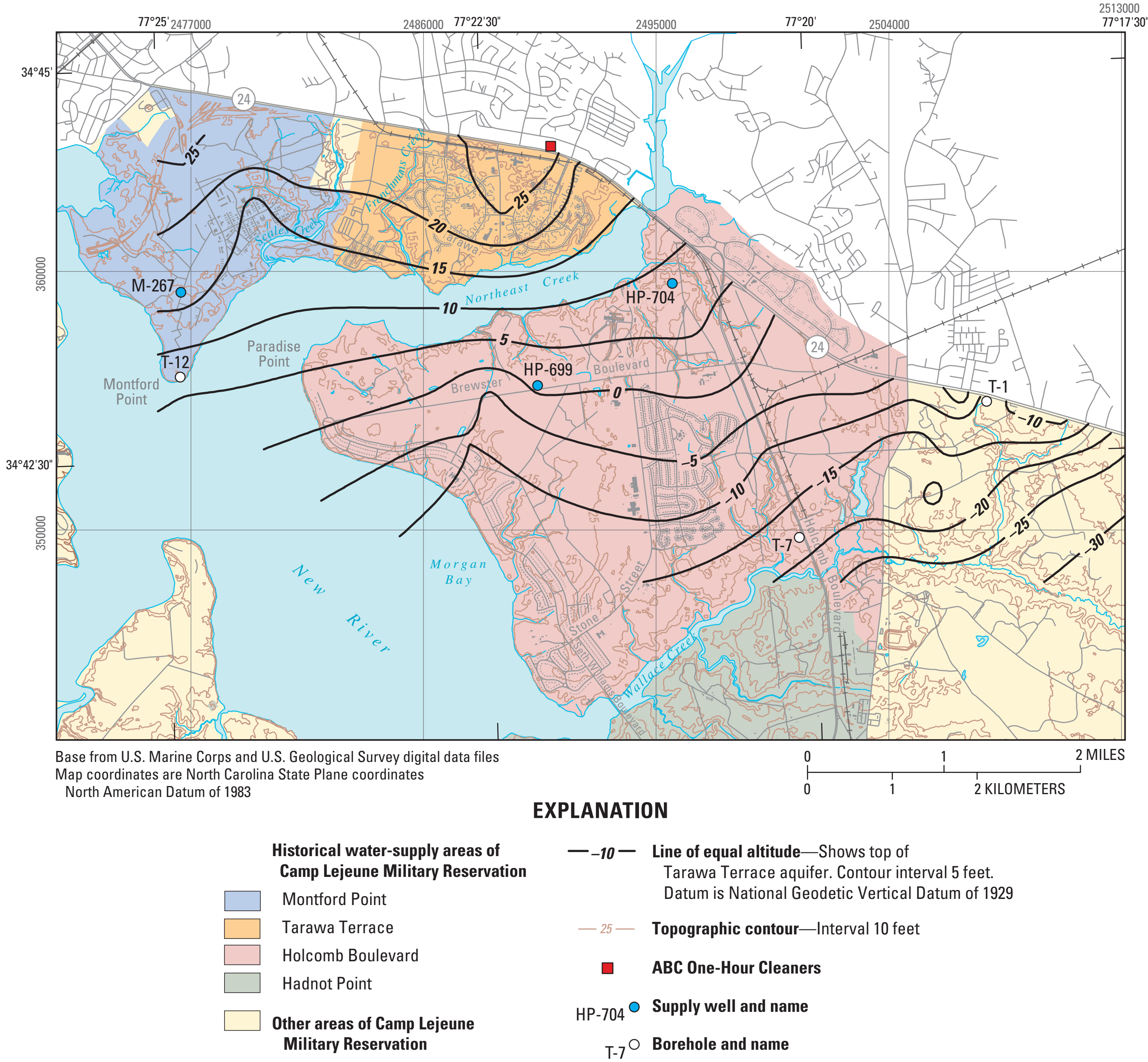


Figure B9. Altitude at the top of the Tarawa Terrace aquifer, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

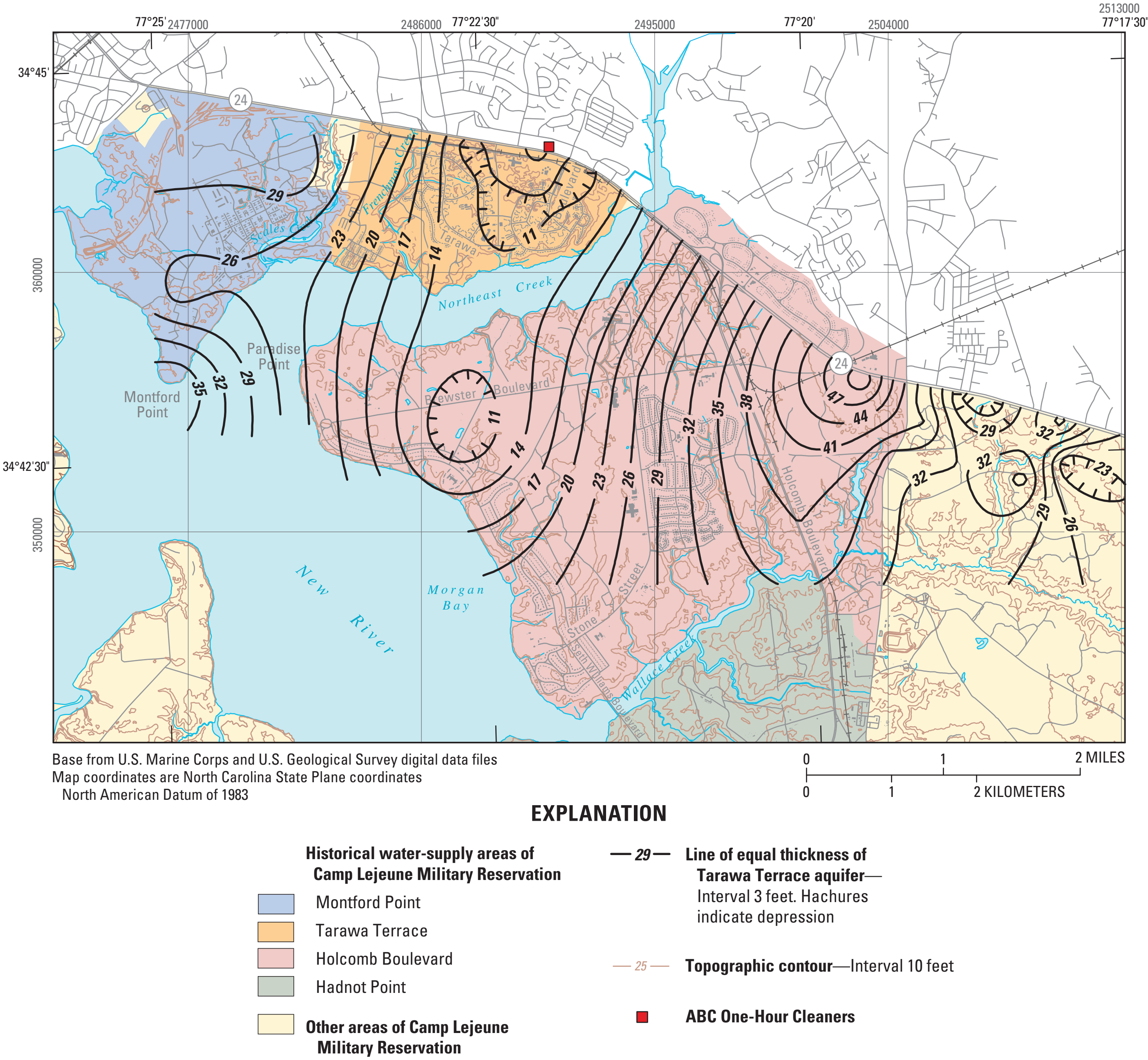


Figure B10. Thickness of the Tarawa Terrace aquifer, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Tarawa Terrace Confining Unit

The Tarawa Terrace confining unit in the vicinity of Tarawa Terrace and Montford Point is comprised of a tan to gray, medium-grained, sandy and silty clay (well M-267). Southeast of Tarawa Terrace and Montford Point, the Tarawa Terrace confining unit is largely undifferentiated in drillers' logs. Based on electric-log signatures and highly generalized descriptions at wells HP-607, HP-623, HP-663, and HP-705, the confining unit is characterized by white, green to blue clay and sandy clay. Altitude at the top of the Tarawa Terrace confining unit varies between a maximum of about 10 ft (Table B6) in the northern part of Tarawa Terrace to a minimum of about –55 ft north of Wallace Creek in the southeastern part of the study area (Table B6, Figure B11). Altitude decreases rapidly to the southeast and southwest across Tarawa Terrace to about –5 ft in the vicinity of Northeast Creek and relatively uniformly and less rapidly from about –10 ft to a minimum of about –55 ft north of Wallace Creek.

Confining unit thickness varies between about 10 ft at Tarawa Terrace and Montford Point to more than 35 ft in the southeastern part of the study area near the headwaters of Wallace Creeks (Figure B12). Patterns of thickness are somewhat irregular but generally trend lesser to greater northwest to southeast.

Table B6. Altitude at the top of the Tarawa Terrace 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	
C3	2491433	364437	23
C9	2491730	364800	18
CCC-1	2483873	360997	4
HP-607 (new)	2496820	352510	–31
HP-614 (new)	2512180	353670	–44
HP-619 (new)	2515870	352640	–46
HP-621 (new)	2505510	354290	–52
HP-622	2494248	353323	–44
HP-623	2495617	350860	–51
HP-629 (new)	2504800	355152	–49
HP-641	2504106	353016	–52
HP-643	2494346	356083	–25
HP-645	2497333	356430	–31
HP-646	2497870	357826	–32
HP-647	2499461	356343	–42
HP-648	2506809	355200	–29
HP-649	2508630	354860	–36
HP-650	2510615	354300	–45
HP-651	2503790	348090	–61
HP-663	2510881	352712	–42
HP-701	2487690	353540	–19
HP-703	2496450	358140	–26
HP-704	2495650	359580	–34
HP-705	2501260	356200	–48
HP-706	2502990	355940	–54
HP-708	2514450	353090	–53
HP-709	2505650	351270	–44
HP-711	2509200	352130	–58
LCH-4009	2499585	358589	–38
M-244	2475713	361306	–7
M-267	2476609	359232	–8
M-628	2479434	362735	–14
ON-T2-87	2487495	353878	–11
PZ-05&06	2490707	364926	17
S2	2490787	364883	16
S5	2491244	364081	20
S6	2490617	364938	11
S8	2491312	364938	15
S9	2491682	364593	19
S190A	2487640	353870	–12
T-1	2507870	355030	–39
T-7	2500628	349685	–56
T-9	2490489	364648	14
T-10	2487680	364960	15
T-11	2485278	365352	1
T-12	2476550	355830	–32
T-13	2481170	363930	–9
T-14	2476788	364170	–5
TT-25	2491984	364042	10
TT-52	2489060	362321	17

[1]See Plate 1 for location

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

Boring logs in the vicinity of ABC One-Hour Cleaners and northern Tarawa Terrace indicate that confining unit occurrence is possibly lensoidal and somewhat to largely discontinuous. The confining unit is thin and possibly entirely missing in the southern part of Tarawa Terrace near Tarawa Boulevard.

Comparison of altitudes at the top of the Tarawa Terrace confining unit to altitudes reported by Cardinell et al. (1993, Table 3, Sections A–A' and B–B') at the top of the "Castle Hayne confining unit" at Tarawa Terrace indicate substantial agreement at borehole sites T-9, T-10, and T-11 and at well TT-25. Poor agreement occurs at Montford Point and, with the exception of a small area in the vicinity of well HP-701, little or no correlation occurs between the Tarawa Terrace confining unit and the "Castle Hayne confining unit" in the remainder of the study area south and southeast of Northeast Creek. The "Castle Hayne confining unit" of Cardinell et al. (1993) typically occurs above the Tarawa Terrace confining unit in these areas.

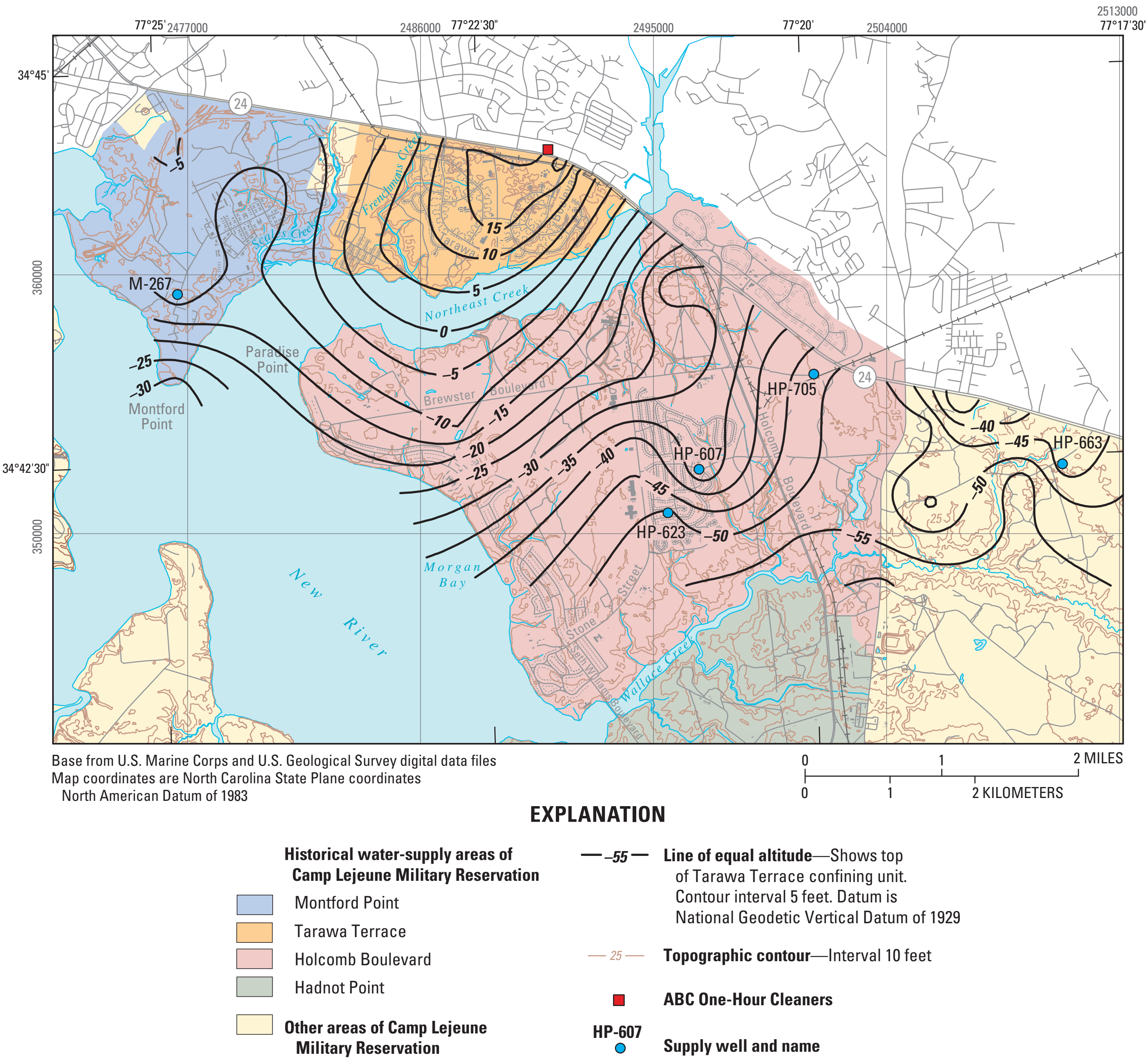
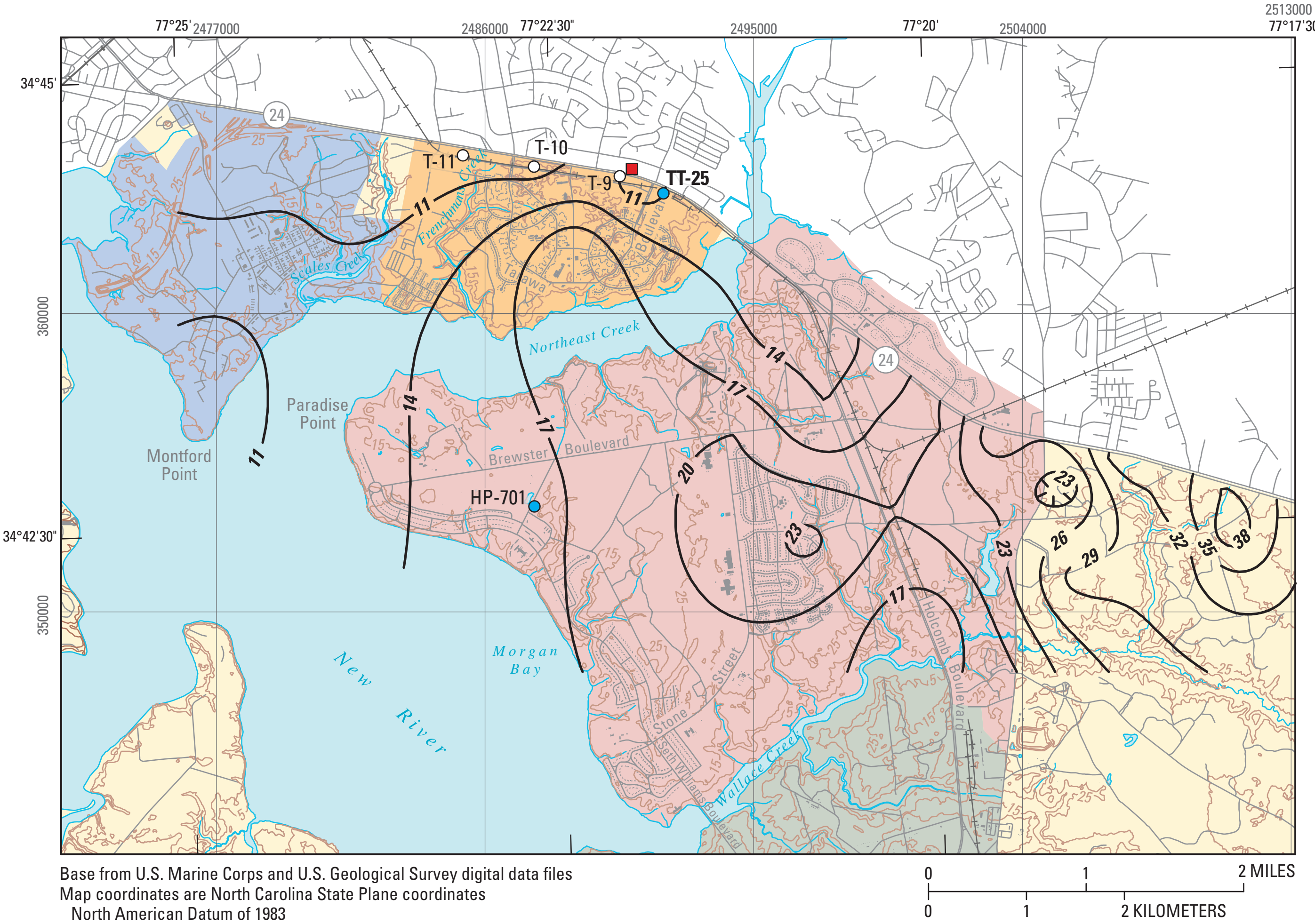


Figure B11. Altitude at the top of the Tarawa Terrace confining unit, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.



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

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

— 17 — **Line of equal thickness of Tarawa Terrace confining unit**—Interval 3 feet. Hachures indicate depression

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

ABC One-Hour Cleaners

HP-701 **Supply well and name**

T-11 **Borehole and name**

Figure B12. Thickness of the Tarawa Terrace confining unit, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Upper Castle Hayne Aquifer–River Bend Unit

Contours at the top of the River Bend unit of the Upper Castle Hayne aquifer represent, as well, the top of the Castle Hayne aquifer system as defined by this study. The surface of the Upper Castle Hayne aquifer–River Bend unit varies from a maximum altitude of about 5 ft north of Tarawa Terrace to a minimum altitude of about –80 ft near the southeastern limit of the study area (Table B7, Figure B13). Altitude appears to dip uniformly from the vicinity of Tarawa Terrace to the southeast, beginning with a relatively rapid decline across Tarawa Terrace to Northeast Creek and continuing at a smaller rate of decline toward Wallace Creek. The surface declines less uniformly to the southwest between Tarawa Terrace and Paradise Point. In the northern part and northwest of Tarawa Terrace, the River Bend unit of the Upper Castle Hayne aquifer consists of well-graded, very fine- to coarse-grained, gray, silty sand. Borehole logs in this area frequently indicate "running" or "flowing" sands at depths ranging from about 20 to 30 ft below ground surface and, typically, immediately beneath a zone of clay or silty sand (Roy F. Weston, Inc. 1992, 1994; O'Brien & Gere Engineers, Inc. 1992; O'Brien & Gere Engineers, Inc. 1993).

Table B7. Altitude at the top of the Upper Castle Hayne aquifer–River Bend 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	
C3	2491433	364437	8
C9	2491730	364800	6
HP-607 (new)	2496820	352510	–55
HP-614 (new)	2512180	353670	–80
HP-619 (new)	2515870	352640	–75
HP-621 (new)	2505510	354290	–73
HP-622	2494248	353323	–55
HP-623	2495617	350860	–64
HP-627 (new)	2508310	354030	–80
HP-629 (new)	2504800	355152	–73
HP-641	2504106	353016	–76
HP-643	2494346	356083	–45
HP-645	2497333	356430	–45
HP-646	2497870	357826	–46
HP-647	2499461	356343	–60
HP-648	2506809	355200	–61
HP-649	2508630	354860	–68
HP-650	2510615	354300	–83
HP-651	2503790	348090	–81
HP-663	2510881	352712	–82
HP-700	2488520	355270	–40
HP-701	2487690	353540	–31
HP-703	2496450	358140	–48
HP-704	2495650	359580	–47
HP-705	2501260	356200	–68
HP-706	2502990	355940	–82
HP-708	2514450	353090	–81
HP-709	2505650	351270	–74
HP-711	2509200	352130	–88
LCH-4009	2499585	358589	–53
M-244	2475713	361306	–20
M-267	2476609	359232	–18
M-628	2479434	362735	–26
ON-T2-87	2487495	353878	–27
PZ-01&02	2490677	364860	0
PZ-05&06	2490707	364926	6
S2	2490787	364883	8
S5	2491244	364081	10
S8	2491312	364938	6
S9	2491682	364593	9
S190A	2487640	353870	–28
STT61to66-MW04	2489186	364740	–1
STT61to66-MW06	2489276	364816	3
STT61to66-MW08	2489219	364885	7
STT61to66-MW10	2489102	364732	1
STT61to66-MW12	2489241	364700	8
STT61to66-MW16	2489247	364603	2
STT61to66-MW20	2489135	364554	2
T-1	2507870	355030	–73
T-7	2500628	349685	–70
T-9	2490489	364648	3
T-10	2487680	364960	5
T-11	2485278	365352	–9
T-12	2476550	355830	–42
T-13	2481170	363930	–18
T-14	2476788	364170	–15
TT-52	2489060	362321	–3

[1]See Plate 1 for location

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

The depth at which the "running" sands were reported was selected for this study as the top of the Upper Castle Hayne aquifer–River Bend unit. The zone of clay and silty sand immediately above the "running" sands was identified as the Tarawa Terrace confining unit. In the eastern part of Tarawa Terrace in the vicinity of well TT-25, the River Bend unit consists of gray, fine- to medium-grained, fossiliferous sand and "shell hash" or possibly coquina. The driller reports a loss of circulation at this site between 61 and 70 ft. At Montford Point and vicinity, the River Bend unit consists of fossiliferous, gray, silty sand, zones of which are possibly cemented or indurated. Locally, the sand may be interbedded with shell limestone and thin lenses or beds of clay. At the base of the unit, in the vicinity of well M-267, is likely a zone of cavernous limestone. The driller reported a complete loss of drilling fluid between 54 and 58 ft below ground surface at this site. Southeast of Northeast Creek, the River Bend unit is poorly differentiated at most sites and is typically described as consisting of "limestone and sand" or "sand, clay and limestone." At borehole T-1, near the southeastern limit of the study area, the River Bend unit

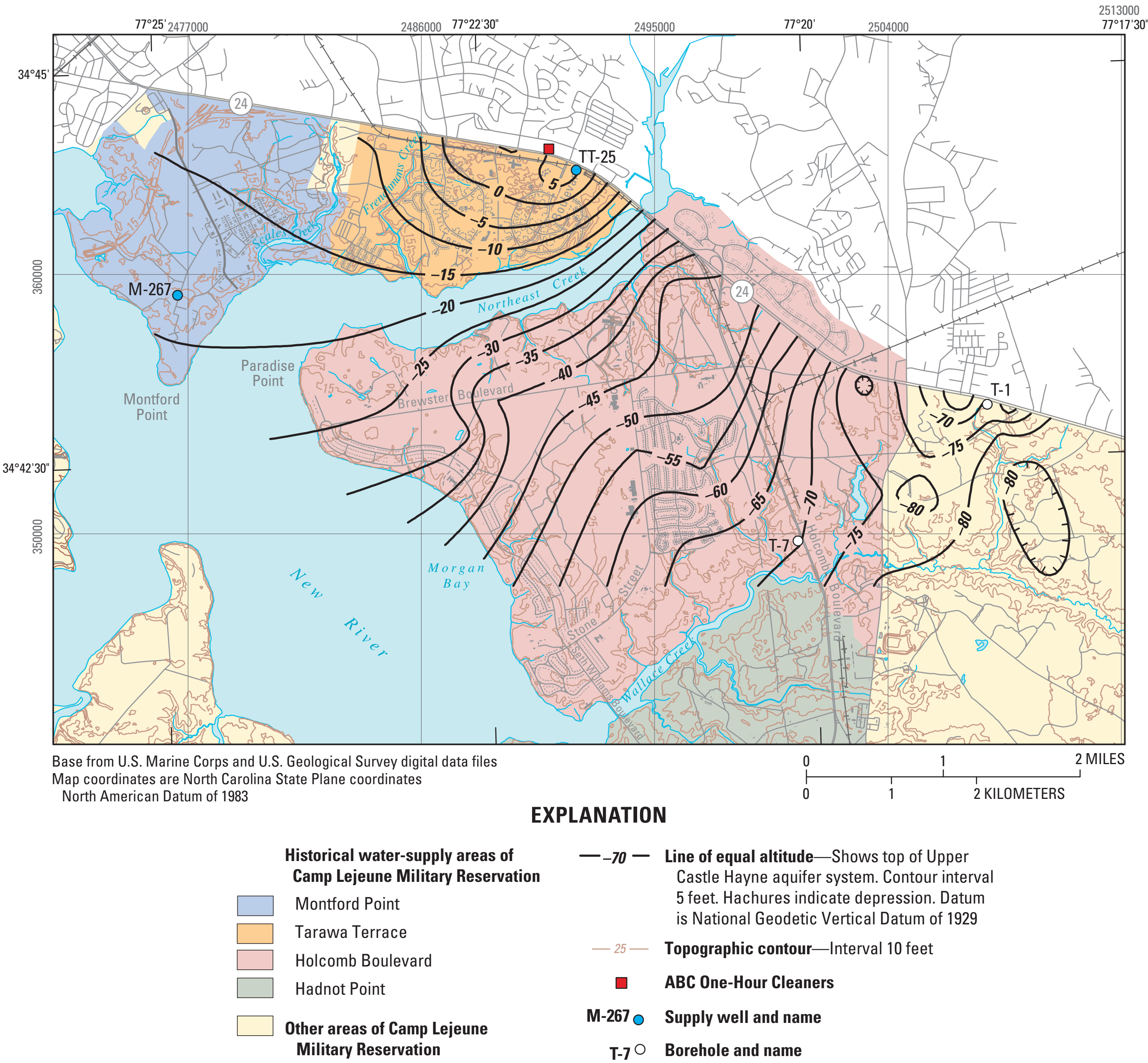


Figure B13. Altitude at the top of the Castle Hayne aquifer system. Corresponds to the top of the Upper Castle Hayne aquifer–River Bend unit, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

reportedly consists of “shellrock and sand” and traces of clay. Similarly, at borehole T-7 south of Brewster Boulevard and just north of Wallace Creek, the River Bend unit is described in the driller’s log as a medium-grained, gray sand with “streaks” and zones of “shellrock.”

Thickness of the River Bend unit varies from a minimum of less than 20 ft northwest of Montford Point to a maximum of about 59 ft, south of Brewster Boulevard in the vicinity of Paradise Point (Figure B14). Thickness contours are somewhat to highly irregular, particularly near the southeastern limit of the study area. Thickness varies substantially across relatively short distances in the vicinity of Paradise Point and north of Wallace Creek in the vicinity of SR 24. The Upper Castle Hayne aquifer–River Bend unit of this study is largely equivalent to the “surficial aquifer” cited in reports of various remedial investigations of leaking underground storage tanks and studies of groundwater contamination at and in the vicinity of Tarawa Terrace (Roy F. Weston, Inc. (1992, 1994); Law Engineering, Inc. (1994a, b, 1995a, b); Richard Catlin & Associates, Inc. (1995a).

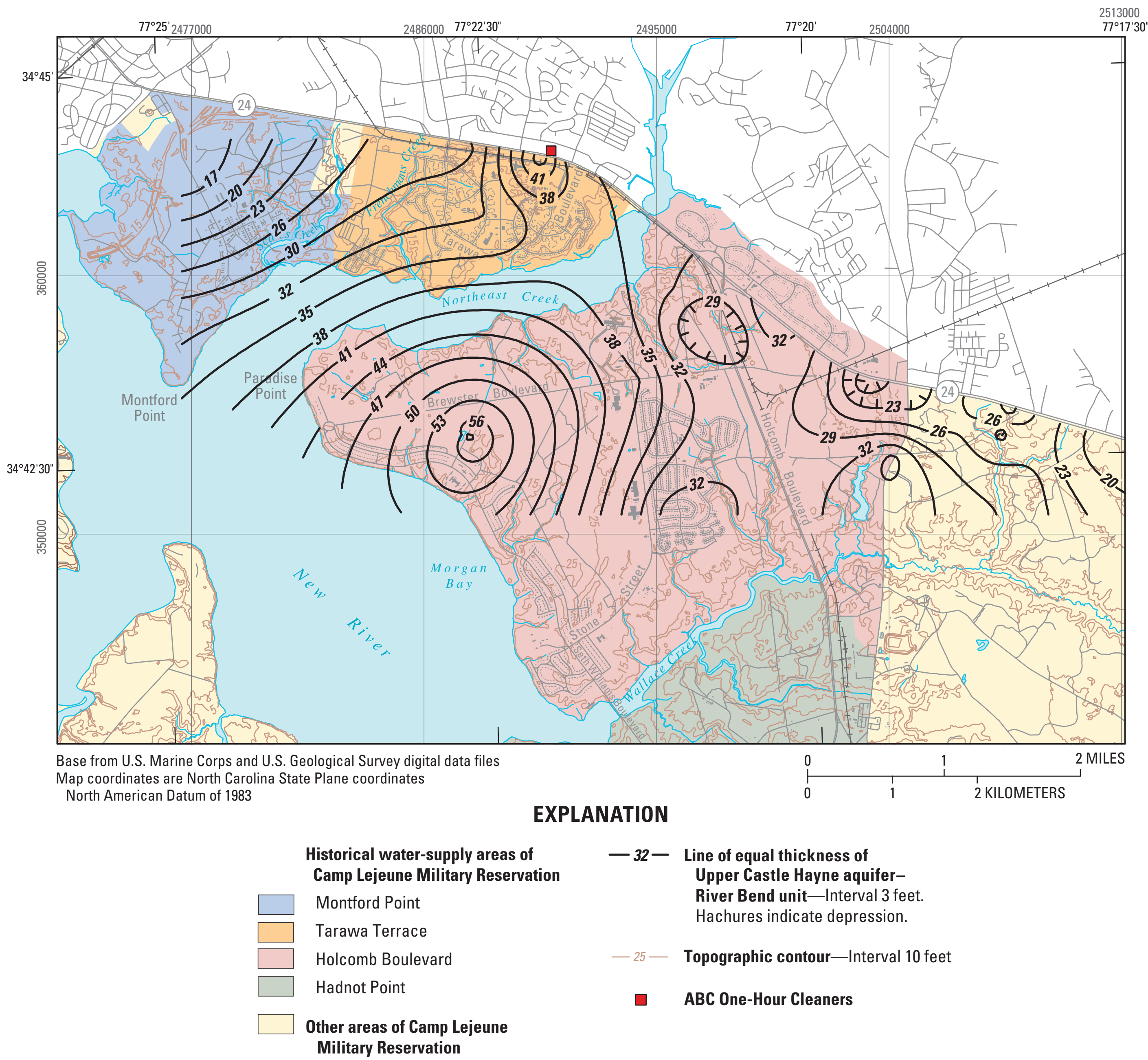


Figure B14. Thickness of the Upper Castle Hayne aquifer–River Bend unit, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Local Confining Unit

The Local confining unit separates the River Bend and Lower units of the Upper Castle Hayne aquifer. As discussed previously, the top of the Local confining unit also conforms approximately to the top of the Castle Hayne Formation. Maximum altitude of the Local confining unit surface occurs northwest of Tarawa Terrace at about –30 ft. Minimum altitude is about –110 ft and occurs in the southeastern part of the study area north of the headwaters of Wallace Creek (Table B8, Figure B15). The top of the Local confining unit generally declines uniformly to the southeast; however, a slight rise occurs in the surface east of Brewster Boulevard near Holcomb Boulevard. Such irregularities are not pronounced and generally equal 10 ft or less.

Local confining unit thickness varies from about 6 to 18 ft. In the vicinity of Tarawa Terrace and Montford Point, thickness increases from east to west and from west to east toward an approximately circular center of thickness of about 18 ft west of Tarawa Terrace (Figure B16). South of Northeast

Table B8. Altitude at the top of the Local confining unit, 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 below NGVD 29
	East	North	
C2	2490793	364902	–28
C5	2491233	364107	–20
C9	2491730	364800	–29
C11	2492130	362300	–56
HP-614 (new)	2512180	353670	–98
HP-619 (new)	2515870	352640	–94
HP-621 (new)	2505510	354290	–98
HP-622	2494248	353323	–91
HP-623	2495617	350860	–91
HP-627 (new)	2508310	354030	–102
HP-629 (new)	2504800	355152	–95
HP-641	2504106	353016	–112
HP-643	2494346	356083	–83
HP-645	2497333	356430	–75
HP-646	2497870	357826	–72
HP-647	2499461	356343	–90
HP-648	2506809	355200	–87
HP-649	2508630	354860	–98
HP-650	2510615	354300	Missing
HP-651	2503790	348090	Missing
HP-663	2510881	352712	–104
HP-698	2492410	355870	–69
HP-699	2490430	355560	–73
HP-700	2488520	355270	Missing
HP-701	2487690	353540	Missing
HP-703	2496450	358140	–74
HP-704	2495650	359580	–79
HP-705	2501260	356200	–96
HP-706	2502990	355940	–100
HP-708	2514450	353090	–99
HP-709	2505650	351270	Missing
HP-710	2507770	351490	Missing
HP-711	2509200	352130	–116
LCH-4009	2499585	358589	–89
M-161	2477550	362560	–34
M-168	2477602	362723	–34
M-197	2477626	361621	–43
M-267	2476609	359232	–47
M-628	2479434	362735	–42
ON-T2-87	2487495	353878	–83
S190A	2487640	353870	–88
T-1	2507870	355030	–101
T-7	2500628	349685	Missing
T-9	2490489	364648	–43
T-10	2487680	364960	–23
T-11	2485278	365352	–37
T-12	2476550	355830	–72
T-13	2481170	363930	–42
T-14	2476788	364170	–29
TT-23	2491024	363208	–39
TT-25	2491984	364042	–44
TT-52	2489060	362321	–35
TT-67	2490160	362730	–32
X24C2	2490640	363540	–30

[1]See Plate 1 for location

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

Creek in the vicinity of Brewster Boulevard, thickness increases from west to east and from east to west toward a relatively large thickness of about 18 ft near Brewster Boulevard in the vicinity of well HP-643.

At borehole T-13, north of Montford Point, the Local confining unit is described as a “clay medium hard,” between 77 and 82 ft. A similar lithology possibly occurs at well HP-649, near the southeastern margin of the study area and adjacent to SR 24, where the Local confining unit is identified in the driller’s log as “clay” between 140 and 150 ft below ground surface. Fine-grained materials such as clays are typically suspended in drilling mud during borehole drilling and frequently are indistinguishable from the drilling mud. Consequently, the Local confining unit is undifferentiated in borehole and drillers’ logs throughout most of the study area. An exception occurs north of Tarawa Terrace in the vicinity of SR 24 where borehole logs collected by Roy F. Weston, Inc. (1992, 1994) refer to a “silty fine sand” or “lean clay” at depths

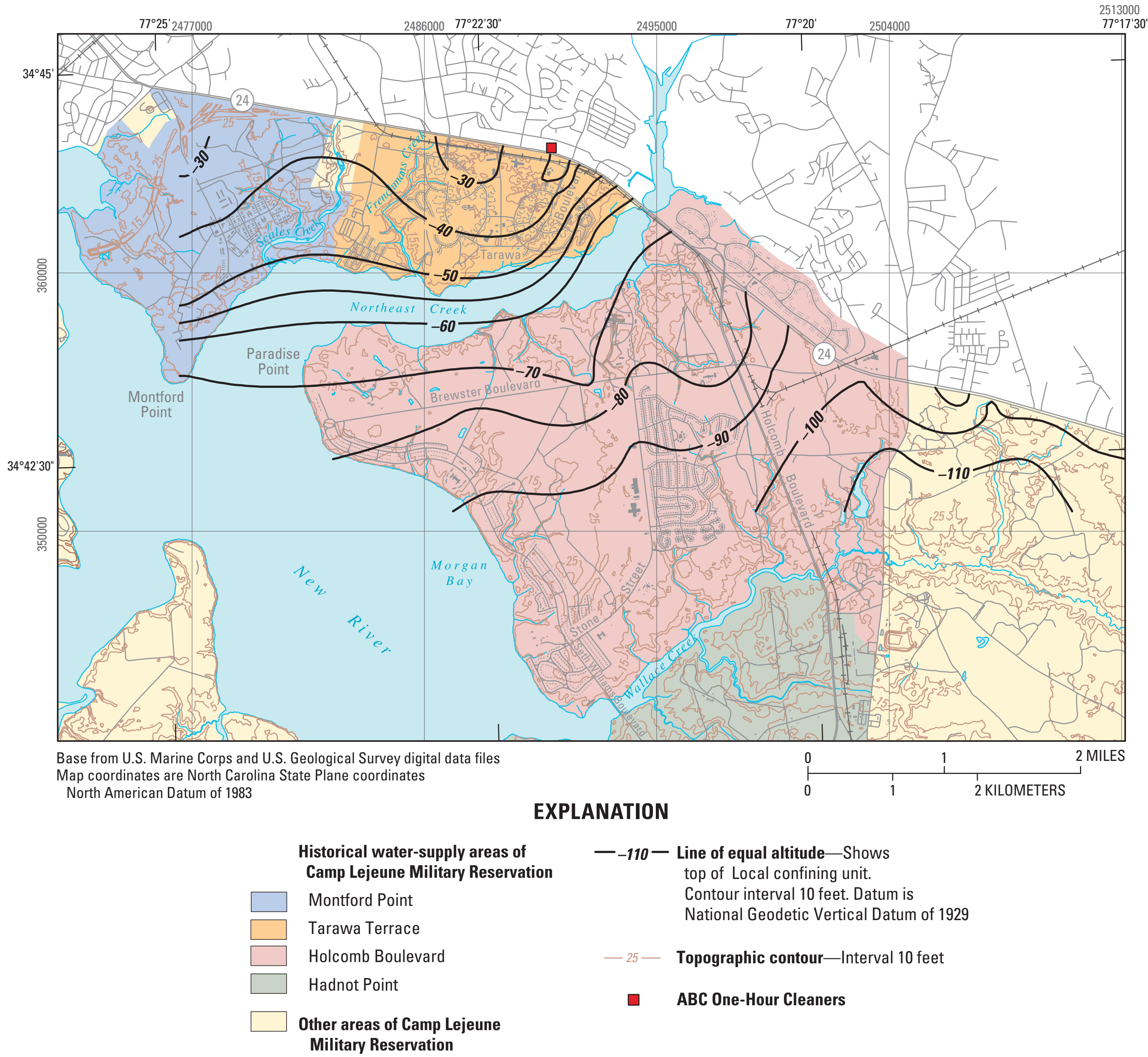


Figure B15. Altitude at the top of the Local confining unit. Approximates the lithostratigraphic top of the Castle Hayne Formation, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

ranging from about 50 to 60 ft. Thickness of the silty sand or clay varied from 3 to about 10 ft and typically was about 10 ft. Underlying the clay or silty sand were fossiliferous, calcareous sands identified by Roy F. Weston, Inc. (1992, 1994) as the Castle Hayne Formation. Findings of this study conform to these interpretations, and the silty sand is identified herein as the Local confining unit in that area. Harned et al. (1989) in their Section B–B' recognized a zone of low resistivity, designated herein the Local confining unit, in the electric log of well HP-643 between 100 and 110 ft, and correlated this unit continuously eastward for about 3 miles to the site of borehole T-1 (Figure B3). The Local confining unit is locally thin or absent in the vicinity of wells HP-641, HP-650, HP-651, HP-709, and HP-710 and borehole T-7. These local anomalies are not considered areally extensive and are not represented on Figures B15 and B16.

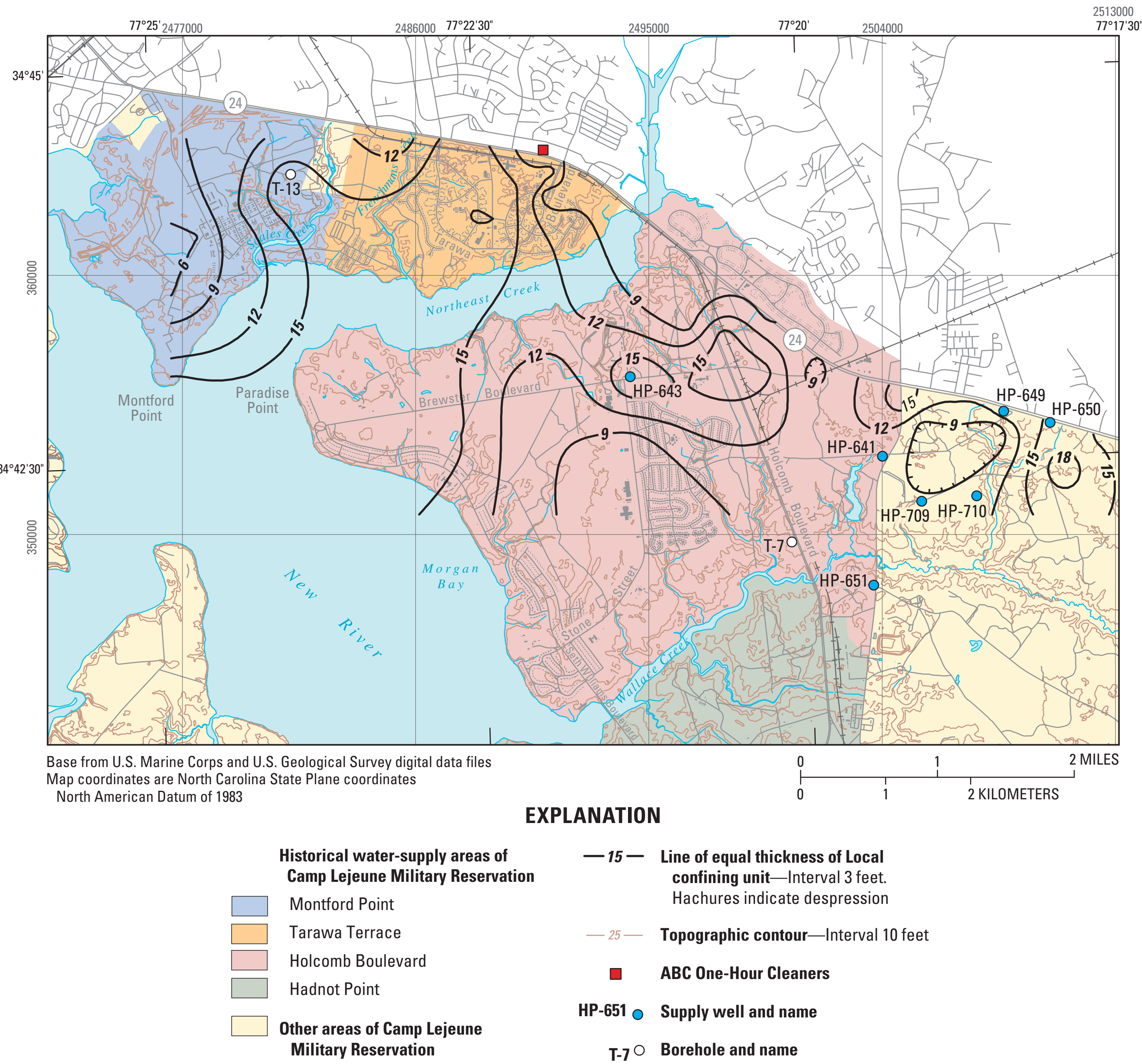


Figure B16. Thickness of the Local confining unit, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Upper Castle Hayne Aquifer–Lower Unit

Contours at the base of the Local confining unit also represent the top of the Lower unit of the Upper Castle Hayne aquifer. The structure of the surface of the Lower unit of the Upper Castle Hayne aquifer is similar to the top of the Local confining unit with lower altitudes. Maximum altitudes occur in the vicinity of Montford Point and Tarawa Terrace at about –40 ft. The surface declines relatively uniformly to the southeast with minor interruptions at local highs or depressions in the vicinity of Brewster Boulevard and near the southeastern margin of the study area. Minimum altitude is about –130 ft and occurs north of the headwaters of Wallace Creek near the southeastern limit of the study area (Table B9, Figure B17).

Maximum thickness of the Lower unit of the Upper Castle Hayne aquifer is about 45 ft and is centered on a zone of high

Table B9. Altitude at the top of the Upper Castle Hayne aquifer–Lower unit, 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 below NGVD 29
	East	North	
C2	2490793	364902	–37
C5	2491233	364107	–33
C11	2492130	362300	–66
HP-614 (new)	2512180	353670	–113
HP-619 (new)	2515870	352640	–104
HP-621 (new)	2505510	354290	–106
HP-622	2494248	353323	–97
HP-623	2495617	350860	–98
HP-627 (new)	2508310	354030	–108
HP-629 (new)	2504800	355152	–112
HP-641	2504106	353016	–122
HP-643	2494346	356083	–101
HP-645	2497333	356430	–91
HP-646	2497870	357826	–88
HP-647	2499461	356343	–106
HP-648	2506809	355200	–99
HP-649	2508630	354860	–112
HP-663	2510881	352712	–124
HP-698	2492410	355870	–81
HP-699	2490430	355560	–83
HP-703	2496450	358140	–82
HP-704	2495650	359580	–85
HP-705	2501260	356200	–104
HP-706	2502990	355940	–112
HP-708	2514450	353090	–111
HP-711	2509200	352130	–130
LCH-4009	2499585	358589	–97
M-161	2477550	362560	–42
M-197	2477626	361621	–49
M-267	2476609	359232	–53
M-628	2479434	362735	–56
ON-T2-87	2487495	353878	–100
S190A	2487640	353870	–103
T-1	2507870	355030	–113
T-9	2490489	364648	–53
T-10	2487680	364960	–41
T-11	2485278	365352	–47
T-12	2476550	355830	–88
T-13	2481170	363930	–58
T-14	2476788	364170	–37
TT-23	2491024	363208	–46
TT-25	2491984	364042	–51
TT-52	2489060	362321	–53
TT-67	2490160	362730	–46
X24C2	2490640	363540	–44

[1]See Plate 1 for location

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

thickness near Brewster Boulevard, about midway between Paradise Point and Holcomb Boulevard (Figure B18). Thickness declines relatively rapidly east, west, and southeast of this zone to a minimum of about 10 ft south of Brewster Boulevard and north of the headwaters of Wallace Creek. Thickness trends are somewhat to highly irregular, and a consistent directional trend does not occur.

The lithology of the Lower unit of the Upper Castle Hayne aquifer north and west of Tarawa Terrace, in the vicinity of SR 24, was described as a calcareous, fossiliferous, somewhat silty sand (Roy F. Weston, Inc. 1992, 1994). In the same area, in the vicinity of borehole T-10, the unit is described as “shellrock and fine sand in streaks.” In the vicinity of well TT-25, located north and slightly east of

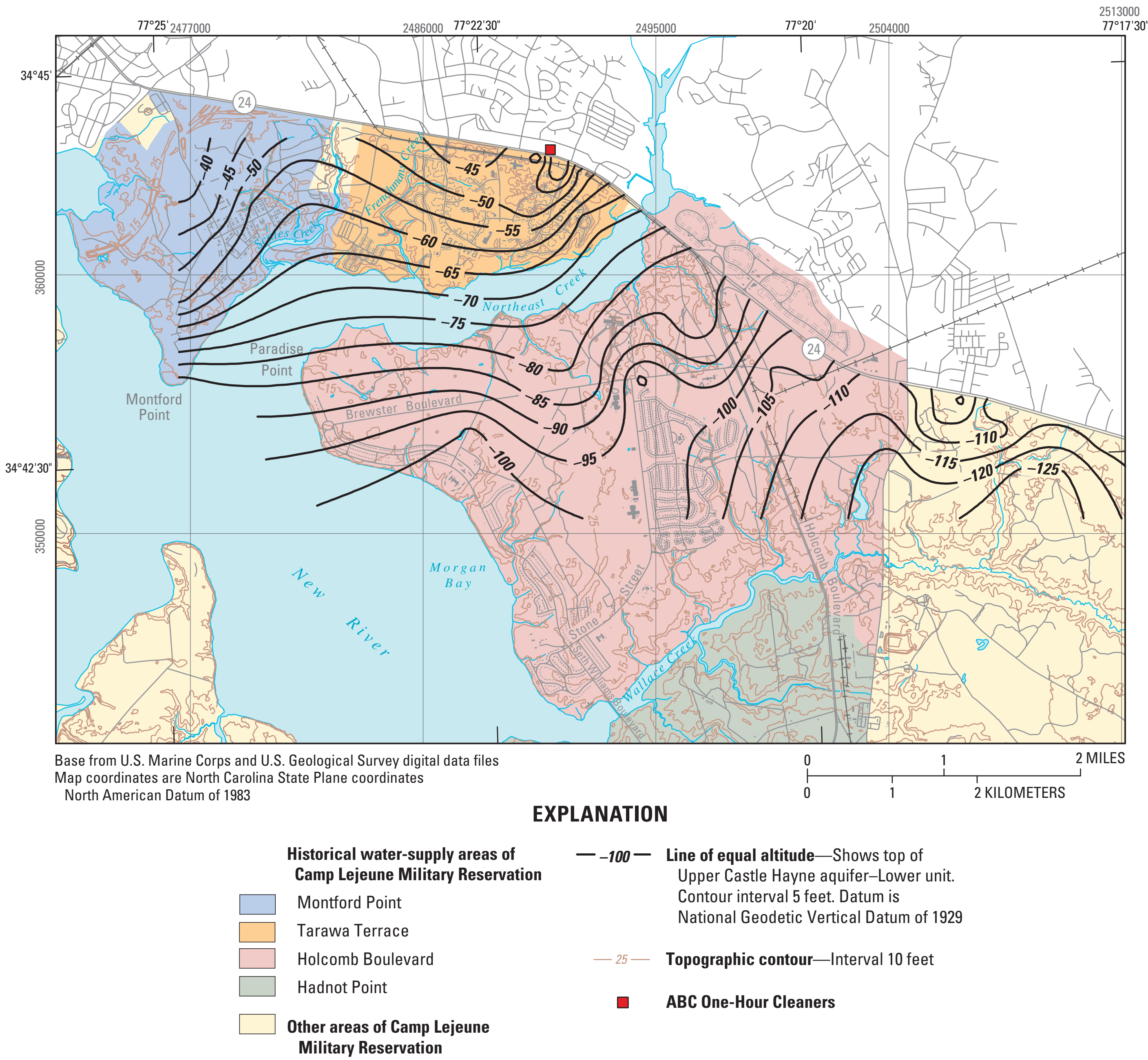


Figure B17. Altitude at the top of the Upper Castle Hayne aquifer–Lower unit, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Tarawa Terrace, the unit is described as a gray, fine sand containing shells and “shell hash.” North of Montford Point, in the vicinity of boreholes T-13 and T-14, the Lower unit of the Upper Castle Hayne aquifer is described as a fine- to medium-grained sand. Between Northeast and Wallace Creeks, this unit is poorly differentiated in drillers’ logs. In the vicinity of borehole T-1, near SR 24 in the southeastern part of the study area, the Lower unit is described as “medium soft shellrock and sand.” North of Wallace Creek near the center of the study area in the vicinity of borehole T-7, the unit is described as a medium-grained, gray sand containing loose shells and “streaks” of shellrock. The Lower unit of the Upper Castle Hayne aquifer of this study is equivalent to the unit variously described by Roy F. Weston, Inc. (1992, 1994) as the Castle Hayne Formation, “Castle Hayne aquifer,” and “Castle Hayne limestone.”

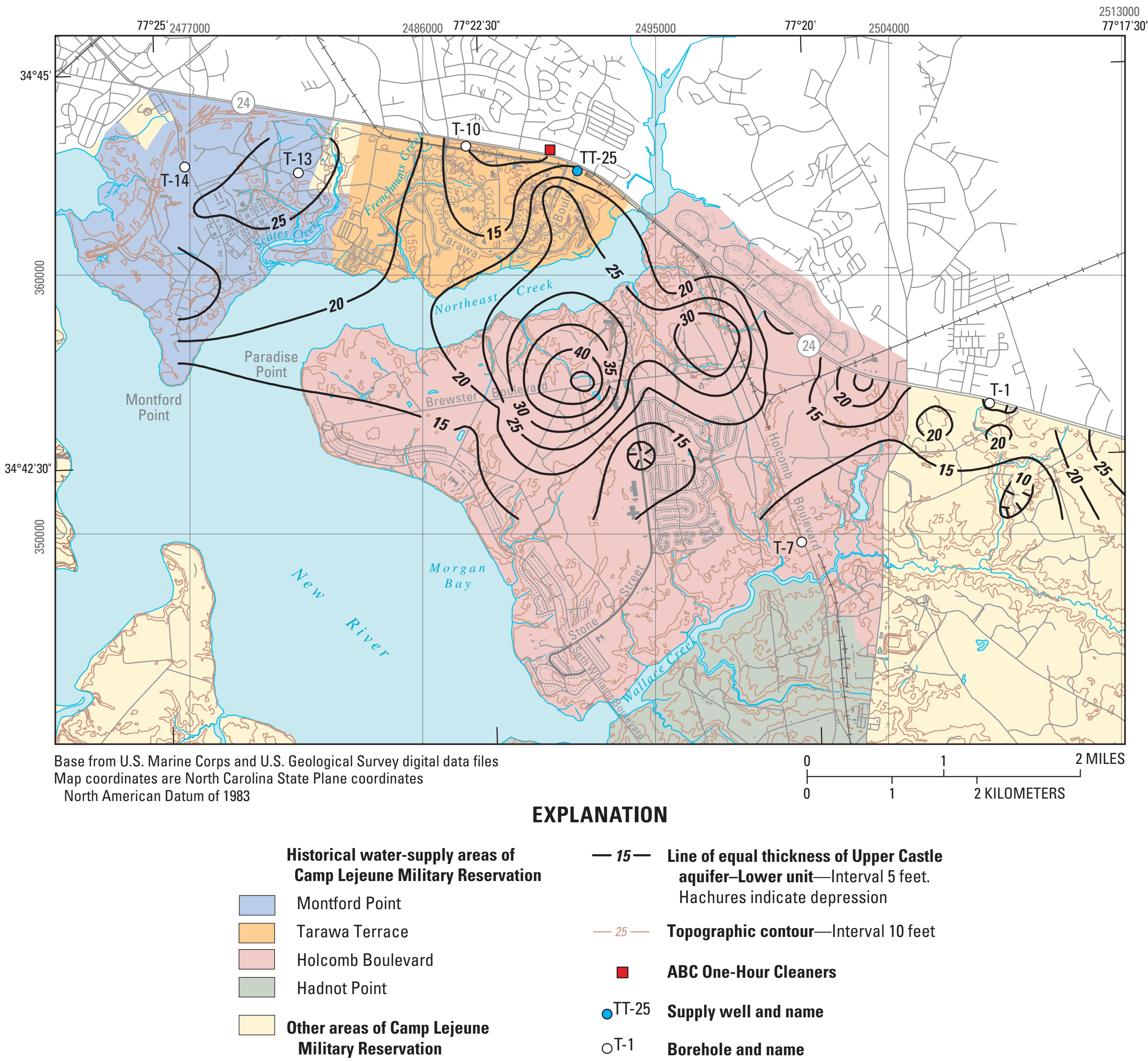


Figure B18. Thickness of the Upper Castle Hayne aquifer–Lower unit, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Middle Castle Hayne Confining Unit

Contours of equal altitude at the top of the Middle Castle Hayne confining unit are shown in Figure B19. Maximum surface altitudes of about –55 or –60 ft occur north of Tarawa Terrace in the vicinity of borehole T-10 and SR 24 and in the northern part of Montford Point in the vicinity of borehole T-14 (Table B10). Surface altitude decreases somewhat irregularly northwest to southeast. Minimum surface altitudes are less than –140 ft and are associated with several minor depressions in the vicinity and south of SR 24 in the east-central part of the study area and north of the headwaters of Wallace Creek in the southeastern part of the study area.

Thickness of the Middle Castle Hayne confining unit is somewhat to highly variable and ranges from a minimum thickness of about 14 ft to a maximum thickness of about 26 ft

Table B10. Altitude at the top of the Middle Castle Hayne confining unit, 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] East	Location coordinates[2] North	Unit altitude, in feet below NGVD 29
C1	2490503	365232	–69
CCC-1	2483873	360997	–66
CCC-2	2483431	362506	–73
HP-607 (new)	2496820	352510	–114
HP-614 (new)	2512180	353670	–140
HP-619 (new)	2515870	352640	–124
HP-621 (new)	2505510	354290	–129
HP-622	2494248	353323	–104
HP-623	2495617	350860	–116
HP-627 (new)	2508310	354030	–131
HP-629 (new)	2504800	355152	–129
HP-641	2504106	353016	–132
HP-643	2494346	356083	–121
HP-645	2497333	356430	–123
HP-646	2497870	357826	–122
HP-647	2499461	356343	–124
HP-648	2506809	355200	–117
HP-649	2508630	354860	–126
HP-650	2510615	354300	–149
HP-651	2503790	348090	–129
HP-663	2510881	352712	–144
HP-698	2492410	355870	–129
HP-699	2490430	355560	–123
HP-700	2488520	355270	–124
HP-701	2487690	353540	–119
HP-703	2496450	358140	–116
HP-704	2495650	359580	–103
HP-705	2501260	356200	–124
HP-706	2502990	355940	–145
HP-708	2514450	353090	–143
HP-709	2505650	351270	–140
HP-710	2507770	351490	–130
HP-711	2509200	352130	–138
LCH-4009	2499585	358589	–108
M-161	2477550	362560	–68
M-168	2477500	362910	–66
M-197	2477626	361621	–71
M-244	2475713	361306	–81
M-267	2476609	359232	–83
M-628	2479434	362735	–82
ON-T2-87	2487495	353878	–115
S190A	2487640	353870	–116
T-1	2507870	355030	–127
T-7	2500628	349685	–120
T-9	2490489	364648	–61
T-10	2487680	364960	–51
T-11	2485278	365352	–71
T-12	2476550	355830	–98
T-13	2481170	363930	–84
T-14	2476788	364170	–59
TT-23	2491024	363208	–76
TT-25	2491984	364042	–67
TT-52	2489060	362321	–65
TT-67	2490160	362730	–66
X24C2	2490640	363540	–66
X24S2	2495523	347221	–133

[1]See Plate 1 for location

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

(Figure B20). Contours of equal thickness indicate local areas of greater or lesser thickness rather than a consistent trend in a single direction across the study area, particularly south and east of Brewster Boulevard. In the vicinity of well TT-25, northeast of Tarawa Terrace, unit lithology is described as a “gray silty clay with shell.” At borehole T-12, near the southern extremity of Montford Point, the Middle Castle Hayne confining unit is comprised of soft clay and “streaks” of rock. In the northern part of Montford Point, in the vicinity of borehole T-13, the unit is described as a “medium soft clay.” At Paradise Point, in the vicinity of well HP-700 and Brewster Boulevard, the unit is a green clay with “limestone.” Elsewhere the unit is poorly differentiated or not differentiated at all in drillers’ logs. The Middle Castle Hayne confining unit is also recognized as a relatively thick zone of low resistivity in borehole electric logs of appropriate depth. Harned et al. (1989)

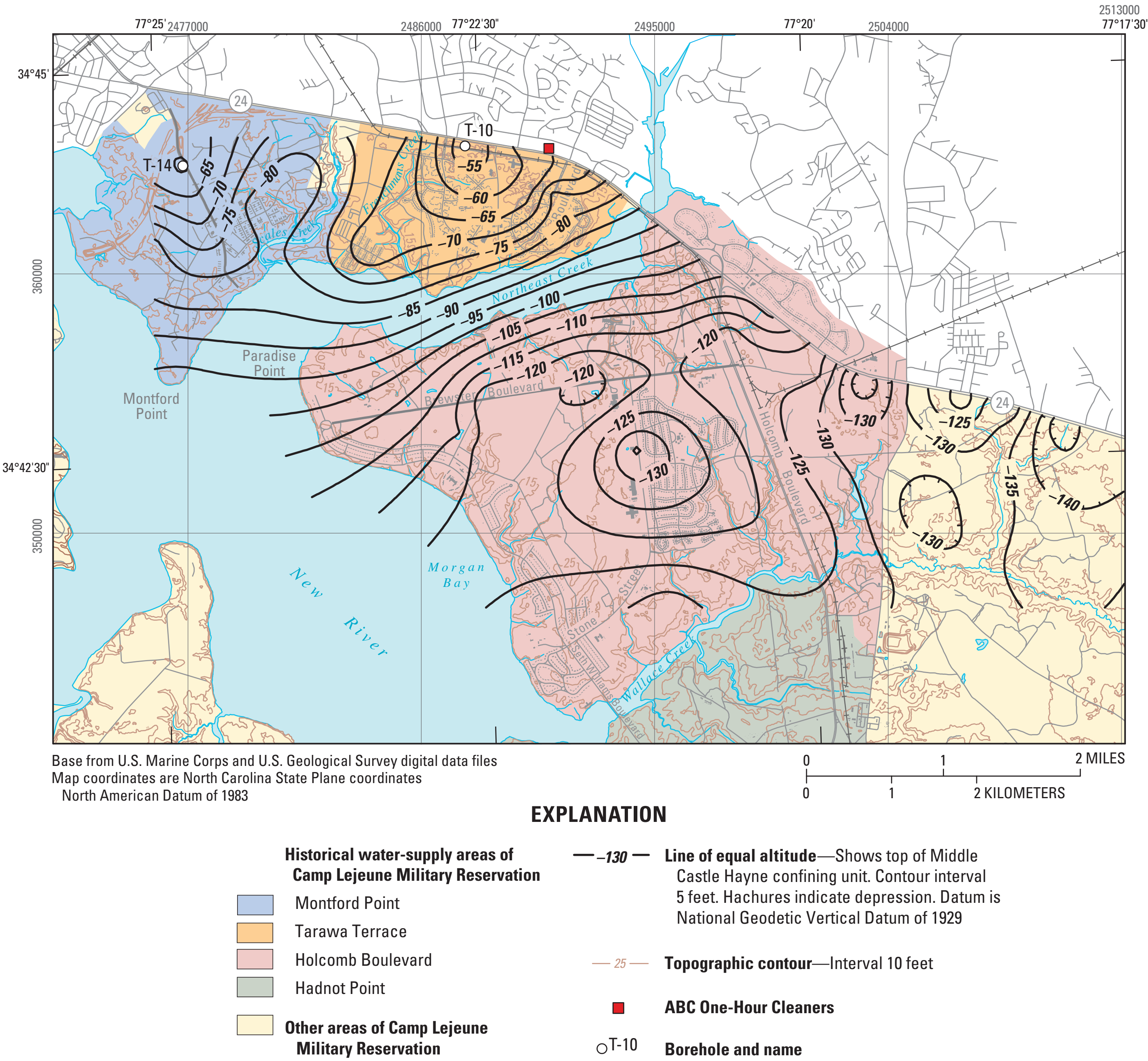


Figure B19. Altitude at the top of the Middle Castle Hayne confining unit, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

and Cardinell et al. (1993, Section A–A') recognized this low-resistivity zone in geophysical logs of several wells and, with minor differences compared to interpretations by this study, correlated the clay identified herein as the Middle Castle Hayne confining unit from well TT-25 near Tarawa Terrace, continuously across Northeast Creek to borehole T-7 and, from there, continuously southeastward across Wallace Creek to the vicinity of Frenchs Creek (Figure B3). On Section B–B' of Cardinell et al. (1993), the low-resistivity zone identified herein as the Middle Castle Hayne confining unit was recognized at a depth of about 100 ft at borehole T-12, near the southernmost extremity of Montford Point, and correlated continuously from well site to well site eastward to the vicinity of well HP-705, east of Brewster Boulevard near SR 24 (Figure B3).

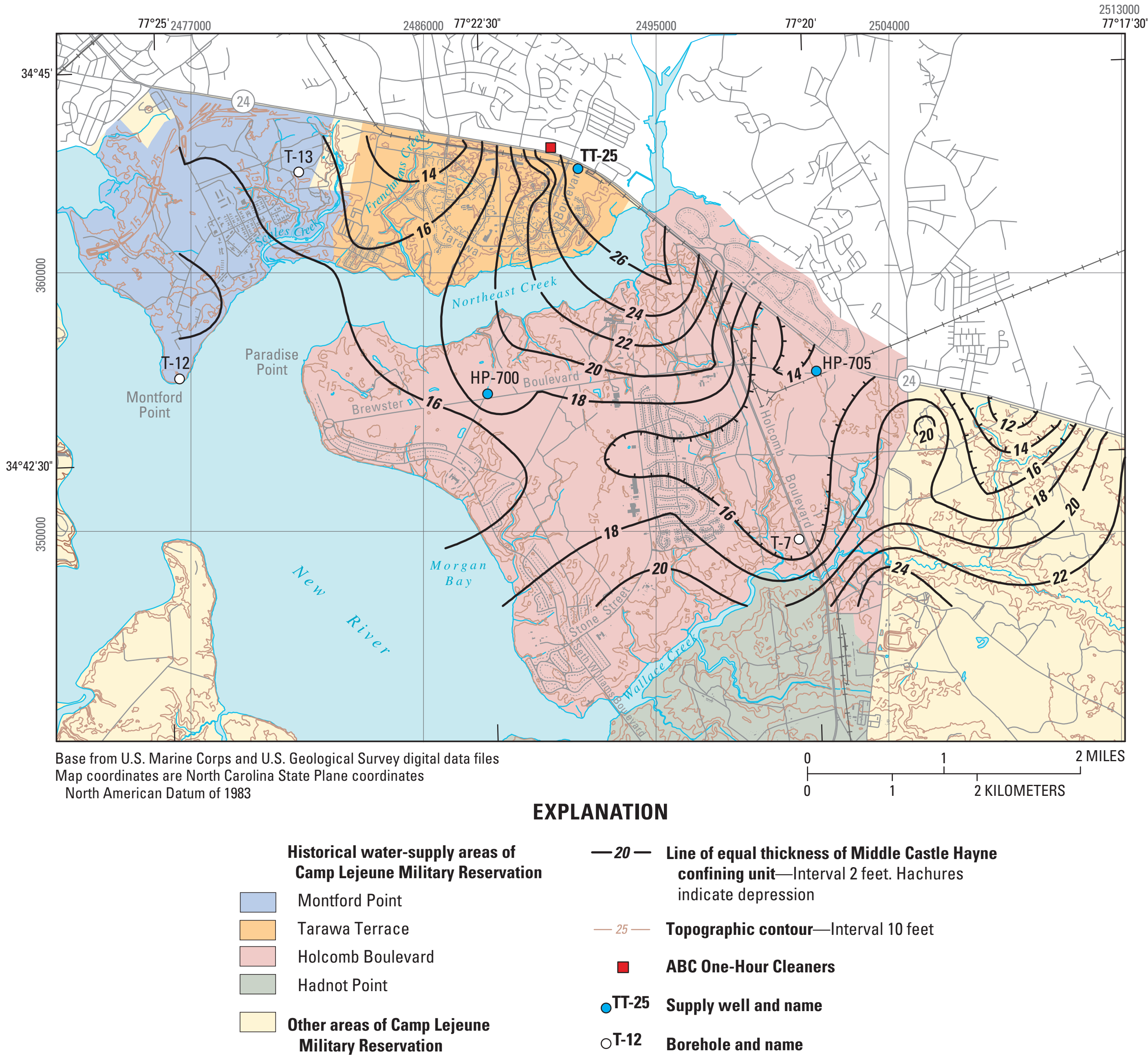


Figure B20. Thickness of the Middle Castle Hayne confining unit, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Middle Castle Hayne Aquifer

The Middle Castle Hayne aquifer is recognized in borehole electric logs as a thick zone of relatively high resistivity and is comprised within most of the study area of fine- to medium-grained, probably calcareous, sand interbedded with silt, clay, and limestone. Northwest of Tarawa Terrace in the vicinity of SR 24 the aquifer is described as a fine sand or fine gray sand in the vicinity of boreholes T-10 and T-11. At Montford Point in the vicinity of well M-267 aquifer lithology is described as a gray, fine- to medium-grained sand with shells and shell fragments. Drillers' logs at several wells in the vicinity of Brewster Boulevard describe the Middle Castle Hayne aquifer as comprised almost entirely of sand and limestone. At borehole T-1, near SR 24 in the southeastern part of the study area, aquifer lithology between 180 and 233 ft below ground surface is described as a fine- to medium-grained gray sand. A loss of drilling fluid is reported across the bottom half of the aquifer at this site, indicating the occurrence of cavernous or highly fractured limestone. At borehole T-7, north of Wallace Creek and near the center of the study area, aquifer lithology is described as "fine gray sand and loose shells."

Contours of equal altitude at the top of the Middle Castle Hayne aquifer are shown in Figure B21. The surface generally declines northwest to southeast but is irregular in the vicinity of several depressions near and south of Brewster Boulevard and to the southeast near SR 24. Maximum altitude occurs northwest of Tarawa Terrace at about –65 ft (Table B11). A minimum altitude of less than –155 ft occurs near the center of a relatively large depression, generally south of SR 24 near the eastern limit of the study area.

Contours of equal thickness of the Middle Castle Hayne aquifer are shown in Figure B22. Thickness varies lesser to greater northwest to southeast and from east to west across the study area toward a maximum of about 120 ft near SR 24 and east southeast of the intersection of Brewster and Holcomb Boulevards. A minimum thickness of about 35 ft occurs just east of Montford Point.

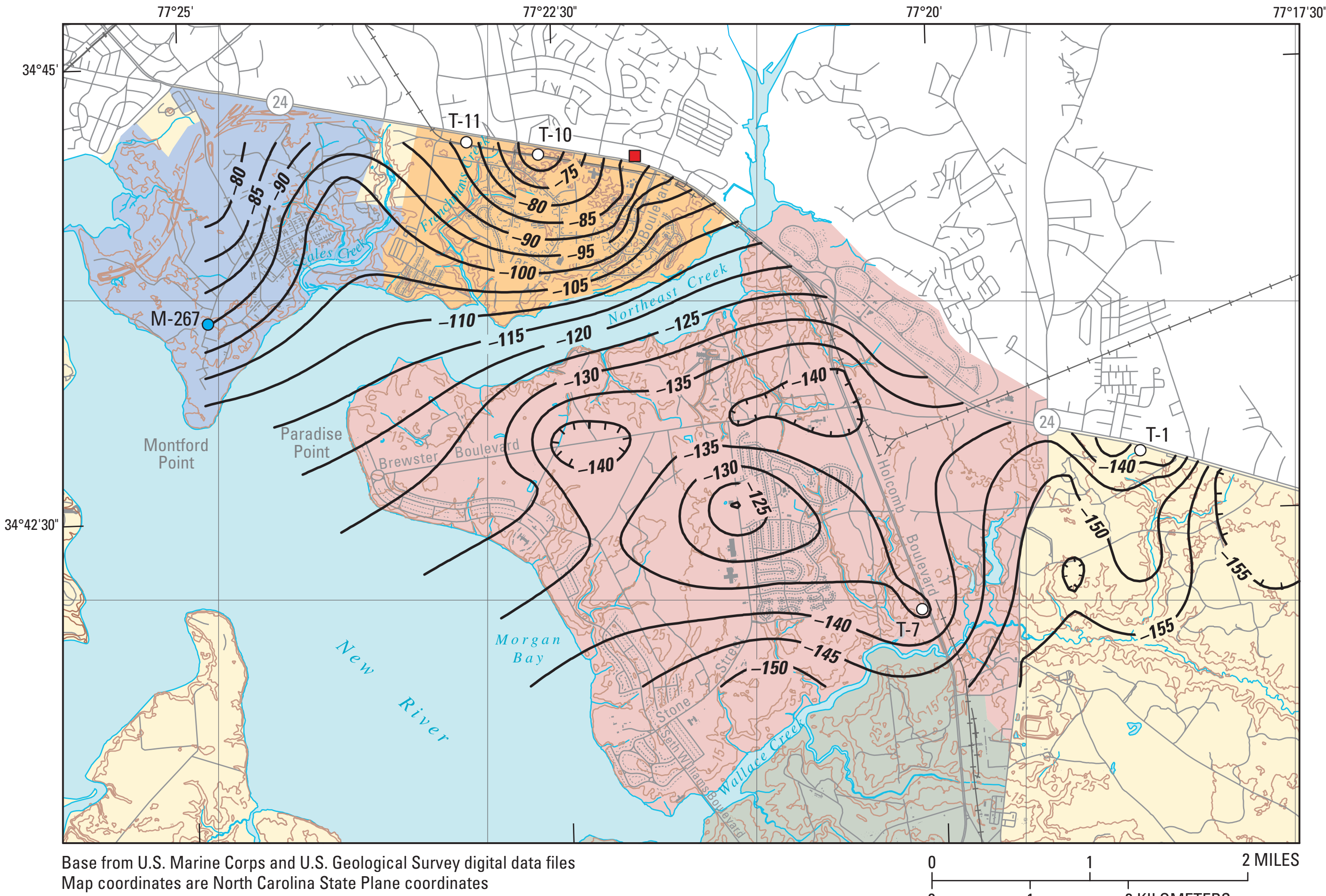
Table B11. Altitude at the top of the Middle Castle Hayne aquifer, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[NGVD 29, National Geodetic Vertical Datum of 1929]

Site name[1]	Location coordinates[2]		Unit altitude, in feet below NGVD 29
	East	North	
HP-607 (new)	2496820	352510	–129
HP-614 (new)	2512180	353670	–160
HP-619 (new)	2515870	352640	–144
HP-621 (new)	2505510	354290	–150
HP-622	2494248	353323	–119
HP-623	2495617	350860	–134
HP-627 (new)	2508310	354030	–147
HP-629 (new)	2504800	355152	–147
HP-643	2494346	356083	–141
HP-645	2497333	356430	–143
HP-646	2497870	357826	–140
HP-647	2499461	356343	–138
HP-648	2506809	355200	–131
HP-649	2508630	354860	–136
HP-650	2510615	354300	–163
HP-651	2503790	348090	–155
HP-663	2510881	352712	–162
HP-699	2490430	355560	–141
HP-700	2488520	355270	–144
HP-703	2496450	358140	–138
HP-704	2495650	359580	–129
HP-708	2514450	353090	–167
HP-709	2505650	351270	–156
HP-710	2507770	351490	–146
HP-711	2509200	352130	–154
LCH-4009	2499585	358589	–122
M-161	2477550	362560	–82
M-197	2477626	361621	–87
M-267	2476609	359232	–95
M-628	2479434	362735	–98
ON-T2-87	2487495	353878	–129
S190A	2487640	353870	–130
T-1	2507870	355030	–139
T-7	2500628	349685	–134
T-9	2490489	364648	–86
T-10	2487680	364960	–65
T-11	2485278	365352	–83
T-12	2476550	355830	–114
T-13	2481170	363930	–102
T-14	2476788	364170	–75
TT-23	2491024	363208	–101
TT-25	2491984	364042	–95
TT-67	2490160	362730	–88
X24C2	2490640	363540	–86
X24S2	2495523	347221	–155

[1]See Plate 1 for location

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



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

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

–140 **Line of equal altitude**—Shows top of Middle Castle Hayne aquifer. Contour interval 5 feet. Hachures indicate depression. Datum is National Geodetic Vertical Datum of 1929

25 **Topographic contour**—Interval 10 feet

ABC One-Hour Cleaners

M-267 **Supply well and name**

T-11 **Borehole and name**

Figure B21. Altitude at the top of the Middle Castle Hayne aquifer, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

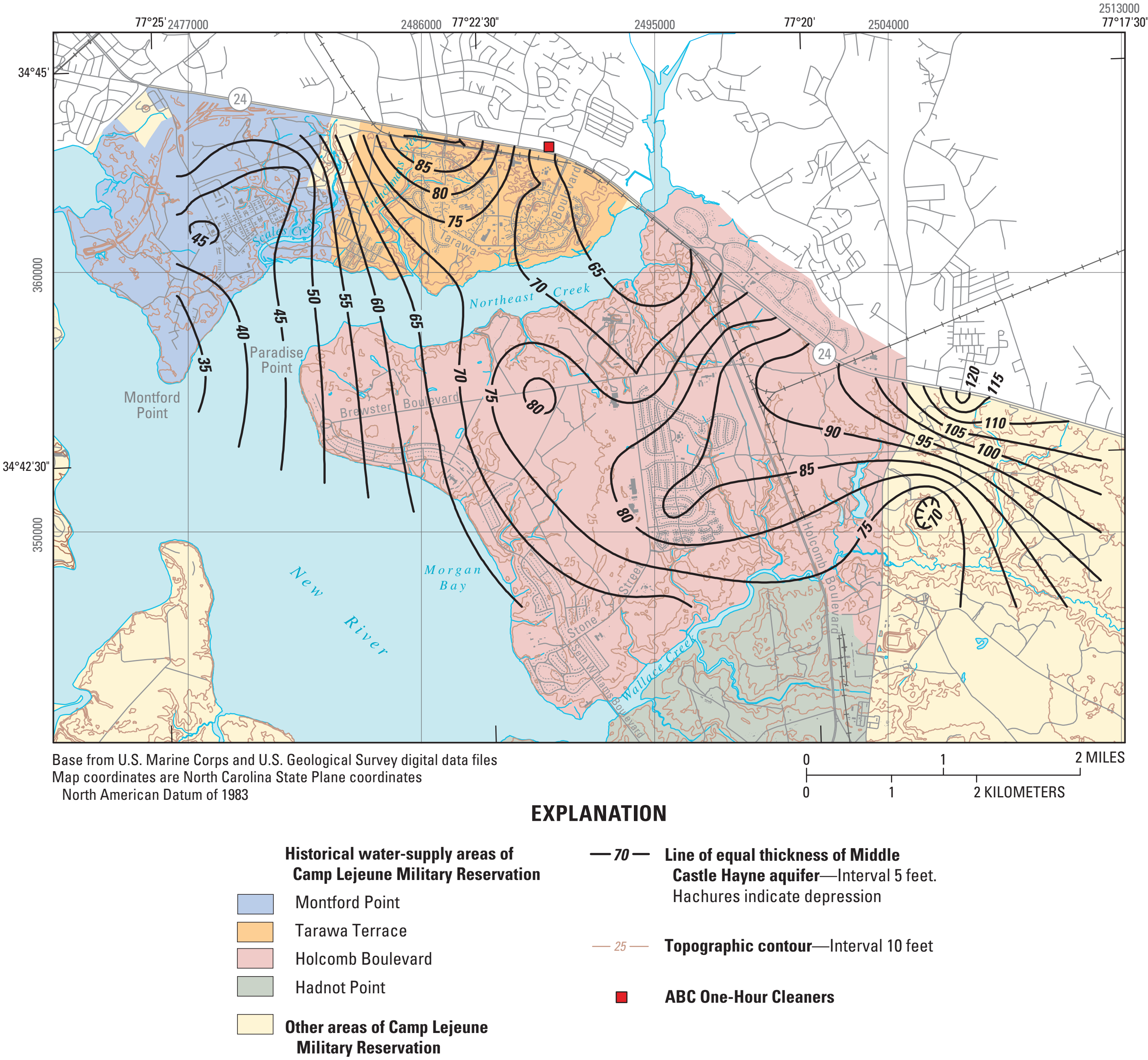


Figure B22. Thickness of the Middle Castle Hayne aquifer, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Lower Castle Hayne Confining Unit

Contours of equal altitude at the top of the Lower Castle Hayne confining unit indicate the top of the unit declines relatively uniformly northwest to southeast and ranges from a maximum altitude of about –125 ft (Table B12) north of Montford Point to about –265 ft near the southeastern limit of the study area (Figure B23). Confining unit thickness also declines gradually northwest to southeast in a pattern somewhat similar to that of surface altitude (Figure B24). Confining unit thickness ranges from a maximum of about 32 ft in the northern part of Tarawa Terrace to a minimum of about 20 ft north of the confluence of Wallace and Northeast Creeks and near the southeastern limit of the study area in the vicinity of SR 24.

The lithology of the Lower Castle Hayne confining unit in the vicinity of Tarawa Terrace and Montford Point is generally described as a gray, sandy or silty, "medium hard," clay containing shells and shell fragments. At borehole T-12, in the southern part of Montford Point, the confining unit is described as a "greenish," soft, sandy clay. At borehole T-1, near SR 24 and the southeastern corner of the study area, the unit is described as a soft sandy clay containing "soft rock." Elsewhere the confining unit is poorly differentiated in drillers' logs and specific descriptions are not available. Cardinell et al. (1993, Section A–A') recognized the clay described herein as the Lower Castle Hayne confining unit at a depth of about 190 ft in the electric log obtained at well TT-25 northeast of Tarawa Terrace and extrapolated this unit to well HP-645 located near the intersection of Brewster and Holcomb Boulevards (Figure B3). Section B–B' of Cardinell et al. (1993) shows a continuous correlation of the zone of low resistivity designated herein as the Lower Castle Hayne confining unit beginning at borehole T-12 in the southern part of Montford Point eastward and southeastward to the vicinity of borehole T-1, near the southeastern corner of the study area.

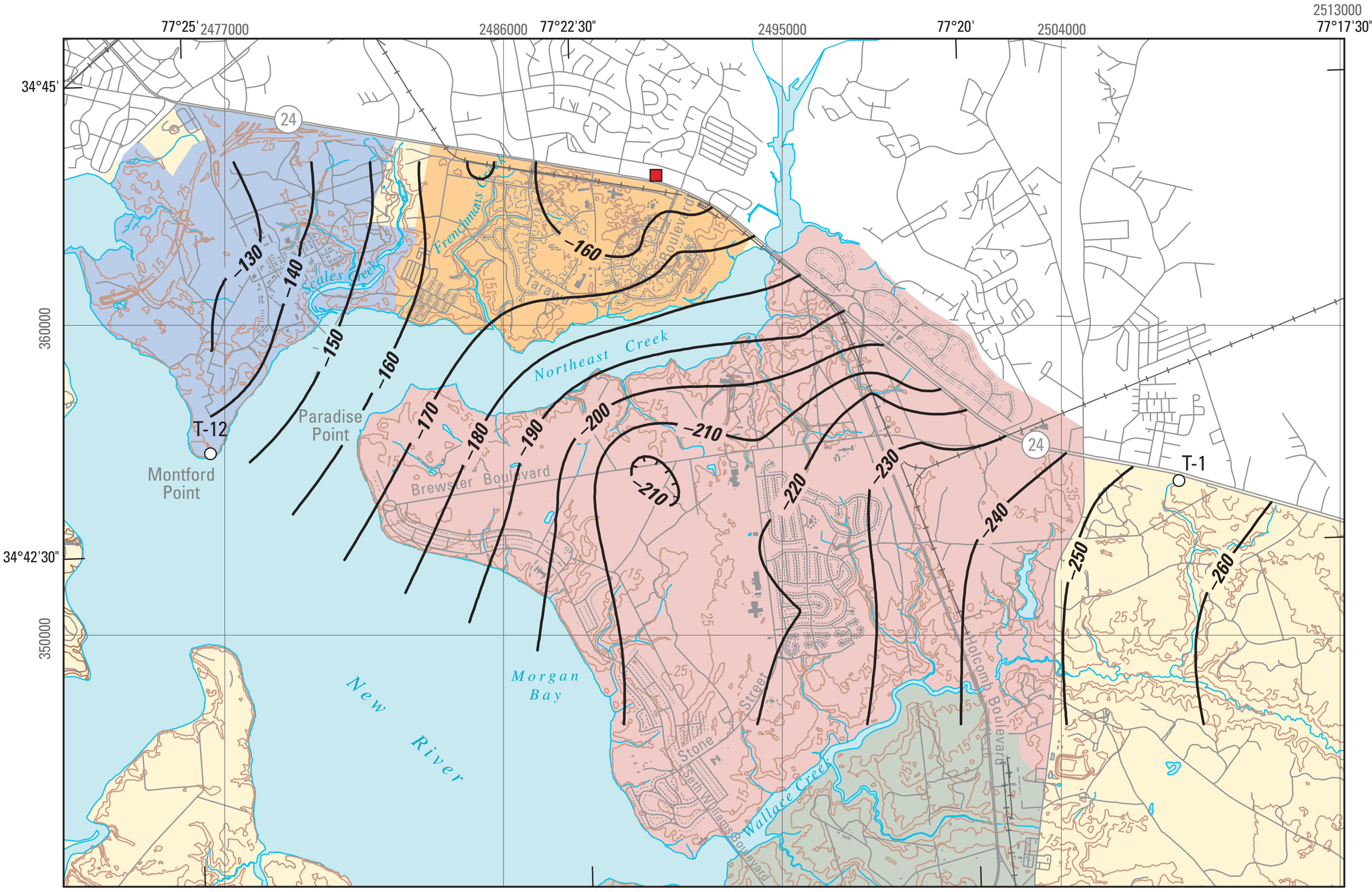
Table B12. Altitude at the top of the Lower Castle Hayne confining unit, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[NGVD 29, National Geodetic Vertical Datum of 1929]

Site name[1]	Location coordinates[2]		Unit altitude, in feet below NGVD 29
	East	North	
HP-614 (new)	2512180	353670	–268
HP-621 (new)	2505510	354290	–252
HP-623	2495617	350860	–220
HP-643	2494346	356083	–211
HP-645	2497333	356430	–227
HP-646	2497870	357826	–221
HP-647	2499461	356343	–230
HP-648	2506809	355200	–253
HP-649	2508630	354860	–250
HP-699	2490430	355560	–223
HP-704	2495650	359580	–191
LCH-4009	2499585	358589	–200
M-161	2477550	362560	–125
M-197	2477626	361621	–134
M-267	2476609	359232	–130
M-628	2479434	362735	–140
ON-T2–87	2487495	353878	–197
S190A	2487640	353870	–200
T-1	2507870	355030	–252
T-9	2490489	364648	–153
T-10	2487680	364960	–155
T-11	2485278	365352	–173
T-12	2476550	355830	–146
T-13	2481170	363930	–146
T-14	2476788	364170	–127
TT-23	2491024	363208	–170
TT-25	2491984	364042	–155
TT-67	2490160	362730	–156
X24C2	2490640	363540	–156
X24S2	2495523	347221	–223

[1]See Plate 1 for location

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



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

–220 **Line of equal altitude**—Shows top of Lower Castle Hayne confining unit. Contour interval 10 feet. Hachures indicate depression. Datum is National Geodetic Vertical Datum of 1929

25 **Topographic contour**—Interval 10 feet

ABC One-Hour Cleaners

T-1 **Borehole and name**

Figure B23. Altitude at the top of the Lower Castle Hayne confining unit, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

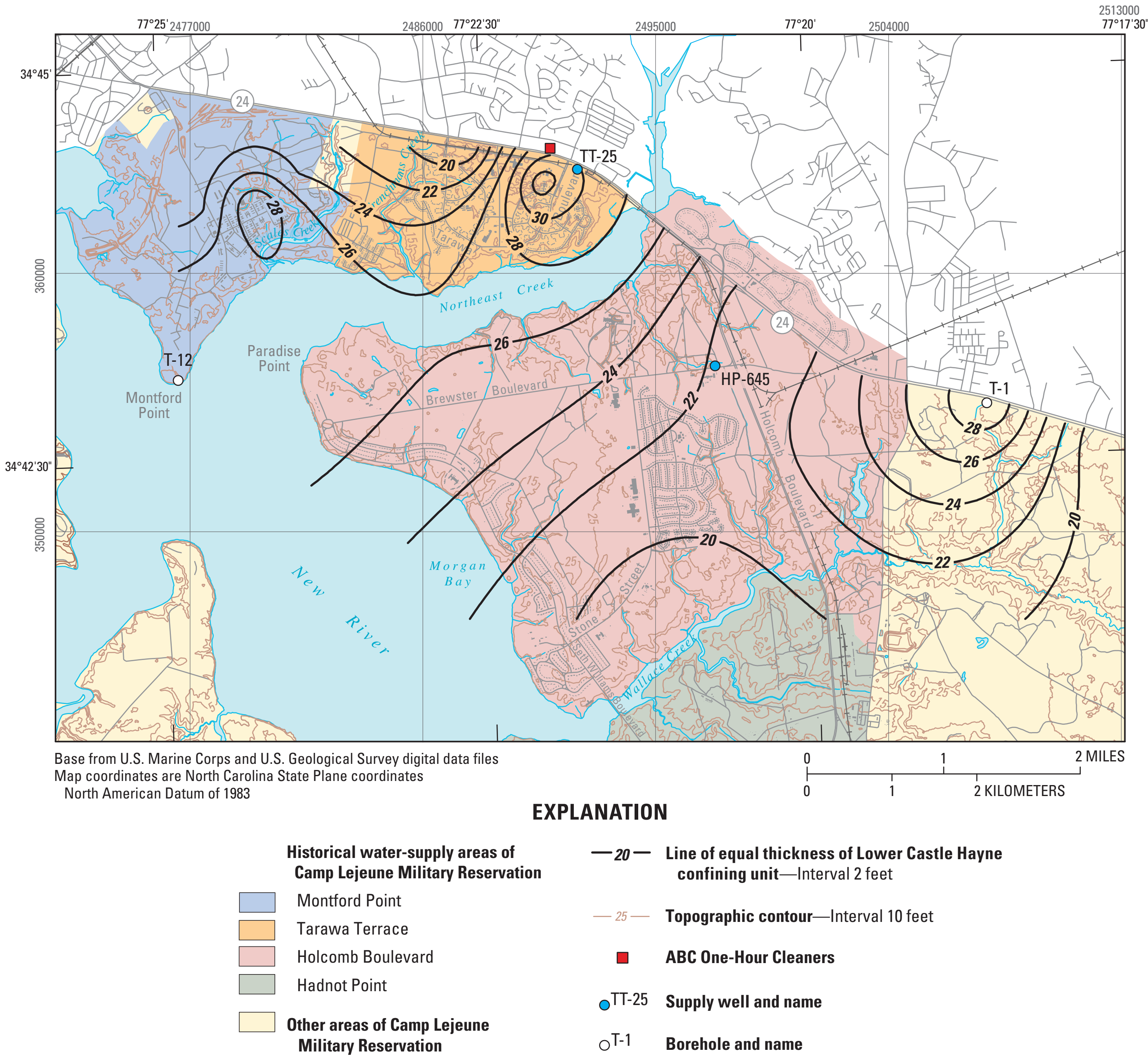


Figure B24. Thickness of the Lower Castle Hayne confining unit, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Lower Castle Hayne Aquifer

The lithology of the Lower Castle Hayne aquifer is poorly described or undifferentiated in the relatively few electric logs and drillers' logs obtained at sufficient depth to intercept the top of the aquifer. In the vicinity of borehole T-10, north and west of Tarawa Terrace, the aquifer is apparently comprised of very fine gray sand and clay "mixed." At borehole T-13, north of Montford Point the upper part of the unit apparently consists of fine sand and interbedded clays while the lower part of the aquifer is largely limestone. At borehole T-12, near the southern extremity of Montford Point, the entire aquifer appears to consist of shell limestone. In the vicinity of borehole T-1 near SR 24 and the southern limit of the study area, the Lower Castle Hayne aquifer is described as clayey sand that grades with depth to a sandy clay and sand with lenses and beds of shell limestone.

Contours of equal altitude at the top of the Lower Castle Hayne aquifer are shown in Figure B25 and range from a high of about –150 ft northwest of Montfort Point to a low of about –280 ft near the southeastern limit of the study area (Table B13). The surface as shown generally declines uniformly northwest to southeast. However, such uniformity may be misleading and is the result of a limited number of point data used for interpolation (Table B9).

Thickness of the Lower Castle Hayne aquifer generally increases southward and northwest to southeast from a minimum of about 45 ft northwest of Tarawa Terrace near SR 24 to a maximum of about 85 ft north of the headwaters of Wallace Creek near the southeastern limit of the study area (Figure B26). The regularity and uniformity of thickness trends as shown is probably not representative of actual unit thickness but rather is the result of using a small number of point data for interpolation.

Table B13. Altitude at the top of the Lower Castle Hayne 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 below NGVD 29
	East	North	
HP-614 (new)	2512180	353670	–286
LCH-4009	2499585	358589	–220
M-161	2477550	362560	–149
M-168	2477602	362723	–160
M-197	2477626	361621	–159
M-267	2476609	359232	–157
M-628	2479434	362735	–170
T-1	2507870	355030	–282
T-10	2487680	364960	–173
T-12	2476550	355830	–174
T-13	2481170	363930	–170
T-14	2476788	364170	–149
TT-23	2491024	363208	–201
X24C2	2490640	363540	–190
X24S2	2495523	347221	–241

[1]See Plate 1 for location

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

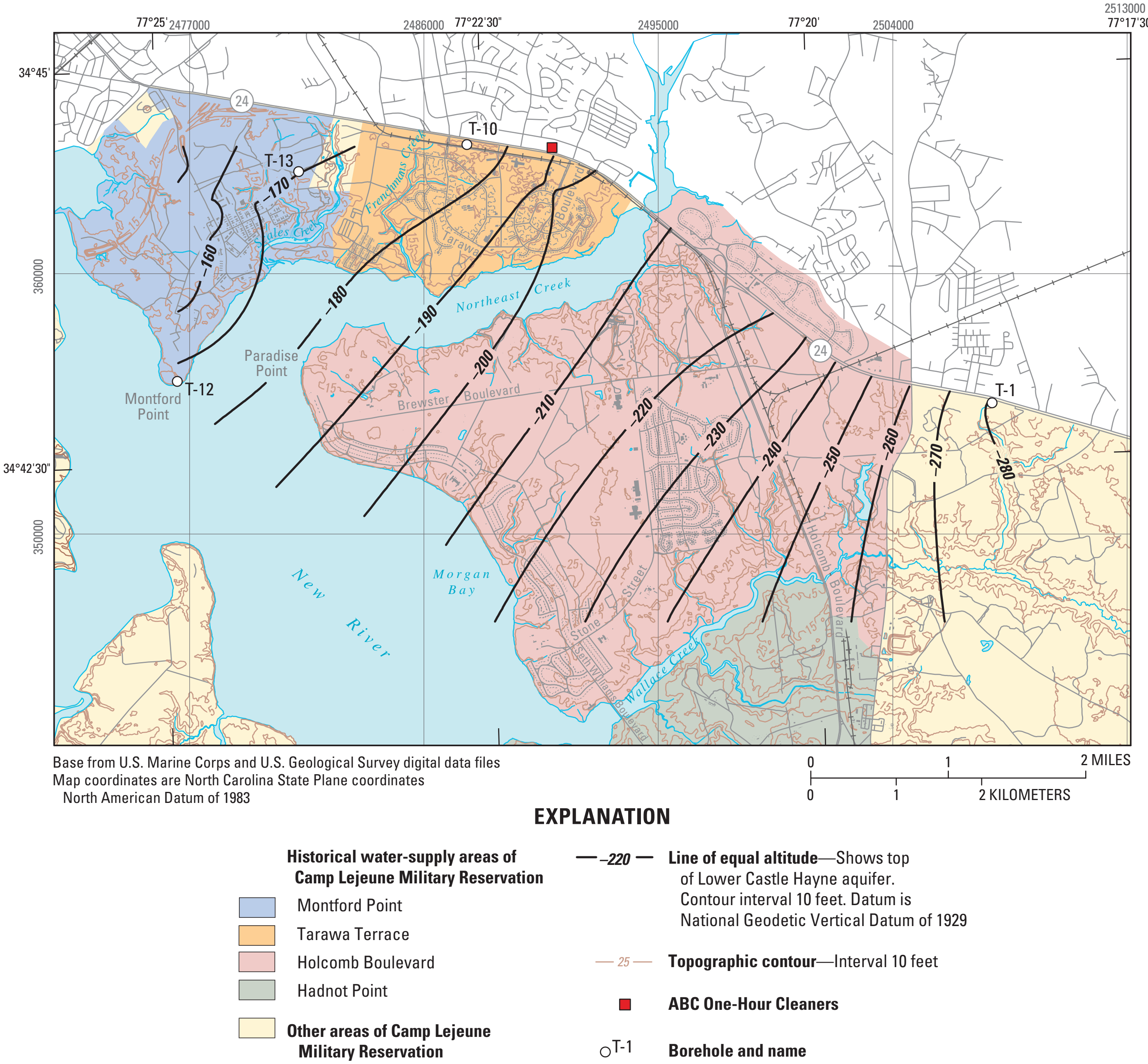


Figure B25. Altitude at the top of the Lower Castle Hayne aquifer, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

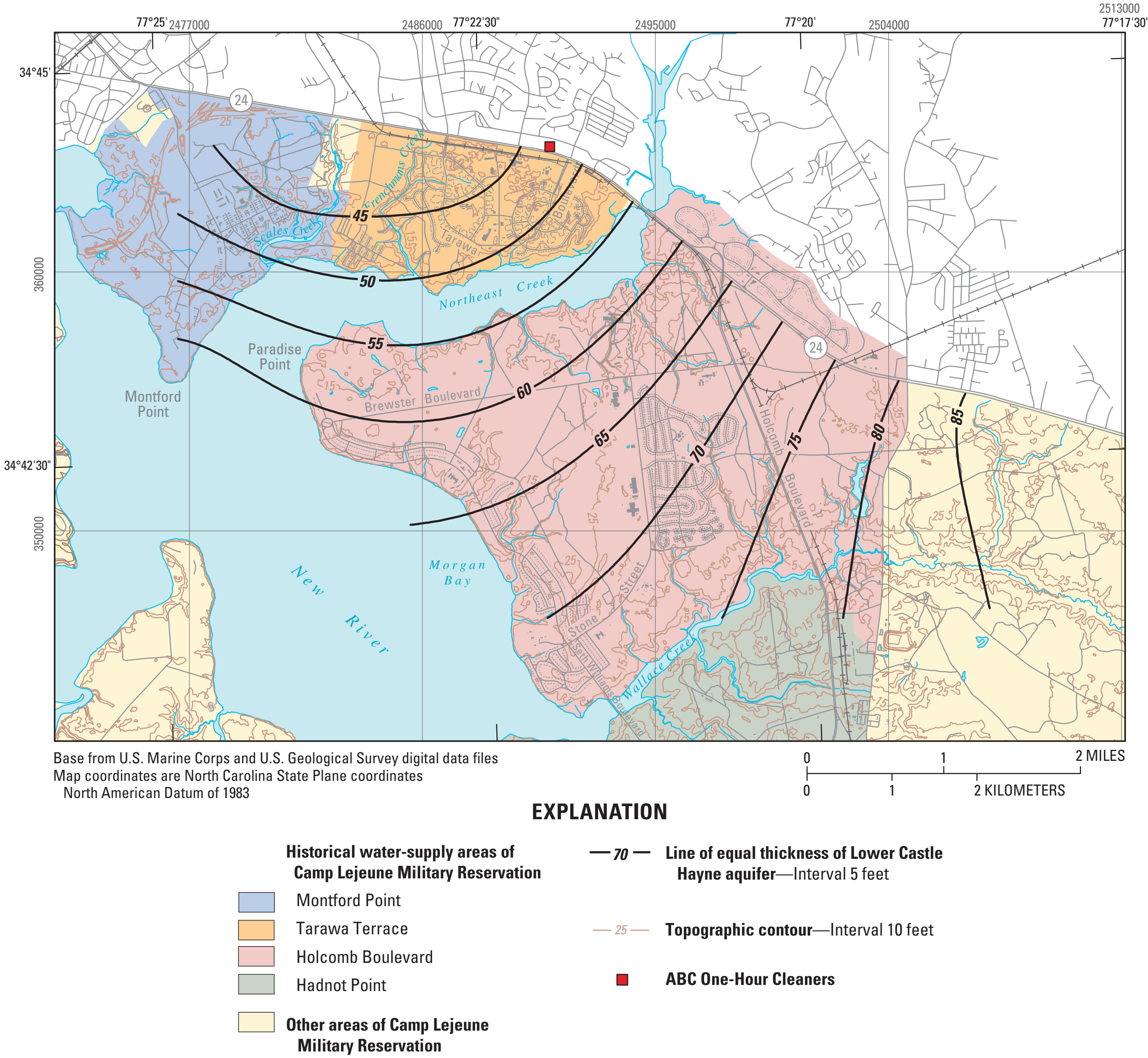


Figure B26. Thickness of the Lower Castle Hayne aquifer, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Beaufort Confining Unit

The base of the Castle Hayne aquifer system and the base of groundwater flow of interest to this study were previously described as the base of the Lower Castle Hayne aquifer and are delimited by the top of the Paleocene age Beaufort confining unit (Figure B27). According to the few descriptions of this confining unit available at Camp Lejeune, the lithology is apparently a sandy clay in the southern part of the study area and is characterized as limestone and possibly sandstone in the vicinity of Montford Point and northwest of Tarawa Terrace.

Cardinell and others (1993) placed the Beaufort confining unit significantly lower in the Tarawa Terrace area than interpretations of borehole and lithologic data used for this study would suggest. The altitudes reported at the top of the Beaufort confining unit by Cardinell and others (1993 Table 3) are far below the bottom hole depth of any borehole geophysical or lithologic log available in the Tarawa Terrace area and were estimates, probably based on interpretations of surface resistivity or seismic surveys. Considerable uncertainty is attached to these data as acknowledged by Cardinell and others (1993) in their heading notes attached to their Table 3 and by questioning the depth of the top of the Beaufort confining unit shown in sections on their Plate 1. The geophysical data utilized by Cardinell and others (1993) to estimate the depth of the Beaufort confining unit were not available to this study. Accordingly, the base of the confining unit for this study was based only on interpolations of data listed in Table B14.

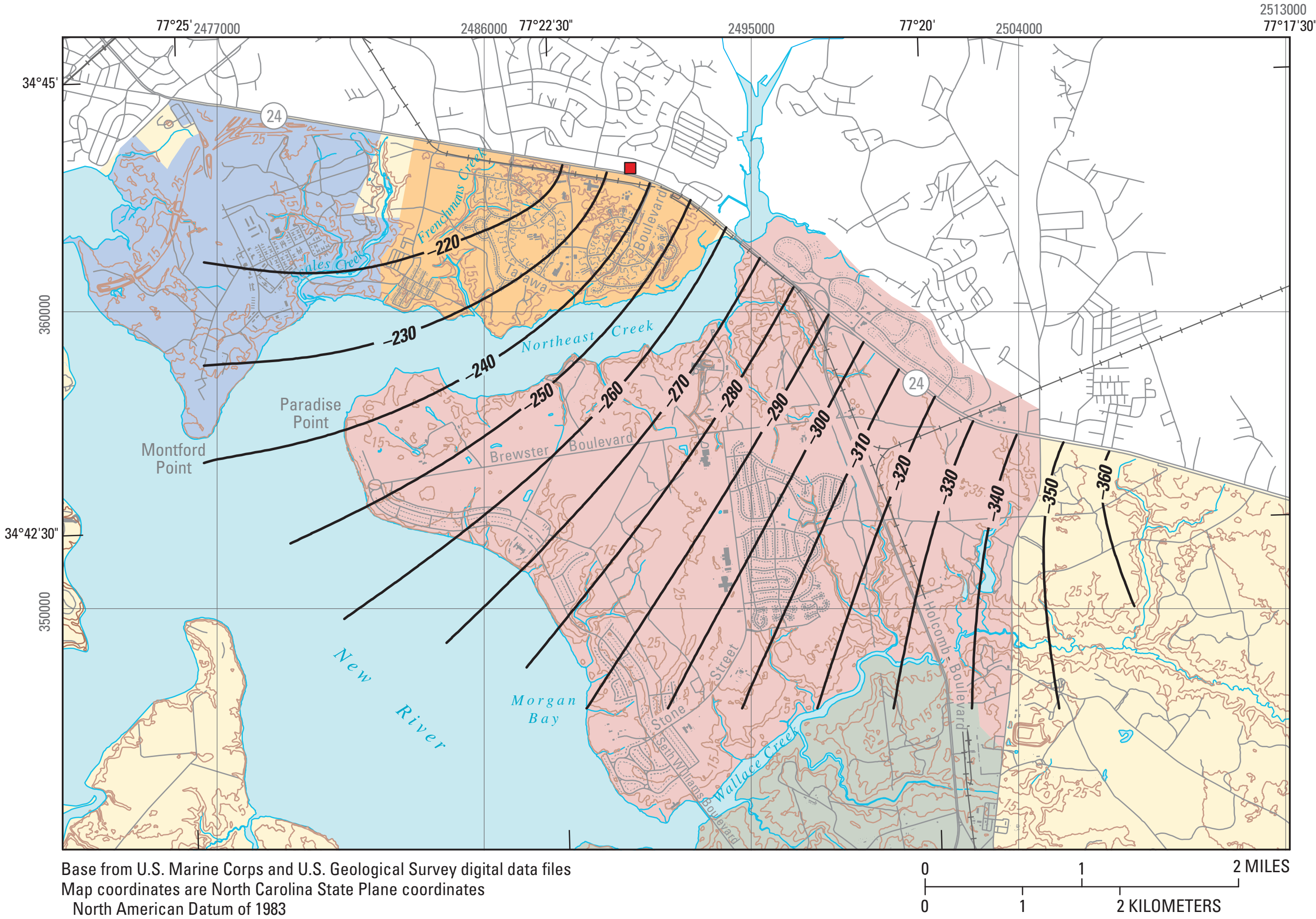
Table B14. Altitude at the top of the Beaufort confining unit, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[NGVD 29, National Geodetic Vertical Datum of 1929]

Site name[1]	Location coordinates[2]		Unit altitude, in feet below NGVD 29
	East	North	
M-628	2479434	362735	–216
T-1	2507870	355030	–366
T-10	2487680	364960	–214
T-12	2476550	355830	–238
T-13	2481170	363930	–212
X24S2	2495523	347221	–314

[1]See Plate 1 for location

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



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

–340 **Line of equal altitude**—Shows top of Beaufort confining unit. Contour interval 10 feet. Datum is National Geodetic Vertical Datum of 1929

25 **Topographic contour**—Interval 10 feet

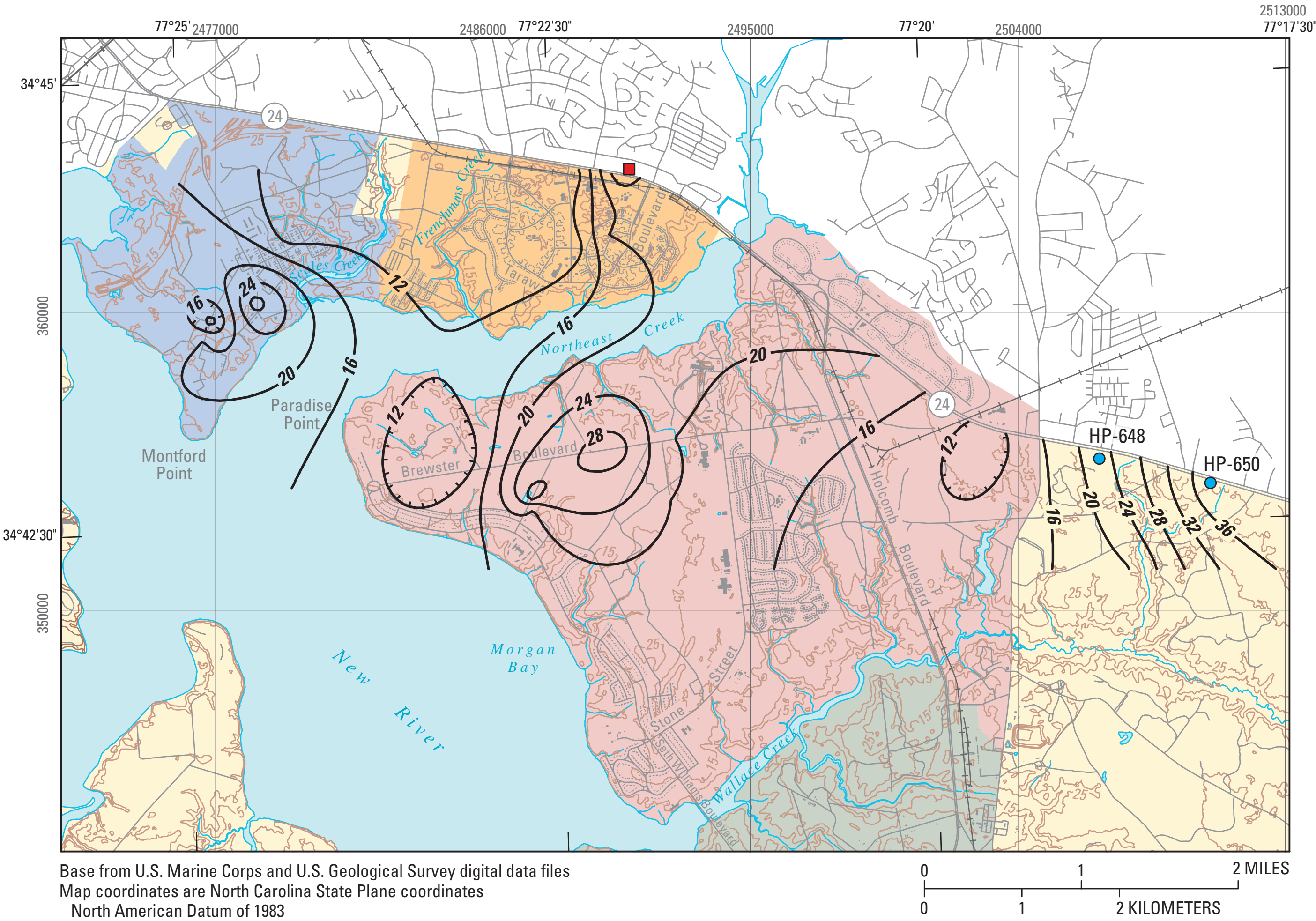
ABC One-Hour Cleaners

Figure B27. Altitude at the top of the Beaufort confining unit, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Horizontal Hydraulic Conductivity

Results of 32 aquifer-test analyses at Camp Lejeune are summarized in Table B15. Computed horizontal hydraulic conductivity ranged from about 5 to 40 ft/d and averaged about 18 ft/d. Standard deviation of test results was about 10 ft/d. The lowest hydraulic conductivity of 5 ft/d was observed at one site (HP-648) where the water-bearing units are generally described as “limestone and sand” in the driller’s log. A maximum horizontal hydraulic conductivity of about 40 ft/d occurred at wells HP-650 and HP-708 (Plate 1). Aquifer lithology at these sites is generally described as sand and limestone or sand and rock.

Most tests included wells with open intervals installed in more than one aquifer. However, tests of a sufficient number of wells open only to the Upper Castle Hayne aquifer were available to allow a highly generalized interpolation of results to other parts of the study area. Interpolation results are shown



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

20 — **Line of equal horizontal hydraulic conductivity**—Upper Castle Hayne aquifer. Interval is 4 feet per day. Hachures indicate area of lower hydraulic conductivity

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

ABC One-Hour Cleaners

HP-650 **Supply well and name**

Figure B28. Horizontal hydraulic conductivity of the Upper Castle Hayne aquifer, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

in Figure B28. Horizontal hydraulic conductivity of the Upper Castle Hayne aquifer in the vicinity of Tarawa Terrace appears to range between 10 and 20 ft/d. Horizontal hydraulic conductivity of the Upper Castle Hayne aquifer in the eastern part of the study area appears to increase from about 16 to 40 ft/d north of the headwaters of Wallace Creek and near SR 24, although data are sparse and poorly distributed in this area. Contour patterns in the vicinity of Montford Point and near Paradise Point are inconsistent and reflect significant changes in horizontal hydraulic conductivity across relatively short distances.

About one-fifth of all aquifer-test analyses refer to wells open to both the Upper and Middle Castle Hayne aquifers. The horizontal hydraulic conductivity determined from these analyses also was interpolated areally (Figure B29). Highly generalized results are somewhat different from those observed uniquely for the Upper Castle Hayne aquifer (Figure B28)

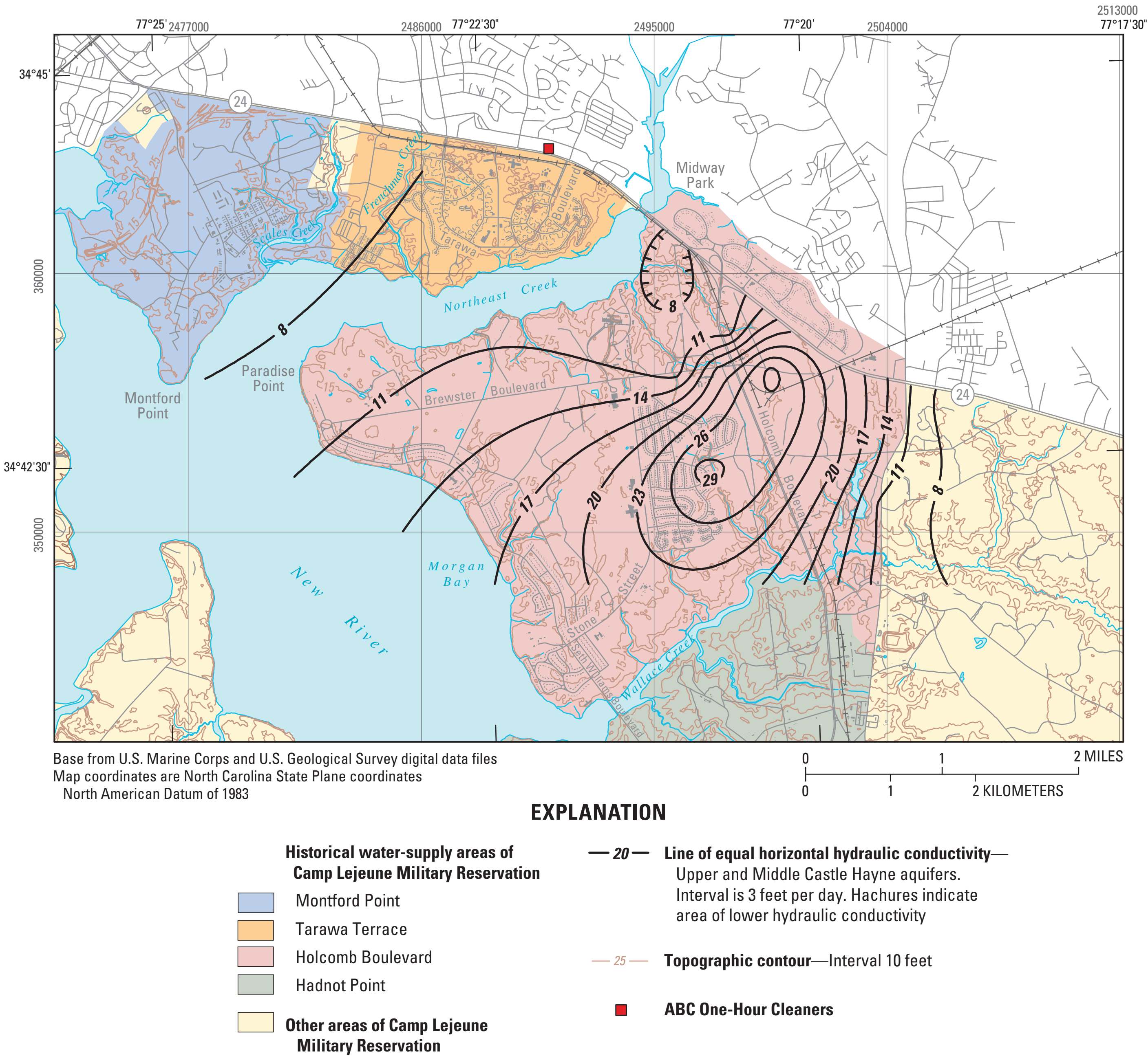


Figure B29. Horizontal hydraulic conductivity of the combined Upper and Middle Castle Hayne aquifers, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

and indicate that the distribution of hydraulic conductivity shown in Figure B29 may largely represent the Middle Castle Hayne aquifer. If so, horizontal hydraulic conductivity of the Middle Castle Hayne aquifer ranges from less than 8 ft/d west of Midway Park to about 30 ft/d east and south of Brewster Boulevard. Comparison of contours shown on Figures B28 and B29 indicates that horizontal hydraulic conductivity of the Middle Castle Hayne aquifer is somewhat to substantially lower than the corresponding conductivity of the Upper Castle Hayne aquifer throughout most of the study area.

The horizontal hydraulic conductivity of the Lower Castle Hayne aquifer was not uniquely determined at any site. Previous descriptions of the lithology of this aquifer, however, indicate a preponderance of fine sands and clayey sands, when compared to lithologies reported for the Upper and Middle Castle Hayne aquifers. Accordingly, the average horizontal hydraulic conductivity of the Lower Castle Hayne aquifer is estimated to be half or less of the average computed for all analyses summarized herein (Table B15).

Well C2 listed in Table B15 refers to a monitor well installed during investigations of groundwater contamination. The location of this well is shown on Plate 1 in the immediate vicinity of ABC One-Hour Cleaners. Well S190A is an irrigation well located near Brewster Boulevard in the vicinity of Paradise Point. Location coordinates of other wells are listed in several tables in this report and also are included in Faye and Green (In press 2007).

Table B15. Summary of aquifer-test analyses, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[Contributing aquifer: UCHLU, Upper Castle Hayne aquifer–Lower unit; UCHRBU, Upper Castle Hayne aquifer–River Bend unit; MCH, Middle Castle Hayne aquifer; UCH, Upper Castle Hayne aquifer–undifferentiated; TT, Tarawa Terrace aquifer; UCHRBU&LU, Upper Castle Hayne aquifer–River Bend and –Lower units; karst, a zone of relatively high hydraulic conductivity indicated on driller's logs by the loss of drilling fluids at a certain depth or a sudden drop of the drill stem during drilling; test method: SD, step drawdown; CJD, Cooper-Jacob, drawdown; CJR, Cooper-Jacob, recovery]

Site name[1]	Horizontal hydraulic conductivity, in feet per day	Contributing aquifers	Test method
C2	30	UCHLU	SD
HP-607 (new)	30	UCHRBU, MCH	CJD
HP-622	20	UCHRBU, MCH	CJR
HP-644	10	UCHRBU, MCH	SD
HP-645	20	UCHRBU, MCH	SD
HP-646	10	UCHRBU, MCH	SD
HP-647	30	UCHRBU, MCH	SD
HP-648	5	UCHRBU, MCH	SD
HP-649	8	UCHRBU, MCH	SD
HP-650	40	UCH	SD
HP-651	10	UCHRBU, MCH	SD
HP-653	10	UCHRBU, MCH	CJR
HP-654	20	TT, UCHRBU&LU	CJR
HP-699	30	UCHRBU	CJR
HP-700	8	UCH	CJD
HP-706	20	UCHRBU	CJR
HP-707	20	UCH	SD
HP-708	40	UCHRBU&LU	CJD
HP-710	20	UCH	CJD
LCH-4009	20	UCHRBU	CJR
M-142	30	UCHRBU, karst	CJD
M-243	10	UCHLU	CJD
M-267	10	UCHRBU&LU	SD
M-628	10	UCH	SD
M-630	20	UCHLU	SD
S190A	30	UCHRBU	CJD
TT-23	10	UCHRBU&LU, MCH	CJR
TT-25	9	UCHRBU&LU, MCH	CJR
TT-26	20	UCHLU, karst(?)	SD
TT-52	10	UCH	CJR
TT-55	10	UCHLU(?)	SD
TT-67	20	UCHLU	SD

[1]See Plate 1 for location

Statistics:

Average horizontal conductivity = 18 feet/day
Standard deviation of horizontal hydraulic conductivity = 10 feet/day

Potentiometric Surfaces

The oldest and/or highest water-level measurements out of a total data set of about 1,300 measurements were selected at 107 locations in the study area to estimate the predevelopment potentiometric surface of the Upper Castle Hayne aquifer (Table B16). Contours of equal potentiometric level based on these measurements are shown in Figure B30. Water levels obtained from supply wells in the Tarawa Terrace and Montford Point areas represent, for the most part, the Upper and Middle Castle Hayne aquifers. Corresponding water levels obtained from monitor wells represent mostly the Tarawa Terrace and Upper Castle Hayne aquifers. Water levels obtained between Northeast and Wallace Creeks are generally a composite of heads in the Upper and Middle Castle Hayne aquifers as well as the Tarawa Terrace aquifer. Detailed water-level data obtained from several investigations of groundwater contamination at Tarawa Terrace and vicinity (Roy F. Weston, Inc. 1992, 1994; Law Engineering, Inc. 1995; O'Brien & Gere Engineers, Inc. 1992) indicate only slight head differences between the River Bend and Lower units of the Upper Castle Hayne aquifer. Water-level data collected at a well cluster representing the Tarawa Terrace and Upper, Middle, and Lower Castle Hayne aquifers at site X24S1-S7, north of Wallace Creek, indicate only a 3-ft head difference between the Tarawa Terrace and Lower Castle Hayne aquifers, although the head measured in the Lower Castle Hayne aquifer was possibly influenced by pumping.

Assuming that lines orthogonal to the potentiometric level contours shown in Figure B30 approximate directions of groundwater flow, groundwater flows from east to west from the vicinity of SR 24 toward Northeast Creek and the New River and generally south and southwest from the vicinity of Tarawa Terrace and Montford Point toward Northeast Creek. The influence of New River and Northeast Creek as lines of discharge from the Castle Hayne aquifer system is clearly indicated. Note that contours shown in Figure B30 were based entirely on point data and as such were not adjusted to completely account for the expected influences of streams and highland areas on potentiometric levels. In particular, contours in the vicinity of Wallace Creek probably would trend upstream to a greater degree, compared to those shown, if water-level data proximate to the creek were sufficiently numerous. In addition, several contours, such as the 5-ft contour in the vicinity of Montford Point and the 15- and 20-ft contours in the southeastern part of the study area were possibly influenced by local pumping.

Site names listed in Table B16 prefaced by "C," "PZ," "S," "STT6," and "TTUST" refer to monitor wells installed during investigations of groundwater contamination or similar groundwater investigations. Locations of some of these wells are not shown on Plate 1; however, all are located at or in the immediate vicinity of Tarawa Terrace. Location coordinates are listed in several tables in this report and are also included in Faye and Green (In press 2007).

Table B16. Estimated predevelopment water levels, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[NGVD 29, National Geodetic Vertical Datum of 1929; contributing aquifers: UCHLU, Upper Castle Hayne aquifer–Lower unit; MCH, Middle Castle Hayne aquifer; UCHRBU, Upper Castle Hayne aquifer–River Bend unit; TT, Tarawa Terrace aquifer; UCHRBU&LU, Upper Castle Hayne aquifer–River Bend and –Lower units; karst, a zone of relatively high hydraulic conductivity indicated on driller's logs by the loss of drilling fluids at a certain depth or a sudden drop of the drill stem during drilling; LCH, Lower Castle Hayne aquifer; UCH, Upper Castle Hayne aquifer–undifferentiated; BB, Brewster Boulevard aquifer]

Site name[1]	Water-level altitude, in feet above NGVD 29	Measurement date	Contributing aquifers
C1	21.5	4/22/92	UCHLU
C2	19.6	4/22/92	UCHLU
C3	15.8	4/22/92	UCHLU
C4	11.9	4/22/92	MCH
C5	15.7	4/22/92	UCHLU
C9	13.0	11/18/93	UCHLU
C10	12.6	11/18/93	MCH
C11	6.3	10/1/93	UCHLU
CCC-1	3.3	9/17/41	UCHRBU
CCC-2	5.2	6/19/42	UCHRBU
HP-37	0.9	8/2/42	TT(?)
HP-611 (old)	15.5	6/27/42	TT
HP-612 (old)	15.0	6/22/42	TT, UCHRBU&LU, MCH
HP-614 (old)	13.4	8/1/42	TT, UCHRBU&LU, MCH
HP-615	14.7	7/2/42	TT, UCHRBU&LU
HP-616	13.3	8/3/42	UCHRBU&LU, MCH
HP-620	14.0	9/28/44	TT, karst
HP-621 (old)	22.8	9/14/53	TT

Table B16. Estimated predevelopment water levels, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.—Continued

[NGVD 29, National Geodetic Vertical Datum of 1929; contributing aquifers: UCHLU, Upper Castle Hayne aquifer–Lower unit; MCH, Middle Castle Hayne aquifer; UCHRBU, Upper Castle Hayne aquifer–River Bend unit; TT, Tarawa Terrace aquifer; UCHRBU&LU, Upper Castle Hayne aquifer–River Bend and –Lower units; karst, a zone of relatively high hydraulic conductivity indicated on driller's logs by the loss of drilling fluids at a certain depth or a sudden drop of the drill stem during drilling; LCH, Lower Castle Hayne aquifer; UCH, Upper Castle Hayne aquifer–undifferentiated; BB, Brewster Boulevard aquifer]

Site name[1]	Water-level altitude, in feet above NGVD 29	Measurement date	Contributing aquifers
HP-622	16.1	5/19/83	UCHRBU, MCH
HP-623	15.5	4/8/87	TT, UCHRBU, MCH
HP-629 (new)	23.0	3/8/83	TT, UCHRBU&LU, MCH
HP-641	16.8	4/18/87	TT, UCHRBU
HP-643	15.8	5/14/86	UCHRBU&LU, LCH
HP-645	11.5	4/9/87	UCHRBU, MCH
HP-647	11.5	4/8/87	UCHRBU, MCH
HP-648	23.9	4/7/87	UCHRBU, MCH
HP-649	25.0	4/7/87	UCHRBU, MCH
HP-650	28.7	11/10/71	UCHRBU&LU
HP-651	15	4/7/87	UCHRBU, MCH
HP-653	14.9	7/15/78	UCHRBU, MCH
HP-654	19.2	5/16/78	TT, UCHRBU&LU
HP-663	19	5/15/86	UCHRBU&LU
HP-698	10	4/9/87	UCHRBU
HP-699	13	4/9/87	UCHRBU
HP-700	3	2/20/86	UCH
HP-701	5	3/3/86	UCH
HP-703	10	3/6/85	UCHRBU&LU
HP-704	5	4/9/87	UCHRBU
HP-705	16	5/15/86	BB, UCH
HP-706	19	4/21/86	UCHRBU
HP-707	10	5/15/86	UCH
HP-708	34	5/30/86	UCHRBU&LU
HP-709	13	3/20/86	TT, UCH
HP-710	15	4/8/86	UCH
HP-711	19	4/14/86	TT, UCH
LCH-4007	16.1	4/7/87	TT, UCHRBU&LU
LCH-4009	16.8	5/16/83	UCHRBU
M-1	22.8	9/16/41	TT, UCHRBU
M-2	17.4	3/30/42	TT, UCHRBU&LU
M-142	9.0	11/2/42	UCHRBU
M-168	8.9	6/23/53	UCHRBU&LU, MCH
M-243	6.2	6/1/42	UCHLU
M-244	7.4	5/16/42	UCHRBU&LU
M-267	3	4/10/87	UCHRBU&LU
M-629	5	4/9/87	UCHLU, MCH
M-630	7	4/9/87	UCHLU
SOW3	9.3	5/14/86	BB, TT
PZ-01	16.7	11/18/93	UCHLU
PZ-02	16.7	11/18/93	UCHRBU
PZ-03	16.6	11/18/93	UCHLU
PZ-04	16.4	11/18/93	UCHRBU
PZ-05	15.7	10/1/93	UCHLU
PZ-06	16.1	10/1/93	UCHRBU
R(1950)	8.0	3/25/42	UCH

Table B16. Estimated predevelopment water levels, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.—Continued

[NGVD 29, National Geodetic Vertical Datum of 1929; contributing aquifers: UCHLU, Upper Castle Hayne aquifer–Lower unit; MCH, Middle Castle Hayne aquifer; UCHRBU, Upper Castle Hayne aquifer–River Bend unit; TT, Tarawa Terrace aquifer; UCHRBU&LU, Upper Castle Hayne aquifer–River Bend and –Lower units; karst, a zone of relatively high hydraulic conductivity indicated on driller's logs by the loss of drilling fluids at a certain depth or a sudden drop of the drill stem during drilling; LCH, Lower Castle Hayne aquifer; UCH, Upper Castle Hayne aquifer–undifferentiated; BB, Brewster Boulevard aquifer]

Site name[1]	Water-level altitude, in feet above NGVD 29	Measurement date	Contributing aquifers
S1	23.7	4/22/92	TT, UCHRBU(?)
S2	19.9	4/22/92	UCHRBU
S3	16.0	4/22/92	TT, UCHRBU
S4	13.6	4/22/92	TT, UCHRBU(?)
S5	16.4	4/22/92	TT, UCHRBU(?)
S6	20.6	4/22/92	TT, UCHRBU
S7	19.8	4/22/92	TT, UCHRBU
S8	20.9	4/22/92	TT, UCHRBU
S9	15.4	4/22/92	TT, UCHRBU
S10	13.3	6/25/92	TT, UCHRBU
S11	19.0	11/18/93	TT, UCHRBU
STT61to66-MW02	21.6	1/29/92	TT, UCHRBU
STT61to66-MW08	20.8	1/29/92	TT, UCHRBU
STT61to66-MW10	20.7	1/9/92	TT, UCHRBU
STT61to66-MW12	20.6	1/29/92	TT, UCHRBU
STT61to66-MW14	20.5	1/29/92	TT, UCHRBU
STT61to66-MW20	20.1	12/17/92	TT, UCHRBU
T-9	23.4	4/87	UCHRBU&LU
TT-25	10.9	4/7/87	UCHRBU&LU, MCH
TT-26	14.0	5/16/51	UCHLU
TT-27	16.6	1/10/63	UCHLU
TT-52	12.9	10/17/61	UCH
TT-53	14	7/22/61	UCHRBU&LU
TT-54	12.1	6/30/61	UCH
TT-55	18.9	11/1/61	UCHLU(?)
TT-67	8.4	4/7/87	UCHLU
TT Dump MW01	2.4	6/26/91	TT
TT Dump MW02	6.2	6/26/91	TT
TTUST-2453 A-2	6.6	6/7/89	TT
TTUST-2453 OB-11	7.4	6/7/89	TT
TTUST-44-MW01	6	11/15/01	TT, UCHRBU
TTUST-48-MW01	19	9/1/98	TT, UCHRBU
TTUST-779-MW01	9	7/25/02	TT
TTUST-2254-MW01	13	7/24/02	TT
TTUST-2258-MW01	12	7/24/02	TT
TTUST-2302-MW01	12	7/24/02	TT
TTUST-TTSC-15	11.2	12/28/94	UCHRBU
TTUST-2478-MW08	12.6	11/22/93	TT
TTUST-3140-MW01	15	7/24/02	TT, UCHRBU(?)
TTUST-3165-MW01	16	7/24/02	TT, UCHRBU(?)
TTUST-3233-MW01	12	7/24/02	TT, UCHRBU(?)
TTUST-3524-MW01	6	7/25/02	TT
TTUST-3546-MW01	5	7/25/02	TT
X24S6	6.4	6/15/87	UCH
X24S7	6.3	6/15/87	TT

[1]See Plate 1 for location

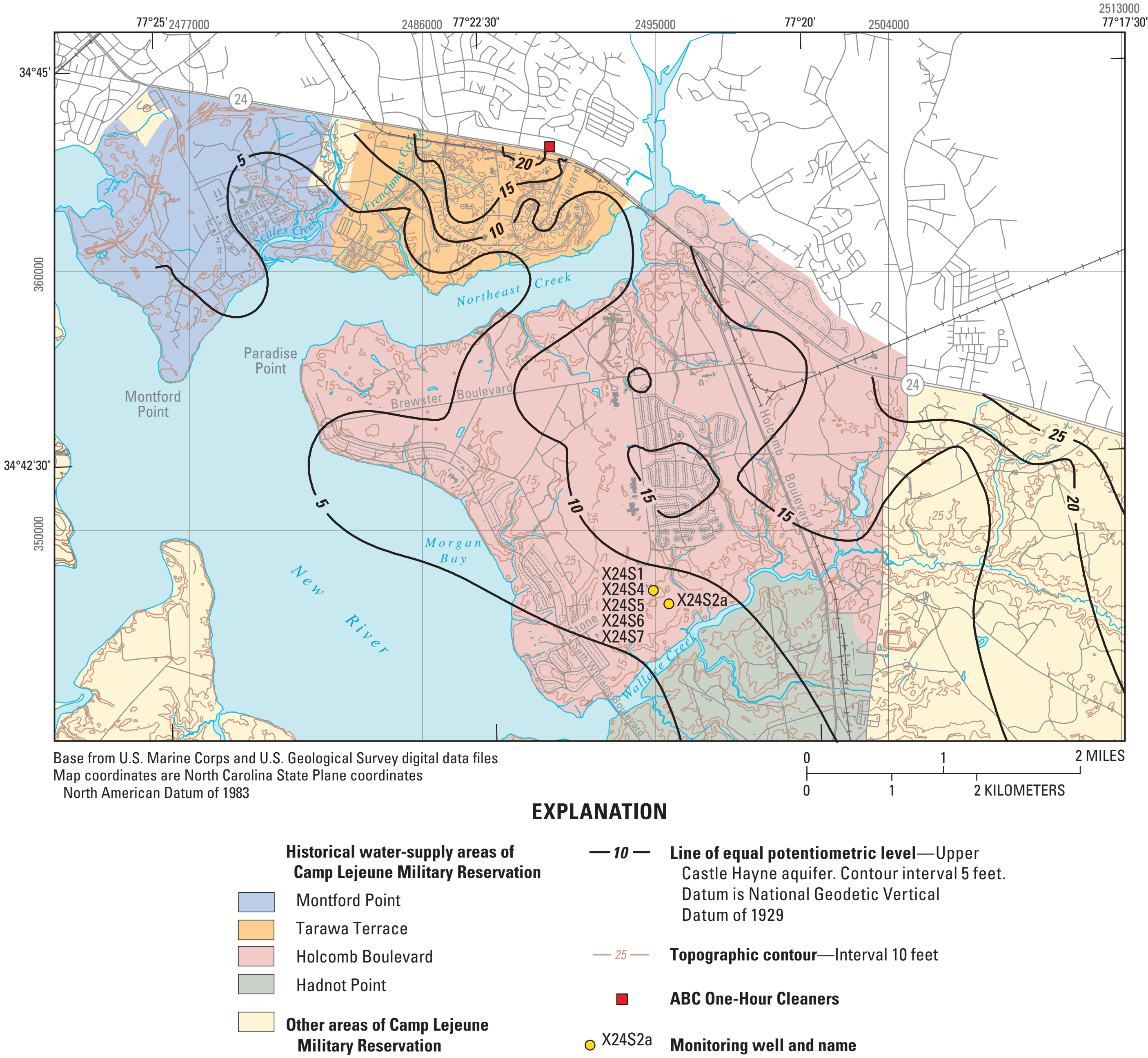


Figure B30. Estimated predevelopment potentiometric surface of the Upper Castle Hayne aquifer, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Discussion

Point data used for interpolation control when plotting unit tops and thickness generally decrease in number and density with unit depth, increasing the subjectivity of interpolated results. For example, a total of 39 data points were used to define the top of the Tarawa Terrace aquifer; whereas, only 6 data points were available to define the top of the Beaufort confining unit (Tables B5 and B14, respectively). Nevertheless, these maps (Figures B4–B27) are considered integral elements of the groundwater-flow model necessary for historical reconstruction, and were used to assign layers and layer geometry during flow model construction.

Limitations and qualifications pertinent to point data used to assign geohydrologic unit tops apply, as well, to hydraulic characteristic data (Table B15). Most test results refer to the shallowest aquifers, namely the Tarawa Terrace and Upper Castle Hayne aquifers. No test results refer uniquely to the Middle or Lower Castle Hayne aquifers. Accordingly, horizontal hydraulic conductivity data assigned to the flow model layers that represent these aquifers (Faye and Valenzuela, In press 2007) was somewhat subjective.

Summary and Findings

Potentiometric levels, horizontal hydraulic conductivity, and the geohydrologic framework of the Castle Hayne aquifer system at Marine Corps Base Camp Lejeune, east of the New River and north of Wallace Creek, are described and quantified. The geohydrologic framework is comprised of 11 units, 7 of which correspond to the Upper, Middle, and Lower Castle Hayne aquifers and related confining units. Overlying the Upper Castle Hayne aquifer are the Brewster Boulevard and Tarawa Terrace aquifers and confining units. Much of the Castle Hayne aquifer system is comprised of fine, fossiliferous sand, limestone, and shell limestone. The sands are frequently silty and contain beds and lenses of clay. Limestone units are probably discontinuous and occasionally cavernous. Confining units are characterized by clays and silty clays of significant thickness and are persistent across much of the study area. Maximum thickness of the Castle Hayne aquifer system within the study area is about 300 ft. In general, geohydrologic units thicken from northwest to the south and southeast. The limestones and sands of the Castle Hayne aquifer system readily yield water to wells. Aquifer-test analyses indicate that horizontal hydraulic conductivities of water-bearing units at supply wells commonly range from 10 to 30 ft/d. Estimated predevelopment potentiometric levels of the Upper and Middle Castle Hayne aquifers indicate that groundwater flow directions are from highland areas north and east of the study area toward the major drainages of New River and Northeast Creek.

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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