Hydrogeology and Ground-Water Quality at Naval Support Activity Memphis, Millington, Tennessee

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS, ABBREVIATED WATER-QUALITY UNITS, VERTICAL DATUM, AND WELL-NUMBERING SYSTEM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
foot per mile (ft/mi)	0.1894	meter per kilometer
square mile (mi^2)	2.59	square kilometer
acre	0.4047	square hectometer
foot per day (ft/d)	30.48	centimeter per day
square foot per day (ft^2/d)	0.0929	square meter per day
gallon per minute (gal/min)	0.06308	liter per second
million gallons per day (Mgal/d)	0.04381	cubic meters per second
pound per cubic foot (lb/ft^3)	1.602	kilogram per cubic meter

ABBREVIATED WATER-QUALITY UNITS

mg/L	milligram per liter
µg/L	microgram per liter
TU	tritium unit

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

Transmissivity: In this report, transmissivity is expressed as foot squared per day (ft^2/d)—The standard unit for transmissivity (T) is cubic foot per day per square foot of aquifer thickness "$[(ft^3/d)/ft^2]ft$." These mathematical expressions reduce to foot squared per day "(ft^2/d)."

Tennessee District well-numbering system: Wells in Tennessee are identified according to the numbering system that is used by the U.S. Geological Survey, Water Resources Division. The well number consists of three parts:
(1) an abbreviation of the name of the county in which the well is located;
(2) a letter designating the 7 1/2-minute topographic quadrangle on which the well is plotted; quadrangles are lettered from left to right across the county beginning in the southwest corner of the county; and
(3) a number generally indicating the numerical order in which the well was inventoried.
For example, Sh:U-99 indicates that the well is located in Shelby County on the "U" quadrangle and is identified as well 99 in the numerical sequence.

ACRONYMS AND DEFINITIONS

AOC	Area of Concern
BRAC	Base Closure and Realignment
BUPERS	Bureau of Personnel
CLEAN	Comprehensive, Long-term, Environmental Action Navy
DPT	Direct Push Technology
HSWA	Hazardous and Solid Waste Amendments
IRP	Installation Restoration Program
MCL	Maximum contaminant level
NACIP	Navy Assessment and Control of Industrial Pollutants
NATTC	Naval Aviation Technical Training Center
NSA	Naval Support Activity
RAB	Restoration Advisory Board
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
SOUTHDIV	Southern Division, Naval Facilities Engineering Command
SWMU	Solid Waste Management Unit
U.S. EPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VOC	Volatile organic compound
ybp	Years before present
<	Less than

Hydrogeology and Ground-Water Quality at Naval Support Activity Memphis, Millington, Tennessee

By John K. Carmichael, William S. Parks, James A. Kingsbury, *and* David E. Ladd

Abstract

Naval Support Activity (NSA) Memphis is a Department of the Navy facility located at the city of Millington in northwestern Shelby County, Tennessee, about 5 miles north of Memphis. As a result of past waste-management practices, 68 sites have been identified for investigation at NSA Memphis as part of the Resource Conservation and Recovery Act Corrective Action Program being conducted under the Department of the Navy's Installation Restoration Program. The U.S. Geological Survey, in cooperation with Southern Division, Naval Facilities Engineering Command, is providing technical assistance in an investigation of the hydrogeology at NSA Memphis under the Corrective Action Program.

Post-Midway Group stratigraphic units beneath NSA Memphis include, from youngest to oldest, the alluvium and loess of Quaternary age; the fluvial deposits of Quaternary and Tertiary(?) age; and the Cockfield and Cook Mountain Formations, Memphis Sand, Flour Island Formation, Fort Pillow Sand, and Old Breastworks Formation of Tertiary age. These units generally can be separated into two groups based on their hydrogeologic importance to assessing the potential for contamination of the shallow aquifers from surface sources, or to determining present or future ground-water supplies from the deeper aquifers.

The lower part of the alluvium, the fluvial deposits, and locally the Cockfield Formation are shallow, minor aquifers; the upper part of the alluvium, the loess, locally the Cockfield Formation, and the Cook Mountain Formation are confining units for these aquifers. In general, these aquifers and confining units are composed of clay, silt, sand, and gravel. The five units have an aggregate thickness ranging from about 150 to 290 feet in the NSA Memphis area. Ground water in the units typically is under artesian pressure with water levels at, or several tens of feet below, land surface. The confining units have vertical hydraulic conductivities that are highly variable and range from about 5×10^{-6} to 2×10^{-2} feet per day. The aquifers have vertical hydraulic conductivities ranging from about 1×10^{-3} to 2.5 feet per day, and the fluvial deposits aquifer has a horizontal hydraulic conductivity of about 5 feet per day.

The Memphis Sand and Fort Pillow Sand constitute the deeper, principal aquifers in the Memphis area and western Tennessee, and the Flour Island Formation and Old Breastworks Formation are confining units for these aquifers. In general, these aquifers and confining units are composed of clay and fine- to medium-grained sand. The four units have an aggregate thickness ranging from about 1,500 to 1,700 feet in the NSA Memphis area. Ground water is under artesian pressure, with water levels about 65 to 90 feet below land surface. Horizontal hydraulic conductivities for the Memphis and Fort Pillow aquifers are estimated to be about 68 and 13 feet per day, respectively.

Ground water from the loess, fluvial deposits aquifer, Cockfield Formation, and the Memphis aquifer is a calcium bicarbonate type; ground water from the Fort Pillow aquifer is a sodium bicarbonate type. Ground water in the loess is very hard and has dissolved-solids concentrations ranging from 320 to 506 milligrams per liter. Generally, dissolved solids, hardness, and concentrations of most major inorganic constituents

decrease with depth. Water in the Fort Pillow aquifer is soft and has dissolved-solids concentrations ranging from 94 to 108 milligrams per liter. Concentrations of most trace inorganic constituents in samples collected from wells screened in the five units were less than method reporting limits, and those constituents detected in concentrations exceeding their reporting limits were less than applicable maximum contaminant levels.

Tritium concentrations in samples collected from the fluvial deposits aquifer near two Memphis aquifer production wells at NSA Memphis were 12 and 16 tritium units, indicating a significant component of post-1952 recharge in the aquifer. Tritium concentrations for samples collected from three wells screened in the Cockfield Formation and the two Memphis aquifer production wells were less than 1 tritium unit, indicating that significant leakage of post-1952 water from the fluvial deposits aquifer to the Cockfield Formation and Memphis aquifer is not occurring in the area of these wells.

INTRODUCTION

Naval Support Activity (NSA) Memphis is a Department of the Navy (Navy) facility located at the city of Millington in northern Shelby County, Tennessee (fig. 1). From 1942 until 1995, NSA Memphis was Naval Air Station (NAS) Memphis, the site of the Naval Aviation Technical Training Center (NATTC) and other support commands. In June 1993, the Base Closure and Realignment (BRAC) Commission decided that NAS Memphis would be partially closed and realigned as part of the BRAC Act of 1990. Under this decision, the NATTC would be moved to NAS Pensacola in Florida and the Navy's Bureau of Personnel (BUPERS) in Arlington, Virginia, would be relocated to NAS Memphis. In October 1995, NAS Memphis was partially closed and realigned, becoming NSA Memphis. The northern part of the base (informally referred to as the "Northside"), consisting mainly of an airfield and former training facilities north of Navy Road (fig. 2), is undergoing transfer to the city of Millington, and the southern part of the base (referred to as the "Southside"), consisting mainly of housing and training facilities south of Navy Road, is being realigned to become the site of the BUPERS beginning in 1997.

As a result of the type of operations conducted while the facility was NAS Memphis, soil, groundwater, and surface-water contamination from past waste-management practices is being investigated and addressed. Sixty-seven Solid Waste Management Units (SWMU's) and one Area of Concern (AOC) have been identified at the facility pursuant to the Navy Installation Restoration Program (IRP) and the Hazardous and Solid Waste Amendments (HSWA) section of the Resource Conservation and Recovery Act (RCRA) permit originally issued to NAS Memphis in 1986 by the U.S. Environmental Protection Agency (U.S. EPA) and renewed for NSA Memphis in 1996. Investigations of environmental conditions at these SWMU's and the AOC presently are underway or have been completed as part of the RCRA Corrective Action Program being conducted at the NSA Memphis Northside and Southside. The objective of the Corrective Action Program at NSA Memphis is to obtain information to fully characterize the nature, extent, and rate of migration of contaminants from identified sites and to interpret these data to determine appropriate corrective measures.

One of the Navy's engineering field divisions, Southern Division, Naval Facilities Engineering Command (SOUTHDIV), is providing engineering and contract services to NSA Memphis to support compliance with the HSWA permit and the associated Corrective Action Program. The U.S. Geological Survey (USGS), in cooperation with SOUTHDIV, is providing technical assistance in an investigation of the hydrogeology at NSA Memphis and the surrounding area under the Corrective Action Program.

The cooperative SOUTHDIV/USGS program at NSA Memphis began in 1990. As the main part of the study objective, the USGS initially was charged with conducting RCRA Facility Investigations (RFI's) of environmental conditions at 13 SWMU's (fig. 2) of the 61 SWMU's then identified at NSA Memphis. These SWMU's consist of inactive sites including the Fire Department Drill Area (SWMU 1), Southside Landfill (SWMU 2), Building N-121 Plating Shop Dry Well (SWMU 3), Building N-121 Plating Shop Storm Sewer and Drainage Ditch (SWMU 4), Building N-126 Battery Shop Storm Sewer and Ditch (SWMU 6), Building N-126 Plating Shop Dry Well (SWMU 7), Cemetery Disposal Area (SWMU 8), Sewage Lagoons (SWMU 9), Building S-140 Site and 7th Avenue Ditch (SWMU 14), Salvage Yard No. 1 (SWMU 40), and Northside Landfill (Western Portion) (SWMU 60); and active sites including the Aircraft

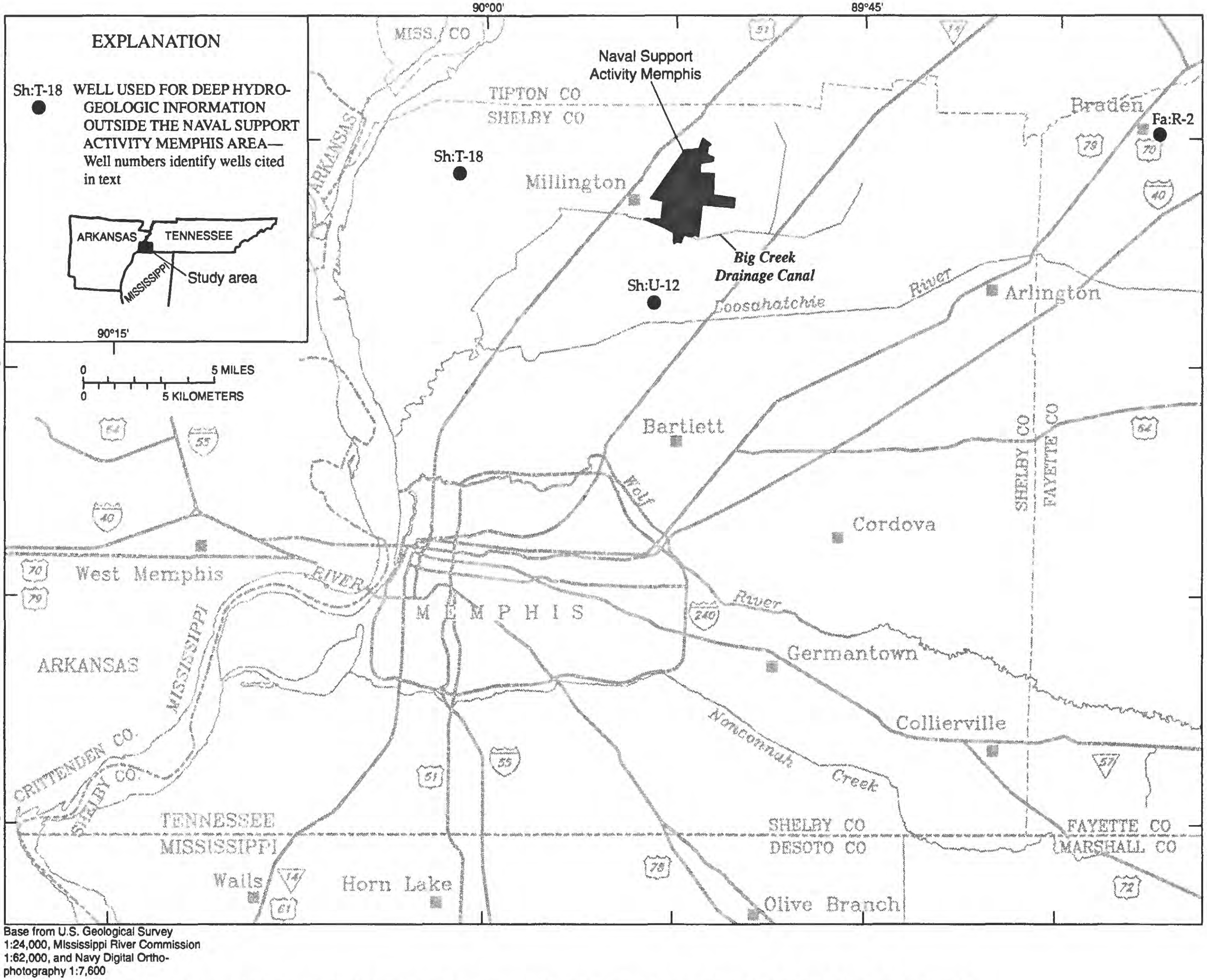


Figure 1. Location of Naval Support Activity Memphis, Millington, Tennessee, and wells Fa:R-2, Sh:T-18, and Sh:U-12.

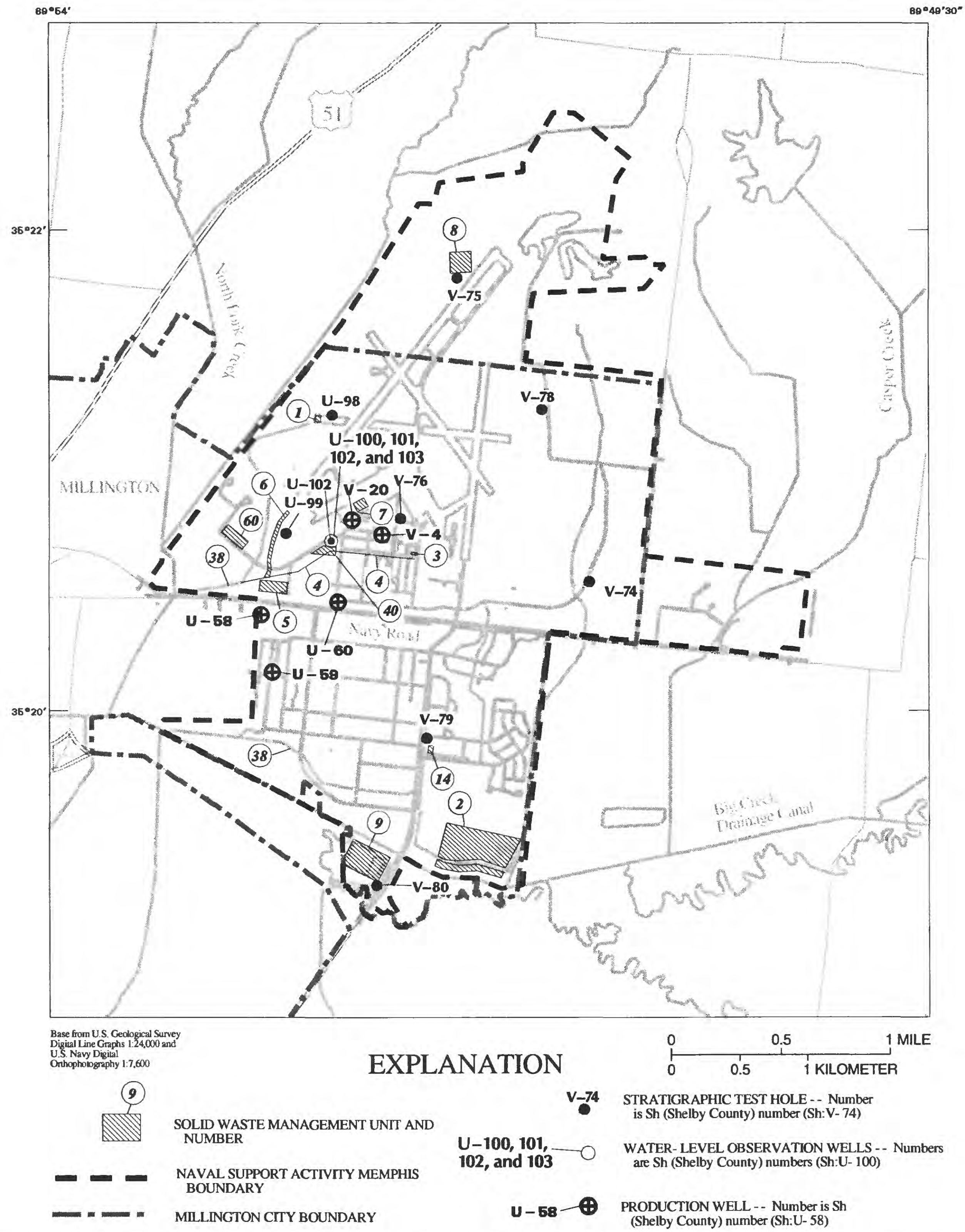


Figure 2. Locations of 13 Solid Waste Management Units, 9 stratigraphic test holes, 4 water-level observation wells, and 5 production wells at Naval Support Activity Memphis.

Fire Fighting Training Area (SWMU 5—closed in September 1996), and Miscellaneous Drainage Ditches (SWMU 38) located throughout the NSA Memphis Northside and Southside. Since 1990, seven additional sites have been identified at NSA Memphis, bringing the total number of sites to 68.

In 1990, the Navy developed a Comprehensive, Long-term, Environmental Action Navy (CLEAN) contract with EnSafe/Allen & Hoshall (E/A&H), Memphis, Tennessee. This contract specified tasks for E/A&H to perform, including preparing a comprehensive work plan for all site investigations under the Corrective Action Program at NSA Memphis, preparing site-specific work plans and final reports for these investigations, and conducting field work for site investigations in conjunction with the USGS.

In 1993, the main study objective of the USGS changed from focusing on site-specific investigations to assessing the overall hydrogeologic framework at NSA Memphis and the surrounding area. In 1995, the role of the USGS was expanded to include calibration of a numerical ground-water-flow model for the NSA Memphis area, which currently (1997) is under development. Through collaborative work with SOUTHDIV and E/A&H, large- and small-scale investigation results have complemented each other by providing a regional and local hydrogeological framework for the Corrective Action Program at NSA Memphis.

In 1994, prior to initiating investigations at SWMU's within the NSA Memphis Northside, the USGS conducted a test-drilling program to determine the hydrogeology of the post-Wilcox Group stratigraphic units beneath this part of the base. Stratigraphic test holes were drilled to depths between about 200 and 220 feet at five locations (fig. 2, test holes Sh:U-98, Sh:U-99, Sh:V-74, Sh:V-75, and Sh:V-76; Appendix 1) to obtain subsurface information in the proximity of selected Northside SWMU's prior to detailed investigations at these sites. Lithologic and geophysical logs of the test holes were made and core samples were collected at various stratigraphic horizons for laboratory analysis of physical characteristics. The results of the study are presented in a report by Kingsbury and Carmichael (1995).

Purpose and Scope

As part of the USGS study objective to assess the overall hydrogeology of the NSA Memphis area, this report was prepared to present descriptions of (1) the hydrogeologic framework, (2) the occurrence and movement of water within this framework, (3) the hydraulic properties of the materials within the framework, and (4) the water quality of the primary water-bearing units in the area. The report summarizes hydrogeologic information and water-quality data collected by the USGS in the NSA Memphis area, and briefly presents selected data collected by various consultants to the Navy during past and present environmental investigations at the facility.

The report also extends information presented in Kingsbury and Carmichael (1995) by including interpretations based on updated information and data for the NSA Memphis Southside that have been collected since 1995. Lithologic information and selected geophysical logs for the five test holes drilled for stratigraphic information by the USGS in 1995 and an additional four test holes (fig. 2, test holes Sh:V-78, Sh:V-79, Sh:V80, and test hole for well Sh:U-102; Appendix 1) drilled by the USGS at NSA Memphis in 1996, and well-construction diagrams for four observation wells installed for the collection of water-level data (fig. 2, wells Sh:U-100, Sh:U-101, Sh:U-102, and Sh:U-103) are included (Appendix 1). The report also includes correlations of geophysical or boring logs for 78 test holes and wells in the NSA Memphis area (Appendixes 2 and 3).

Major tasks conducted by the USGS during this investigation include:

1. describing lithologic samples from and making of geophysical logs in nine test holes drilled for stratigraphic information;
2. collecting piezocone lithologic and Hydrocone water-quality information with Direct Push Technology (DPT);
3. describing lithologic samples from continuous cores collected by Rotasonic drilling techniques;
4. monitoring water levels continuously in observation wells screened in the loess, fluvial deposits, and Cockfield Formation;
5. collecting ground-water samples from 18 wells screened in the loess, fluvial deposits aquifer, Cockfield Formation, Memphis aquifer, and Fort Pillow aquifer and analyzing these samples for properties of water and major and trace inorganic constituents;
6. collecting ground-water samples with a Hydrocone tool from the fluvial deposits aquifer at two locations and ground-water samples from three wells screened in the Cockfield Formation and two production wells screened in the Memphis

aquifer and analyzing the samples for tritium concentrations;
7. conducting a 24-hour, multiple-well aquifer test to determine the hydraulic properties of the fluvial deposits aquifer;
8. providing hydrogeologic data for a numerical ground-water-flow model of the shallow aquifer and confining units system;
9. reviewing planning documents and final reports prepared by Navy contractors for investigations at individual and groups of SWMU's for technical accuracy as the work progressed; and
10. analyzing and interpreting the hydrogeologic and water-quality data for the study area.

As defined for this investigation, the NSA Memphis study area consists of approximately 20 square miles (mi^2). This study area (fig. 2) is centered on NSA Memphis and extends no further than about 1 mile beyond the base boundary in any of the four principal compass directions. Hydrogeologic units summarized (table 1) include the aquifers and confining units from land surface to about 1,700 feet in depth.

Previous Investigations

Previous investigations pertinent to the NSA Memphis study area include results from site-specific studies conducted by various consultants to the Navy, and base-wide or regional reports prepared by the USGS for NSA Memphis, the Memphis area, and western Tennessee.

Investigations of environmental conditions at NSA Memphis began in 1983. From 1983 until 1987, site-specific environmental investigations at the facility were conducted under the Navy Assessment and Control of Industrial Pollutants (NACIP) program. In 1987, the NACIP program was renamed the Navy IRP to conform with U.S. EPA and other Department of Defense agency terminology. Subsequent to issuance of the HSWA permit in 1986, all investigations at NSA Memphis also have been conducted as part of the RCRA Corrective Action Program. These studies consist of work conducted at individual sites within NSA Memphis. The results are presented in reports prepared by individual consultants to the Navy and are available at local repositories developed for NSA Memphis by the Restoration Advisory Board (RAB). In addition to results of these site-specific environmental investigations, other hydrogeological information is available for the base that summarizes the results of drilling and aquifer-testing activities performed as part of improvements to the NSA Memphis public water system (Layne Geosciences, written commun., 1983).

In addition to Kingsbury and Carmichael (1995), other reports that provide information relevant to NSA Memphis include publications by the USGS describing the hydrogeology of the Memphis area and western Tennessee. The most recent comprehensive report for the Memphis area presents refinements to the hydrogeology in terms of stratigraphic and structural relations of the key geologic units with emphasis on the locations of faults based on correlations of 227 geophysical logs made in test holes or wells in the area (Kingsbury and Parks, 1993). Graham and Parks (1986) and Parks (1990) present the results of an initial and a follow-up investigation to determine the potential for contamination of the Memphis aquifer in the Memphis area. McMaster and Parks (1988) describe the results of an investigation of selected trace inorganic constituents and synthetic organic compounds in the water-table (shallow) aquifers in the Memphis area. Brahana and others (1987) summarize the chemical quality of ground water from the freshwater aquifers and principal well fields in the Memphis area.

Graham (1979) and Kingsbury (1992, 1996) present potentiometric maps of the Memphis aquifer in 1978 and 1990, and the Memphis and Fort Pillow aquifers in 1995, respectively, in the Memphis area. Reports published as part of the West Gulf Coast Regional Aquifer-System Analysis program of the USGS include those by Parks and Carmichael (1989, 1990a, b) that describe the geology and ground-water resources of the Fort Pillow Sand, Memphis Sand, and Cockfield Formation, respectively, in western Tennessee; and Parks and Carmichael (1990c, d) that present maps and information describing the potentiometric surfaces in the Fort Pillow and Memphis aquifers, respectively, in western Tennessee in 1985.

Acknowledgments

The authors gratefully acknowledge Mark Taylor and David Porter of the Navy, SOUTHDIV, who provided cooperation and support for all phases of the USGS investigation; Tonya Barker, Rob Williamson, and other personnel of NSA Memphis, Public Works–Environmental Division, for assistance with logistics for field work conducted during the investigation; Lawson Anderson and other personnel with E/A&H in Memphis for their role in coordination of much of the field work from which data presented in this report

Table 1. Post-Midway Group geologic units underlying Naval Support Activity (NSA) Memphis, Millington, Tennessee, and their hydrologic significance

[Modified from Parks and Carmichael, 1989, 1990c, d; Kingsbury and Parks, 1993; Kingsbury and Carmichael, 1995]

System	Series	Group	Stratigraphic unit (and local name)	Thickness (in feet)	Lithology and hydrologic significance
Quaternary	Holocene and Pleistocene		Alluvium (alluvial deposits)	0-70	Silt, clay, sand, and gravel. Underlies the alluvial plains of Big Creek and tributary streams. A lower sand and gravel is connected to the fluvial deposits and constitutes part of the alluvial-fluvial deposits aquifer.
	Pleistocene		Loess	15-45	Silt, clay, and sand. Predominantly silt with silty clay and silty, fine sand at various horizons. Principal unit at the surface in upland areas. Thinnest on the tops of hills and ridges; thickest on the valley slopes. Generally serves as the upper confining unit for the alluvial-fluvial deposits aquifer. Locally contains perched water tables in the upper part.
Quaternary and Tertiary(?)	Pleistocene and Pliocene(?)		Fluvial deposits (terrace deposits)	5-70	Sand and gravel; minor clay and ferruginous sandstone. Underlies the loess in upland areas. Thickness varies greatly because of erosional surfaces at top and base. Constitutes part of the alluvial-fluvial deposits aquifer. Provides water to some domestic and farm wells in the NSA Memphis area.
Tertiary	Eocene	Claiborne	Cockfield Formation	0-185	Sand, silt, clay, and lignite. Complexly interbedded and interlensed. Thickness of formation is highly variable because of erosional surfaces at top and base. Locally contains sand lenses in which domestic and farm wells are made. Sand lenses are more prevalent in northern and eastern NSA Memphis. Commonly consists predominantly of fine sediments and serves as part of the upper confining unit for the Memphis aquifer.
			Cook Mountain Formation	10-60	Clay, silt, and sand. Generally consists of clay and silt, but locally contains some very fine sand. Locally serves as part of the lower confining unit for the Cockfield aquifer and is the principal upper confining unit for the Memphis aquifer.
			Memphis Sand	865-880	Sand, silt, clay, and minor lignite. Consists of a thick body of sand with clay lenses at various horizons. Sand is fine to medium or medium to coarse. Upper part contains lenses of fine sand and clay. Constitutes the Memphis aquifer—the principal aquifer providing water for most domestic, commercial, industrial, and municipal supplies in the Memphis area. Provides water to two wells at NSA Memphis and three wells at Millington.
	— ? —	Wilcox	Flour Island Formation	225-290	Clay, silt, sand, and lignite. Consists predominantly of clay and silt with lenses of fine sand. Serves as the lower confining unit for the Memphis aquifer and the upper confining unit for the Fort Pillow aquifer.
	Paleocene		Fort Pillow Sand	125-180	Sand, with minor clay. Sand is fine or fine to medium; clay is present as lenses. Constitutes the Fort Pillow aquifer—the second principal aquifer in the Memphis area. Provides water to three wells at NSA Memphis and two wells at Millington.
			Old Breastworks Formation[1]	245-310	Clay, silt, sand, and lignite. Only uppermost part penetrated by test holes at NSA Memphis; thickness range is from two deep test holes drilled in northern Shelby County. Serves as the lower confining unit for the Fort Pillow aquifer, along with the Porters Creek Clay and the Clayton Formation of the underlying Midway Group of Tertiary age and the Owl Creek Formation of Cretaceous age.

[1]Frederiksen and others (1982) tentatively placed the Old Breastworks Formation in the Midway Group, but for the purposes of this report, the Old Breastworks Formation of the Wilcox Group is used as defined by Moore and Brown (1969).

were obtained; and Jim Morrison, Tennessee Department of Environment and Conservation (TDEC), Division of Superfund, and Brian Donaldson, U.S. EPA, Region IV, Atlanta, Georgia, for their contributions and knowledge of regulatory requirements during the investigation. The authors also thank past and present members of the BRAC Cleanup Team, a group of persons whose function is to oversee all aspects of environmental work at NSA Memphis, for their part in supporting decisions made during the investigation.

SITE DESCRIPTION

Prior to 1995, NSA Memphis consisted of the Northside (2,233 acres) and Southside (1,257 acres), divided east to west by Navy Road (fig. 2). In 1995, NSA Memphis began to lease parcels of property within the Northside to the city of Millington under BRAC. Because the investigation described in this report covers the entire facility, prior and subsequent reference to the "base" or "facility" in this report includes both the NSA Memphis Northside and Southside. NSA Memphis is bounded on the west by the city of Millington; on the north by rural and agricultural land; on the east by urban and suburban development both inside and outside the Millington city limits; and on the south by undeveloped agricultural land in the flood plain of Big Creek Drainage Canal (fig. 2).

The NSA Memphis Southside lies within the flood plain of Big Creek Drainage Canal, the major stream draining the study area (fig. 1). However, this part of the base was filled and graded in most areas during construction of base facilities. Most of the NSA Memphis Southside is drained by a series of storm sewers and open ditches that empty into Big Creek Drainage Canal at the southwestern corner of the base (fig. 2). Big Creek Drainage Canal is a tributary to the Loosahatchie River (fig. 1) and is the present course of the former Big Creek which has been straightened and channelized for flood control. Big Creek Drainage Canal flows from east to west, marking the southern extent of NSA Memphis along most of this boundary. At its mouth, Big Creek Drainage Canal has a total contributing area of 154 mi^2. Tributaries to Big Creek Drainage Canal in the study area, from east to west, are Casper Creek, which drains an area east of the base, an unnamed tributary that drains some of the northern and eastern parts of the base, and North Fork Creek and its unnamed tributary that flow along the northwestern boundary of NSA Memphis and drain the area west and northwest of the base (fig. 2). These streams flow north to south and also have been channelized along their lower to middle reaches to assist with flood control within NSA Memphis and the city of Millington.

The NSA Memphis Northside is situated in the upland (off-stream) area between Casper and North Fork Creeks. Much of the NSA Memphis Northside is drained by an underground storm-sewer system that was constructed during development of the airfield. This system empties into an open ditch near the south end of the main (northeast-southwest) runway (fig. 2) that flows into North Fork Creek near the southwest corner of the NSA Memphis Northside.

Topography in the study area ranges from relatively flat to gently rolling terrain in the valley of Big Creek in the south, to the steep-sloping headward valleys of streams draining the dissected uplands in the northern part of the area. Land-surface altitudes in the area range from about 250 feet along the channel of Big Creek Drainage Canal in the southwestern part of the area to about 370 feet at a few hilltop locations in the northern part of the study area.

HYDROGEOLOGY

The NSA Memphis study area is located in the north-central part of the Mississippi embayment, a broad syncline that plunges southward along an axis that approximates the Mississippi River (Cushing and others, 1964). In the NSA Memphis area, the embayment contains more than 2,500 feet of unconsolidated to semi-consolidated sediments of Cretaceous, Tertiary, and Quaternary age that overlie "bedrock" of Paleozoic age. Post-Midway Group stratigraphic units described in this report include, from youngest to oldest, the alluvium and loess of Quaternary age; the fluvial deposits of Quaternary and Tertiary(?) age; and the Cockfield and Cook Mountain Formations, Memphis Sand, Flour Island Formation, Fort Pillow Sand, and Old Breastworks Formation of Tertiary age (table 1). For this report, descriptions of the post-Midway units are based on information and data from nine stratigraphic test holes (fig. 2; Appendix 1) and from the correlations of geophysical and boring logs of other test holes and wells (Appendixes 2 and 3) at locations within the NSA Memphis study area (fig. 3). The description of the Old Breastworks Formation is based on geophysical logs of three deep wells (wells Fa:R-2, Sh:T-18, and Sh:U-12) drilled outside the NSA Memphis area (fig. 1).

The alluvium, loess, fluvial deposits, and Cockfield and Cook Mountain Formations (table 1; figs. 4a and 4b) are post-Midway Group stratigraphic units

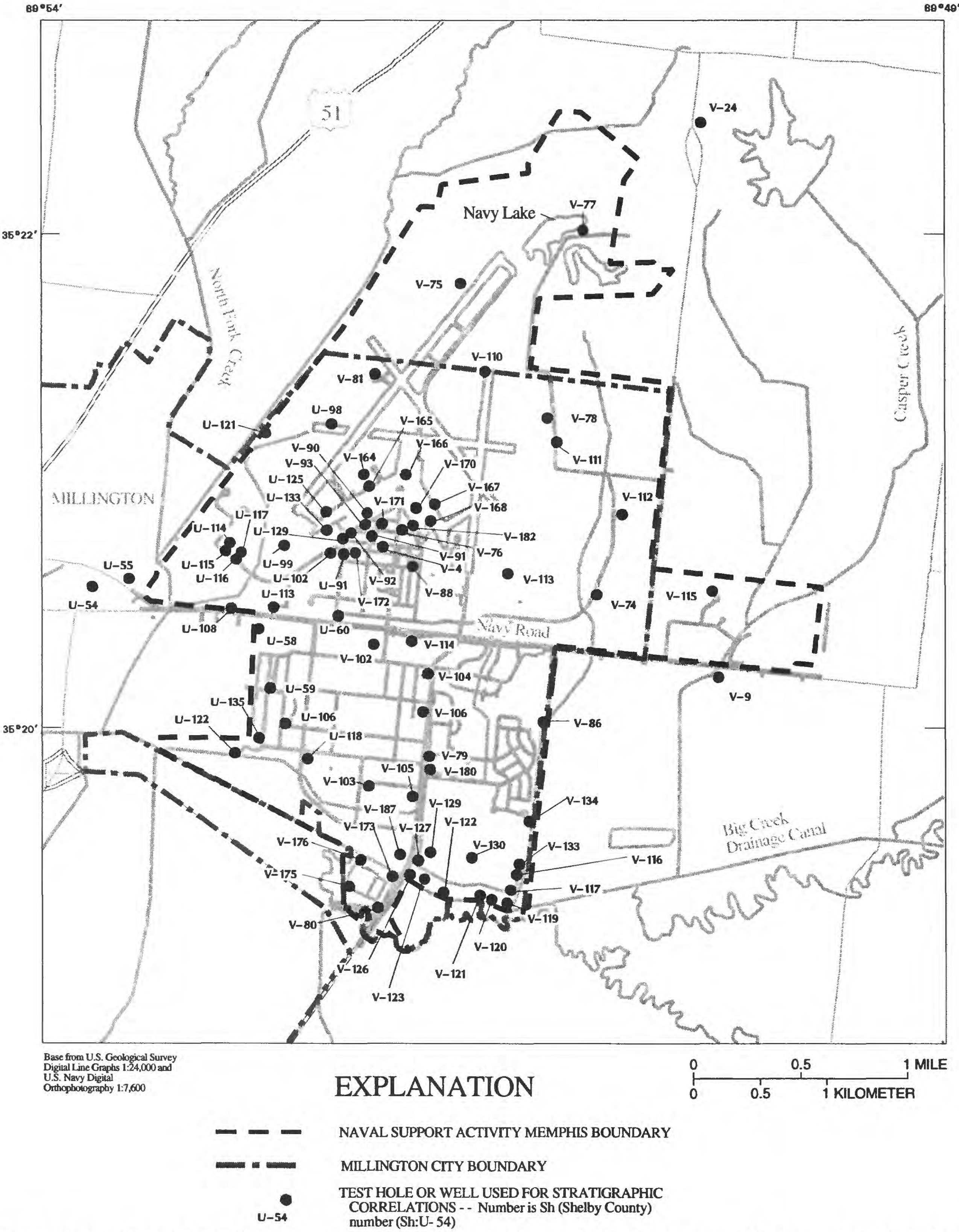
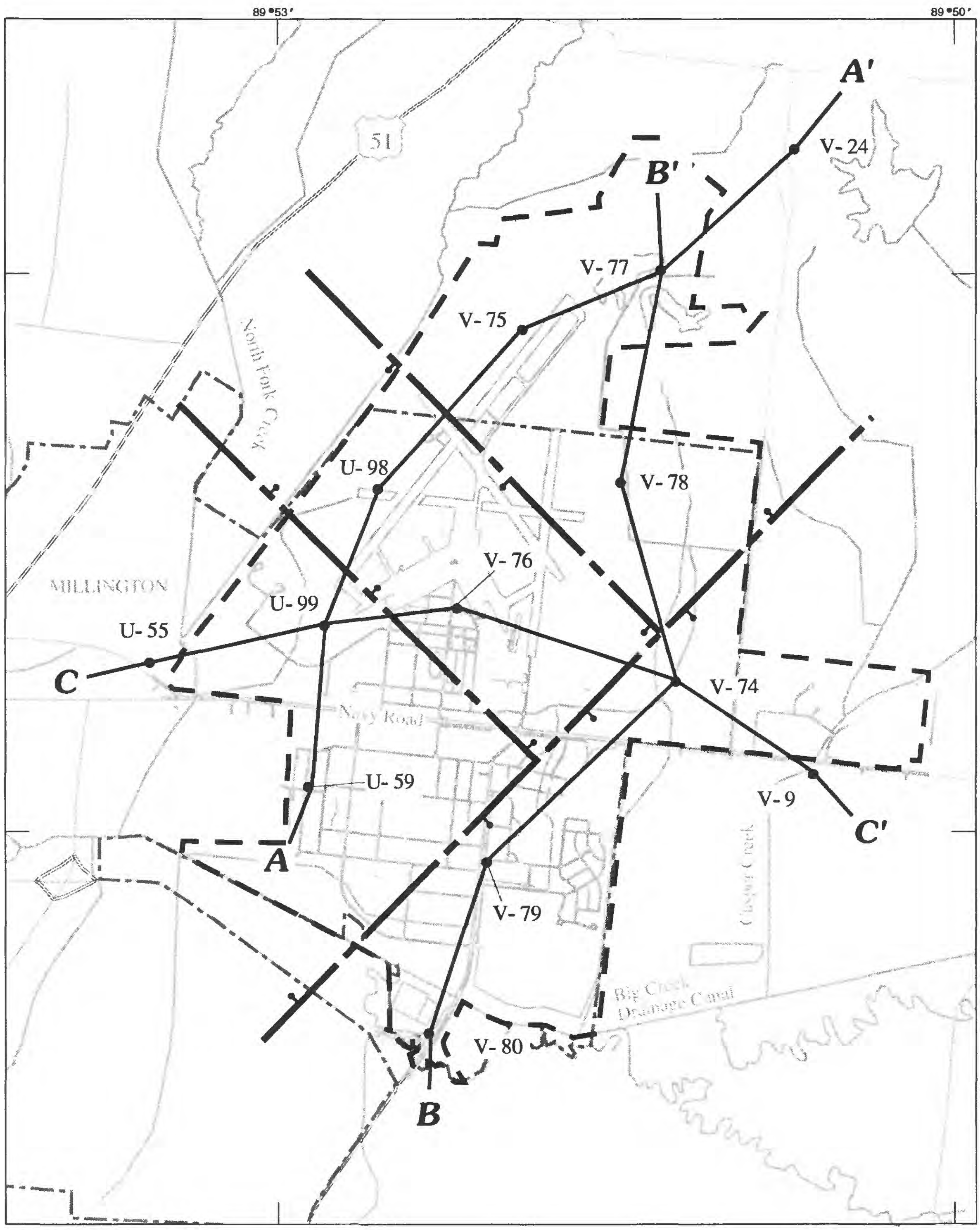


Figure 3. Locations of test holes and wells for which geophysical logs or boring logs were used for correlations of stratigraphic units beneath Naval Support Activity Memphis.



Base from U.S. Geological Survey Digital Line Graphs 1:24,000, and U.S. Navy Digital Orthophotography 1:7,600

EXPLANATION

0 0.5 1 MILE
0 0.5 1 KILOMETER

NAVAL SUPPORT ACTIVITY MEMPHIS BOUNDARY

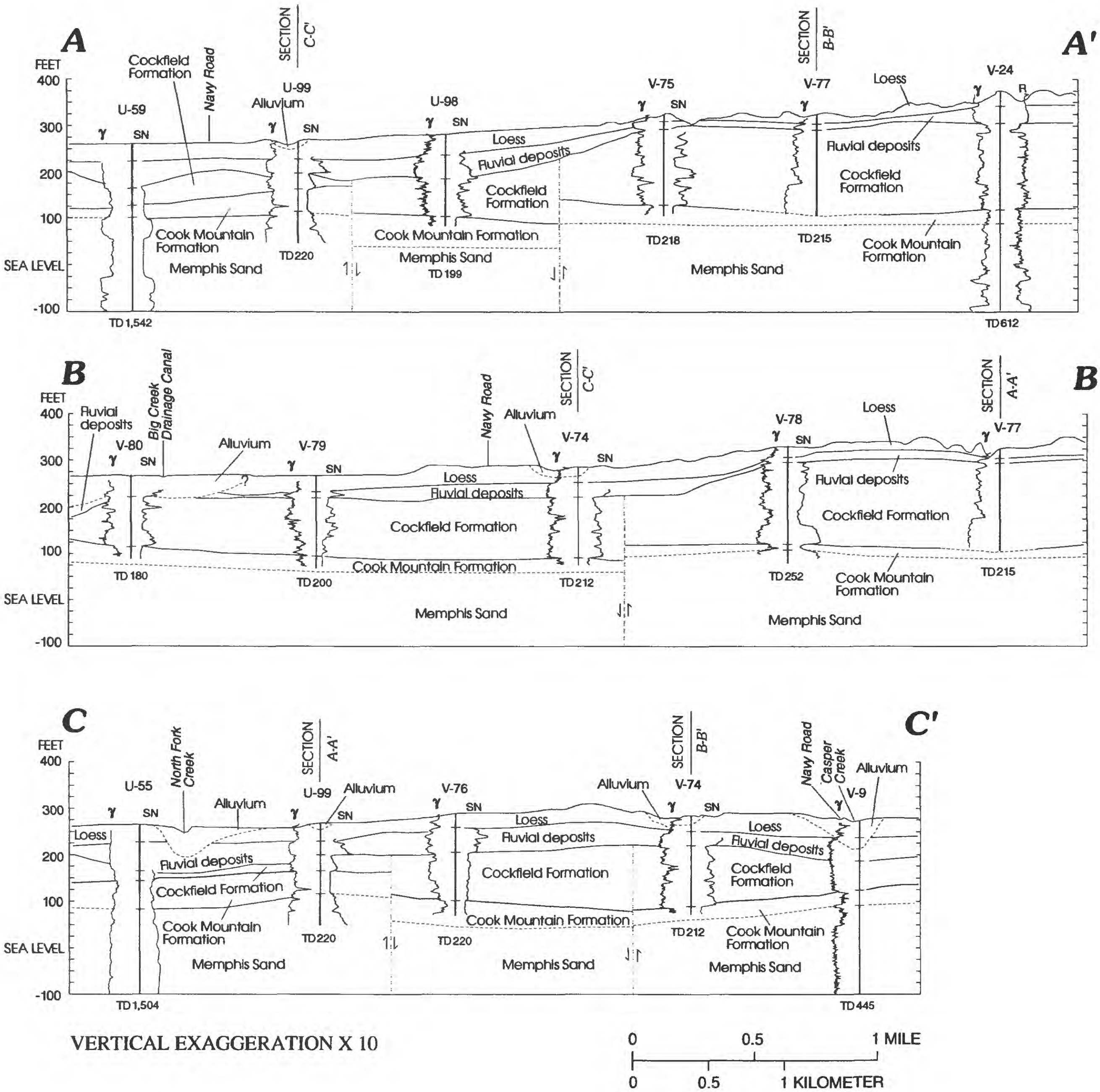
MILLINGTON CITY BOUNDARY

APPROXIMATE LOCATION OF FAULT LINE WITH BALL AND BAR INDICATING DOWN-THROWN SIDE

A——A′ HYDROGEOLOGIC SECTION

U-55 ● WELL USED FOR HYDROGEOLOGIC SECTION -- Number is Sh (Shelby County) number (Sh:U-55)

Figure 4a. Locations of hydrogeologic sections *A–A′*, *B–B′*, and *C–C′*, and faults that displace the Cockfield Formation, Cook Mountain Formation, and Memphis Sand at Naval Support Activity Memphis.



EXPLANATION

A——A' HYDROGEOLOGIC SECTION

FORMATION CONTACT. DASHED WHERE APPROXIMATE

APPROXIMATE LOCATION OF FAULT, AND RELATIVE DIRECTION OF DISPLACEMENT

V-79 TEST HOLE OR WELL — Number is Sh (Shelby County) number (Sh:V-79). Tick marks indicate formation contacts

TD 200 TOTAL DEPTH OF WELL OR TEST HOLE

GEOPHYSICAL LOGS

γ GAMMA-RAY LOG

SN SHORT-NORMAL RESISTIVITY LOG

R RESISTANCE LOG

Figure 4b. Hydrogeologic sections *A–A´*, *B–B´*, and *C–C´*, and geophysical logs of test holes or wells in the area of Naval Support Activity Memphis.

investigated at NSA Memphis because of their importance to assessing the potential for contamination of the shallow aquifers from surface sources. The lower part of the alluvium, the fluvial deposits, and locally the Cockfield Formation are minor aquifers in the NSA Memphis area; and the upper part of the alluvium, the loess, locally the Cockfield Formation, and the Cook Mountain Formation are confining units. The Memphis Sand, Flour Island Formation, Fort Pillow Sand, and Old Breastworks Formation (table 1; fig. 5) are post-Midway Group stratigraphic units described in this report because of their importance for present or future ground-water supplies in the NSA Memphis area. The Memphis Sand and Fort Pillow Sand are the principal water-supply aquifers in the Memphis area and western Tennessee, and the Flour Island and Old Breastworks Formations are the confining units for these aquifers.

Alluvium

Alluvium is present in areas estimated at 1/2 to 3/4 mile wide along Big Creek Drainage Canal and about 1/2 mile wide along its tributaries and to depths as great as 70 feet beneath the alluvial plains of these streams that cross the NSA Memphis area (table 1; fig. 4b). The alluvium in this area generally consists of silt and clay with minor amounts of sand in the upper part and sand and gravel in the lower part (Kingsbury and Carmichael, 1995). Stratigraphic test hole Sh:V-80 (fig. 2) shows that the alluvium on the south side of Big Creek Drainage Canal is about 45 feet thick and consists of silt in the upper 35 feet and sand and gravel in the lower 10 feet (Appendix 1). Silt encountered in the upper 15 feet of this test hole may be loess, the other surficial unit present at NSA Memphis (table 1), but this silt probably is reworked. Before channelization, Big Creek flowed along a meandering course south of Big Creek Drainage Canal. In this area, the lower part of the alluvium may have a thicker section of sand and gravel.

Alluvium also underlies the alluvial plains of the small tributaries of Big Creek Drainage Canal and North Fork Creek that drain the NSA Memphis area. The location of most of these alluvial plains now is obscured as a result of leveling of the landscape and construction of drainage ditches and culverts across the facility. Silt and silty clay in the upper 10 feet in stratigraphic test hole Sh:V-74 and the upper 15 feet in test hole Sh:U-99 (fig. 2) may be alluvium (Appendix 1) because these sites are near small tributaries. Silt and clay in the upper part of the alluvium are similar to and grade laterally to silt and clay in undisturbed loess, thus making difficult the distinction between the two units and the definition of the extent of the alluvial valleys of streams at NSA Memphis based on general lithologic descriptions. For this reason, no distinction could be made between the base of the loess or silt and clay in the upper alluvium in preparing a map showing the altitude of this surface (fig. 6).

Results of radiocarbon (^{14}C) analyses of wood samples collected from depths of 18 feet below land surface in the boring for well Sh:U-122, 28 feet in boring Sh:V-120, and 40 feet in the boring for well Sh:V-117 at SWMU 2 (figs. 2 and 3), indicate ages of 10,220 years before present (ybp), +/- 70 years; 17,690 ybp, +/- 100 years; and greater than 40,440 ybp, respectively. No error range is associated for the sample from Sh:V-117 because its age exceeded limits of the conventional ^{14}C dating technique (Beta Analytic Inc., written commun., 1996). Based on these radiocarbon age estimates, strata between the depths of 18 and 28 feet below land surface were deposited as valley fill between about 17,000 and 10,000 ybp during the transition from Wisconsin full-glacial to late-glacial climate conditions. Strata between the depths of 28 and 40 feet below land surface probably were deposited during mid-Wisconsin interstadial climate conditions. The chronology of valley filling along Big Creek is similar to valley-fill sequences elsewhere in the central Mississippi Valley (Royall and others, 1991).

In the Memphis area, sand and gravel in the lower part of the alluvium constitute the alluvial aquifer. A map of the altitude of the base of the sand and gravel in the lower part of the alluvium or fluvial deposits in the NSA Memphis area shows that this surface is highly irregular (fig. 7). In the area of SWMU's 2 and 9 (fig. 2) near Big Creek Drainage Canal at NSA Memphis, the relatively thin section of sand and gravel in the lower part of the alluvium as shown on a thickness map of this unit (fig. 8) is in hydraulic connection with the relatively thin section of fluvial deposits in the area of SWMU 14 (fig. 2). In this area, the alluvium constitutes a part of the alluvial-fluvial deposits aquifer.

Depths to ground water in the alluvium vary depending on land surface altitude, proximity to surface drainages, grain-size composition of the sediments, and time of year. In the alluvial plains of Big Creek Drainage Canal and its major tributaries,

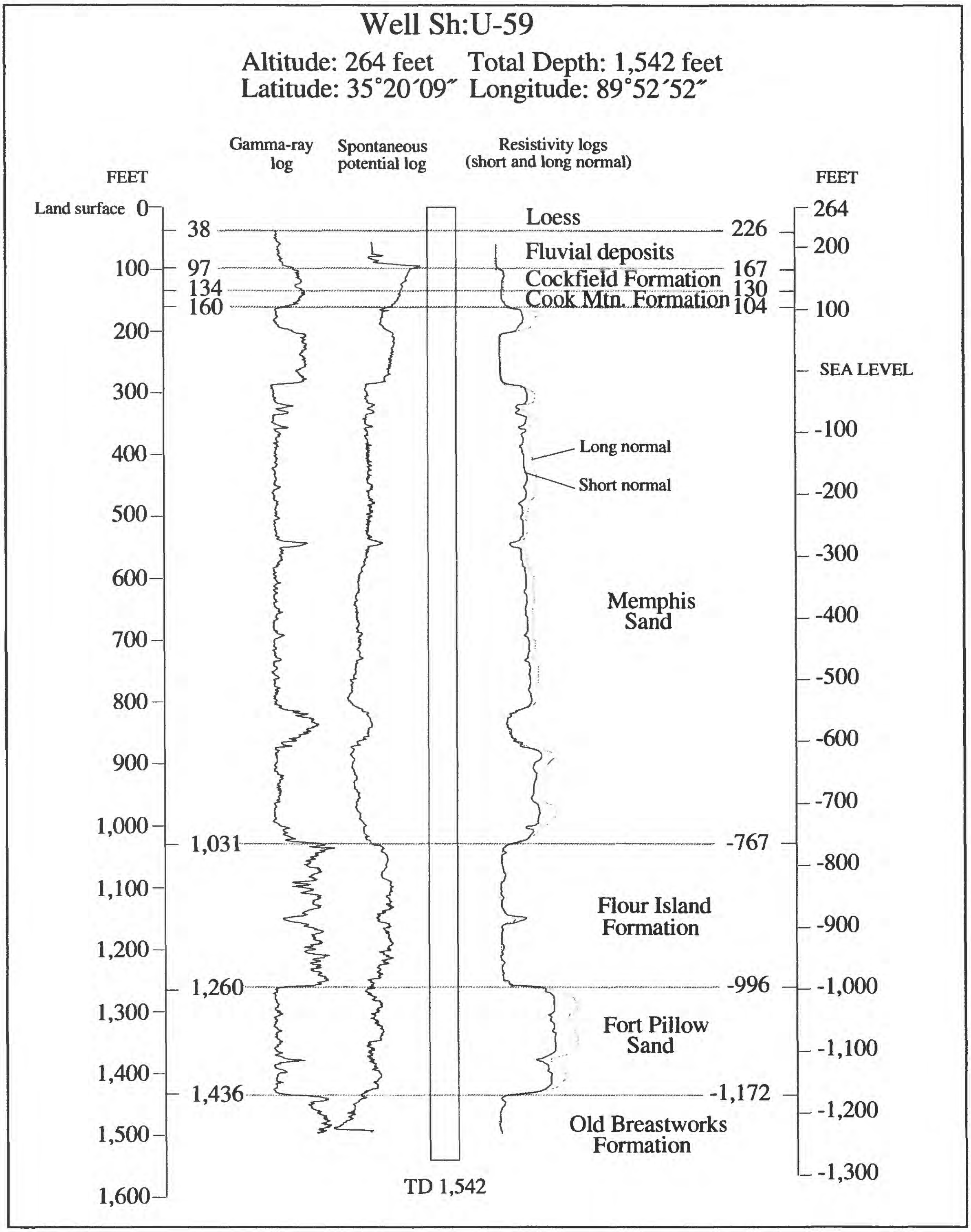


Figure 5. Geophysical logs showing post-Midway Group geologic units at Naval Support Activity Memphis.

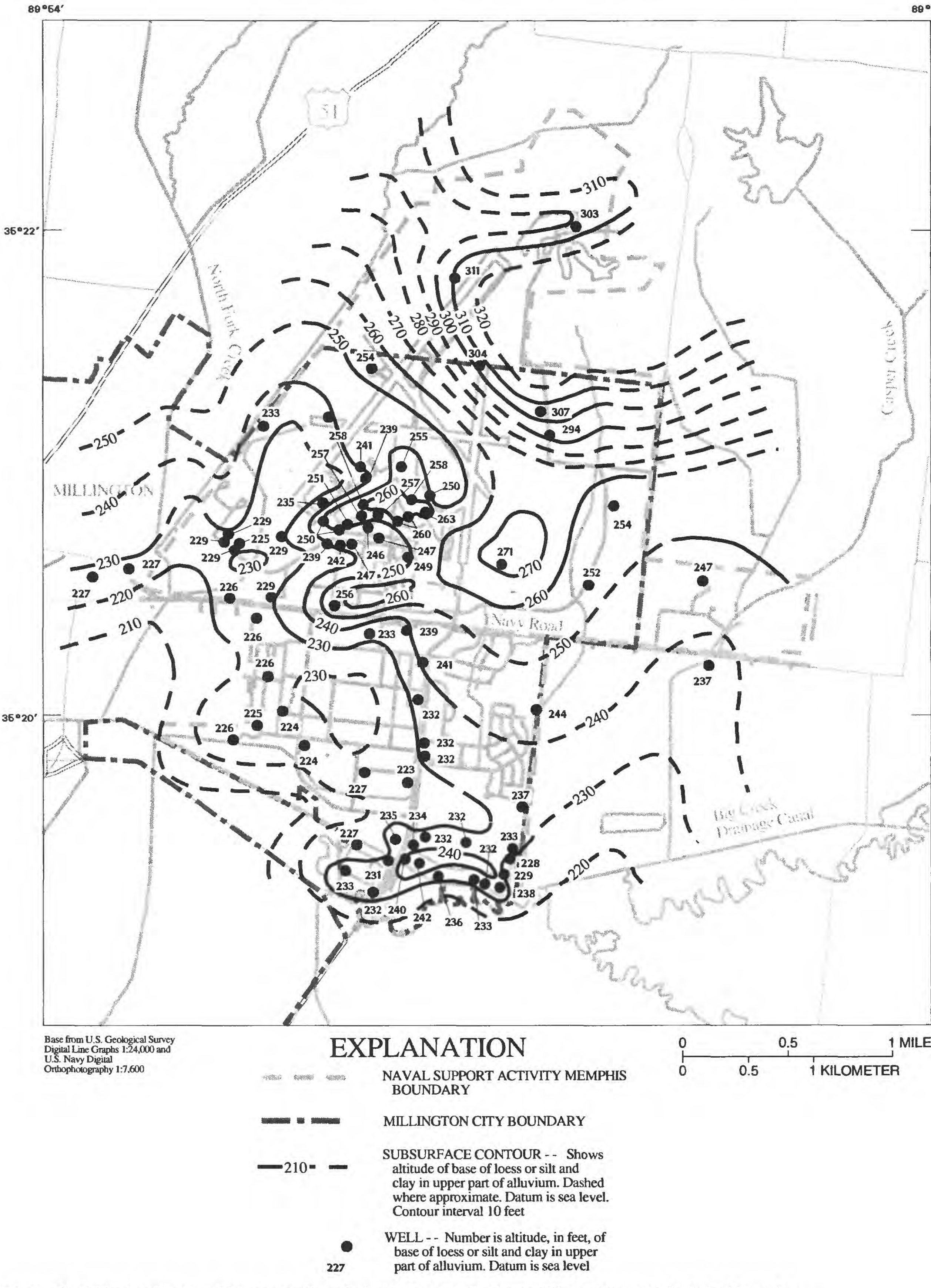
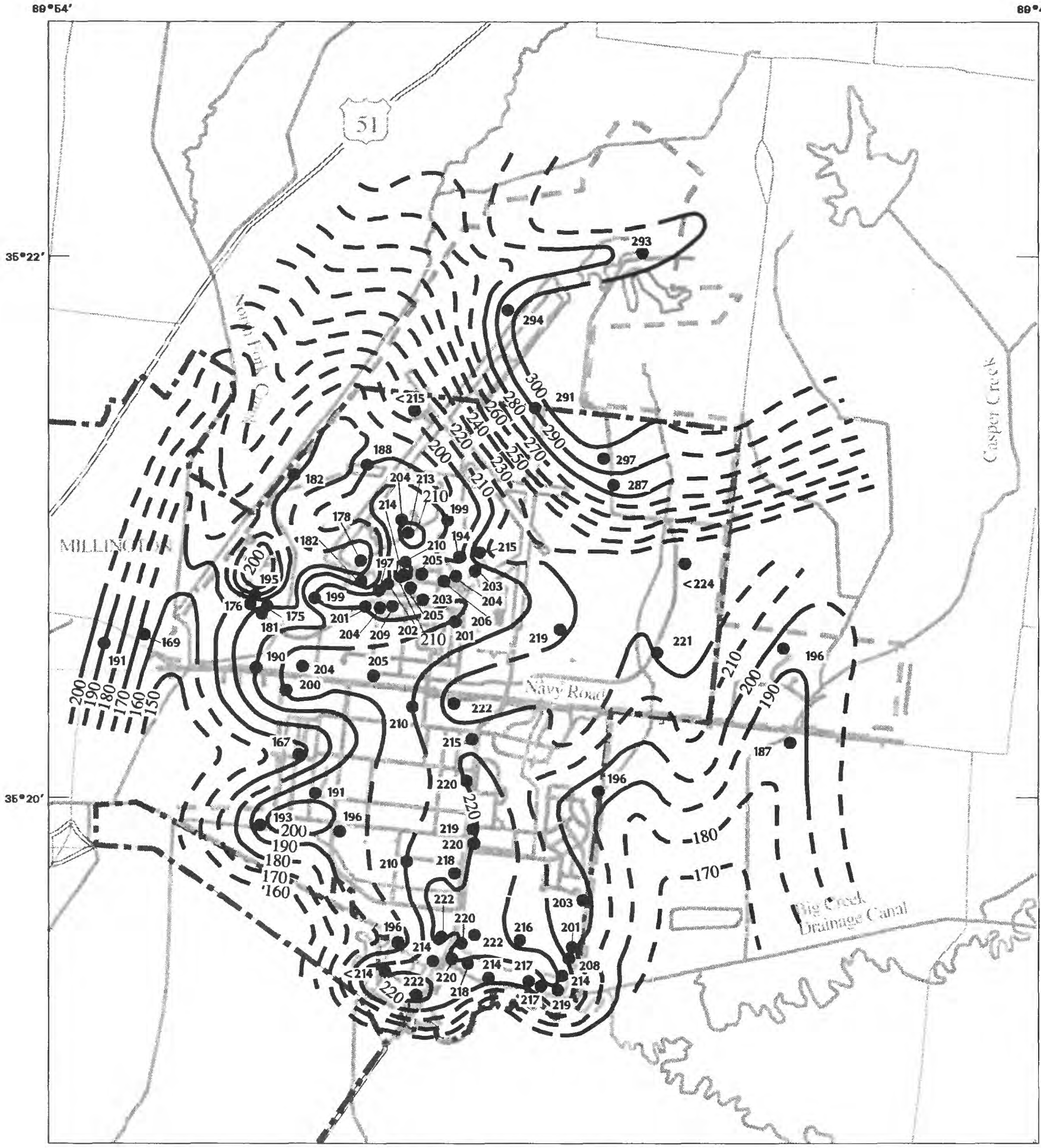


Figure 6. Altitude of base of loess or silt and clay in upper alluvium at Naval Support Activity Memphis.



Base from U.S. Geological Survey Digital Line Graphs 1:24,000 and U.S. Navy Digital Orthophotography 1:7,600

0 0.5 1 MILE

0 0.5 1 KILOMETER

EXPLANATION

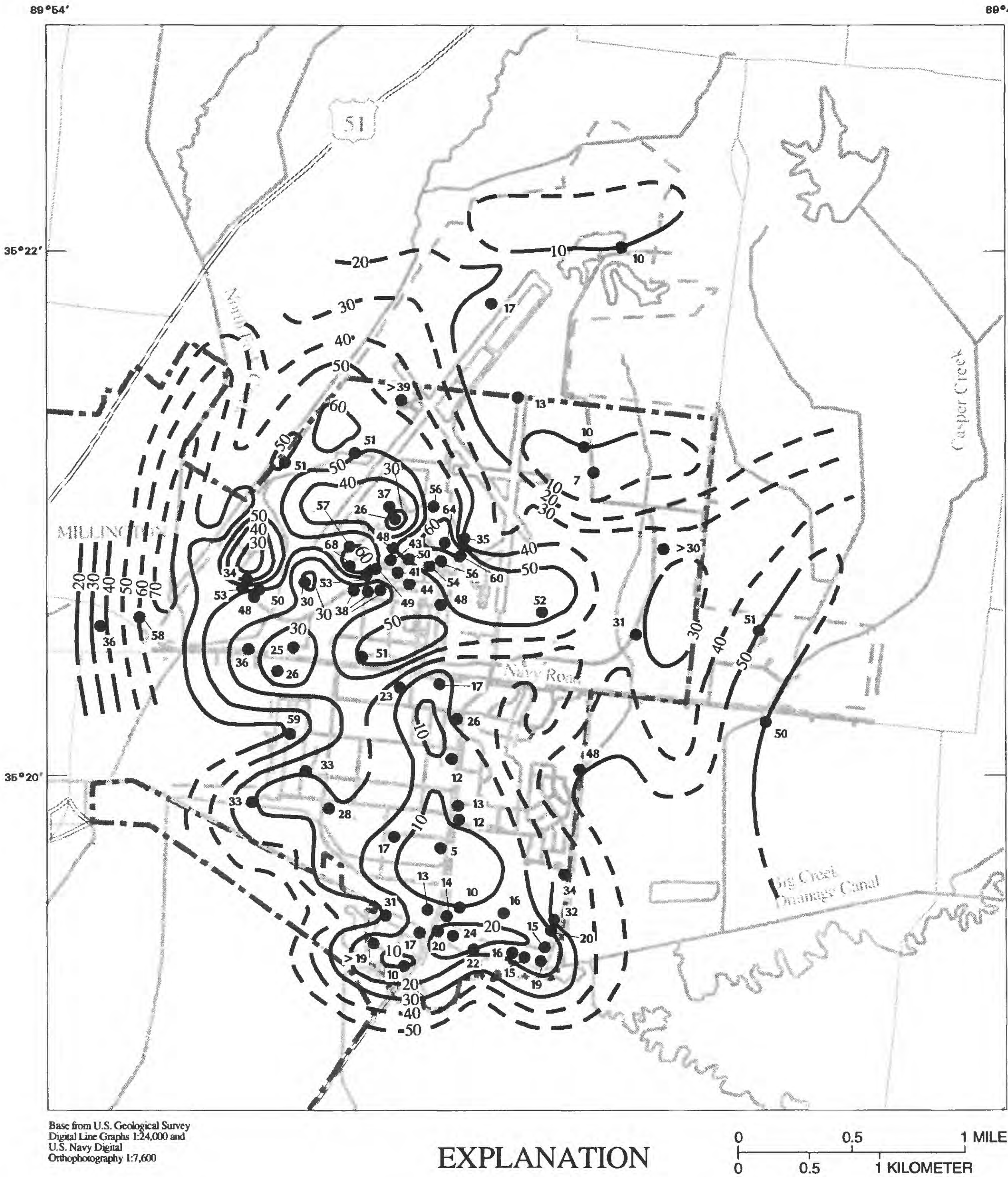
NAVAL SUPPORT ACTIVITY MEMPHIS BOUNDARY

MILLINGTON CITY BOUNDARY

—210— SUBSURFACE CONTOUR -- Shows altitude of base of sand and gravel in lower part of alluvium or fluvial deposits. Dashed where approximate. Datum is sea level. Contour interval 10 feet

● 191 WELL -- Number is altitude, in feet, of base of sand and gravel in lower part of alluvium or fluvial deposits. Datum is sea level

Figure 7. Altitude of base of sand and gravel in lower alluvium or fluvial deposits at Naval Support Activity Memphis.



EXPLANATION

0 0.5 1 MILE
0 0.5 1 KILOMETER

NAVAL SUPPORT ACTIVITY MEMPHIS BOUNDARY

MILLINGTON CITY BOUNDARY

—30— — LINE OF EQUAL THICKNESS OF SAND AND GRAVEL IN LOWER PART OF ALLUVIUM OR FLUVIAL DEPOSITS -- Number is thickness. Dashed where approximate. Contour interval 10 feet

● 36 WELL -- Number is thickness, in feet, of sand and gravel in lower part of alluvium or fluvial deposits

Figure 8. Thickness of sand and gravel in lower alluvium or fluvial deposits at Naval Support Activity Memphis.

ground water generally is first encountered in the upper finer grained part of the alluvium. Water levels measured in wells screened in the upper alluvium at various locations within the NSA Memphis Southside ranged from about 1.5 to about 22 feet below land surface during April (relative high-water levels) and September (relative low-water levels) 1996 conditions (E/A&H, written commun., 1997). Among all wells screened in the upper alluvium, minimum and maximum water-level fluctuations between these two periods ranged from about 3 to 12 feet.

Ground water in the alluvial aquifer generally is semi-confined to confined by the overlying finer grained deposits in the upper alluvium, especially along Big Creek Drainage Canal and the lower reaches of its major tributaries where sand and gravel in the lower alluvium are a part of the alluvial-fluvial deposits aquifer. Water levels measured in 19 wells screened in the alluvial aquifer at NSA Memphis near Big Creek Drainage Canal (table 2; fig. 9) ranged from about 2.5 to about 21 feet below land surface during April and October 1996 conditions. Among all wells screened in the alluvial aquifer, minimum and maximum water-level fluctuations between these two periods ranged from about 3 to 8 feet. Water-level measurements made in monitoring well pairs at SWMU 2 (fig. 2) indicate that head differences between the upper alluvium and the alluvial aquifer generally vary by only a few feet, with no consistent upward or downward gradient between the two zones from well site to well site or from time to time at a single site.

Potentiometric-surface maps were constructed for the alluvial-fluvial deposits aquifer for April and October 1996 conditions (figs. 10 and 11). Water-level data for three additional wells screened in the Cockfield Formation (wells Sh:V-108, Sh:V-110, and Sh:V-111; table 2) were included in the maps for supplemental control. The maps show ground water in the alluvial-fluvial deposits aquifer beneath NSA Memphis generally moves toward Big Creek Drainage Canal and the larger tributaries in the study area. Based on altitudes estimated from 7.5-minute topographic maps, however, the potentiometric surface in the alluvial parts of the aquifer is lower than the beds of many stream reaches in the study area, with the exceptions being some reaches of Big Creek Drainage Canal along the NSA Memphis Southside and possibly the lower-most reaches of its larger tributaries.

As described in a previous section, Big Creek Drainage Canal and the lower reaches of its major tributaries in the study area have been straightened and channelized for flood control; therefore, their present and former courses do not necessarily coincide. Where streambeds are at higher altitudes than the potentiometric surface in the alluvial-fluvial deposits aquifer, ground water in the aquifer moves beneath the streams without discharging to them. Water in the aquifer may be moving toward and down the stream valleys through thicker, more permeable alluvial deposits beneath the locations of Big Creek and its larger tributaries that coincide with the former positions of these streams before channelization. If this is the case, baseflow to the perennial parts of these streams (the upper reaches of many of the tributaries to Big Creek Drainage Canal are dry during the summer and fall) probably is supplied by ground-water discharge from the loess or upper, finer grained part of the alluvium in the vicinity of the streams. However, as noted as an exception above, along some reaches of the re-routed Big Creek Drainage Canal, the stream may be incised deeply enough to be in hydraulic connection with and receive discharge of ground water from the alluvial aquifer during part or all of the year. The potentiometric-surface maps for April and October were prepared assuming down-valley movement of ground water along the axis of an inferred area of thicker alluvium south of the present location of Big Creek Drainage Canal.

Samples of the upper alluvium silt collected by the USGS from two of the nine stratigraphic test holes drilled at NSA Memphis (fig. 2) had laboratory-determined total porosities of 38 and about 48 percent and vertical hydraulic conductivities of 1.5×10^{-3} feet per day (ft/d) and 6.8×10^{-3} ft/d (table 3). Laboratory analyses of cores collected from borings for monitoring wells installed by various consultants to the Navy at selected SWMU locations near Big Creek Drainage Canal indicate total porosities ranging from 40 to 44 percent and vertical hydraulic conductivities ranging from 1.9×10^{-3} to 2.4×10^{-2} ft/d for the upper part of the alluvium (Geraghty & Miller, written commun., 1985; E/A&H, written commun., 1997), and 22 to 34 percent and 5.1×10^{-1} to 2.4 ft/d for the lower part of the unit (E/A&H, written commun., 1997).

Loess

Loess is the surficial unit in upland parts of the NSA Memphis area (table 1). The loess consists predominantly of silt, clayey silt, and silty clay, but locally

Table 2. Water levels measured in 62 wells screened in the alluvial-fluvial deposits aquifer, and Cockfield Formation at Naval Support Activity Memphis, Millington, Tennessee, April 8-26 and October 22-24, 1996

[USGS, U.S. Geological Survey; °, degrees; ′, minutes; ″, seconds; ~, approximate measured total depth, screened interval unknown]

USGS local well number	Project well number or location	Latitude	Longitude	Altitude of land surface, in feet above sea level	Screened interval, in feet below land surface	Water level, in feet below land surface	
						Depth on April 8-26, 1996	Depth on October 22-24, 1996
				Alluvial aquifer			
Sh:U-122	BG11MA	35°19′54″	89°53′03″	262	38-48	14.39	17.15
Sh:V-27	GM-01	35°19′30″	89°51′35″	267	44-49	3.40	7.95
Sh:V-116	02MW01DA	35°19″24″	89°51′38″	267	48-58	3.84	10.96
Sh:V-117	02MW02DA	35°19′20″	89°51′40″	267	41-51	7.27	13.51
Sh:V-119	02MW03DA	35°19′17″	89°51′41″	267	38-48	8.45	14.37
Sh:V-121	02MW05DA	35°19′19″	89°51′49″	267	40-50	10.82	14.48
Sh:V-122	02MW06DA	35°19′20″	89°52′00″	268	44-54	14.69	18.02
Sh:V-124	02MW08DA	35°19′23″	89°52′08″	267	35-45	15.31	20.62
Sh:V-126	02MW09DA	35°19′24″	89°52′10″	266	36-46	14.70	18.67
Sh:V-127	02MW10DA	35°19′28″	89°52′08″	270	40-50	9.55	17.12
Sh:V-129	02MW11DA	35°19′29″	89°52′04″	265	32-42	2.57	10.46
Sh:V-130	02MW12DA	35°19′28″	89°51′52″	267	38-48	3.95	10.96
Sh:V-133	02MW13DA	35°19′27″	89°51′38″	267	55-65	3.29	9.51
Sh:V-134	02MW14DA	35°19′37″	89°51′35″	269	40-50	4.90	10.28
Sh:V-173	09MW01DA	35°19′24″	89°52′16″	270	46-56	17.94	21.26
Sh:V-174	09MW02DA	35°19′18″	89°52′20″	269	36-46	9.70	13.72
Sh:V-175	09MW03DA	35°19′21″	89°52′29″	267	45-55	13.92	17.50
Sh:V-176	09MW04DA	35°19′28″	89°52′25″	268	62-72	17.95	20.84
Sh:V-187	65MW06DA	35°19′29″	89°52′13″	264	32-42	7.68	12.50
				Fluvial deposits aquifer			
Sh:U-101	USGS well WL-1F	35°20′42″	89°52′34″	275	59-69	[a]17.64	21.20
Sh:U-105	BG4UF	35°20′01″	89°52′48″	262	40-50	[b]11.69	14.41
Sh:U-107	BG5UF	35°20′29″	89°53′04″	266	43-53	[c]12.90	16.18
Sh:U-109	05MW01UF	35°20′29″	89°52′51″	269	42-52	11.86	15.12
Sh:U-110	05MW02UF	35°20′30″	89°52′55″	268	40-50	11.55	14.96
Sh:U-111	05MW03UF	35°20′33″	89°52′51″	265	40-50	8.81	12.10
Sh:U-112	05MW04UF	35°20′30″	89°52′48″	267	40-50	9.73	12.95
Sh:U-115	60MW02LF	35°20′43″	89°53′05″	269	84-94	17.96	21.43
Sh:U-117	60MW04LF	35°20′42″	89°53′01″	270	87-97	18.75	21.32
Sh:U-119	McNamara well	35°21′49″	89°52′45″	282	~95	[a]53.08	54.35
Sh:U-121	BG10UF	35°21′11″	89°52′53″	274	56-66	28.66	30.46
Sh:U-125	07MW18LF	35°20′52″	89°52′35″	278	90-100	23.72	26.12
Sh:U-129	15MW02LF	35°20′46″	89°52′30″	283	75-85	26.97	29.51
Sh:U-133	15MW04LF	35°20′48″	89°52′35″	278	86-96	23.17	25.64
Sh:U-135	59MW03UF	35°19′57″	89°52′55″	264	44-54	14.82	17.69
Sh:U-138	Jones well	35°18′50″	89°52′53″	291	~70	[a]46.18	46.73
Sh:V-32	GM-06	35°20′40″	89°52′09″	286	46-51	[c]26.92	29.95
Sh:V-81	Runway well	35°21′26″	89°52′20″	294	~79	[a]48.20	49.43
Sh:V-83	BG1UF	35°20′32″	89°51′14″	284	36-46	[d]28.31	31.20
Sh:V-85	BG2UF	35°20′01″	89°51′30″	272	35-45	[b]9.06	13.18
Sh:V-89	03MW05MF	35°20′38″	89°52′09″	284	55-65	24.90	27.81
Sh:V-107	Officer's Club well	35°20′10″	89°51′37″	296	~70	[a]34.34	38.36
Sh:V-112	BG8UF	35°20′52″	89°51′07″	300	50-60	46.02	48.24
Sh:V-113	BG9MF	35°20′37″	89°51′41″	313	62-72	53.48	56.08
Sh:V-114	BG12UF	35°20′21″	89°52′10″	269	36-46	9.28	12.03

Table 2. Water levels measured in 62 wells screened in the alluvial-fluvial deposits aquifer, and Cockfield Formation at Naval Support Activity Memphis, Millington, Tennessee, April 8-26 and October 22-24, 1996—Continued

USGS local well number	Project well number or location	Latitude	Longitude	Altitude of land surface, in feet above sea level	Screened interval, in feet below land surface	Water level, in feet below land surface	
						Depth on April 8-26, 1996	Depth on October 22-24, 1996
			Fluvial deposits aquifer—Continued				
Sh:V-115	BG13UF	35°20′33″	89°50′40″	290	45-55	34.33	36.48
Sh:V-146	07MW04LF	35°20′52″	89°52′23″	284	60-70	25.64	28.04
Sh:V-148	07MW05LF	35°20′51″	89°52′28″	283	66-76	26.22	28.66
Sh:V-151	07MW06LF	35°20′45″	89°52′22″	284	67-77	26.00	28.58
Sh:V-158	07MW08LF	35°20′46″	89°52′28″	281	66-76	23.63	26.17
Sh:V-164	07MW10LF	35°21′01″	89°52′24″	282	68-78	33.68	35.07
Sh:V-165	07MW11LF	35°20′59″	89°52′22″	283	60-70	30.97	32.36
Sh:V-166	07MW12LF	35°21′01″	89°52′11″	289	80-90	36.00	37.23
Sh:V-167	07MW13LF	35°20′54″	89°52′03″	293	66-76	35.09	37.54
Sh:V-168	07MW14LF	35°20′50″	89°20′04″	297	84-94	38.21	40.81
Sh:V-170	07MW15LF	35°20′53″	89°52′08″	294	90-100	35.95	38.29
Sh:V-171	07MW16LF	35°20′49″	89°52′18″	285	70-80	26.94	29.45
Sh:V-172	07MW17LF	35°20′42″	89°52′27″	281	62-72	22.88	25.53
Sh:V-180	14MW06LF	35°19′50″	89°52′04″	269	39-49	8.37	9.87
Sh:V-182	21MW01LF	35°20′49″	89°52′09″	294	80-90	35.27	37.83
			Cockfield Formation				
Sh:V-108	Longmire well	35°19′44″	89°50′29″	289	~120	[e]23.46	28.68
Sh:V-110	BG6UC	35°21′26″	89°51′48″	320	52-62	36.69	38.63
Sh:V-111	BG7UC	35°21′09″	89°51′26″	321	50-60	34.90	35.80

All April 1996 measurements made 4-08 through 4-10-96 except :

[a] Depth to water measured on 4-25-96.

[b] Depth to water measured on 4-18-96.

[c] Depth to water measured on 4-19-96.

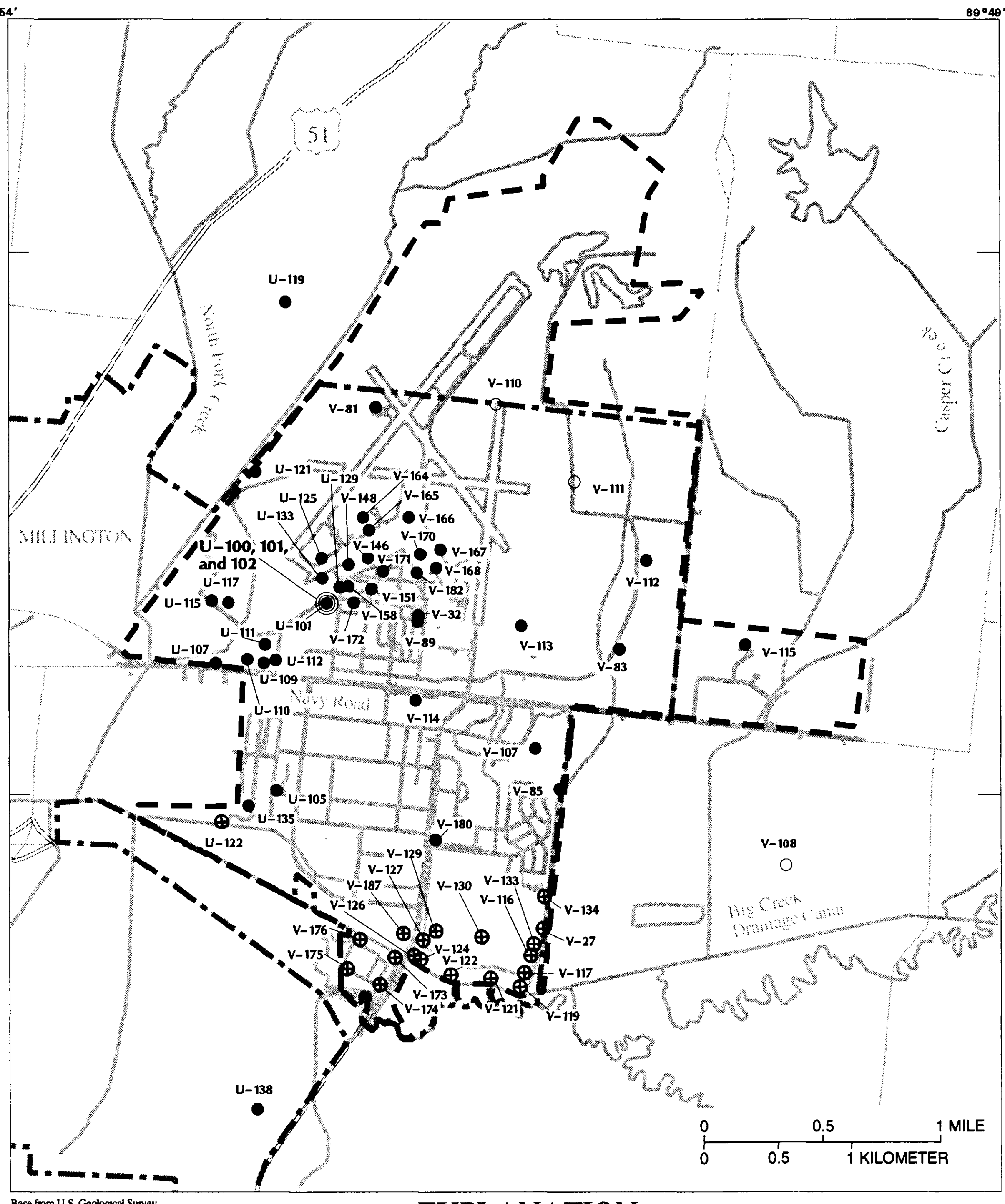
[d] Depth to water measured on 4-23-96.

[e] Depth to water measured on 4-26-96.

contains some lenses of fine sand, small iron-manganese nodules, rare calcareous concretions, and "smuts" of carbonaceous material. The loess ranges from 15 to 45 feet in thickness at NSA Memphis (table 1). In general, it is thinnest on the hilltops and thickest on the valley slopes. The silt and clay on the valley slopes locally may include loess reworked and redeposited as colluvial or alluvial deposits. In many areas of NSA Memphis, the lithologic similarity and subtle transition laterally from undisturbed loess to reworked loess or alluvium makes differentiation between these deposits difficult based solely on general lithologic descriptions.

As many as four layers of loess of different ages have been identified in the Mississippi River bluff areas of western Tennessee (Buntley and others, 1977; Parks, 1993; Mirecki and Miller, 1994; Rodbell, 1996). These layers, from youngest to oldest, are (1) the Peoria Loess, (2) the Roxanna Silt, (3) the "Loveland/Sicily Island loess" (Parks, 1993), and (4) the Crowleys Ridge Loess (Parks, 1993). Descriptions of outcrops along the bluffs and correlations of the loess layers on natural gamma-ray logs of water-level-observation wells indicate that the loess layers have geosols (ancient soil zones) developed in their upper parts (Parks, 1993).

Point-stress logs made while conducting DPT piezocone soundings at some locations at NSA Memphis, particularly at SWMU's 5 and 7 (fig. 2), indicate the existence of at least two layers of loess based on relative differences in formation density. In addition, continuous cores collected by Rotasonic drilling methods indicate that locally the two layers of loess have recognizable differences in color and texture. The upper layer, equivalent to the Peoria Loess, is a light-brown to yellowish-brown silt that is more homogeneous and contains less clay than the lower layer. This



Base from U.S. Geological Survey Digital Line Graphs 1:24,000 and U.S. Navy Digital Orthophotography 1:7,600

EXPLANATION

NAVAL SUPPORT ACTIVITY MEMPHIS BOUNDARY

MILLINGTON CITY BOUNDARY

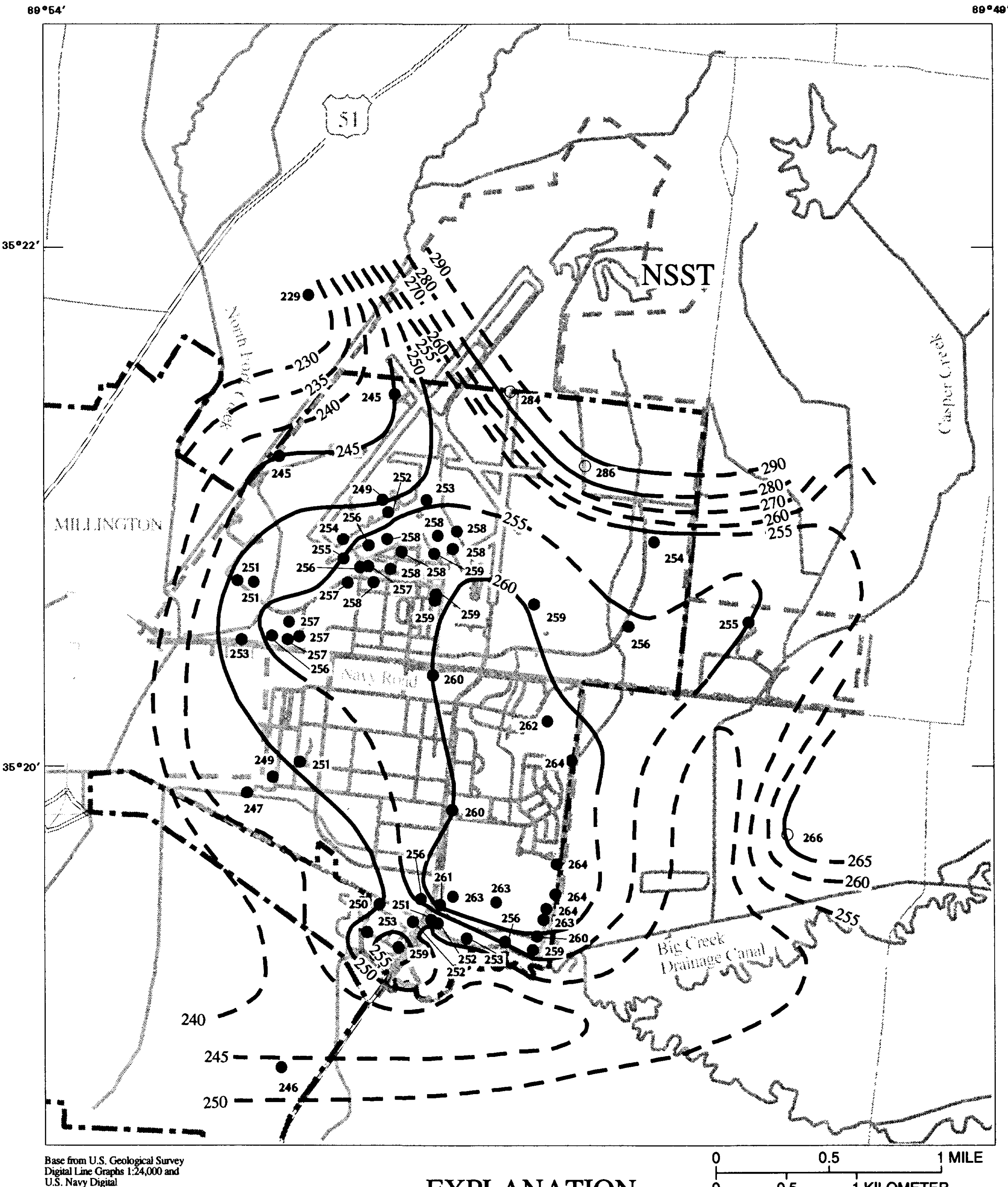
V-134 WELL SCREENED IN THE ALLUVIUM -- Number is Sh (Shelby County) number (Sh:V-134)

V-113 WELL SCREENED IN THE FLUVIAL DEPOSITS -- Number is Sh (Shelby County) number (Sh:V-113)

V-108 WELL SCREENED IN THE COCKFIELD FORMATION -- Number is Sh (Shelby County) number (Sh:V-108)

U-100, 101, and 102 WELLS EQUIPPED WITH CONTINUOUS WATER-LEVEL RECORDERS -- Numbers are Sh (Shelby County) numbers (Sh:U-100)

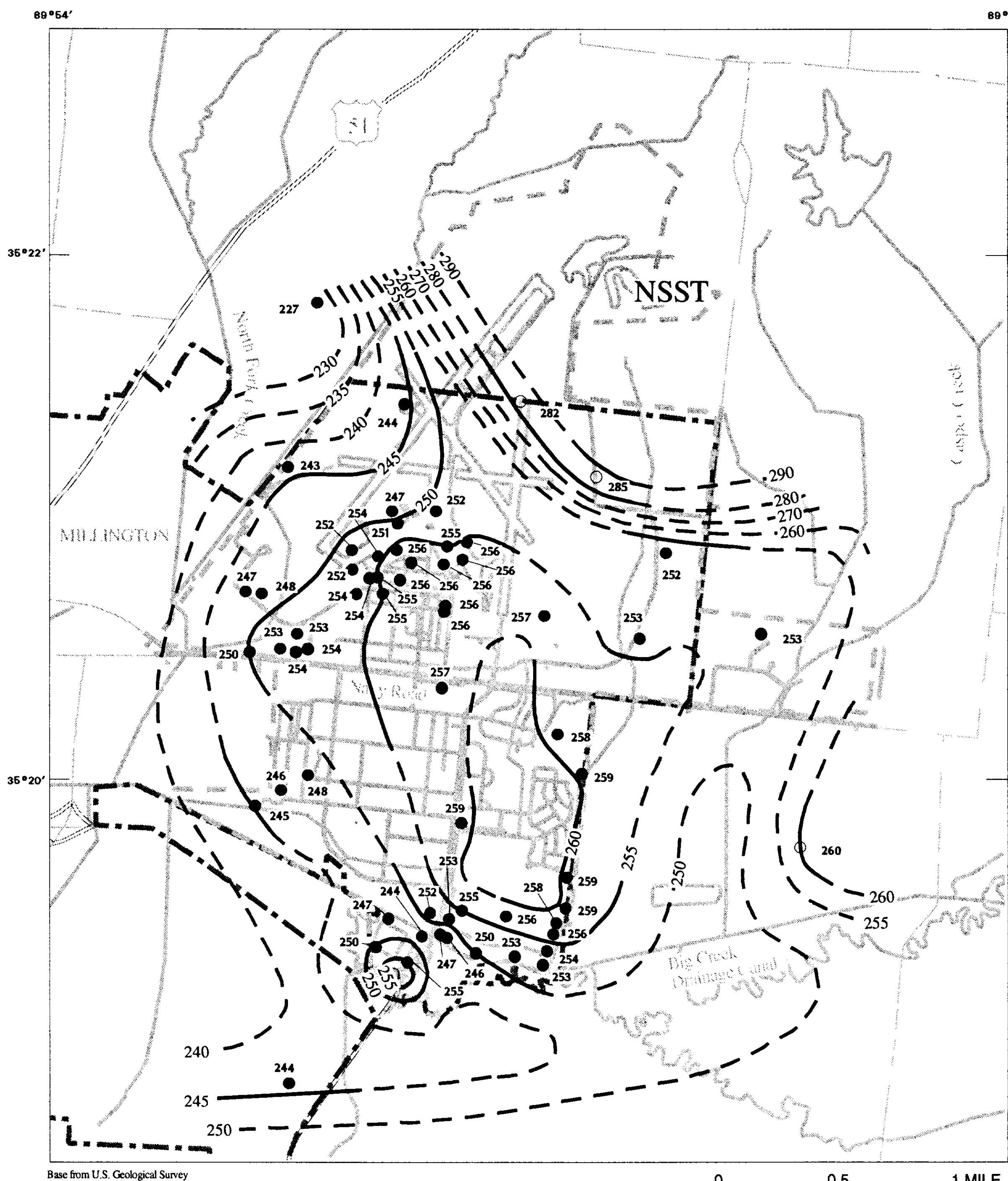
Figure 9. Locations of wells in which water levels were measured at Naval Support Activity Memphis, April and October 1996, and locations of wells Sh:U–100, Sh:U–101, and Sh:U–102 equipped with continuous water-level recorders.



EXPLANATION

- NAVAL SUPPORT ACTIVITY MEMPHIS BOUNDARY
- MILLINGTON CITY BOUNDARY
- 240 — POTENTIOMETRIC CONTOUR -- Shows altitude, in feet, at which water level would have stood in tightly cased wells. Dashed where approximate. Datum is sea level. Contour intervals 5 and 10 feet
- 229 ● WELL SCREENED IN THE LOWER PART OF ALLUVIUM OR FLUVIAL DEPOSITS -- Number is altitude of water level, in feet. Datum is sea level
- ○ 284 WELL SCREENED IN THE COCKFIELD FORMATION -- Number is altitude of water level, in feet. Datum is sea level
- NSST AREA OF NO SIGNIFICANT SATURATED THICKNESS

Figure 10. Altitude of the potentiometric surface of the alluvial-fluvial deposits aquifer at Naval Support Activity Memphis, April 1996.



Base from U.S. Geological Survey Digital Line Graphs 1:24,000 and U.S. Navy Digital Orthophotography 1:7,600

0 0.5 1 MILE
0 0.5 1 KILOMETER

EXPLANATION

NAVAL SUPPORT ACTIVITY MEMPHIS BOUNDARY

MILLINGTON CITY BOUNDARY

—240— — POTENTIOMETRIC CONTOUR -- Shows altitude, in feet, at which water level would have stood in tightly cased wells. Dashed where approximate. Datum is sea level. Contour intervals 5 and 10 feet

257 ● WELL SCREENED IN THE LOWER PART OF ALLUVIUM OR FLUVIAL DEPOSITS -- Number is altitude of water level, in feet. Datum is sea level

○ 260 WELL SCREENED IN THE COCKFIELD FORMATION -- Number is altitude of water level, in feet. Datum is sea level

NSST AREA OF NO SIGNIFICANT SATURATED THICKNESS

Figure 11. Altitude of the potentiometric surface of the alluvial-fluvial deposits aquifer at Naval Support Activity Memphis, October 1996.

Table 3. Selected geotechnical properties of silt and clay in the upper alluvium and loess, and clay in the Cockfield and Cook Mountain Formations at Naval Support Activity Memphis, Millington, Tennessee

[Analyses conducted by Inberg-Miller Engineers, Cheyenne, Wyoming; USGS, U.S. Geological Survey; ft, foot; lb/ft³, pounds per cubic foot; ft/d, feet per day; LL, liquid limit; PL, plastic limit; PI, plasticity index; °, degrees; ′, minutes; ″, seconds]

USGS local number	USGS project test-hole number	Latitude	Longitude	Sample depth (ft)	Sample classification	Moisture content (percent)	Dry density (lb/ft³)	Specific gravity	Total porosity (percent)	Atterberg limits			Vertical hydraulic conductivity (ft/d)
										LL	PL	PI	
					Alluvium								
Sh:U-99	USGS test hole 4	35°20′44″	89°52′48″	13-15	Silt	28.7	105.5	2.73	38.0	29.4	27.4	2.0	1.5×10^{-3}
Sh:V-80	USGS test hole 8	35°19′16″	89°52′20″	17-19	Lean silt	29.7	86.8	2.69	48.3	31.4	29.7	1.7	6.8×10^{-3}
					Loess								
Sh:U-102	USGS test hole WL-1C	35°20′42″	89°52′34″	12-14	Lean clay	32.0	96.9	2.70	42.6	31.1	23.0	8.1	7.7×10^{-3}
Sh:V-75	USGS test hole 3	35°21′48″	89°51′55″	11-13	Lean clay	25.5	103.3	2.71	38.9	29.6	19.0	10.6	3.4×10^{-4}
Sh:V-76	USGS test hole 5	35°20′48″	89°52′13″	11-13	Lean clay	30.9	93.7	2.73	45.1	43.6	22.2	21.4	4.5×10^{-4}
Sh:V-78	USGS test hole 6	35°21′15″	89°51′29″	18-20	Lean clay	25.8	97.3	2.72	42.6	27.9	20.8	7.1	1.6×10^{-2}
Sh:V-79	USGS test hole 7	35°19′53″	89°52′05″	10-12	Lean silt	33.5	96.5	2.64	41.4	33.0	26.7	6.3	8.0×10^{-4}
					Cockfield Formation								
Sh:U-102	USGS test hole WL-1C	35°20′42″	89°52′34″	120-122	Lean clay	32.6	82.4	2.36	43.9	36.5	23.1	13.4	2.2×10^{-3}
Sh:V-79	USGS test hole 7	35°19′53″	89°52′05″	160-162	Lean clay	24.2	98.3	2.67	41.0	37.6	23.5	14.1	2.9×10^{-4}
					Cook Mountain Formation								
Sh:U-98	USGS test hole 2	35°21′14″	89°52′33″	199-200	Lean clay	25.5	106.9	2.73	37.2	43.5	17.4	26.1	4.5×10^{-5}
Sh:V-74	USGS test hole 1	35°20′32″	89°51′14″	209-211	Lean clay	16.9	116.0	2.69	30.8	41.6	15.3	26.3	8.1×10^{-6}
Sh:V-75	USGS test hole 3	35°21′48″	89°51′55″	218-220	Sandy clay	35.9	97.5	2.69	42.0	37.3	14.1	23.2	1.6×10^{-4}
Sh:V-76	USGS test hole 5	35°20′48″	89°52′13″	195-197	Fat clay	24.7	115.7	2.67	30.4	60.6	20.5	40.1	4.0×10^{-5}
Sh:V-79	USGS test hole 7	35°19′53″	89°52′05″	200-201	Lean clay	20.6	107.6	2.68	35.6	49.9	18.9	31.0	9.9×10^{-4}
Sh:V-80	USGS test hole 8	35°19′16″	89°52′20″	180-182	Fat clay	23.8	101.2	2.69	39.8	59.5	28.7	30.8	5.0×10^{-6}

upper unit generally ranges from about 15 to 25 feet in thickness. The lower unit, equivalent to the Roxanna Silt and perhaps older loesses, is a medium-gray, olive-gray, light-gray, yellowish-gray, or pinkish-gray silt that may change vertically and laterally from silt to clayey silt to silty clay over short intervals or distances. This lower unit also generally ranges from about to 15 to 25 feet in thickness.

A transitional zone is present between silt in the loess and sand and gravel in the fluvial deposits. This transitional zone changes downward from sandy silt at the top to silty sand at the base. This sandy silt or silty sand locally contains scattered chert or quartz pebbles similar to those in the underlying fluvial deposits. The transitional zone ranges from about 3 to 7 feet in thickness at NSA Memphis.

Because of the relatively low permeability of the silt, the loess generally retards downward movement of recharge water to the underlying fluvial deposits. Geosols within the loess sequence consist of clayey silt or silty clay intervals that further retard downward movement of ground water and may result in locally perched water tables. Many shallow borings for monitoring wells installed at underground storage tank locations and SWMU's at NSA Memphis encountered ground water at depths of 10 to 15 feet below land surface, and this water commonly rose to within 3 to 7 feet of land surface once wells were completed in the borings. This shallow, perched water table may form at the base of the modern weathering and root zone in the loess or at the base of reworked loess in colluvial deposits or alluvium. Unsuccessful attempts to collect ground-water samples using a DPT Hydrocone tool at many locations at NSA Memphis indicated that the loess is dry or less than saturated below this upper saturated zone to a depth within a few feet of the top of the fluvial deposits. Ground water in the fluvial deposits commonly is confined and water levels rise in tightly cased wells to levels above the base of the loess. Where this occurs, the loess serves as an upper confining unit for the fluvial deposits aquifer. Similar conditions also exist locally at NSA Memphis where ground water in the alluvial aquifer is confined by the overlying finer grained upper alluvium.

Three observation wells (Sh:U-100, Sh:U-101, and Sh:U-102) were installed in April 1995 by the USGS southwest of the airfield area on the NSA Memphis Northside (fig. 2) to collect continuous water-level data for the loess, fluvial deposits, and Cockfield Formation. Saturated conditions were first encountered in the loess at about 12 feet below land surface in the boring for well Sh:U-100, and water levels rose to within about 6 feet below land surface in the well less than 24 hours after its completion. Well Sh:U-100 is screened in this perched zone in silt and clay in the loess from 8 to 18 feet below land surface (Appendix 1). A water-level recorder was installed on this well in May 1995. The hydrograph for well Sh:U-100 shows that water levels have ranged from about 11 feet below land surface in December 1995 to about 3.5 feet below land surface in June 1996, for a range of about 7.5 feet for the period of record (fig. 12). Comparison of the hydrograph to precipitation data for the NSA Memphis area (fig. 12) indicates a pattern of short-term water-level rises and declines in response to recharge events superimposed on seasonal fluctuations.

An additional fluvial deposits observation well was installed by the USGS in August 1995 at the site of the three existing observation wells for use in an aquifer test to determine the hydraulic characteristics of the fluvial deposits aquifer. The new well, Sh:U-103 (fig. 2), was pumped for 24 hours and water levels were monitored. Water levels also were monitored in the three existing wells, and a nearby monitoring-well cluster located about 550 feet northeast of the site. From the aquifer test, a vertical hydraulic conductivity of 3.5×10^{-2} ft/d and a specific storage of 5.8×10^{-5} per foot were estimated for the loess (K. Halford, USGS, written commun., 1995).

Samples of the loess silt and clay collected by the USGS from five of the nine stratigraphic test holes drilled at NSA Memphis (fig. 2) had laboratory-determined total porosities ranging from about 39 to about 45 percent and vertical hydraulic conductivities ranging from 3.4×10^{-4} to 1.6×10^{-2} ft/d (table 3). Laboratory analyses of cores collected from the loess in borings for monitoring wells installed by various consultants to the Navy at selected SWMU locations indicate total porosities ranging from 35 to 44 percent and vertical hydraulic conductivities ranging from 8.5×10^{-5} to 3.7×10^{-2} ft/d (Geraghty & Miller, written commun., 1985; E/A&H, written commun., 1997).

Fluvial Deposits

The fluvial deposits underlie the loess in upland parts of the NSA Memphis area and consist of sand and gravel with minor amounts of clay (table 1). The sand ranges from fine to very coarse and generally is

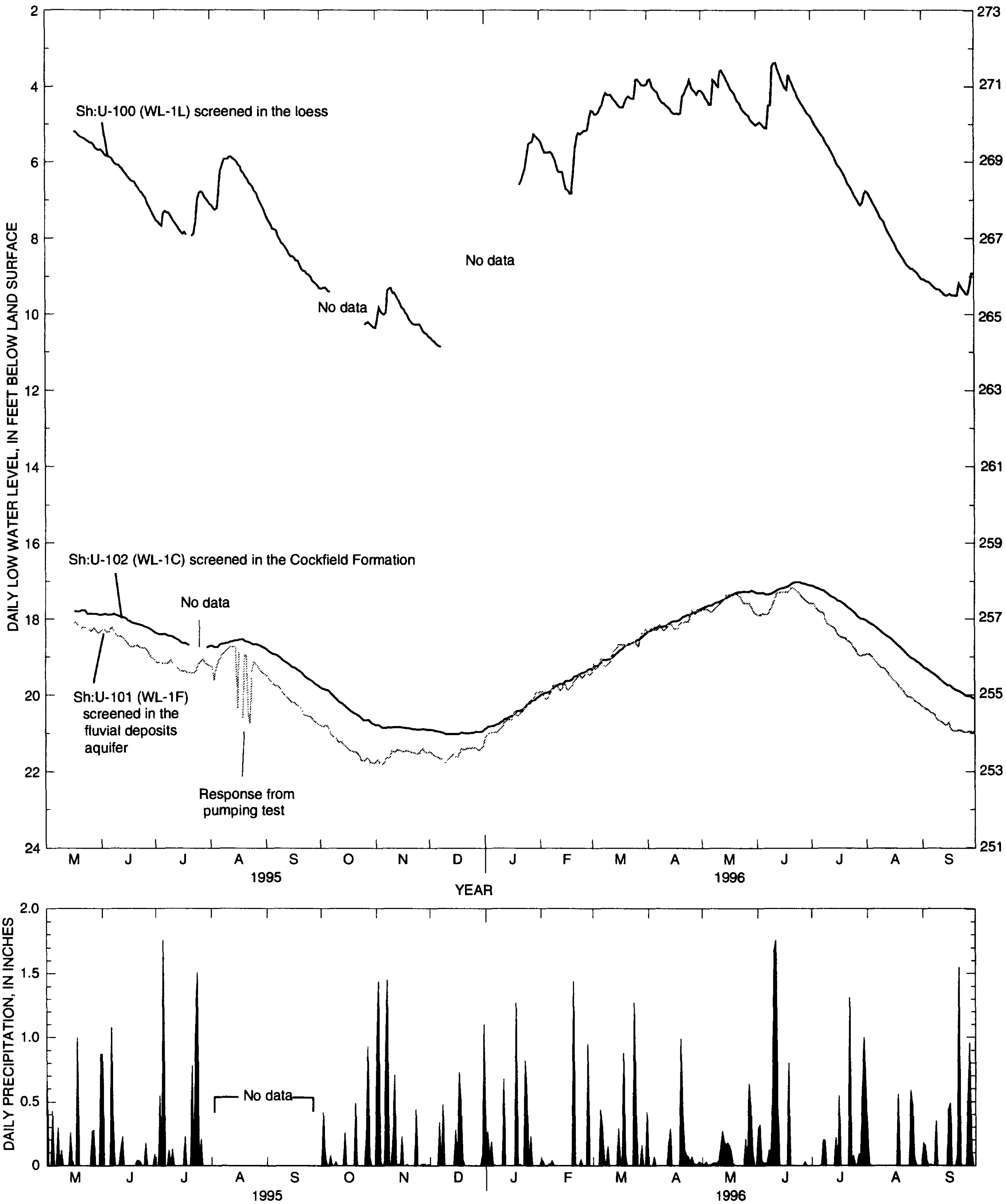


Figure 12. Hydrographs showing water levels recorded in wells Sh:U–100, Sh:U–101, and Sh:U–102, and daily precipitation at Naval Support Activity Memphis, May 1995 through September 1996 (precipitation data for May through July 1995 from Naval Support Activity Memphis; precipitation data for October 1995 through September 1996 from USGS gage near Millington, Tennessee).

poorly sorted. Some sand, however, is clean and moderately well sorted. Locally, sand in the upper part of the fluvial deposits is very fine to fine and silty or clayey. Gravel is present as lenses at various horizons in the fluvial deposits but it is more common in the lower part. The gravel is predominantly chert with some pebbles as large as 3 to 4 inches in the longest dimension. Quartz and quartzite are common in the smaller-size fraction. Locally, the sand and gravel may be cemented to form thin layers of ferruginous sandstone or conglomerate, particularly in the lower part of the fluvial deposits. Clay is present in the sand and gravel as interstitial material, balls, or lenses.

Two levels of fluvial deposits have been identified at NSA Memphis. The bases of these two levels of fluvial deposits are relatively flat or low rolling, except where they have been incised by modern streams. Most of the NSA Memphis area is underlain by fluvial deposits with a basal altitude of about 220 feet above sea level (figs. 4b and 7). The fluvial deposits making up this lower level range from 5 to about 70 feet in thickness (fig. 8). The northeastern part of the NSA Memphis area is underlain by fluvial deposits with a basal altitude of about 300 feet above sea level (figs. 4b and 7). The fluvial deposits making up this upper level range from less than 10 to about 20 feet in thickness (fig. 8).

The fluvial deposits constitute the fluvial deposits aquifer. The lower level fluvial deposits generally are saturated, and ground water commonly is under artesian pressure. The upper level fluvial deposits generally are dry or have no significant saturated thickness (NSST; figs. 10 and 11). The two levels of fluvial deposits locally may be hydraulically connected along their boundary (fig. 4b). In these places, the two levels of fluvial deposits may be a single aquifer.

A water-level recorder was installed on well Sh:U-101 (fig. 2) in May 1995. This well is screened in sand and gravel in the fluvial deposits from 59 to 69 feet below land surface (table 2 and Appendix 1). The hydrograph for well Sh:U-101 shows water levels have ranged from about 22 feet below land surface in late October, early November, and in mid-December 1995 to about 17 feet below land surface in June 1996, for a range of about 5 feet during the period of record (fig. 12). The contact between the base of the loess or top of the fluvial deposits was encountered at 36 feet below land surface in well Sh:U-102 which is adjacent to well Sh:U-101. Therefore, artesian conditions are present in the fluvial deposits aquifer at this location. Comparison of the hydrograph for well Sh:U-101 to precipitation data for the NSA Memphis area (fig. 12) indicates that short-term water-level responses to recharge occur in the fluvial deposits aquifer in addition to seasonal fluctuations. Because the fluvial deposits are confined at this location, these short-term changes in response to recharge events are smaller than those in the loess and may be the result of loading effects from recharge to the loess as well as recharge to the fluvial deposits aquifer in areas where it is unconfined or semi-confined. The hydrographs for the loess and fluvial deposits wells also indicate that between about 11 and 14 feet of downward head difference existed between the two zones during the period of lowest and highest water levels, respectively.

The potentiometric-surface maps (figs. 10 and 11) show water levels measured in 59 wells (table 2; fig. 9) screened in the alluvial-fluvial deposits aquifer and three supplemental wells screened in the Cockfield Formation in the NSA Memphis area for April and October 1996 conditions. Water-level measurements made at locations where well pairs are screened in the upper and lower parts of the fluvial deposits show little head difference, indicating a small component of vertical flow in the aquifer. Water levels in the fluvial deposits generally fluctuated about 2 to 4 feet between relative high and low water-level periods during 1996 (table 2). Depths to water measured in wells installed in this unit ranged from about 8.5 to 56 feet below land surface. Among all wells screened in the fluvial deposits aquifer, minimum and maximum water-level fluctuations between these two periods ranged from about 0.5 to 5 feet. Based on these measurements, wells screened in the fluvial deposits showed less fluctuation than wells screened in parts of the alluvial-fluvial deposits aquifer consisting of alluvium.

A high in the potentiometric surface in the alluvial-fluvial deposits aquifer was present beneath the southeastern part of NSA Memphis during both measurement periods (figs. 10 and 11). This high is interpreted to result from several possible factors including the relatively high basal altitude (fig. 7) and thinning (fig. 8) of the lower alluvium-fluvial deposits in this area, the influence of additional recharge to the aquifer from leaks in the NSA Memphis water-distribution system or watering of lawns in the northern part of the mound, and increased recharge through the former main landfill (SWMU 2; fig. 2) in the southern part of the mound. Water in the fluvial deposits moves away from this potentiometric high toward alluvial sections of the aquifer in the interpreted buried stream valleys along North Fork Creek, Casper Creek, and Big Creek Drainage Canal to the west, east, and south, respectively, and toward a potentiometric low coincident with an interpreted fault (figs. 4a and 4b) to the north.

From results of the aquifer test at the location of the water-level observation well cluster (fig. 2), a horizontal hydraulic conductivity of 5.3 ft/d and a specific storage of 1.2 x 10^{-6} per foot were estimated for the fluvial deposits aquifer (K.J. Halford, USGS, written commun., 1995). Laboratory analyses of cores collected from the fluvial deposits in borings for monitoring wells installed by consultants to the Navy at selected SWMU locations indicate total porosities ranging from 26 to about 39 percent and vertical hydraulic conductivities ranging from 1.1 x 10^{-3} to 7.4 x 10^{-1} ft/d (E/A&H, written commun., 1997).

Cockfield Formation

The Cockfield Formation (Vaughn, 1895, p. 220) is the uppermost unit in the Claiborne Group in the NSA Memphis area (table 1). The Cockfield Formation consists of sand, silt, clay, and lignite. Individual beds in the Cockfield Formation are lenticular and locally can be discontinuous over short distances (Parks and Carmichael, 1990b).

A gentle dip of about 10 to 15 feet per mile (ft/mi) to the west-northwest would be expected for the Cockfield Formation and the underlying Cook Mountain Formation in the area of NSA Memphis based on regional control (Parks and Carmichael, 1990b). However, a map (fig. 13) of the altitude of the base of the Cockfield Formation (top of the Cook Mountain Formation), prepared from correlations of geophysical logs of test holes and lithologic data from boring logs, indicates a relatively complex geologic structure beneath NSA Memphis. This map, although highly interpretative, shows an anticline cut in the central part by a northwest-trending graben and on the southeast by a northeast-trending fault. The location of the southwest fault bounding the graben (fig. 13) is constrained by control data to several hundred feet laterally, and the map indicates that this fault displaces the base of the Cockfield Formation about 40 to 70 feet vertically. The location of the northeast fault bounding the graben (fig. 13) is constrained by control data to several thousand feet laterally, and the map indicates that the fault displaces the base of the Cockfield Formation about 45 to 55 feet vertically. Except for the convergence of dip from two directions, the northeast-trending fault (fig. 13) probably would be imperceptible because displacement of the Cockfield Formation is only about 5 to 20 feet vertically. The direction of dip of the Cockfield Formation southeast of this fault is consistent with what would be expected based on regional control (Parks and Carmichael, 1990b), but the rate of dip at about 50 ft/mi is steeper than would be expected.

Hydrogeologic sections (figs. 4a and 4b) and a map of the thickness of the Cockfield Formation (fig. 14) indicate the existence of the faults in the NSA Memphis area. However, maps (figs. 6 and 7) of the base of the loess or silt and clay in the upper alluvium (top of sand and gravel in the fluvial deposits or lower alluvium) and of the base of the sand and gravel in the fluvial deposits or lower part of the alluvium (top of the Cockfield Formation) provide no evidence that the faults displace the fluvial deposits, loess, or alluvium of Quaternary age (table 1). Consequently, the last movement on the faults in the NSA Memphis area may have taken place during the Tertiary, which also is suspected to be the likely time of last movement along other faults identified in the Memphis area (Kingsbury and Parks, 1993).

Thickness of the Cockfield Formation is variable as a result of erosional surfaces at both the top and base. The thickness generally ranges from about 25 to 185 feet in the NSA Memphis area, but locally the Cockfield Formation may be absent (fig. 14; Appendix 2). The thickest preserved section of the Cockfield Formation is in the northern part of the area beneath the upper level fluvial deposits (figs. 4b and 14).

Throughout much of the Memphis area, the Cockfield Formation consists of clay, silt, and very fine sand and, along with the underlying Cook Mountain Formation, serves as a lower confining unit for the overlying fluvial deposits aquifer or upper confining unit for the Memphis aquifer (Parks, 1990). Locally, however, the Cockfield Formation contains relatively thick lenses (as much as 50 to 60 feet) of fine sand or fine to medium sand in which small capacity [as much as 10 gallons per minute (gal/min)] domestic wells are completed. These sand lenses in the Cockfield Formation make up the Cockfield aquifer (Parks and Carmichael, 1990b).

At NSA Memphis, the Cockfield Formation generally consists of clay, silt, and very fine sand of low hydraulic conductivity, although lenses of fine or fine to medium sand as much as 53 feet thick were encountered in stratigraphic test holes Sh:V-74, Sh:V-75, Sh:V-76, and Sh:V-78 (Appendix 1). These test holes were located in the eastern, central, and

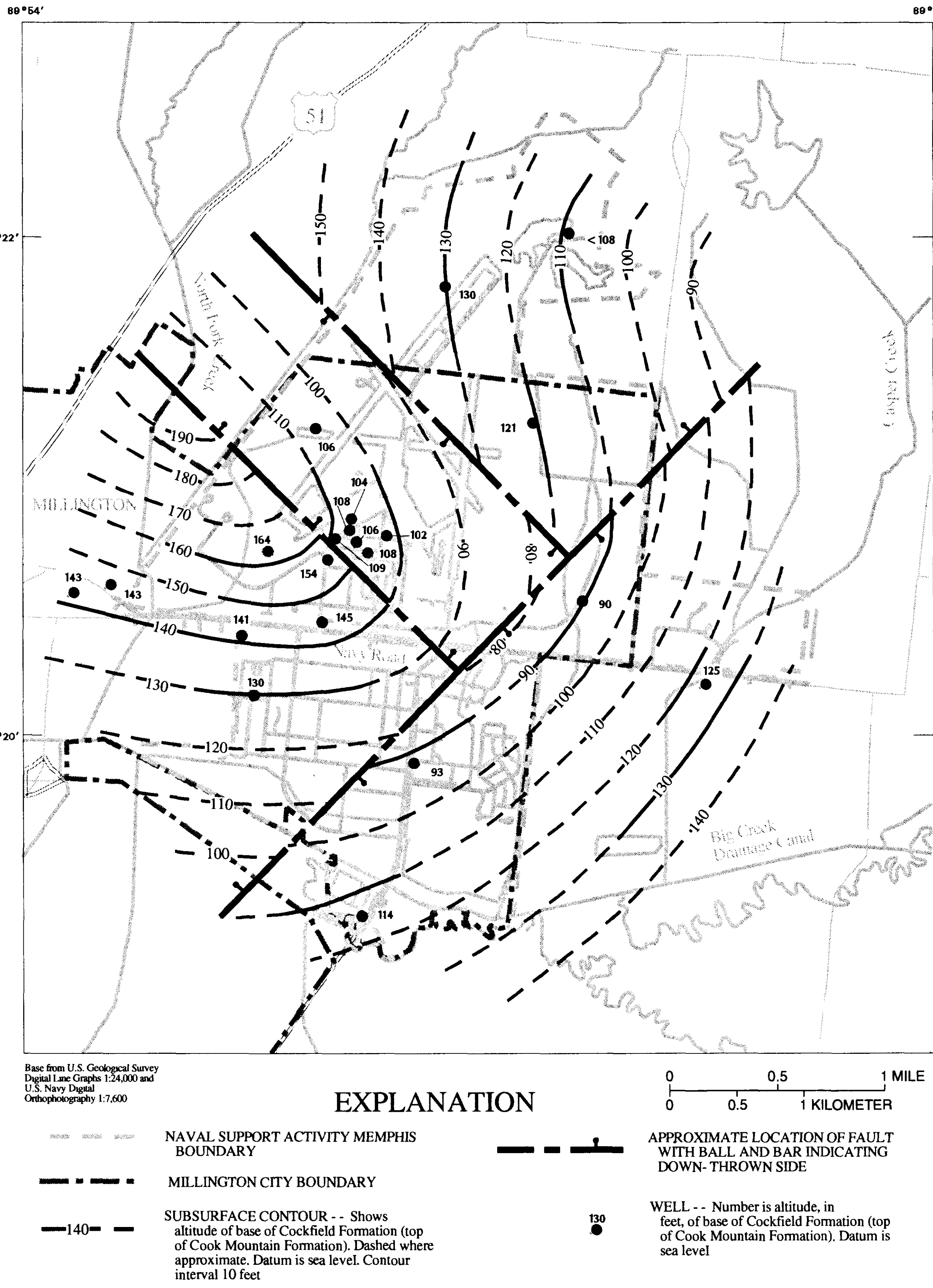
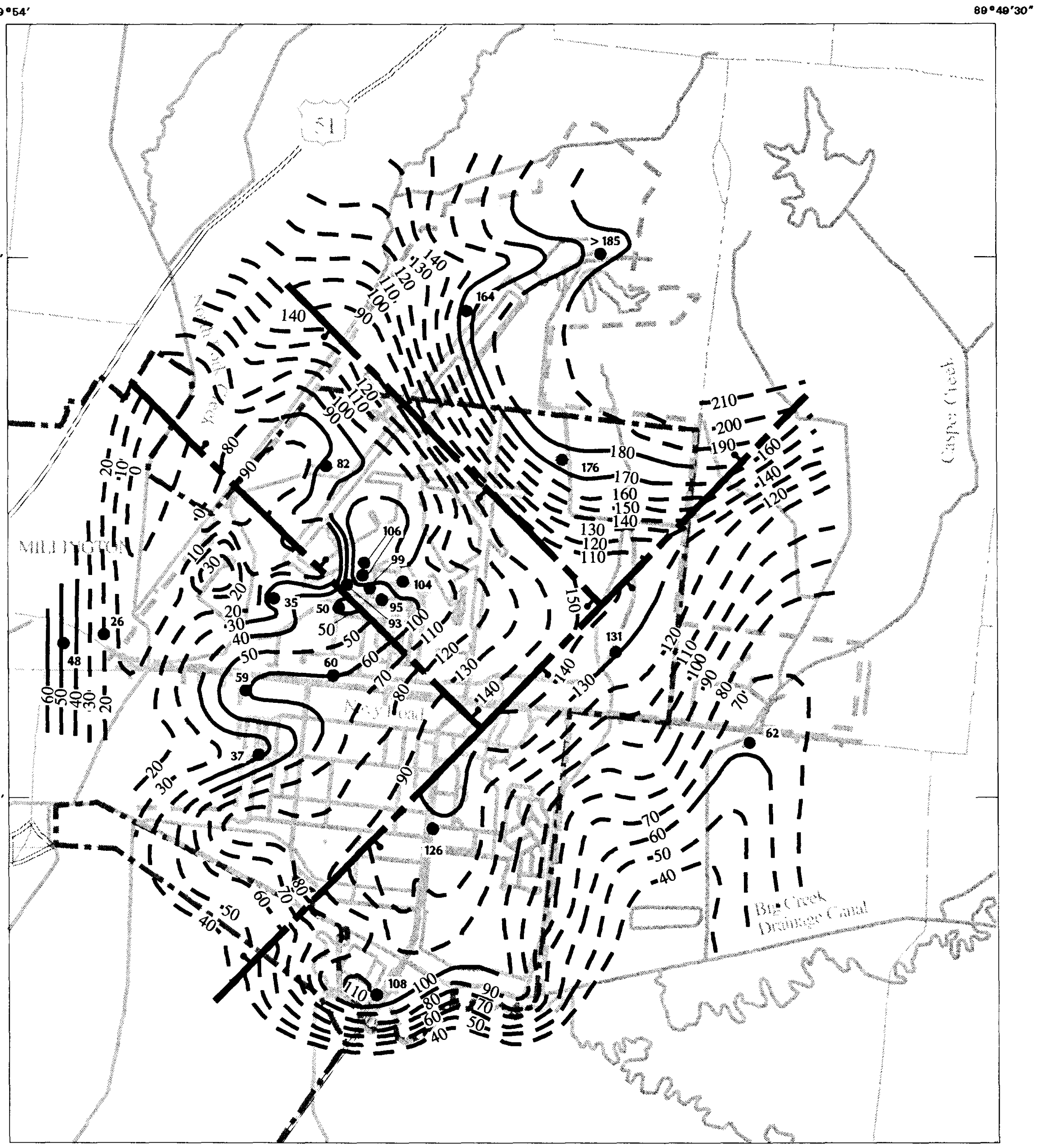


Figure 13. Altitude of base of Cockfield Formation (top of Cook Mountain Formation) and locations of faults that displace these formations at Naval Support Activity Memphis.



Base from U.S. Geological Survey Digital Line Graphs 1:24,000 and U.S. Navy Digital Orthophotography 1:7,600

EXPLANATION

0 0.5 1 MILE
0 0.5 1 KILOMETER

NAVAL SUPPORT ACTIVITY MEMPHIS BOUNDARY

MILLINGTON CITY BOUNDARY

—60— — LINE OF EQUAL THICKNESS OF THE COCKFIELD FORMATION - - Number is thickness. Dashed where approximate. Datum is sea level. Contour interval 10 feet

APPROXIMATE LOCATION OF FAULT WITH BALL AND BAR INDICATING DOWN-THROWN SIDE

● 48 WELL - - Number is thickness, in feet, of the Cockfield Formation

Figure 14. Thickness of the Cockfield Formation and locations of faults that displace the Cockfield and Cook Mountain Formations at Naval Support Activity Memphis.

northern parts of the base (fig. 2). In addition, well Sh:V-77 once supplied water for the "Lake house" at Navy Lake in the northern part of the NSA Memphis Northside (fig. 3). Where sand lenses in the Cockfield Formation underlie the fluvial deposits, the two units probably are hydraulically connected. However, clay lenses in the upper part of the Cockfield Formation in the NSA Memphis area (Appendix 1) retard the downward movement of ground water.

A water-level recorder was installed on well Sh:U-102 (fig. 2) in May 1995. This well is screened in an interval of clay with interbedded fine sand beneath a fine sand with clay in the upper part of the Cockfield Formation from 105 to 115 feet below land surface (Appendix 1). The hydrograph for well Sh:U-102 shows water levels fluctuated from about 21 feet below land surface in December 1995 to about 17 feet below land surface in June 1996, for a range of about 4 feet during the period of record (fig. 12). The zone in which this well is screened is artesian. Water levels ranged from essentially equal (January through May 1996) to as much as 1 foot higher (late October and early November 1995) than those measured in well Sh:U-101, which is screened in the fluvial deposits (fig. 12). The intervals screened in these wells appear to be in poor hydraulic connection based on the response of water levels in the Cockfield Formation to pumping in the fluvial deposits during the aquifer test conducted in August 1995 (K.J. Halford, USGS, written commun., 1995). Unlike the hydrograph for wells Sh:U-100 and Sh:U-101, the hydrograph for well Sh:U-102 is relatively smooth, showing little short-term fluctuation during the seasonal low to high water-level cycle (fig. 12).

The April and October 1996 potentiometric-surface maps (figs. 10 and 11) for the alluvial-fluvial deposits aquifer contain water-level data for three wells screened in the Cockfield Formation. These wells were used as supplemental control points in the northern part of NSA Memphis where the upper level fluvial deposits are either dry or not significantly saturated (wells Sh:V-110 and Sh:V-111), and in an off-base area east of the NSA Memphis Southside (well Sh:V-108) where no sand and gravel in the alluvial-fluvial deposits aquifer were reported to exist by a local well driller (G.H. Mize, Mize Drilling, oral commun., 1995). Other than the water-level observation well Sh:U-102 (fig. 2), only a few monitoring wells have been installed in the Cockfield Formation as part of the Corrective Action Program at NSA Memphis. These wells are located near SWMU 7 in the airfield area (fig. 2) and are screened in sandy clay or clayey sand in the upper to middle part of the formation at depths equivalent to well Sh:U-102. Water-level measurements made in these wells and fluvial deposits wells with which they are paired also indicate that little vertical gradient exists between the two zones, as was observed in wells Sh:U-101 and Sh:U-102.

From the results of the aquifer test conducted at the location of the water-level observation-well cluster (fig. 2), a specific storage of 1.2×10^{-6} per foot was estimated for the Cockfield Formation (K.J. Halford, USGS, written commun., 1995). During the test, the water level in well Sh:U-102, which is screened in the Cockfield Formation, rose in response to pumping in well Sh:U-103, which is screened through the full thickness of the fluvial deposits from 40 to 70 feet below land surface. The observed water-level response in well Sh:U-102 indicates that the change in pore pressure observed in this well was dominated by deformation of the Cockfield Formation instead of leakage, and that a high degree of confinement exists between the upper part of the Cockfield Formation and the overlying fluvial deposits (K.J. Halford, USGS, written commun., 1995).

Samples of the Cockfield Formation clay collected by the USGS from two of the nine stratigraphic test holes drilled at NSA Memphis (fig. 2), including the test hole for well Sh:U-102, had laboratory-determined total porosities of 41 and 44 percent and vertical hydraulic conductivities of 2.9×10^{-4} and 2.2×10^{-3} ft/d (table 3). Laboratory analyses of cores collected from the Cockfield Formation in borings for monitoring wells installed by consultants to the Navy at SWMU 7 (fig. 2) indicate total porosities ranging from about 50 to about 55 percent and vertical hydraulic conductivities ranging from 4.5×10^{-5} to 2.5×10^{-3} ft/d (E/A&H, written commun., 1997).

Cook Mountain Formation

The Cook Mountain Formation (Kennedy, 1892, p. 54-57) of the Claiborne Group consists predominantly of clay and silt (table 1); minor lenses of silty fine sand or lignite may be present locally. The Cook Mountain Formation contains the most areally extensive clay in the upper part of the Claiborne Group in Shelby County (Parks, 1990). Most of the test holes drilled for this investigation did not penetrate the full thickness of the Cook Mountain Formation. However, geophysical logs of other test holes or wells in the area that penetrated the entire formation indicate that the thickness ranges from about 10 to 60 feet (fig. 4b; Appendixes 2 and 3).

The Cook Mountain Formation, along with the clay, silt, and fine sand in the overlying Cockfield Formation, serves as the upper confining unit for the Memphis aquifer in the Memphis area. Beneath much of NSA Memphis also, the two units serve as a hydraulic barrier that provides confinement between water in the alluvial-fluvial deposits aquifer and the Memphis aquifer. This confinement is indicated primarily by heads that are higher in the alluvial-fluvial deposits aquifer (and upper Cockfield Formation) than heads in the Memphis aquifer, and by differences in water quality between the two zones. However, interpretation of geologic data from stratigraphic test holes drilled at the NSA Memphis Northside suggests that vertical displacement of the Cockfield and Cook Mountain confining unit along the northeast fault may provide hydraulic connection between the fluvial deposits and Memphis aquifers in this area (fig. 4b, section *B-B′*). The potentiometric low in the fluvial deposits that is oriented along this fault (figs. 10 and 11) also suggests that downward leakage of water from the fluvial deposits is occurring along this feature.

Clay samples from the Cook Mountain Formation were collected by the USGS in six of the nine test holes for mineralogical and geotechnical analysis (table 3). Results from X-ray diffraction analysis of the <1-micron clay particles separated from each of the samples indicate interstratified smectite, well-crystallized kaolinite, and minor amounts of illite (B.F. Jones and D.M. Webster, USGS, written commun., 1994). Total porosities of the clay samples from the Cook Mountain Formation ranged from about 30 to 42 percent and vertical hydraulic conductivities ranged from 5.0×10^{-6} to 9.9×10^{-4} ft/d (table 3).

Memphis Sand

The Memphis Sand (Moore and Brown, 1969) of the Claiborne Group consists of a thick body of fine to medium or medium to coarse sand with lenses of clay, silt, and lignite at various stratigraphic horizons (table 1). Lenses of clay, silt, and fine sand commonly are present in the upper part of the Memphis Sand (fig. 5), sometimes causing difficulty in distinguishing between the Memphis Sand and Cook Mountain Formation on geophysical logs of stratigraphic test holes (Kingsbury and Parks, 1993). The Memphis Sand ranges from about 865 to 880 feet in thickness in the NSA Memphis area, based on the geophysical logs of six deep test holes drilled in the area (fig. 5; Appendix 3). The Memphis Sand makes up the Memphis aquifer, which is the principal aquifer in the Memphis area and western Tennessee that provides water for public, industrial, and commercial supplies (Parks and Carmichael, 1990a).

Part of the ground water used for public supply at NSA Memphis is withdrawn from the Memphis aquifer (Parks and Carmichael, 1990a). Wells Sh:V-4 (NSA Memphis well 2) and Sh:V-20 (NSA Memphis well 1) located within the NSA Memphis Northside (fig. 2) are screened in the Memphis aquifer at total depths of 466 and 523 feet, respectively. Both of these wells have capacities of about 700 gal/min. In 1993, about 0.8 million gallons per day (Mgal/d) was withdrawn from the Memphis aquifer wells at NSA Memphis (R.E. Harris, NSA Memphis water plant, oral commun., 1994). To assure public safety, pumping from well Sh:V-4 was discontinued in January 1995 after ground-water contamination was detected in the fluvial deposits aquifer near this well. The well is now on standby for use in the event of an emergency shortage of water supply at NSA Memphis.

A potentiometric-surface map of the Memphis aquifer in the Memphis area was prepared by the USGS for September 1995 conditions (Kingsbury, 1996). The map includes the NSA Memphis area and shows that the altitude of the potentiometric surface in the Memphis aquifer in this area is about 215 feet above sea level (water level of about 65 feet below land surface). Comparison of this value with an average altitude of about 255 feet above sea level for the potentiometric surface of the alluvial-fluvial deposits aquifer at NSA Memphis (figs. 10 and 11) indicates a vertical head difference of about 40 feet and a downward hydraulic gradient from the alluvial-fluvial deposits aquifer to the Memphis aquifer through the Cockfield and Cook Mountain confining unit. These data, along with results of selected water-quality analyses and the apparent lack of observed effects on the water level in well Sh:U-101 (fig. 12) screened in the fluvial deposits aquifer from intermittent withdrawal of water from the Memphis aquifer at the facility, indicate that the two zones are isolated hydraulically by the Cockfield and Cook Mountain confining unit beneath the central part of NSA Memphis. The potentiometric map for the Memphis aquifer also shows that water in the aquifer moves to the southwest at a gradient of about 5.5 ft/mi [0.001 foot per foot (ft/ft)] toward the large cone of depression that results from withdrawals from the Memphis aquifer by the city of Memphis (Kingsbury, 1996).

In 1983, as part of an investigation of water quality and quantity in the lower part of the Memphis aquifer and the underlying Fort Pillow aquifer, a test well was drilled to a depth of 1,608 feet below land surface in the northwest corner of the NSA Memphis Southside near well Sh:U-58 (fig. 2). After reaching the total depth, a temporary well was screened in the lower part of the Memphis aquifer, reportedly from about 900 to 1,020 feet below land surface. From results of an aquifer test conducted in this well, a transmissivity of about 11,400 feet squared per day (ft^2/d) and storativity of 1×10^{-4} were estimated for this interval of the Memphis aquifer (Layne Geosciences Div., written commun., 1983). Using this value of transmissivity and a reported thickness of 167 feet for a lower sand interval of the Memphis aquifer in this well, a horizontal hydraulic conductivity of about 68 ft/d is estimated for this interval of the aquifer.

Flour Island Formation

The Flour Island Formation (Moore and Brown, 1969) consists of clay, silt, sand, and lignite (table 1). Geophysical logs of six deep test holes drilled in the NSA Memphis area show that the formation ranges from about 225 to 290 feet in thickness (fig. 5; Appendix 3). The Flour Island Formation serves as a confining unit separating the Memphis aquifer from the Fort Pillow aquifer. On September 25, 1995, water levels were measured by the USGS in well Sh:V-20 (NSA Memphis well 1), screened in the Memphis aquifer, and well Sh:U-60 (NSA Memphis well 3), screened in the Fort Pillow aquifer, after these wells had not been pumped for a few days. These measured water levels indicate a vertical head difference of 32 feet and a downward hydraulic gradient from the Memphis aquifer to the Fort Pillow aquifer through the Flour Island confining unit.

Based on analysis of data from a water-temperature geophysical log made by the USGS in water-level observation well Fa:R-1 located in northwestern Fayette County, Tennessee, about 19 miles east of NSA Memphis (Graham and Parks, 1986), the vertical velocity of ground water moving through the Flour Island confining unit was estimated to be 6.6×10^{-4} ft/d. Using this value for ground-water velocity, a vertical hydraulic conductivity of the Flour Island confining unit was calculated to be about 1.1×10^{-2} ft/d.

Fort Pillow Sand

The Fort Pillow Sand (Moore and Brown, 1969) consists primarily of sand with some thin lenses of clay (table 1). The sand is very fine to fine or fine to medium grained. Thickness ranges from about 125 to 180 feet based on the geophysical logs of six test holes drilled at NSA Memphis and the city of Millington (fig. 5; Appendix 3) to determine the suitability of the Fort Pillow aquifer as a source of additional ground-water supply. As a result of this drilling program, NSA Memphis installed three supply wells to the Fort Pillow aquifer and the city of Millington installed two wells. The wells at NSA Memphis range from 1,435 to 1,450 feet in depth and pump at rates ranging from 900 to 1,400 gal/min. In 1993, about 1.2 Mgal/d was withdrawn from the Fort Pillow aquifer for water supply at NSA Memphis (R.E. Harris, NSA Memphis water plant, oral commun., 1994).

A potentiometric-surface map of the Fort Pillow aquifer in the Memphis area was prepared by the USGS for September 1995 conditions (Kingsbury, 1996). The map includes the NSA Memphis area and shows that a cone of depression centered beneath the city of Millington and NSA Memphis has developed in the aquifer from withdrawals of water for public supply. The depth to water measured in a well screened in the Fort Pillow aquifer at NSA Memphis was about 90 feet below land surface in September 1995, indicating a water-level altitude in the center of the cone of about 170 feet above sea level. Based on the area outside the influence of pumping at Millington and NSA Memphis, the potentiometric surface of the Fort Pillow aquifer should be about 185 feet above sea level in this area (Kingsbury, 1996). The map also indicates that water in the aquifer moves to the southwest at a gradient of about 5 ft/mi (0.001 ft/ft) toward the relatively large cone of depression that results from withdrawals from the Fort Pillow aquifer by the cities of Memphis, Tennessee, and West Memphis, Arkansas (Kingsbury, 1996).

Following the aquifer test of the lower part of the Memphis aquifer in 1983, the test well in the northwest part of the NSA Memphis Southside near well Sh:U-58 (fig. 2) was drilled deeper and screened from 1,360 to 1,440 feet below land surface in the Fort Pillow aquifer. From results of an aquifer test conducted in this deepened well, a transmissivity of about 2,300 ft^2/d and a storativity of 1×10^{-4} were estimated for this interval of the Fort Pillow aquifer (Layne Geosciences Div., written commun., 1983). Using this value of transmissivity and a thickness of 180 feet for the Fort Pillow aquifer in well Sh:U-58 (Appendix 3), a horizontal hydraulic conductivity of about 13 ft/d is estimated for the aquifer.

Old Breastworks Formation

The Old Breastworks Formation (Moore and Brown, 1969) consists primarily of clay, silt, fine sand, and lignite (table 1). The six deep test holes drilled in the NSA Memphis area penetrated only the uppermost part of this formation. Therefore, a thickness range of about 245 to 310 feet for the Old Breastworks Formation (table 1) was determined from the geophysical logs of the oil and gas test well Sh:U-12 (Lion Oil Co., Bateman No. 1) drilled near the Loosahatchie River, about 2 miles south-southwest of NSA Memphis, and stratigraphic test hole Sh:T-18 drilled in Meeman-Shelby Forest, about 8 miles west of the facility (fig. 1).

Because the Old Breastworks Formation consists primarily of fine sediments, it is included with the underlying Porters Creek Clay and Clayton Formation of Tertiary age and the Owl Creek Formation of Cretaceous age in the confining unit that separates the Fort Pillow aquifer from the deeper McNairy aquifer (Parks and Carmichael, 1989). The Porters Creek Clay, Clayton Formation, and Owl Creek Formation form a thick, widespread clay of low permeability. Based on the geophysical logs of test holes Sh:U-12 and Sh:T-18, the total aggregate thickness of the confining unit ranges from 690 to 765 feet in these test holes. From these data, the thickness of the lower confining unit for the Fort Pillow aquifer beneath NSA Memphis is estimated to be about 700 feet.

GROUND-WATER QUALITY

As a result of the investigations at some of the 67 SWMU's and the one AOC at NSA Memphis, a large amount of data has been collected by consultants to the Navy on contaminant concentrations in the shallow ground-water system (primarily the alluvial-fluvial deposits aquifer). The contaminants most often detected in ground-water samples have been volatile organic compounds (VOC's)—primarily fuel-related constituents in the loess and chlorinated solvents in the alluvial-fluvial deposits aquifer (L.A. Anderson, E/A&H, written commun., 1996). Generally, these contaminants only have been identified at a few sites, and concentrations detected were less than applicable maximum contaminant levels (MCL's). However, locally elevated concentrations of several contaminants have been detected. Contaminants detected exceeding their MCL's and the maximum concentration detected include: tetrachloroethene, 230 micrograms per liter (μg/L); trichloroethene, 1,300 μg/L; 1,2 dichloroethene, 770 μg/L; 1,1 dicholorethene, 290 μg/L; chloroform, 180 μg/L; vinyl chloride, 24 μg/L; benzene, 4,600 μg/L; carbon tetrachloride, 199 μg/L; chromium, 680 μg/L; nickel, 470 μg/L; and lead, 39 μg/L (L.A. Anderson, E/A&H, written commun., 1997).

Although a large number of samples have been collected to determine the nature and extent of ground-water contamination, samples for analysis of common water-quality characteristics at NSA Memphis were not collected as part of the SWMU investigations. Consequently, ground-water samples were collected by the USGS from 18 wells screened in five water-bearing hydrogeologic units during July 1995 (table 4). The five units sampled are the loess, fluvial deposits aquifer, Cockfield Formation, Memphis aquifer, and Fort Pillow aquifer. Sampling sites were selected and the samples were collected to provide data on the physical properties and major and trace inorganic constituent concentrations at background locations in wells screened in the loess, fluvial deposits aquifer, and Cockfield Formation, and from production wells screened in the Memphis and Fort Pillow aquifers at NSA Memphis (fig. 15). Where possible, samples from the shallow units were collected at well clusters. Tritium samples also were collected from the fluvial deposits aquifer, the Cockfield Formation, and the Memphis aquifer to demonstrate that recent recharge to the fluvial deposits aquifer is occurring and to determine whether significant leakage from this unit to the Cockfield Formation and Memphis aquifer is occurring.

Major Inorganic Constituents

Ground-water samples were collected and processed according to standard USGS methods (Wood, 1976). Specific conductance, pH, temperature, and alkalinity were measured in the field at the time of sample collection (table 5). Analyses of ground-water

Table 4. Eighteen wells sampled for analysis of major and trace inorganic constituent concentrations in ground water at Naval Support Activity Memphis, Millington, Tennessee, July 17-24, 1995

[USGS, U.S. Geological Survey; NSA, Naval Support Activity; °, degrees; ′, minutes; ″ seconds; A, aquifer; C, confining unit; GW, ground water; WL, water level; WQ, water quality; wells Sh:U-58, Sh:U-59, and Sh:U-60 include various lengths of blank pipe near the middle of screened intervals; ~, approximate measured total depth, screened interval unknown]

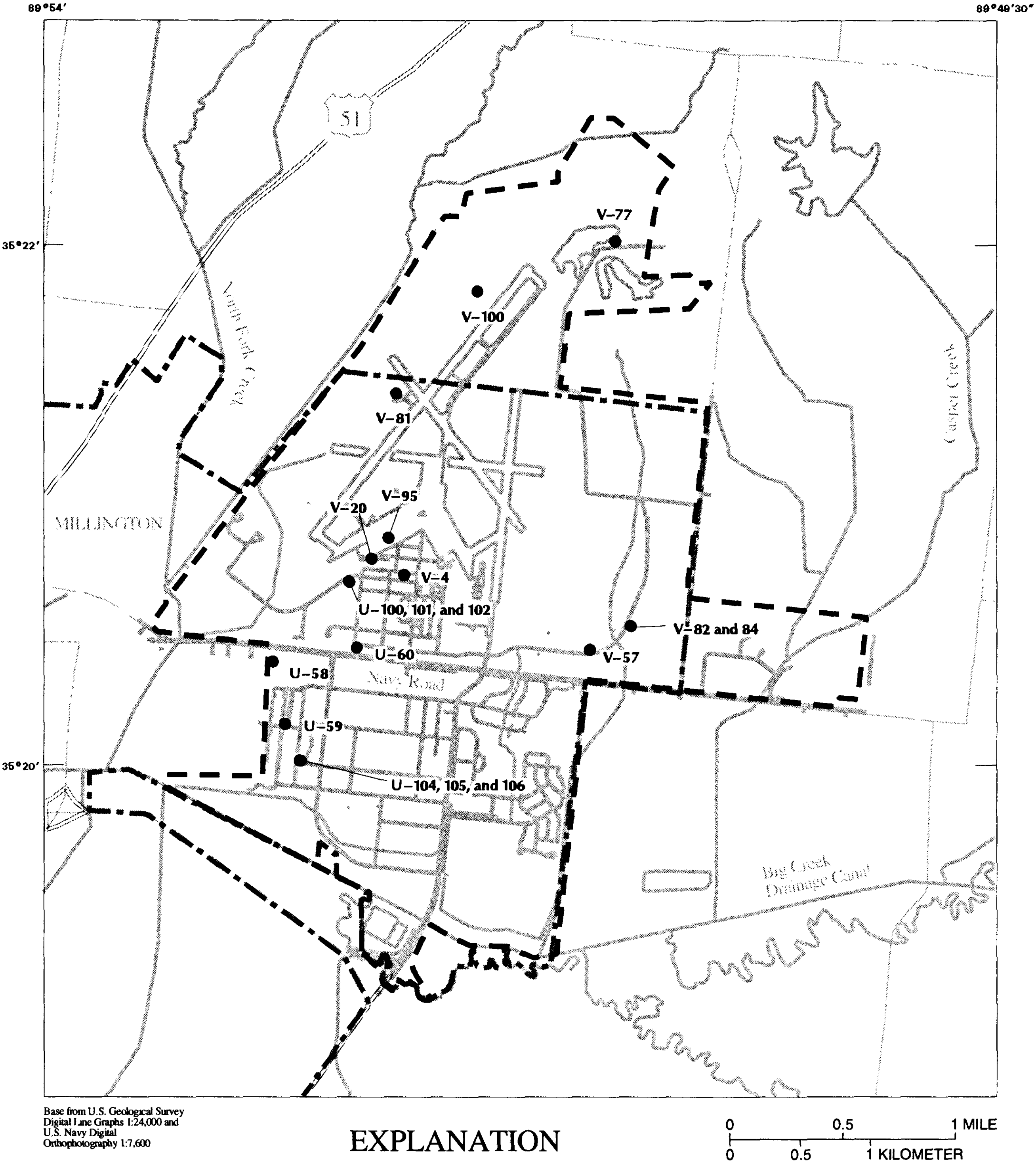
USGS local well number	Project well number or location	Latitude	Longitude	Screened interval below land surface, in feet	Stratigraphic unit in which well is screened	Type of well
Sh:U-58	NSA Memphis well 4	35°20′24″	89°52′55″	1,346-1,449	Fort Pillow (A)	GW production
Sh:U-59	NSA Memphis well 5	35°20′09″	89°52′52″	1,272-1,434	Fort Pillow (A)	GW production
Sh:U-60	NSA Memphis well 3	35°20′27″	89°52′32″	1,335-1,450	Fort Pillow (A)	GW production
Sh:U-100	USGS well WL-1L	35°20′42″	89°52′34″	8-18	Loess (C)	WL observation
Sh:U-101	USGS well WL-1F	35°20′42″	89°52′34″	59-69	Fluvial deposits (A)	WL observation
Sh:U-102	USGS well WL-1C	35°20′42″	89°52′34″	105-115	Cockfield (C-A)	WL observation
Sh:U-104	BG4L	35°20′01″	89°52′48″	10-20	Loess (C)	WQ monitoring
Sh:U-105	BG4UF	35°20′01″	89°52′48″	40-50	Fluvial deposits (A)	WQ monitoring
Sh:U-106	BG4LF	35°20′01″	89°52′48″	60-70	Fluvial deposits (A)	WQ monitoring
Sh:V-4	NSA Memphis well 2	35°20′44″	89°52′18″	412-452	Memphis (A)	GW production
Sh:V-20	NSA Memphis well 1	35°20′47″	89°52′27″	463-518	Memphis (A)	GW production
Sh:V-57	Golf course well	35°20′27″	89°51′26″	428-468	Memphis (A)	GW production
Sh:V-77	Lake house well	35°22′01″	89°51′18″	195-215	Cockfield (C-A)	WL observation
Sh:V-81	Runway well	35°21′26″	89°52′20″	~79	Fluvial deposits (A)	WL observation
Sh:V-82	BG1L	35°20′32″	89°51′14″	8-18	Loess (C)	WQ monitoring
Sh:V-84	BG1LF	35°20′32″	89°51′14″	55-65	Fluvial deposits (A)	WQ monitoring
Sh:V-95	07MW04MC	35°20′52″	89°52′23″	128-138	Cockfield (C-A)	WQ monitoring
Sh:V-100	08MW02F	35°21′49″	89°51′57″	29-34	Fluvial deposits (A)	WQ monitoring

samples collected from the five hydrogeologic units indicate that water from the loess, fluvial deposits aquifer, Cockfield Formation, and the Memphis aquifer is a calcium bicarbonate type. Samples collected from the Fort Pillow aquifer indicate ground water is a sodium bicarbonate type. Generally, dissolved solids, hardness, and concentrations of most major inorganic constituents decrease with depth (fig. 16). Samples collected from the loess indicate that the water is very hard and has dissolved-solids concentrations ranging from 320 to 506 milligrams per liter (mg/L) (table 5). Ground water collected from the Fort Pillow aquifer is soft with dissolved-solids concentrations ranging from 94 to 108 mg/L (table 5). At NSA Memphis, water from wells screened in the Fort Pillow aquifer is mixed with water from one of the wells screened in the Memphis aquifer (Sh:V-4) to reduce hardness in the finished water.

Trace Inorganic Constituents

Of the trace inorganic constituents analyzed for, only iron, manganese, barium, and strontium were present at concentrations significantly greater than the method reporting limits (table 6). Barium has an MCL of 1,000 µg/L and is the only one of these constituents that has been assigned an MCL (Tennessee Department of Environment and Conservation, 1994). The maximum concentration of barium detected at NSA Memphis was 190 µg/L (table 6) in a well screened in the fluvial deposits aquifer. Strontium concentrations generally were less than 200 µg/L for all of the units sampled (table 6). The highest concentrations of strontium in the fluvial deposits aquifer (250 µg/L) and Cockfield Formation (620 µg/L) occurred in the only wells installed by hydraulic (mud) rotary drilling methods for this study. These higher concentrations, as well as elevated concentrations of a few major inorganic constituents and physical properties, may be an artifact of remnant drilling mud in the formations around the screened intervals in these wells.

Iron and manganese concentrations varied considerably, particularly in samples collected from the fluvial deposits aquifer and the Cockfield Formation (table 6). Maximum concentrations detected for iron and manganese were in the Cockfield Formation. The



Base from U.S. Geological Survey Digital Line Graphs 1:24,000 and U.S. Navy Digital Orthophotography 1:7,600

EXPLANATION

- NAVAL SUPPORT ACTIVITY MEMPHIS BOUNDARY
- MILLINGTON CITY BOUNDARY
- ● V-57 WELL SAMPLED FOR WATER-QUALITY ANALYSIS -- Number is Sh (Shelby County) number (Sh:V-57)

Figure 15. Locations of wells sampled for water-quality analysis at Naval Support Activity Memphis.

Table 5. Water-quality properties and major inorganic constituent concentrations in water samples from 18 wells screened in the loess, fluvial deposits aquifer, Cockfield Formation, Memphis aquifer, and Fort Pillow aquifer at Naval Support Activity Memphis, Millington, Tennessee, July 17-24, 1995

[°C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; USGS, U.S. Geological Survey; NSA, Naval Support Activity]

USGS local well number	Project well number or location	Date sampled	Temperature water (°C)	Field pH (standard units)	Field specific conductance (µS/cm at 25°C)	Solids, residue at 180°C dissolved (mg/L)	Field alkalinity (mg/L as $CaCO_3$)	Hardness, total (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)
							Loess									
Sh:U-100	USGS well WL-1L	07-21-95	18.5	7.1	609	346	302	300	69	30	21	0.30	0.90	26	0.70	24
Sh:U-104	BG4L	07-19-95	22.0	7.2	765	506	448	310	65	36	60	.30	2.7	64	.80	27
Sh:V-82	BG1L	07-18-95	19.0	7.2	572	320	294	290	59	34	12	.40	3.3	19	.50	25
							Fluvial deposits aquifer									
Sh:U-101	USGS well WL-1F	07-20-95	19.0	6.9	844	474	466	410	100	40	33	1.8	5.4	21	.30	17
Sh:U-105	BG4UF	07-19-95	23.0	6.2	418	222	198	180	39	20	15	1.2	10	4.7	.10	21
Sh:U-106	BG4LF	07-19-95	21.5	6.3	331	174	162	140	30	16	12	2.0	7.3	2.7	.10	16
Sh:V-81	Runway well	07-24-95	19.5	6.6	261	158	128	120	25	13	8.2	.40	2.3	0.90	.20	35
Sh:V-84	BG1LF	07-17-95	19.5	6.8	533	260	289	260	59	28	11	.50	3.6	11	.30	21
Sh:V-100	08MW02F	07-21-95	19.0	6.4	303	178	128	89	19	10	28	.40	4.6	18	.20	21
							Cockfield Formation									
Sh:U-102	USGS well WL-1C	07-21-95	18.0	7.0	487	284	228	180	46	15	37	6.5	2.5	34	.30	19
Sh:V-77	Lake house well	07-24-95	20.5	6.3	168	112	70	61	14	6.4	8.8	.80	2.6	.90	.20	32
Sh:V-95	07MW04MC	07-19-95	22.0	6.7	308	158	164	140	32	14	8.1	.60	1.7	1.5	.30	23
							Memphis aquifer									
Sh:V-4	NSA Memphis well 2.	07-18-95	18.0	6.5	251	136	125	110	24	12	8.1	.60	1.9	5.6	.20	22
Sh:V-20	NSA Memphis well 1.	07-20-95	18.0	6.5	194	110	99	85	19	9.2	7.0	.80	1.8	2.8	.10	19
Sh:V-57	Golf course well	07-17-95	18.0	6.7	274	152	129	120	28	13	8.6	1.6	8.9	3.2	.20	16
							Fort Pillow aquifer									
Sh:U-58	NSA Memphis well 4.	07-18-95	23.5	6.9	186	108	89	6	1.3	0.60	40	1.5	.70	6.0	.10	11
Sh:U-59	NSA Memphis well 5.	07-18-95	23.5	6.8	183	94	90	7	1.6	.80	40	1.5	.70	6.1	.10	11
Sh:U-60	NSA Memphis well 3.	07-20-95	23.0	7.0	185	106	90	6	1.3	.60	41	1.5	.70	6.0	.10	12

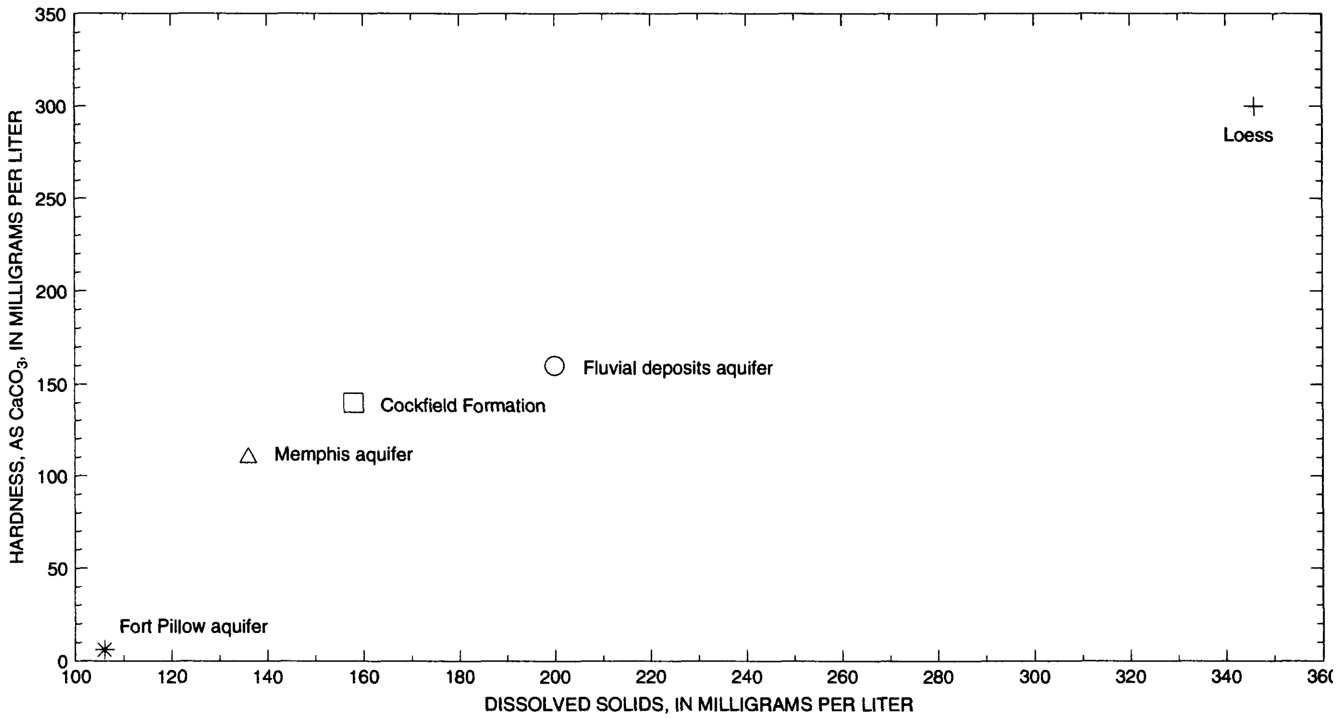


Figure 16. Median concentrations of dissolved solids and values of hardness measured in water samples from wells screened in the loess, fluvial deposits aquifer, Cockfield Formation, Memphis aquifer, and Fort Pillow aquifer.

maximum concentration for iron was 4,300 µg/L and for manganese was 1,300 µg/L. Iron and manganese concentrations in ground water are affected by the redox conditions in the aquifers. The range in concentrations in these two units may reflect varying redox conditions as well as heterogeneity in the composition of sediments that make up the aquifers. However, the two highest concentrations of manganese detected were in samples collected from the two wells installed by hydraulic (mud) rotary drilling methods.

Tritium Concentrations

Tritium is a naturally occurring unstable isotope of hydrogen that is used in hydrogeologic studies to determine the relative age of ground water. Atmospheric testing of thermonuclear weapons between 1952 and 1963 increased tritium concentrations in precipitation by several orders of magnitude above naturally occurring levels. As a result of tritium's short half-life (12.43 years) and concentrations in precipitation prior to 1952, tritium is not detectable in ground water that was recharged before 1952. A concentration of tritium greater than 1 tritium unit (TU) in ground water generally indicates a component of recent (post-1952) recharge to a ground-water system.

Ground-water samples were collected by the USGS from the fluvial deposits aquifer adjacent to the two Memphis aquifer production wells (fig. 15) using a Hydrocone tool during the DPT phase of the investigation. These two samples were collected to confirm that the fluvial deposits aquifer contains tritium, which would indicate a component of post-1952 recharge. Tritium concentrations in samples from the fluvial deposits aquifer were 12 TU or greater (table 7), indicating a significant component of post-1952 recharge to the aquifer. Samples also were collected from three observation wells screened in the Cockfield Formation and from the two production wells screened in the Memphis aquifer (table 7; fig. 15). Tritium concentrations in samples collected from the Cockfield Formation and the Memphis aquifer were less than 1 TU, indicating that significant downward leakage of post-1952 water from the fluvial deposits aquifer to and through the Cockfield and Cook Mountain confining unit and into the Memphis aquifer is not occurring in the areas of these wells.

Table 6. Trace inorganic constituent concentrations in water samples from 18 wells screened in the loess, fluvial deposits aquifer, Cockfield Formation, Memphis aquifer, and Fort Pillow aquifer at Naval Support Activity Memphis, Millington, Tennessee, July 17-24, 1995

[µg/L, micrograms per liter; values given as < (less than) indicate that the concentration was below the reporting limit of the analytical method used and do not indicate the presence or absence of a constituent; USGS, U.S. Geological Survey; NSA, Naval Support Activity]

USGS local well number	Project well number or location	Date sampled	Barium, dissolved (µg/L as Ba)	Beryllium, dissolved (µg/L as Be)	Cobalt, dissolved (µg/L as Co)	Iron, dissolved (µ/L as Fe)	Manganese, dissolved (µg/L as Mn)	Molybdenum, dissolved (µg/L as Mo)	Nickel, dissolved (µg/L as Ni)	Silver, dissolved (µg/L as Ag)	Strontium, dissolved (µg/L as Sr)	Vanadium, dissolved (µg/L as V)	Aluminum, dissolved (µg/L as Al)	Lithium, dissolved (µg/L as Li)	Selenium, dissolved (µg/L as Se)
							Loess								
Sh:U-100	USGS well WL-1L	07-21-95	67	<0.5	<3	<3	72	<10	3	<1	140	<6	<20	6	3
Sh:U-104	BG4L	07-19-95	75	.5	3	3	74	10	1	1	180	6	20	10	<1
Sh:V-82	BG1L	07-18-95	39	<.5	<3	<3	14	<10	3	<1	90	<6	20	<4	<1
							Fluvial deposits aquifer								
Sh:U-101	USGS well WL-1F	07-20-95	190	<.5	<3	12	1,100	<10	1	<1	250	<6	<20	<4	<1
Sh:U-105	BG4UF	07-19-95	110	<.5	<3	120	36	<10	<1	<1	110	<6	<20	<4	<1
Sh:U-106	BG4LF	07-19-95	120	<.5	<3	1,900	50	<10	<1	<1	120	<6	<20	4	<1
Sh:V-81	Runway well	07-24-95	28	<.5	<3	11	<1	<10	<1	<1	30	<6	<20	<4	<1
Sh:V-84	BG1LF	07-17-95	140	.5	3	4,000	690	10	1	1	110	6	20	4	<1
Sh:V-100	08MW02F	07-21-95	95	<.5	4	15	460	<10	8	<1	40	<6	<20	<4	<1
							Cockfield Formation								
Sh:U-102	USGS well WL-1C	07-21-95	170	<.5	<3	520	1,300	<10	2	<1	620	<6	<20	10	<1
Sh:V-77	Lake house well	07-24-95	80	<.5	<3	8	10	<10	2	<1	80	<6	<20	6	<1
Sh:V-95	07MW04MC	07-19-95	75	<.5	<3	4,300	260	<10	<1	<1	50	<6	<20	<4	<1
							Memphis aquifer								
Sh:V-4	NSA Memphis well 2	07-18-95	59	<.5	<3	470	10	<10	<1	<1	60	<6	<20	<4	<1
Sh:V-20	NSA Memphis well 1	07-20-95	61	<.5	<3	570	12	<10	<1	<1	50	<6	<20	<4	<1
Sh:V-57	Golf course well	07-17-95	120	<.5	<3	1,800	62	<10	7	<1	140	<6	<20	<4	<1
							Fort Pillow aquifer								
Sh:U-58	NSA Memphis well 4	07-18-95	24	<.5	<3	940	37	<10	<1	<1	60	<6	<20	10	<1
Sh:U-59	NSA Memphis well 5	07-18-95	29	<.5	<3	1,100	38	<10	<1	<1	80	<6	<20	10	<1
Sh:U-60	NSA Memphis well 3	07-20-95	26	<.5	<3	1,500	43	<10	<1	<1	60	<6	<20	10	<1

Table 7. Tritium concentrations in water samples from the fluvial deposits aquifer, the Cockfield Formation, and the Memphis aquifer at Naval Support Activity Memphis, Millington, Tennessee

[TU, tritium units; °, degrees; ′, minutes; ″, seconds; USGS, U.S. Geological Survey; NSA, Naval Support Activity; values given as < (less than) indicate that the concentration was below the reporting limit of the analytical method used and do not indicate the presence or absence of a constituent]

USGS local well number	Project well number or location	Latitude	Longitude	Screened interval or depth of sample, in feet	Date sampled	Tritium concentration (TU)
			Fluvial deposits aquifer			
None	SWMU 7	35°20′47″	89°52′27″	42-43	12-10-94	16
None	7GH23	35°20′44″	89°52′18″	42-43	12-10-94	12
			Cockfield Formation			
Sh:V-95	07MW4MC	35°20′52″	89°52′23″	128-138	07-19-95	<1
Sh:U-102	WL-1C	35°20′42″	89°52′34″	105-115	07-21-95	<1
Sh:V-77	Lake House	35°22′01″	89°51′18″	195-215	07-24-95	<1
			Memphis aquifer			
Sh:V-4	NSA PW-2	35°20′44″	89°52′18″	412-452	07-07-94	<1
Sh:V-20	NSA PW-1	35°20′47″	89°52′27″	463-518	07-07-94	<1

SUMMARY

Naval Support Activity (NSA) Memphis, formerly Naval Air Station (NAS) Memphis, is a Department of the Navy (Navy) facility located at the city of Millington in northern Shelby County, Tennessee, about 5 miles north of Memphis. As a result of operations conducted while the facility was NAS Memphis, soil, ground-water, and surface-water contamination from past waste-management practices is being investigated and addressed. Sixty-eight sites with the potential for contamination have been identified at the facility and presently are under investigation as part of the Resource Conservation and Recovery Act Corrective Action Program being conducted at NSA Memphis under the Navy's Installation Restoration Program. The U.S. Geological Survey, in cooperation with Southern Division, Naval Facilities Engineering Command, is providing technical assistance in an investigation of the hydrogeology at NSA Memphis under the Corrective Action Program.

NSA Memphis consists of a Northside and Southside that comprise 3,490 acres. The NSA Memphis Southside lies within the flood plain of Big Creek Drainage Canal, the major stream draining the study area. The NSA Memphis Northside is situated in the upland area between Casper and North Fork Creeks, which are tributaries to Big Creek Drainage Canal. NSA Memphis is bounded on the west by the city of Millington, on the north by rural and agricultural land, on the east by urban and suburban development both inside and outside the Millington city limits, and on the south by undeveloped agricultural land in the flood plain of Big Creek Drainage Canal.

For this investigation, the NSA Memphis study area consists of approximately 20 square miles that are centered on NSA Memphis and extends no further than about 1 mile beyond the base boundary in any of the four principal compass directions. Topography in the area ranges from relatively flat to gently rolling terrain in the valley of Big Creek in the south, to the steep-sloping headward valleys of streams draining the dissected uplands in the northern part of the area. Land-surface altitudes range from about 250 feet along the channel of Big Creek Drainage Canal in the southwestern part of the area to about 370 feet at a few hilltop locations in the northern part of the study area.

Post-Midway Group stratigraphic units beneath NSA Memphis include, from youngest to oldest, the alluvium and loess of Quaternary age; the fluvial deposits of Quaternary and Tertiary(?) age; and the Cockfield and Cook Mountain Formations, Memphis Sand, Flour Island Formation, Fort Pillow Sand, and Old Breastworks Formation of Tertiary age. The alluvium, loess, fluvial deposits, and Cockfield and Cook Mountain Formations are post-Midway Group stratigraphic units investigated at NSA Memphis because of their importance to assessing the potential for contamination of the shallow aquifers from surface sources. The lower part of the alluvium, the fluvial deposits, and locally the Cockfield Formation are minor aquifers; and the upper part of the alluvium, the loess, locally the Cockfield Formation, and the Cook Mountain Formation are confining units. The Memphis Sand, Flour Island Formation, Fort Pillow Sand, and Old Breastworks Formation are stratigraphic units described in this report because of their importance for present or future ground-water supplies in the NSA Memphis area. The Memphis Sand and Fort Pillow Sand are the principal water-supply aquifers in the Memphis area and western Tennessee, and the Flour Island and Old Breastworks Formations are confining units for these aquifers.

Alluvium is present beneath the alluvial plains of streams that cross the NSA Memphis area. The alluvium generally consists of silt, clay, and minor amounts of sand in the upper part, and sand and gravel in the lower part (alluvial aquifer). The thickness of the alluvium ranges from 0 to 70 feet in the area. Where sand and gravel in the lower part of the alluvium is in hydraulic connection with the fluvial deposits, the two units constitute the alluvial-fluvial deposits aquifer. Ground water in the alluvial aquifer is semiconfined to confined by the overlying finer grained deposits of the upper alluvium. Water levels in wells screened in the alluvial aquifer ranged from about 2.5 to 21 feet below land surface between April (relative high) and October (relative low) 1996. Potentiometric-surface maps show that ground water in the alluvial-fluvial deposits aquifer generally moves toward Big Creek Drainage Canal and the larger tributaries in the study area. Locally, ground water in the aquifer may move beneath these streams without discharging to them where bed altitudes are higher than the potentiometric surface. Samples of silt and clay collected from the upper alluvium at NSA Memphis had laboratory-determined total porosities ranging from 38 to about 48 percent and vertical hydraulic conductivities of 1.5×10^{-3} to 2.4×10^{-2} ft/d. Samples of sand and gravel collected from the lower alluvium had total porosities ranging from 22 to 34 percent and vertical hydraulic conductivities from 5.1×10^{-1} to 2.4 ft/d.

Loess, the surficial unit in upland parts of the NSA Memphis area, consists predominantly of silt, clayey silt, and silty clay, but locally may contain some fine sand. The loess ranges from 15 to 45 feet in thickness in the area. Subsurface data collected at NSA Memphis indicate at least two layers of loess based on relative differences in formation density, color, and texture. A transitional zone is present between silt in the lower part of the loess and sand and gravel in the underlying fluvial deposits. Because of its relatively low permeability, the loess generally retards downward movement of recharge water to the underlying fluvial deposits. However, a perched water table is present in the loess at about 10 to 15 feet below land surface throughout much of the area. Water levels in an observation well screened in this zone ranged from about 3.5 to 11 feet below land surface between December 1995 and June 1996. Information collected using Direct Push Technology indicates that the loess is dry or less than saturated below the perched zone to a depth within a few feet of the top of the fluvial deposits. From an aquifer test conducted at NSA Memphis, a vertical hydraulic conductivity of 3.5×10^{-2} ft/d and a specific storage of 5.8×10^{-5} per foot were estimated for the loess. Samples of silt and clay collected from the loess at NSA Memphis had laboratory-determined total porosities ranging from 35 to about 45 percent and vertical hydraulic conductivities from 8.5×10^{-5} to 3.7×10^{-2} ft/d.

The fluvial deposits underlie the loess in upland parts of the NSA Memphis area and consist of poorly sorted fine to coarse sand and gravel with minor amounts of clay. Gravel and local ferruginous sandstone or conglomerate layers may be present throughout the unit, but are more common in the lower part. The fluvial deposits range from 5 to about 70 feet in thickness in the area. Two levels of fluvial deposits have been identified at NSA Memphis, a lower level and upper level unit with basal altitudes of about 220 and about 300 feet above sea level, respectively. The fluvial deposits constitute the fluvial deposits aquifer and ground water in this aquifer commonly is under artesian pressure. Water levels in wells screened in the aquifer ranged from about 8.5 to 56 feet below land surface between April and October 1996. From results of the aquifer test conducted at NSA Memphis, a horizontal hydraulic conductivity of 5.3 ft/d and a specific storage of 1.2 x 10^{-6} per foot were estimated for the fluvial deposits aquifer. Samples of sand and gravel collected from the fluvial deposits at NSA Memphis had laboratory-determined total porosities ranging from 26 to about 39 percent and vertical hydraulic conductivities from 1.1 x 10^{-3} to 7.4 x 10^{-1} ft/d.

The Cockfield Formation, the uppermost unit in the Claiborne Group in the NSA Memphis area, consists of sand, silt, clay, and lignite. Individual beds in the Cockfield Formation are lenticular and locally can be discontinuous over short distances. Thickness of the Cockfield Formation is variable as a result of erosional surfaces at both the top and base. The thickness generally ranges from about 25 to 185 feet in the area, but locally the Cockfield Formation may be absent. Correlations of geophysical logs from test holes drilled for this study and from test holes for production wells at NSA Memphis indicate the presence of faults that displace the base of the Cockfield Formation by as much as 70 feet. Offsets are not apparent at the base of the fluvial deposits or lower part of the alluvium, indicating movement along the faults ceased before deposition of these units. Sand lenses in the Cockfield Formation make up the Cockfield aquifer. Where these sand lenses underlie the fluvial deposits, the two units probably are hydraulically connected. However, clay lenses in the upper part of the Cockfield Formation in parts of the NSA Memphis area retard the downward movement of ground water and serve as the lower confining unit for the alluvial-fluvial deposits aquifer. Water levels in an observation well screened in the Cockfield Formation ranged from about 17 to 21 feet below land surface between December 1995 and June 1996. From results of the aquifer test, a specific storage of 1.2 x 10^{-6} per foot was estimated for the Cockfield Formation. Samples of clay and silt collected from the Cockfield Formation at NSA Memphis had laboratory-determined total porosities ranging from about 41 to about 55 percent and vertical hydraulic conductivities from 4.5 x 10^{-5} to 2.5 x 10^{-3} ft/d.

The Cook Mountain Formation of the Claiborne Group consists predominantly of clay and silt; minor lenses of silty fine sand or lignite may be present locally. The Cook Mountain Formation ranges from about 10 to 60 feet in thickness in the NSA Memphis area. The Cook Mountain Formation, along with clay, silt, and fine sand in the overlying Cockfield Formation, serves as the upper confining unit for the Memphis aquifer in the Memphis area, including much of the NSA Memphis area. However, geologic and potentiometric data suggest that hydraulic connection between the fluvial deposits and Memphis aquifers may exist along an interpreted fault beneath the northern part of NSA Memphis. Samples of clay collected from the Cook Mountain Formation at NSA Memphis had laboratory-determined total porosities ranging from about 30 to 42 percent and vertical hydraulic conductivities from 5.0 x 10^{-6} to 9.9 x 10^{-4} ft/d.

The Memphis Sand of the Claiborne Group consists of fine to medium or medium to coarse sand with lenses of clay, silt, and lignite at various stratigraphic horizons. The Memphis Sand ranges from about 865 to 880 feet in thickness in the NSA Memphis area. The Memphis Sand constitutes the Memphis aquifer, which is the principal water-supply aquifer in the Memphis area and western Tennessee. In 1993, about 0.8 million gallons per day was withdrawn from the Memphis aquifer at NSA Memphis. Potentiometric data for the alluvial-fluvial deposits and Memphis aquifers at NSA Memphis indicate a vertical head difference of about 40 feet and a downward hydraulic gradient between the two units through the Cockfield and Cook Mountain confining unit. Water-quality data and the apparent lack of observed effects on water levels in observation well Sh:U-101 screened in the fluvial deposits aquifer from intermittent withdrawals from the Memphis aquifer at the facility indicate that the two zones are isolated hydraulically beneath the central part of NSA Memphis. From the results of an aquifer test, a horizontal hydraulic conductivity of about 68 ft/d, a transmissivity of about 11,400 ft^2/d, and a storativity of about 1 x 10^{-4} have been estimated for the lower part of the Memphis aquifer at NSA Memphis.

The Flour Island Formation consists of clay, silt, sand, and lignite, and ranges from about 225 to 290 feet in thickness in the NSA Memphis area. The Flour Island Formation serves as a confining unit separating the Memphis aquifer from the Fort Pillow aquifer. Water-level measurements made in production wells Sh:V-20 and Sh:U-60 at NSA Memphis in 1995 indicate a vertical head difference of 32 feet and a downward hydraulic gradient between the Memphis and Fort Pillow aquifers through the Flour Island confining unit.

The Fort Pillow Sand consists primarily of sand with some thin lenses of clay. The sand is very fine to fine or fine to medium grained. The Fort Pillow Sand ranges from about 125 to 180 feet in thickness in the

NSA Memphis area. The Fort Pillow Sand constitutes the Fort Pillow aquifer. In 1993, about 1.2 million gallons per day was withdrawn from the Fort Pillow aquifer at NSA Memphis. From results of an aquifer test, a horizontal hydraulic conductivity of about 13 ft/d, a transmissivity of about 2,300 ft^2/d, and a storativity of 1×10^{-4} have been estimated for the Fort Pillow aquifer at NSA Memphis.

The Old Breastworks Formation consists primarily of clay, silt, fine sand, and lignite. The unit has an estimated thickness range of about 245 to 310 feet in the northern part of Shelby County, including the NSA Memphis area. It is included with the underlying Porters Creek Clay and Clayton Formation of Tertiary age and the Owl Creek Formation of Cretaceous age as the confining unit that separates the Fort Pillow aquifer from the deeper McNairy aquifer. This confining unit is estimated to be about 700 feet thick beneath NSA Memphis.

As a result of the investigations at potential contamination sites at NSA Memphis, a large amount of data has been collected on contaminant concentrations in the shallow ground-water system. Contaminants most often detected in ground-water samples have been volatile organic compounds—primarily fuel-related constituents in the loess and chlorinated solvents in the alluvial-fluvial deposits aquifer. Generally, concentrations detected were less than applicable maximum contaminant levels. However, locally elevated concentrations of several contaminants have been detected. Contaminants detected exceeding their respective maximum contaminant levels and the maximum concentration detected include: tetrachloroethene, 230 micrograms per liter (μg/L); trichloroethene, 1,300 μg/L; 1,2 dichloroethene, 770 μg/L; 1,1 dicholorethene, 290 μg/L; vinyl chloride, 24 μg/L; benzene, 4,600 μg/L; carbon tetrachloride, 199 μg/L; chromium, 680 μg/L; nickel, 470 μg/L; and lead, 39 μg/L.

Ground-water samples were collected from 18 monitoring and production wells and analyzed for physical properties and major and trace inorganic constituents. Results of the analyses indicate that water from the loess, fluvial deposits aquifer, Cockfield Formation, and the Memphis aquifer is a calcium bicarbonate type. Ground water from the Fort Pillow aquifer is a sodium bicarbonate type. Samples collected from the loess indicate that the water is very hard and has dissolved-solids concentrations ranging from 320 to 506 milligrams per liter. Generally, dissolved solids, hardness, and concentrations of most major inorganic constituents decrease with depth. Water in the Fort Pillow aquifer is soft and has dissolved-solids concentrations ranging from 94 to 108 mg/L. Concentrations of most trace inorganic constituents were less than method reporting limits, and those constituents exceeding these limits were less than applicable maximum contaminant levels.

Tritium concentrations for two ground-water samples collected from the fluvial deposits aquifer near two Memphis aquifer production wells at NSA Memphis were 12 and 16 tritium units, indicating a significant component of post-1952 recharge to the aquifer. Tritium concentrations for samples collected from three wells screened in the Cockfield Formation and the two Memphis aquifer production wells were less than 1 tritium unit, indicating that significant leakage of post-1952 water from the fluvial deposits aquifer to the Cockfield Formation and Memphis aquifer is not occurring in the area of these wells.

REFERENCES CITED

Brahana, J.V., Parks, W.S., and Gaydos, M.W., 1987, Quality of water from freshwater aquifers and principal well fields in the Memphis area, Tennessee: U.S. Geological Survey Water-Resources Investigations Report 87-4052, 22 p.

Buntley, G.J., Daniels, R.B., Gamble, E.E., and Brown, W.T., 1977, Fragipan horizons in soils of the Memphis-Loring-Grenada sequence in west Tennessee: Soil Science Society of America Journal, v. 41, p. 400-407.

Cushing, E.M., Boswell, E.H., and Hosman, R.L., 1964, General geology of the Mississippi embayment: U.S. Geological Survey Professional Paper 448-B, 28 p.

Frederiksen, N.O., Bybell, L.M., Christopher, R.A., Crone, A.J., Edwards, L.E., Gibson, T.G., Hazel, J.E., Repetski, J.E., Russ, D.P., Smith, C.C., and Ward, L.W., 1982, Biostratigraphy and paleoecology of lower Paleozoic, Upper Cretaceous, and lower Tertiary rocks, *in* U.S. Geological Survey New Madrid test wells, southeastern Missouri: Tulane Studies in Geology and Paleontology, v. 17, no. 2, p. 23-45.

Graham, D.D., 1979, Potentiometric map of the Memphis Sand in the Memphis area, Tennessee, August 1978: U.S. Geological Survey Water-Resources Investigations Report 79-80, scale 1:125,000, 1 sheet.

Graham, D.D., and Parks, W.S., 1986, Potential for leakage among principal aquifers in the Memphis area, Tennessee: U.S. Geological Survey Water-Resources Investigations Report 85-4295, 46 p.

Kennedy, William, 1892, A section from Terrell, Kaufman County, to Sabine Pass on the Gulf of Mexico: Texas Geological Survey, 3rd Annual Report, p. 43-125.

Kingsbury, J.A., 1992, Altitude of the potentiometric surface, September 1990, and historic water-level changes in the Memphis aquifer in the Memphis area, Tennessee: U.S. Geological Survey Water-Resources Investigations Report 92-4002, 1 sheet.

———1996, Altitude of the potentiometric surfaces, September 1995, and historical water-level changes in the Memphis and Fort Pillow aquifers in the Memphis area, Tennessee: U.S. Geological Survey Water-Resources Investigations Report 96-4278, 1 sheet.

Kingsbury, J.A., and Carmichael, J.K., 1995, Hydrogeology of post-Wilcox Group stratigraphic units in the area of the Naval Air Station Memphis, near Millington, Tennessee: U.S. Geological Survey Water-Resources Investigations Report 95-4011, 1 sheet.

Kingsbury, J.A., and Parks, W.S., 1993, Hydrogeology of the principal aquifers and relation of faults to interaquifer leakage in the Memphis area, Tennessee: U.S. Geological Survey Water-Resources Investigations Report 93-4075, 18 p.

McMaster, B.W., and Parks, W.S., 1988, Concentrations of selected trace inorganic constituents and synthetic organic compounds in the water-table aquifers in the Memphis area, Tennessee: U.S. Geological Survey Open-File Report 88-485, 23 p.

Mirecki, J.E., and Miller, B.B., 1994, Aminostratigraphic correlation and geochronology of two Quaternary loess localities, central Mississippi Valley: Quaternary Research, no. 41, p. 289-297.

Moore, G.K., and Brown, D.L., 1969, Stratigraphy of the Fort Pillow test well, Lauderdale County, Tennessee: Tennessee Division of Geology Report of Investigations 26, 1 sheet.

Parks, W.S., 1990, Hydrogeology and preliminary assessment of the potential for contamination of the Memphis aquifer in the Memphis area, Tennessee: U.S. Geological Survey Water-Resources Investigations Report 90-4092, 39 p.

———1993, Use of geophysical well logs to determine loess thicknesses and correlate loesses and geosols in the Memphis, Tennessee - northern Mississippi area: Mississippi Geology, v. 14, no. 3, p. 41-46.

Parks, W.S., and Carmichael, J.K., 1989, Geology and ground-water resources of the Fort Pillow Sand in western Tennessee: U.S. Geological Survey Water-Resources Investigations Report 89-4120, 20 p.

———1990a, Geology and ground-water resources of the Memphis Sand in western Tennessee: U.S. Geological Survey Water-Resources Investigations Report 88-4182, 30 p.

———1990b, Geology and ground-water resources of the Cockfield Formation in western Tennessee: U.S. Geological Survey Water-Resources Investigations Report 88-4181, 17 p.

———1990c, Altitude of potentiometric surface, fall 1985, and historic water-level changes in the Fort Pillow aquifer in western Tennessee: U.S. Geological Survey Water-Resources Investigations Report 89-4048, 8 p.

———1990d, Altitude of potentiometric surface, fall 1985, and historic water-level changes in the Memphis aquifer in western Tennessee: U.S. Geological Survey Water-Resources Investigations Report 88-4180, 8 p.

Rodbell, D.T., 1996, Subdivision, subsurface stratigraphy, and estimated age of fluvial-terrace deposits in northwestern Tennessee: U.S. Geological Survey Bulletin 2128, 24 p.

Royall, P.D., Delcourt, P.A., and Delcourt, H.R., 1991, Late Quaternary paleoecology and paleoenvironments of the central Mississippi Alluvial Valley: Geological Society of America Bulletin, v. 103, no. 2, p. 157-170.

Tennessee Department of Environment and Conservation, 1994, Regulations for public water systems and drinking water quality: Division of Water Supply, chapter 1200-5-1, 207 p.

Vaughn, T.W., 1895, The stratigraphy of northwestern Louisiana: American Geologist, v. 15, p. 205-229.

Wood, W.W., 1976, Guidelines for collection and field analysis of ground-water samples for selected unstable constituents: Techniques of Water-Resources Investigations of the United States Geological Survey, Book 1, Chap. D2, 24 p.

— PAGE 45 FOLLOWS —

APPENDIX 1

Lithologic logs and selected geophysical logs for nine stratigraphic test holes drilled and well-construction diagrams for four water-level observation wells installed at Naval Support Activity Memphis, Millington, Tennessee

APPENDIX 1

Lithologic logs and selected geophysical logs for nine stratiraphic test holes drilled and well-construction diagrams for four water-level observation wells installed at Naval Support Activity Memphis, Millington, Tennessee

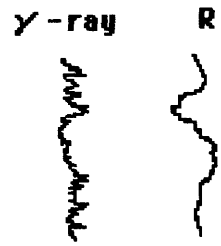
EXPLANATION

USGS local well number for Tennessee
(Project well number)
SH:V-74 (STRATIGRAPHIC TEST HOLE 1)

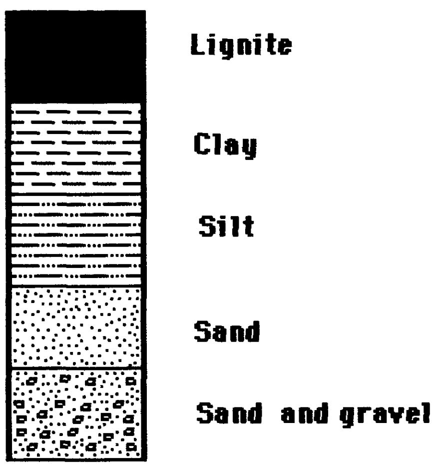
GEOPHYSICAL LOGS

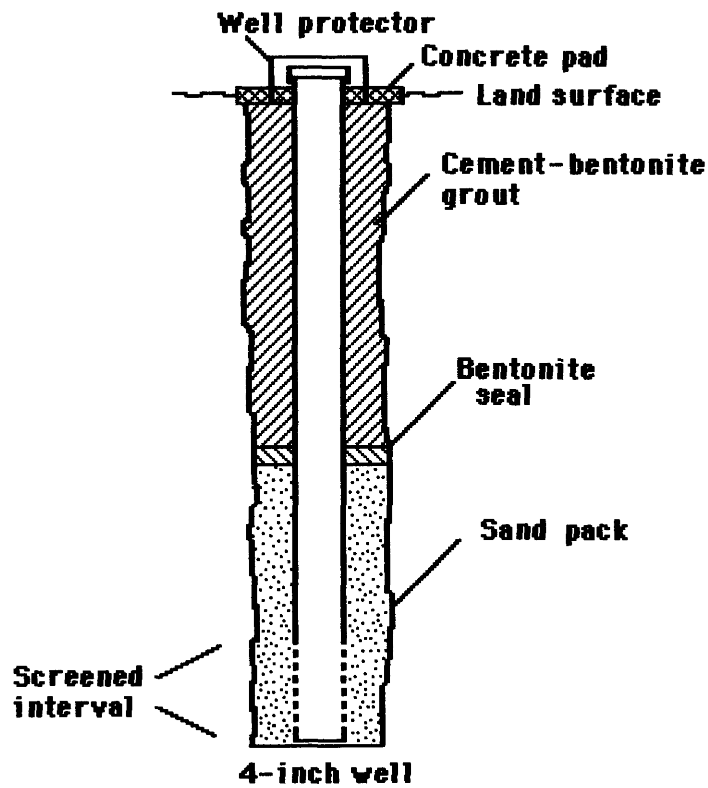
γ-ray NATURAL GAMMA-RAY LOG, RADIOACTIVITY INCREASES ⟶

R SHORT-NORMAL RESISTIVITY TRACE OF ELECTRIC LOG



LITHOLOGIC SYMBOLS



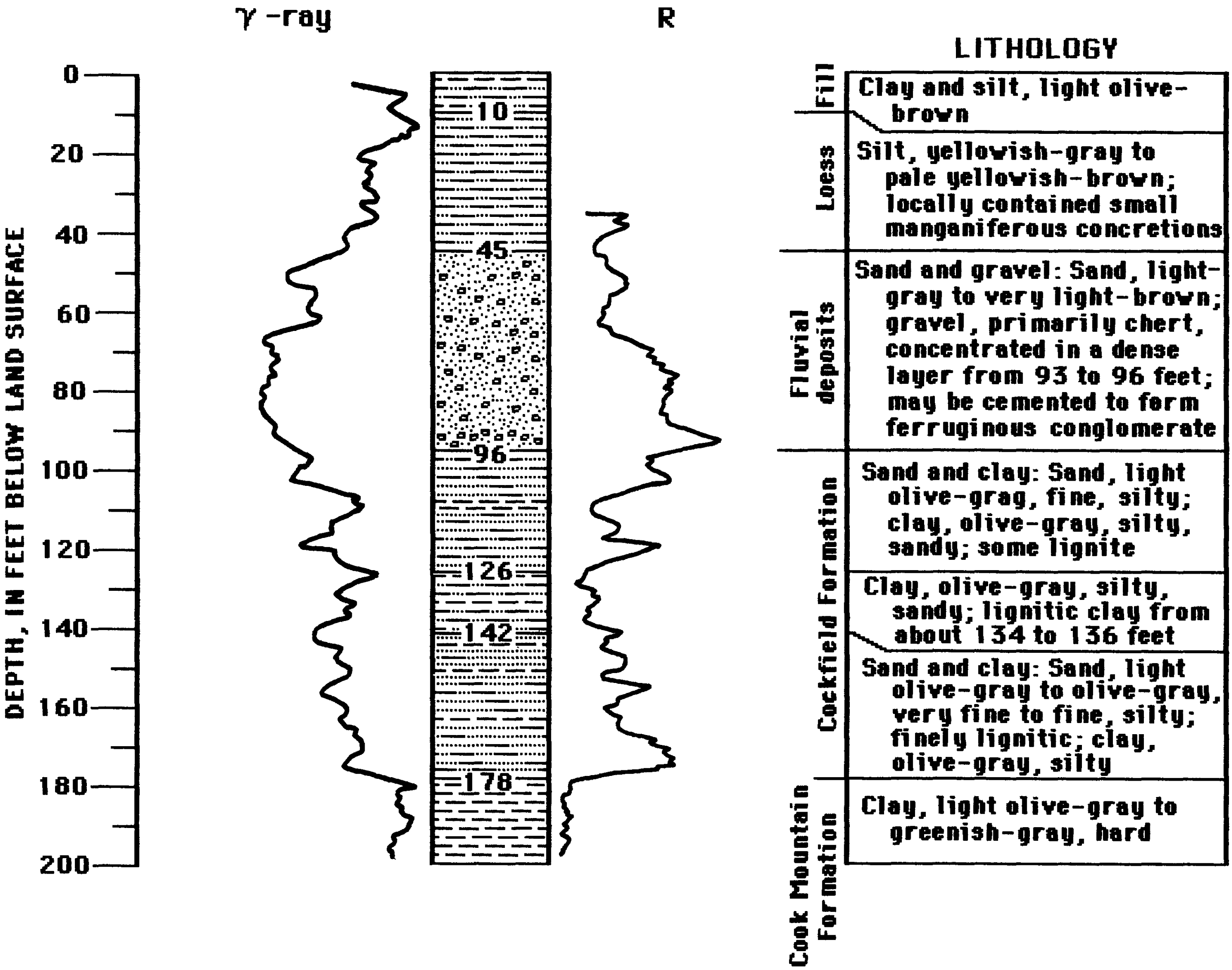


Lithology is from drillers' logs, geophysical logs, and geologists' descriptions of 10-foot-interval samples. Colors are after the "Rock Color Chart" of the Geological Society of America. Sand sizes are from a visual comparison card based on the Wentworth grade scale of particle size.

The observation wells were installed by hydraulic rotary methods. Well casings and screens are polyvinyl chloride (PVC). The wells were developed with a submersible pump until the water was clear of drilling mud.

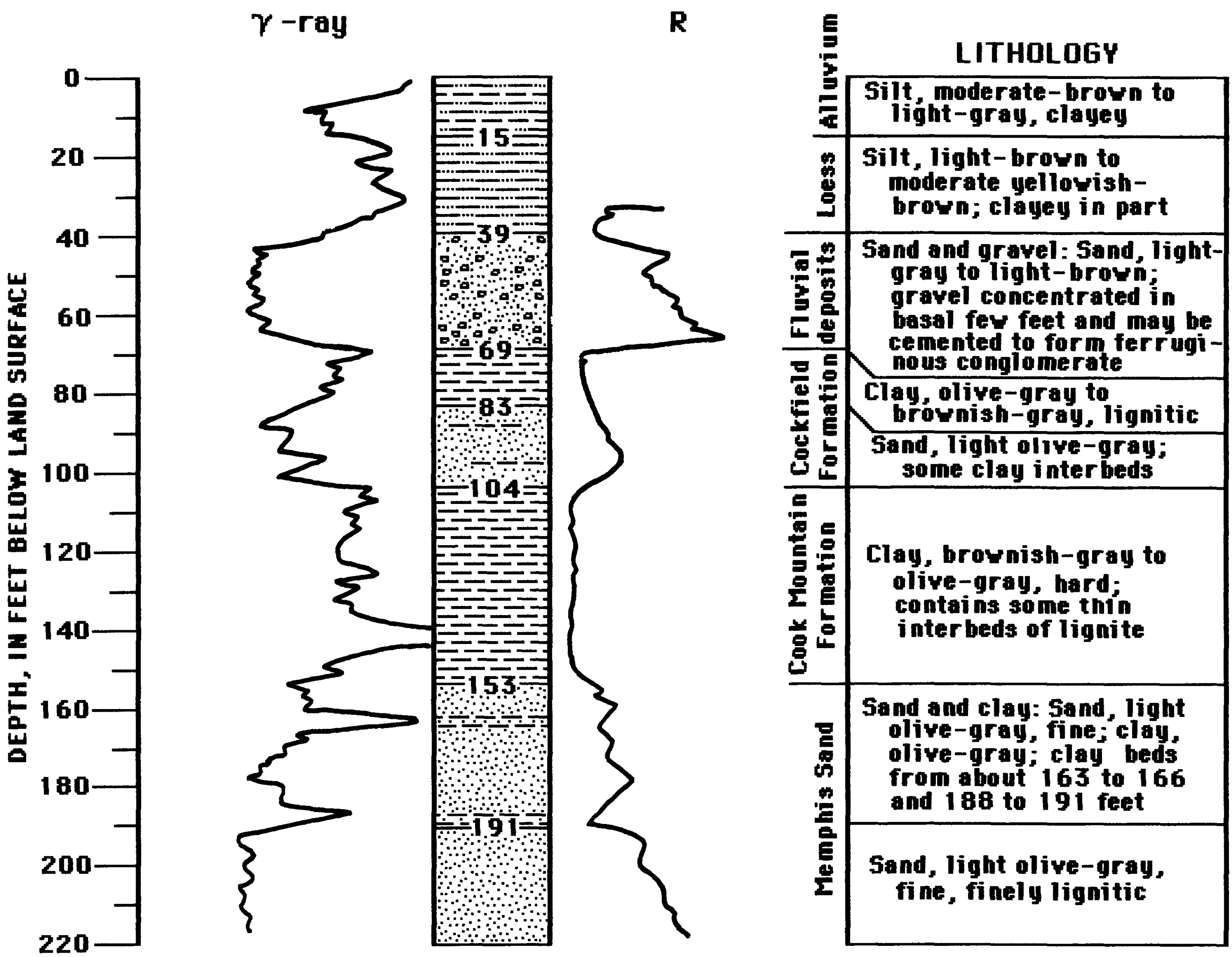
SH:U-98 (STRATIGRAPHIC TEST HOLE 2)

Latitude: 35°21'14" Longitude: 89°52'33"
Altitude of land surface: 284 feet
Date completed: April 16, 1994
Total depth: 199 feet below land surface



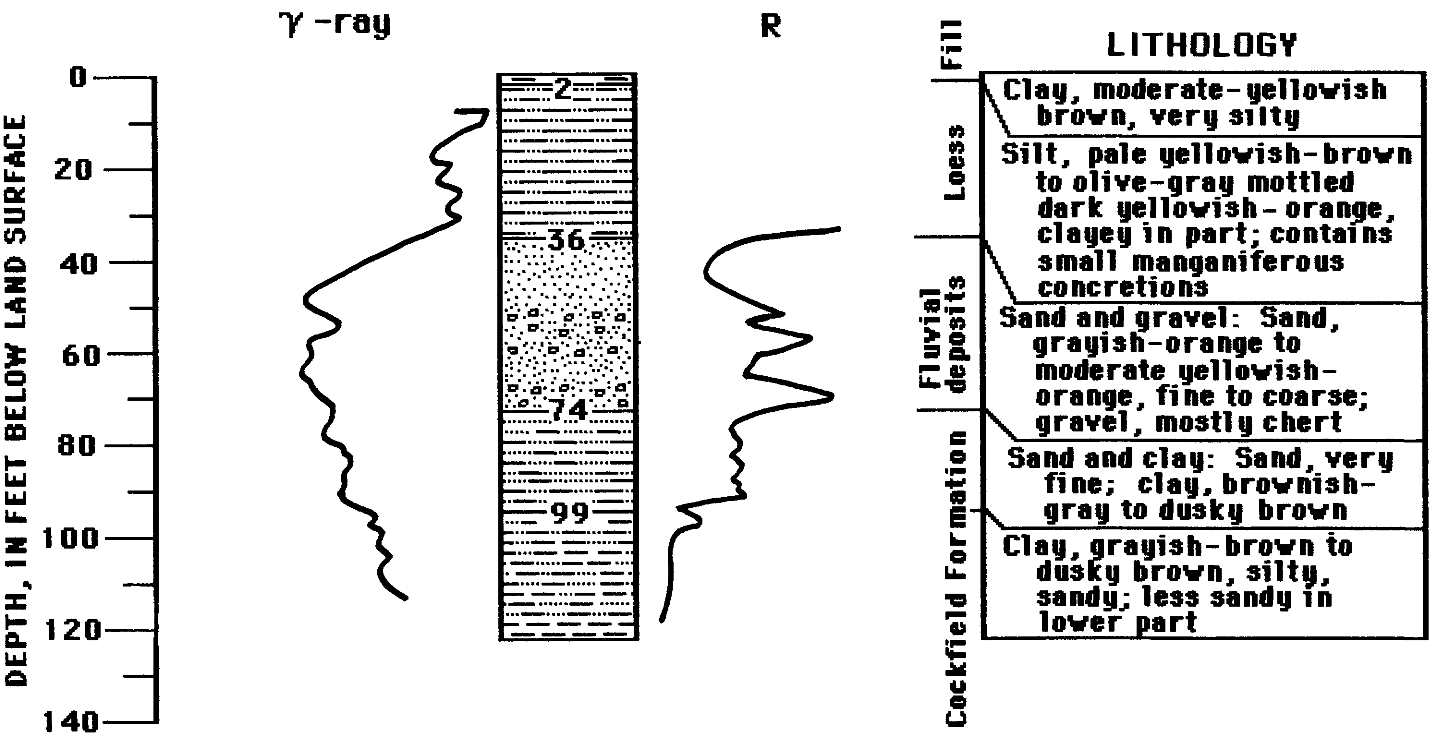
SH:U-99 (STRATIGRAPHIC TEST HOLE 4)

Latitude: 35°20'44" Longitude: 89°52' 48"
Altitude of land surface: 268 feet
Date completed: April 25, 1994
Total depth: 220 feet below land surface



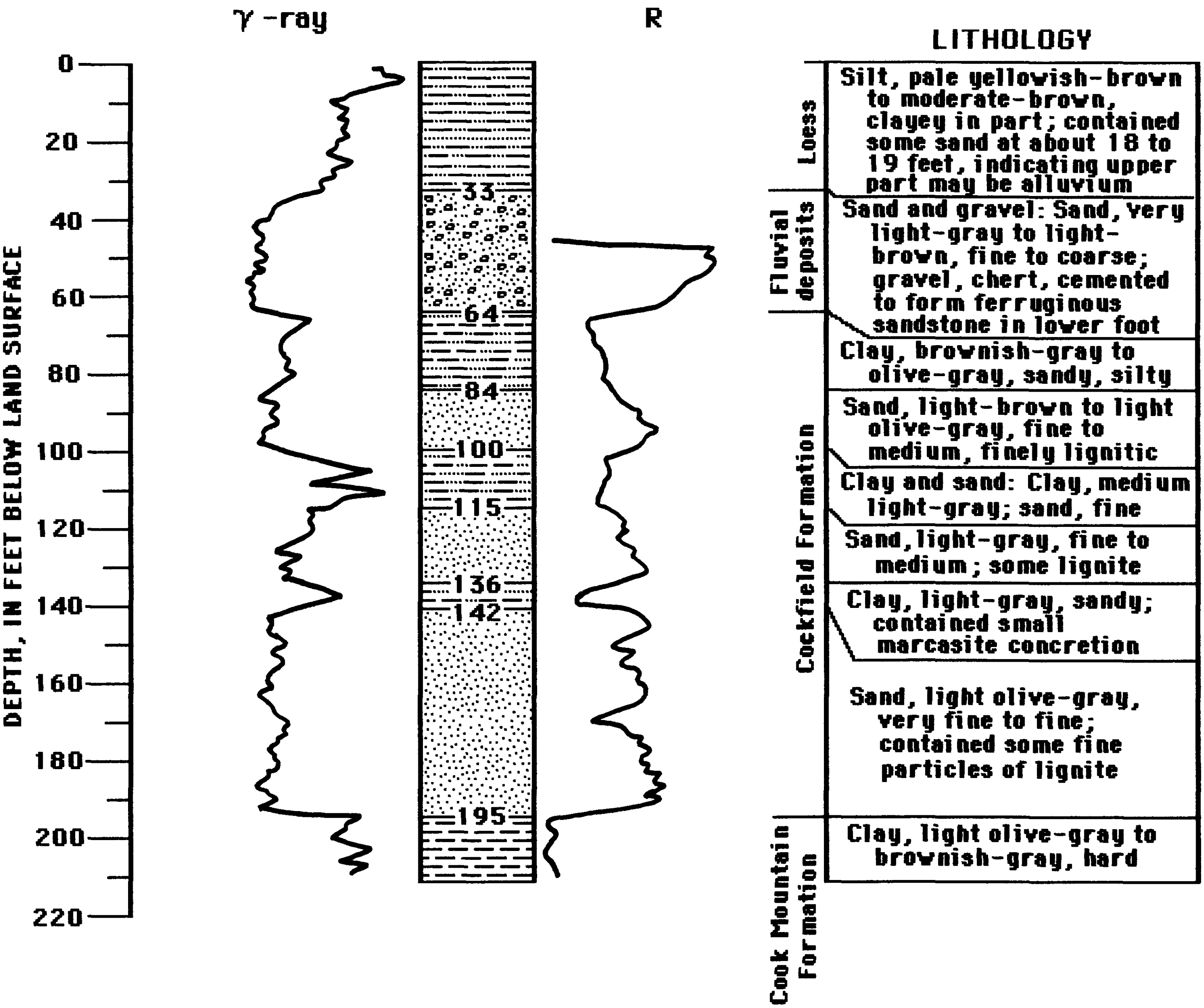
SH:U-102 (STRATIGRAPHIC TEST HOLE 9 FOR WATER-LEVEL OBSERVATION WELL WL-1C)

Latitude: 35° 20' 42" Longitude: 89° 52' 34"
Altitude of land surface: 275 feet
Date completed: April 13, 1995
Total depth: 120 feet below land surface



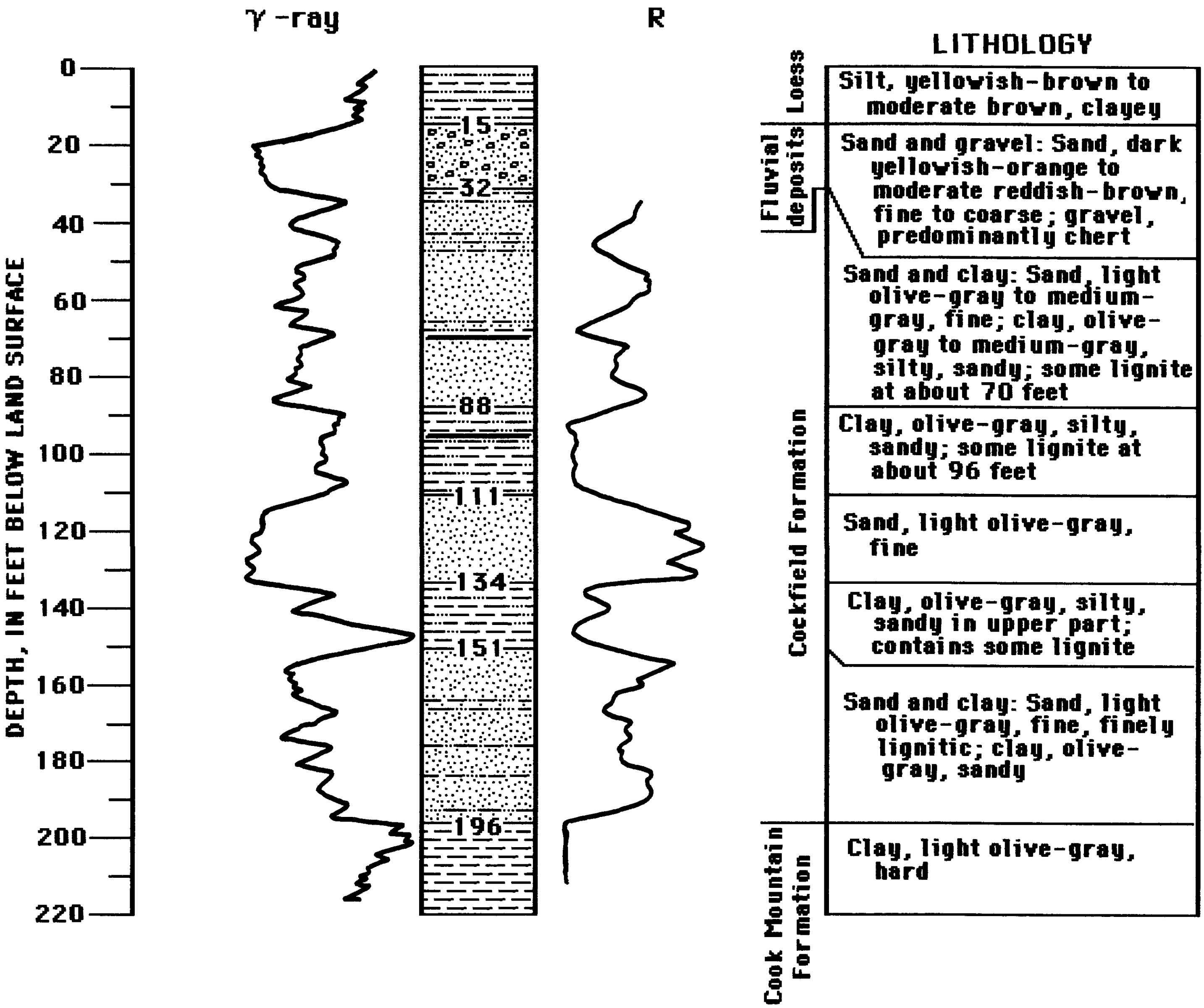
SH:V-74 (STRATIGRAPHIC TEST HOLE 1)

Latitude: 35° 20' 32" Longitude: 89° 51' 14"
Altitude of land surface: 285 feet
Date completed: April 12, 1994
Total depth: 212 feet below land surface



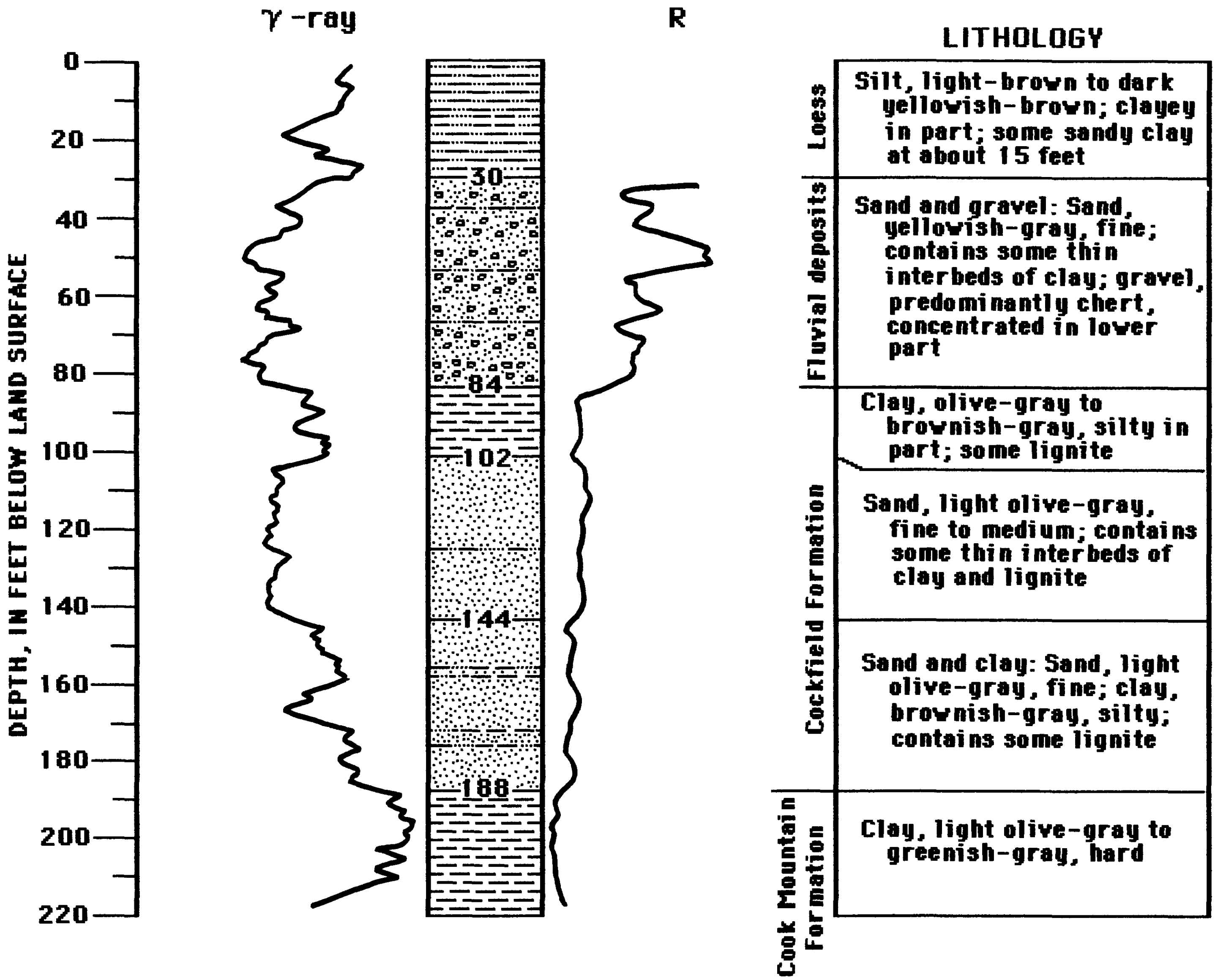
SH:V-75 (STRATIGRAPHIC TEST HOLE 3)

Latitude: 35°21'48" Longitude: 89°51'55"
Altitude of land surface: 326 feet
Date completed: April 20, 1994
Total depth: 218 feet below land surface



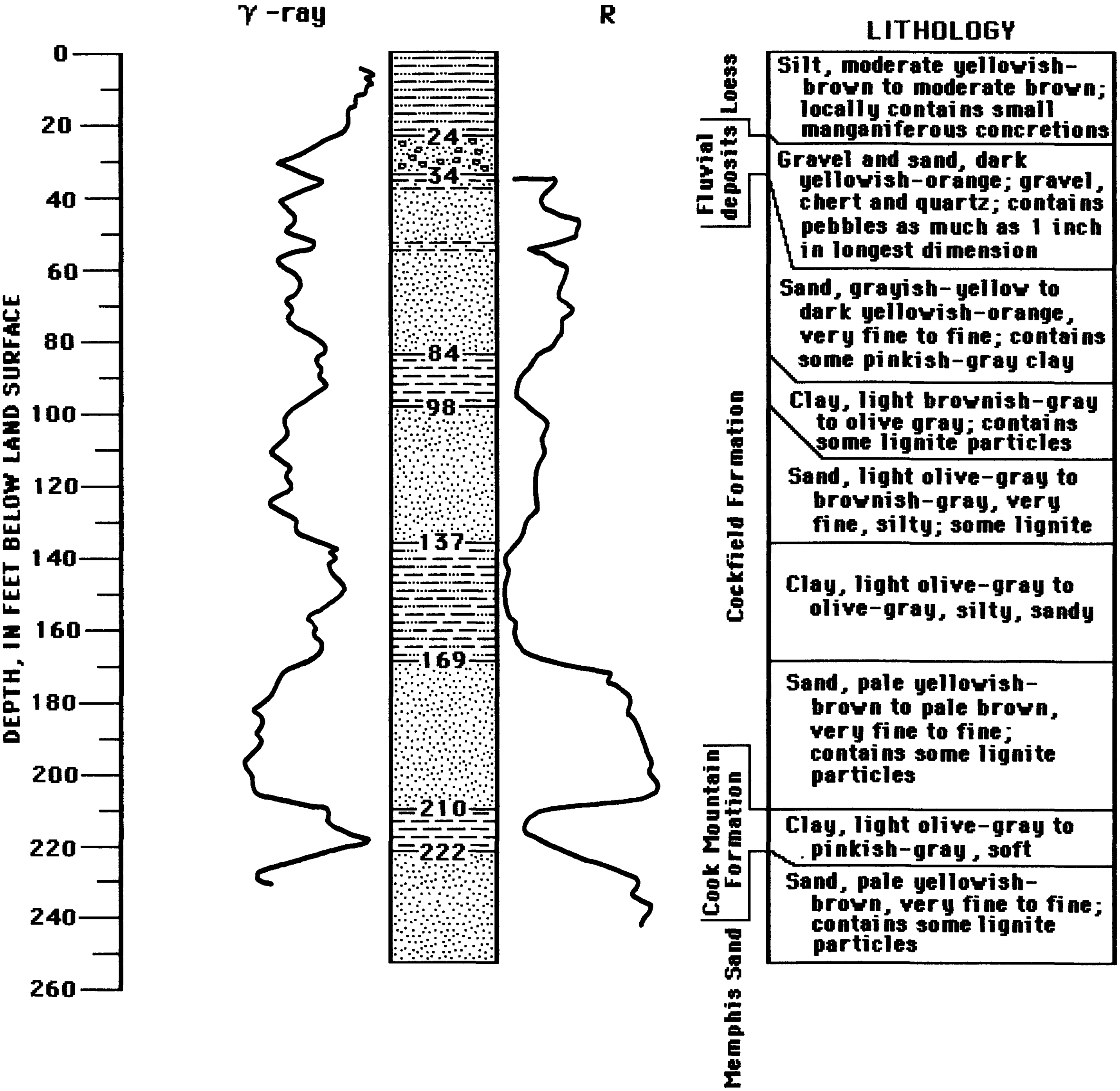
SH:V-76 (STRATIGRAPHIC TEST HOLE 5)

Latitude: 35° 20' 48" Longitude: 89° 52' 13"
Altitude of land surface: 290 feet
Date completed: April 28, 1994
Total depth: 220 feet below land surface



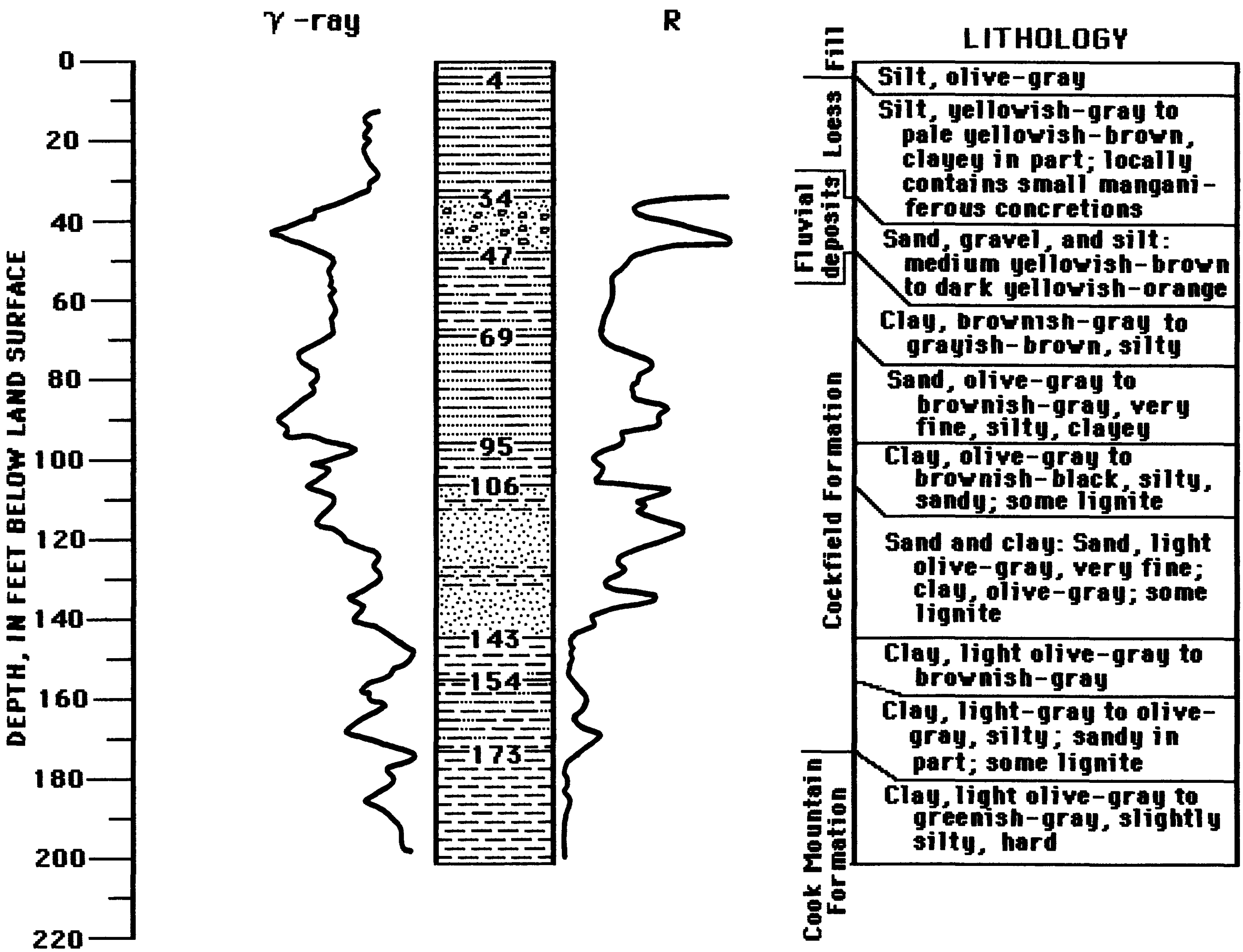
SH:V-78 (STRATIGRAPHIC TEST HOLE 6)

Latitude: 35° 21' 15" Longitude: 89° 51' 29"
Altitude of land surface: 331 feet
Date completed: April 5, 1995
Total depth: 252 feet below land surface



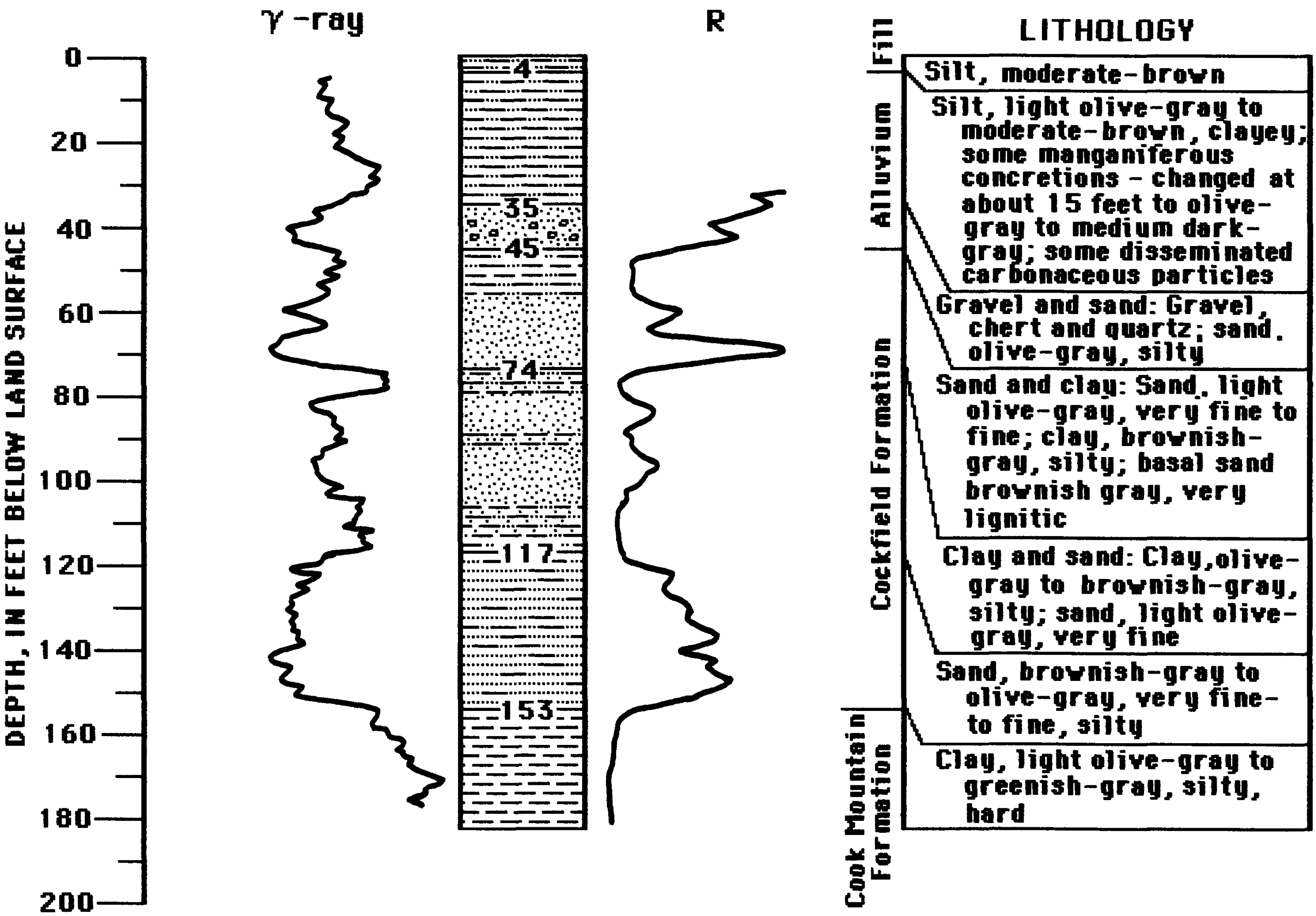
SH:V-79 (STRATIGRAPHIC TEST HOLE 7)

Latitude: 35°19'53" Longitude: 89°52'05"
Altitude of land surface: 266 feet
Date completed: April 8, 1995
Total depth: 200 feet below land surface

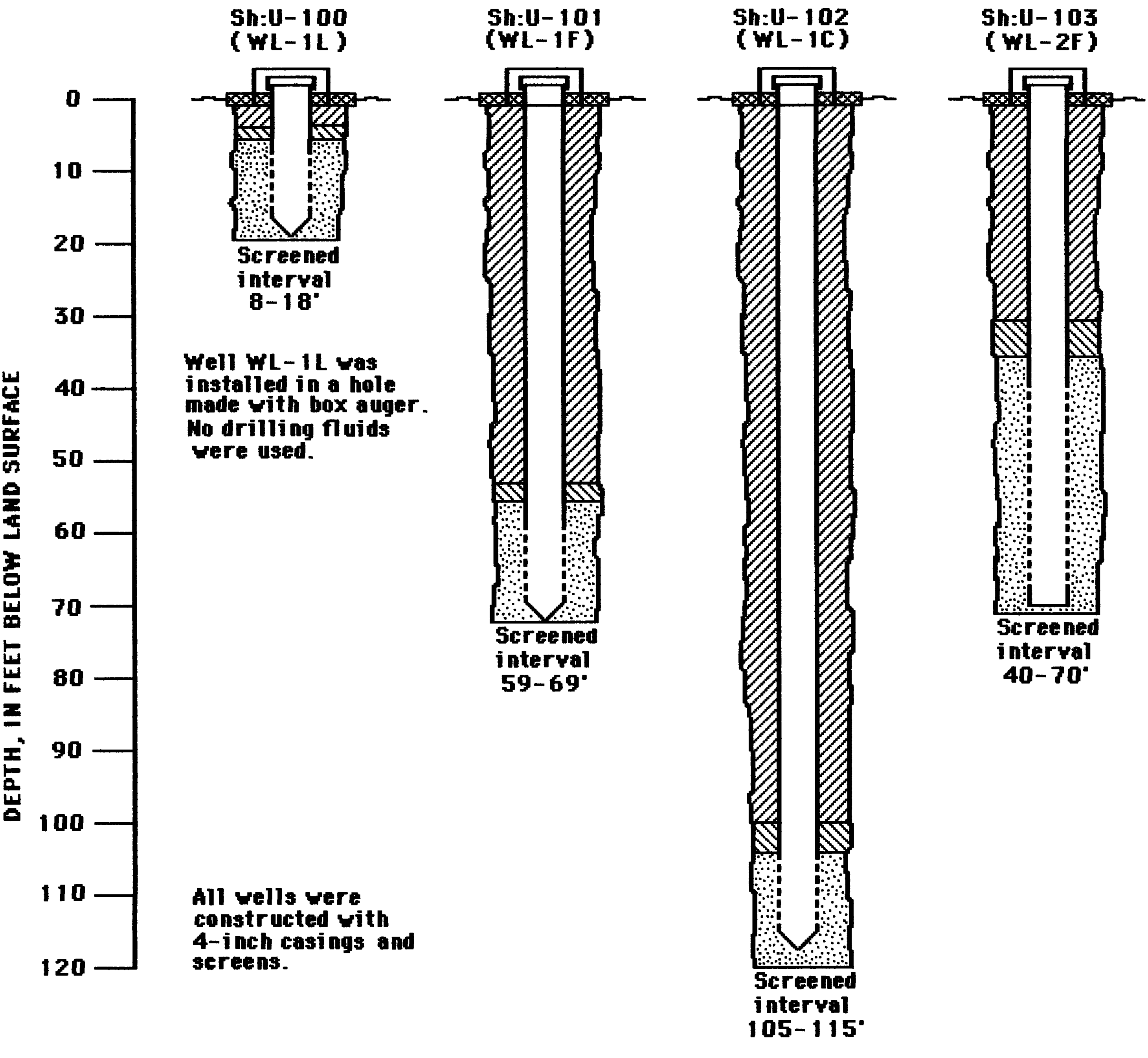


SH:V-80 (STRATIGRAPHIC TEST HOLE 8)

Latitude: 35° 19' 16" Longitude: 89° 52' 20"
Altitude of land surface: 267 feet
Date completed: April 12,1995
Total depth: 180 feet below land surface



WELL CONSTRUCTION DIAGRAMS FOR WATER-LEVEL OBSERVATION WELLS



APPENDIX 2

Depth to bases and calculated thicknesses of the loess or silt and clay in upper alluvium, sand and gravel in lower alluvium or fluvial deposits, the Cockfield Formation, and the Cook Mountain Formation from correlations of geophysical and boring logs of 78 selected test holes at Naval Support Activity Memphis, Millington, Tennessee

Appendix 2. Depth to bases and calculated thicknesses of the loess or silt and clay in upper alluvium, sand and gravel in lower alluvium or fluvial deposits, the Cockfield Formation, and the Cook Mountain Formation from correlations of geophysical and boring logs of 78 selected test holes at Naval Support Activity Memphis, Millington, Tennessee

[USGS, U.S. Geological Survey; NSA, Naval Support Activity; °, degrees; ′, minutes; ″ seconds; altitude, in feet above sea level; base, in feet below land surface; numbers in parentheses are altitudes of base; --, indicates that test hole did not penetrate base or that part of hole was not logged and no thickness could be calculated; <, less than; >, greater than]

USGS local well number	Project well or test-hole number, or well location	Latitude	Longitude	Altitude of land surface	Base of loess or silt and clay in upper alluvium	Thickness of loess or silt and clay in upper alluvium	Base of sand and gravel in lower alluvium or fluvial deposits	Thickness of sand and gravel in lower alluvium or fluvial deposits	Base of Cockfield Formation	Thickness of Cockfield Formation	Base of Cook Mountain Formation	Thickness of Cook Mountain Formation
Sh:U-54	City of Millington well 5	35°20′34″	89°53′45″	265	38 (227)	38	74 (191)	36	122 (143)	48	182 (83)	60
Sh:U-55	City of Millington well 6	35°20′36″	89°53′34″	265	38 (227)	38	96 (169)	58	122 (143)	26	182 (83)	60
Sh:U-58	NSA Memphis well 4	35°20′24″	89°52′55″	266	40 (226)	40	66 (200)	26	125 (141)	59	174 (92)	49
Sh:U-59	NSA Memphis well 5	35°20′09″	89°52′52″	264	38 (226)	38	97 (167)	59	134 (130)	37	160 (104)	26
Sh:U-60	NSA Memphis well 3	35°20′27″	89°52′32″	293	37 (256)	37	88 (205)	51	148 (145)	60	204 (89)	56
Sh:U-91	Fort Pillow test hole 4	35°20′42″	89°52′30″	278	36 (242)	36	74 (204)	38	124(154)	50	166 (112)	42
Sh:U-98	USGS test hole 2	35°21′14″	89°52′33″	284	45 (239)	45	96 (188)	51	178 (106)	82	--	--
Sh:U-99	USGS test hole 4	35°20′44″	89°52′48″	268	39 (229)	39	69 (199)	30	104 (164)	35	153 (115)	49
Sh:U-102	USGS test hole WL-1C	35°20′42″	89°52′34″	275	36 (239)	36	74 (201)	38	--	--	--	--
Sh:U-106	BG4LF	35°20′01″	89°52′48″	262	38 (224)	38	71 (191)	33	--	--	--	--
Sh:U-108	BG5LF	35°20′29″	89°53′04″	266	40 (226)	40	76 (190)	36	--	--	--	--
Sh:U-113	05MW05LF	35°20′29″	89°52′51″	269	40 (229)	40	65 (204)	25	--	--	--	--
Sh:U-114	60MW01LF	35°20′45″	89°53′04″	269	40 (229)	40	74 (195)	34	--	--	--	--
Sh:U-115	60MW02LF	35°20′43″	89°53′05″	269	40 (229)	40	93 (176)	53	--	--	--	--
Sh:U-116	60MW03LF	35°20′41″	89°53′02″	269	40 (229)	40	88 (181)	48	--	--	--	--
Sh:U-117	60MW04LF	35°20′42″	89°53′01″	270	45 (225)	45	95(175)	50	--	--	--	--
Sh:U-118	S-241(boring 11)	35°19′52″	89°52′41″	264	40 (224)	40	68 (196)	28	--	--	--	--
Sh:U-121	BG10UF	35°21′11″	89°52′53″	274	41 (233)	41	92 (182)	51	--	--	--	--
Sh:U-122	BG11MA	35°19′54″	89°53′03″	262	36 (226)	36	69 (193)	33	--	--	--	--
Sh:U-125	07MW18LF	35°20′52″	89°52′35″	278	43 (235)	43	100 (178)	57	--	--	--	--

Appendix 2. Depth to bases and calculated thicknesses of the loess or silt and clay in upper alluvium, sand and gravel in lower alluvium or fluvial deposits, the Cockfield Formation, and the Cook Mountain Formation from correlations of geophysical and boring logs of 78 selected test holes at Naval Support Acitvity Memphis, Millington, Tennessee—Continued

USGS local well number	Project well or test-hole number, or well location	Latitude	Longi-tude	Alti-tude of land sur-face	Base of loess or silt and clay in upper alluvium	Thick-ness of loess or silt and clay in upper alluvium	Base of sand and gravel in lower alluvium or fluvial deposits	Thick-ness of sand and gravel in lower alluvium or fluvial deposits	Base of Cockfield Formation	Thick-ness of Cockfield Forma-tion	Base of Cook Mountain Forma-tion	Thick-ness of Cook Mountain Forma-tion
Sh:U-129	15MW02LF	35°20′46″	89°52′30″	283	33 (250)	33	86 (197)	53	--	--	--	--
Sh:U-133	15MW04LF	35°20′48″	89°52′35″	278	28 (250)	28	96 (182)	68	--	--	--	--
Sh:U-135	59MW03UF	35°19′57″	89°52′55″	264	39 (225)	39	--	--	--	--	--	--
Sh:V-4	NSA Memphis well 2	35°20′44″	89°52′18″	285	38 (247)	38	82 (203)	44	177 (108)	95	209 (76)	32
Sh:V-9	Cloverhaven UD well	35°20′12″	89°50′38″	273	36 (237)	36	86 (187)	50	148 (125)	62	180 (93)	32
Sh:V-24	Edmund Orgill Park well	35°22′27″	89°50′43″	375	32 (343)	32	69 (306)	37	256 (119)	187	286 (89)	30
Sh:V-74	USGS test hole 1	35°20′32″	89°51′14″	285	33 (252)	33	64 (221)	31	195 (90)	131	--	--
Sh:V-75	USGS test hole 3	35°21′48″	89°51′55″	326	15 (311)	15	32 (294)	17	196 (130)	164	--	--
Sh:V-76	USGS test hole 5	35°20′48″	89°52′13″	290	30 (260)	30	84 (206)	54	188 (102)	104	--	--
Sh:V-77	Lake house well	35°22′01″	89°51′18″	323	20 (303)	20	30 (293)	10	>215 (<108)	>185	--	--
Sh:V-78	USGS test hole 6	35°21′15″	89°51′29″	331	24 (307)	24	34 (297)	10	210 (121)	176	222 (109)	12
Sh:V-79	USGS test hole 7	35°19′53″	89°52′05″	266	34 (232)	34	47 (219)	13	173 (93)	126	--	--
Sh:V-80	USGS test hole 8	35°19′16″	89°52′20″	267	35 (232)	35	45 (222)	10	153 (114)	108	--	--
Sh:V-81	Runway well	35°21′26″	89°52′20″	294	40 (254)	40	>79 (<215)	>39	--	--	--	--
Sh:V-86	BG2LF	35°20′01″	89°51′30″	273	29 (244)	29	77 (196)	48	--	--	--	--
Sh:V-88	03MW03MF	35°20′39″	89°52′09″	285	36 (249)	36	84 (201)	48	--	--	--	--
Sh:V-90	07SB01	35°20′52″	89°52′23″	284	26 (258)	26	74 (210)	48	180 (104)	106	--	--
Sh:V-91	07SB02	35°20′46″	89°52′22″	284	38 (246)	38	79 (205)	41	178 (106)	99	--	--
Sh:V-92	07SB03	35°20′47″	89°52′28″	283	32 (251)	32	81 (202)	49	174 (109)	93	--	--
Sh:V-93	07SB04	35°20′49″	89°52′23″	283	26 (257)	26	69 (214)	43	175 (108)	106	--	--
Sh:V-102	S-400 (boring 8)	35°20′20″	89°52′21″	268	35 (233)	35	58 (210)	23	--	--	--	--
Sh:V-103	S-784 (boring B8)	35°19′46″	89°52′23″	267	40 (227)	40	57 (210)	17	--	--	--	--
Sh:V-104	S-794 (boring 1)	35°20′13″	89°52′05″	268	27 (241)	27	53 (215)	26	--	--	--	--
Sh:V-105	S-786 (boring 4)	35°19′43″	89°52′10″	268	45 (223)	45	50 (218)	5	--	--	--	--
Sh:V-106	S-760 (boring 3)	35°20′04″	89°52′06″	268	36 (232)	36	48 (220)	12	--	--	--	--

Appendix 2. Depth to bases and calculated thicknesses of the loess or silt and clay in upper alluvium, sand and gravel in lower alluvium or fluvial deposits, the Cockfield Formation, and the Cook Mountain Formation from correlations of geophysical and boring logs of 78 selected test holes at Naval Support Acitvity Memphis, Millington, Tennessee—Continued

USGS local well number	Project well or test-hole number, or well location	Latitude	Longi-tude	Alti-tude of land sur-face	Base of loess or silt and clay in upper alluvium	Thick-ness of loess or silt and clay in upper alluvium	Base of sand and gravel in lower alluvium or fluvial deposits	Thick-ness of sand and gravel in lower alluvium or fluvial deposits	Base of Cockfield Formation	Thick-ness of Cockfield Forma-tion	Base of Cook Mountain Forma-tion	Thick-ness of Cook Mountain Forma-tion
Sh:V-110	BG6UC	35°21′26″	89°51′48″	320	16 (304)	16	29 (291)	13	--	--	--	--
Sh:V-111	BG7UC	35°21′09″	89°51′26″	321	27 (294)	27	34 (287)	7	--	--	--	--
Sh:V-112	BG8UF	35°20′52″	89°51′07″	300	46 (254)	46	>76 (<224)	>30	--	--	--	--
Sh:V-113	BG9MF	35°20′37″	89°51′41″	313	42 (271)	42	94 (219)	52	--	--	--	--
Sh:V-114	BG12UF	35°20′21″	89°52′10″	269	30 (239)	30	47 (222)	17	--	--	--	--
Sh:V-115	BG13UF	35°20′33″	89°50′40″	290	43 (247)	43	94 (196)	51	--	--	--	--
Sh:V-116	02MW01DA	35°19′24″	89°51′38″	267	39 (228)	39	59 (208)	20	--	--	--	--
Sh:V-117	02MW02DA	35°19′20″	89°51′40″	267	38 (229)	38	53 (214)	15	--	--	--	--
Sh:V-119	02MW03DA	35°19′17″	89°51′41″	267	29 (238)	29	48 (219)	19	--	--	--	--
Sh:V-120	02SB04DA	35°19′18″	89°51′46″	267	35 (232)	35	50 (217)	15	--	--	--	--
Sh:V-121	02MW05DA	35°19′19″	89°51′49″	267	34 (233)	34	50 (217)	16	--	--	--	--
Sh:V-122	02MW06DA	35°19′20″	89°52′00″	268	32 (236)	32	54 (214)	22	--	--	--	--
Sh:V-123	02SB07DA	35°19′23″	89°52′06″	266	24 (242)	24	48 (218)	24	--	--	--	--
Sh:V-126	02MW09DA	35°19′24″	89°52′10″	266	26 (240)	26	46 (220)	20	--	--	--	--
Sh:V-127	02MW10DA	35°19′28″	89°52′08″	270	36 (234)	36	50 (220)	14	--	--	--	--
Sh:V-129	02MW11DA	35°19′29″	89°52′04″	265	33 (232)	33	43 (222)	10	--	--	--	--
Sh:V-130	02MW12DA	35°19′28″	89°51′52″	267	35 (232)	35	51 (216)	16	--	--	--	--
Sh:V-133	02MW13DA	35°19′27″	89°51′38″	267	34 (233)	34	66 (201)	32	--	--	--	--
Sh:V-134	02MW14DA	35°19′37″	89°51′35″	269	32 (237)	32	66 (203)	34	--	--	--	--
Sh:V-164	07MW10LF	35°21′01″	89°52′24″	282	41 (241)	41	78 (204)	37	--	--	--	--
Sh:V-165	07MW11LF	35°20′59″	89°52′22″	283	44 (239)	44	70 (213)	26	--	--	--	--
Sh:V-166	07MW12LF	35°21′01″	89°52′11″	289	34 (255)	34	90 (199)	56	--	--	--	--
Sh:V-167	07MW13LF	35°20′54″	89°52′03″	293	43 (250)	43	78 (215)	35	--	--	--	--
Sh:V-168	07MW14LF	35°20′50″	89°52′04″	297	34 (263)	34	94 (203)	60	--	--	--	--
Sh:V-170	07MW15LF	35°20′53″	89°52′08″	294	36 (258)	36	100 (194)	64	--	--	--	--

Appendix 2. Depth to bases and calculated thicknesses of the loess or silt and clay in upper alluvium, sand and gravel in lower alluvium or fluvial deposits, the Cockfield Formation, and the Cook Mountain Formation from correlations of geophysical and boring logs of 78 selected test holes at Naval Support Acitvity Memphis, Millington, Tennessee—Continued

USGS local well number	Project well or test-hole number, or well location	Latitude	Longi-tude	Alti-tude of land sur-face	Base of loess or silt and clay In upper ailuvium	Thick-ness of loess or silt and clay in upper alluvium	Base of sand and gravel in lower alluvium or fluvial deposits	Thick-ness of sand and gravel in lower ailuvium or fluvial deposits	Base of Cockfield Formation	Thick-ness of Cockfield Forma-tion	Base of Cook Mountain Forma-tion	Thick-ness of Cook Mountain Forma-tion
Sh:V-171	07MW16LF	35°20′49″	89°52′18″	285	30 (255)	30	80 (205)	50	--	--	--	--
Sh:V-172	07MW17LF	35°20′42″	89°52′27″	281	34 (247)	34	72 (209)	38	--	--	--	--
Sh:V-173	09MW01DA	35°19′24″	89°52′16″	270	39 (231)	39	56 (214)	17	--	--	--	--
Sh:V-175	09MW03DA	35°19′21″	89°52′29″	267	34 (233)	34	>53 (<214)	>19	--	--	--	--
Sh:V-176	09MW04DA	35°19′28″	89°52′25″	268	41 (227)	41	72 (196)	31	--	--	--	--
Sh:V-180	14MW06LF	35°19′50″	89°52′04″	269	37 (232)	37	49 (220)	12	--	--	--	--
Sh:V-182	21MW01LF	35°20′49″	89°52′09″	294	34 (260)	34	90 (204)	56	--	--	--	--
Sh:V-187	65MW06DA	35°19′29″	89°52′13″	264	29 (235)	29	42 (222)	13	--	--	--	--

— PAGE 63 FOLLOWS —

APPENDIX 3

Depth to bases and calculated thicknesses of the Cook Mountain Formation, Memphis Sand, Flour Island Formation, and Fort Pillow Sand from correlations of geophysical logs of six deep test holes in the area of Naval Support Activity Memphis, Millington, Tennessee

Appendix 3. *Depth to bases and calculated thicknesses of the Cook Mountain Formation, Memphis Sand, Flour Island Formation, and Fort Pillow Sand from correlations of geophysical logs of six deep test holes in the area of Naval Support Activity Memphis, Millington, Tennessee*

[USGS, U.S. Geological Survey; NSA, Naval Support Activity; °, degrees; ′, minutes; ″, seconds; altitude, in feet above sea level; base, in feet below land surface; numbers in parentheses are altitudes of base (+) above or (-) below sea level]

USGS local well number	Well or test-hole number	Latitude	Longi-tude	Alti-tude of land sur-face	Base of Cook Mountain Forma-tion	Thick-ness of Cook Mountain Forma-tion	Base of Memphis Sand	Thick-ness of Mem-phis Sand	Base of Flour Island Formation	Thick-ness of Flour Island Forma-tion	Base of Fort Pillow Sand	Thick-ness of Fort Pillow Sand
Sh:U-54	City of Millington well 5	35°20′34″	89°53′45″	265	182 (+83)	60	1,062(-797)	880	1,316(-1,051)	254	1,470(-1,205)	154
Sh:U-55	City of Millington well 6	35°20′36″	89°53′34″	265	182 (+83)	60	1,061(-796)	879	1,350(-1,085)	289	1,476(-1,211)	126
Sh:U-58	NSA Memphis well 4	35°20′24″	89°52′55″	266	174 (+92)	49	1,048(-782)	874	1,274(-1,008)	226	1,454(-1,188)	180
Sh:U-59	NSA Memphis well 5	35°20′09″	89°52′52″	264	160(+104)	26	1,031(-767)	871	1,260 (-996)	229	1,436(-1,172)	176
Sh:U-60	NSA Memphis well 3	35°20′27″	89°52′32″	293	204 (+89)	56	1,070(-777)	866	1,308(-1,015)	238	1,458(-1165)	150
Sh:U-91	Fort Pillow test hole 4	35°20′42″	89°52′30″	278	166(+112)	42	1,034(-756)	868	1,286(-1,008)	252	1,448(-1,170)	162