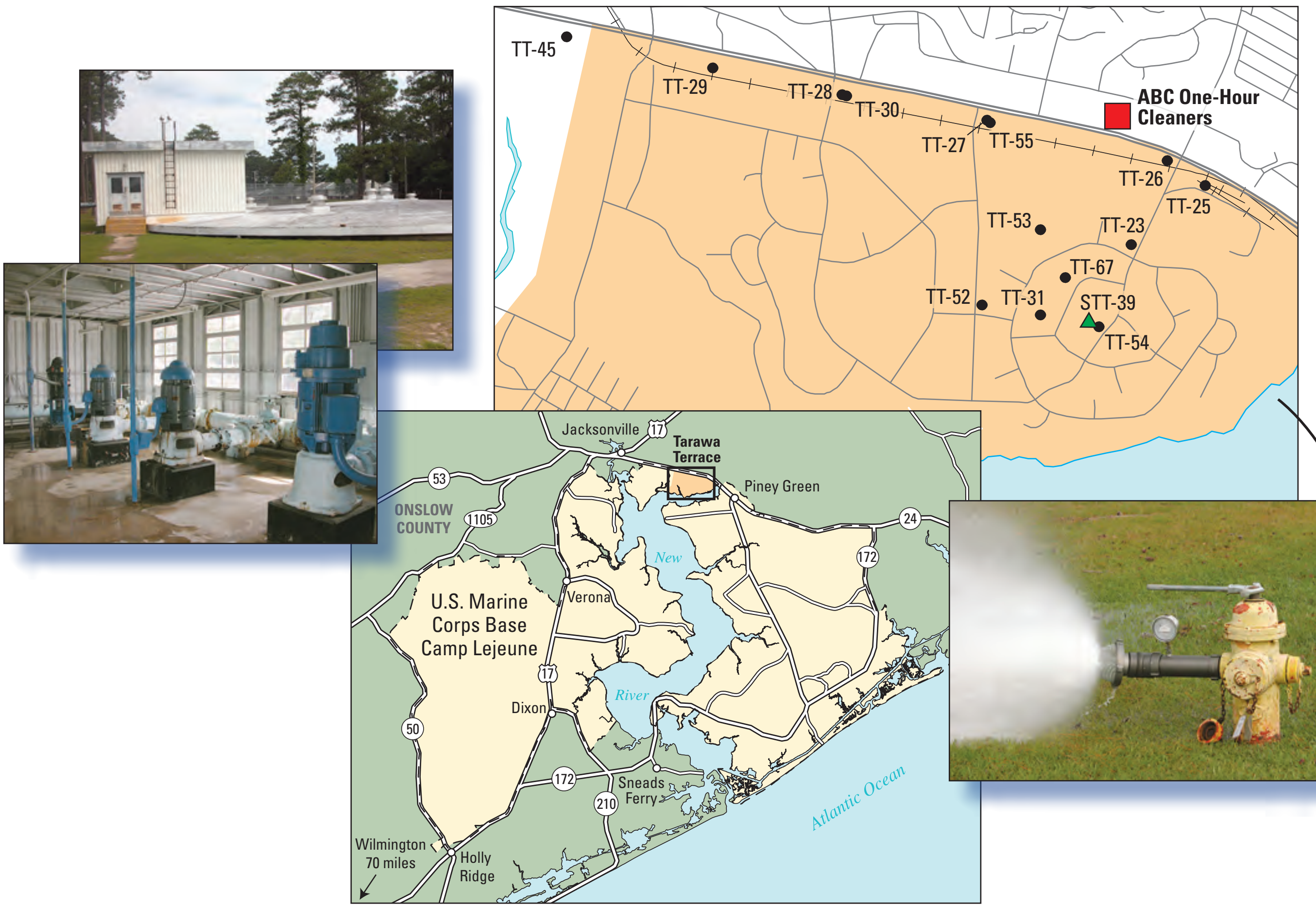
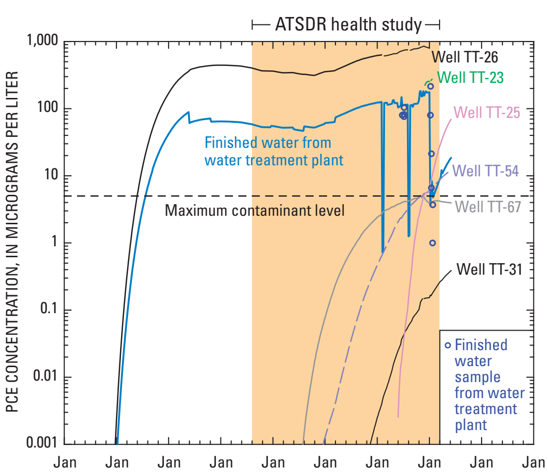
Analyses of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water at Tarawa Terrace and Vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina: Historical Reconstruction and Present-Day Conditions

Chapter C: Simulation of Groundwater Flow





ATSDR

AGENCY FOR TOXIC SUBSTANCES AND DISEASE REGISTRY

DEPARTMENT OF HEALTH & HUMAN SERVICES • USA

Atlanta, Georgia–November 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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Chapter C: Simulation of Groundwater Flow

By Robert E. Faye and Claudia Valenzuela

Agency for Toxic Substances and Disease Registry
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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 C: Simulation of Groundwater Flow*, 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	
inch	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
million gallons (MG)	3,785	cubic meter (m^3)
	Flow rate	
foot per day (ft/d)	0.3048	meter per day (m/d)
cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gallons per day (MGD)	0.04381	cubic meter per second (m^3/s)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
	Mass	
pound, avoirdupois (lb)	4.535 x10^{-4}	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Transmissivity	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

Concentration Conversion Factors

Unit	To convert to	Multiply by
microgram per liter (µg/L)	milligram per liter (mg/L)	0.001
microgram per liter (µg/L)	milligram per cubic meter (mg/m^3)	1
microgram per liter (µg/L)	microgram per cubic meter (µg/m^3)	1,000
parts per billion by volume (ppbv)	parts per million by volume (ppmv)	1,000

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

1,1,1-TCA	1,1,1-trichloroethane
1,1- and 1,2-DCA	1,1- and 1,2-dichloroethane
AKA	also known as
ATSDR	Agency for Toxic Substances and Disease Registry
BTEX	benzene, toluene, ethylbenzene, and xylene
cfs	cubic foot per second
CEE	School of Civil and Environmental Engineering
CLP	Clinical Laboratory Program
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
GC/MS	chromatograph/mass spectrometer
MGD	million gallons per day
MODFLOW	original version of the numerical code for a three-dimensional groundwater-flow model, developed by the U.S. Geological Survey
MODFLOW-96	a three-dimensional groundwater-flow model, 1996 version, developed by the U.S. Geological Survey
NCDNRCD	North Carolina Department of Natural Resources and Community Development
PCE	tetrachloroethene, tetrachloroethylene, 1,1,2,2-tetrachloroethylene, or perchloroethylene; also know as PERC® or PERK®
PMWINPro™	Processing MODFLOW Pro, version 7.017
psi	pound per square inch
RASA	Regional Aquifer-System Analysis
TCE	1,1,2-trichloroethene, 1,1,2-trichloroethylene, or trichloroethylene
TCLP	Toxicity Characteristic Leaching Procedure
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
UST	underground storage tank
VOC	volatile organic compound
WTP	water treatment plant

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 C: Simulation of Groundwater Flow

By Robert E. Faye[1] and Claudia Valenzuela[2]

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 (PCE), and Hadnot Point was contaminated mostly with trichloroethylene (TCE). 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 C, describes the development and calibration of a digital model applied to the simulation of groundwater flow within the Tarawa Terrace aquifer and Upper Castle Hayne aquifer system at and in the vicinity of the Tarawa Terrace housing areas.

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Background

U.S. Marine Corps Base Camp Lejeune is located in the Coastal Plain of North Carolina, in Onslow County, south 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 C1 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, U.S. Marine Corps Base Camp Lejeune, Map of Tarawa Terrace II Quarters, June 30, 1961; Sheet 7 of 34, U.S. Marine Corps Base Camp Lejeune, 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 (Plate 1).

Groundwater is the source of contaminants that occurred in the water-distribution networks at Tarawa Terrace and was supplied to the distribution networks via water-supply wells open to one or several water-bearing zones of the Castle Hayne aquifer system. Faye (2007) provides a complete description of the geohydrologic framework at and in the vicinity of Tarawa Terrace, including data and maps that summarize the geometry of individual aquifers and confining units.

Contamination of groundwater by a halogenated hydrocarbon—tetrachloroethylene (PCE)—was first detected in water supplies at Tarawa Terrace during 1982 (Grainger Laboratories, written communication, August 10, 1982). The source

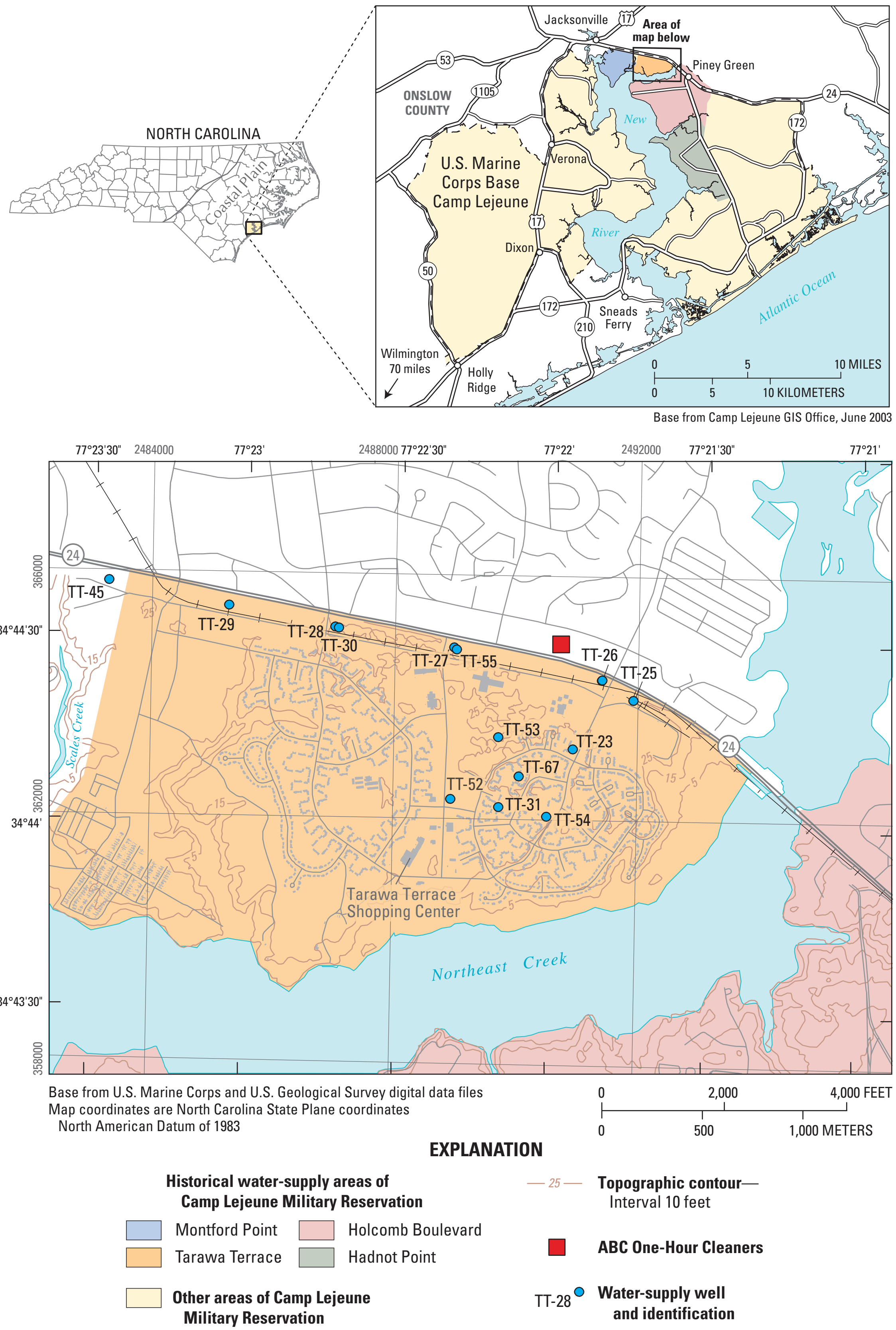


Figure C1. U.S. Marine Corps Base Camp Lejeune, Tarawa Terrace water-supply wells, Tarawa Terrace Shopping Center, and ABC One-Hour Cleaners, Onslow County, North Carolina.

of contamination was later determined to be ABC One-Hour Cleaners, located on North Carolina Highway 24 (SR 24) and less than a half-mile west and slightly north of several Tarawa Terrace water-supply wells (Shiver 1985, Figure 4). Production at supply wells TT-26 and TT-23 (Figure C1) was terminated during February 1985 because of contamination by PCE and related degradation products—trichloroethylene (TCE) and dichloroethylene (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 models are based to a large degree on groundwater-flow velocities or specific discharges simulated by a calibrated groundwater-flow model. 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 composed 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).

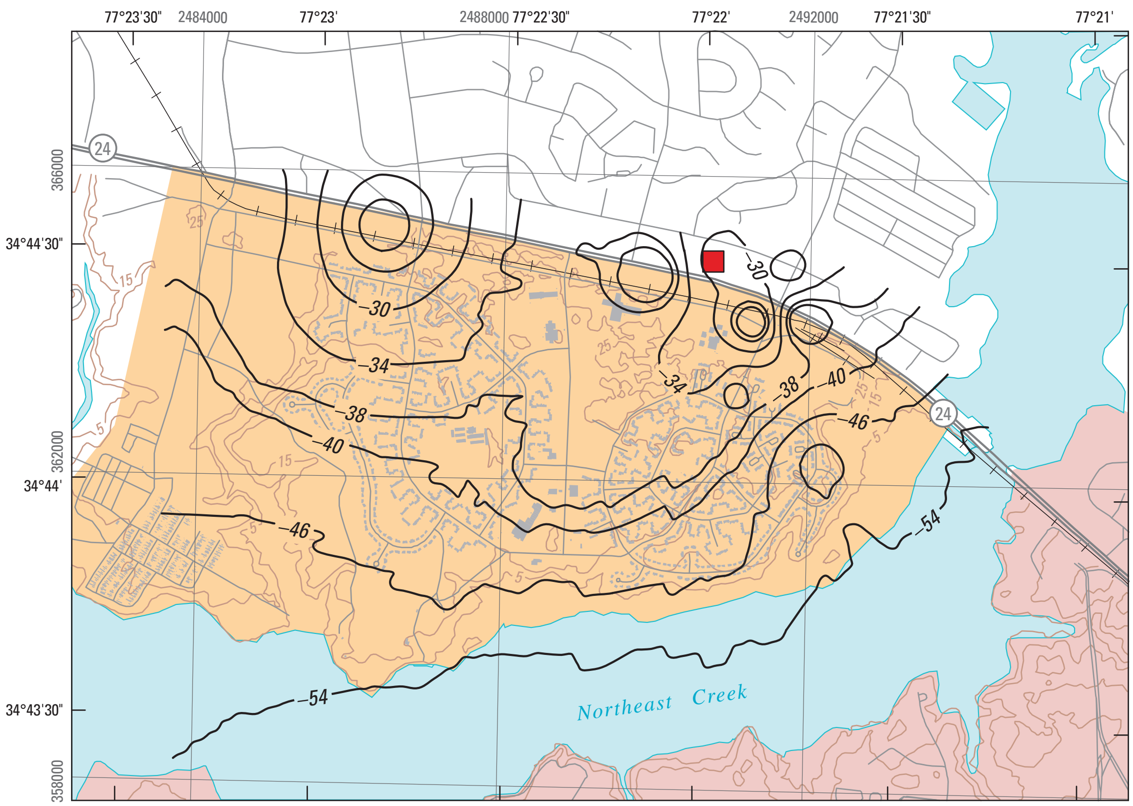
Purpose of Study

This study seeks to construct and calibrate a groundwater-flow model that represents the geohydrologic framework (Faye, 2007) and related groundwater-flow conditions at and in the vicinity of Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune. A groundwater-flow model is characterized by the vertical and spatial distribution of aquifers and confining units, their respective boundaries, and their hydraulic characteristics, such as hydraulic conductivity and specific storage. The assemblage of these and related geologic, hydraulic, and hydrologic elements into a multilayer, calibrated model that reasonably simulates groundwater flow in vertically contiguous aquifers and confining units at Tarawa Terrace and vicinity is the focus of studies summarized in this report.

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 depths ranging from about 60 to 70 feet (ft) at most sites but ranging in depth to about 90 ft at one location. Borehole and other drillers' and geophysical logs in the remainder of the study area do not indicate the top of the Castle Hayne Formation. Overlying the limestone or fossiliferous rock in the Roy F. Weston, Inc. logs 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 and is part of a well-recognized, somewhat to highly persistent geohydrologic unit that occurs throughout most of Camp Lejeune east of Northeast Creek (Harned et al. 1989, Sections A–A' and B–B', and C–C'; Cardinell et al. 1993, Sections A–A' and B–B'). This unit is designated herein the Local confining unit. Consequently, contours of equal altitude at the top of the Local confining unit are considered to also approximate the top of the Castle Hayne Formation (Figure C2). As shown, the top of the Castle Hayne Formation occurs near land surface in the northern part of and west of Tarawa Terrace, at altitudes ranging from about –20 to –30 ft, and dips to the east-southeast at a generally uniform rate to the vicinity of Northeast Creek, where the altitude at the top of the formation is less than –50 ft. Harned et al. (1989) and Cardinell et al. (1993) report that the base of the Castle Hayne Formation occurs at the top of the Beaufort Formation, which is 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. The top of the Beaufort confining unit occurs at about altitude –215 ft in the northern and western parts of the study area and dips gradually to the south and southeast to a minimum altitude of about –250 ft in the vicinity of Northeast Creek (Figure C3). Comparing the maps that show the approximate top and base of the Castle Hayne Formation (Figures C2 and C3), the thickness of the Castle Hayne Formation is shown to range from about 180 ft west of Tarawa Terrace to a maximum thickness of about 200 ft near Northeast Creek (Figure C4). Irregularities of contours shown in Figures C2–C4 are caused by interpolation of the small set of point data used to define the unit altitude or thickness. The base of the Castle Hayne Formation or the top of the Beaufort confining unit is considered the base of groundwater flow of interest to this study.

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. LeGrand (1959) indicates a "tendency toward layering" with respect to the alternating (with depth) beds of predominantly sandy or clayey sediments. LeGrand (1959) also points out that at Tarawa Terrace, Montford Point, and Hadnot Point (Plate 1) the "shellrock is subordinate in quantity to sand" within the Castle Hayne Formation. The sand is fine, often gray in color, and frequently fossiliferous. Much of the limestone is shell limestone, also called “shell hash,” “shellrock,” or coquina in drillers’ logs. Several of the clay deposits, such as the Local confining unit, 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 and discontinuous clay units probably occur frequently. The occurrence of limestone is probably also discontinuous, particularly in the vicinity of Tarawa Terrace. Limestone units of the Castle Hayne Formation at Camp Lejeune are marine and likely were deposited in near shore environments. Clastic units are probably beach deposits or were formed in deltaic or other near shore transitional environments.



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 2,000 4,000 FEET
0 500 1,000 METERS

EXPLANATION

Historical water-supply area

Tarawa Terrace

Holcomb Boulevard

ABC One-Hour Cleaners

–54 **Line of equal altitude**—Shows top of Local confining unit. Contour interval variable. Datum is National Geodetic Vertical Datum of 1929

25 **Topographic contour**—Interval 10 feet

Figure C2. Altitude at the top of the Local confining unit, approximates the lithostratographic top of the Castle Hayne Formation, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

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

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 (Harned et al. 1989; Cardinell et al. 1993). These sediments consist mainly of fine to medium, silty, gray and white sand interbedded with clay and sandy clay. Clays and sands are generally unfossiliferous at Tarawa Terrace but are fossiliferous southeast of Tarawa Terrace in the vicinities of Holcomb Boulevard and Hadnot Point (Plate 1), particularly at depths greater than 30 ft. The base of these units conforms to the top of the Castle Hayne Formation (Figure C2) and dips uniformly to the south and southeast. Unit thickness is zero at land surface and ranges from about 50 to 75 ft within the study area.

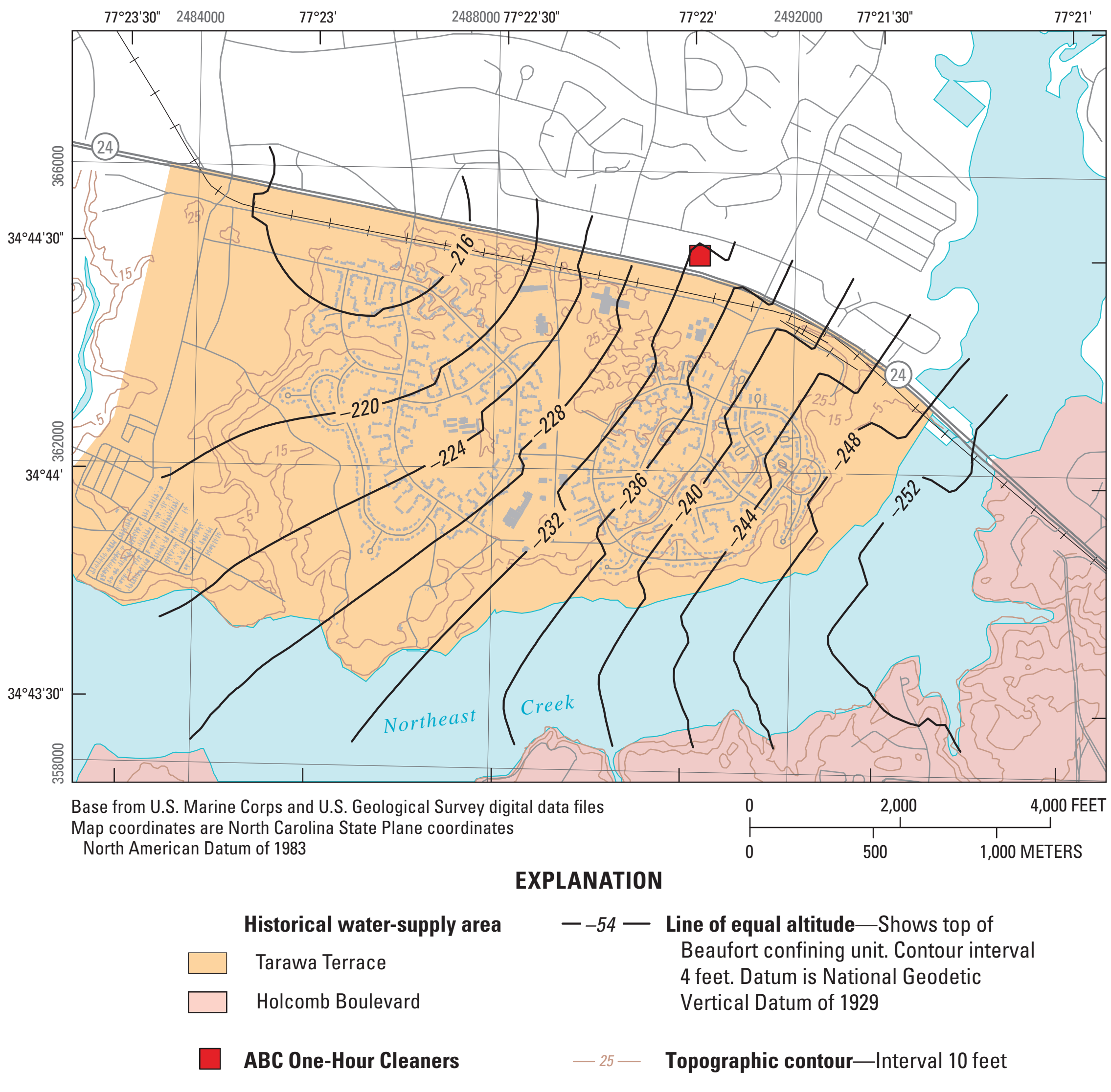


Figure C3. Altitude at the top of the Beaufort confining unit, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

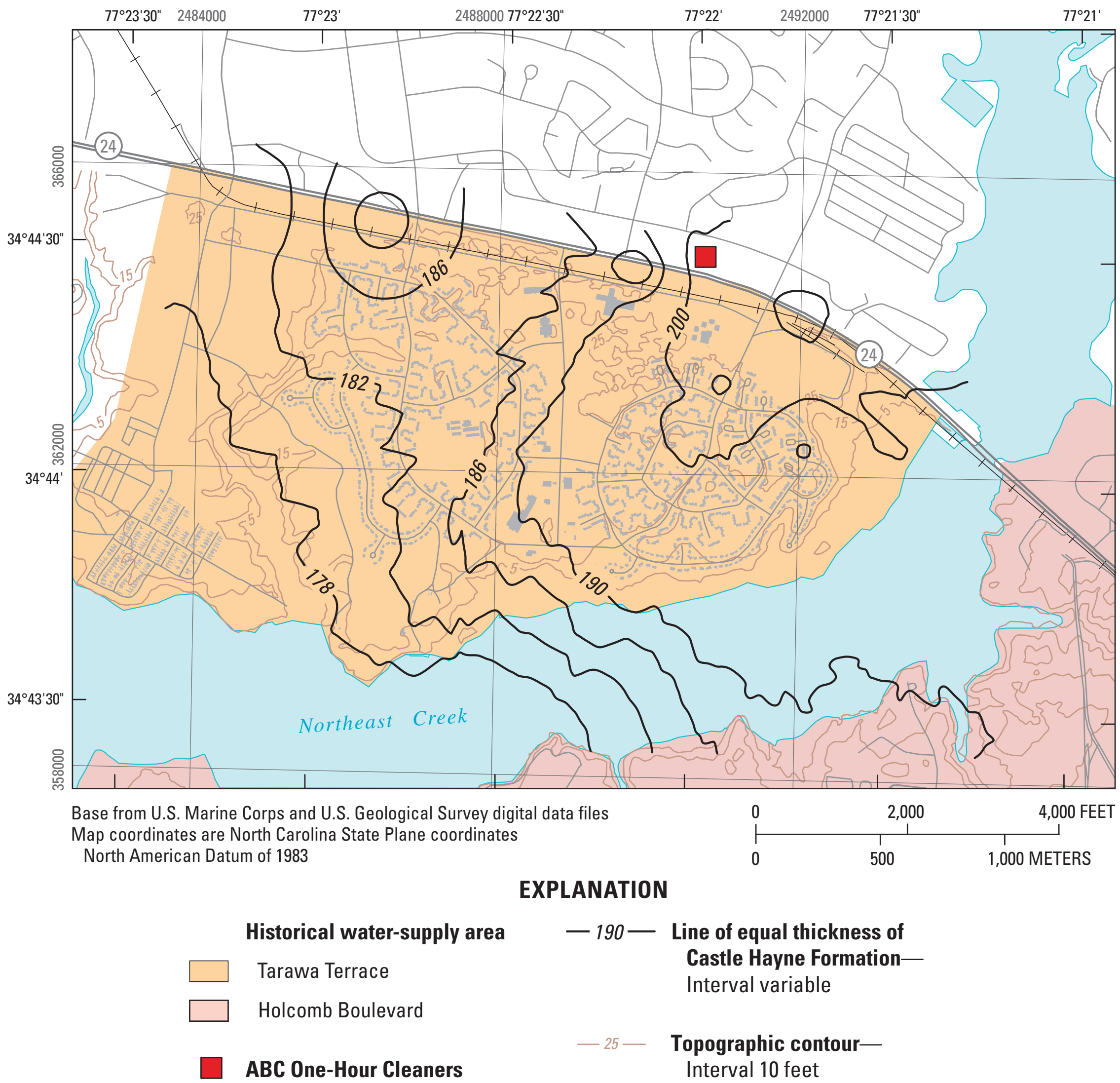


Figure C4. Thickness of the Castle Hayne Formation, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Geohydrologic Framework

A total of nine aquifers and confining units that occur between land surface and the top of the Beaufort Formation in the vicinity of Tarawa Terrace 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 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 C1). 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 in 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 and Lower units of the Upper Castle Hayne aquifer and conforms in areal extent and thickness to the silty or sandy clay described previously at the top of the Castle Hayne Formation (Figure C2). The aquifers and confining units, ranging from the top of the Upper Castle Hayne aquifer–River Bend unit to the top of the Beaufort confining unit, are inclusive of the Castle Hayne aquifer system, as defined in this study. The water table in the northern part of the study area generally occurs near the base of the Tarawa Terrace confining unit or near the top of the Upper Castle Hayne aquifer–River Bend unit. During periods of significant and prolonged rainfall, the water table possibly resides temporarily near the base of the Tarawa Terrace aquifer; however, sediments equivalent to the Tarawa Terrace

Table C1. Geohydrologic units, unit thickness, and corresponding model layer, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[Units are listed shallowest to deepest and youngest to oldest; N/A, not applicable]

Geohydrologic unit	Thickness range, in feet	Model layer
Tarawa Terrace aquifer	8 to 30	1
Tarawa Terrace confining unit	8 to 20	1
Castle Hayne aquifer system		
Upper Castle Hayne aquifer–River Bend unit	16 to 56	1
Local confining unit	7 to 17	2
Upper Castle Hayne aquifer–Lower unit	8 to 30	3
Middle Castle Hayne confining unit	12 to 28	4
Middle Castle Hayne aquifer	32 to 90	5
Lower Castle Hayne confining unit	18 to 30	6
Lower Castle Hayne aquifer	41 to 64	7
Beaufort confining unit	N/A	Base of model

aquifer are generally unsaturated. Available water-level data from paired wells individually open to the Upper Castle Hayne aquifer–River Bend and Lower units indicate little or no head difference between the aquifers or a slightly downward gradient from the River Bend unit to the Lower unit (Roy F. Weston, Inc. 1992, 1994). In the southern part of the study area, in the vicinity of the Tarawa Terrace Shopping Center, the Tarawa Terrace confining unit is mainly absent and the Tarawa Terrace aquifer and the Upper Castle Hayne aquifer–River Bend unit are undifferentiated. The water table in this area probably occurs consistently within the middle or base of sediments equivalent to the Tarawa Terrace aquifer.

Altitudes at the top of the Local confining unit and the Beaufort confining unit were shown previously in Figures C2 and C3. Point data used for interpolation control when plotting unit tops and thicknesses generally decrease in number and density with unit depth, increasing the subjectivity of interpolated results. Nevertheless, such maps 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. Contour maps showing altitude at the unit top and unit thickness for all flow-model layers (Table C1) and lists of related point data are included in Faye (2007). Most unit surfaces trend to the south and southeast and increase in thickness in the same directions, similar to contours shown in Figures C2 and C3. The tops of most units exhibit a moderate to high degree of irregularity at one or several locations and probably at one or several times since their deposition were erosional surfaces, exposed to the effects of rain, ice, runoff, weathering, dissolution, and similar agents. Accordingly, surface irregularities may represent relict stream channels or hilltops. Where a unit is mainly limestone in composition, surface irregularities possibly represent the remnants of a karst terrain such as sinkholes or related solution or fracture features.

Previous Investigations

Reports and documents that describe or refer to the geology, hydrology, groundwater quality, and water supply at Tarawa Terrace and vicinity can be classified into two general categories—geohydrology and groundwater contamination. Previous investigations discussed herein are grouped into these two categories according to their dominant subject matter. Many reports and documents also contain ancillary information related to both geohydrology and groundwater contamination, as well as other topics of interest.

Geohydrology

Investigations of groundwater supplies in the area that would later become U.S. Marine Corps Base Camp Lejeune were conducted by David G. Thompson of the U.S. Geological Survey (USGS) 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, ranging in depth from about 200 to 500 ft. Detailed construction and lithologic data were collected at each test site along with geophysical logs, water-level, and water-quality data. Test wells T-9–T-14 (Plate 1) were constructed at or nearby Tarawa Terrace and provided the first detailed description of the Castle Hayne aquifer system in that part of Camp Lejeune. Downward leakage as recharge was estimated to be about 19 inches per year (in/yr) in the vicinity of most well fields operating at Camp Lejeune during the period of investigation.

Harned et al. (1989) conducted a comprehensive and detailed review of groundwater data and conditions throughout Camp Lejeune for the period 1986–1987. 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 1986–1987. Construction and well-capacity test data also were reported for numerous wells. Annual water use as an average in million gallons per day (MGD) were 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 the majority of supply wells were constructed at Camp Lejeune. Significantly, three "hydrogeologic" sections were constructed, located generally 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 (Faye 2007). Correlation of units from site to site was mainly based on borehole electric log signatures. Well locations, well-capacity tests, well construction, pumpage, and water-level data reported by Harned et al. (1989) were essential and necessary elements of flow-model construction and calibration described in this report.

Cardinell et al. (1993) used much of the borehole data collected previously by Harned et al. (1989), slightly modified the geohydrologic interpretations of Harned et al. (1989), and extended their "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 Camp Lejeune area.

Giese and Mason (1991, Plate 1) subdivided the North Carolina Coastal Plain into three "hydrologic areas," mainly based on soil type and topography. These areas were classified as clay soils, sandy soils, and sand hills. Low streamflow characteristics were computed for each unique hydrologic area. The area classification assigned to U.S. Marine Corps Base Camp Lejeune, including the Tarawa Terrace area, was HA2 or "sandy soils." Using generally the same hydrologic area classifications and respective area boundaries of Giese and Mason (1991), Heath (1994) assigned groundwater recharge rates ranging from about 4 to 13 in/yr to North Carolina Coastal Plain "hydrogeologic units," with the highest rates assigned to "sand hills and sandy soils" (Heath 1994, Figure 21, Table 6). The recharge rates of Heath (1994) probably represent effective recharge; that is, net recharge to the water table after accounting for evapotranspiration and surface runoff.

Giese et al. (1997) developed and calibrated a groundwater-flow model of the entire North Carolina Coastal Plain as a part of the USGS Regional Aquifer-System Analysis (RASA) program. The "Castle Hayne aquifer" was modeled as a single aquifer for the RASA study. Simulated information specific to Tarawa Terrace or the Camp Lejeune area is highly generalized as a result. For example, the Tarawa Terrace area of interest to this study is located entirely within a single cell of the RASA flow model.

Baker Environmental, Inc. (1998) constructed a groundwater-flow model of the entire Camp Lejeune area to evaluate water-level changes and related effects of groundwater pumping at various groundwater remediation sites. 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). Maps were not provided that illustrate the spatial distribution or thickness of aquifers and confining units. Horizontal hydraulic conductivity assigned to the model aquifer units was 5, 7, and 10 feet per day (ft/d) for the "surficial," "Upper Castle Hayne," and "Lower Castle Hayne" aquifers, respectively, and was applied uniformly throughout the model layers. Horizontal hydraulic conductivity assigned to the "Castle Hayne confining unit" was 0.1 ft/d throughout most of the model domain but was selectively assigned as 0.00073 and 5 ft/d, depending on conditions observed during field investigations. A horizontal hydraulic conductivity of 100 ft/d was assigned uniformly to the "Fractured Limestone unit." All wells assigned to the model pumped only from the "Fractured Limestone unit." Vertical hydraulic conductivities assigned to each model layer equaled one-tenth the horizontal hydraulic conductivity. Recharge to the water table was simulated at a rate of 11 in/yr. Model cells were square with dimensions of 1,000 ft per side. The total model grid consisted of 101 rows and 80 columns. Model run conditions were steady state. Model calibration was based on 142 water-level measurements at wells open to the four designated aquifers. These wells were located mostly north and east of New River (Plate 1). Water-level data represented conditions during 1992–1993. Simulated water levels matched observed water levels within 10 ft at all but one site.

Groundwater Contamination

During August 1982, routine chromatograph/mass-spectrometer (GC/MS) analyses for trihalomethane in water samples collected from the Tarawa Terrace and Hadnot Point WTPs at U.S. Marine Corps Base Camp Lejeune were interrupted by interference from constituents in the water samples thought to be halogenated hydrocarbons (Grainger Laboratories, written communication, August 10, 1982; Elizabeth A. Betz, written communication, August 19, 1982; AH Environmental Consultants, Inc., written communication, June 18, 2004; Camp Lejeune water documents CLW 592–595 and CLW 606–607). Subsequent analyses confirmed the presence of PCE in samples of finished water supplies from both locations ranging in concentration from 76 to 104 micrograms per liter (μg/L) at Tarawa Terrace and from 15 μg/L to below detectable limits at Hadnot Point. Concentrations of TCE determined in samples from the Hadnot Point WTP ranged from 19 to 1,400 μg/L. Samples analyzed were collected during May and July 1982 (Faye and Green 2007, Table E12).

During July 1984, routine sampling and analyses of community water-supply wells at Camp Lejeune, as a part of the Base Naval Assessment and Control of Installation Pollutants Program, indicated the occurrence of TCE in samples obtained from wells TT-23 (37 μg/L), TT-25 (trace), and TT-26 (3.9 μg/L) (Maslia et al. 2007). Well TT-26 was open only to the Upper Castle Hayne aquifer; whereas, wells TT-23 and TT-25 were open to both the Upper and Middle Castle Hayne aquifers (Faye and Green 2007, Table E2).

Beginning during January 1985 and continuing into September 1985, the North Carolina Department of Natural

Resources and Community Development (NCDNRCD) periodically sampled wells TT-23, TT-25, and TT-26 and water treated at the Tarawa Terrace WTP for PCE and its degradation products, TCE, DCE, and vinyl chloride (McMorris 1987). On occasion, duplicate samples were analyzed by NCDNRCD and by JTC Environmental Consultants Inc. (Shiver 1985; R.A. Tiebout, Memorandum for the Commanding General, Chief of Staff, written communication, November 6, 1985; J.R. Bailey to U.S. Environmental Protection Agency, written communication, April 25, 1986; Camp Lejeune water documents CLW 1338–1339, 1475–1483). Concentrations of PCE in samples from water-supply well TT-26 ranged from 3.8 to 1,580 µg/L in seven samples collected during this period. Concentrations in 10 samples from water-supply well TT-23 ranged from "not detected" to 132 µg/L. Concentrations also were detected of TCE, *trans*-1,2-dichloroethylene (1,2-tDCE), and vinyl chloride. Tarawa Terrace water-supply wells TT-30, TT-31, TT-52, TT-54, and TT-67 also were sampled during this period, and subsequent analyses detected no concentrations of PCE or related degradation products above detection limits at these wells (JTC Environmental Consultants Report 85-047, Report 19, written communication, February 5–6, 1985). However, JTC Environmental Consultants detected benzene at a concentration of 6.3 µg/L in a sample collected at well TT-23 on February 19, 1985 (JTC Environmental Consultants Report 85-072, Report 37, written communication, March 1, 1985). An estimated concentration of 0.43 µg/L PCE was determined in a sample from well TT-25 during September 1985. The sampling and analyses for volatile organic compounds (VOCs) during January and February 1985 caused wells TT-23 and TT-26 to be removed from service during February 1985. Well TT-26 was permanently closed at this time; however, well TT-23 was used to deliver water to the Tarawa Terrace WTP for several days during March and April 1985 (Camp Lejeune water document CLW 1182; Camp Lejeune water document CLW 1193, "Direction to Operators at Tarawa Terrace," April 30, 1985; Camp Lejeune water document CLW 1194, "Procedures for operating the 'New Well' at Tarawa Terrace," date unknown). At the time of discovery of PCE and related contaminants at Tarawa Terrace supply wells, the Tarawa Terrace WTP provided drinking water to about 6,200 people in the service area (McMorris 1987).

During April 1985, the NCDNRCD began a field investigation to determine the source or sources of PCE and related constituents occurring at wells TT-23 and TT-26. Samples were collected at these wells and at well TT-25 for analyses of VOCs. Three monitor wells were installed in the "Water Table aquifer" northwest of well TT-26 parallel to SR 24 to collect additional samples and water-level data (Shiver, 1985; wells X24B4, X24B5, X24B6 [shown on Plate 1 as B4, B5, and B6, respectively]). Results of analyses of samples collected at supply and monitor wells were sufficient to delineate a highly generalized plume of PCE in groundwater of the aquifer. The northwest apex of the plume was located at monitor well X24B6, immediately opposite the entrance of ABC One-Hour Cleaners at 2127 Lejeune Boulevard (SR 24). The PCE concentration determined in the sample from this well was 12,000 µg/L. These and ancillary water-level data, indicating the direction of groundwater flow to the southeast toward supply well TT-26, pinpointed ABC One-Hour Cleaners as the source of PCE in Tarawa Terrace water-supply wells (Shiver 1985, Figure 4).

ABC One-Hour Cleaners always used PCE in its dry-cleaning operations, beginning during 1953 when the business opened (Hopf & Higley, P.A., "Deposition of Victor John Melts," written communication, April 12, 2001). A primary pathway of contaminants from the dry-cleaning operations at ABC One-Hour Cleaners to the soil and subsequently to groundwater was apparently through a septic tank-soil absorption system to which ABC One-Hour Cleaners discharged waste and wastewater. Shiver (1985) reports that an inspection of the PCE storage area at ABC One-Hour Cleaners indicated that PCE releases could and did enter the septic system through a floor drain, probably as a result of spillage in the storage area (Roy F. Weston, Inc. 1994). In addition, spent PCE was routinely reclaimed using a filtration-distillation process that produced dry "still bottoms," which until about 1982 (Hopf & Higley, P.A., "Deposition of Victor John Melts," written communication, April 12, 2001) or 1984/1985 (McMorris 1987), were disposed of onsite, generally by filling potholes in a nearby alleyway. When ABC One-Hour Cleaners totally discontinued the use of the floor drain and the onsite disposal of still bottoms is not known exactly, but such practices probably terminated completely during 1985.

The disposal of dry-cleaning solvents to the septic system and subsequently to groundwater placed ABC One-Hour Cleaners in violation of various State laws and statutes. During January 1986, the owners were ordered by the State of North Carolina to cease such disposal and propose a plan to restore the quality of affected groundwater to an acceptable level as determined by the State (Roy F. Weston, Inc. 1994). Pursuant to this plan, ABC One-Hour Cleaners hired Law Engineering and Testing Company, Inc., to investigate the septic tank and the surrounding soil for contaminant content. Samples collected and analyzed by Law Engineering and Testing Company, Inc., indicated PCE concentrations of the septic tank sludge were as high as 1,400 milligrams per liter (mg/L) and that soil 4 ft below the tank contained PCE concentrations as high as 400 milligrams per kilogram (mg/kg) (Law Engineering and Testing Company, Inc. 1986a; Roy F. Weston, Inc. 1992). Subsequently Law Engineering and Testing Company, Inc., conducted additional investigations to determine the vertical and horizontal extent of contamination within the soil profile. These investigations were completed by December 1986 and indicated the depth of PCE contamination in the vicinity of the septic tank to be in excess of 16 ft. A PCE concentration at a depth of 8 ft was 860 mg/kg (Law Engineering and Testing Company, Inc. 1986b; Roy F. Weston, Inc. 1992; Faye and Green 2007, Table E4).

By March 1987, all water-supply wells at Tarawa Terrace were removed from service. During March 1989, the ABC One-Hour Cleaners site was placed on the U.S.

Environmental Protection Agency's (USEPA) National Priority List (Final List); and during June 1990, USEPA hired Roy F. Weston, Inc., to conduct a remedial investigation at the site aimed at determining the areal and vertical extent of contaminant plumes (Operable Unit 1) and characterizing the source of contaminants in the unsaturated soils beneath and in the vicinity of the septic disposal system at ABC One-Hour Cleaners (Operable Unit 2) (Roy F. Weston, Inc. 1994; event chronology, no author, written communication, "as of October 1998").

Operable Unit 1 of the remedial investigation included the installation of eight soil borings to depths ranging from 16 to 20 ft surrounding and in the immediate vicinity of ABC One-Hour Cleaners (SB-1–SB-6, SB-10, and SB-12; Faye and Green 2007, Table E4). These borings occurred entirely within the unsaturated zone. Ten shallow and five deep monitor wells also were installed during Operable Unit 1, not only in the immediate vicinity of ABC One-Hour Cleaners, but northwest of the site as well as proximate to wells TT-26 and TT-25. Several monitor wells also were located between SR 24 (Lejeune Boulevard) and the Tarawa Terrace housing area. The shallow wells, S1–S10, were constructed to depths ranging from 28 to 40 ft and were open at the base of the well to the Upper Castle Hayne aquifer–River Bend unit (Table C1.10). Four of the deep wells—C1, C2, C3, and C5—ranged in depth from about 90 to 100 ft and were open at the base to the Upper Castle Hayne aquifer–Lower unit. Well C4 was constructed to a depth of about 200 ft and was open to the Middle Castle Hayne aquifer.

Operable Unit 2 included the construction of an additional shallow well (S11) about 1,000 ft northwest of ABC One-Hour Cleaners. Two additional deep wells, C9 and C10, were constructed east and south of the cleaners. Additional well C11 was located in the northeast part of the Tarawa Terrace housing area. Depths of the additional deep wells ranged from about 75 to 175 ft. Wells C9 and C11 were open to the Upper Castle Hayne aquifer–Lower unit. Well C10 was open to the Middle Castle Hayne aquifer. Also installed as part of Operable Unit 2 were six piezometers, three shallow (PZ-02, -04, -06) and three deep (PZ-01, -03, -05), in the immediate vicinity of ABC One-Hour Cleaners and open to the Upper Castle Hayne aquifer–River Bend and Lower units, respectively. The depths of PZ-02, -03, and -04 ranged from 29.5 to 34.5 ft. Depths of PZ-01, -03, and -05 ranged from 74.5 to 79.5 ft.

Results of analyses of periodic water samples collected from the monitor wells during Operable Units 1 and 2 indicated that concentrations of PCE ranged from below detectable limits at several wells to 5,400 μg/L at well S3. Samples from monitor wells also were analyzed for various metals and semivolatile compounds.

During Operable Unit 2, similar constituent-analysis schedules were used during analyses of effluent from the septic tank at ABC One-Hour Cleaners and of soil samples obtained from the unsaturated zone in the vicinity of the tank. PCE concentration in the tank effluent was 6,800 μg/L during June 1991. Concentrations of PCE in soil borings at various depths in the immediate vicinity of ABC One-Hour Cleaners ranged from not detected to more than 2,000,000 micrograms per kilogram (μg/kg) (Faye and Green 2007, Table E4).

Deep monitor wells C1–C5 were paired with their respective shallow well counterparts S1–S5. Piezometers with odd and even numbers were likewise paired, in an effort to determine vertical hydraulic gradients. Water levels at paired wells and piezometers were measured to hundredths of a foot periodically during 1992–1993 (Appendix C1, Table C1.10). Vertical-head gradients were downward at all paired wells at all times, with the exception of slightly upward gradients at PZ-01/02 and PZ-03/04 during November 1993. A maximum head difference of 2.23 ft occurred at paired wells S1/C1 during April 1992. Head differences between the Upper Castle Hayne aquifer–River Bend unit and the Middle Castle Hayne aquifer were always less than 2 ft. These and similar water-level measurements at all monitor wells were used to map local potentiometric surfaces in the vicinity and downgradient of ABC One-Hour Cleaners (Roy F. Weston, Inc. 1992, Figures 4-6 and 4-9). Potentiometric levels in the Upper Castle Hayne aquifer–River Bend and Lower units were similar and ranged from about 23 to 10 ft, National Geodetic Vertical Datum of 1929 (NGVD 29). Potentiometric levels trended from northwest to southeast, greater to lesser, and generally corresponded to groundwater-flow directions. The potentiometric gradient of the Upper Castle Hayne aquifer–River Bend unit ranged from about 0.006 to 0.007 foot per foot (ft/ft) (Roy F. Weston, Inc. 1992). Corresponding gradients for the Upper Castle Hayne aquifer–Lower unit were from 0.005 to 0.006 ft/ft. Aquifer-tests were conducted in conjunction with several monitor wells. Test results indicated that values of horizontal hydraulic conductivity ranged from about 10 to 30 ft/d for the "surficial aquifer" (Upper Castle Hayne aquifer–River Bend unit). Corresponding storativity ranged from magnitude 10^{-4} to 10^{-3}. Water-levels at supply and monitor wells at and in the vicinity of Tarawa Terrace are listed in Appendix C1, Tables C1.1–C1.11. Corresponding well-construction data are listed in Appendix C2, Tables C2.1–C2.3.

In order to characterize the depth, areal extent, and water quality of the contaminant plumes emanating from the vicinity of ABC One-Hour Cleaners, hydrocone penetrations using direct-push technology were accomplished at 47 sites, near, east, and south of the cleaners. Two levels of samples were collected at each site, generally from about 20 and 40 ft, respectively. The constituent-analysis schedule used for hydrocone sample analyses included PCE, TCE, 1,2-tDCE and vinyl chloride, as well as 1,1,1-trichloroethane (1,1,1-TCA), 1,1- and 1,2-dichloroethane (1,1-, 1,2-DCA), and carbon tetrachloride. Samples were analyzed in the field using a mobile laboratory. Several duplicate samples were submitted to "CLP" laboratories for quality assurance of results. Although not defined in the respective Operable Unit reports, CLP probably refers to "Clinical Laboratory Program," a process that inspects State and Federal public health laboratories for purposes of certification. The CLP laboratories also determined concentrations of carbon disulfide, benzene, ethylbenzene, and total xylenes, in addition to the constituents discussed previously. Benzene and related toluene, ethylbenzene, and total xylenes (BTEX) were detected infrequently in the hydrocone samples. Benzene concentrations ranged from below detectable limits to 12 µg/L (Faye and Green 2007, Table E9). Results of mobile and CLP laboratory analyses were not highly consistent (Roy F. Weston, Inc. 1992, Table 5-12). Most constituents were noted in one or more samples. PCE was detected most frequently and was found in 75 samples at concentrations ranging from 1 to 30,000 µg/L. The maximum depth of PCE occurrence determined by hydrocone penetration was 64 ft (sample HC-6-64), which is near the base or slightly below the Upper Castle Hayne aquifer–River Bend unit (Faye and Green 2007, Table E7).

During 1990, the Agency for Toxic Substances and Disease Registry (ATSDR) completed an assessment of public health effects related to groundwater contamination at ABC One-Hour Cleaners and expressed a public health concern that offsite (namely Tarawa Terrace) exposure of contaminants to humans had occurred through the groundwater pathway. During 1997, ATSDR conducted a comprehensive Public Health Assessment of U.S. Marine Corps Base Camp Lejeune, which included an assessment of human exposure to contaminated groundwater at Tarawa Terrace. Maximum contaminant concentrations for PCE (215 µg/L), TCE (8 µg/L), and DCE (12 µg/L) determined from samples obtained within the Tarawa Terrace water-distribution system were listed, and a definitive exposure timeframe was identified for the period 1982–1985. The period 1954–1982 was identified as an unknown exposure timeframe (ATSDR 1997).

Investigations of groundwater contamination at and near Tarawa Terrace not related to ABC One-Hour Cleaners also have occurred since 1990, mainly in conjunction with known or suspected releases to groundwater of refined-petroleum products from underground and above-ground storage tanks. Six large (30,000 gallons [gal]) above-ground petroleum storage tanks (STT61–STT66) were located just west of Tarawa Terrace in the narrow strip between the railroad tracks and SR 24 (Plate 1). Tarawa Terrace water-supply wells TT-27 and TT-55 were located just south and slightly west of these tanks. The tanks were constructed during 1942; and until about 1980, petroleum product deliveries were offloaded from railcars. About 1980, the tanks were converted to waste oil storage (O'Brien & Gere Engineers, Inc. 1992, 1993). Well TT-27 was installed during 1951 and was mostly out of service by 1962. Well TT-55 was installed during 1961 and was out of service by 1971. At least one spill is documented at the tank site—a spill from tank STT66 occurred about 1986 or 1987 (O'Brien & Gere Engineers, Inc. 1992, 1993).

Field investigations of groundwater conditions at and in the vicinity of the tanks included the installation of 20 monitor wells during 1991–1992. Half the wells were installed to a depth of about 15 ft and half to a depth of about 30 ft (Appendix C2, Table C2.3). Ten-foot slotted screens were installed at the base of all wells. The shallow wells were open to the base of the Tarawa Terrace aquifer. The deep wells were open to the Upper Castle Hayne aquifer–River Bend unit. Water-level data collected in monitor wells indicated potentiometric levels ranged from about 20 to 27 ft during January 1992 (Appendix C1, Table C1.10). Groundwater was shown to flow in a generally southerly direction away from the tanks. Hydrocone samples obtained using direct-push techniques were collected at 10 additional sites about 4 ft below the water table. Samples obtained from each well and hydrocone site were analyzed for a great variety of constituents. Most constituents are included in the Toxicity Characteristic Leaching Procedure (TCLP) protocols. Of major interest to this study were concentrations of benzene, which ranged from not detected to 23 µg/L. All occurrences of benzene were in four of the deep wells. Benzene also was detected in three hydrocone samples and ranged in concentration from 7 to 22 µg/L (Faye and Green 2007, Table E9). A highly generalized boundary of a benzene plume was constructed using these data representing conditions during 1993. The elongated part of the plume is pointed almost directly south, corresponding to groundwater-flow directions (O'Brien and Gere Engineers Inc. 1992, 1993). An aquifer test conducted during December 1992, using several monitor wells as observation wells, indicated a transmissivity of water-bearing sands open to the wells of about 500 feet squared per day (ft^2/d) and a storativity of about 0.05. Discharge at the pumped well during the test was 5.5 gallons per minute (gal/min).

A "strong gasoline-type odor" was noted at supply well TT-53 (Figure C1) during October 1986 while USGS personnel performed a routine well reconnaissance (U.S. Geological Survey well inventory, written communication, October 21, 1986). The well at the time was out of service, and the pump had been removed. This well is located about 1,500 ft southeast of the benzene plume located in the vicinity of the STT storage tanks and is the nearest most recently active Tarawa Terrace supply well to the plume.

The Tarawa Terrace Shopping Center is located in the southern part of Tarawa Terrace north of the shoreline of Northeast Creek (Figure C1). Eleven buildings associated with the shopping center are numbered beginning at TT-2455 and ending at TT-2475. The construction date of the shopping center is unknown, but the major buildings and the name "Shopping Center" are shown on maps of Tarawa Terrace dated June 1961 (Sheet 3 of 18, U.S. Marine Corps Base Camp Lejeune, Map of Tarawa Terrace II Quarters, June 30, 1961). Twelve underground storage tanks (USTs) ranging in capacity from 300 to 500 gal and several above-ground storage tanks were associated with various buildings at the shopping center. The installation and release history of these tanks is unknown; however, releases from two tanks were confirmed during 1994. Many of these tanks were abandoned by 1995 or possibly earlier (Richard Catlin & Associates, Inc. 1994a,b, 1995a,b).

Adjacent to or nearby the shopping center are Buildings TT-2477, TT-2478, and TT-2453. Building TT-2477 was constructed during the 1950s as a full-service gasoline station. This building originally contained one 10,000-gal gasoline UST and one 550-gal UST for hydraulic/gear fluids. These tanks were probably installed at the time of the construction of Building TT-2477. The 550-gal tank was removed during 1992, and the 10,000-gal tank was abandoned in place at that time (Law Engineering, Inc. 1995a). The release history of both tanks is unknown.

Building TT-2478 is located about 250 ft north of Building TT-2477 and was constructed during 1986. Three 10,000-gal gasoline USTs were installed at the time of construction. By 1992, at least two of the tanks were determined to be leaking (Law Engineering, Inc. 1994a,b).

Building TT-2453, located slightly southeast of Building TT-2455 of the shopping center and about 450 ft south of Building TT-2477, was also a gasoline station at one time. The installation and release history of tanks at Building TT-2453 is unknown, but this building also is shown on maps of Tarawa Terrace dated June 1961 and is identified on same as a “filling station” (Sheet 3 of 18, U.S. Marine Corps Base Camp Lejeune, Map of Tarawa Terrace II Quarters, June 30, 1961). DiGiano et al. (1988) summarized the results of gasoline plume discovery and delineation at Building TT-2453 (Industrial Marine Services, Inc. 1985). The presence of gasoline in the subsurface at Building TT-2453 apparently originated from two sources: (1) a catastrophic tank failure on September 21, 1985, with a subsequent loss of 4,400 gal of unleaded gasoline to the subsurface; and (2) a 3,000-gal tank of leaded gasoline discovered leaking on July 23, 1986. A release history by DiGiano et al. (1988, Table 3) indicates that small leaks of product probably occurred at this site beginning during the 1950s. As of May 4, 1987, more than 2 ft of “free product” was identified above the water table in the vicinity of Building TT-2453. The contamination associated with Building TT-2453 was undergoing active remediation as of May 1987 (DiGiano et al. 1988).

About 1995, Buildings TT-2455, TT-2463, TT-2465, TT-2467, TT-2469, and TT-2471 of the shopping center were subjects of active investigations of groundwater contamination as were UST sites associated with Buildings TT-2477 and TT-2478 (Richard Catlin & Associates, Inc. 1994a,b, 1995a,b, 1996, 1998; Law Engineering, Inc. 1994a,b, 1995a,b; Law Engineering and Environmental Services, Inc. 1996; OHM Remediation Services, Corp. 2001). Numerous monitor wells were installed during these investigations and were the locations of periodic collections of water levels and water-quality samples (Appendix C1, Table C1.11; Faye and Green 2007, Tables E9 and E10). All wells were installed in the Tarawa Terrace aquifer or the Upper Castle Hayne aquifer–River Bend unit.

Water-level measurements, accurate to a hundredth of a foot, were collected at paired wells collected in conjunction with investigations at Buildings TT-2477 and TT-2478 and indicated that vertical-head gradients between depths of 15 and 50 ft were generally downward and ranged from zero to order of magnitude 10^{-4} ft/ft (Law Engineering, Inc. 1994a). Water-level data also indicated the direction of groundwater flow in the shopping center area to be almost directly south toward Northeast Creek. Water-table altitudes ranged from about 8 to 11 ft, NGVD 29 (Law Engineering, Inc. 1995a, drawing 5.1).

Water-quality samples collected at monitor wells and at several hydrocone sampling sites were analyzed for all BTEX constituents. The approximate extent of a benzene plume delineated during 1994 in front of the shopping center extended about 600 ft from north to south (Law Engineering, Inc. 1995a, drawing 5.3). This plume possibly represents the merger of older plumes originally emanating from near Buildings TT-2477 and TT-2453. Benzene concentrations at the northern apex of the plume were in excess of 6,000 μg/L. This northern apex is located about 700 ft almost directly south of Tarawa Terrace water-supply well TT-52, which was placed in service during 1961 and removed from service during March 1987. Tarawa Terrace water-supply well TT-31 is located about 1,300 ft northeast of the plume’s northern apex. Well TT-31 was placed in service during 1973 and also was removed from service during March 1987.

In addition to active remedial investigations at buildings of and in the vicinity of the Tarawa Terrace Shopping Center and at storage tanks, several other sites within the Tarawa Terrace housing areas were the subject of UST removal and related soil and groundwater investigations. The site designators at these locations also correspond to Tarawa Terrace building addresses and include: TT-44, TT-48, TT-779, TT-2254/2256, TT-2258/2260, TT-2302/2304, TT-2634, TT-3140/3142, TT-3165/3167, TT-3233/3235, TT-3524/3526, and TT-3546/3548 (Law Engineering and Environmental Services, Inc. 1998; Catlin Engineers and Scientists 2002a,b; Mid-Atlantic Associates, P.A. 2002a,b,c,d,e,f,g; Mid-Atlantic Associates, Inc. 2003a,b). Monitor wells were installed at most of these sites in conjunction with the collection of soil borings and boring logs. Water levels were measured at least once, and concentrations of BTEX constituents were determined at most monitor wells. Concentrations of benzene ranged from 290 μg/L at monitor well 14 near Building TT-2478 in the vicinity of the shopping center to “not detected.” A concentration of benzene at the vast majority of sites was “not detected” (Faye and Green 2007, Table E9).

During 1991, Haliburton NUS Environmental Corporation (1992) conducted soil borings and installed several monitor wells at the Tarawa Terrace Dump (TT-Dump) located immediately south of the shopping center and between it and Northeast Creek (Figure C1). Concentrations of constituents of interest to this study were determined in soil samples from several locations and were generally low or below detectable limits. Water-level data collected during this investigation indicated groundwater flow was entirely from the dump site toward Northeast Creek. Water-level altitudes at monitor wells ranged from about 2 to 6 ft.

Periodic water levels measured at Camp Lejeune supply wells, at monitor wells installed during ABC One-Hour Cleaners Operable Units 1 and 2, and at monitor wells installed during investigations of USTs and petroleum-product spills are listed in Appendix C1, Tables C1.1–C1.11. Construction data for these wells are listed in Appendix C2, Tables C2.1–C2.3 (U.S. Geological Survey well inventory, written communication, October 21, 1986; DiGiano et al. 1988; Haliburton NUS Environmental Corporation 1992; O'Brien & Gere Engineers, Inc. 1992, 1993; Law Engineering, Inc. 1994a,b, 1995a,b; Richard Catlin & Associates, Inc. 1994a,b, 1995a,b, 1996, 1998; Law Engineering and Environmental Services, Inc. 1996, 1998; OHM Remediation Services, Corp. 2001; Catlin Engineers and Scientists 2002a,b; Mid-Atlantic Associates, P.A. 2002a,b,c,d,e,f,g; Mid-Atlantic Associates, Inc. 2003a,b). Results of aquifer tests at Camp Lejeune water-supply wells and at monitor wells installed during various investigations of groundwater contamination at and in the vicinity of Tarawa Terrace are listed in Tables C2–C4. Faye and Green (In press 2007) provide a detailed history of groundwater contamination at Tarawa Terrace supply wells and compute an approximate mass of PCE remaining in the Upper Castle Hayne aquifer during 1991.

Conceptual Model of Groundwater Flow

A conceptual model of groundwater-flow directions and budget quantities is a necessary element of model development and calibration. The source of water to the Tarawa Terrace and underlying aquifers in the study area is recharge from precipitation. Recharge to the Castle Hayne aquifer system occurs originally as infiltration of precipitation to the water table. Average annual effective recharge, defined herein as recharge to the water table remaining after discharge to evapotranspiration, is described in previous investigations as ranging from about 11 to about 19 in/yr in the study area (LeGrand 1959; Heath 1994; Giese et al. 1997; Baker Environmental, Inc. 1998). These rates conform to maps of average annual rainfall and annual potential evaporation by Heath (1994, Figures 9 and 12), which indicate rates of about 56 to 60 in/yr and 42 in/yr, respectively, for Onslow County. Within the study area, surface soils are generally sands or silty sands and the land surface is mainly undissected by streams, indicating little or minimal runoff. Thus long-term, average annual effective recharge rates in the study area could be as much as 18 in/yr, the maximum difference between rates of average annual rainfall and annual potential evaporation (Heath 1994, Figures 9 and 12).

The spatial configuration of the water table prior to development of local aquifers by wells probably resembled to a large degree a subdued replica of surface topography (Plate 1). Consequently, precipitation recharged to the water table flowed laterally from highland to lowland areas and eventually discharged to surface-water bodies. Northeast Creek and New River are partially or completely incised within the Tarawa Terrace aquifer and the Upper Castle Hayne aquifer–River Bend unit and receive water directly from these aquifers. Frenchmans Creek, near the western limit of the study area, is apparently a perennial stream through most of its reach and also probably derives baseflow directly from the Tarawa Terrace aquifer and the Upper Castle Hayne aquifer–River Bend unit.

Lateral flow directions within the Middle and Lower Castle Hayne aquifers probably mimic, to a large degree, corresponding directions within the Upper Castle Hayne aquifer–River Bend unit, except in the immediate vicinity of discharge areas such as Northeast Creek and New River, where flow directions within the deeper confined aquifers are vertically upward. Diffuse vertical leakage across confining units and between aquifers is probably pronounced in the vicinity of pumping wells where vertical-head gradients are relatively large but is limited elsewhere by small vertical-head gradients and the thickness and vertical hydraulic conductivity of confining units. Groundwater probably flows vertically downward through the Upper and Middle Castle Hayne aquifers in the northern part of the study area near and somewhat south of Lejeune Boulevard (SR 24) and is probably vertically upward within these same aquifers in the vicinity of New River and Northeast Creek. Paired observations that measure water levels in individual aquifers of the Upper Castle Hayne aquifer system are not available for the study area; however, long-term measurements are available for the Upper and Lower Castle Hayne aquifers at site X24S located just north of Wallace Creek. These data are possibly influenced by local pumping but indicate less than a 3-ft head difference occurred between the Upper and Lower Castle Hayne aquifers during 1987–2004. The head gradient was vertically upward (North Carolina Division of Water Resources, written communication, August 30, 2005). Similar flow conditions probably occurred within the study area during the period of interest to this investigation in the vicinities of Northeast Creek and New River.

Following the onset of pumping at water-supply wells, groundwater flow that under predevelopment conditions was entirely directed toward Northeast Creek, New River, and Frenchmans Creek was partially diverted to pumping wells. Consequently, (1) predevelopment potentiometric levels near and in the vicinity of pumping wells declined in the aquifers open to the wells, (2) predevelopment flow directions changed preferentially toward wells from natural points of discharge such as Northeast Creek, and (3) potentiometric levels possibly declined near groundwater/topographic divides resulting in the migration of boundaries farther west or north of predevelopment locations. Water-level declines near or in the vicinity of Northeast Creek or New River possibly caused a complete reversal in the direction of groundwater flow such that saltwater or brackish water from these surface-water bodies intruded landward into the Tarawa Terrace or Upper Castle Hayne aquifers.

Horizontal Hydraulic Conductivity

Results of 36 aquifer-test analyses at Tarawa Terrace and adjacent areas of Montford Point and Paradise Point are summarized in Tables C2–C4. Test data are summarized, respectively, for the combined Tarawa Terrace aquifer and Upper Castle Hayne aquifer–River Bend unit, Upper Castle Hayne aquifer–Lower unit, and Middle Castle Hayne aquifer. Most well locations are shown on Plate 1. Site names prefaced with "C," "PZ," and "S" indicate wells constructed during ABC One-Hour Cleaners Operable Units 1 and 2, which are located in the immediate vicinity of ABC One-Hour Cleaners and in the northern part of Tarawa Terrace. Well names prefaced with "TTSC" are located at or in the vicinity of the shopping center, in the southernmost part of Tarawa Terrace, just north of the shoreline of Northeast Creek. A site name prefaced with "TTUST" indicates monitor wells constructed during investigations of possible groundwater contamination caused by the leakage of refined-petroleum products from USTs and are located somewhat randomly throughout the Tarawa Terrace housing areas. Site names prefaced with "LCH," "M," and "HP" refer to wells located in the vicinity of Montford Point and between Northeast Creek and Wallace Creek, respectively, and were used to provide lateral control to interpolated flow model arrays of horizontal hydraulic conductivity at Tarawa Terrace and vicinity. Well S190A is an irrigation well at a golf course at Paradise Point. Coordinate locations of Hadnot Point (HP- and LCH-) 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.

Calculated horizontal hydraulic conductivity at all sites ranged from about 5 to 50 ft/d and averaged about 19 ft/d. Standard deviation was about 10 ft/d. With the exception of two tests, at least one open interval at tested wells was open to the Upper Castle Hayne aquifer. Horizontal hydraulic conductivity at these sites ranged from about 5 to 40 ft/d. Several tests included wells open to the Upper and Middle Castle Hayne aquifers. Horizontal hydraulic conductivity at these sites ranged from 5 to 30 ft/d. Horizontal-hydraulic-conductivity data unique to the Tarawa Terrace aquifer are located, with one exception, only in the immediate vicinity of Tarawa Terrace and ranged from 20 to 50 ft/d. Horizontal hydraulic conductivity at a test well open to the Tarawa Terrace aquifer and confining unit at the STT site was 2 ft/d. These data were not included in Table C2.

The horizontal hydraulic conductivity of the Lower Castle Hayne aquifer was not uniquely determined at any site. 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 (Faye 2007). 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 (Tables C2–C4).

Table C2. Horizontal hydraulic-conductivity data used to create a cell-by-cell distributed array for the combined Tarawa Terrace aquifer and Upper Castle Hayne aquifer–River Bend unit (model layer 1), Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[Contributing aquifers: UCH, Upper Castle Hayne aquifer-undifferentiated; TT, Tarawa Terrace aquifer; UCHRBU, Upper Castle Hayne aquifer–River Bend unit; karst, a zone of relatively high hydraulic conductivity indicated on drillers' logs by the loss of drilling fluids at a certain depth or a sudden drop of the drill stem during drilling]

Site name[1]	Location coordinates[2]		Horizontal hydraulic conductivity, in feet per day	Contributing aquifers
	East	North		
HP-710	2507781	351490	20	UCH
HP-711	2509200	352130	10	TT, UCH
LCH-4009	2499585	358589	20	UCHRBU
M-142	2478313	360422	30	UCHRBU, karst
M-628	2479434	362735	10	UCH
PZ-06	2490707	364926	20	UCHRBU
S190A	2487640	353870	30	UCHRBU
S2	2490787	364883	20	UCHRBU
S6	2490617	364938	10	TT, UCHRBU
STT61to66-MW03	2489186	364740	50	TT
[3]TTUST-2477-MW01	2488759	361550	20	TT
[3]TTUST-2477-MW06	2488738	361521	20	TT, UCHRBU
[3]TTUST-2478-PW01	2488879	361898	10	TT(?), UCHRBU

[1]See Plate 1 for location

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

[3]Because of scale, not shown on Plate 1

Table C3. Horizontal hydraulic-conductivity data used to create a cell-by-cell distributed array for the Upper Castle Hayne aquifer–Lower unit (model layer 3), Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[Contributing aquifers: UCHLU, Upper Castle Hayne aquifer–Lower unit; UCHRBU&LU, Upper Castle Hayne aquifer–River Bend and Lower units; UCH, Upper Castle Hayne aquifer–undifferentiated; karst, a zone of relatively high hydraulic conductivity indicated on drillers' logs by the loss of drilling fluids at a certain depth or a sudden drop of the drill stem during drilling]

Site name[1]	Location coordinates[2]		Horizontal hydraulic conductivity, in feet per day	Contributing aquifers
	East	North		
C2	2490793	364902	30	UCHLU
HP-650	2510615	354320	40	UCHRBU&LU
HP-663	2510881	352712	10	UCHRBU&LU
HP-700	2488520	355270	8	UCH
HP-705	2501260	356200	30	UCH
HP-707	2492300	353850	20	UCH
M-243	2476839	359734	10	UCHLU
M-267	2476609	359232	10	UCHRBU&LU
M-630	2475763	361256	20	UCHLU
PZ-03	2490812	364858	20	UCHLU
TT-26	2491461	364356	20	UCHLU, karst(?)
TT-52	2489060	362321	10	UCH
TT-55	2489070	364767	10	UCHLU (?)
TT-67	2490160	362730	20	UCHLU

[1]See Plate 1 for location

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

Table C4. Horizontal hydraulic-conductivity data used to create a cell-by-cell distributed array for the Middle Castle Hayne aquifer (model layer 5), Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[Contributing aquifers: UCHRBU, Upper Castle Hayne aquifer–River Bend unit; MCH, Middle Castle Hayne aquifer; TT, Tarawa Terrace aquifer; UCH, Upper Castle Hayne aquifer–undifferentiated; UCHRBU&LU, Upper Castle Hayne aquifer–River Bend and –Lower units]

Site name[1]	Location coordinates[2]		Horizontal hydraulic conductivity, in feet per day	Contributing aquifers
	East	North		
HP-622	2494248	353323	20	UCHRBU, MCH
HP-623	2495617	350860	20	TT, UCH, MCH
HP-644	2485841	356243	10	UCHRBU, MCH
HP-645	2497333	356430	20	UCHRBU, MCH
HP-646	2497870	357826	10	UCHRBU, MCH
HP-647	2499461	356343	30	UCHRBU, MCH
M-197	2477521	361501	5	UCH, MCH
TT-23	2491024	363208	10	UCHRBU&LU, MCH
TT-25	2491984	364042	9	UCHRBU&LU, MCH

[1]See Plate 1 for location

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

Potentiometric Surfaces

The oldest and/or highest water-level measurements out of a total data set of several hundred measurements were selected at 59 locations in the study area to estimate the predevelopment potentiometric surface of the Tarawa Terrace aquifer and the Castle Hayne aquifer system (Table C5). Potentiometric levels are predominantly from wells open only to the Tarawa Terrace and Upper Castle Hayne aquifers. Detailed water-level measurements obtained at paired monitor wells in conjunction with investigations of groundwater contamination at various locations throughout Tarawa Terrace and vicinity indicate that little or no head difference exists between the River Bend and Lower units of the Upper Castle Hayne aquifer (Roy F. Weston, Inc. 1992, 1994; O'Brien & Gere Engineers, Inc. 1992, 1993; Law Engineering, Inc. 1994a,b, 1995a,b; Richard Catlin & Associates, Inc. 1994a,b, 1995a,b, 1996; Law Engineering and Environmental Testing, Inc. 1996). In addition, water-level data collected at a well cluster representing the Tarawa Terrace and Upper and Lower Castle Hayne aquifers at site X24S1-S7, north of Wallace Creek (Plate 1), indicate only about 3 ft of head difference occurred between the Upper and Lower Castle Hayne aquifers between 1987 and 2004 (Harned and others, 1989; North Carolina Division of Water Resources, written communication, August 30, 2005). Head gradients were generally vertically upward at this site. Although the water level measured in the Lower Castle Hayne aquifer was possibly influenced by pumping, a head difference slightly greater than 3 ft probably also is representative of head differences within the Castle Hayne aquifer system in the vicinity of Northeast Creek and New River at Tarawa Terrace. The small differences in head measured between the Tarawa Terrace and Upper Castle Hayne aquifers in the study area, as well as at site X24S, indicate that potentiometric surfaces of the individual Upper, Middle, and Lower Castle Hayne aquifers are highly similar.

Contours of equal potentiometric level based on all measurements listed in Table C5 and selected measurements from Appendix C1, Table C1.10 are shown in Figure C5. The spatial distribution of potentiometric levels conforms to the conceptual model discussed previously. Assuming that lines orthogonal to the potentiometric level contours approximate directions of groundwater flow, groundwater flows west to east from highland areas toward Northeast Creek and south toward Northeast Creek and New River. As noted previously, the potentiometric surface shown in Figure C5 probably closely resembles corresponding potentiometric surfaces within the Middle and Lower Castle Hayne aquifers.

Table C5. Estimated predevelopment water levels at 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; UCH, Upper Castle Hayne aquifer–undifferentiated]

Site name[1]	Measuring date	Water-level altitude, in feet above NGVD 29	Contributing aquifers
C1	4/22/1992	21.5	UCHLU
C2	4/22/1992	19.6	UCHLU
C3	4/22/1992	15.8	UCHLU
C4	4/22/1992	11.9	MCH
C5	4/22/1992	15.7	UCHLU
C9	11/18/1993	13.0	UCHLU
C10	11/18/1993	12.6	MCH
C11	10/1/1993	6.3	UCHLU
CCC-1	9/17/1941	3.3	UCHRBU
CCC-2	6/19/1942	5.2	UCHRBU
PZ-01	11/18/1993	16.7	UCHLU
PZ-02	11/18/1993	16.7	UCHRBU
PZ-03	11/18/1993	16.6	UCHLU
PZ-04	11/18/1993	16.4	UCHRBU
PZ-05	10/1/1993	15.7	UCHLU
PZ-06	10/1/1993	16.1	UCHRBU
S1	4/22/1992	23.7	TT, UCHRBU(?)
S2	4/22/1992	19.9	UCHRBU
S3	4/22/1992	16.0	TT, UCHRBU
S4	4/22/1992	13.6	TT, UCHRBU(?)

Table C5. Estimated predevelopment water levels at 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; UCH, Upper Castle Hayne aquifer–undifferentiated]

Site name[1]	Measuring date	Water-level altitude, in feet above NGVD 29	Contributing aquifers
S5	4/22/1992	16.4	TT, UCHRBU(?)
S6	4/22/1992	20.6	TT, UCHRBU
S7	4/22/1992	19.8	TT, UCHRBU
S8	4/22/1992	20.9	TT, UCHRBU
S9	4/22/1992	15.4	TT, UCHRBU
S10	6/25/1992	13.3	TT, UCHRBU
S11	11/18/1993	19.0	TT, UCHRBU
STT61to66-MW01	1/29/1992	21.6	TT
STT61to66-MW20	12/17/1992	20.1	TT, UCHRBU
T-9	4/10/1987	23.4	TT, UCHRBU
TT-25	4/7/1987	10.9	UCHRBU&LU, MCH
TT-26	5/16/1951	14.0	UCHLU
TT-52	10/17/1961	12.9	UCH
TT-53	7/22/1961	14	UCHRBU&LU
TT-54	6/30/1961	12.1	UCH
TT-55	11/1/1961	18.9	UCHLU(?)
TTDump MW01	6/26/1991	2.4	TT
TTDump MW02	6/26/1991	6.2	TT
TTDump MW03	6/26/1991	2.2	TT
[2]TTUST-44-MW01	11/15/2001	6.0	TT, UCHRBU
[2]TTUST-48-MW01	9/1/1998	19	TT, UCHRBU
[2]TTUST-779-MW01	7/25/2002	9	TT
[2]TTUST-2254-MW01	7/24/2002	13	TT
[2]TTUST-2258-MW01	7/24/2002	12	TT
[2]TTUST-2302-MW01	7/24/2002	12	TT
[2]TTUST-2455-MW13	10/28/1993	9.2	TT, UCHRBU
[2]TTUST-2455-MW15	10/28/1993	5.6	TT, UCHRBU
[2]TTUST-2477-MW11	11/4/1994	11.6	UCHRBU
[2]TTUST-2477-MW14	11/9/1994	7.9	TT
[2]TTUST-2478-MW08	11/22/1993	12.6	TT
[2]TTUST-2478-MW23	9/28/2000	6.2	TT, UCHRBU
[2]TTUST-2634-MW01	11/1/2001	14	TT, UCHRBU(?)
[2]TTUST-3140-MW01	7/24/2002	15	TT, UCHRBU(?)
[2]TTUST-3165-MW01	7/24/2002	16	TT, UCHRBU(?)
[2]TTUST-3233-MW01	7/24/2002	12	TT, UCHRBU(?)
[2]TTUST-3524-MW01	7/25/2002	6	TT
[2]TTUST-3546-MW01	7/25/2002	5	TT
[2]TTUST-TTSC-09	12/28/1994	8.8	TT
[2]TTUST-TTSC-15	12/28/1994	11.2	UCHRBU

[1]See Plate 1 for location

[2]Because of scale, not shown on Plate 1

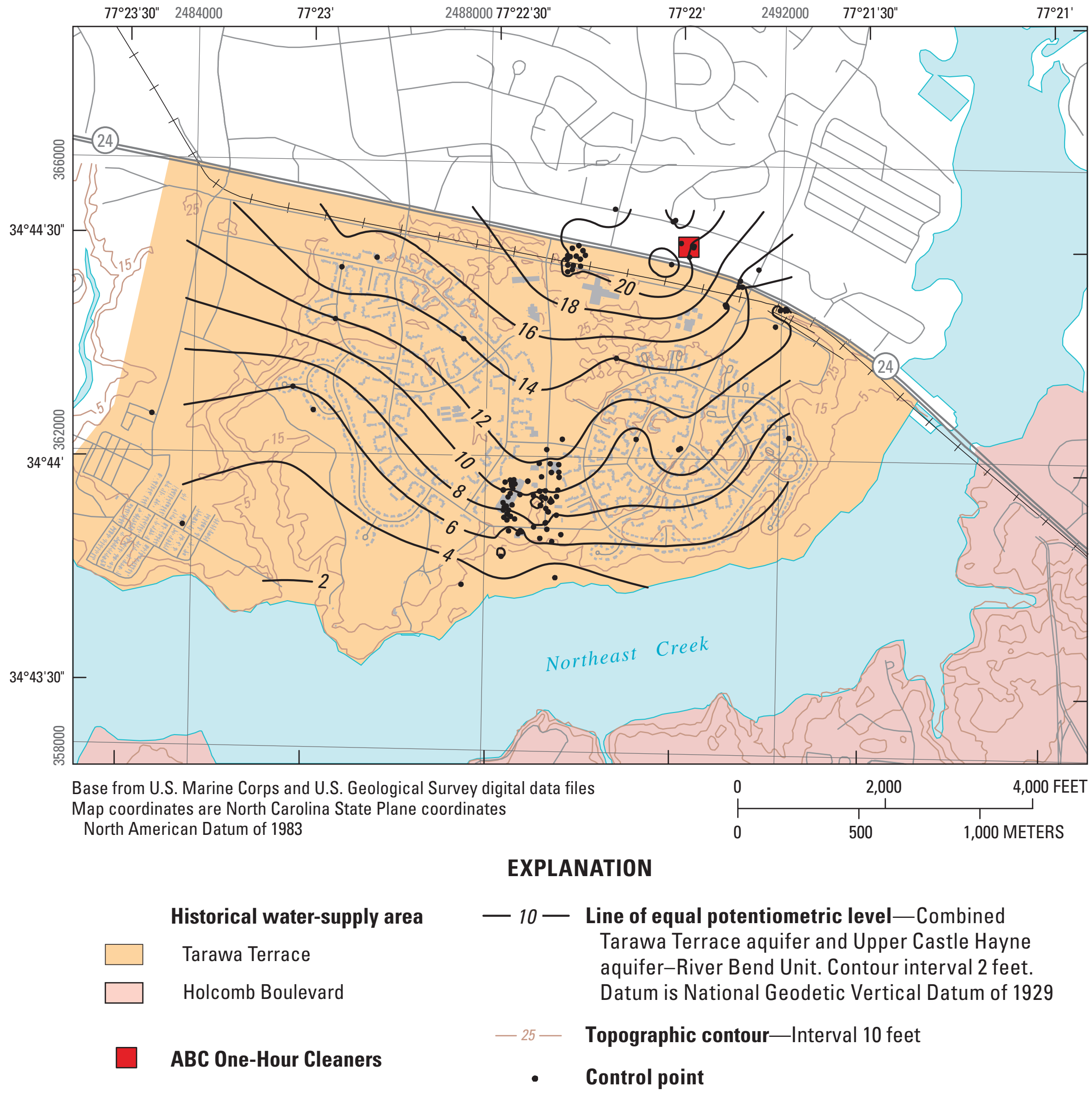


Figure C5. Estimated predevelopment potentiometric levels of the combined Tarawa Terrace aquifer and Upper Castle Hayne aquifer–River Bend unit, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Tarawa Terrace Groundwater-Flow Model

The original version of the numerical code used in this study to simulate groundwater flow was written by McDonald and Harbaugh (1984) and was designated a modular finite-difference groundwater-flow model (MODFLOW). The code simulates groundwater flow in a three-dimensional heterogeneous and anisotropic porous medium. Updates to the original MODFLOW code were developed periodically along with various modules to expand simulation capability and computational performance. The MODFLOW version used in this study is known as MODFLOW-96 (Harbaugh and McDonald, 1996) and is part of a highly integrated simulation system called PMWINPro™ (Processing MODFLOW Pro, version 7.017), which also includes codes that support and augment groundwater-flow simulation using techniques such as particle tracking and inverse modeling (Chiang and Kinzelbach 2001). The capability to simulate advective transport also is integrated within PMWINPro™ and is based on techniques and codes first published by Pollock (1989, 1994). Two flow models were calibrated: a predevelopment model representing long-term, average groundwater-flow conditions prior to the development of the Castle Hayne aquifer system, and a transient model representing pumping of the Castle Hayne aquifer system as a water supply for Tarawa Terrace. The transient model is temporally subdivided into 528 stress periods, representing monthly conditions beginning January 1951 and ending December 1994. The active model domain, the model grid, model boundary conditions, model geometry, hydraulic characteristic arrays, and all other model elements common to the calibrated predevelopment and transient models are identical.

Model Domain and Boundary Conditions

The total domain of the Tarawa Terrace flow model comprises most of the area north and west of the mid-channel line of Northeast Creek shown in Figure C6. Approximate State Plane coordinates (North American Datum of 1983) of the four corners of the model domain are listed in Table C6. The total area shown in Figure C6 is the model domain, which, for modeling purposes, is subdivided into active and inactive domains. The active domain, which corresponds to the area pertinent to the simulation of groundwater flow, is the blue gridded area and also includes the dark blue area that extends to the mid-channel of Northeast Creek. The remaining area within the total model domain, but outside the gridded area, is the inactive domain. The total model domain was subdivided into 270 columns and 200 rows of square cells representing a length of 50 ft per side. The model was subdivided vertically into seven layers. Model layer 1 corresponds to the combined Tarawa Terrace aquifer, the Tarawa Terrace confining unit, and the Upper Castle Hayne aquifer–River Bend unit (Table C1). The remaining six layers correspond, respectively, to the Local confining unit, the Upper Castle Hayne aquifer–Lower unit, the Middle Castle Hayne confining unit, the Middle Castle Hayne aquifer, the Lower Castle Hayne confining unit, and the Lower Castle Hayne aquifer. The area represented by the total model domain is about 135,000,000 square feet (ft^2) or about 4.8 square miles (mi^2). The active model domain corresponds to an area of about 59,400,000 ft^2, about 2.1 mi^2 or about 1,360 acres. Model layer 1 is specified as an unconfined aquifer and contains the water table. All other model layers are specified as confined.

The base of simulated groundwater flow corresponds to the top of the Beaufort confining unit and is implicitly a no-flow boundary. Boundaries assigned to the eastern, western, and southern perimeters of the active model domain were all no-flow and are equal in location and condition for each layer. The southern and most of the eastern boundary conform to the mid-channel line of Northeast Creek. The western boundary conforms to the topographic divide that separates the drainage areas of Scales and Frenchmans Creeks (Figure C6). The northern boundary also generally conforms to a topographic divide but was assigned as a general-head (head-dependent) boundary in all model layers because of the proximity of water-supply wells to the boundary in the northwestern and north-central parts of the active model domain. Conductance values applied to general-head boundary cells were computed using the equation:

$$C = (K_h bW)/L, \qquad (1)$$

where

- K_h equals the cell horizontal hydraulic conductivity, in ft/d;
- b equals the cell thickness, in ft;
- W equals the width of the cell face perpendicular to the direction of flow, in ft; and
- L equals the distance between the source-head boundary and the model general-head boundary, in ft.

To compute cell conductances, values of K_h for each layer at each boundary cell were determined from the calibrated predevelopment flow model. Cell widths (W) were assigned a constant value of 50 ft. The layer thickness at each cell was determined by subtracting the assigned value of the altitude at the top of each layer at each boundary cell from the assigned altitude at the bottom of each corresponding boundary cell. The distance L from each boundary cell to the source-head boundary was arbitrarily assigned as the length of 10 grid cells or 500 ft and was constant for the entire boundary for each layer. The assigned potentiometric level at each source-head boundary cell was estimated using as guidelines potentiometric levels simulated at respective cells by the calibrated predevelopment flow model. Source heads closely resemble or equal the respective simulated predevelopment water levels with the possible exception of source heads at several cells in the central part of the active model domain in model layer 1. Potentiometric levels at these cells were assigned 1–3 ft higher than calibrated predevelopment water levels, conforming to slightly higher land-surface altitudes at the source-head boundary compared to those at the northern boundary of the active model domain (Figure C6).

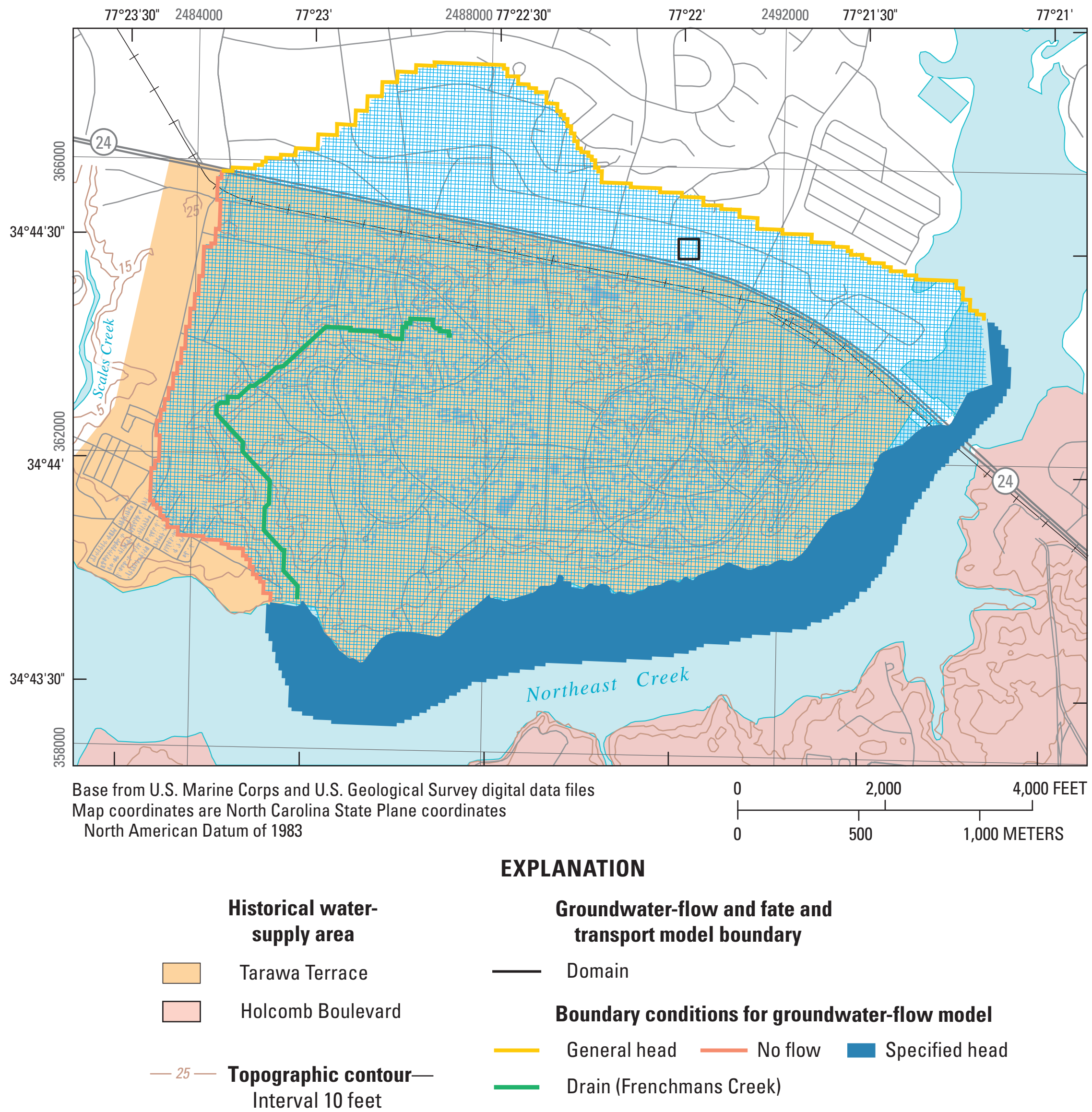


Figure C6. Groundwater-flow model grid and model boundaries, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Table C6. Approximate location coordinates of the corners of the Tarawa Terrace groundwater-flow model domain, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Position	Location coordinates[1]	
	North	East
Northeastern corner	367370	2495790
Northwestern corner	367370	2482290
Southeastern corner	357370	2495790
Southwestern corner	357370	2482290

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

The surface of Northeast Creek within the active domain was assigned a specified head of zero in model layer 1, corresponding to sea level. A drain also was assigned to model layer 1 along the channel of Frenchmans Creek in the western part of the model area. An initial hydraulic conductance of 50 ft^2/d was assigned to every drain cell. The final calibrated conductance of 200 ft^2/d was determined by trial-and-error calibration. Drain altitudes were interpolated to the center of drain cells using detailed topographic maps and ranged from zero to about 16 ft.

Effective recharge was assigned to the uppermost active cells regardless of layer at a rate that varied by stress period and annual rainfall. Precipitation data used for this study are daily values recorded at the Maysville–Hoffman Forest station located about 8.5 miles northeast of Jacksonville, North Carolina, along U.S. Highway 17, and about midway between Jacksonville and Maysville, North Carolina. The Maysville–Hoffman Forest record is the most complete of 10 precipitation station records local to the general vicinity of Camp Lejeune and pertinent to the period of interest of this study (1951–1994). Daily precipitation values are substantially complete beginning January 1951 and were used to compute total monthly precipitation for the period January 1951–December 1994. Incomplete data prevented the reasonable computation of a monthly total for 23 months during 12 years of this period (Table C7). Average monthly precipitation computed using these records was 4.72 inches or 56.64 in/yr. Long-term average annual effective recharge was estimated at 13.31 in/yr during calibration of the predevelopment-flow model. The ratio of the rates of long-term, average effective groundwater recharge computed using the calibrated predevelopment-flow model (13.31 in/yr) and average annual precipitation for the period 1951–1994 (56.64 in/yr) equals 0.235. The product of this ratio and total annual rainfall measured at the Maysville–Hoffman Forest station was considered the average rate of effective groundwater recharge for the respective year and was assigned, as such, to the groundwater-flow model at a constant rate in feet per day for each stress period (month of the year). The long-term average rate of effective groundwater recharge (13.31 in/yr) was assigned to each month of 1951, in order to establish a predevelopment distribution of potentiometric levels and flow prior to the onset of simulated pumping during January 1952.

Table C7. Summary of annual rainfall and effective recharge rates assigned during flow model calibration, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Year	Rainfall,[1] inches per year	Effective groundwater recharge, inches per year	Effective groundwater recharge, in feet per day
1952	56.37	13.2	0.0030
1953	63.81	15.0	0.0034
1954	58.30	13.7	0.0031
1955	[2]57.59	13.5	0.0031
1956	[2]48.44	11.4	0.0026
1957	[2]44.63	10.5	0.0024
1958	[2]58.18	13.7	0.0031
1959	42.47	10.0	0.0023
1960	69.94	16.4	0.0038
1961	61.32	14.4	0.0033
1962	53.37	12.5	0.0029
1963	58.65	13.8	0.0031
1964	[2]50.38	11.8	0.0027
1965	[2]50.93	12.0	0.0027
1966	50.65	11.9	0.0027
1967	[2]41.06	9.6	0.0022
1968	[2]28.72	6.7	0.0015
1969	53.66	12.6	0.0029
1970	37.99	8.9	0.0020
1971	54.61	12.8	0.0029
1972	51.02	12.0	0.0027
1973	[2]34.28	8.1	0.0018
1974	81.86	19.2	0.0044
1975	49.46	11.6	0.0027
1976	57.33	13.5	0.0031
1977	61.81	14.5	0.0033
1978	57.79	13.6	0.0031
1979	53.95	12.7	0.0029
1980	54.49	12.8	0.0029
1981	64.48	15.2	0.0035
1982	50.24	11.8	0.0027
1983	[2]52.71	12.4	0.0028
1984	51.75	12.2	0.0028
1985	61.25	14.4	0.0033
1986	51.18	12.0	0.0027
1987	[2]38.92	9.1	0.0021
1988	52.92	12.4	0.0028
1989	55.84	13.1	0.0030
1990	71.88	16.9	0.0039
1991	[2]55.90	13.1	0.0030
1992	55.28	13.0	0.0030
1993	60.54	14.2	0.0032
1994	67.64	15.9	0.0036

[1]Rainfall data from the Maysville–Hoffman Forest station

[2]Incomplete record

Model Geometry and Initial Conditions

Model-layer geometry was assigned as distributed arrays of altitude at the top of each layer (geohydrologic unit; Table C1). Representations of distributed arrays are similar to contour maps shown herein in Figures C2 and C3 and were based on appropriate site (point) data interpolated to the entire active model domain using the Shepard's Inverse Distance method. The PMWINPro™ flow model automatically checks each cell to verify that assigned altitudes do not overlap vertically adjacent layers. Site data for each geohydrologic unit component of the Tarawa Terrace flow models are listed in Faye (2007, Tables B3–B14).

Hydraulic characteristic data assigned to each model layer are horizontal and vertical hydraulic conductivity and specific storage. Horizontal hydraulic conductivities at selected locations within and adjacent to the model domain were selected from Tables C2 – C4 as representative of model layers 1, 3, and 5, respectively. These point data were interpolated by the Shepard's Inverse Distance method to the entire model domain to provide an initial distributed array of horizontal hydraulic conductivity for the specified model layers. The interpolated array originally assigned to model layer 1 was uniformly increased by a factor of 1.35 during model calibration. Horizontal hydraulic conductivity of model layer 7 (Lower Castle Hayne aquifer) was assigned uniformly at 5 ft/d. Initially, horizontal hydraulic conductivity of each confining unit was assigned uniformly at 1.0 ft/d.

Initial cell-by-cell vertical hydraulic conductivities assigned to each layer equaled one-tenth the respective cell horizontal hydraulic conductivity. During model calibration, the ratio of vertical to horizontal hydraulic conductivity for model layers 1 and 3 was increased from 1:10 to 1:7.3 and 1:8.3, respectively. At model cells that correspond to the location of water-supply wells, the vertical hydraulic conductivity of confining units penetrated by the well was increased to 100 ft/d to duplicate the effect of gravel and sand packs used to complete well construction. At several supply wells (TT-23, TT-26, and TT-67), the well bore was drilled to a depth substantially greater than the completed well. The unused well bore was then typically backfilled with gravel or sand. At these sites, the assigned vertical hydraulic conductivity of confining layers penetrated by the unused well bore was also 100 ft/d.

Specific storage for model layers 2 through 7 was assigned based on an assumed storativity of 0.0004 for each layer divided by respective cell-by-cell thickness. The distributed thickness array for each layer was computed as the difference between cell-by-cell altitudes at the top of vertically adjacent layers. A specific yield of 0.05 was assigned uniformly to model layer 1. The same array of initial potentiometric levels was assigned to each model layer and corresponds to the potentiometric surface shown in Figure C5.

Pumpage Data

Data indicating pumpage at individual Tarawa Terrace water-supply wells were unavailable for the period of interest to this study. Accordingly, pumping rates at supply wells were estimated and were assigned to monthly stress periods based on: (1) reported well-capacity data, (2) average annual and monthly rates of water-supply demand reported for the Tarawa Terrace WTP, and (3) records of supply well operations. Annualized daily rates of raw water treated by the Tarawa Terrace WTP for the years 1975–1987 are listed in Table C8 and were obtained from the USGS (U.S. Geological Survey, Raleigh, North Carolina, "Water Use for Camp Lejeune Military Base Water Systems," written communications, March 2004). Monthly operation records of Tarawa Terrace water-supply wells during 1978–1985 included notes regarding equipment replacement and periods when individual wells were out of service (Camp Lejeune water documents CLW 3559–4053; monthly well operation reports, written communications, September 22, 2004).

Well-capacity records are available for most Tarawa Terrace water-supply wells, many from the onset of well operation. These records are summarized in Appendix C3, Tables C3.1– C3.10, and were used to estimate well capacity for monthly pumping rates assigned to stress periods of the groundwater-flow model. The actual date (month and year) when a supply well began service is unknown. With the exception of well TT-23, all supply wells were placed in service, for purposes of model simulation, during January

Table C8. Annualized daily average flow rate of raw water treated at the Tarawa Terrace water treatment plant, 1975–1987, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Year	Raw water treated,[1] in million gallons per day
1975	0.83
1976	0.85
1977	0.86
1978	0.90
1979	0.83
1980	0.78
1981	0.88
1982	0.98
1983	0.94
1984	0.85
1985	0.83
1986	0.90
1987	0.12

[1]U.S. Geological Survey, Raleigh, North Carolina, "Water Use for Camp Lejeune Military Base Water Systems," written communications, March 2004

following the year of construction. Simulation of pumpage from well TT-23 began during August 1984. Construction of well TT-23 was completed during March 1983.

Annualized daily average flow rates of total water treated at the Tarawa Terrace WTP for the period 1975–1987 are listed in Table C8. The average rate for the period 1975–1986 was 0.87 MGD or about 116,200 cubic feet per day (ft^3/d) and ranged from 0.78 to 0.98 MGD. The Tarawa Terrace WTP was closed during March 1987; hence, the partial rate of 0.12 MGD was reported for 1987. These annual average rates are considered for this study to equal average annual total pumpage from all active Tarawa Terrace water-supply wells for the respective years. Pumpage data and surrogate pumpage information pertinent to Tarawa Terrace prior to 1975 are not available. Accordingly, the average rate of 116,200 ft^3/d determined for the period 1975–1986 also was considered the average rate of total pumpage cumulative to all active Tarawa Terrace water-supply wells for the period January 1952–December 1974.

Total monthly pumpage cumulative to all active Tarawa Terrace water-supply wells was reported by Camp Lejeune for all of 1984 and February, March, April, and July 1985 (Camp Lejeune water documents CLW 1056, 1118, 1125, 1197, and 1290, written communications, no date). Additional total monthly pumpage and treated water rates during 1978 at Tarawa Terrace are included in Henry Von Oesen and Associates, Inc. (1979), who reported that the average daily rate of water delivered to the Tarawa Terrace WTP during 1978 was 0.90 MGD, the identical rate reported by the USGS (Table C8). Monthly cumulative pumpage rates at Tarawa Terrace for the period January 1980–December 1984 were provided by Camp Lejeune (Steven Whited, U.S. Marine Corps Base Camp Lejeune, written communication, March 18, 2005). These data are incomplete for several months during 1981 and most of 1982. The USGS provided cumulative pumpage rates for active Tarawa Terrace water-supply wells for January–March 1987 (U.S. Geological Survey, "Water Treatment Plants-Water Flow," written communication, January–March 1987). These documents probably were originally obtained from U.S. Marine Corps Base Camp Lejeune.

Pumping rates assigned to individual Tarawa Terrace water-supply wells were applied to the transient model for 528 stress periods. Each stress period represents a single month beginning January 1951 and ending December 1994. Stress periods were not subdivided into time steps. Accordingly, each stress period equaled 28, 29, 30, or 31 days. Assigned pumpage for stress periods 1–12 (January–December 1951) was zero. Pumping at Tarawa Terrace water-supply wells is assumed to have commenced during January 1952 at all wells located within the active model domain at that time; that is, wells TT-26 (#1), TT-27 (#2), TT-28 (#3), and TT-29 (#4) (Figure C1). Three additional water-supply wells—#6, #7, and TT-45—also delivered water to the Tarawa Terrace WTP at this time but were located outside the active model domain (Tarawa Terrace well capacity list, written communication, June 24, 1958; LeGrand 1959; North Carolina State Plane coordinates: #6 [highly approximate] North 369730, East 2481720; #7 [highly approximate] North 370500, East 2481530; and TT-45 North 365688, East 2483352).

The month and year when a particular water-supply well was placed in service, for simulation purposes, are indicated in Appendix C3, Tables C3.1–C3.10, along with the corresponding date that service was terminated. Other operational conditions such as dates when the well was out of service or tested also are listed. The dates and operational conditions listed in these tables are honored explicitly in the groundwater-flow model by changing pumping rates, adding or deleting pumping for a particular stress period (month), or removing a well entirely or adding a well to the model at a given month and year. Well capacities listed in Appendix C3, Tables C3.1–C3.10, were used to assign pumping rates to individual water-supply wells for each stress period and were changed periodically over time as indicated. Well capacities, as listed, were originally intended as guidelines but also were honored explicitly for most stress periods.

Pumping rates at individual water-supply wells for each stress period were estimated based on a percentage of total well capacity available at Tarawa Terrace at the given time. An example allocation is shown in Table C9 for stress period 408, December 1984. Active water-supply wells at that time were TT-23, TT-25, TT-26, TT-30, TT-31, TT-52, TT-54, and TT-67. Total raw water delivered to the Tarawa Terrace WTP during December 1984 was 25,092,000 gal or about 108,211 ft^3/d. Total well capacity was estimated to be 1,083 gal/min. Pumping rates assigned to individual Tarawa Terrace wells during each stress period, using the method of allocation shown in Table C9, are listed in Maslia et al (In press 2008).

Table C9. Example allocation of pumping rates to Tarawa Terrace water-supply wells, stress period 408 (December 1984), U.S. Marine Corps Base Camp Lejeune, North Carolina.

[gpm, gallon per minute; ft^3/d, cubic foot per day]

Site name[1]	Well capacity, in gpm	Percentage of total capacity, decimal	Estimated pumping rate, in ft^3/d
TT-23	254	0.2345	25,379
TT-25	130	0.1200	12,989
TT-26	150	0.1385	14,988
TT-30	50	0.0462	4,996
TT-31	119	0.1099	11,890
TT-52	130	0.1200	12,989
TT-54	150	0.1385	14,988
TT-67	100	0.0923	9,992
Total	**1,083**	**1.0000**	**108,211**

[1]See Figure C1 for location

Model Calibration

Calibration of the Tarawa Terrace flow model was accomplished in a hierarchical process consisting of four successive stages or levels. Simulation results achieved for each calibration level were iteratively adjusted and compared to simulation results of previous levels until results at all levels satisfactorily conformed to calibration standards. Hydraulic characteristic arrays and model boundary conditions were equivalent at all calibration levels. All flow model calibrations also were required to conform to the conceptual flow model described previously. In hierarchical order, calibration levels consisted of the simulation of (1) predevelopment conditions, (2) transient or pumping conditions, (3) the fate and transport of a PCE source at ABC One-Hour Cleaners, and (4) the concentration of PCE at the Tarawa Terrace WTP and within the Tarawa Terrace water-distribution network. Calibration levels 1 and 2 are described in detail in this report. Calibration levels 3 and 4 are similarly described in Faye (In press 2007).

Calibration standards for the predevelopment flow model calibration (level 1) required that simulated water levels at water-supply and monitor well locations match estimated observed predevelopment water levels within an absolute difference of 3 ft. This standard is derived from the least accurate water levels used for predevelopment calibration, which were obtained by estimating land-surface altitude at the well site from a topographic map and subtracting a reported depth to water. The contour interval of the topographic maps was 5 ft, and land-surface altitudes were estimated at an accuracy of ± 2.5 ft or one-half contour interval. The half-contour interval level of accuracy was rounded upward to 3 ft to provide a predevelopment calibration standard. Most of the water levels listed in Table C5 were used to evaluate predevelopment simulation results (Table C10).

Water-level data listed in Appendix C1, Tables C1.1–C1.11, were used to evaluate the quality of the level 2 or transient model calibration. The bulk of these data represent water levels at Tarawa Terrace water-supply wells. Data listed in Appendix C1, Tables C1.10 and C1.11, are water levels observed at various monitor wells installed during ABC One-Hour Cleaners Operable Units 1 and 2 at and in the vicinity of ABC One-Hour Cleaners and during remedial investigations of petroleum product spills and leaks from surface and underground storage tanks at Tarawa Terrace.

Monthly logs of operational information at Tarawa Terrace water-supply wells were obtained from USGS and Camp Lejeune records (Camp Lejeune water documents CLW 3559–4053, monthly well operation reports, written communication, September 22, 2004). Monthly logs were obtained for the period January 1978–April 1986. "Static" water levels were reported per month and were obtained by airline measurements. The actual date of measurement was not reported and, for this study, each measurement is assumed to have occurred on the last day of the designated month. Typically, reported water levels vary in excess of 20 ft during the period of measurement, and frequently 10 ft or more from month to month. Large changes in water levels from month to month may be indicative of water-level measurements obtained shortly after the termination of pumping and may not represent a static or near static measurement. Such variability also may indicate leaking or damaged airlines or pressure gages. LeGrand (1959) describes various problems associated with the use of airlines to measure water levels at Camp Lejeune including airline obstructions, leaks, and poor gage resolution. Similar problems probably occurred, as well, relative to airline measurements used for this study. For example, such problems possibly occurred at water-supply well TT-23 during its brief period of operation (August 1984–April 1985). The earliest static water-level measurement at a supply well is typically obtained immediately following well construction and is the highest measurement until routine operation is terminated for an extended period of time (Appendix C1, Tables C1.1–C1.3, C1.6–C1.8). However, at well TT-23, the earliest static water level, obtained prior to a well capacity test (March 1983), is substantially lower than subsequent airline measurements obtained during well operation (Appendix C1, Table C1.1), but is similar to water levels obtained by tape measurements reported by Shiver (September 1985) and the USGS (October 1986). A possible explanation for these differences is an improperly calibrated airline gage.

Pressure gages attached to airlines at Tarawa Terrace water-supply wells were not available for inspection but probably were accurate only to within ± 5 pounds per square inch (psi) or greater or within an estimated range of about ± 12 ft. Accordingly, for transient model calibration, the calibration standard applied to water-level data obtained from airline measurements was an absolute difference of 12 ft between simulated and observed water levels.

Highly accurate water-level measurements, obtained using tapes or similar devices, were available for the period 1992–1994 at monitor wells installed during investigations of groundwater contamination in the northern and southern parts of Tarawa Terrace (Appendix C1, Tables C1.10 and C1.11). The USGS also measured water levels periodically at Tarawa Terrace water-supply wells during 1986–1987 using similar methods. The calibration standard applied to these measurements and miscellaneous measurements of water levels obtained at supply wells by drillers immediately following well construction was an absolute difference of 3 ft between simulated and observed levels. A standard of 3 ft again refers to the least accurate estimates of water-level altitude, which were obtained by estimating land-surface altitude from topographic maps.

Final calibration results for levels 1 and 2 are described in the following text and are the result of several trial-and-error iterations at each calibration level and feedback of results to previous calibration levels.

Table C10. Simulated and observed predevelopment water levels in wells and related statistics, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[NGVD 29, National Geodetic Vertical Datum of 1929]

Site name[1]	Simulated water level, in feet above NGVD 29	Observed water level, in feet above NGVD 29	Absolute water-level difference, in feet
C1	18.4	21.5	3.1
C2	17.2	19.6	2.4
C3	14.6	15.8	1.2
C4	11.7	11.9	0.2
C5	14.2	15.9	1.7
C9	14.9	13.0	1.9
C10	14.3	12.6	1.7
C11	6.7	6.3	0.4
CCC-1	6.2	3.3	2.9
PZ-01	17.3	16.7	0.6
PZ-02	17.5	16.7	0.8
PZ-03	17.1	16.6	0.5
PZ-04	17.2	16.4	0.8
PZ-05	17.4	15.7	1.7
PZ-06	17.6	16.1	1.5
S1	18.7	23.7	5.0
S2	17.3	19.9	2.6
S3	14.6	16.0	1.4
S4	12.3	13.6	1.3
S5	14.3	16.4	2.1
S6	17.8	20.6	2.8
S7	17.1	19.8	2.7
S8	16.3	21.1	4.8
S9	14.5	15.4	0.9
S10	12.0	13.3	1.3
S11	20.1	19.0	1.1
STT61to66-MW01	19.4	21.6	2.2
STT61to66-MW20	18.6	20.1	1.5
T-9	17.0	23.4	6.4
TT-25	12.0	10.9	1.1
TT-26	14.4	14.0	0.4
TT-52	11.1	12.9	1.8
TT-53	14.7	14.0	0.7
TT-54	9.2	12.1	2.9
TT-55	19.1	18.9	0.2
TTDump MW02	4.3	6.2	1.9
TTDump MW03	2.9	2.2	0.7
[2]TTUST-44-MW01	5.6	6.0	0.4
[2]TTUST-48-MW01	11.7	19	7.3
[2]TTUST-779-MW01	10.6	9	1.6
[2]TTUST-2254-MW01	9.7	13	3.3
[2]TTUST-2258-MW01	9.6	12	2.4
[2]TTUST-2302-MW01	8.3	12	3.7
[2]TTUST-2453-A1	7.1	8.4	1.3
[2]TTUST-2453-OB8	5.7	6.5	0.8
[2]TTUST-2455-MW13	8.2	9.2	1.0
[2]TTUST-2455-MW15	6.0	5.6	0.4
[2]TTUST-TTSC-MW09	7.6	8.8	1.2
[2]TTUST-TTSC-MW15	8.8	11.2	2.4
[2]TTUST-2477-MW11	7.3	11.6	4.3
[2]TTUST-2477-MW14	6.5	7.9	1.4
[2]TTUST-2478-MW08	10.7	12.6	1.9
[2]TTUST-2478-MW23	4.7	6.2	1.5
[2]TTUST-2634-MW01	15.0	14	1.0
[2]TTUST-3140-MW01	17.4	15	2.4
[2]TTUST-3165-MW01	16.3	16	0.3
[2]TTUST-3233-MW01	12.3	12	0.3
[2]TTUST-3524-MW01	8.6	6	2.6
[2]TTUST-3546-MW01	8.8	5	3.8

[1]See Plate 1 for location

[2]Because of scale, not shown on Plate 1

Statistics:

Average water-level difference = 1.9 feet
Standard deviation of water-level difference = 1.5 feet
Root-mean square error of water-level difference = 2.1 feet

Level 1 Calibration (Predevelopment Conditions)

Level 1 calibration of the Tarawa Terrace groundwater-flow model was accomplished by successfully simulating estimated predevelopment conditions; that is, flow and water-level conditions prior to development of the various aquifers by wells. Predevelopment conditions are considered representative of long-term, average annual flow and water-level conditions within the Tarawa Terrace aquifer and the Upper Castle Hayne aquifer system at Tarawa Terrace and vicinity. Criteria used to determine a satisfactory predevelopment calibration were (1) conformance of simulated conditions to the conceptual model and (2) a satisfactory comparison of simulated and observed water levels within the active model

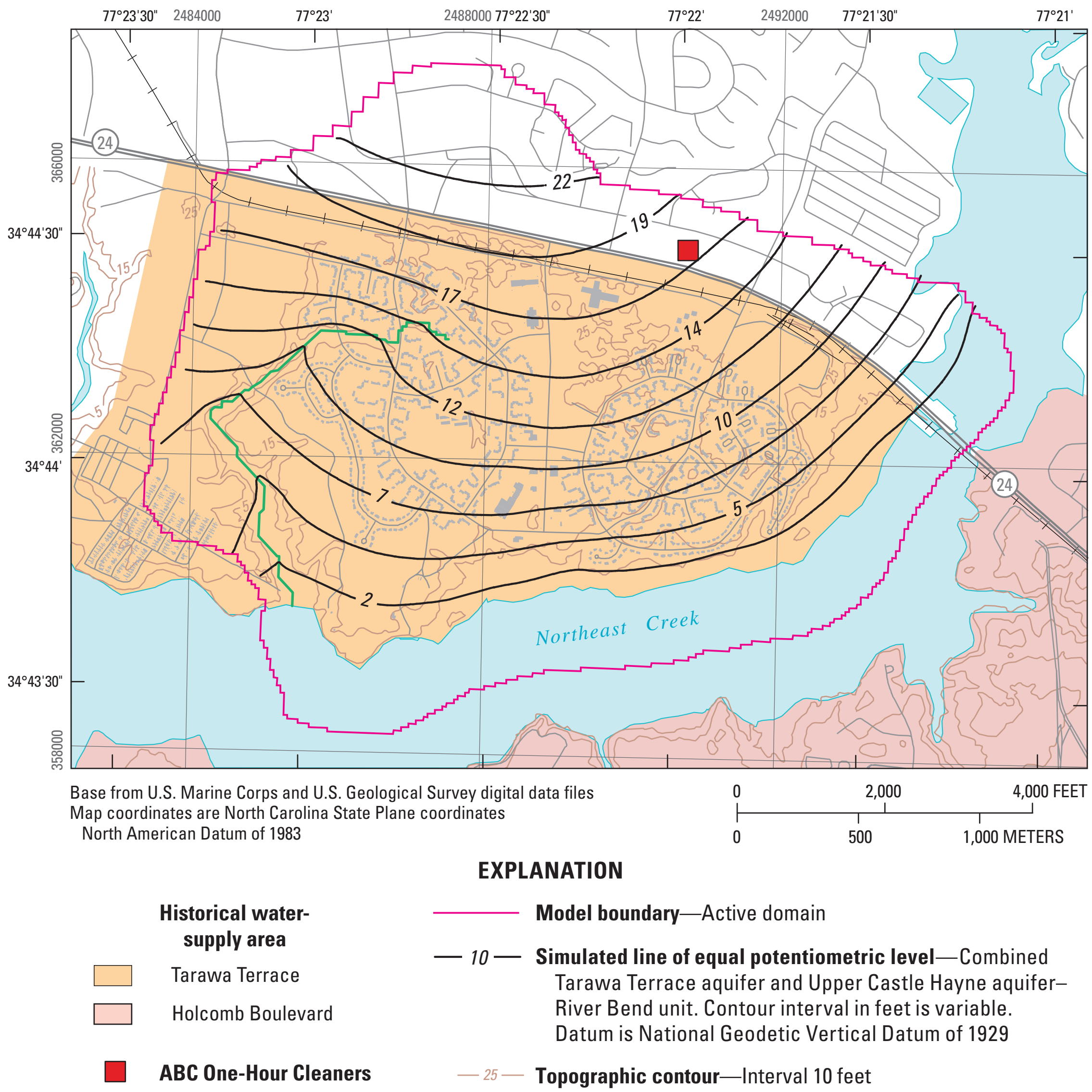


Figure C7. Simulated predevelopment potentiometric levels of the combined Tarawa Terrace aquifer and Upper Castle Hayne aquifer–River Bend unit (model layer 1), Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

domain. Observed water levels included most of the water levels listed in Table C5. Model runs representing predevelopment conditions were steady state. Simulated predevelopment potentiometric levels in the combined Tarawa Terrace aquifer and Upper Castle Hayne aquifer–River Bend unit (model layer 1) and the Lower Castle Hayne aquifer (model layer 7) are shown in Figures C7 and C8, respectively. Note that potentiometric-level distributions in both layers are highly similar with simulated potentiometric levels in highland areas in the northern part of the study area slightly higher in model layer 1 than in model layer 7. Conversely, simulated levels in the vicinity of Northeast and Frenchmans Creeks are slightly higher in model layer 7 than in model layer 1; both conditions conform explicitly to the conceptual model.

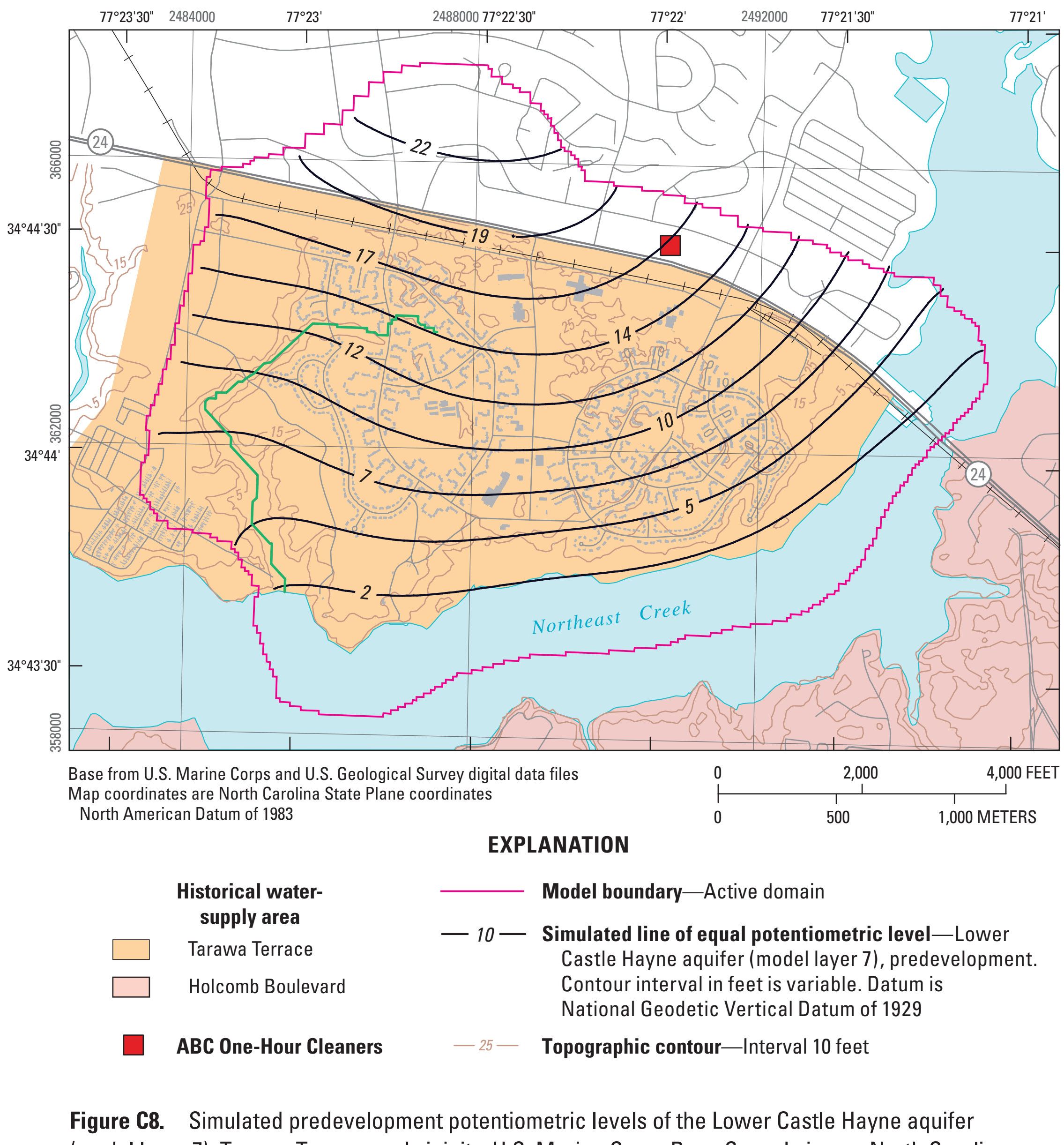


Figure C8. Simulated predevelopment potentiometric levels of the Lower Castle Hayne aquifer (model layer 7), Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

A scatter diagram showing the agreement between simulated and observed water levels for simulated predevelopment conditions is shown in Figure C9. The flow model spatially interpolates simulated results from cell centers to the location coordinates assigned to various observation points, such as well locations, in order to facilitate direct comparisons of simulated and observed conditions. All Tarawa Terrace water-supply wells and several monitor wells are open to multiple aquifers. At these sites, simulated water levels were processed post calibration by proportioning simulated water levels in several aquifers at multiaquifer wells to compute a composite water level. This composite water level was then compared to the observed water level to evaluate calibration "goodness." Proportions were based on the percentage of interval open to individual aquifers (model layers) compared to the total open interval at the well (Hill et al. 2000).

Simulated and observed predevelopment water levels are listed in Table C10. Of the 59 paired data, the absolute difference between simulated and observed water levels at only nine sites exceeded the calibration standard of 3 ft or less. Of these nine sites, the absolute water-level difference at four sites was between 3 and 4 ft, and the largest difference was 7.3 ft. Absolute water-level differences at 17 sites were 1.0 ft or less. The average of all absolute differences between observed and simulated water levels was 1.9 ft, and the root-mean-square error of all absolute water-level differences was 2.4 ft.

Total simulated flow to the active model domain occurred at a rate of about 2.09 cubic feet per second (cfs) from effective recharge and about 0.26 cfs from the general-head boundaries. Of this, about 1.62 cfs was discharged to Northeast Creek and about 0.73 cfs was discharged to Frenchmans Creek. The mass balance error between simulated rates of recharge and discharge was 0.00 percent.

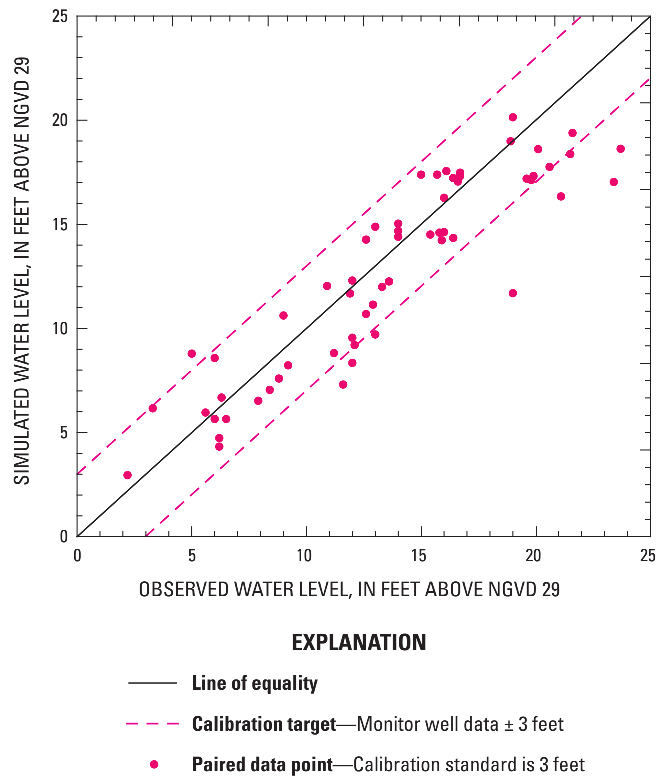


Figure C9. Simulated and observed predevelopment water levels, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Level 2 Calibration (Transient Conditions)

Calibration of the transient flow model was achieved using pumpage (Tables C8 and C9), water-level (Appendix C1, Tables C1.1–C1.11), and well capacity (Appendix C3, Tables C3.1–C3.10) data collected at Tarawa Terrace and vicinity. Effective recharge was assigned uniformly to the highest active model cell and was varied annually according to annual rainfall (Table C7). The hydraulic characteristic, drain, and general-head and specified-head arrays assigned to the calibrated predevelopment-flow model were applied exactly to the transient-flow model. A storativity of 0.0004 was assigned uniformly to model layers 2–7. A specific yield of 0.05 was assigned uniformly to model layer 1. Transient flow was simulated for a total of 528 stress periods (Appendix C4). Each stress period represented a single month beginning January 1951 and ending December 1994. A single month corresponded to a single stress period, and each stress period represented a single time step. The unit of time was days. Thus, the appropriate number of days representing a particular month was assigned as the time interval of the stress period. Pumpage was assigned to the transient model at Tarawa Terrace water-supply wells based on flow, capacity, construction, and operational data described previously. Calibration was based on comparisons of simulated and observed water levels at supply and monitor wells and conformance of simulated results to predetermined calibration standards and the conceptual model.

Available construction data for Tarawa Terrace water-supply wells are incomplete (Appendix C2, Tables C2.1–C2.3) but indicate that most of the wells probably were open to the Upper Castle Hayne aquifer–River Bend unit and the Upper Castle Hayne aquifer–Lower unit either directly by open interval or indirectly by gravel or sand packing within the annular space of the well bore. In addition, supply wells TT-23 and TT-25 were directly open, as well, to the Middle Castle Hayne aquifer. Total estimated pumpage at wells TT-23, TT-25, TT-26, TT-27, TT-28, TT-29, TT-30, and TT-67 was assigned to model layer 3. Total estimated pumpage at wells TT-53 and TT-55 was assigned to model layer 1. Total estimated pumpage at wells TT-31, TT-52, and TT-54 was subdivided equally between model layers 1 and 3.

Simulated and observed transient water levels at discrete time intervals are listed in Appendix C5, Tables C5.1–C5.11. Hydrographs of simulated and observed monthly water levels are shown at most Tarawa Terrace water-supply wells in Figures C10–C17. Most plots generally represent conditions occurring between January 1978 and April 1987. Simulated water levels represent an average condition for the respective stress period (month and year). Observed water levels represent conditions during a single measurement day. With few exceptions, observed data plotted in Figures C10–C17 were determined by airline measurements. Accordingly, the absolute differences between observed and simulated water levels are subject to a calibration standard of 12 ft. A similar standard applies to most of the data listed in Appendix C5, Tables C5.1–C5.8. Observed water-level data listed in Appendix C5, Tables C5.9–C5.11, were determined by tape or similar measurement. The absolute difference between simulated and observed water levels listed on these tables is, thus, subject to a calibration standard of 3 ft. These data at a single site are few in number and are compressed in time to 1 or 2 years, and observed water levels were not plotted against simulated water levels.

Based on these standards, calibration of the transient-flow model is generally good and ranges from fair to excellent, depending on comparisons at specific water-supply or monitor wells. For example, the average absolute difference between simulated and observed water levels at wells TT-25 and TT-67 is 5.7 and 4.0 ft, respectively (Appendix C5, Tables C5.1 and C5.8), and simulated and observed water-level trends are similar (Appendix C1, Tables C1.2 and C1.9). The root-mean-square error of absolute water-level differences at these sites is 6.6 and 5.0 ft; whereas, the calibration standard applied to these data was 12 ft. On the other hand, the average absolute difference between simulated and observed water levels at wells TT-31 and TT-53 is 8.7 and 8.6 ft, respectively, and simulated and observed water levels are, at best, somewhat similar (Appendix C5, Tables C5.4 and C5.6). Of the 509 paired water levels listed in Appendix C5, Tables C5.1–C5.8, 83 absolute differences, or about 16 percent, exceed the 12-ft calibration standard. Of the 280 paired water levels listed in Appendix C5, Tables C5.9–C5.11, only 26 absolute differences, or about 9 percent, exceed the 3-ft calibration standard. Two hundred and sixty-three measurements are at monitor wells installed during investigations of groundwater contamination at Tarawa Terrace and vicinity (Appendix C5, Tables C5.10 and C5.11). The average and root-mean-square error of absolute water-level differences at these sites ranges from about 1.2 to 1.8 ft and from 1.4 to 2.1 ft, respectively.

Absolute differences between simulated and observed water levels at well TT-30 exceeded 12 ft on 18 occasions (Appendix C5, Table C5.3). Observed water levels began to decline sharply at this site beginning about August 1978 and continued downward until about March 1982, when a sharp recovery occurred (Appendix C1, Table C1.4). Such trends are typically caused by pumping from a nearby well. Well TT-30 was located just south of SR 24, an area of considerable commercial development, and far to the west of any active Tarawa Terrace water-supply wells during 1978–1982. A likely cause of the declining water levels at TT-30 was the use of an unknown supply well in the nearby commercial area north of SR 24, a use that was terminated about March 1982. This well and the related pumpage were not accounted for during transient simulations. Following termination of the presumed commercial pumping, simulated and observed water levels at well TT-30 were highly similar (Appendix C1, Table C1.4).

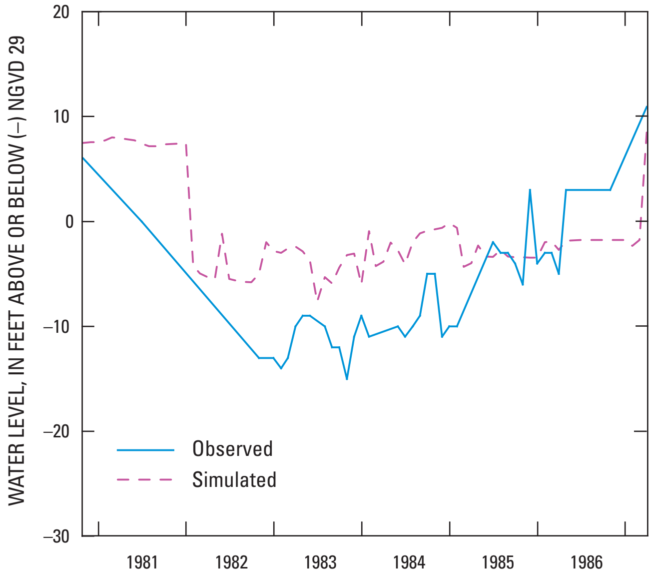


Figure C10. Simulated and observed water levels in supply well TT–25, November 1980–April 1987, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

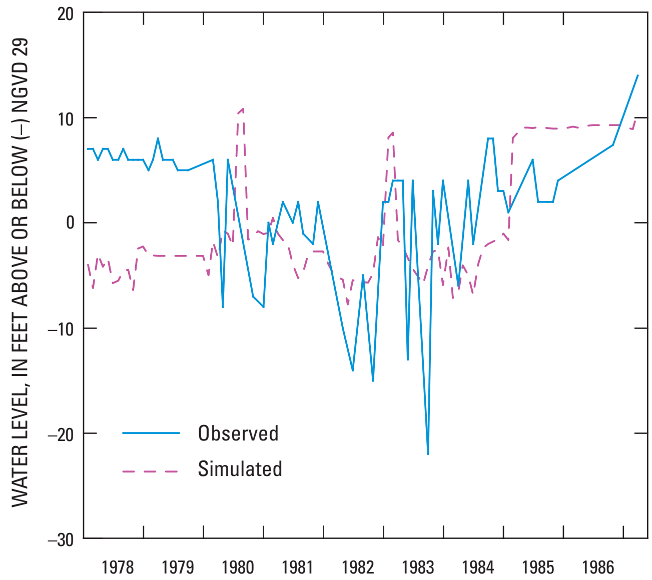


Figure C11. Simulated and observed water levels in supply well TT–26, January 1978–April 1987, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

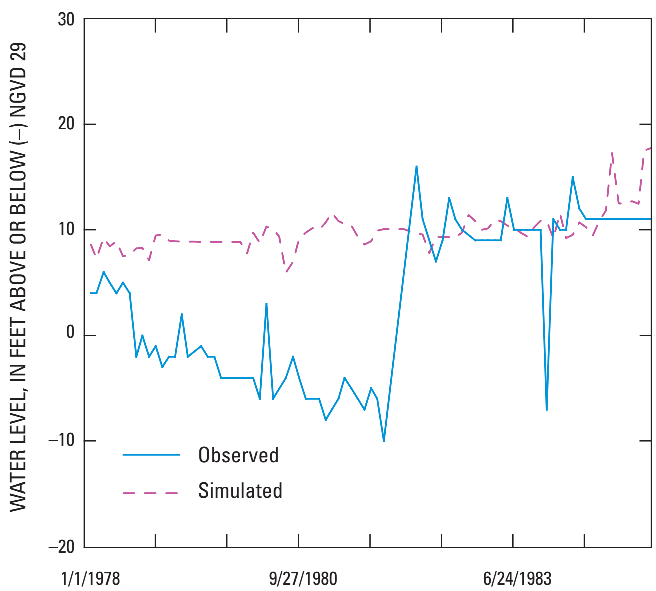


Figure C12. Simulated and observed water levels in supply well TT–30, January 1978–April 1985, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

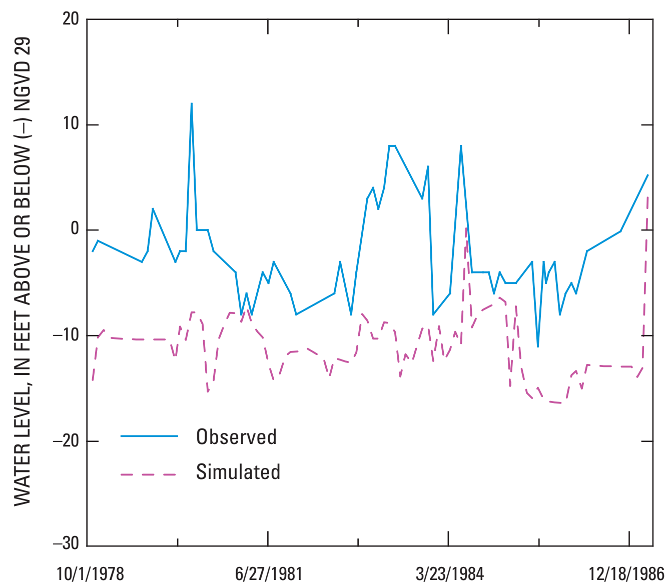


Figure C13. Simulated and observed water levels in supply well TT–31, October 1978–April 1987, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

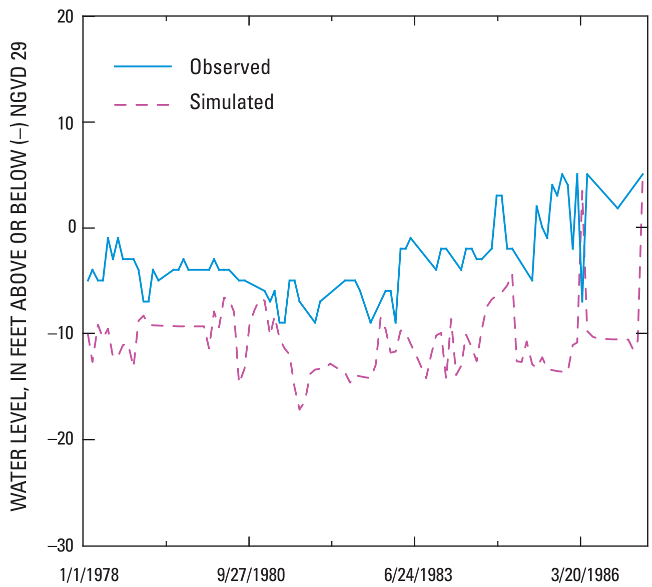


Figure C14. Simulated and observed water levels in supply well TT–52, January 1978–April 1987, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

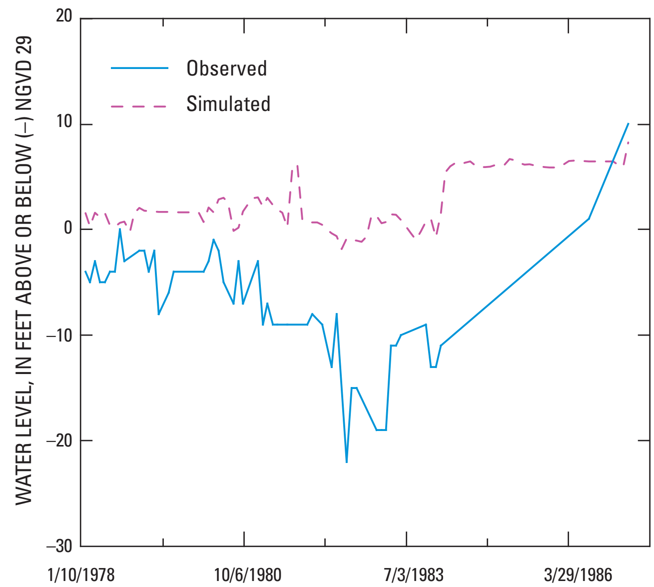


Figure C15. Simulated and observed water levels in supply well TT–53, January 1978–January 1984, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

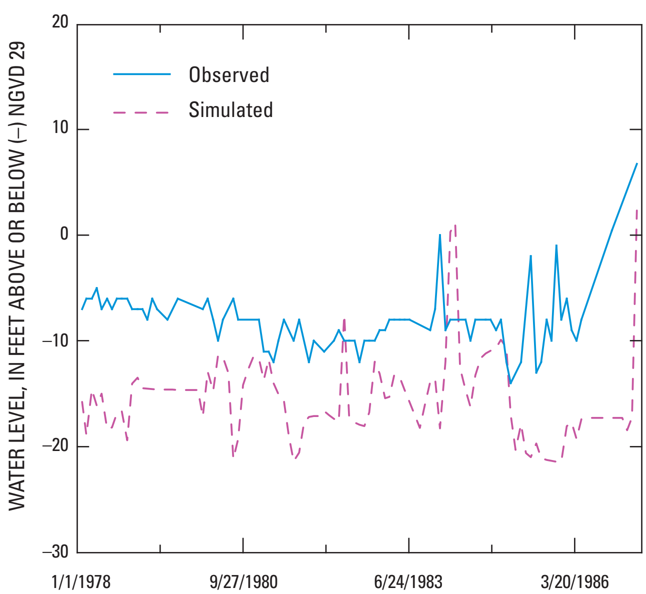


Figure C16. Simulated and observed water levels in supply well TT–54, January 1978–April 1987, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

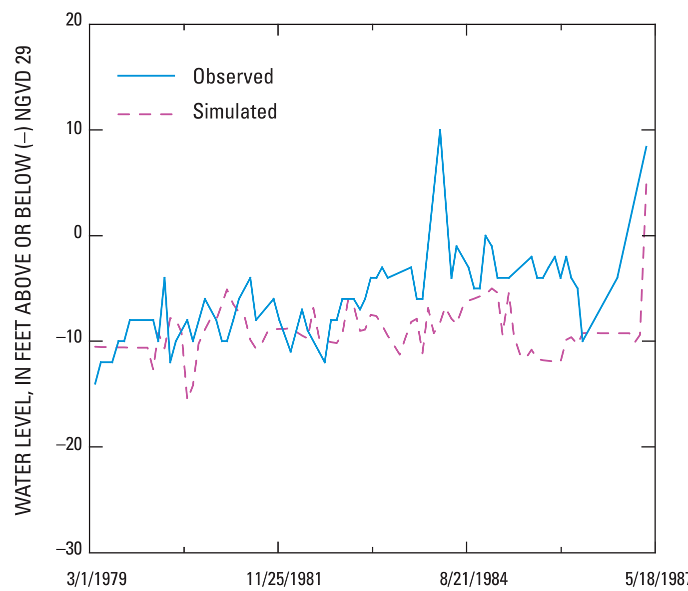


Figure C17. Simulated and observed water levels in supply well TT–67, March 1979–April 1987, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Simulated layer-by-layer groundwater flow to and from the Tarawa Terrace flow model for stress period 408 (December 1984) is summarized in Tables C11 and C12, respectively. With the exception of well TT-23, pumping at active Tarawa Terrace water-supply wells at this time had been ongoing for several years and, at several wells, for several decades. Accordingly, changes in storage are insignificant, even in model layers 1 and 3, where all of the assigned pumpage occurs. Discharge to Northeast Creek occurs at a rate of about 0.9 cfs, considerably less than the corresponding rate noted during predevelopment simulations (1.6 cfs). Similar reductions from predevelopment conditions were noted in the discharge to Frenchmans Creek (from 0.73 to 0.56 cfs). Such reductions are the result of disruptions in the predevelopment flow gradients away from natural lines of discharge and toward pumping wells. Conversely, flow from general-head

Table C11. Simulated layer-by-layer groundwater flow *into* the Tarawa Terrace model, stress period 408 (December 1984), U.S. Marine Corps Base Camp Lejeune, North Carolina.

[N/A, not applicable]

Model layer	Layer to layer	Budget components (rates in cubic foot per second)				
		Storage	Recharge	Constant head	General head	Totals
1		0.00	1.92	0.00	0.49	
2 to 1	0.34					2.74
2		0.00	0.00	N/A	0.00	
1 to 2	1.02					
3 to 2	0.33					1.35
3		0.00	0.00	N/A	0.07	
2 to 3	1.02					
4 to 3	0.59					1.68
4		0.00	0.00	N/A	0.00	
3 to 4	0.33					
5 to 4	0.57					0.90
5		0.00	0.00	N/A	0.18	
4 to 5	0.32					
6 to 5	0.16					0.66
6		0.00	0.00	N/A	0.00	
5 to 6	0.09					
7 to 6	0.14					0.23
7		0.00	0.00	N/A	0.06	
6 to 7	0.08					0.15
Total	**4.99**		**1.92**		**0.80**	**7.71/7.71**

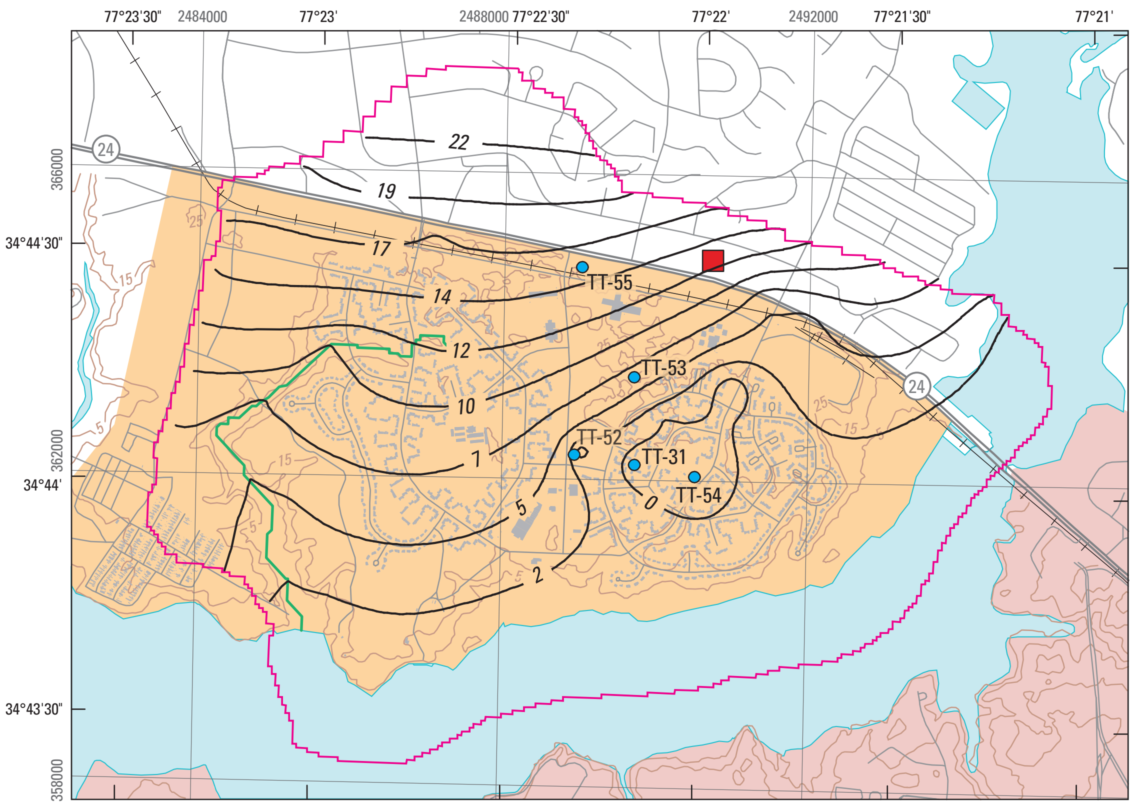
boundaries to the active model domain increased during transient conditions compared to predevelopment conditions from 0.26 to 0.80 cfs, also as a result of pumping at water-supply wells, particularly at wells TT-25 and TT-26, which were located relatively close to the boundary. Differences between total inflow and outflow rates listed in Tables C11 and C12 are caused by rounding errors at the second decimal place. Simulated flow conditions conform explicitly to the conceptual model of groundwater flow described previously.

Simulated potentiometric surfaces of model layers 1 and 3 for stress period 408 are illustrated in Figures C18 and C19, respectively. A substantial cone of depression occurs in the immediate vicinity of the Tarawa Terrace housing area where the majority of active water-supply wells are located and reflects a coalescing of several cones developed at individual wells. A comparatively small coalesced cone of depression is evident in model layer 3 north of Tarawa Terrace near SR 24 and is caused by pumping at wells TT-25 and TT-26.

Table C12. Simulated layer-by-layer groundwater flow *out of* the Tarawa Terrace model, stress period 408 (December 1984), U.S. Marine Corps Base Camp Lejeune, North Carolina.

[N/A, not applicable]

Model layer	Layer to layer	Budget components (rates in cubic foot per second)					
		Storage	Wells	Constant head	General head	Drains	Totals
1		0.06	0.23	0.88	0.00	0.56	0.06
1 to 2	1.02						2.75
2		0.00	0.00	N/A	0.00	N/A	
2 to 1	0.34						
2 to 3	1.02						1.36
3		0.00	1.02	N/A	0.00	N/A	
3 to 2	0.33						
3 to 4	0.33						1.68
4		0.00	0.00	N/A	0.00	N/A	
4 to 3	0.59						
4 to 5	0.32						0.91
5		0.00	0.00	N/A	0.00	N/A	
5 to 4	0.57						
5 to 6	0.09						0.66
6		0.00	0.00	N/A	0.00	N/A	
6 to 5	0.16						
6 to 7	0.08						0.24
7							
7 to 6	0.14	0.00	0.00	N/A	0.00	N/A	0.15
Total	**4.99**	**0.06**	**1.25**	**0.88**	**0.00**	**0.56**	**7.74/7.75**



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 2,000 4,000 FEET
0 500 1,000 METERS

EXPLANATION

Historical water-supply area
- Tarawa Terrace
- Holcomb Boulevard

Model boundary—Active domain

— 2 — **Simulated potentiometric contour**—Shows simulated potentiometric surface during December 1984. Contour interval variable. Datum is National Geodetic Vertical Datum of 1929

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

TT-31 **Pumping water-supply well and identification**

ABC One-Hour Cleaners

Figure C18. Simulated potentiometric levels, combined Tarawa Terrace aquifer and Upper Castle Hayne aquifer–River Bend unit (model layer 1), stress period 408 (December 1984), Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

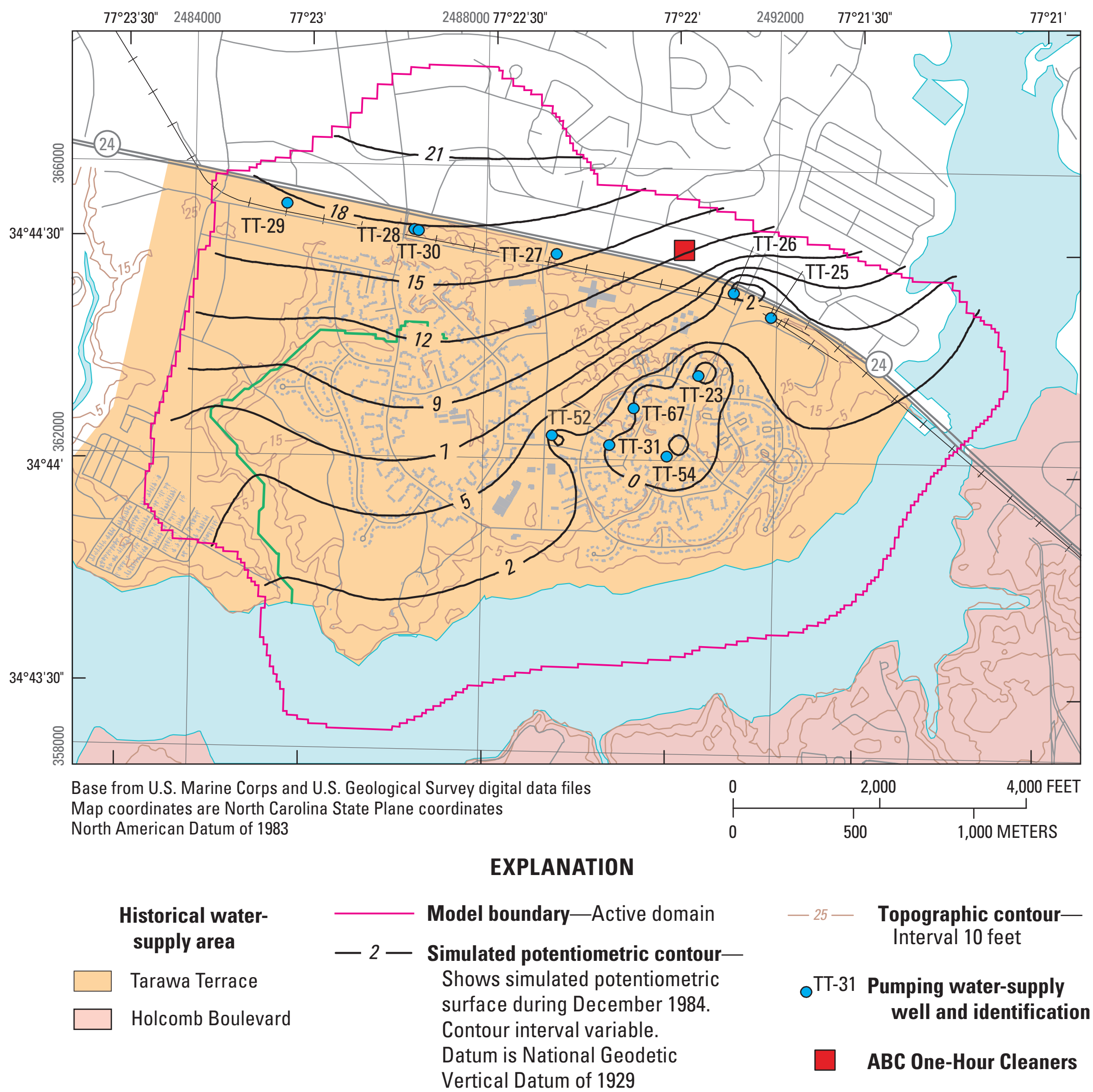


Figure C19. Simulated potentiometric levels, Upper Castle Hayne aquifer–Lower unit (model layer 3), stress period 408 (December 1984), Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

An indication of gross model calibration is shown in the scatter diagram of Figure C20. Paired data shown within the bottom half of the diagram generally correspond to water-supply well data listed in Appendix C5, Tables C5.1–C5.8. Paired data within the upper part of the diagram generally correspond to data listed in Appendix C5, Tables C5.9–C5.11. The average absolute difference between simulated and observed water levels for the 789 paired water levels shown in Figure C20 is 5.2 ft. The root-mean-square error of the absolute differences is 7.0 ft.

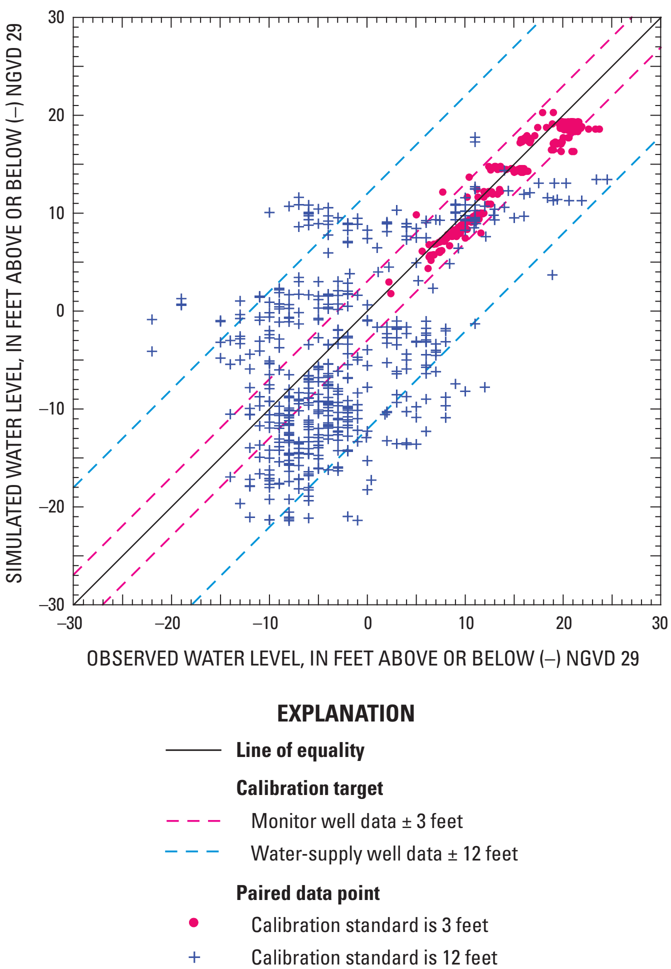


Figure C20. Simulated and observed transient water levels, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Sensitivity Analysis

Sensitivity analyses determine the relative importance of hydraulic characteristic and model input parameters, such as recharge, to simulated results. Sensitivity analysis quantitatively evaluates the effects of changes in calibrated model parameters by individually adjusting these parameters and comparing the simulated results to a predetermined measure of calibration quality. Two measures of calibration quality were used for this study: (1) variance and (2) root-mean-square error. Variance is a measure of the absolute water-level difference between simulated and observed water levels around the mean difference. The square root of the variance is the standard deviation around the mean. Root-mean-square error is a direct measure of the absolute difference between simulated and observed water levels. Variance and root-mean-square error were computed using the simulated and observed water levels listed in Appendix C5, Tables C5.1–C5.11. Sensitivity of simulation results to changes in parameter values is substantially affected by model boundary conditions. Assigned potentiometric levels that occur in every layer along the northern perimeter of the active model domain as part of general-head boundaries and specified heads assigned to model layer 1 along the southern and eastern perimeters where active cell locations coincide with Northeast Creek tend to dampen sensitivity.

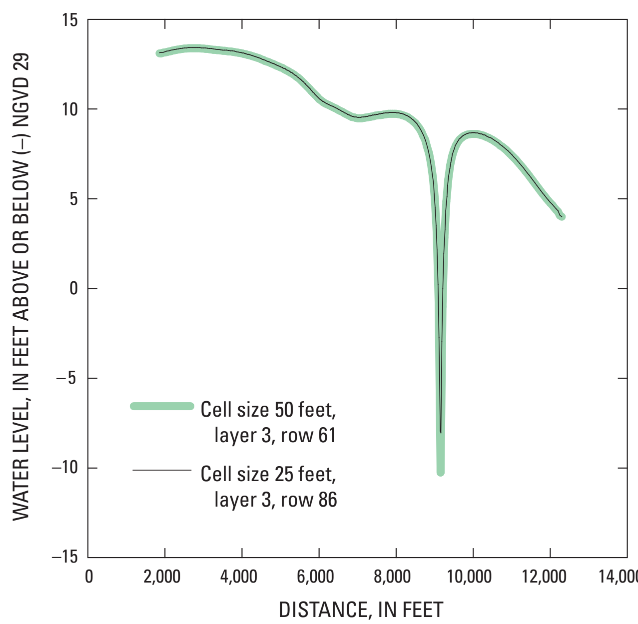


Figure C21. Simulated water levels for stress period 157 in supply well TT-26 along designated rows using model cell dimensions of 50 feet per side and 25 feet per side, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Implementation of sensitivity analyses was accomplished by globally increasing or decreasing the calibrated value of a specified parameter within a range of values considered reasonable for the study area. Model parameters tested for sensitivity were recharge, horizontal and vertical hydraulic conductivity, drain conductance, specific storage, and assigned potentiometric levels at general-head boundaries. Results of the sensitivity analyses are listed in Table C13. Changes in horizontal hydraulic conductivity most significantly affected simulation results. Variance and root-mean-square error were degraded by about 57 and 29 percent, respectively, when horizontal hydraulic conductivity was increased globally by a factor of 2.5 compared to calibrated arrays. A global increase in vertical hydraulic conductivity by a factor of 2.5 resulted in the lowest variance and root-mean-square error values, an improvement of about 3 and 2 percent, respectively, compared to calibrated arrays. Sensitivity of simulation results to increased recharge and decreased water levels within the general-head boundary arrays was not significant. Sensitivity of simulation results to changes in drain conductance and specific storage was minimal.

Sensitivity of simulation results to model cell dimensions also was tested. Cell dimensions were uniformly changed from 50 ft per side to 25 ft per side throughout the model domain. Simulated water levels were compared along model rows that included the location of water-supply well TT-26 for stress periods 60, 133, 157, and 253. Simulated water levels were nearly identical for all stress periods regardless of cell size and are shown for stress period 157 in Figure C21.

Table C13. Summary of sensitivity analyses of the Tarawa Terrace transient flow model, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[(ft/d)^2, feet per day squared; N/A, not applicable; +, plus; –, minus; feet^{-1}, 1/foot]

Model parameter	Global change	Variance, in (ft/d)^2	Root-mean-square error, in feet	Remarks
Horizontal hydraulic conductivity, in feet per day	Multiplied by			
	0.25	N/A	N/A	Wells pumped dry
	0.5	N/A	N/A	Wells pumped dry
	1.0	53.3	7.3	
	1.5	61.2	7.82	
	2.5	83.7	9.15	
Vertical hydraulic conductivity, in feet per day	Multiplied by			
	0.25	N/A	N/A	Wells pumped dry
	0.5	N/A	N/A	Wells pumped dry
	1.0	53.3	7.3	
	1.5	52.4	7.24	
	2.5	51.5	7.17	
Recharge, in inches per year	Annual rate			
	10	N/A	N/A	Wells pumped dry
	12	N/A	N/A	Wells pumped dry
	Calibrated rate	53.3	7.30	
	14.5	53.5	7.31	
	16	54.6	7.39	
Assigned head at general head boundaries	Increased +5 feet	61.4	7.84	
	Calibrated head	53.3	7.30	
	Decreased –5 feet	N/A	N/A	Wells pumped dry
Specific storage, in feet^{-1}	Multiplied by			
	1	53.3	7.30	
	5	53.2	7.29	
	10	53.0	7.28	
	20	52.9	7.27	
Drain conductance, in feet per day	Multiplied by			
	0.25	52.8	7.26	
	0.5	53.0	7.28	
	1	53.3	7.30	
	2.5	53.7	7.33	

Discussion

Results and interpretations described in this report are substantially dependent on the accuracy of water-level and site-location data. The accuracy of water-level data used for model calibration was discussed previously and qualified in terms of methods of measurement. Highly accurate water levels were classified as those probably or possibly measured with tapes or similar methods and are listed in Table C5 and Appendix C5, Tables C5.9–C5.11. Less accurate water levels, probably measured using airlines, are listed in Appendix C5, Tables C5.1–C5.8; observed water levels listed in these tables reported only to the nearest foot are indicative of altitudes computed using land-surface altitude estimated from topographic maps or obtained from airline measurements. Absolute water-level differences and related statistics, however, are reported to the nearest tenth of a foot in order to maintain consistent bases of comparison with corresponding data listed in Table C5 and Appendix C5, Tables C5.9–C5.11. According to accepted rules of reporting significant figures, the statistics reported in Appendix C5, Tables C5.1–C5.8, are accurate only to the nearest unit value.

Location Coordinates

Locations of Tarawa Terrace water-supply wells are probably highly accurate and are based, for the most part, on large-scale site maps of individual wells developed prior to well and well house construction (NAVFAC drawings 4049523, 1244002, 4001327, and 1244061, written communication, various dates; Y & D drawing 765472, written communication, various dates; P.W. drawing 13060, written communication, various dates) and U.S. Marine Corps Base Camp Lejeune Quarters Maps (U.S. Marine Corps Base Camp Lejeune, Map of Tarawa Terrace II Quarters Map, written communication, June 30, 1961; U.S. Marine Corps Base Camp Lejeune, Tarawa Terrace I Quarters Map, written communication, July 31, 1984). Accordingly, location coordinates of Tarawa Terrace water-supply wells listed in various tables are considered accurate within a radius of about 50 ft.

Many reports that describe the investigation and removal of USTs within the Tarawa Terrace housing areas also contained detailed maps showing monitor well and soil boring locations as well as a single latitude and longitude site locator. For this study, the latitude and longitude location was considered the location of the tank or the number one monitor well, and all other site locations were georeferenced to that point using the various site plans and maps provided in the report. Monitor well locations at these sites are considered accurate to within a radius of 100 ft (Appendix C1, Table C1.11). Location coordinates at monitor wells installed during ABC One-Hour Cleaners Operable Unit 1 (Appendix C1, Table C1.10) were based on the mapped location of well sites and coordinates of a local grid established during the operable unit (Roy F. Weston, Inc. 1992). Unfortunately, the origin of the local grid was not referenced to any typical map coordinate system, such as North Carolina State Plane coordinates. In addition, comparison of mapped well locations to the local coordinates indicated that the north and east local coordinates were possibly reversed at several sites. Not even local coordinates were provided for the several monitor wells constructed during ABC One-Hour Cleaners Operable Unit 2. Location coordinates at these sites were determined by referencing the mapped location to an obvious cultural feature, such as intersecting roads, that was easily recognized on USGS 1:24,000-scale maps. Operable Unit 1 local site coordinates also were cross-referenced with their mapped locations in a similar manner. Accordingly, the accuracy of location coordinates of monitor wells installed during Operable Units 1 and 2 varies by location and proximity to cultural features as well as the accuracy of the original well-location maps, which is unknown. Locations of wells constructed during Operable Unit 1 with assigned local coordinates and in the immediate vicinity of ABC One-Hour Cleaners and Tarawa Terrace water-supply wells are considered accurate within a radius of about 50 ft. Other wells constructed during Operable Unit 1 and all wells and piezometers constructed during Operable Unit 2 are located within unknown accuracy limits but probably within distances ranging from several dozen to several hundred feet. The locations of monitor wells installed during the investigations of refined-petroleum products in the subsurface at storage tanks STT61–66 were georeferenced using the published well-location map and the estimated State Plane coordinates of the southeast corner of Building TT-47, which was included on the well-location map and also could be located on a 1:24,000-scale topographic map. Locations are considered accurate to within a radius of about 50 ft. Locations of monitor wells installed during remedial investigations at and in the vicinity of the Tarawa Terrace Shopping Center were determined using published maps and easily identified cultural features as described previously and also are considered accurate to within a radius of about 50 ft (Appendix C1, Table C1.11).

Flow Model

Numerical models of groundwater flow, such as MODFLOW, even when supported by excessive quantities of high-quality data and excellent ancillary analytical tools, represent, at best, a gross approximation of real-world conditions. Accordingly, simulation results must be evaluated and qualified within the context of the quality and density of data used for model construction and calibration and within the context of the completeness and validity of the conceptual model. The quality and completeness of water-level and pumpage data were discussed previously. Historical water-level data were mainly unavailable prior to 1978, with the exception of one or two measurements at the time of construction of several wells. Thus, for the most part, simulation results are unqualified for the years 1951–1977, based on comparisons of observed and simulated water levels. In addition, an inherent disparity between simulated and observed water levels must be kept in mind when such data are compared, regardless of the origin or date of the water-level measurement; that is, simulated levels always represent average monthly conditions, whereas observed data may represent short-term hourly or daily conditions. This disparity is at least partly addressed for comparative purposes by using static or recovered water levels, as reported, at water-supply wells.

Pumpage data were unavailable prior to 1975 and much of the data used for years 1975–1986 were limited to average annual or monthly rates for all wells, rather than known rates that could be assigned to individual wells. Accordingly, an average annual pumping rate representing 1975–1986 conditions was applied to the model for all stress periods representing the years 1952–1974 (Table C9). This assumption is partly justified because the number of housing units and population of Tarawa Terrace was probably constant, or nearly so, during these years, as was the corresponding average household water use. The use of well capacity as a surrogate for the computation of pumpage at individual wells also was necessary, given the total lack of pumpage data pertinent to individual water-supply wells. Pumpage computation errors caused by this approach and introduced into model simulations may partially explain the relatively poor comparisons between observed and simulated water levels at several supply wells (Figures C10–C17). Water-supply well operations as simulated and as actually occurred were also somewhat different. Changes in simulated operations could occur only at a stress period (monthly) interval. However, actual changes in well operation, such as cycling pumps on and off, probably occurred on an hourly or daily basis. Whether or not disparities between actual and simulated well operations introduced substantial error into simulated average monthly water levels and groundwater-flow rates is unknown. Operations, such as removing wells from service for repair or equipment replacement for weeks or several months, were noted in operation logs beginning during 1978. Such intervals are represented in the flow model pumpage array.

Well construction data also were somewhat limited and possibly affected the assignment of pumpage to model layers (Appendix C2, Tables C2.1–C2.3). Pumping intervals at water-supply wells were assigned to either model layer 1 or 3 in conformance with known construction information. Construction data were incomplete at supply wells TT-28 and TT-29, which were completed during 1951 (LeGrand 1959), as were wells TT-26 and TT-27. Based on construction information at wells TT-26 and TT-27, the completed depths of wells TT-28 and TT-29 probably ranged between 50 and 100 ft (LeGrand 1959). Accordingly, pumpage at these wells was assigned to model layer 3. The depth of well TT-55 is reported to be greater than 50 ft. Additional construction information for this well is not available and pumpage from this well was assigned to model layer 1. Several or all of these wells may have been, and probably were, open to water-bearing units that correspond to layer 3 of the flow model. Only the depth of the finished well is known at supply wells TT-31, TT-52, and TT-54; these depths range between 94 and 104 ft. However, these wells were all constructed during 1961, as was well TT-53 where construction is known. Well TT-53 was constructed with screens open to model layers 1 and 3. Accordingly, one-half of total estimated pumpage at wells TT-31, TT-52, and TT-54 was assigned equally to model layers 1 and 3.

Water-supply-well boreholes were typically drilled to depths substantially greater than the depth of the finished wells and unused borehole volume was backfilled with coarse sand or pea gravel. Such construction techniques created a substantial, if not direct, hydraulic connection between the backfilled volume and the gravel pack placed opposite the well screens of the open well interval. To account for multiaquifer construction of supply wells, vertical hydraulic conductivities of cells in layers representing confining units penetrated by the supply well boreholes were increased from 0.1 to 100 ft/d. Borehole continuity across confining units was, thus, at least partially accounted for by modifying the vertical hydraulic conductivity of appropriate model cells, and increased multiaquifer flow was simulated at supply wells regardless of the model layer to which pumpage was assigned. Regardless of these modifications, however, a substantial disparity probably occurs between actual (real-world) multiaquifer flow in a pumping supply well and the model's ability to simulate such flow. Much, if not most, of this disparity occurs as a result of model cell resolution where, for example, pumpage at a 10-inch diameter supply well is assigned within a 50-ft by 50-ft cell area. Accordingly, a composite potentiometric level was computed at each supply well for each stress period based on the percentage of total open interval known or estimated to occur at discrete model layers (aquifers). The methodology described by Hill et al. (2000) was used to proportion the discrete layer-by-layer simulated water levels.

Horizontal hydraulic conductivity data based on aquifer tests are limited geographically to the eastern half of the model domain and stratigraphically to the Tarawa Terrace aquifer and Upper Castle Hayne aquifer–River Bend unit (Table C2). To partially compensate for the limited number of point data, horizontal hydraulic conductivity at well sites at Montford Point ("M" sites) and in the vicinity of Brewster Boulevard ("HP" and "LCH" sites) was used to establish east-west trends for interpolating arrays throughout the model domain (Tables C2–C4). No hydraulic-conductivity data unique to the Middle and Lower Castle Hayne aquifers are available. Data assigned exclusively to the Middle Castle Hayne aquifer (model layer 5; Table C4) were segregated from other hydraulic characteristic data based on borehole geophysical logs, which generally indicated that the Middle Castle Hayne aquifer is composed of higher percentages of clays and fine sands than sediments of the Upper Castle Hayne aquifer–River Bend unit and Tarawa Terrace aquifer. A horizontal hydraulic conductivity of 5 ft/d was assigned uniformly to the Lower Castle Hayne aquifer (model layer 7), also partly based on interpretations of borehole geophysical logs. Bias or selective distribution from east to west within model horizontal hydraulic conductivity arrays possibly occurs because of the geographically restricted point data used to create the arrays. The degree of bias, if it occurs, is unknown. The influence of such bias on simulation results also is unknown; however, sensitivity analyses indicate that substantial global increases and decreases in horizontal hydraulic conductivity substantially degrade simulated results compared to results based on calibrated arrays.

Only four aquifer tests in the vicinity of Tarawa Terrace used observation wells, and these tests were conducted using wells completed either in the Tarawa Terrace aquifer or Upper Castle Hayne aquifer–River Bend unit. Aquifer storativity computed as a result of these tests ranged from 0.05 to 0.009. The largest of these values, 0.05, was assigned uniformly to model layer 1 as specific yield. The majority of aquifer tests conducted at Tarawa Terrace and vicinity were single-well, step-drawdown tests. Resulting test data were analyzed using methods published by Halford and Kuniansky (2002). The default storativity used in these analyses to compute head losses caused by skin effects is 0.0004, a reasonable value of storativity for confined Southeastern Coastal Plain aquifers (Faye and McFadden 1986; Newcome 1993; Giese et al. 1997). An equivalent storativity was assigned uniformly to model layers 2–7 and then divided by cell-by-cell thickness to compute cell-by-cell specific storage. The resulting specific storage arrays were used to simulate transient-flow conditions. Sensitivity analyses indicate that order-of-magnitude changes in specific storage from calibrated values are insignificant with respect to simulated results.

Other uncertainties that potentially influence simulation results are the no-flow boundaries assigned to the western, southern, and eastern boundaries of the active model domain. These boundaries and the general-head boundary to the north generally conform to topographic boundaries. An additional constant-head boundary of zero potentiometric level was assigned to those cells in model layer 1 that correspond to the location of Northeast Creek. Northeast Creek is an estuary of the Atlantic Ocean and long-term, average water levels probably closely approximate sea level or zero potentiometric level.

Mainly based on regional flow concepts articulated by Hubbard (1940) and quantified by Toth (1962, 1963) and Freeze and Witherspoon (1966, 1967), topographic boundaries were considered to approximate the respective limits of the water table as groundwater divides. The water table and, by extension, potentiometric surfaces of underlying confined aquifers, were considered subdued replicas of surface topography. Accordingly, the no-flow and general-head boundaries defined for model layer 1 also were assigned to the same locations in model layers 2–7. These boundaries are probably entirely appropriate for predevelopment conditions, as indicated by the simulated predevelopment budget wherein only about 12 percent of total discharge originated at general-head boundaries, and almost all of that was contributed to model layer 1. Simulated predevelopment discharge was entirely to model cells representing Northeast Creek and Frenchmans Creek, either directly or by diffuse upward leakage. Such conditions exactly conform to the conceptual model as well as to regional flow concepts. The high degree of similarity between the predevelopment water table simulated for model layer 1 and the potentiometric surface simulated for model layer 7 also conforms to regional flow concepts and the conceptual model (Figures C7 and C8).

During simulation of transient conditions, however, groundwater pumping at water-supply wells lowered water table and potentiometric surfaces and possibly significantly disrupted water-level and flow conditions at model boundaries, especially where supply wells were located in close proximity to model boundaries. Wells TT-25 and TT-26 were located about 1,000 ft from the general-head boundary. In addition, the coalescing of drawdown caused by pumping at supply wells in the vicinity of the Tarawa Terrace housing area possibly lowered water levels and altered flow directions in the vicinity of Northeast Creek (Figure C18). A test of the reasonableness of the assigned no-flow boundaries was accomplished by (1) comparing simulated predevelopment and transient water-levels at assigned no-flow boundaries to determine water-level changes and (2) comparing simulated predevelopment and transient flow to or from constant-head cells that represent Northeast Creek. Substantial changes in water levels at layer-by-layer model boundaries west of Frenchmans Creek, along the western part of the northern boundary, and at the no-flow boundary assigned along the mid-channel of Northeast Creek or a reversal of flow from constant-head cells to model layer 1 could indicate an inappropriate assignment of boundary conditions. Although contour values are not exactly comparable, the simulated potentiometric surfaces of model layer 1 during predevelopment conditions and for stress period 408 (December 1984) are everywhere nearly identical within the western half of the active model domain (Figures C7 and C18). In addition, budget components simulated for stress period 408 indicate that no reverse flow occurred from constant-head cells to model layer 1 anywhere along the shoreline boundary with Northeast Creek (Table C11). Within the eastern part of the model domain, which is most significantly affected by pumping from supply wells, simulated potentiometric levels in model layers 2–7 in the vicinity of Northeast Creek for stress period 408 were lower than simulated predevelopment water levels by about a foot. Simulated potentiometric levels immediately at the no-flow boundary near the mid-channel of Northeast Creek were lower than corresponding predevelopment water levels by about 0.5 ft or less in model layers 4–7. Corresponding differences within model layers 1–3 were about 0.2 ft or less. Simulated potentiometric levels within all layers along the general-head boundary in the vicinity of pumping wells were lower by a maximum of about 3 ft, and this change is reflected in increased flow across the boundary in model layers 1, 3, and 5, as expected (Table C11). These tests and the overall conformance of simulated predevelopment and transient conditions to the conceptual model indicate that boundaries and boundary conditions assigned to the active model domain are appropriate and that assigned no-flow and constant-head boundary conditions exerted only minimal influence on simulated transient results.

Monthly rates of effective recharge could not be computed because corresponding rates of surface runoff and evapotranspiration were not available from literature sources and could not be calculated with any reasonable accuracy, given available streamflow and meteorological data. To test the sensitivity of simulated results to monthly rather than annual variations in assigned recharge rates, a partial hydrologic budget for each month of the transient simulation was computed using total monthly precipitation and pan evaporation. The difference between monthly rates of precipitation and pan evaporation was assigned as effective recharge. Negative differences were assigned as zero recharge. These simulated results could not be directly compared to calibrated model results because surface runoff was not accounted for; also, pan evaporation does not equal evapotranspiration. However, simulated water-level changes from month to month and from year to year using the partial hydrologic budget were compared at model cells in the western part of the active model domain, far removed from areas of active pumping. Simulated month-to-month and year-to-year water-level changes were shown to be small, equaling only plus or minus several tenths of feet for any given year. Year-to-year changes were highly comparable to calibrated model results. This test indicates that varying annual, rather than monthly, rates of assigned effective recharge does not materially affect simulated water levels or water budgets from month to month or from year to year.

Summary

The MODFLOW code was used to simulate predevelopment and transient groundwater flow at Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina. Seven layers were assigned to the flow model mainly representing the Castle Hayne aquifer system. No-flow, constant-head, and general-head boundaries were assigned to define the active model domain. No-flow boundaries were assigned to the mid-channel of Northeast Creek, to the east and south, and to a topographic divide to the west. The general-head boundary was assigned along the northern perimeter of the active model domain and also approximately conformed to a topographic boundary. No-flow boundaries were equal in condition and location for each model layer. A constant head of zero was assigned in model layer 1 to the cells representing Northeast Creek. The base of simulated groundwater flow corresponds to the top of the Beaufort confining unit and is implicitly a no-flow boundary. Simulated predevelopment potentiometric levels indicated groundwater flows from highland areas toward Northeast and Frenchmans Creeks. Simulated potentiometric levels and flow directions were highly similar in all model layers. Simulated predevelopment recharge to the active model domain equaled about 2.1 cubic feet per second (cfs) from rainfall infiltration and 0.3 cfs from the general-head boundary and was discharged at rates of 1.6 cfs to Northeast Creek and 0.7 cfs to Frenchmans Creek. A difference in mass balance of 0.1 cfs is due to rounding error. Comparison of 59 observed water levels representing estimated predevelopment conditions and corresponding simulated potentiometric levels indicated a high degree of similarity throughout most of the study area. The average absolute difference between simulated and observed predevelopment water levels was 1.9 feet (ft), and the root-mean-square error of differences was 2.1 ft.

Transient simulations represented pumping at Tarawa Terrace water-supply wells for the period January 1951–December 1994. Groundwater flow was simulated for 528 stress periods representing 528 months. Assigned pumpage at supply wells was estimated using reported well capacity rates and annual rates of raw water treated at the Tarawa Terrace water treatment plant during 1975–1986. A total pumpage rate of 116,200 cubic feet per day was applied to the model for the period January 1952–December 1974 and represented the average rate reported during 1975–1986. Assigned pumpage at individual supply wells also conformed to known operational conditions, such as periods when a well was reportedly out of production for equipment repair or maintenance. Transient calibration was mainly based on comparisons of simulated and observed water levels. Several hundred measurements of water levels at Tarawa Terrace water-supply wells and at monitor wells installed during investigations of groundwater contamination were available for the period 1978–1994. Calibrated model results based on 789 paired water levels representing observed and simulated water levels at monitor wells and water-supply wells indicated an average absolute difference between simulated and observed water levels of 5.2 ft. The root-mean-square error of the absolute differences was 7.0 ft. Similar statistics varied considerably from supply well to supply well. The average absolute difference between simulated water levels at well TT-67 for the period 1979–1987 was 4.0 ft. The corresponding statistic at well TT-31 was 8.7 ft for about the same period of time.

Sensitivity analyses using transient calibration criteria indicated that simulation results were most sensitive to changes in horizontal hydraulic conductivity and assigned potentiometric levels along the general-head boundary. Simulation results were insensitive to changes in model arrays representing effective recharge, drain conductance, and specific storage.

Availability of Input Data Files, Models, and Simulation Results

Calibrated model input data files developed for simulating predevelopment groundwater flow, transient groundwater flow, the fate and transport of PCE as a single specie, and the distribution of water and contaminants in a water-distribution system are provided with Chapter A (Morris et al. 2007) of this report in a digital video disc (DVD) format. Public domain model codes used with these input files are available on the Internet at the following Web sites:

- Predevelopment and transient groundwater flow
  - Model code: MODFLOW-96
  - Web site: *http://water.usgs.gov/nrp/gwsoftware/modflow.html*
- Fate and transport of PCE as a single specie
  - Model code: MT3DMS
  - Web site: *http://hydro.geo.ua.edu/*
- Distribution of water and contaminants in a water-distribution system
  - Model code: EPANET 2
  - Web site: *http://www.epa.gov/nrmrl/wswrd/epanet.html*

Readers desiring information about the model input data files or the simulation results contained on the DVDs also may contact the Project Officer of ATSDR's Exposure-Dose Reconstruction Project at the following address:

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References

Baker Environmental, Inc. Basewide Remediation Assessment, Groundwater Study (BRAGS), U.S. Marine Corps Base, Camp Lejeune, North Carolina; 1998.

Cardinell AP, Berg SA, and Lloyd OB Jr. Hydrogeologic Framework of U.S. Marine Corps Base at Camp Lejeune, North Carolina. U.S. Geological Survey Water-Resources Investigations Report 93-4049; 1993.

Catlin Engineers and Scientists. Leaking Underground Storage Tank (LUST) Phase I, Limited Site Assessment Report for TT-44, Marine Corps Base Camp Lejeune, North Carolina. Raleigh, NC: Catlin Engineers and Scientists; 2002a. Report No.: N62470-95-D-6009.

Catlin Engineers and Scientists. Leaking Underground Storage Tank (LUST) Phase I, Limited Site Assessment Report for TT-2634, Marine Corps Base Camp Lejeune, North Carolina. Raleigh, NC: Catlin Engineers and Scientists; 2002b. Report No.: N62470-95-D-6009.

Chiang W-H and Kinzelbach W. 3D-Groundwater Modeling with PMWIN: Springer-Verlag; 2001.

CLW, Camp Lejeune Water Documents, 0001–8761 (not consecutively available), provided on DVD format, in Maslia ML, Sautner JB, Faye RE, Suárez-Soto RJ, Aral MM, Grayman WM, Jang W, Wang J, Bove FJ, Ruckart PZ, Valenzuela C, Green JW Jr, and Krueger AL. 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 A: Summary of Findings. Atlanta, GA: Agency for Toxic Substances and Disease Registry; 2007.

DiGiano FA, Miller CT, Roche AC, and Wallingford ED. Methodology for Assessment of Contamination of the Unsaturated Zone by Leaking Underground Storage Tanks: Water Resources Research Institute of the University of North Carolina; 1988.

Faye RE. 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. Atlanta, GA: Agency for Toxic Substances and Disease Registry; 2007.

Faye RE. 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 F: Simulation of the Fate and Transport of Tetrachloroethylene (PCE) Atlanta, GA: Agency for Toxic Substances and Disease Registry; In press 2007.

Faye RE, and Green JW Jr. Analyses of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Potable Water at Tarawa Terrace and Vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina: Historical Reconstruction and Present-Day Conditions—Chapter E: Occurrence of Contaminants in Groundwater. Atlanta, GA: Agency for Toxic Substances and Disease Registry; 2007.

Faye RE, and McFadden KW. Hydraulic Characteristics of Upper Cretaceous and Lower Tertiary Clastic Aquifers—Eastern Alabama, Georgia, and Western South Carolina: U.S. Geological Survey Water-Resources Investigations Report 86-4210; 1986.

Freeze RA, and Witherspoon PA. Theoretical Analysis of Regional Groundwater Flow: 1. Analytical and Numerical Solutions to the Mathematical Model: Water Resources Research, v. 2, no. 4; 1966.

Freeze RA, and Witherspoon PA. Theoretical Analysis of Regional Groundwater Flow: 2. Effect of Water-Table Configuration and Subsurface Permeability Variation: Water Resources Research, v. 3, no. 2; 1967.

Giese GL, and Mason RR Jr. Low-Flow Characteristics of Streams in North Carolina: U.S. Geological Survey Open-File Report 90-399; 1991.

Giese GL, Eimers JL, and Coble RW. Simulation of Groundwater Flow in the Coastal Plain Aquifer System of North Carolina: U.S. Geological Survey Professional Paper 1404-M; 1997.

Halford KJ, and Kuniansky EL. Documentation of Spreadsheets for the Analysis of Aquifer-Test and Slug-Test Data: U.S. Geological Survey Open-File Report 02-197; 2002.

Haliburton NUS Environmental Corporation. Draft Site Inspection Report, Site 07: Tarawa Terrace Dumps; 1992. Report No.: N62470-90-B-7629.

Harbaugh AW, and McDonald MG. User's Documentation for MODFLOW-96, and Update to the U.S. Geological Survey Modular Finite-Difference Groundwater-Flow Model: U.S. Geological Survey Open-File Report 96-458; 1996.

Harbaugh AW, Banta ER, Hill MC, and McDonald MG. MODFLOW-2000, The U.S. Geological Survey Modular Groundwater Model, User Guide to Modularization Concepts and the Groundwater Flow Process: U.S. Geological Survey Open-File Report 00-92; 2000.

Harned DA, Lloyd OB Jr, and Treece MW Jr. Assessment of Hydrologic and Hydrogeologic Data at Camp Lejeune Marine Corps Base, North Carolina. Raleigh, NC: U.S. Geological Survey Water-Resources Investigations Report 89-4096; 1989.

Heath RC. Groundwater Recharge in North Carolina: Groundwater Section, Division of Environmental Management, North Carolina Department of Environment, Health, and Natural Resources; 1994.

Henry Von Oesen and Associates, Inc. Study of Two Water Plants, Tarawa Terrace–Montford Point, Camp Lejeune, North Carolina; 1979.

Hill MC, Banta ER, Harbaugh AW, and Anderman ER. MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model—User Guide to the Observation, Sensitivity, and Parameter-Estimation Processes and Three Post-Processing Programs: U.S. Geological Survey Open-File Report 00-184; 2000.

Hubbard MK. The Theory of Groundwater Motion, Part 1, Part 2: The Journal of Geology, v. XLVIII; 1940.

Industrial Marine Services, Inc. Delineation and Proposed Recovery of a Subsurface Fuel Plume, Camp Lejeune. Norfolk, VA: IMS Inc.; 1985.

Law Engineering, Inc. Leaking Underground Storage Tank Site Assessment Report, Building TT2478, Marine Corps Base, Camp Lejeune, North Carolina, vol. I & II; 1994a,b.

Law Engineering, Inc. Leaking Underground Storage Tank Site Assessment Report, Building TT2477, Marine Corps Base, Camp Lejeune, North Carolina, vol. I & II; 1995a,b.

Law Engineering and Environmental Services, Inc. Corrective Action Plan for the Recovery of Free Product and the Restoration of Petroleum Contaminated Soil and Groundwater, Building TT-2477/2478, Marine Corps Base, Camp Lejeune, Onslow County, North Carolina; 1996. Report No.: 7176.

Law Engineering and Environmental Services, Inc. Leaking Underground Storage Tank Limited Site Assessment Addendum, UST TT-48-2, Tarawa Terrace II Elementary School, Marine Corps Base Camp Lejeune, North Carolina; 1998. Report No.: 30740-6-06009.

Law Engineering and Testing Company, Inc. On-Site Sampling—Septic Tank and Outlying Area, ABC One-Hour Cleaners Inc., Jacksonville, North Carolina LETCO Job; 1986a. Report No.: J-473-86-1623.

Law Engineering and Testing Company, Inc. On-Site Sampling ABC One-Hour Cleaners Inc., Jacksonville, North Carolina; 1986b.

LeGrand HE. Evaluation of Well-Water Supply, Marine Corps Base, Camp Lejeune, North Carolina: Project Report, Contract NBy-7595; 1959.

Maslia ML, Sautner JB, Faye RE, Suárez-Soto RJ, Aral MM, Grayman WM, Jang W, Wang J, Bove FJ, Ruckart PZ, Valenzuela C, Green JW Jr, and Krueger AL. 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 K: Supplemental Information. Atlanta, GA: Agency for Toxic Substances and Disease Registry; In press 2008.

McDonald MG, and Harbaugh AW. A Modular Three-Dimensional Finite-Difference Groundwater-Flow Model: U.S. Geological Survey Open-File Report 83-875; 1984.

McMorris CA. Site Inspection Report—ABC One Hour Cleaners, NC DO24644494, 2127 Lejeune Boulevard, Jacksonville, NC, 28340: North Carolina Solid and Hazardous Waste Branch, Environmental Health Section; 1987.

Mid-Atlantic Associates, Inc. Leaking Underground Storage Tank, Phase I Limited Site Assessment, UST TT-2302/2304, Tarawa Terrace II Housing Area, Marine Corps Base Camp Lejeune, North Carolina: Mid-Atlantic Associates, Inc.; 2003a. Report No.: N62470-90-R-7626.

Mid-Atlantic Associates, Inc. Leaking Underground Storage Tank, Phase I Limited Site Assessment, UST TT-3546/3548 Site, Tarawa Terrace II Housing Area, Marine Corps Base Camp Lejeune, North Carolina: Mid-Atlantic Associates, Inc.; 2003b. Report No.: N62740-95-D-6009.

Mid-Atlantic Associates, P.A. Leaking Underground Storage Tank (LUST), Phase I Limited Site Assessment Report for UST TT-779 Site, Tarawa Terrace I Housing Area, Marine Corps Base Camp Lejeune, North Carolina: Mid-Atlantic Associates, P.A.; 2002a. Report No.: N62470-01-D-3009.

Mid-Atlantic Associates, P.A. Leaking Underground Storage Tank (LUST), Phase I Limited Site Assessment Report for UST TT-2254/2256 Site, Tarawa Terrace II Housing Area, Marine Corps Base Camp Lejeune, North Carolina: Mid-Atlantic Associates, P.A.; 2002b. Report No.: N62470-01-D-3009.

Mid-Atlantic Associates, P.A. Leaking Underground Storage Tank (LUST), Phase I Limited Site Assessment Report for UST TT-2258/2260 Site, Tarawa Terrace II Housing Area, Marine Corps Base Camp Lejeune, North Carolina: Mid-Atlantic Associates, P.A.; 2002c. Report No.: N62470-01-D-3009.

Mid-Atlantic Associates, P.A. Leaking Underground Storage Tank (LUST), Phase I Limited Site Assessment Report for UST TT-3140/3142 Site, Tarawa Terrace II Housing Area, Marine Corps Base Camp Lejeune, North Carolina: Mid-Atlantic Associates, P.A.; 2002d. Report No.: N62470-01-D-3009.

Mid-Atlantic Associates, P.A. Leaking Underground Storage Tank, Phase I Limited Site Assessment, UST TT-3165/3167, Marine Corps Base Camp Lejeune, North Carolina: Mid-Atlantic Associates, P.A.; 2002e. Report No.: N62470-01-D-3009.

Mid-Atlantic Associates, P.A. Leaking Underground Storage Tank, Phase I Limited Site Assessment, UST TT-3233/3235, Marine Corps Base Camp Lejeune, North Carolina: Mid-Atlantic Associates P.A.; 2002f. Report No.: N62470-01-D-3009.

Mid-Atlantic Associates, P.A. Leaking Underground Storage Tank (LUST), Phase I Limited Site Assessment Report for UST TT-3524/3526 Site, Tarawa Terrace II Housing Area, Marine Corps Base Camp Lejeune, North Carolina: Mid-Atlantic Associates, P.A.; 2002g. Report No.: N62470-01-D-3009.

Newcome R Jr. Pumping Tests of the Coastal Plain Aquifers in South Carolina: South Carolina Water Resources Commission Report 174; 1993.

O'Brien & Gere Engineers, Inc. Site Assessment, Tank STT61–STT66, Tarawa Terrace, Marine Corps Base, Camp Lejeune, North Carolina; 1992.

O'Brien & Gere Engineers, Inc. Addendum Site Assessment, Tanks STT61–STT66, Tarawa Terrace, Marine Corps Base Camp Lejeune; 1993.

OHM Remediation Services Corp. Final Additional Investigation Report, Buildings TT-2477/78, Marine Corps Base Camp Lejeune, North Carolina, Contract No. N62470-97-D-9000; 2001.

Poland JF, Lofgren BF, and Riley FS. Glossary of Selected Terms Useful in Studies of the Mechanics of Aquifer System and Land Subsidence Due to Fluid Withdrawal: U.S. Geological Survey Water-Supply Paper 2025; 1972.

Pollock DW. Documentation of Computer Programs to Compute and Display Pathlines Using Results from the U.S. Geological Survey Modular Three-Dimensional Finite-Difference Groundwater Model: U.S. Geological Survey Open-File Report 89-381; 1989.

Pollock DW. User's Guide for MODPATH/MODPATH-PLOT, Version 3: A Particle Tracking Post-Processing Package for MODFLOW, the U.S. Geological Survey Finite-Difference Groundwater-Flow Model: U.S. Geological Survey Open-File Report 94-464; 1994.

Richard Catlin & Associates, Inc. Leaking Underground Storage Tank Comprehensive Site Assessment, Building TT-2455, Marine Corps Air Station New River, Jacksonville, North Carolina, Volume I: Richard Catlin & Associates, Inc.; 1994a. Contract No.: N62470-93-D-4020.

Richard Catlin & Associates, Inc. Leaking Underground Storage Tank Comprehensive Site Assessment, Building TT-2455, Marine Corps Air Station New River, Jacksonville, North Carolina, Volume II: Richard Catlin & Associates, Inc.; 1994b. Contract No.: N62470-93-D-4020.

Richard Catlin & Associates, Inc. Leaking Underground Storage Tank Comprehensive Site Assessment Buildings TT-2465, TT-2465, TT-2467 and TT-2471, Marine Corps Base, Camp Lejeune, North Carolina, Volume I: Richard Catlin & Associates, Inc.; 1995a. Contract No.: N62470-93-D-4020.

Richard Catlin & Associates, Inc. Leaking Underground Storage Tank Comprehensive Site Assessment, Buildings TT-2463, TT-2465, TT-2467 and TT-2471, Marine Corps Base Camp Lejeune, North Carolina. Volume II: Richard Catlin & Associates, Inc.; 1995b. Contract No.: N62470-93-D-4020.

Richard Catlin & Associates, Inc. Leaking Underground Storage Tanks Corrective Action Plan, UST TT-2463-2473, Marine Corps Base, Camp Lejeune, North Carolina: Richard Catlin & Associates, Inc.; 1996. Contract No.: N62470-93-D-4020.

Richard Catlin & Associates, Inc. Leaking Underground Storage Tanks Corrective Action Plan Building TT-2455, Marine Corps Base Camp Lejeune, North Carolina: Richard Catlin & Associates, Inc.; 1998. Contract No.: N62470-93-D-4020.

Roy F. Weston, Inc. Remedial Investigation Report, ABC One-Hour Cleaners, Jacksonville, North Carolina: Roy F. Weston, Inc.; 1992.

Roy F. Weston, Inc. Remedial Investigation Report, ABC One-Hour Cleaners, Operable Unit 2, Jacksonville, North Carolina: Roy F. Weston, Inc.; 1994.

Shiver RA. Groundwater Investigation to Define the Source(s) of Tetrachloroethylene that Have Contaminated Three Community Water Supply Wells at Tarawa Terrace I, Camp Lejeune Marine Corps Base, Onslow County: North Carolina Department of Natural Resources and Community Development; 1985.

Thompson DG. Groundwater Supplies in the Vicinity of Jacksonville, North Carolina: U.S. Geological Survey Memorandum to the Record, May 20, 1941, to Rear Admiral, Ben Moreell, Chief, Bureau of Yards and Docks, Navy Department; 1941.

Toth JA. Theoretical Analysis of Groundwater Motion in Small Drainage Basins in Central Alberta, Canada: Journal of Geophysical Research, v. 67, no. 11; 1962.

Toth JA. Theoretical Analysis of Groundwater Flow in Small Drainage Basins: Journal of Geophysical Research, v. 68, no. 16; 1963.

Appendix C1. Water-Level Measurements in Selected Wells, Tarawa Terrace and Vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina

Tables

Sources:
Catlin Engineers and Scientists 2002a,b
DiGiano et al. 1988
Haliburton NUS Environmental Corporation 1992
Law Engineering and Environmental Services, Inc. 1996, 1998
Law Engineering, Inc. 1994a,b, 1995a,b
Mid-Atlantic Associates, Inc. 2003a,b
Mid-Atlantic Associates, P.A. 2002a,b,c,d,e,f,g
O'Brien & Gere Engineers, Inc. 1992, 1993
OHM Remediation Services Corp, 2001
Richard Catlin & Associates, Inc. 1994a,b, 1995a,b, 1996, 1998
U.S. Geological Survey well inventory, written communication, October 21, 1986

Table C1.1. Water-level measurements in Tarawa Terrace supply wells TT-23, TT-27, and TT-55, test well T-9, and Civilian Conservation Corps well CCC-1 used during model calibration, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[NGVD, National Geodetic Vertical Datum of 1929; –, below NGVD 29; contributing aquifers: UCHRBU&LU, Upper Castle Hayne aquifer–River Bend and Lower units; MCH, Middle Castle Hayne aquifer; UCH, Upper Castle Hayne aquifer–undifferentiated; UCHRBU, Upper Castle Hayne aquifer–River Bend unit]

Site name[1]	Location coordinates[2]		Land-surface altitude, in feet above NGVD 29	Contributing aquifers	Measurement date	Water-level altitude, in feet above or below NGVD 29
	North	East				
TT-23	363208	2491024	23.9	UCHRBU&LU, MCH	3/14/1983	–1.8
					9/25/1985	1.1
					10/21/1986	2.2
					4/7/1987	9.3
					9/4/1984	[3]19
					9/31/1984	[3]12
					10/14/1984	[3]16
					10/31/1984	[3]16
					11/30/1984	[3]16
					1/31/1985	[3]16
TT-27	364794	2489026	26.4	UCH	1/10/1963	16.6
					4/17/1963	18.4
					1/16/1964	19.4
					7/14/1964	19.0
					9/17/1964	20.6
					10/14/1964	21.9
TT-55	364767	2489069	26.4	UCH	11/1/1961	18.9
T-9	364648	2490489	28.7	UCHRBU&LU	9/24/1986	17.5
					10/21/1986	19.1
					4/10/1987	23.4
CCC-1	360997	2483873	24.3	UCHRBU	9/17/1941	3.3

[1]See Plate 1 for location

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

[3]Airline measurements. Not used for model calibration

Table C1.2. Water-level measurements in supply well TT-25[1] used during model calibration, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

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

Contributing aquifer—Middle Castle Hayne aquifer, Upper Castle Hayne aquifer–River Bend unit and –Lower unit

Location coordinates[2], 364042 North, 2491984 East

Land-surface altitude, 32.0 feet above NGVD 29

Measurement date	Water-level altitude, in feet above or below NGVD 29	Measurement date	Water-level altitude, in feet above or below NGVD 29
11/14/1980	6.0	11/30/1984	–11
7/9/1981	0.0	12/31/1984	–10
10/31/1982	–13	1/31/1985	–10
12/31/1982	–13	6/30/1985	–2
1/31/1983	–14	7/31/1985	–3
2/28/1983	–13	8/31/1985	–3
3/31/1983	–10	9/11/1985	–6
4/30/1983	–9	9/25/1985	–26.2
5/31/1983	–9	9/30/1985	–4
7/31/1983	–10	10/31/1985	–6
8/31/1983	–12	11/30/1985	3
9/30/1983	–12	12/31/1985	–6
10/31/1983	–15	1/31/1986	–3
11/30/1983	–11	2/28/1986	–3
12/31/1983	–9	3/31/1986	–5
1/31/1984	–11	4/30/1986	3
5/31/1984	–10	10/21/1986	3
6/30/1984	–11	4/7/1987	10.9
7/31/1984	–10		
8/31/1984	–9		
9/30/1984	–5		
10/31/1984	–5		

[1]See Figure C1 for location

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

Table C1.3. Water-level measurements in supply well TT-26[1] used during model calibration, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

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

Contributing aquifer—Upper Castle Hayne aquifer–Lower unit

Location coordinates[2], 364356 North, 2491461 East

Land-surface altitude, 34.0 feet above NGVD 29

Measurement date	Water-level altitude, in feet above or below NGVD 29	Measurement date	Water-level altitude, in feet above or below NGVD 29
5/16/1951	14.0	11/30/1981	2
1/31/1978	7	4/30/1982	–10
2/28/1978	7	6/30/1982	–14
3/31/1978	6	9/14/1982	–5
4/30/1978	7	10/31/1982	–15
5/31/1978	7	12/31/1982	2
6/30/1978	6	1/31/1983	2
7/31/1978	6	2/28/1983	4
8/31/1978	7	3/31/1983	4
9/30/1978	6	4/30/1983	4
10/31/1978	6	5/31/1983	–13
11/30/1978	6	6/30/1983	4
12/31/1978	6	9/30/1983	–22
1/31/1979	5	10/31/1983	3
2/28/1979	6	11/30/1983	–2
3/31/1979	8	12/31/1983	4
4/30/1979	6	3/31/1984	–6
6/30/1979	6	5/31/1984	4
7/31/1979	5	6/30/1984	–2
9/30/1979	5	9/30/1984	8
2/29/1980	6	10/31/1984	8
3/31/1980	2	11/30/1984	3
4/30/1980	–8	12/31/1984	3
5/31/1980	6	1/31/1985	1
10/31/1980	–7	6/30/1985	6
12/31/1980	–8	7/31/1985	2
1/31/1981	0	9/30/1985	2
2/28/1981	–2	10/31/1985	2
3/31/1981	0	11/30/1985	4
4/30/1981	2	10/21/1986	7.4
6/30/1981	0	4/7/1987	14.0
7/31/1981	2		
8/31/1981	–1		
10/31/1981	–2		

[1]See Figure C1 for location

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

Table C1.4. Water-level measurements in supply well TT-30[1] used during model calibration, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

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

Contributing aquifers—Upper Castle Hayne aquifer–River Bend unit and –Lower unit

Location coordinates[2], 365044 North, 2487130 East

Land-surface altitude, 26 feet above NGVD 29

Measurement date	Water-level altitude, in feet above or below NGVD 29	Measurement date	Water-level altitude, in feet above or below NGVD 29
1/31/1978	4	9/30/1981	–6
2/28/1978	4	10/31/1981	–10
3/31/1978	6	3/31/1982	16
4/30/1978	5	4/30/1982	11
5/31/1978	4	6/30/1982	7
6/30/1978	5	7/31/1982	9
7/31/1978	4	8/31/1982	13
8/31/1978	–2	9/30/1982	11
9/30/1978	0	10/31/1982	10
10/31/1978	–2	12/31/1982	9
11/30/1978	–1	1/31/1983	9
12/31/1978	–3	2/28/1983	9
1/31/1979	–2	3/31/1983	9
2/28/1979	–2	4/30/1983	9
3/31/1979	2	5/31/1983	13
4/30/1979	–2	6/30/1983	10
6/30/1979	–1	7/31/1983	10
7/31/1979	–2	8/31/1983	10
8/31/1979	–2	9/30/1983	10
9/30/1979	–4	10/31/1983	10
1/31/1980	–4	11/30/1983	–7
2/29/1980	–4	12/31/1983	11
3/31/1980	–6	1/31/1984	10
4/30/1980	3	2/29/1984	10
5/31/1980	–6	3/31/1984	15
7/31/1980	–4	4/30/1984	12
8/31/1980	–2	5/31/1984	11
9/30/1980	–4	6/30/1984	11
10/31/1980	–6	7/31/1984	11
12/31/1980	–6	9/30/1984	11
1/31/1981	–8	10/31/1984	11
2/28/1981	–7	11/30/1984	11
3/31/1981	–6	12/31/1984	11
4/30/1981	–4	1/31/1985	11
5/31/1981	–5	4/30/1985	11
6/30/1981	–6		
7/31/1981	–7		
8/31/1981	–5		

[1]See Figure C1 for location

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

Table C1.5. Water-level measurements in supply well TT-31[1] used during model calibration, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

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

Contributing aquifer—Upper Castle Hayne aquifer–undifferentiated

Location coordinates[2], 362224 North, 2489843 East

Land-surface altitude, 25.8 feet above NGVD 29

Measurement date	Water-level altitude, in feet above or below NGVD 29
10/31/1978	–2
11/30/1978	–1
7/31/1979	–3
8/31/1979	–2
9/30/1979	2
1/31/1980	–3
2/29/1980	–2
3/31/1980	–2
4/30/1980	12
5/31/1980	0
7/31/1980	0
8/31/1980	–2
12/31/1980	–4
1/31/1981	–8
2/28/1981	–6
3/31/1981	–8
5/31/1981	–4
6/30/1981	–5
7/31/1981	–3
10/31/1981	–6
11/30/1981	–8
6/30/1982	–6
7/31/1982	–3
9/14/1982	–8
10/31/1982	–4
12/31/1982	3
1/31/1983	4
2/28/1983	2
3/31/1983	4
4/30/1983	8
5/31/1983	8
10/31/1983	3
11/30/1983	6
12/31/1983	–8
3/31/1984	–6
5/31/1984	8
7/6/1984	–4
9/30/1984	–4
10/31/1984	–4
11/30/1984	–6
12/31/1984	–4
1/31/1985	–5
3/31/1985	–5
6/30/1985	–3
7/31/1985	–11
8/31/1985	–3
9/30/1985	–4
9/13/1985	–5
9/30/1985	–3
10/31/1985	–3
11/30/1985	–8
12/31/1985	–6
1/31/1986	–5
2/29/1986	–6
4/30/1986	–2
10/21/1986	–0.1
4/7/1987	5.2

[1]See Figure C1 for location

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

Table C1.6. Water-level measurements in supply well TT-52[1] used during model calibration, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

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

Contributing aquifer—Upper Castle Hayne aquifer–undifferentiated

Location coordinates[2], 362321 North, 2489060 East

Land-surface altitude, 24.9 feet above NGVD 29

Measurement date	Water-level altitude, in feet above or below NGVD 29
10/17/1961	12.9
3/28/1962	9
1/31/1978	–5
2/28/1978	–4
3/31/1978	–5
4/30/1978	–5
5/31/1978	–1
6/30/1978	–3
7/31/1978	–1
8/31/1978	–3
9/30/1978	–3
10/31/1978	–3
11/30/1978	–4
12/31/1978	–7
1/31/1979	–7
2/28/1979	–4
3/31/1979	–5
6/30/1979	–4
7/31/1979	–4
8/31/1979	–3
9/30/1979	–4
1/31/1980	–4
2/29/1980	–3
3/31/1980	–4
4/30/1980	–4
5/31/1980	–4
7/31/1980	–5
8/31/1980	–5
12/31/1980	–6
1/31/1981	–7
2/28/1981	–6
3/31/1981	–9
4/30/1981	–9
5/31/1981	–5
6/30/1981	–5
7/31/1981	–7
10/31/1981	–9
11/30/1981	–7
4/30/1982	–5
6/30/1982	–5
7/31/1982	–6
9/14/1982	–9
12/31/1982	–6
1/31/1983	–6
2/28/1983	–9
3/31/1983	–2
4/30/1983	–2
5/31/1983	–1
10/31/1983	–4
11/30/1983	–2
12/31/1983	–2
3/31/1984	–4
4/30/1984	–2
5/31/1984	–2
6/30/1984	–3
7/31/1984	–3
9/30/1984	–2
10/31/1984	3
11/30/1984	3
12/31/1984	–2
1/31/1985	–2
5/31/1985	–5
6/30/1985	2
7/31/1985	0
8/31/1985	–1
9/11/1985	5
9/30/1985	4
10/31/1985	3
11/30/1985	5
12/31/1985	4
1/31/1986	–2
2/28/1986	5
3/31/1986	–7
4/30/1986	5
10/21/1986	1.8
4/7/1987	5.0

[1]See Figure C1 for location

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

Table C1.7. Water-level measurements in supply well TT-53[1] used during model calibration, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

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

Contribution aquifer—Upper Castle Hayne aquifer–River Bend and –Lower units

Location coordinates[2], 363360 North, 2489800 East

Land-surface altitude, 25 feet above NGVD 29

Measurement date	Water-level altitude, in feet above or below NGVD 29
7/22/1961	14
3/28/1962	11
1/31/1978	–4
2/28/1978	–5
3/31/1978	–3
4/30/1978	–5
5/31/1978	–5
6/30/1978	–4
7/31/1978	–4
8/31/1978	0
9/30/1978	–3
12/31/1978	–2
1/31/1979	–2
2/28/1979	–4
3/31/1979	–2
4/30/1979	–8
6/30/1979	–6
7/31/1979	–4
1/31/1980	–4
2/29/1980	–5
3/31/1980	–1
4/30/1980	–2
5/31/1980	–5
7/31/1980	–7
8/31/1980	–3
9/30/1980	–7
12/31/1980	–3
1/31/1981	–9
2/28/1981	–7
3/31/1981	–9
4/30/1981	–9
6/30/1981	–9
10/31/1981	–9
11/30/1981	–8
1/31/1982	–9
3/31/1982	–13
4/30/1982	–8
6/30/1982	–22
7/31/1982	–15
8/31/1982	–15
12/31/1982	–19
1/31/1983	–19
2/28/1983	–19
3/31/1983	–11
4/30/1983	–11
5/31/1983	–10
10/31/1983	–9
11/30/1983	–13
12/31/1983	–13
1/31/1984	–11
8/6/1986	1
4/7/1987	10

[1]See Figure C1 for location

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

Table C1.8. Water-level measurements in supply well TT-54[1] used during model calibration, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

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

Contribution aquifer—Upper Castle Hayne aquifer–undifferentiated

Location coordinates[2], 362090 North, 2490630 East

Land-surface altitude, 22.1 feet above NGVD 29

Measurement date	Water-level altitude, in feet above or below NGVD 29	Measurement date	Water-level altitude, in feet above or below NGVD 29
6/30/1961	12.1	7/31/1982	–10
3/28/1962	6	9/30/1982	–10
1/31/1978	–7	9/14/1982	–12
2/28/1978	–6	10/31/1982	–10
3/31/1978	–6	11/30/1982	–10
4/30/1978	–5	12/31/1982	–9
5/31/1978	–7	1/31/1983	–9
6/30/1978	–6	2/28/1983	–8
7/31/1978	–7	3/31/1983	–8
8/31/1978	–6	4/30/1983	–8
9/30/1978	–6	5/31/1983	–8
10/31/1978	–6	6/30/1983	–8
11/30/1978	–7	10/31/1983	–9
12/31/1978	–7	11/30/1983	–7
1/31/1979	–7	12/31/1983	0
2/28/1979	–8	1/31/1984	–9
3/31/1979	–6	2/29/1984	–8
4/30/1979	–7	5/31/1984	–8
6/30/1979	–8	6/30/1984	–10
8/31/1979	–6	7/31/1984	–8
1/31/1980	–7	9/30/1984	–8
2/29/1980	–6	10/31/1984	–8
3/31/1980	–8	11/30/1984	–9
4/30/1980	–10	12/1/1984	–8
5/31/1980	–8	1/31/1985	–12
7/31/1980	–6	2/28/1985	–14
8/31/1980	–8	4/30/1985	–12
12/31/1980	–8	6/30/1985	–2
1/31/1981	–11	7/31/1985	–13
2/28/1981	–11	8/31/1985	–12
3/31/1981	–12	9/30/1985	–8
4/30/1981	–10	9/13/1985	–8
5/31/1981	–8	10/31/1985	–10
7/31/1981	–10	11/30/1985	–1
8/31/1981	–8	12/31/1985	–8
10/31/1981	–12	1/31/1986	–6
11/30/1981	–10	2/30/1986	–9
1/31/1982	–11	3/31/1986	–10
3/31/1982	–10	4/30/1986	–8
4/30/1982	–9	10/21/1986	0.4
5/31/1982	–10	4/7/1987	6.7
6/30/1982	–10		

[1]See Figure C1 for location

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

Table C1.9. Water-level measurements in supply well TT-67[1] used during model calibration, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

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

Measurement date	Water-level altitude, in feet above or below NGVD 29	Measurement date	Water-level altitude, in feet above or below NGVD 29
Contribution aquifer—Upper Castle Hayne aquifer–Lower unit			
Location coordinates[2], 362730 North, 2490160 East			
Land-surface altitude, 27.5 feet above NGVD 29			
3/31/1979	–14	4/30/1983	–4
4/30/1979	–12	5/18/1983	–5
6/30/1979	–12	5/31/1983	–5
7/31/1979	–10	6/30/1983	–4
8/31/1979	–10	10/31/1983	–3
9/30/1979	–8	11/30/1983	–6
1/31/1980	–8	12/31/1983	–6
2/29/1980	–10	3/31/1984	10
3/31/1980	–4	5/31/1984	–4
4/30/1980	–12	6/30/1984	–1
5/31/1980	–10	8/21/1984	–3
7/31/1980	–8	9/30/1984	–5
8/31/1980	–10	10/31/1984	–5
10/31/1980	–6	11/30/1984	0
12/31/1980	–8	12/31/1984	–1
1/31/1981	–10	1/31/1985	–4
2/28/1981	–10	3/31/1985	–4
3/31/1981	–8	7/31/1985	–2
4/30/1981	–6	8/31/1985	–4
6/30/1981	–4	9/13/1985	–2
7/31/1981	–8	9/30/1985	–4
10/31/1981	–6	10/31/1985	–3
11/30/1981	–8	11/30/1985	–2
1/31/1982	–11	12/31/1985	–4
3/31/1982	–7	1/31/1986	–2
4/30/1982	–9	2/29/1986	–4
6/30/1982	–11	3/31/1986	–5
7/31/1982	–12	4/30/1986	–10
9/14/1982	–8	4/7/1987	8.4
10/31/1982	–6		
12/31/1982	–6		
1/31/1983	–7		
2/28/1983	–6		
3/31/1983	–4		

[1]See Figure C1 for location

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

Table C1.10. Water-level measurements in ABC One-Hour Cleaners Operable Units 1 and 2 monitor wells and North Carolina Department of Natural Resources and Community Development monitor wells used during model calibration, 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]

Site name[1]	Location coordinates[2]		Land-surface altitude, in feet above NGVD 29	Contributing aquifers	Measurement date	Water-level altitude, in feet above NGVD 29
	North	East				
C1	365232	2490503	30.6	UCHLU	4/22/1992	21.5
					6/2/1992	20.8
					6/25/1992	21.2
C2	364902	2490793	32.0	UCHLU	4/22/1992	19.6
					6/2/1992	19.0
					6/25/1992	19.6
C3	364437	2491433	33.4	UCHLU	4/22/1992	15.8
					6/2/1992	14.7
					6/25/1992	15.6
C4	364045	2492080	32.2	MCH	4/22/1992	11.9
					6/2/1992	11.3
					6/25/1992	10.2
C5	364107	2491233	32.0	UCHLU	4/22/1992	15.7
					6/2/1992	15.0
					6/25/1992	15.9
C9	364800	2491730	32.1	UCHLU	10/1/1993	12.4
					11/18/1993	13.0
C10	364360	2491380	32.5	MCH	11/18/1993	12.6
C11	362300	2492130	31.0	UCHLU	10/1/1993	6.3
PZ-01	364860	2490667	31.9	UCHLU	10/1/1993	15.9
					11/18/1993	16.7
PZ-02	364860	2490677	31.9	UCHRBU	10/1/1993	16.0
					11/18/1993	16.7
PZ-03	364858	2490812	32.5	UCHLU	10/1/1993	15.6
					11/18/1993	16.6
PZ-04	364858	2490812	32.5	UCHRBU	10/1/1993	15.8
					11/18/1993	16.4
PZ-05	364926	2490707	32.0	UCHLU	10/1/1993	15.7
PZ-06	364926	2490707	32.0	UCHRBU	10/1/1993	16.1
S1	365251	2490534	30.6	TT, UCHRBU(?)	4/22/1992	23.7
					6/2/1992	23.3
					6/25/1992	22.6
					10/1/1993	17.4
					11/18/1993	18.3
S2	364883	2490787	32.5	UCHRBU	4/22/1992	19.9
					6/2/1992	19.2
					6/25/1992	19.8
					10/1/1993	16.4
					11/18/1993	16.6
S3	364357	2491413	33.4	TT, UCHRBU	4/22/1992	16.0
					6/2/1992	14.8
					6/25/1992	15.8
					10/1/1993	13.1
					11/18/1993	13.6

Table C1.10. Water-level measurements in ABC One-Hour Cleaners Operable Units 1 and 2 monitor wells and North Carolina Department of Natural Resources and Community Development monitor wells used during model calibration, 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]

Site name[1]	Location coordinates[2]		Land-surface altitude, in feet above NGVD 29	Contributing aquifers	Measurement date	Water-level altitude, in feet above NGVD 29
	North	East				
S4	364065	2492060	32.2	TT, UCHRBU(?)	4/22/1992	13.6
					6/2/1992	12.4
					6/25/1992	11.9
					10/1/1993	11.2
					11/18/1993	13.5
S5	364081	2491244	31.9	TT, UCHRBU(?)	4/22/1992	16.4
					6/2/1992	15.2
					6/25/1992	16.2
					10/1/1993	13.5
					11/18/1993	13.7
S6	364938	2490617	31.1	TT, UCHRBU	4/22/1992	20.6
					6/2/1992	20.0
					6/25/1992	20.5
					10/1/1993	16.3
					11/18/1993	17.1
S7	364753	2490732	31.3	TT, UCHRBU	4/22/1992	19.8
					6/2/1992	19.0
					6/25/1992	19.4
					10/1/1993	15.8
					11/18/1993	16.6
S8	364938	2491312	30.8	TT, UCHRBU	4/22/1992	20.9
					6/2/1992	19.8
					6/25/1991	21.1
					10/1/1993	18.8
					11/18/1993	19.0
S9	364593	2491682	32.7	TT, UCHRBU	4/22/1992	15.4
					6/2/1992	14.2
					6/25/1992	13.3
					10/1/1993	12.5
					11/18/1993	13.0
S10	363818	2491922	31.6	TT, UCHRBU	4/22/1992	12.2
					6/2/1992	12.8
					6/25/1992	13.3
					10/1/1993	12.4
					11/18/1993	12.7
S11	365390	2489710	30.8	TT, UCHRBU	10/1/1993	17.9
					11/18/1993	19.0
[3]X24B4	364530	2491570	32.3	UCHRBU	9/25/1985	5.0
[3]X24B5	364640	2491050	31.0	UCHRBU	9/25/1985	7.7
[3]X24B6	364810	2490710	33.2	UCHRBU	9/25/1985	10.4

[1]See Plate 1 for location

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

[3]On Plate 1 shown as B4, B5, and B6, respectively

Table C1.11. Water-level measurements in monitor wells installed during investigations of releases of refined petroleum products to groundwater and used during model calibration, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[NGVD 29, National Geodetic Vertical Datum of 1929; contributing aquifers: TT, Tarawa Terrace aquifer; UCHRBU, Upper Castle Hayne aquifer–River Bend unit]

Site name[1]	Location coordinates[2]		Land-surface altitude, in feet above NGVD 29	Contributing aquifers	Measurement date	Water-level altitude, in feet above NGVD 29
	North	East				
STT61to66-MW01	364847	2489130	26.9	TT	1/8/1992	20.6
					1/11/1992	20.7
					1/29/1992	21.6
					12/17/1992	21.1
STT61to66-MW02	364847	2489130	26.8	TT, UCHRBU	1/8/1992	20.2
					1/11/1992	20.1
					1/29/1992	21.6
					12/17/1992	20.4
STT61to66-MW03	364740	2489186	27.1	TT	1/9/1992	20.4
					1/11/1992	20.3
					1/29/1992	21.3
					12/17/1992	21.0
STT61to66-MW04	364740	2489186	27	TT, UCHRBU	1/9/1992	20.1
					1/11/1992	20.9
					1/29/1992	20.7
					12/17/1992	20.4
STT61to66-MW05	364818	2489276	27.5	TT	1/9/1992	20.9
					1/11/1992	18.9
					1/29/1992	19.6
					12/17/1992	21.3
STT61to66-MW06	364816	2489276	27.6	TT, UCHRBU	1/9/1992	20.4
					1/11/1992	20.1
					1/29/1992	20.8
					12/17/1992	20.5
STT61to66-MW07	364885	2489219	27.7	TT	1/9/1992	20.9
					1/11/1992	20.9
					1/29/1992	21.5
					12/17/1992	21.1
STT61to66-MW08	364885	2489219	27.7	TT, UCHRBU	1/9/1992	19.8
					1/11/1992	19.9
					1/29/1992	20.8
					12/17/1992	20.5
STT61to66-MW09	364732	2489102	27.1	TT	1/9/1992	20.9
					1/11/1992	20.8
					1/29/1992	21.6
					12/17/1992	21.4
STT61to66-MW10	364732	2489102	27	TT, UCHRBU	1/9/1992	20.7
					1/11/1992	20.0
					1/29/1992	20.7
					12/17/1992	20.4
STT61to66-MW11	364700	2489241	27.6	TT	1/10/1992	20.1
					1/11/1992	20.9
					1/29/1992	21.9
					12/17/1992	21.5

Table C1.11. Water-level measurements in monitor wells installed during investigations of releases of refined petroleum products to groundwater and used during model calibration, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.—Continued

[NGVD 29, National Geodetic Vertical Datum of 1929; contributing aquifers: TT, Tarawa Terrace aquifer; UCHRBU, Upper Castle Hayne aquifer–River Bend unit]

Site name[1]	Location coordinates[2]		Land-surface altitude, in feet above NGVD 29	Contributing aquifers	Measurement date	Water-level altitude, in feet above NGVD 29
	North	East				
STT61to66-MW12	364700	2489241	27.5	TT, UCHRBU	1/10/1992	19.7
					1/11/1992	19.8
					1/29/1992	20.6
					12/17/1992	20.3
STT61to66-MW13	364612	2489148	26.2	TT	1/11/1992	20.4
					1/11/1992	20.2
					1/29/1992	21.8
					12/17/1992	21.2
STT61to66-MW14	364612	2489148	26.2	TT, UCHRBU	1/11/1992	19.8
					1/11/1992	19.7
					1/29/1992	20.5
					12/17/1992	20.3
STT61to66-MW15	364754	2489310	26.3	TT	12/17/1992	21.0
STT61to66-MW16	364603	2489247	25.6	TT, UCHRBU	12/17/1992	20.2
STT61to66-MW17	364693	2489062	24.7	TT	12/17/1992	21.3
STT61to66-MW18	364616	2489072	25.7	TT, UCHRBU	12/17/1992	20.2
STT61to66-MW19	364525	2489072	26.4	TT	12/17/1992	20.5
STT61to66-MW20	364554	2489135	26.5	TT, UCHRBU	12/17/1992	20.1
TTDump MW01	360343	2488970	2.6	TT	6/26/1991	2.4
TTDump MW02	360623	2488230	6.4	TT	6/26/1991	6.2
TTDump MW03	360230	2487690	2.9	TT	6/26/1991	2.2
[3]TTUST-44-MW01	360936	2488458	24.4	TT, UCHRBU	11/15/2001	6.0
[3]TTUST-44-MW02	360962	2488506	24.4	TT, UCHRBU	11/15/2001	5.7
[3]TTUST-44-MW03	360978	2488487	23.8	TT, UCHRBU	11/15/2001	5.9
[3]TTUST-48-MW01	362540	2487640	25	TT	9/1/1998	19
[3]TTUST-779-MW01	362251	2490046	25	TT	7/25/2002	9
[3]TTUST-2254-MW01	362204	2486721	24	TT	7/24/2002	13
[3]TTUST-2258-MW01	362175	2486658	24	TT	7/24/2002	12
[3]TTUST-2302-MW01	361702	2486831	24	TT	7/24/2002	12
[3]TTUST-2453-A1	361286	2488830	26.9	TT	6/7/1989	8.4
[3]TTUST-2453-A2	361090	2488716	25.7	TT	6/7/1989	6.6
[3]TTUST-2453-A3	361092	2488773	26.5	TT	6/7/1989	6.6
[3]TTUST-2453-A4	361187	2488760	26.8	TT	6/7/1989	7.6
[3]TTUST-2453-A5	361160	2488901	25.2	TT	6/7/1989	7.4
[3]TTUST-2453-A6	361102	2488864	26.8	TT	6/7/1989	6.4
[3]TTUST-2453-A7	361109	2488874	26.6	TT	6/7/1989	6.7
[3]TTUST-2453-A8	361092	2488868	26.2	TT	6/7/1989	6.5
[3]TTUST-2453-A9	361109	2488881	26.4	TT	6/7/1989	6.7
[3]TTUST-2453-OB1	361111	2488903	25.2	TT(?)	6/7/1989	6.8
[3]TTUST-2453-OB2	361104	2488812	27.1	TT(?)	6/7/1989	6.6

Table C1.11. Water-level measurements in monitor wells installed during investigations of releases of refined petroleum products to groundwater and used during model calibration, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.—Continued

[NGVD 29, National Geodetic Vertical Datum of 1929; contributing aquifers: TT, Tarawa Terrace aquifer; UCHRBU, Upper Castle Hayne aquifer–River Bend unit]

Site name[1]	Location coordinates[2]		Land-surface altitude, in feet above NGVD 29	Contributing aquifers	Measurement date	Water-level altitude, in feet above NGVD 29
	North	East				
[3]TTUST-2453-OB3	361061	2488867	24.8	TT(?)	6/7/1989	6.4
[3]TTUST-2453-OB4	361166	2488864	26.6	TT(?)	6/7/1989	7.3
[3]TTUST-2453-OB7	361228	2488907	25.4	TT(?)	6/7/1989	1.9
[3]TTUST-2453-OB8	361002	2488849	23.8	TT(?)	6/7/1989	6.5
[3]TTUST-2453-OB9	361099	2488852	24.9	TT(?)	6/7/1989	6.6
[3]TTUST-2453-OB10	361067	2488814	24.9	TT(?)	6/7/1989	6.3
[3]TTUST-2453-OB11	361181	2488817	27.8	TT(?)	6/7/1989	7.4
[3]TTUST-2453-RW	361111	2488874	26.8	TT	6/7/1989	6.8
[3]TTUST-2455-MW01	361322	2488307	24.4	TT	10/7/1993	9.0
[3]TTUST-2455-4	361356	2488245	[4]22.1	TT, UCHRBU	10/28/1993	8.6
[3]TTUST-2455-5	361436	2488312	[4]22.9	TT, UCHRBU	10/28/1993	9.0
[3]TTUST-2455-6	361255	2488250	[4]22.7	TT, UCHRBU	10/28/1993	8.0
[3]TTUST-2455-7	361120	2488302	[4]24.2	TT, UCHRBU	10/28/1993	6.8
[3]TTUST-2455-8	361203	2488302	[4]21.5	TT, UCHRBU	10/28/1993	7.6
[3]TTUST-2455-9	361255	2488321	[4]21.9	TT, UCHRBU	10/28/1993	7.9
[3]TTUST-2455-10	361171	2488350	[4]22.6	TT, UCHRBU	10/28/1993	7.4
[3]TTUST-2455-11	361155	2488259	[4]22.8	TT, UCHRBU	10/28/1993	7.3
[3]TTUST-2455-12	361292	2488261	[4]21.2	TT, UCHRBU	10/28/1993	8.2
[3]TTUST-2455-13	361484	2488341	[4]23.1	TT, UCHRBU	10/28/1993	9.2
					12/14/1993	9.2
[3]TTUST-2455-14	361136	2488407	[4]25.5	TT, UCHRBU	10/28/1993	7.0
[3]TTUST-2455-15	360972	2488327	[4]17.2	TT, UCHRBU	10/28/1993	5.6
[3]TTUST-2455-16	361310	2488291	[4]25.5	TT, UCHRBU	10/28/1993	8.3
[3]TTUST-2455-18	361196	2488312	[4]22.0	TT, UCHRBU	10/28/1993	7.6
[3]TTUST-2477-MW01	361550	2488738	25.2	TT	12/6/1994	10.0
[3]TTUST-2477-MW02	361562	2488738	25.1	TT	12/6/1994	10.1
[3]TTUST-2477-MW06	361521	2488738	24.5	TT, UCHRBU	10/28/1994	10.0
					12/6/1994	9.8
[3]TTUST-2477-MW07	361519	2488745	24.8	UCHRBU	12/6/1994	9.8
[3]TTUST-2477-MW08	361459	2488658	24.6	TT	11/3/1994	9.8
					12/6/1994	9.5
[3]TTUST-2477-MW09	361447	2488774	25.4	TT	11/3/1994	9.5
					12/6/1994	9.3
[3]TTUST-2477-MW10	361324	2488759	26.3	TT	11/3/1994	8.8
					12/6/1994	8.6
[3]TTUST-2477-MW11	361329	2488754	26.3	UCHRBU	11/4/1994	11.6
					12/6/1994	8.6
[3]TTUST-2477-MW12	361243	2488858	26.2	UCHRBU	11/8/1994	10.0
					12/6/1994	8.1

Table C1.11. Water-level measurements in monitor wells installed during investigations of releases of refined petroleum products to groundwater and used during model calibration, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.—Continued

[NGVD 29, National Geodetic Vertical Datum of 1929; contributing aquifers: TT, Tarawa Terrace aquifer; UCHRBU, Upper Castle Hayne aquifer–River Bend unit]

Site name[1]	Location coordinates[2]		Land-surface altitude, in feet above NGVD 29	Contributing aquifers	Measurement date	Water-level altitude, in feet above NGVD 29
	North	East				
[3]TTUST-2477-MW13	361240	2488865	26.2	TT	11/9/1994	8.1
					12/6/1994	8.1
[3]TTUST-2477-MW14	361197	2488975	22.9	TT	11/9/1994	7.9
					12/6/1994	7.8
[3]TTUST-2478-MW08	362092	2488829	24.4	TT	11/22/1993	12.6
					1/9/1994	12.3
[3]TTUST-2478-MW09	361888	2488997	22	TT	11/23/1993	11.8
					1/9/1994	11.4
[3]TTUST-2478-MW10	361785	2488999	21.8	TT	11/23/1993	11.4
					1/9/1994	11.0
					12/6/1994	11.2
[3]TTUST-2478-MW11	361716	2489004	21.9	TT	11/29/1993	9.9
					1/9/1994	10.6
					12/6/1994	10.9
					9/28/2000	10.4
[3]TTUST-2478-MW11D	361716	2489004	22.0	UCHRBU	12/15/1993	11.0
					1/9/1994	10.6
					12/6/1994	10.8
[3]TTUST-2478-MW12	361540	2488990	22.6	TT	12/2/1993	10.2
					1/9/1994	9.7
					12/6/1994	9.9
[3]TTUST-2478-MW13	361718	2488764	24.9	TT	11/30/1993	11.1
					1/9/1994	10.7
					12/6/1994	11.0
[3]TTUST-2478-MW14	361780	2488898	24.2	TT	11/30/1993	11.3
					1/9/1994	10.9
					12/6/1994	11.2
					9/28/2000	8.1
[3]TTUST-2478-MW14D	361780	2488898	24.3	UCHRBU	12/16/1993	11.4
					1/9/1994	10.9
					12/6/1994	11.2
[3]TTUST-2478-MW15	361900	2488730	24.6	TT	11/30/1993	11.9
					1/9/1994	11.6
[3]TTUST-2478-MW16	361452	2488973	23.2	TT	12/6/1993	9.5
					1/9/1994	9.1
					12/6/1994	9.3
[3]TTUST-2478-MW17	361377	2488896	25.6	TT	12/7/1993	9.1
					1/9/1994	8.6
					12/6/1994	8.8
					9/28/2000	10.6

Table C1.11. Water-level measurements in monitor wells installed during investigations of releases of refined petroleum products to groundwater and used during model calibration, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.—Continued

[NGVD 29, National Geodetic Vertical Datum of 1929; contributing aquifers: TT, Tarawa Terrace aquifer; UCHRBU, Upper Castle Hayne aquifer–River Bend unit]

Site name[1]	Location coordinates[2]		Land-surface altitude, in feet above NGVD 29	Contributing aquifers	Measurement date	Water-level altitude, in feet above NGVD 29
	North	East				
[3]TTUST-2478-MW17D	361377	2488896	25.7	UCHRBU	12/14/1993	9.1
					1/9/1994	8.7
					12/6/1994	8.9
					9/28/2000	10.5
[3]TTUST-2478-MW18	361425	2488824	26.1	TT	12/7/1993	9.4
					1/9/1994	8.9
					1/6/1994	9.2
[3]TTUST-2478-MW19	361528	2488819	25.4	TT	1/9/1994	10.0
					1/9/1994	9.6
					12/6/1994	9.9
[3]TTUST-2478-MW20	361093	2488831	26.5	TT, UCHRBU(?)	9/28/2000	8.3
[3]TTUST-2478-MW21D	361087	2488826	27.2	UCHRBU	9/28/2000	8.4
[3]TTUST-2478-MW22	360933	2489041	20.5	TT, UCHRBU(?)	9/28/2000	7.1
[3]TTUST-2478-MW23	360836	2488918	19.3	TT, UCHRBU	9/28/2000	6.2
[3]TTUST-2478-MW24	360877	2488755	23.6	TT, UCHRBU	9/28/2000	6.5
[3]TTUST-2478-MW25	361031	2488668	25.8	TT, UCHRBU(?)	9/28/2000	7.8
[3]TTUST-2478-PW01	361898	2488879	24.7	TT(?), UCHRBU	1/9/1994	11.6
[3]TTUST-2634-MW01	363587	2487670	22	TT, UCHRBU(?)	11/1/2001	14
[3]TTUST-3140-MW01	364679	2486468	26	TT, UCHRBU(?)	7/24/2002	15
[3]TTUST-3165-MW01	364540	2485990	26	TT, UCHRBU(?)	7/24/2002	16
[3]TTUST-3233-MW01	363831	2485914	25	TT, UCHRBU(?)	7/24/2002	12
[3]TTUST-3524-MW01	362897	2485350	20	TT	7/25/2002	6
[3]TTUST-3546-MW01	362583	2485633	21	TT	7/25/2002	5
[3]TTUST-TTSC-1	361637	2488268	[4]25.7	TT	12/28/1994	10.8
[3]TTUST-TTSC-2	361532	2488246	[4]23.4	TT	12/28/1994	10.1
[3]TTUST-TTSC-3	361589	2488360	[4]23.5	TT	1/9/1994	9.6
					12/28/1994	10.4
[3]TTUST-TTSC-4	361666	2488337	[4]26.5	TT	1/9/1994	10.4
					12/28/1994	11.0
[3]TTUST-TTSC-5	361619	2488355	[4]23.5	TT	12/28/1994	10.6
[3]TTUST-TTSC-6	361552	2488374	[4]23.8	TT	12/28/1994	10.3
[3]TTUST-TTSC-7	361470	2488474	[4]23.8	TT	12/28/1994	9.9
[3]TTUST-TTSC-8	361653	2488577	[4]23.6	TT	12/28/1994	11.1
[3]TTUST-TTSC-9	361328	2488369	[4]23.5	TT	12/28/1994	8.8
[3]TTUST-TTSC-10	361671	2488387	[4]23.7	TT	12/28/1994	11.0
[3]TTUST-TTSC-13	361614	2488404	[4]23.9	UCHRBU	12/28/1994	10.6
[3]TTUST-TTSC-14	361526	2488244	[4]23.5	UCHRBU	12/28/1994	10.0
[3]TTUST-TTSC-15	361657	2488579	[4]23.8	UCHRBU	12/28/1994	11.2
[3]TTUST-TTSC-16	361619	2488397	[4]24.0	TT, UCHRBU	12/28/1994	10.5

[1]See Plate 1 for location

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

[3]Because of scale, not shown on Plate 1

[4]Measuring point altitude, in feet NGVD 29

Appendix C2. Construction Data for Selected Wells, Tarawa Terrace and Vicinity, U.S. Marine Corps Base Camp Lejuene, North Carolina

Tables

Sources:

Catlin Engineers and Scientists, 2002a,b

DiGiano et al. 1988

Haliburton NUS Environmental Corporation 1992

Law Engineering and Environmental Services, Inc. 1996, 1998

Law Engineering, Inc. 1994a,b, 1995a,b

Mid-Atlantic Associates, Inc. 2003a,b

Mid-Atlantic Associates, P.A. 2002a,b,c,d,e,f,g

O'Brien & Gere Engineers, Inc. 1992, 1993

OHM Remediation Services Corp 2001

Richard Catlin & Associates, Inc. 1994a,b, 1995a,b, 1996, 1998

U.S. Geological Survey well inventory, written communication, October 21, 1986

Table C2.1. Construction data for Tarawa Terrace water-supply wells, test well T-9, and Civilian Conservation Corps well CCC-1, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[NGVD 29, National Geodetic Vertical Datum of 1929; N/A, data not available; AKA, also known as; >, greater than]

Site name[1]	Land-surface altitude, in feet above NGVD 29	Completion date	Borehole depth, in feet	Well depth, in feet	Screen diameter, in inches	Open interval, in feet below land surface
2A	26	5/24/1951	130	130	8	93–130
[2]#6	22	1951(?)	N/A	150–200(?)	N/A	N/A
[2]#7	24	1951(?)	N/A	150–200(?)	N/A	N/A
CCC-1	24.3	9/17/1941	105	75	10	52–75
T-9	28.7	3/1959	202	88	8	37–42
						50–60
						68–72
						83–88
TT-23	23.9	3/14/1983	263	147	10	70–95
						132–42
TT-25	32.0	7/9/1981	200	180	8	70–75
						85–95
						150–75
TT-26, AKA #1	34.0	5/18/1951	180	108	8	91–108
TT-27, AKA #2B	26.4	5/31/1951	90	90	10	77–90
TT-28, AKA #3	26	1951	N/A	50–100(?)	N/A	N/A
TT-29, AKA #4	25	1951	N/A	50–100(?)	N/A	N/A
TT-30, AKA #13	26	1971	N/A	128	N/A	50–70
						98–113
TT-31, AKA #14	25.8	1973	N/A	94	N/A	N/A
TT-45, AKA #5	26	1951	N/A	50–100(?)	N/A	N/A
TT-52, AKA #9	24.9	6/27/1961	102	98	N/A	N/A[2]
TT-53, AKA #10	25	7/22/1961	N/A	90	10	42–62
						68–83
TT-54, AKA #11	22.1	6/30/1961	N/A	104	N/A	N/A[3]
TT-55, AKA #8	26.4	11/1/1961	N/A	>50	N/A	N/A[3]
TT-67, AKA #12	27.5	11/15/1971	200	104	8	70–94

[1]See Plate 1 for location

[2]Out of map area, location not shown. North Carolina State Plane coordinates: #6 (highly approximate) North 369730, East 2481720; #7 (highly approximate) North 370500, East 2481530; and TT-45 North 365688, East 2483352

[3]Construction is probably similar to TT-53

Table C2.2. Construction data for monitor wells installed during ABC One-Hour Cleaners Operable Units 1 and 2 and by the North Carolina Department of Natural Resources and Community Development, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[NGVD 29, National Geodetic Vertical Datum of 1929]

Site name[1]	Land-surface altitude, in feet above NGVD 29	Completion date	Borehole depth, in feet	Well depth, in feet	Screen diameter, in inches	Open interval, in feet below land surface
C1	30.6	4/4/1992	104.0	100.6	4	90–100
C2	32.0	4/8/1992	87.0	85	4	74.5–84.5
C3	33.4	4/9/1992	90.5	90.5	4	79.1–89.1
C4	32.2	4/2/1992	200.0	130.4	4	120–130
C5	32.0	4/7/1992	92.5	91	4	80.5–90.5
C9	32.1	9/1993	76	76	4	66–76
C10	32.5	10/1993	175	175	4	165–175
C11	31.0	9/1993	108	108	4	98–108
PZ-01	31.9	9/1993	80	80	2	74.5–79.5
PZ-02	31.9	9/1993	35	35	2	29.5–34.5
PZ-03	32.5	9/1993	80	80	2	74.5–79.5
PZ-04	32.5	9/1993	35	35	2	29.5–34.5
PZ-05	32.0	9/1993	80	80	2	74.5–79.5
PZ-06	32.0	9/1993	35	35	2	29.5–34.5
S1	30.6	3/22/1992	28.0	25.5	4	5.5–25.5
S2	32.5	3/26/1992	39.7	39.7	4	19.7–39.7
S3	33.4	4/2/1992	39.5	39.5	4	19.5–39.5
S4	32.2	4/3/1992	34.0	34	4	14–34
S5	31.9	4/1/1992	30.0	28	4	8–28
S6	31.1	3/26/1992	40.5	40.5	4	20.5–40.5
S7	31.3	4/5/1992	30.3	30.3	4	10–30
S8	30.8	4/4/1992	28.0	28	4	8–28
S9	32.7	3/21/1992	40.0	28.3	4	8–28
S10	31.6	3/19/1992	40.0	35	4	15–35
S11	30.8	9//1993	35	35	4	15–35
[2]X24B4	33.3	9/25/1985	59	59	2	42–52
[2]X24B5	31.4	9/25/1985	59	59	2	42–52
[2]X24B6	33.4	9/25/1985	59	59	2	42–52

[1]See Plate 1 for location

[2]On Plate 1 shown as B4, B5, and B6, respectively

Table C2.3. Construction data for monitor wells installed during investigations of releases of refined-petroleum products to groundwater, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[NGVD 29, National Geodetic Vertical Datum of 1929; N/A, data not available]

Site name[1]	Measuring point altitude, in feet above NGVD 29	Completion date	Borehole depth, in feet	Well depth, in feet	Screen diameter, in inches	Open interval, in feet below land surface
STT61to66-MW01	26.9	12/12/1991	15	15	2	5–15
STT61to66-MW02	26.8	12/13/1991	30	30	2	20–30
STT61to66-MW03	27.1	12/12/1991	15	15	2	5–15
STT61to66-MW04	27.0	12/13/1991	30	30	2	20–30
STT61to66-MW05	27.5	12/12/1991	15	15	2	5–15
STT61to66-MW06	27.6	12/13/1991	30	30	2	19–29
STT61to66-MW07	27.7	1/7/1992	15	15	2	5–15
STT61to66-MW08	27.7	1/8/1992	30	30	2	20–30
STT61to66-MW09	27.1	1/8/1992	14	14	2	4–14
STT61to66-MW10	27.0	1/8/1992	30	30	2	20–30
STT61to66-MW11	27.6	1/8/1992	15	15	2	5–15
STT61to66-MW12	27.5	1/9/1992	30	30	2	20–30
STT61to66-MW13	26.2	1/9/1992	12	12	2	2–12
STT61to66-MW14	26.2	1/9/1992	27	27	2	17–27
STT61to66-MW15	26.3	12/9/1992	14	14	2	4–14
STT61to66-MW16	25.6	12/9/1992	30	30	2	20–30
STT61to66-MW17	24.7	12/11/1992	14	14	2	4–14
STT61to66-MW18	25.7	12/9/1992	30	30	2	20–30
STT61to66-MW19	26.4	12/15/1992	14	14	2	4–14
STT61to66-MW20	26.5	12/9/1992	30	30	2	20–30
TTDump-MW01	2.6	6/25/1991	13.0	13.0	2	3.0–13.0
TTDump-MW02	6.4	6/18/1991	15.0	14.0	2	4.0–14.0
TTDump-MW03	2.9	6/24/1991	14.0	5.5	2	2.5–5.5
[2]TTUST-44-MW01	24.4	8/3/1994	N/A	25.8	N/A	15–25
[2]TTUST-44-MW02	24.4	8/3/1994	N/A	25.8	N/A	15–25
[2]TTUST-44-MW03	23.8	8/3/1994	N/A	25.8	N/A	15–25
[2]TTUST-48-MW01	25	8//1997	12	12	N/A	2–12
[2]TTUST-779-MW01	25	7/22/2002	19.5	19.5	2	4.5–19.5
[2]TTUST-2254-MW01	24	7/22/2002	14.5	14.5	2	4.5–14.5
[2]TTUST-2258-MW01	24	7/22/2002	16.5	16.5	2	6.5–16.5
[2]TTUST-2302-MW01	24	7/24/2002	19.5	19.5	2	4.5–19.5
[2]TTUST-2453-A1	26.9	1987	N/A	39.7	2	23.6–39.7
[2]TTUST-2453-A2	25.7	1987	N/A	37.9	2	24.1–37.9
[2]TTUST-2453-A3	26.5	1987	N/A	39.3	2	23.4–39.3
[2]TTUST-2453-A4	26.8	1987	N/A	40.2	2	25.0–40.2
[2]TTUST-2453-A5	25.2	1987	N/A	39.5	2	24.3–39.5
[2]TTUST-2453-A6	26.8	1987	N/A	41.2	2	28.9–41.2
[2]TTUST-2453-A7	26.7	1987	N/A	41.0	2	26.1–41.0
[2]TTUST-2453-A8	26.2	1987	N/A	42.2	2	25.1–26.2
[2]TTUST-2453-A9	26.4	1987	N/A	40.5	2	25.4–40.5
[2]TTUST-2453-OB1	25.2	1989	N/A	N/A	N/A	N/A
[2]TTUST-2453-OB2	27.1	1989	N/A	N/A	N/A	N/A

Table C2.3. Construction data for monitor wells installed during investigations of releases of refined-petroleum products to groundwater, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.—Continued

[NGVD 29, National Geodetic Vertical Datum of 1929; N/A, data not available]

Site name[1]	Measuring point altitude, in feet above NGVD 29	Completion date	Borehole depth, in feet	Well depth, in feet	Screen diameter, in inches	Open interval, in feet below land surface
[2]TTUST-2453-OB3	24.8	1989	N/A	N/A	N/A	N/A
[2]TTUST-2453-OB4	26.6	1989	N/A	N/A	N/A	N/A
[2]TTUST-2453-OB7	[3]26.7	1989	N/A	N/A	N/A	N/A
[2]TTUST-2453-OB8	23.8	1989	N/A	N/A	N/A	N/A
[2]TTUST-2453-OB9	24.4	1989	N/A	N/A	N/A	N/A
[2]TTUST-2453-OB10	24.8	1989	N/A	N/A	N/A	N/A
[2]TTUST-2453-OB11	27.3	1989	N/A	N/A	N/A	N/A
[2]TTUST-2453-RW	26.8	1989	N/A	N/A	N/A	N/A
[2]TTUST-2455-4	22.1	10/14/1993	25	25	2	10–25
[2]TTUST-2455-5	22.9	10/4/1993	25	25	2	10–25
[2]TTUST-2455-6	22.7	10/13/1993	25	25	2	10–25
[2]TTUST-2455-7	24.2	10/4/1993	25	25	2	10–25
[2]TTUST-2455-8	21.5	10/5/1993	25	25	2	10–25
[2]TTUST-2455-9	21.9	10/14/1993	25	25	2	10–25
[2]TTUST-2455-10	22.6	10/5/1993	25	25	2	10–25
[2]TTUST-2455-11	22.8	10/5/1993	25	25	2	10–25
[2]TTUST-2455-12	21.2	10/5/1993	25	25	2	10–25
[2]TTUST-2455-13	23.1	10/14/1993	25	25	2	10–25
[2]TTUST-2455-14	25.5	10/14/1993	25	25	2	10–25
[2]TTUST-2455-15	17.2	11/18/1993	20	20	2	4–20
[2]TTUST-2455-16	25.5	10/8/1993	47	47	2	42–47
[2]TTUST-2455-18	22.0	10/6/1993	47	47	2	42–47
[2]TTUST-2477-MW01	24.0	10/26/1993	N/A	19.5	4	N/A
[2]TTUST-2477-MW06	24.5	10/28/1994	32	32	6	12–32
[2]TTUST-2477-MW07	24.8	11/1/1994	50	50	2	45–50
[2]TTUST-2477-MW08	24.6	11/3/1994	22	22	2	12–22
[2]TTUST-2477-MW09	25.4	11/3/1994	22	22	2	12–22
[2]TTUST-2477-MW10	26.3	11/3/1994	22	22	2	12–22
[2]TTUST-2477-MW11	26.3	11/4/1994	50	50	2	45–50
[2]TTUST-2477-MW12	26.2	11/8/1994	50	50	2	43–50
[2]TTUST-2477-MW13	26.2	11/9/1994	22	22	2	12–22
[2]TTUST-2477-MW14	22.9	11/9/1994	21	21	2	11–21
[2]TTUST-2478-MW08	24.4	11/22/1993	19	19	2	8.5–18.5
[2]TTUST-2478-MW09	22.0	11/23/1993	18	18	2	7.5–17.5
[2]TTUST-2478-MW10	21.8	11/23/1993	18	18	2	7.5–17.5
[2]TTUST-2478-MW11	21.9	11/29/1993	18	18	2	7.5–17.5
[2]TTUST-2478-MW11D	22.0	12/15/1993	50	50	2	45–50
[2]TTUST-2478-MW12	22.6	12/2/1993	18	18	2	8–18
[2]TTUST-2478-MW13	24.9	11/30/1993	18	18	2	7.5–17.5
[2]TTUST-2478-MW14	24.2	11/30/1993	18	18	2	7.5–17.5
[2]TTUST-2478-MW14D	24.3	12/16/1993	50	50	2	45–50
[2]TTUST-2478-MW15	24.6	11/30/1993	18	18	2	7.5–17.5

Table C2.3. Construction data for monitor wells installed during investigations of releases of refined-petroleum products to groundwater, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.—Continued

[NGVD 29, National Geodetic Vertical Datum of 1929; N/A, data not available]

Site name[1]	Measuring point altitude, in feet above NGVD 29	Completion date	Borehole depth, in fee	Well depth, in feet	Screen diameter, in inches	Open interval, in feet below land surface
[2]TTUST-2478-MW16	23.2	12/6/1993	18.5	18.5	2	8.5–18.5
[2]TTUST-2478-MW17	25.6	12/7/1993	22	22	2	11.5–21.5
[2]TTUST-2478-MW17D	25.7	12/14/1993	50	50	2	43–48
[2]TTUST-2478-MW18	26.1	12/7/1993	22.5	22.5	2	12–22
[2]TTUST-2478-MW19	25.4	12/7/1993	20.5	20.5	2	10–20
[2]TTUST-2478-PW01	24.7	N/A	N/A	20.5	N/A	N/A
[2]TTUST-2478-MW20	26.5	9/14/2000	24	24	2	14–24
[2]TTUST-2478-MW21D	27.2	9/12/2000	50	50	2	45–50
[2]TTUST-2478-MW22	20.5	9/13/2000	21	20	2	10–21
[2]TTUST-2478-MW23	19.3	9/13/2000	19	19	2	9–19
[2]TTUST-2478-MW24	23.6	9/13/2000	23.5	23.5	2	13.5–23.5
[2]TTUST-2478-MW25	25.8	9/13/2000	23	23	2	13–23
[2]TTUST-2634-MW01	22	11/1/2001	16	16	2	6–16
[2]TTUST-3140-MW01	26	7/23/2002	19	19	2	4–19
[2]TTUST-3165-MW01	26	7/23/2002	19	19	2	4–19
[2]TTUST-3233-MW01	25	7/23/2002	18	18	2	3–18
[2]TTUST-3524-MW01	20	7/23/2002	17.8	17.8	2	7.8–17.8
[2]TTUST-3546-MW01	21	7/23/2002	18.5	18.5	2	8.5–18.5
[2]TTUST-TTSC-1	25.7	11/21/1994	20	20	2	10–20
[2]TTUST-TTSC-2	23.4	11/21/1994	20	20	2	9–19
[2]TTUST-TTSC-3	23.5	11/21/1994	20	20	2	9.5–19.5
[2]TTUST-TTSC-4	26.5	11/22/1994	20	20	2	10–20
[2]TTUST-TTSC-5	23.5	11/22/1994	20	20	2	10–20
[2]TTUST-TTSC-6	23.8	11/22/1994	20	20	2	5–20
[2]TTUST-TTSC-7	23.8	11/22/1994	20	20	2	10–20
[2]TTUST-TTSC-8	23.6	12/6/1994	20	20	2	10–20
[2]TTUST-TTSC-9	23.5	12/6/1994	20	20	2	10–20
[2]TTUST-TTSC-10	23.7	12/6/1994	20	20	2	10–20
[2]TTUST-TTSC-13	23.9	12/1/1994	50.5	50.5	2	43.5–50.5
[2]TTUST-TTSC-14	23.5	11/28/1994	50	50	2	43–50
[2]TTUST-TTSC-15	23.8	11/29/1994	50	50	2	43–50
[2]TTUST-TTSC-16	24.0	12/1/1994	38	38	2	6.5–38

[1]See Plate 1 for location

[2]Because of scale, not shown on Plate 1

[3]Estimated altitude

Appendix C3. Capacity and Operational History for Selected Wells, Tarawa Terrace, U.S. Marine Corps Base Camp Lejuene, North Carolina

Tables

Table C3.1. Capacity and operational history of water-supply well TT-26[1] (AKA #1), Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[gpm, gallons per minute; do., ditto]

Date	Capacity, in gpm	Operational status	Data source
5/19/1951	215		Well capacity test[2]
1/1952		In service	Estimated date
1/1952	200	do.	Henry Von Oesen & Associates[3]
6/24/1958	182	do.	Well capacity summary
2/7/1966	130	do.	Raw water-supply list
1973 (?)	104	do.	Well capacity summary
3/31977	110	do.	Well survey sheet
1978	175	do.	Henry Von Oesen & Associates[3]
7/1980		Out of service	Operation records
9/1980		In service	do.
5/1982		"Ran all month"	do.
12/28/1982		Out of service	do.
3/1983		In service	do.
3/1/1983	133	do.	Well capacity test
6/20/1984	150	do.	Well survey sheet
2/1985		Out of service	Operation records
2/1985		Service terminated	do.
6/1993		Abandonment	AH Environmental Consultants[4]

[1]See Figure C1 for location

[2]R.E. Peterson, Public Works, written communication, May 31, 1951

[3]Henry Von Oesen and Associates, Inc. 1979

[4]AH Environmental Consultants, Inc., written communication, September 3, 2004

Table C3.2. Capacity and operational history of water-supply wells TT-27, TT-28, TT-29, TT-45, #6, #7, and TT-55, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[gpm, gallons per minute; —, operational status unknown; USGS, U.S. Geological Survey; do., ditto]

Well name[1]	Date	Capacity, in gpm	Operational status	Data source
TT-27 (AKA #2b)	5/31/1951	100	—	Well capacity test[3]
	1/1952		In service	Estimated date
	1/1952	100	—	Estimated rate[3]
	6/24/1958	75	In service	Well capacity summary
	12/1961		Service terminated	Estimated date
	1/10/1963		Out of service	USGS well schedule
	2/27/1967		Abandonment	List for Mr. Tew[5]
TT-28 (AKA #3)	1/1952		In service	Estimated date
	1/1952	100	—	Estimated rate[6]
	6/24/1958	20	In service	Well capacity summary
	2/7/1966	110	do.	Raw water-supply list
	8/3/1971		do.	Building dimensions list
	12/1971		Service terminated	Estimated date
	3/1973		Abandonment	AH Environmental Consultants[7]
TT-29 (AKA#4)	1/1952		In service	Estimated date
	1/1952	100	—	Estimated rate[6]
	6/24/1958		Out of service	Well capacity summary
	6/1958		Service terminated	Estimated date
	10/1958		"Abandoned"	LeGrand[4]
	2/27/1967		Abandonment	List for Mr. Tew[5]
TT-45 (AKA #5)	1/1952		In service	Estimated date
	1/1952	100	do.	Estimated rate[6]
	6/24/1958	70	do.	Well capacity summary
	2/7/1966	50	do.	Raw water-supply list
	8/3/1971		"Abandoned"	Building dimensions list
	12/1971		Service terminated	Estimated date
	3/1973		Abandonment	AH Environmental Consultants[7]
[2]#6	1/1952		In service	Estimated date
	1/1952	100	—	Estimated rate[6]
	6/24/1958	80	In service	Well capacity summary
	12/1961		Service terminated	Estimated date
[2]#7	1/1952		In service	Estimated date
	1/1952	120	—	Estimated rate[6]
	6/24/1958	100	In service	Well capacity summary
	12/1961		Service terminated	Estimated date
TT-55 (AKA #8)	11/1/1961	100	—	Driller[8]
	1/1962		In service	Estimated date
	1/1962	100	—	Estimated rate[7]
	3/28/1962	100	In service	Well capacity summary
	2/7/1966	95	do.	Raw water-supply list
	8/3/1971		do.	Building dimensions list
	12/1971		Service terminated	Estimated date

[1]See Plate 1 for location

[2]Out of map area, location not shown. North Carolina State Plane coordinates: #6 (highly approximate) North 369730, East 2481720; #7 (highly approximate) North 370500, East 2481530; and TT-45 North 365688, East 2483352

[3]R.E. Peterson, Public Works, written communication, May 31, 1951

[4]H.E. LeGrand, written communication, October 25, 1958

[5]List furnished to Mr. Tew for abandonment, written communication, February 27, 1967

[6]LeGrand (1959)

[7]AH Environmental Consultants, Inc., written communication, September 3, 2004

[8]Hartsfield Water Company, Inc., written communication, November 1, 1961

Table C3.3. Capacity and operational history of water-supply well TT-52[1] (AKA #9A), Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[gpm, gallons per minute; —, operational status unknown; do., ditto]

Date	Capacity, in gpm	Operational status	Data source
10/17/1961	348	—	Driller[2]
1/1962		In service	Estimated date
1/1962	300	—	Henry Von Oesen & Associates[3]
3/28/1962	300	In service	Well capacity summary
2/7/1966	300	—	Raw water-supply list
1973(?)	174	In service	Well capacity summary
3/3/1977		do.	Well survey sheet
1978	200	do.	Henry Von Oesen & Associates[3]
5/1982		"Ran all month"	Operation records
9/14/1982	128	In service	Well capacity test
6/20/1984	200	do.	Well survey sheet
12/27/1984	170	do.	Well capacity test
2/1985		"Running 24 hours"	Operation records
3/1985		do.	do.
9/11/1985	201	In service	Well capacity test
3/1986		Out of service	Operation records
4/1986		In service	do.
4/1987		Service terminated	Water flow records
4/1987		do.	Estimated date
6/1993		Abandonment	AH Environmental Consultants[4]

[1]See Figure C1 for location

[2]Hartsfield Water Company, Inc., written communication, October 17, 1961

[3]Henry Von Oesen and Associates, Inc. 1979

[4]AH Environmental Consultants, Inc., written communication, September 3, 2004

Table C3.4. Capacity and operational history of water-supply well TT-53[1] (AKA #10), Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[gpm, gallons per minute; —, operational status unknown; do., ditto]

Date	Capacity, in gpm	Operational status	Data source
7/22/1961	350	—	Driller[2]
1/1962		In service	Estimated date
1/1962	350	do.	Henry Von Oesen & Associates[3]
3/28/1962	350	do.	Well capacity summary
2/7/1966	320	do.	Raw water-supply list
1973(?)	174	do.	Well capacity summary
1978	75	do.	Henry Von Oesen & Associates[3]
8/3/1971		do.	Building dimensions list
3/3/1977		do.	Well survey sheet
7/1981		Out of service	Operation records
9/1981		In service	do.
5/1982		"Ran all month"	do.
2/1984		Out of service	do.
2/1984		Service terminated	do.
6/1993		Abandonment	AH Environmental Consultants[4]

[1]See Figure C1 for location

[2]Hartsfield Water Company, Inc., written communication, July 22, 1961

[3]Henry Von Oesen and Associates, Inc. 1979

[4]AH Environmental Consultants, Inc., written communication, September 3, 2004

Table C3.5. Capacity and operational history of water-supply well TT-54[1] (AKA #11), Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[gpm, gallons per minute; —, operational status unknown; do., ditto]

Date	Capacity, in gpm	Operational status	Data source
6/30/1961	250	—	Driller[2]
1/1962		In service	Estimated date
1/1962	200	do.	Henry Von Oesen & Associates[3]
3/28/1962	200	do.	Well capacity summary
2/7/1966	200	do.	Raw water-supply list
8/3/1971		do.	Building dimensions list
1973(?)	139	do.	Well capacity summary
3/3/1977		do.	Well survey sheet
1978	170	do.	Henry Von Oesen & Associates[3]
9/14/1982	140	do.	Well capacity test
2/1984		Out of service	Operation records
4/1984		In service	do.
6/20/1984	150	do.	Well survey sheet
3/1985		"Running 24 hours"	Operation records
4/1987		Out of service	Water flow records
4/1987		Service terminated	do.
6/1994		Abandonment	AH Environmental Consultants[4]

[1]See Figure C1 for location

[2]Hartsfield Water Company, Inc., written communication, June 30, 1961

[3]Henry Von Oesen and Associates, Inc. 1979

[4]AH Environmental Consultants, Inc., written communication, September 3, 2004

Table C3.6. Capacity and operational history of water-supply well TT-67[1] (AKA #12) Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[gpm, gallons per minute; —, operational status unknown; do., ditto]

Date	Capacity, in gpm	Operational status	Data source
11/15/1971	140	—	Driller[2]
1/1972		In service	Estimated date
1/1972	168	do.	Henry Von Oesen & Associates[3]
1973(?)	83	do.	Well capacity summary
3/3/1977		do.	Well survey sheet
1978	140	do.	Henry Von Oesen & Associates[3]
9/14/1982	90	do.	Well capacity test
5/18/1983	108	do.	do.
6/20/1984	100	do.	Well survey sheet
8/21/1984	125	do.	Well capacity test
12/23/1984	119	do.	do.
9/13/1985	119	do.	do.
4/1987		Out of service	Water flow records
4/1987		Service terminated	do.
6/1993		Abandonment	AH Environmental Consultants[4]

[1]See Figure C1 for location

[2]Sydnor Hydrodynamics, Inc., written communication, November 15, 1971

[3]Henry Von Oesen and Associates, Inc. 1979

[4]AH Environmental Consultants, Inc., written communication, September 3, 2004

Table C3.7. Capacity and operational history of water-supply well TT-30[1] (AKA #13), Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[gpm, gallons per minute; do., ditto]

Date	Capacity, in gpm	Operational status	Data source
1/1972		In service	Estimated date
1/1972	100	do.	Henry Von Oesen & Associates[2]
1973(?)	76	do.	Well capacity summary
3/3/1977		do.	Well survey sheet
1978	70	do.	Henry Von Oesen & Associates[2]
5/1982		"Ran all month"	Operation records
12/27/1982		"New pump"	do.
6/20/1984	50	In service	Well survey sheet
9/1984		"Well won't pump"	Operation records
2/1985		Out of service	do.
2/1985		Service terminated	do.

[1]See Figure C1 for location

[2]Henry Von Oesen and Associates, Inc. 1979

Table C3.8. Capacity and operational history of water-supply well TT-31[1] (AKA #14), Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[gpm, gallons per minute; do., ditto]

Date	Capacity, in gpm	Operational status	Data source
1/1973		In service	Estimated date
1/1973	145	do.	Henry Von Oesen & Associates[2]
1973(?)	83	do.	Well capacity summary
3/3/1977		do.	Well survey sheet
1978	125	do.	Henry Von Oesen & Associates[2]
5/1982		"Ran all month"	Operation records
9/14/1982	104	In service	Well capacity test
6/1983		"Low on water"	Operation records
6/1984		Out of service	Operation records
6/20/1984	150	do.	Well survey sheet
7/6/1984	119	In service	Well capacity test
2/1985		"Running 24 hours"	Operation records
9/13/1985	111	In service	Well capacity test
3/1986		"Ran all month"	Operation records
4/1987		Out of service	Operation records
4/1987		Service terminated	Water flow records
6/1993		Abandonment	AH Environmental Consultants[3]

[1]See Figure C1 for location
[2]Henry Von Oesen and Associates, Inc. 1979
[3]AH Environmental Consultants, Inc., written communication, September 3, 2004

Table C3.9. Capacity and operational history of water-supply well TT-25,[1] Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[gpm, gallons per minute; —, operational status unknown; do., ditto]

Date	Capacity, in gpm	Operational status	Data source
7/1981	150	—	Driller[2]
12/27/1981	150	—	Well capacity test
1/1982		In service	Operation Records
1/1982	150	do.	Well capacity test[2]
6/1983		"Ran all month"	Operation records
6/20/1984		In service	Well survey sheet
2/1985		"Running 24 hours"	Operation records
3/1985		"Running 24 hours"	do.
9/11/1985	130	In service	Well capacity test
4/1987		Out of service	Operation records
4/1987		Service terminated	Water flow records
6/1993		Abandonment	AH Environmental Consultants[3]

[1]See Figure C1 for location
[2]Carolina Well and Pump Company, written communication, July 9, 1981
[3]AH Environmental Consultants, Inc., written communication, September 3, 2004

Table C3.10. Capacity and operational history of water-supply well TT-23,[1] Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[gpm, gallons per minute; —, operational status unknown; do., ditto; hrs, hours]

Date	Capacity, in gpm	Operational status	Data source
3/15/1983	162	—	Driller[2]
8/1984		In service	Estimated date
9/4/1984	254	do.	Well capacity test
10/4/1984	252	do.	do.
2/1985		Out of service	Operation records
3/11/1985		In service, 24 hrs	CLW documents[3]
3/12/1985		Out of service	do.
4/22/1985		In service, 7 hrs	do.
4/23/1985		do.	do.
4/29/1985		do.	do.
4/30/1985		Out of service	Estimated date
4/1985		Service terminated	do.
6/1993		Abandonment	AH Environmental Consultants[4]

[1]See Figure C1 for location

[2]C.W. Brinkley & Son, Inc., written communication, March 14, 1983

[3]Camp Lejeune water document 1194, written communication, May 1985

[4]AH Environmental Consultants, Inc., written communication, September 3, 2004

Appendix C4. Simulation Stress Periods and Corresponding Month and Year

[Jan, January; Feb, February; Mar, March; Apr, April; Aug, August; Sept, September; Oct, October; Nov, November; Dec, December]

Stress period	Month and year	Stress period	Month and year	Stress period	Month and year	Stress period	Month and year	Stress period	Month and year	Stress period	Month and year
1	Jan 1951	49	Jan 1955	97	Jan 1959	145	Jan 1963	193	Jan 1967	241	Jan 1971
2	Feb 1951	50	Feb 1955	98	Feb 1959	146	Feb 1963	194	Feb 1967	242	Feb 1971
3	Mar 1951	51	Mar 1955	99	Mar 1959	147	Mar 1963	195	Mar 1967	243	Mar 1971
4	Apr 1951	52	Apr 1955	100	Apr 1959	148	Apr 1963	196	Apr 1967	244	Apr 1971
5	May 1951	53	May 1955	101	May 1959	149	May 1963	197	May 1967	245	May 1971
6	June 1951	54	June 1955	102	June 1959	150	June 1963	198	June 1967	246	June 1971
7	July 1951	55	July 1955	103	July 1959	151	July 1963	199	July 1967	247	July 1971
8	Aug 1951	56	Aug 1955	104	Aug 1959	152	Aug 1963	200	Aug 1967	248	Aug 1971
9	Sept 1951	57	Sept 1955	105	Sept 1959	153	Sept 1963	201	Sept 1967	249	Sept 1971
10	Oct 1951	58	Oct 1955	106	Oct 1959	154	Oct 1963	202	Oct 1967	250	Oct 1971
11	Nov 1951	59	Nov 1955	107	Nov 1959	155	Nov 1963	203	Nov 1967	251	Nov 1971
12	Dec 1951	60	Dec 1955	108	Dec 1959	156	Dec 1963	204	Dec 1967	252	Dec 1971
13	Jan 1952	61	Jan 1956	109	Jan 1960	157	Jan 1964	205	Jan 1968	253	Jan 1972
14	Feb 1952	62	Feb 1956	110	Feb 1960	158	Feb 1964	206	Feb 1968	254	Feb 1972
15	Mar 1952	63	Mar 1956	111	Mar 1960	159	Mar 1964	207	Mar 1968	255	Mar 1972
16	Apr 1952	64	Apr 1956	112	Apr 1960	160	Apr 1964	208	Apr 1968	256	Apr 1972
17	May 1952	65	May 1956	113	May 1960	161	May 1964	209	May 1968	257	May 1972
18	June 1952	66	June 1956	114	June 1960	162	June 1964	210	June 1968	258	June 1972
19	July 1952	67	July 1956	115	July 1960	163	July 1964	211	July 1968	259	July 1972
20	Aug 1952	68	Aug 1956	116	Aug 1960	164	Aug 1964	212	Aug 1968	260	Aug 1972
21	Sept 1952	69	Sept 1956	117	Sept 1960	165	Sept 1964	213	Sept 1968	261	Sept 1972
22	Oct 1952	70	Oct 1956	118	Oct 1960	166	Oct 1964	214	Oct 1968	262	Oct 1972
23	Nov 1952	71	Nov 1956	119	Nov 1960	167	Nov 1964	215	Nov 1968	263	Nov 1972
24	Dec 1952	72	Dec 1956	120	Dec 1960	168	Dec 1964	216	Dec 1968	264	Dec 1972
25	Jan 1953	73	Jan 1957	121	Jan 1961	169	Jan 1965	217	Jan 1969	265	Jan 1973
26	Feb 1953	74	Feb 1957	122	Feb 1961	170	Feb 1965	218	Feb 1969	266	Feb 1973
27	Mar 1953	75	Mar 1957	123	Mar 1961	171	Mar 1965	219	Mar 1969	267	Mar 1973
28	Apr 1953	76	Apr 1957	124	Apr 1961	172	Apr 1965	220	Apr 1969	268	Apr 1973
29	May 1953	77	May 1957	125	May 1961	173	May 1965	221	May 1969	269	May 1973
30	June 1953	78	June 1957	126	June 1961	174	June 1965	222	June 1969	270	June 1973
31	July 1953	79	July 1957	127	July 1961	175	July 1965	223	July 1969	271	July 1973
32	Aug 1953	80	Aug 1957	128	Aug 1961	176	Aug 1965	224	Aug 1969	272	Aug 1973
33	Sept 1953	81	Sept 1957	129	Sept 1961	177	Sept 1965	225	Sept 1969	273	Sept 1973
34	Oct 1953	82	Oct 1957	130	Oct 1961	178	Oct 1965	226	Oct 1969	274	Oct 1973
35	Nov 1953	83	Nov 1957	131	Nov 1961	179	Nov 1965	227	Nov 1969	275	Nov 1973
36	Dec 1953	84	Dec 1957	132	Dec 1961	180	Dec 1965	228	Dec 1969	276	Dec 1973
37	Jan 1954	85	Jan 1958	133	Jan 1962	181	Jan 1966	229	Jan 1970	277	Jan 1974
38	Feb 1954	86	Feb 1958	134	Feb 1962	182	Feb 1966	230	Feb 1970	278	Feb 1974
39	Mar 1954	87	Mar 1958	135	Mar 1962	183	Mar 1966	231	Mar 1970	279	Mar 1974
40	Apr 1954	88	Apr 1958	136	Apr 1962	184	Apr 1966	232	Apr 1970	280	Apr 1974
41	May 1954	89	May 1958	137	May 1962	185	May 1966	233	May 1970	281	May 1974
42	June 1954	90	June 1958	138	June 1962	186	June 1966	234	June 1970	282	June 1974
43	July 1954	91	July 1958	139	July 1962	187	July 1966	235	July 1970	283	July 1974
44	Aug 1954	92	Aug 1958	140	Aug 1962	188	Aug 1966	236	Aug 1970	284	Aug 1974
45	Sept 1954	93	Sept 1958	141	Sept 1962	189	Sept 1966	237	Sept 1970	285	Sept 1974
46	Oct 1954	94	Oct 1958	142	Oct 1962	190	Oct 1966	238	Oct 1970	286	Oct 1974
47	Nov 1954	95	Nov 1958	143	Nov 1962	191	Nov 1966	239	Nov 1970	287	Nov 1974
48	Dec 1954	96	Dec 1958	144	Dec 1962	192	Dec 1966	240	Dec 1970	288	Dec 1974

Appendix C4.1. Simulation stress periods and corresponding month and year.—Continued

[Jan, January; Feb, February; Mar, March; Apr, April; Aug, August; Sept, September; Oct, October; Nov, November; Dec, December]

Stress period	Month and year	Stress period	Month and year	Stress period	Month and year	Stress period	Month and year	Stress period	Month and year
289	Jan 1975	337	Jan 1979	385	Jan 1983	433	Jan 1987	481	Jan 1991
290	Feb 1975	338	Feb 1979	386	Feb 1983	434	Feb 1987	482	Feb 1991
291	Mar 1975	339	Mar 1979	387	Mar 1983	435	Mar 1987	483	Mar 1991
292	Apr 1975	340	Apr 1979	388	Apr 1983	436	Apr 1987	484	Apr 1991
293	May 1975	341	May 1979	389	May 1983	437	May 1987	485	May 1991
294	June 1975	342	June 1979	390	June 1983	438	June 1987	486	June 1991
295	July 1975	343	July 1979	391	July 1983	439	July 1987	487	July 1991
296	Aug 1975	344	Aug 1979	392	Aug 1983	440	Aug 1987	488	Aug 1991
297	Sept 1975	345	Sept 1979	393	Sept 1983	441	Sept 1987	489	Sept 1991
298	Oct 1975	346	Oct 1979	394	Oct 1983	442	Oct 1987	490	Oct 1991
299	Nov 1975	347	Nov 1979	395	Nov 1983	443	Nov 1987	491	Nov 1991
300	Dec 1975	348	Dec 1979	396	Dec 1983	444	Dec 1987	492	Dec 1991
301	Jan 1976	349	Jan 1980	397	Jan 1984	445	Jan 1988	493	Jan 1992
302	Feb 1976	350	Feb 1980	398	Feb 1984	446	Feb 1988	494	Feb 1992
303	Mar 1976	351	Mar 1980	399	Mar 1984	447	Mar 1988	495	Mar 1992
304	Apr 1976	352	Apr 1980	400	Apr 1984	448	Apr 1988	496	Apr 1992
305	May 1976	353	May 1980	401	May 1984	449	May 1988	497	May 1992
306	June 1976	354	June 1980	402	June 1984	450	June 1988	498	June 1992
307	July 1976	355	July 1980	403	July 1984	451	July 1988	499	July 1992
308	Aug 1976	356	Aug 1980	404	Aug 1984	452	Aug 1988	500	Aug 1992
309	Sept 1976	357	Sept 1980	405	Sept 1984	453	Sept 1988	501	Sept 1992
310	Oct 1976	358	Oct 1980	406	Oct 1984	454	Oct 1988	502	Oct 1992
311	Nov 1976	359	Nov 1980	407	Nov 1984	455	Nov 1988	503	Nov 1992
312	Dec 1976	360	Dec 1980	408	Dec 1984	456	Dec 1988	504	Dec 1992
313	Jan 1977	361	Jan 1981	409	Jan 1985	457	Jan 1989	505	Jan 1993
314	Feb 1977	362	Feb 1981	410	Feb 1985	458	Feb 1989	506	Feb 1993
315	Mar 1977	363	Mar 1981	411	Mar 1985	459	Mar 1989	507	Mar 1993
316	Apr 1977	364	Apr 1981	412	Apr 1985	460	Apr 1989	508	Apr 1993
317	May 1977	365	May 1981	413	May 1985	461	May 1989	509	May 1993
318	June 1977	366	June 1981	414	June 1985	462	June 1989	510	June 1993
319	July 1977	367	July 1981	415	July 1985	463	July 1989	511	July 1993
320	Aug 1977	368	Aug 1981	416	Aug 1985	464	Aug 1989	512	Aug 1993
321	Sept 1977	369	Sept 1981	417	Sept 1985	465	Sept 1989	513	Sept 1993
322	Oct 1977	370	Oct 1981	418	Oct 1985	466	Oct 1989	514	Oct 1993
323	Nov 1977	371	Nov 1981	419	Nov 1985	467	Nov 1989	515	Nov 1993
324	Dec 1977	372	Dec 1981	420	Dec 1985	468	Dec 1989	516	Dec 1993
325	Jan 1978	373	Jan 1982	421	Jan 1986	469	Jan 1990	517	Jan 1994
326	Feb 1978	374	Feb 1982	422	Feb 1986	470	Feb 1990	518	Feb 1994
327	Mar 1978	375	Mar 1982	423	Mar 1986	471	Mar 1990	519	Mar 1994
328	Apr 1978	376	Apr 1982	424	Apr 1986	472	Apr 1990	520	Apr 1994
329	May 1978	377	May 1982	425	May 1986	473	May 1990	521	May 1994
330	June 1978	378	June 1982	426	June 1986	474	June 1990	522	June 1994
331	July 1978	379	July 1982	427	July 1986	475	July 1990	523	July 1994
332	Aug 1978	380	Aug 1982	428	Aug 1986	476	Aug 1990	524	Aug 1994
333	Sept 1978	381	Sept 1982	429	Sept 1986	477	Sept 1990	525	Sept 1994
334	Oct 1978	382	Oct 1982	430	Oct 1986	478	Oct 1990	526	Oct 1994
335	Nov 1978	383	Nov 1982	431	Nov 1986	479	Nov 1990	527	Nov 1994
336	Dec 1978	384	Dec 1982	432	Dec 1986	480	Dec 1990	528	Dec 1994

Appendix C5. Simulated and Observed Transient Water Levels in Selected Wells and Related Statistics, Tarawa Terrace and Vicinity, U.S. Marine Corps Base Camp Lejuene, North Carolina

Tables

Table C5.1. Simulated and observed transient water levels in supply well TT-25[1] and related statistics, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

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

Date	Simulated water level, in feet above or below NGVD 29	Observed water level, in feet above or below NGVD 29	Absolute water-level difference, in feet
10/31/1980	7.5	6.0	1.5
6/30/1981	7.4	0.0	7.4
10/31/1982	–5.0	–13	8.0
12/31/1982	–2.8	–13	10.2
1/31/1983	–3.0	–14	11.0
2/28/1983	–2.6	–13	10.4
3/31/1983	–2.4	–10	7.6
4/30/1983	–2.9	–9	6.1
5/31/1983	–3.7	–9	5.3
7/31/1983	–5.3	–10	4.7
8/31/1983	–5.9	–12	6.1
9/30/1983	–4.4	–12	7.6
10/31/1983	–3.2	–15	11.8
11/30/1983	–3.1	–11	7.9
12/31/1983	–6.0	–9	3.0
1/31/1984	–0.9	–11	10.1
5/31/1984	–2.7	–10	7.3
6/30/1984	–4.1	–11	6.9
7/31/1984	–2.0	–10	8.0
8/31/1984	–1.1	–9	7.9
9/30/1984	–0.9	–5	4.1
10/31/1984	–0.7	–5	4.3
11/30/1984	–0.6	–11	10.4
12/31/1984	–0.2	–10	9.8
1/31/1985	–0.6	–10	9.4
6/30/1985	–3.4	–2	1.4
7/31/1985	–2.7	–3	0.3
8/31/1985	–3.4	–3	0.4
9/30/1985	–3.4	–4	0.6
10/31/1985	–3.4	–6	2.6
11/30/1985	–3.5	3	6.5
12/31/1985	–3.5	–4	0.5
1/31/1986	–2.0	–3	1.0
2/28/1986	–1.9	–3	1.1
3/31/1986	–2.7	–5	2.3
4/30/1986	–1.9	3	4.9
10/31/1986	–1.8	3.0	4.8
3/31/1987	8.5	10.9	2.4

[1]See Figure C1 for location

Statistics:

Average of water-level difference = 5.7 feet
Standard deviation of water-level difference = 3.5 feet
Root-mean-square error of water-level difference = 6.6 feet

Table C5.2. Simulated and observed transient water levels in supply well TT-26[1] and related statistics, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

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

Date	Simulated water level, in feet above or below NGVD 29	Observed water level, in feet above or below NGVD 29	Absolute water-level difference, in feet
5/31/1951	14.4	14.0	0.4
1/31/1978	–4.0	7	11.0
2/28/1978	–6.2	7	13.2
3/31/1978	–2.9	6	8.9
4/30/1978	–4.2	7	11.2
5/31/1978	–3.4	7	10.4
6/30/1978	–5.7	6	11.7
7/31/1978	–5.5	6	11.5
8/31/1978	–4.5	7	11.5
9/30/1978	–4.5	6	10.5
10/31/1978	–6.4	6	12.4
11/30/1978	–2.5	6	8.5
12/31/1978	–2.3	6	8.3
1/31/1979	–3.1	5	8.1
2/28/1979	–3.1	6	9.1
3/31/1979	–3.1	8	11.1
4/30/1979	–3.1	6	9.1
6/30/1979	–3.2	6	9.2
7/31/1979	–3.2	5	8.2
9/30/1979	–3.2	5	8.2
2/29/1980	–1.8	6	7.8
3/31/1980	–3.3	2	5.3
4/30/1980	–0.7	–8	7.3
5/31/1980	–1.0	6	7.0
10/31/1980	–1.3	–7	5.7
12/31/1980	–1.1	–8	6.9
1/31/1981	–0.9	0	0.9
2/28/1981	0.5	–2	2.5
3/31/1981	–1.0	0	1.0
4/30/1981	–1.6	2	3.6
6/30/1981	–4.0	0	4.0
7/31/1981	–5.3	2	7.3
8/31/1981	–4.7	–1	3.7
10/31/1981	–2.7	–2	0.7
11/30/1981	–2.7	2	4.7
4/30/1982	–5.4	–10	4.6
6/30/1982	–5.4	–14	8.6
8/31/1982	–5.7	–5	0.7
10/31/1982	–4.8	–15	10.2
12/31/1982	–2.3	2	4.3
1/31/1983	8.1	2	6.1
2/28/1983	8.6	4	4.6
3/31/1983	–1.6	4	5.6
4/30/1983	–2.3	4	6.3
5/31/1983	–3.3	–13	9.7
6/30/1983	–4.4	4	8.4
9/30/1983	–4.1	–22	17.9
10/31/1983	–2.7	3	5.7
11/30/1983	–2.6	–2	0.6
12/31/1983	–5.9	4	9.9
3/31/1984	–6.6	–6	0.6
5/31/1984	–5.0	4	9.0
6/30/1984	–6.9	–2	4.9
9/30/1984	–2.0	8	10.0
10/31/1984	–1.8	8	9.8
11/30/1984	–1.6	3	4.6
12/31/1984	–1.0	3	4.0
1/31/1985	–1.6	1	2.6
6/30/1985	9.0	6	3.0
7/31/1985	9.1	2	7.1
9/30/1985	9.0	2	7.0
10/31/1985	9.0	2	7.0
11/18/1985	8.9	11.1	2.2
11/30/1985	8.9	4	4.9
10/31/1986	9.3	7.4	1.9
3/31/1987	10.6	14.0	3.4

[1]See Figure C2 for location

Statistics:

Average of water-level difference = 6.8 feet
Standard deviation of water-level difference = 3.7 feet
Root-mean-square error of water-level difference = 7.7 feet

Table C5.3. Simulated and observed transient water levels in supply well TT-30[1] and related statistics, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

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

Date	Simulated water level, in feet above or below NGVD 29	Observed water level, in feet above or below NGVD 29	Absolute water-level difference, in feet	Date	Simulated water level, in feet above or below NGVD 29	Observed water level, in feet above or below NGVD 29	Absolute water-level difference, in feet
1/31/1978	8.6	4	4.6	3/31/1982	9.7	16	6.3
2/28/1978	7.3	4	3.3	4/30/1982	9.6	11	1.4
3/31/1978	9.2	6	3.2	6/30/1982	9.3	7	2.3
4/30/1978	8.4	5	3.4	7/31/1982	9.3	9	0.3
5/31/1978	8.9	4	4.9	8/31/1982	9.3	13	3.7
6/30/1978	7.5	5	2.5	9/30/1982	9.3	11	1.7
7/31/1978	7.7	4	3.7	10/31/1982	9.7	10	0.3
8/31/1978	8.2	–2	10.2	12/31/1982	10.8	9	1.8
9/30/1978	8.3	0	8.3	1/31/1983	10.0	9	1.0
10/31/1978	7.1	–2	9.1	2/28/1983	10.1	9	1.1
11/30/1978	9.5	–1	10.5	3/31/1983	10.9	9	1.9
12/31/1978	9.5	–3	12.5	4/30/1983	10.8	9	1.8
1/31/1979	9.0	–2	11.0	5/31/1983	10.4	13	2.6
2/28/1979	8.9	–2	10.9	6/30/1983	10.2	10	0.2
3/31/1979	8.9	2	6.9	7/31/1983	9.7	10	0.3
4/30/1979	8.9	–2	10.9	8/31/1983	9.4	10	0.6
6/30/1979	8.9	–1	9.9	9/30/1983	10.2	10	0.2
7/31/1979	8.9	–2	10.9	10/31/1983	10.8	10	0.8
8/31/1979	8.9	–2	10.9	11/30/1983	10.9	-7	17.9
9/30/1979	8.9	–4	12.9	12/31/1983	9.2	11	1.8
1/31/1980	7.8	–4	11.8	1/31/1984	11.6	10	1.6
2/29/1980	9.7	–4	13.7	2/29/1984	9.2	10	0.8
3/31/1980	8.8	–6	14.8	3/31/1984	9.5	15	5.5
4/30/1980	10.3	3	7.3	4/30/1984	10.7	12	1.3
5/31/1980	10.1	–6	16.1	5/31/1984	10.3	11	0.7
7/31/1980	5.9	–4	9.9	6/30/1984	9.4	11	1.6
8/31/1980	7.0	–2	9.0	7/31/1984	10.8	11	0.2
9/30/1980	9.2	–4	13.2	9/30/1984	17.3	11	6.3
10/31/1980	9.7	–6	15.7	10/31/1984	12.5	11	1.5
12/31/1980	10.0	–6	16.0	11/30/1984	12.5	11	1.5
1/31/1981	10.7	–8	18.7	12/31/1984	12.7	11	1.7
2/28/1981	11.6	–7	18.6	1/31/1985	12.5	11	1.5
3/31/1981	10.8	–6	16.8	3/31/1985	17.8	11	6.8
4/30/1981	10.6	–4	14.6				
5/31/1981	10.4	–5	15.4				
6/30/1981	9.3	–6	15.3				
7/31/1981	8.6	–7	15.6				
8/31/1981	8.9	–5	13.9				
9/30/1981	9.9	–6	15.9				
10/31/1981	10.1	–10	20.1				

[1]See Figure C1 for location

Statistics:

Average of water-level difference = 7.3 feet
Standard deviation of water-level difference = 6.1 feet
Root-mean-square error of water-level difference = 9.5 feet

Table C5.4. Simulated and observed transient water levels in supply well TT-31[1] and related statistics, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

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

Date	Simulated water level, in feet above or below NGVD 29	Observed water level, in feet above or below NGVD 29	Absolute water-level difference, in feet
10/31/1978	–14.2	–2	12.2
11/30/1978	–10.1	–1	9.1
7/31/1979	–10.4	–3	7.4
8/31/1979	–10.4	–2	8.4
9/30/1979	–10.4	2	12.4
1/31/1980	–12.4	–3	9.4
2/29/1980	–9.1	–2	7.1
3/31/1980	–10.4	–2	8.4
4/30/1980	–7.8	12	19.8
5/31/1980	–7.8	0	7.8
7/31/1980	–15.3	0	15.3
8/31/1980	–14.3	–2	12.3
12/31/1980	–7.9	–4	3.9
1/31/1981	–8.7	–8	0.7
2/28/1981	–7.2	–6	1.2
3/31/1981	–8.8	–8	0.8
5/31/1981	–10.2	–4	6.2
6/30/1981	–12.6	–5	7.6
7/31/1981	–14.3	–3	11.3
10/31/1981	–11.6	–6	5.6
11/30/1981	–11.5	–8	3.5
6/30/1982	–12.1	–6	6.1
7/31/1982	–12.3	–3	9.3
9/30/1982	–12.5	–8	4.5
10/31/1982	–11.6	–4	7.6
12/31/1982	–8.5	3	11.5
1/31/1983	–10.3	4	14.3
2/28/1983	–10.3	2	12.3
3/31/1983	–8.7	4	12.7
4/30/1983	–8.8	8	16.8
5/31/1983	–9.7	8	17.7
10/31/1983	–9.3	3	12.3
11/30/1983	–9.0	6	15.0
12/31/1983	–12.4	–8	4.4
3/31/1984	–11.3	–6	5.3
5/31/1984	–10.9	8	18.9
7/31/1984	–9.2	–4	5.2
9/30/1984	–7.6	–4	3.6
10/31/1984	–7.2	–4	3.2
11/30/1984	–7.0	–6	1.0
12/31/1984	–6.4	–4	2.4
1/31/1985	–6.8	–5	1.8
3/31/1985	–7.2	–5	2.2
6/30/1985	–15.9	–3	12.9
7/31/1985	–14.9	–11	3.9
8/31/1985	–16.0	–3	13.0
9/13/1985	–16.0	–5	11.0
9/30/1985	–16.2	–4	12.2
10/31/1985	–16.3	–3	13.3
11/30/1985	–16.4	–8	8.4
12/31/1985	–16.4	–6	10.4
1/31/1986	–13.7	–5	8.7
2/28/1986	–13.3	–6	7.3
4/30/1986	–12.8	–2	10.8
10/31/1986	–12.9	–0.1	12.8
3/31/1987	3.1	5.2	2.1

[1]See Figure C1 for location

Statistics:

Average of water-level difference = 8.7 feet
Standard deviation of water-level difference = 4.9 feet
Root-mean-square error of water-level difference = 9.9 feet

Table C5.5. Simulated and observed transient water levels in supply well TT-52[1] and related statistics, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

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

Date	Simulated water level, in feet above or below NGVD 29	Observed water level, in feet above or below NGVD 29	Absolute water-level difference, in feet
10/31/1961	9.8	12.9	3.1
3/31/1962	–7.4	9	16.4
1/31/1978	–10.1	–5	5.1
2/28/1978	–12.7	–4	8.7
3/31/1978	–9.2	–5	4.2
4/30/1978	–10.5	–5	5.5
5/31/1978	–9.6	–1	8.6
6/30/1978	–12.3	–3	9.3
7/31/1978	–12.2	–1	11.2
8/31/1978	–11.1	–3	8.1
9/30/1978	–11.0	–3	8.0
10/31/1978	–13.2	–3	10.2
11/30/1978	–8.8	–4	4.8
12/31/1978	–8.3	–7	1.3
1/31/1979	–9.2	–7	2.2
2/28/1979	–9.2	–4	5.2
3/31/1979	–9.3	–5	4.3
6/30/1979	–9.3	–4	5.3
7/31/1979	–9.3	–4	5.3
8/31/1979	–9.3	–3	6.3
9/30/1979	–9.3	–4	5.3
1/31/1980	–11.4	–4	7.4
2/29/1980	–7.9	–3	4.9
3/31/1980	–9.4	–4	5.4
4/30/1980	–6.6	–4	2.6
5/31/1980	–6.8	–4	2.8
7/31/1980	–14.7	–5	9.7
8/31/1980	–13.3	–5	8.3
12/31/1980	–6.9	–6	0.9
1/31/1981	–10.2	–7	3.2
2/28/1981	–8.4	–6	2.4
3/31/1981	–10.5	–9	1.5
4/30/1981	–11.4	–9	2.4
5/31/1981	–12.0	–5	7.0
6/30/1981	–15.1	–5	10.1
7/31/1981	–17.2	–7	10.2
10/31/1981	–13.4	–9	4.4
11/30/1981	–13.4	–7	6.4
4/30/1982	–13.7	–5	8.7
6/30/1982	–14.0	–5	9.0
7/31/1982	–14.0	–6	8.0
9/30/1982	–14.2	–9	5.2
12/31/1982	–9.6	–6	3.6
1/31/1983	–11.8	–6	5.8
2/28/1983	–11.7	–9	2.7
3/31/1983	–9.7	–2	7.7
4/30/1983	–9.9	–2	7.9
5/31/1983	–11.0	–1	10.0
10/31/1983	–10.2	–4	6.2
11/30/1983	–10.0	–2	8.0
12/31/1983	–14.3	–2	12.3
3/31/1984	–13.1	–4	9.1
4/30/1984	–10.1	–2	8.1
5/31/1984	–11.3	–2	9.3
6/30/1984	–12.6	–3	9.6
7/31/1984	–9.7	–3	6.7
9/30/1984	–6.8	–2	4.8
10/31/1984	–6.4	3	9.4
11/30/1984	–6.2	3	9.2
12/31/1984	–5.5	–2	3.5
1/31/1985	–4.4	–2	2.4
5/31/1985	–12.9	–5	7.9
6/30/1985	–13.3	2	15.3
7/31/1985	–12.3	0	12.3
8/31/1985	–13.3	–1	12.3
9/30/1985	–13.5	4	17.5
10/31/1985	–13.6	3	16.6
11/30/1985	–13.6	5	18.6
12/31/1985	–13.6	4	17.6
1/31/1986	–11.1	–2	9.1
2/28/1986	–10.9	5	15.9
3/31/1986	3.4	–7	10.4
4/30/1986	–9.8	5	14.8
10/31/1986	–10.6	1.8	12.4
3/31/1987	4.9	5.0	0.1

[1]See Figure C1 for location

Statistics:

Average of water-level difference = 7.7 feet
Standard deviation of water-level difference = 4.3 feet
Root-mean-square error of water-level difference = 8.8 feet

Table C5.6. Simulated and observed transient water levels in supply well TT-53[1] and related statistics, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

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

Date	Simulated water level, in feet above or below NGVD 29	Observed water level, in feet above or below NGVD 29	Absolute water-level difference, in feet
7/31/1961	11.9	16	4.1
3/31/1962	–1.3	11	12.3
1/31/1978	1.5	–4	5.5
2/28/1978	0.3	–5	5.3
3/31/1978	1.6	–3	4.6
4/30/1978	1.2	–5	6.2
5/31/1978	1.5	–5	6.5
6/30/1978	0.4	–4	4.4
7/31/1978	0.2	–4	4.2
8/31/1978	0.6	0	0.6
9/30/1978	0.7	–3	3.7
12/31/1978	2.0	–2	4.0
1/31/1979	1.8	–2	3.8
2/28/1979	1.7	–4	5.7
3/31/1979	1.7	–2	3.7
4/30/1979	1.7	–8	9.7
6/30/1979	1.7	–6	7.7
7/31/1979	1.6	–4	5.6
1/31/1980	0.7	–4	4.7
2/29/1980	2.1	–3	5.1
3/31/1980	1.6	–1	2.6
4/30/1980	2.8	–2	4.8
5/31/1980	3.0	–5	8.0
7/31/1980	–0.2	–7	6.8
8/31/1980	0.2	–3	3.2
9/30/1980	1.7	–7	8.7
12/31/1980	3.0	–3	6.0
1/31/1981	2.2	–9	11.2
2/28/1981	3.0	–7	10.0
3/31/1981	2.3	–9	11.3
4/30/1981	1.9	–9	10.9
6/30/1981	0.2	–9	9.2
10/31/1981	0.7	–9	9.7
11/30/1981	0.7	–8	8.7
1/31/1982	0.4	–9	9.4
3/31/1982	–0.4	–13	12.6
4/30/1982	–0.6	–8	7.4
6/30/1982	–0.9	–22	21.1
7/31/1982	–1.0	–15	14.0
8/31/1982	–1.1	–15	13.9
12/31/1982	1.3	–19	20.3
1/31/1983	0.6	–19	19.6
2/28/1983	0.7	–19	19.7
3/31/1983	1.4	–11	12.4
4/30/1983	1.4	–11	12.4
5/31/1983	0.9	–10	10.9
10/31/1983	0.7	–9	9.7
11/30/1983	1.0	–13	14.0
12/31/1983	–0.8	–13	12.2
1/31/1984	1.5	–11	12.5
7/31/1986	6.5	1	5.5
3/31/1987	8.2	10	1.8

[1]See Figure C1 for location

Statistics:

Average of water-level difference = 8.6 feet
Standard deviation of water-level difference = 4.8 feet
Root-mean-square error of water-level difference = 9.9 feet

Table C5.7. Simulated and observed transient water levels in supply well TT-54[1] and related statistics, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

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

Date	Simulated water level, in feet above or below NGVD 29	Observed water level, in feet above or below NGVD 29	Absolute water-level difference, in feet
6/30/1961	7.6	12.1	4.5
3/31/1962	–12.3	6	18.3
1/31/1978	–15.8	–7	8.8
2/28/1978	–18.9	–6	12.9
3/31/1978	–14.6	–6	8.6
4/30/1978	–16.1	–5	11.1
5/31/1978	–15.0	–7	8.0
6/30/1978	–18.3	–6	12.3
7/31/1978	–18.2	–7	11.2
8/31/1978	–16.8	–6	10.8
9/30/1978	–16.6	–6	10.6
10/31/1978	–19.4	–6	13.4
11/30/1978	–14.0	–7	7.0
12/31/1978	–13.5	–7	6.5
1/31/1979	–14.5	–7	7.5
2/28/1979	–14.5	–8	6.5
3/31/1979	–14.6	–6	8.6
4/30/1979	–14.6	–7	7.6
6/30/1979	–14.6	–8	6.6
8/31/1979	–14.6	–6	8.6
1/31/1980	–17.1	–7	10.1
2/29/1980	–12.9	–6	6.9
3/31/1980	–14.7	–8	6.7
4/30/1980	–11.3	–10	1.3
5/31/1980	–11.6	–8	3.6
7/31/1980	–21.2	–6	15.2
8/31/1980	–19.2	–8	11.2
12/31/1980	–11.7	–8	3.7
1/31/1981	–13.7	–11	2.7
2/28/1981	–11.7	–11	0.7
3/31/1981	–14.0	–12	2.0
4/30/1981	–15.0	–10	5.0
5/31/1981	–15.6	–8	7.6
7/31/1981	–21.3	–10	11.3
8/31/1981	–20.5	–8	12.5
10/31/1981	–17.2	–12	5.2
11/30/1981	–17.1	–10	7.1
1/31/1982	–16.6	–11	5.6
3/31/1982	–17.3	–10	7.3
4/30/1982	–17.6	–9	8.6
5/31/1982	–7.5	–10	2.5
6/30/1982	–17.1	–10	7.1
7/31/1982	–17.7	–10	7.7
8/31/1982	–17.9	–12	5.9
9/30/1982	–18.0	–10	8.0
10/31/1982	–16.7	–10	6.7
11/30/1982	–11.9	–10	1.9
12/31/1982	–13.1	–9	4.1
1/31/1983	–15.4	–9	6.4
2/28/1983	–15.3	–8	7.3
3/31/1983	–13.2	–8	5.2
4/30/1983	–13.4	–8	5.4
5/31/1983	–14.6	–8	6.6
6/30/1983	–15.7	–8	7.7
10/31/1983	–13.9	–9	4.9
11/30/1983	–13.6	–7	6.6
12/31/1983	–18.3	0	18.3
1/31/1984	–12.0	–9	3.0
2/29/1984	0.3	–8	8.3
5/31/1984	–14.6	–8	6.6
6/30/1984	–16.2	–10	6.2
7/31/1984	–13.3	–8	5.3
9/30/1984	–11.2	–8	3.2
10/31/1984	–10.9	–8	2.9
11/30/1984	–10.7	–9	1.7
12/31/1984	–9.9	–8	1.9
1/31/1985	–10.6	–12	1.4
2/28/1985	–16.9	–14	2.9
4/30/1985	–17.9	–12	5.9
6/30/1985	–21.0	–2	19.0
7/31/1985	–19.7	–13	6.7
8/31/1985	–21.1	–12	9.1
9/13/1985	–21.1	–8	13.1
9/30/1985	–21.2	–8	13.2
10/31/1985	–21.3	–10	11.3
11/30/1985	–21.4	–1	20.4
12/31/1985	–21.4	–8	13.4
1/31/1986	–18.0	–6	12.0
2/28/1986	–17.7	–9	8.7
3/31/1986	–19.2	–10	9.2
4/30/1986	–17.4	–8	9.4
10/31/1986	–17.3	0.4	17.7
3/31/1987	2.3	6.7	4.4

[1]See Figure C1 for location

Statistics:

Average of water-level difference = 7.9 feet
Standard deviation of water-level difference = 4.3 feet
Root-mean-square error of water-level difference = 9.0 feet

Table C5.8. Simulated and observed transient water levels in supply well TT-67[1] and related statistics, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

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

Date	Simulated water level, in feet above or below NGVD 29	Observed water level, in feet above or below NGVD 29	Absolute water-level difference, in feet
3/31/1979	–10.5	–14	3.5
4/30/1979	–10.6	–12	1.4
6/30/1979	–10.6	–12	1.4
7/31/1979	–10.6	–10	0.6
8/31/1979	–10.6	–10	0.6
9/30/1979	–10.6	–8	2.6
1/31/1980	–12.7	–8	4.7
2/29/1980	–9.2	–10	0.8
3/31/1980	–10.7	–4	6.7
4/30/1980	–7.8	–12	4.2
5/31/1980	–7.9	–10	2.1
7/31/1980	–15.6	–8	7.6
8/31/1980	–14.2	–10	4.2
10/31/1980	–8.9	–6	2.9
12/31/1980	–8.0	–8	0.0
1/31/1981	–6.5	–10	3.5
2/28/1981	–5.1	–10	4.9
3/31/1981	–6.5	–8	1.5
4/30/1981	–7.2	–6	1.2
6/30/1981	–9.9	–4	5.9
7/31/1981	–10.7	–8	2.7
10/31/1981	–8.9	–6	2.9
11/30/1981	–8.8	–8	0.8
1/31/1982	–8.8	–11	2.2
3/31/1982	–9.5	–7	2.5
4/30/1982	–9.7	–9	0.7
6/30/1982	–9.7	–11	1.3
7/31/1982	–9.9	–12	2.1
8/31/1982	–10.1	–8	2.1
9/30/1982	–10.2	–8	2.2
10/31/1982	–9.4	–6	3.4
12/31/1982	–6.6	–6	0.6
1/31/1983	–9.0	–7	2.0
2/28/1983	–8.9	–6	2.9
3/31/1983	–7.5	–4	3.5
4/30/1983	–7.6	–4	3.6
5/18/1983	–8.5	–5	3.5
5/31/1983	–8.5	–3	5.5
6/30/1983	–9.5	–4	5.5
10/31/1983	–8.2	–3	5.2
11/30/1983	–7.9	–6	1.9
12/31/1983	–11.1	–6	5.1
3/31/1984	–8.2	10	18.2
5/31/1984	–7.9	–4	3.9
6/30/1984	–8.4	–1	7.4
8/21/1984	–6.1	–3	3.1
8/31/1984	–6.1	–3	3.1
9/30/1984	–6.0	–5	1.0
10/31/1984	–5.8	–5	0.8
11/30/1984	–5.6	0	5.6
12/31/1984	–5.0	–1	4.0
1/31/1985	–5.4	–4	1.4
3/31/1985	–5.4	–4	1.4
7/31/1985	–10.8	–2	8.8
8/31/1985	–11.7	–4	7.7
9/13/1985	–11.7	–2	9.7
9/30/1985	–11.8	–4	7.8
10/31/1985	–11.9	–3	8.9
11/30/1985	–11.9	–2	9.9
12/31/1985	–11.9	–4	7.9
1/31/1986	–9.9	–2	7.9
2/28/1986	–9.6	–4	5.6
3/31/1986	–10.3	–5	5.3
4/30/1986	–9.2	–10	0.8
10/31/1986	–9.2	–4	5.2
3/31/1987	4.8	8.4	3.6

[1]See Figure C1 for location

Statistics:

Average of water-level difference = 4.0 feet
Standard deviation of water-level difference = 3.1 feet
Root-mean-square error of water-level difference = 5.0 feet

Table C5.9. Simulated and observed transient water levels in test well T-9 and supply wells TT-23, TT-27, and TT-55 and related statistics, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.

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

Site name[1]	Measurement date	Simulated water level, in feet above NGVD 29	Observed water level, in feet above or below NGVD 29	Absolute water-level difference, in feet
T-9	9/24/1986	13.1	17.5	4.4
	10/19/1986	13.1	20.3	7.2
	10/21/1986	13.1	19.1	6.0
	4/7/1987	13.4	24.5	11.1
	4/10/1987	13.4	23.4	10.0
TT-23	3/14/1983	3.8	–1.8	5.6
	9/25/1985	4.0	1.1	2.9
	10/21/1986	4.5	2.2	2.3
	4/7/1987	6.4	9.3	2.9
TT-27	1/10/1963	12.1	16.6	4.5
	4/17/1963	11.6	18.4	6.8
	1/16/1964	11.4	19.4	8.0
	7/14/1964	11.3	19.0	7.7
	9/17/1964	11.3	20.6	9.3
	10/14/1964	11.3	21.9	10.6
TT-55	11/1/1961	3.7	18.9	15.2
	3/28/1962	12.3	14.4	2.1

[1]See Plate 1 for location

Statistics:

Average of water-level difference = 6.9 feet
Standard deviation of water-level difference = 3.6 feet
Root-mean-square error of water-level difference = 7.7 feet

Table C5.10. Simulated and observed transient water levels and related statistics in monitor wells installed during ABC One-Hour Cleaners Operable Units 1 and 2 and during similar investigations by the North Carolina Department of Natural Resources and Community Development, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[NGVD 29, National Geodetic Vertical Datum of 1929]

Site name[1]	Measurement date	Simulated water level, in feet above NGVD 29	Observed water level, in feet above NGVD 29	Absolute water-level difference, in feet
C1	4/22/1992	18.3	21.5	3.2
	6/2/1992	18.3	20.8	2.5
	6/25/1992	18.3	21.2	2.9
C2	4/22/1992	17.1	19.6	2.5
	6/2/1992	17.1	19.0	1.9
	6/25/1992	17.1	19.6	2.5
C3	4/22/1992	14.6	15.8	1.2
	6/2/1992	14.6	14.7	0.1
	6/25/1992	14.6	15.6	1.0
C4	4/22/1992	11.6	11.9	0.3
	6/2/1992	11.6	11.3	0.3
	6/25/1992	11.6	10.2	1.4
C5	4/22/1992	14.2	15.7	1.5
	6/2/1992	14.2	15.0	0.8
	6/25/1992	14.2	15.9	1.7
C9	10/1/1993	14.8	12.4	2.4
	11/18/1993	14.8	13.0	1.8
C10	11/18/1993	14.4	12.6	1.8
C11	10/1/1993	6.8	6.3	0.5
PZ-01	10/1/1993	17.5	15.9	1.6
	11/18/1993	17.5	16.7	0.8
PZ-02	10/1/1993	17.6	16.0	1.6
	11/18/1993	17.6	16.7	0.9
PZ-03	10/1/1993	17.2	15.6	1.6
	11/18/1993	17.2	16.6	0.6
PZ-04	10/1/1993	17.4	15.8	1.6
	11/18/1993	17.4	16.4	1.0
PZ-05	10/1/1993	17.5	15.7	1.8
PZ-06	10/1/1993	17.7	16.1	1.6
S1	4/22/1992	18.6	23.7	5.1
	6/2/1992	18.6	23.3	4.7
	6/25/1992	18.6	22.6	4.0
	10/1/1993	18.8	17.4	1.4
	11/18/1993	18.8	18.3	0.5
S2	4/22/1992	17.3	19.9	2.6
	6/2/1992	17.3	19.2	1.9
	6/25/1992	17.3	19.8	2.5
	10/1/1993	17.5	16.4	1.1
	11/18/1993	17.5	16.6	0.9
S3	4/22/1992	14.5	16.0	1.5
	6/2/1992	14.5	14.8	0.3
	6/25/1992	14.5	15.8	1.3
	10/1/1993	14.8	13.1	1.7
	11/18/1993	14.8	13.6	1.2

Table C5.10. Simulated and observed transient water levels and related statistics in monitor wells installed during ABC One-Hour Cleaners Operable Units 1 and 2 and during similar investigations by the North Carolina Department of Natural Resources and Community Development, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.—Continued

[NGVD 29, National Geodetic Vertical Datum of 1929]

Site name[1]	Measurement date	Simulated water level, in feet above NGVD 29	Observed water level, in feet above NGVD 29	Absolute water-level difference, in feet
S4	4/22/1992	12.2	13.6	1.4
	6/2/1992	12.2	12.4	0.2
	6/25/1992	12.2	11.9	0.3
	10/1/1993	12.4	11.2	1.2
	11/18/1993	12.4	13.5	1.1
S5	4/22/1992	14.3	16.4	2.1
	6/2/1992	14.3	15.2	0.9
	6/25/1992	14.3	16.2	1.9
	10/1/1993	14.5	13.5	1.0
	11/18/1993	14.5	13.7	0.8
S6	4/22/1992	17.7	20.6	2.9
	6/2/1992	17.7	20.0	2.3
	6/25/1992	17.7	20.5	2.8
	10/1/1993	17.9	16.3	1.6
	11/18/1993	17.9	17.1	0.8
S7	4/22/1992	17.1	19.8	2.7
	6/2/1992	17.1	19.0	1.9
	6/25/1992	17.1	19.4	2.3
	10/1/1993	17.3	15.8	1.5
	11/18/1993	17.3	16.6	0.7
S8	4/22/1992	16.3	20.9	4.6
	6/2/1992	16.3	19.8	3.5
	6/25/1991	16.3	21.1	4.8
	10/1/1993	16.5	18.8	2.3
	11/18/1993	16.5	19.0	2.5
S9	4/22/1992	14.5	15.4	0.9
	6/2/1992	14.5	14.2	0.3
	6/25/1992	14.5	13.3	1.2
	10/1/1993	14.7	12.5	2.2
	11/18/1993	14.7	13.0	1.7
S10	4/22/1992	11.9	12.2	0.3
	6/2/1992	11.9	12.8	0.9
	6/25/1992	11.9	13.3	1.4
	10/1/1993	12.2	12.4	0.2
	11/18/1993	12.2	12.7	0.5
S11	10/1/1993	20.3	17.9	2.4
	11/18/1993	20.3	19.0	1.3
[2]X24B4	9/25/1985	9.8	5.0	4.8
[2]X24B5	9/25/1985	12.2	7.7	4.5
[2]X24B6	9/25/1985	13.7	10.4	3.3

[1]See Plate 1 for location

[2]Shown on Plate 1 as B4, B5, and B6, respectively

Statistics:

Average of water-level difference = 1.8 feet
Standard deviation of water-level difference = 1.2 feet
Root-mean-square error of water-level difference = 2.1 feet

Table C5.11. Simulated and observed transient water levels in monitor wells installed during investigations of releases of refined-petroleum products to groundwater and related statistics, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[NGVD 29, National Geodetic Vertical Datum of 1929]

Site name[1]	Measurement date	Simulated water level, in feet above NGVD 29	Observed water level, in feet above NGVD 29	Absolute water-level difference, in feet
STT61to66-MW01	1/8/1992	19.3	20.6	1.3
	1/11/1992	19.3	20.7	1.4
	1/29/1992	19.3	21.6	2.3
	12/17/1992	19.3	21.1	1.8
STT61to66-MW02	1/8/1992	19.3	20.2	0.9
	1/11/1992	19.3	20.1	0.8
	1/29/1992	19.3	21.6	2.3
	12/17/1992	19.3	20.4	1.1
STT61to66-MW03	1/9/1992	19.0	20.4	1.4
	1/11/1992	19.0	20.3	1.3
	1/29/1992	19.0	21.3	2.3
	12/17/1992	18.9	21.0	2.1
STT61to66-MW04	1/9/1992	19.0	20.1	1.1
	1/11/1992	19.0	20.9	1.9
	1/29/1992	19.0	20.7	1.7
	12/17/1992	18.9	20.4	1.5
STT61to66-MW05	1/9/1992	19.1	20.9	1.8
	1/11/1992	19.1	18.9	0.2
	1/29/1992	19.1	19.6	0.5
	12/17/1992	19.1	21.3	2.2
STT61to66-MW06	1/9/1992	19.1	20.4	1.3
	1/11/1992	19.1	20.1	1.0
	1/29/1992	19.1	20.8	1.7
	12/17/1992	19.1	20.5	1.4
STT61to66-MW07	1/9/1992	19.3	20.9	1.6
	1/11/1992	19.3	20.9	1.6
	1/29/1992	19.3	21.5	2.2
	12/17/1992	19.3	21.1	1.8
STT61to66-MW08	1/9/1992	19.3	19.8	0.5
	1/11/1992	19.3	19.9	0.6
	1/29/1992	19.3	20.8	1.5
	12/17/1992	19.3	20.5	1.2
STT61to66-MW09	1/9/1992	19.0	20.9	1.9
	1/11/1992	19.0	20.8	1.8
	1/29/1992	19.0	21.6	2.6
	12/17/1992	19.0	21.4	2.4
STT61to66-MW10	1/9/1992	19.0	20.7	1.7
	1/11/1992	19.0	20.0	1.0
	1/29/1992	19.0	20.7	1.7
	12/17/1992	19.0	20.4	1.4
STT61to66-MW11	1/10/1992	18.8	20.1	1.3
	1/11/1992	18.8	20.9	2.1
	1/29/1992	18.8	21.9	3.1
	12/17/1992	18.8	21.5	2.7
STT61to66-MW12	1/10/1992	18.8	19.7	0.9
	1/11/1992	18.8	19.8	1.0
	1/29/1992	18.8	20.6	1.8
	12/17/1992	18.8	20.3	1.5

Table C5.11. Simulated and observed transient water levels in monitor wells installed during investigations of releases of refined-petroleum products to groundwater and related statistics, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.—Continued

[NGVD 29, National Geodetic Vertical Datum of 1929]

Site name[1]	Measurement date	Simulated water level, in feet above NGVD 29	Observed water level, in feet above NGVD 29	Absolute water-level difference, in feet
STT61to66-MW13	1/10/1992	18.7	20.4	1.7
	1/11/1992	18.7	20.2	1.5
	1/29/1992	18.7	21.8	3.1
	12/17/1992	18.7	21.2	2.5
STT61to66-MW14	1/10/1992	18.7	19.8	1.1
	1/11/1992	18.7	19.7	1.0
	1/29/1992	18.7	20.5	1.8
	12/17/1992	18.7	20.3	1.6
STT61to66-MW15	12/17/1992	18.9	21.0	2.1
STT61to66-MW16	12/17/1992	18.6	20.2	1.6
STT61to66-MW17	12/17/1992	18.9	21.3	2.4
STT61to66-MW18	12/17/1992	18.7	20.2	1.5
STT61to66-MW19	12/17/1992	18.5	20.5	2.0
STT61to66-MW20	12/17/1992	18.5	20.1	1.6
TTDump MW01	6/26/1991	1.8	2.4	0.6
TTDump MW02	6/26/1991	4.3	6.2	1.9
TTDump MW03	6/26/1991	3.0	2.2	0.8
[2]TTUST-2453-A-1	6/7/1989	6.7	8.4	1.7
[2]TTUST-2453-A-2	6/7/1989	5.7	6.6	0.9
[2]TTUST-2453-A-3	6/7/1989	5.7	6.6	0.9
[2]TTUST-2453-A-4	6/7/1989	6.2	7.6	1.4
[2]TTUST-2453-A-5	6/7/1989	6.0	7.4	1.4
[2]TTUST-2453-A-6	6/7/1989	5.7	6.4	0.7
[2]TTUST-2453-A-7	6/7/1989	5.7	6.7	1.0
[2]TTUST-2453-A-8	6/7/1989	5.6	6.5	0.9
[2]TTUST-2453-A-9	6/7/1989	5.7	6.7	1.0
[2]TTUST-2453-OB-1	6/7/1989	5.7	6.8	1.1
[2]TTUST-2453-OB-2	6/7/1989	5.7	6.6	0.9
[2]TTUST-2453-OB-3	6/7/1989	5.5	6.4	0.9
[2]TTUST-2453-OB-4	6/7/1989	6.0	7.3	1.3
[2]TTUST-2453-OB-8	6/7/1989	5.2	6.5	1.3
[2]TTUST-2453-OB-9	6/7/1989	5.7	6.6	0.9
[2]TTUST-2453-OB-1	6/7/1989	5.5	6.3	0.8
[2]TTUST-2453-OB-1	6/7/1989	6.1	7.4	1.3
[2]TTUST-2453-RW	6/7/1989	5.8	6.8	1.0
[2]TTUST-2455-1	10/7/1993	7.8	9.0	1.2
[2]TTUST-2455-2	10/7/1993	7.7	8.5	0.8
[2]TTUST-2455-3	10/7/1993	7.8	8.2	0.4
[2]TTUST-2455-4	10/28/1993	7.9	8.6	0.7
[2]TTUST-2455-5	10/28/1993	8.2	9.0	0.8
[2]TTUST-2455-6	10/28/1993	7.5	8.0	0.5
[2]TTUST-2455-7	10/28/1993	6.8	6.8	0.0
[2]TTUST-2455-8	10/28/1993	7.2	7.6	0.4
[2]TTUST-2455-9	10/28/1993	7.5	7.9	0.4
[2]TTUST-2455-10	10/28/1993	7.1	7.4	0.3
[2]TTUST-2455-11	10/28/1993	7.0	7.3	0.3

Table C5.11. Simulated and observed transient water levels in monitor wells installed during investigations of releases of refined-petroleum products to groundwater and related statistics, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.—Continued

[NGVD 29, National Geodetic Vertical Datum of 1929]

Site name[1]	Measurement date	Simulated water level, in feet above NGVD 29	Observed water level, in feet above NGVD 29	Absolute water-level difference, in feet
[2]TTUST-2455-12	10/28/1993	7.6	8.2	0.6
[2]TTUST-2455-13	10/28/1993	8.4	9.2	0.8
	12/14/1993	8.4	9.2	0.8
[2]TTUST-2455-14	10/28/1993	6.9	7.0	0.1
[2]TTUST-2455-15	10/28/1993	6.1	5.6	0.5
[2]TTUST-2455-16	10/28/1993	7.7	8.3	0.6
[2]TTUST-2455-18	10/28/1993	7.1	7.6	0.5
[2]TTUST-2477-MW01	12/6/1994	9.1	10.0	0.9
[2]TTUST-2477-MW02	12/6/1994	9.1	10.1	1.0
[2]TTUST-2477-MW06	10/26/1994	8.9	10.0	1.1
	12/6/1994	8.9	9.8	0.9
[2]TTUST-2477-MW07	12/6/1994	8.9	9.8	0.9
[2]TTUST-2477-MW08	11/3/1994	8.7	9.8	1.1
	12/6/1994	8.7	9.5	0.8
[2]TTUST-2477-MW09	11/3/1994	8.5	9.5	1.0
	12/6/1994	8.5	9.3	0.8
[2]TTUST-2477-MW10	11/3/1994	7.9	8.8	0.9
	12/6/1994	7.9	8.6	0.7
[2]TTUST-2477-MW11	11/4/1994	8.0	11.6	3.6
	12/6/1994	8.0	8.6	0.6
[2]TTUST-2477-MW12	11/8/1994	7.5	10.0	2.5
	12/6/1994	7.5	8.1	0.6
[2]TTUST-2477-MW13	11/9/1994	7.4	8.1	0.7
	12/6/1994	7.4	8.1	0.7
[2]TTUST-2477-MW14	11/9/1994	7.1	7.9	0.8
	12/6/1994	7.1	7.8	0.7
[2]TTUST-2478-MW08	11/22/1993	10.9	12.6	1.7
	1/9/1994	10.9	12.3	1.4
[2]TTUST-2478-MW09	11/23/1993	9.9	11.8	1.9
	1/9/1994	9.9	11.4	1.5
[2]TTUST-2478-MW10	11/23/1993	9.4	11.4	2.0
	1/9/1994	9.4	11.0	1.6
	12/6/1994	10.0	11.2	1.2
[2]TTUST-2478-MW11	11/29/1993	9.1	9.9	0.8
	1/9/1994	9.1	10.6	1.5
	12/6/1994	9.7	10.9	1.2
[2]TTUST-2478-MW11D	12/15/1993	9.1	11.0	1.9
	1/9/1994	9.1	10.6	1.5
	12/6/1994	9.6	10.8	1.2
[2]TTUST-2478-MW12	12/2/1993	8.3	10.2	1.9
	1/9/1994	8.3	9.7	1.4
	12/6/1994	8.9	9.9	1.0
[2]TTUST-2478-MW13	11/30/1993	9.2	11.1	1.9
	1/9/1994	9.2	10.7	1.5
	12/6/1994	9.8	11.0	1.2

Table C5.11. Simulated and observed transient water levels in monitor wells installed during investigations of releases of refined-petroleum products to groundwater and related statistics, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.—Continued

[NGVD 29, National Geodetic Vertical Datum of 1929]

Site name[1]	Measurement date	Simulated water level, in feet above NGVD 29	Observed water level, in feet above NGVD 29	Absolute water-level difference, in feet
[2]TTUST-2478-MW14	11/30/1993	9.4	11.3	1.9
	1/9/1994	9.4	10.9	1.5
	12/6/1994	10.0	11.2	1.2
[2]TTUST-2478-MW14D	12/16/1993	9.4	11.4	2.0
	1/9/1994	9.4	10.9	1.5
	12/6/1994	10.0	11.2	1.2
[2]TTUST-2478-MW15	11/30/1993	10.0	11.9	1.9
	1/9/1994	10.0	11.6	1.6
[2]TTUST-2478-MW16	12/6/1993	7.9	9.5	1.6
	1/9/1994	8.0	9.1	1.1
	12/6/1994	8.5	9.3	0.8
[2]TTUST-2478-MW17	12/7/1993	7.6	9.1	1.5
	1/9/1994	7.6	8.6	1.0
	12/6/1994	8.1	8.8	0.7
[2]TTUST-2478-MW17D	12/14/1993	7.6	9.1	1.5
	1/9/1994	7.6	8.7	1.1
	12/6/1994	8.1	8.9	0.8
[2]TTUST-2478-MW18	12/7/1993	7.9	9.4	1.5
	1/9/1994	7.9	8.9	1.0
	12/6/1994	8.4	9.2	0.8
[2]TTUST-2478-MW19	12/7/1993	8.4	10.0	1.6
	1/9/1994	8.4	9.6	1.2
	12/6/1994	8.9	9.9	1.0
[2]TTUST-2478-PW01	1/9/1994	10.0	11.6	1.6
[2]TTUST-TTSC-1	12/28/1994	9.5	10.8	1.3
[2]TTUST-TTSC-2	12/28/1994	9.1	10.1	1.0
[2]TTUST-TTSC-3	1/9/1994	8.8	9.6	0.8
	12/28/1994	9.3	10.4	1.1
[2]TTUST-TTSC-4	1/9/1994	9.0	10.4	1.4
	12/28/1994	9.6	11.0	1.4
[2]TTUST-TTSC-5	12/28/1994	9.4	10.6	1.2
[2]TTUST-TTSC-6	12/28/1994	9.2	10.3	1.1
[2]TTUST-TTSC-7	12/28/1994	8.9	9.9	1.0
[2]TTUST-TTSC-8	12/28/1994	9.6	11.1	1.5
[2]TTUST-TTSC-9	12/28/1994	8.3	8.8	0.5
[2]TTUST-TTSC-10	12/28/1994	9.6	11.0	1.4
[2]TTUST-TTSC-13	12/28/1994	9.4	10.6	1.2
[2]TTUST-TTSC-14	12/28/1994	9.0	10.0	1.0
[2]TTUST-TTSC-15	12/28/1994	9.5	11.2	1.7
[2]TTUST-TTSC-16	12/28/1994	9.4	10.5	1.1

[1]See Plate 1 for location

[2]Because of scale, not shown on Plate 1

Statistics:

Average of water-level difference = 1.3 feet
Standard deviation of water-level difference = 0.6 feet
Root-mean-square error of water-level difference = 1.4 feet

ATSDR
AGENCY FOR TOXIC SUBSTANCES AND DISEASE REGISTRY

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 C: Simulation of Groundwater Flow