Hydrogeology and Ground-Water-Flow Simulation in the Former Airfield Area of Naval Support Activity Mid-South, Millington, Tennessee

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Abstract

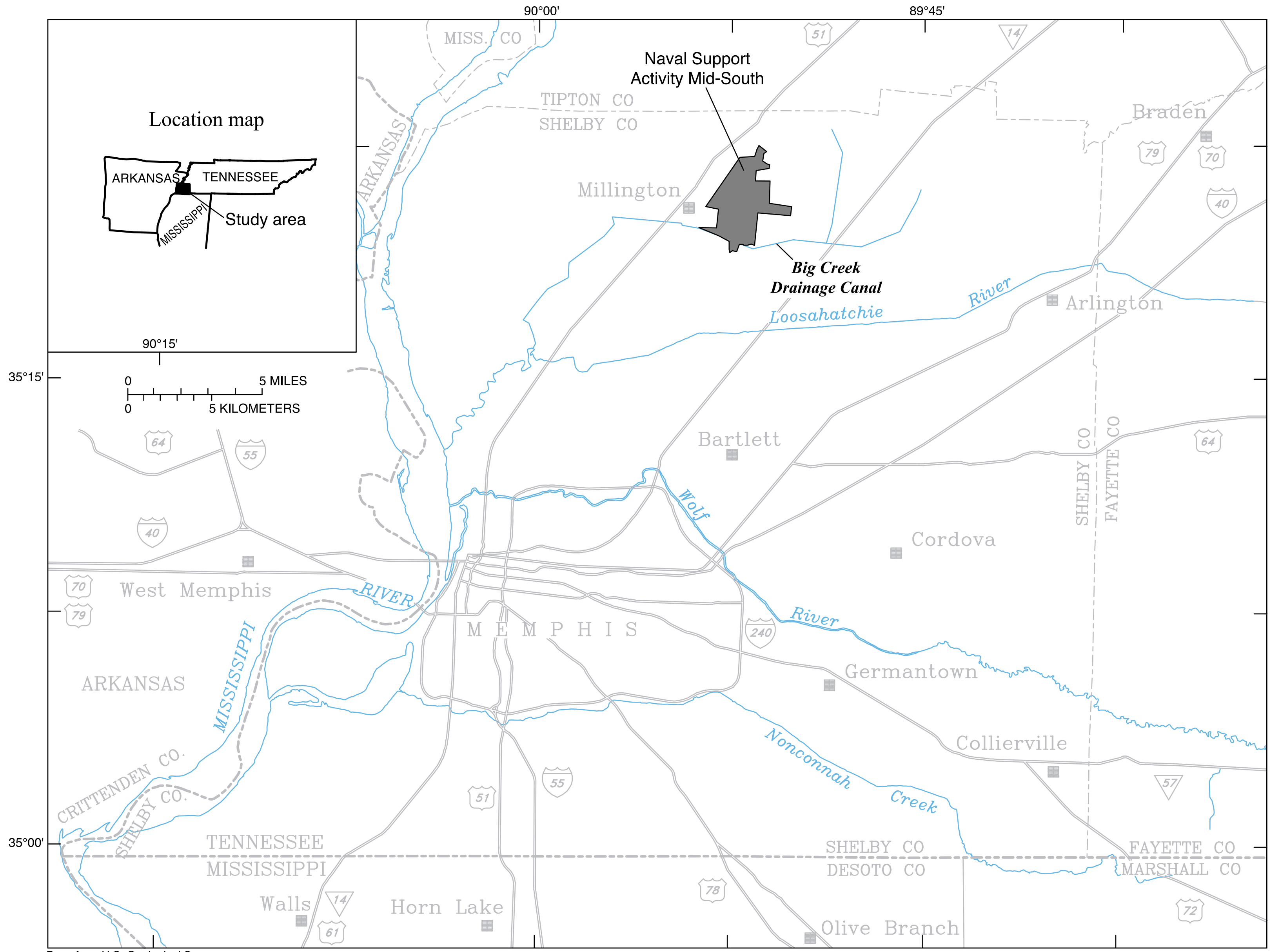
Naval Support Activity Mid-South is a Department of the Navy base located in Millington, Tennessee. The facility was home to the Naval Aviation Technical Training Center from 1943 until 1996. As part of the Base Closure and Realignment Act of 1990, the primary training mission of the facility was realigned and most of the northern part of the base, referred to as the Northside and consisting primarily of an airfield, was transferred to the city of Millington in January 2000. During environmental investigations at the base, plumes of dissolved chlorinated solvents resulting from past aircraft maintenance and training operations were identified in shallow ground water beneath the airfield area. The airfield area containing the plumes has been designated as Area of Concern (AOC) A. Chlorinated solvents, primarily trichloroethene (TCE), are the principal contaminants in ground water at AOC A, with TCE identified in concentrations as high as 4,400 micrograms per liter. The nature and extent of these plumes at AOC A were addressed during a Resource Conservation and Recovery Act Facility Investigation, and selected options for remediation currently are being implemented under a corrective action program. As part of these efforts, the U.S. Geological Survey (USGS) is working with the Navy and its consultants to study the hydrogeologic framework of the base and surrounding area, with a focus on AOC A.

Since 1997, investigations at and near the facility have produced data prompting revisions and additions to information published that year in two USGS reports. The updates are presented in this report and consist primarily of (1) refinements to selected hydrogeologic maps presented in the 1997 reports, on the basis of data collected from new wells at on- and off-base locations, (2) additional hydraulic-conductivity data collected for the alluvial-fluvial deposits aquifer at AOC A, and (3) construction of a potentiometric-surface map of the shallow aquifer for the former part of the Naval Support Activity Mid-South Northside and adjacent off-base locations for February and March 2000 water-level conditions. Additionally, a numerical ground-water-flow model of AOC A was developed and calibrated to the February and March 2000 potentiometric-surface data, the results of which also are presented in this report. Particle-tracking simulations were used with the model to simulate ground-water-flow paths from two sites suspected of being contaminant source areas at AOC A. The flow paths indicated by the particle tracking simulations agree reasonably well with maps of the interpreted extents of TCE plumes. The time-of-travel plots show that advective travel times from the two suspected source areas to the model boundary are controlled by relative proximities of the source areas to a part of AOC A identified from investigations and simulated with the model as having the highest horizontal hydraulic conductivity.

Introduction

Naval Support Activity (NSA) Mid-South is a Department of the Navy (Navy) base located in Millington, Tennessee (fig. 1). The facility was commissioned in 1942 as the Naval Reserve Aviation Base. From 1943 until 1995, the base was known as the Naval Air Station (NAS) Memphis. During this period, NAS Memphis was the home of the Naval Aviation Technical Training Center (NATTC) and consisted of two parts informally referred to as the Northside, which included an airfield and supporting structures, and the Southside, which included housing and training facilities (fig. 2). In 1993, as part of the Base Closure and Realignment (BRAC) Act of 1990, NAS Memphis was designated for realignment of its primary training mission and partial closure. In 1995, NAS Memphis became NSA Memphis as part of the BRAC process. In 1996, the Navy relocated its NATTC operations from NSA Memphis to NAS Pensacola. In 1998, NSA Memphis became NSA Mid-South, and the Navy's Bureau of Personnel was relocated to the facility. In January 2000, a large part of the Northside, including the airfield, was transferred to the city of Millington. Currently (2004), the base includes all of the Southside and the southernmost part of the Northside (fig. 2).

Plumes of dissolved chlorinated solvents have been identified in ground water in the alluvial-fluvial deposits aquifer, part of the shallow aquifer that is present from about 40 to 100 ft below land surface, beneath the airfield area of the former northern part of the NSA Mid-South Northside. The plumes, identified during environmental investigations conducted under



Base from U.S. Geological Survey
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1:62,000, and Navy Digital Ortho-
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Figure 1. Location of Naval Support Activity Mid-South, Millington, Tennessee.

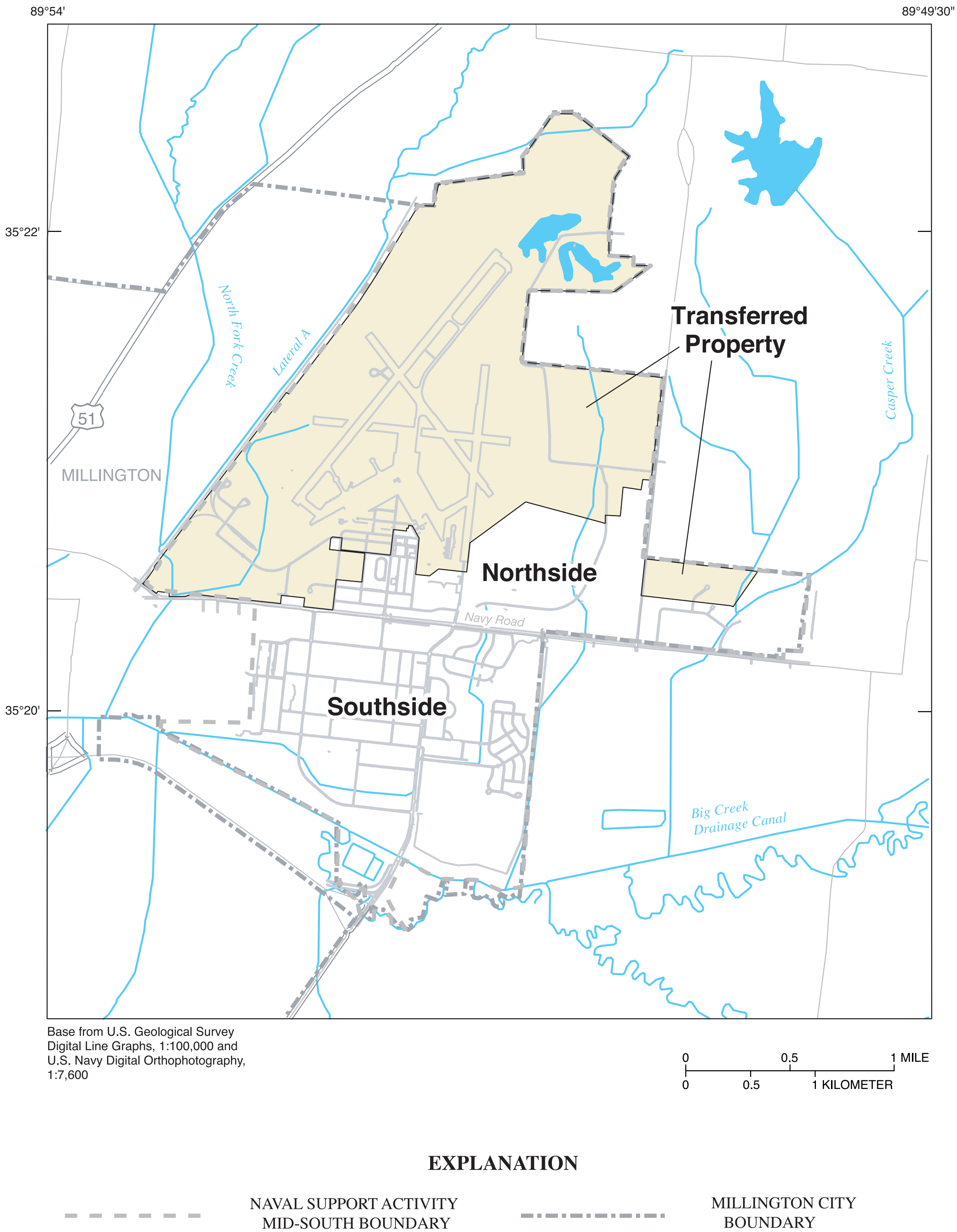


Figure 2. Naval Support Activity Mid-South, the Northside and Southside, and property transferred to the city of Millington.

the Navy's Installation Restoration Program (IRP) at the base, are the result of past aircraft maintenance and training operations conducted in the airfield apron area when the base was NAS Memphis. Chlorinated solvents, primarily trichloroethene (TCE), are the principal contaminants in ground water beneath the airfield. TCE has been identified in ground-water samples near one of the suspected primary source areas in concentrations as high as 4,400 micrograms per liter (µg/L). Tetrachloroethene (PCE), dichloroethene (DCE), and carbon tetrachloride also have been detected in lower concentrations. The presence of low concentrations of the cis- isomer of DCE and weakly reducing geochemical conditions identified in ground water at some locations indicates that natural attenuation of PCE and TCE by reductive dechlorination and possibly other processes may be occurring within the plumes.

The identification of multiple chlorinated-solvent plumes in the airfield area has led to interpretations of multiple source areas, most of which are thought to have resulted from relatively small-volume releases of the contaminants. The two largest plumes, however, appear to be the result of significantly larger releases; the plume containing the highest solvent concentrations extends about 1 mi downgradient of the suspected source areas. Defining the nature and extent of individual source areas and resulting plumes has been complicated by the apparent coalescing of some of the plumes as they migrate northwestward with ground-water flow in the alluvial-fluvial deposits aquifer. Rather than attempt to investigate all possible sources and plumes within the airfield, an area has been delineated that contains all confirmed and probable locations of solvent contamination in the alluvial-fluvial deposits aquifer that are suspected of originating from releases in and near the airfield. This area is designated as Area of Concern (AOC) A. Work conducted under the IRP in compliance with the Resource Conservation and Recovery Act (RCRA) Correction Action Program at AOC A has focused primarily on the two largest plumes containing the highest concentrations of chlorinated solvents present at NSA Mid-South (fig. 3). The nature and extent of these plumes were addressed during a RCRA Facility Investigation (RFI), and selected options for remediation, including monitored natural attenuation and enhanced biodegradation, currently are being implemented under a corrective action program. As part of the RFI process, the U.S. Geological Survey (USGS) has been assisting the Navy, Southern Division, Naval Facilities Engineering Command, and its contractors in hydrogeologic investigations, including development and calibration of a numerical ground-water-flow model of AOC A.

Purpose and Scope

This report provides revisions to maps and interpretations of the hydrogeology of NSA Mid-South, including AOC A, that appear in previously published reports prepared by the USGS. Information from the previous reports is updated for use in the design and construction of a ground-water-flow model of AOC A and nearby areas. This report documents the AOC A model, including data and parameters used in model development and calibration, and presents a description and the results of advective-flow particle-tracking simulations that were used to estimate ground-water-flow direction and time-of-travel from selected locations suspected as being contaminant-plume source areas within AOC A.

Previous Investigations

Several reports describe studies of the hydrogeology of NSA Mid-South and the surrounding area. Kingsbury and Carmichael (1995) present the hydrogeology of the post-Wilcox Group stratigraphic units in the area of NSA Mid-South as interpreted from available geologic data for the area, including the results of a test-drilling program conducted on the NSA Mid-South Northside by the USGS in 1994 prior to the onset of site-specific subsurface investigations on this part of the base. Carmichael and others (1997) update information on the hydrogeology at NSA Mid-South following a second series of test holes drilled by the USGS on the NSA Mid-South Southside in 1995 prior to the onset of site-specific subsurface investigations on this part of the base, and include a description of water quality in the principal water-bearing units beneath the facility. Robinson and others (1997) present the results of a study conducted by the USGS from 1995 through 1997 to simulate ground-water flow in the shallow aquifer system using a numerical model calibrated for an approximately 30 square-mile (mi^2) area that included all of the NSA Mid-South Southside and most of the Northside. A series of reports prepared by EnSafe, Inc., Memphis, Tenn., and other consultants to the Navy also describe the results of site-specific environmental investigations conducted under the IRP at NSA Mid-South.

Hydrogeology

Descriptions of the physical setting of NSA Mid-South and the hydrogeologic framework of the base and surrounding area are presented in previous reports by Kingsbury and Carmichael (1995), Carmichael and others (1997), and Robinson and others (1997). Carmichael and others (1997) describe the post-Wilcox Group geologic units underlying the NSA Mid-South area (table 1). Primary geologic units studied under the RFI at AOC A include the alluvium, loess, fluvial deposits, and Cockfield Formation. Brief descriptions of these units and their hydrogeologic significance provide a framework for the ground-water-flow model of AOC A.

Alluvium of Pleistocene through Holocene age is present in the valleys of streams in the Memphis area, including Big Creek Drainage Canal and its tributaries that drain NSA Mid-South (fig. 2). In the valley of Big Creek Drainage Canal and along the lower reaches of its larger tributaries such as North Fork Creek, the alluvium consists of silt and clay with minor amounts of sand in the upper part, and sand and gravel in the

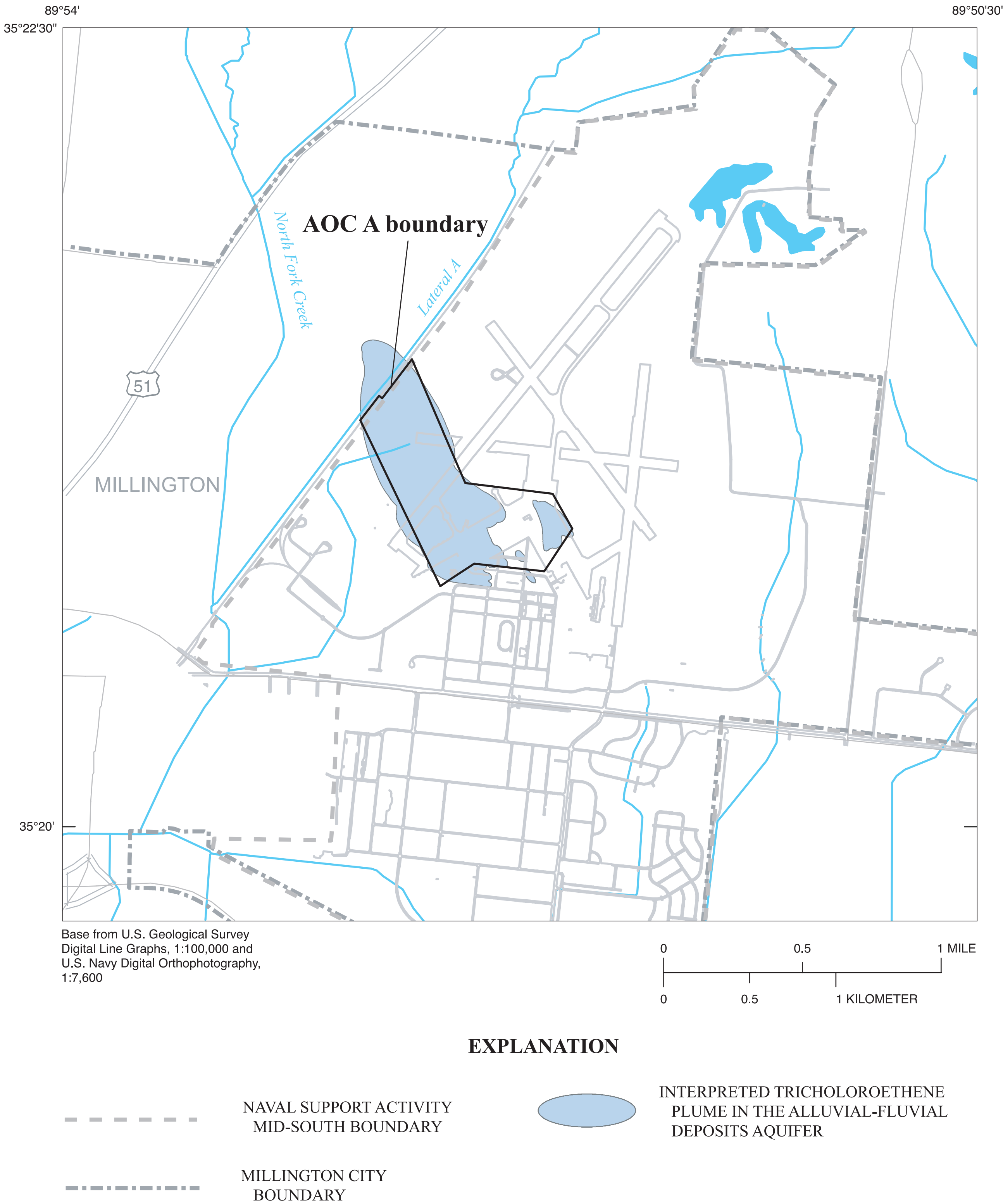


Figure 3. Locations of study area, Area of Concern (AOC) A, and interpreted plumes of trichloroethene in the alluvial-fluvial deposits aquifer beneath the former airfield area part of the Naval Support Activity Mid-South Northside, Millington, Tennessee.

Table 1. Post-Wilcox Group geologic units underlying Naval Support Activity Mid-South, Millington, Tennessee, and their hydrologic significance

[Modified from Parks and Carmichael, 1989, 1990; Kingsbury and Parks, 1993; Kingsbury and Carmichael, 1995; Carmichael and others, 1997]

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 sand and gravel horizon in the lower part of the unit 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)	5-80	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 Mid-South area.
Tertiary	Eocene	Claiborne	Cockfield Formation	0-185	Sand, silt, clay, and lignite. Interbedded and interlensed. Thickness of formation is variable because of erosional surfaces at top and base. Locally contains sand lenses (which compose the Cockfield aquifer) in which domestic and farm wells are screened. Sand lenses are more prevalent in northern and eastern NSA Mid-South. 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 part of the 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 three wells at NSA Mid-South and four wells at Millington.

lower part (Carmichael and others, 1997). Thickness of the alluvium ranges from 0 to 70 ft at NSA Mid-South (table 1). The alluvium thins as the altitude of its base rises and the coarse-grained lower part becomes absent in the middle and upper reaches of the valleys of the main tributaries to Big Creek Drainage Canal. The upper part of the alluvium is interpreted to grade laterally and to be hydraulically similar to the loess, and the lower part of the alluvium is interpreted to grade laterally and to be hydraulically similar to the fluvial deposits. Saturated sand and gravel in the lower part of the alluvium constitute the alluvial aquifer in the Memphis area. At NSA Mid-South, ground water in the alluvial aquifer is confined locally by the overlying finer-grained upper alluvium.

Loess of Pleistocene age, which overlies the fluvial deposits in upland parts of the Memphis area outside the alluvial plains of streams, consists of silt with silty clay and silty, fine sand. Thickness of the loess ranges from less than 15 to 45 ft at NSA Mid-South (table 1). In general, the loess is thinnest on the hilltops and thickest on the valley slopes. Locally, silt and clay on the valley slopes may include loess reworked or redeposited as colluvial or alluvial deposits. At NSA Mid-South, 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 (Carmichael and others, 1997). A transitional zone ranging from about 3 to 7 ft thick and grading from sandy silt at the top to silty sand at the base is present between silt in the loess and sand and gravel in the fluvial deposits at NSA Mid-South. Because of the low permeability of the silt, the loess generally serves both to retard downward movement of recharge to and as the upper semi-confining to confining unit for the fluvial deposits. Locally, however, the base of the loess lies above the potentiometric surface of the fluvial deposits beneath the higher land-surface altitude parts of the NSA Mid-South area. The loess commonly contains a perched saturated zone with water levels that fluctuate seasonally from about 1 to 15 ft below land surface.

The fluvial (terrace) deposits of Pliocene(?) and Pleistocene age underlie the loess in upland parts of the Memphis area and consist of sand and gravel with minor amounts of clay. Thickness of the fluvial deposits ranges from 5 to 80 feet at NSA Mid-South (table 1). Locally, the sand in the upper part of the formation is very fine to fine and silty or clayey, and is similar in character to the transitional zone between the loess and fluvial deposits described by Carmichael and others (1997). Gravel is present in the fluvial deposits as lenses at various horizons but is more common in the lower part. Therefore, the fluvial deposits may be described as a coarsening downward sequence that generally is composed of silty sand or sandy silt in the upper part, and sand or sand and gravel through the remaining part, but with gravel more common in the lower part.

Two levels of fluvial deposits are present at NSA Mid-South, a lower level having a basal altitude of about 220 feet above NGVD 29 and ranging from about 5 to 80 feet in thickness, and an upper level having a basal altitude of about 300 feet above NGVD 29 and ranging from about 10 to 20 feet in thickness. At NSA Mid-South, the lower-level fluvial deposits are located beneath most of the facility outside the stream valleys where land-surface altitudes generally range from about 265 to 300 feet above NGVD 29, and the upper-level fluvial deposits are located beneath the northernmost former part of the North-side where land-surface altitudes generally range from about 320 to 350 feet above NGVD 29. The transition between the two levels of fluvial deposits is thought to be present in the north-central part of the airfield area, northeast of the north-west-southeast trending runway (fig. 2), and where land-surface altitudes range between about 300 and 320 feet above NGVD 29. An erosional scarp in the underlying Cockfield Formation also is thought to be present in the transition area across which the two levels of fluvial deposits may be hydraulically connected. The lower-level fluvial deposits generally are saturated and ground water locally is under artesian pressure. The upper-level fluvial deposits commonly are dry or contain only a thin perched-water zone at their base.

Saturated sand and gravel in the fluvial deposits constitute the fluvial deposits aquifer in the Memphis area. Where hydraulically connected, saturated sand and gravel in the lower alluvium and the fluvial deposits constitute the alluvial-fluvial deposits aquifer, the primary part of the "shallow" aquifer at NSA Mid-South (Carmichael and others, 1997). Within the AOC A study area, however, the alluvial-fluvial deposits aquifer is composed of only the fluvial deposits because the coarse-grained lower part of the alluvium is not known to be present beneath the middle to upper reaches of the alluvial valleys of North Fork Creek and its tributary Lateral A located in the western part of the area (fig. 2).

The Cockfield Formation of Eocene age is the uppermost unit in the Claiborne Group in the Memphis and NSA Mid-South area (table 1). The Cockfield Formation consists of interbedded clay, silt, and sand. Thickness of the Cockfield Formation generally ranges from about 25 to 185 feet in the NSA Mid-South area, but locally the Cockfield Formation may be absent as a result of structural relief from faulting and subsequent erosion (Carmichael and others, 1997). The thickest preserved section of the Cockfield Formation is located in the northernmost part of the NSA Mid-South area beneath the upper-level fluvial deposits. Because of its primarily fine-grained texture, the Cockfield Formation and the underlying predominantly clay-rich Cook Mountain Formation together serve as the lower confining unit for the alluvial-fluvial deposits aquifer and the upper confining unit for the Memphis aquifer throughout most of the Memphis area. In western Tennessee, including the Memphis area, the Cockfield Formation locally contains discontinuous sand lenses that supply water to wells and compose the Cockfield aquifer (Parks and Carmichael, 1990). At NSA Mid-South, sand lenses in the upper part of the Cockfield aquifer that lie beneath the upper-level fluvial deposits are thought to grade laterally into and thus be hydraulically connected to the alluvial-fluvial deposits aquifer across and southwest of the erosional scarp area. Together, the alluvial-fluvial deposits aquifer and the upper part of the Cockfield aquifer lying northeast of the erosional scarp comprise the shallow aquifer at NSA Mid-South and are referred to as the A1 aquifer (Robinson and others, 1997). The A1 aquifer is confined from below by clay and silt lenses of the Cockfield Formation that form the Cockfield confining unit.

Since the publication of Carmichael and others (1997) and Robinson and others (1997), additional hydrogeologic data have been collected at and near NSA Mid-South as a result of the installation of new monitoring and production wells and the identification of existing domestic wells at both on- and off-base locations. On the basis of these additional data, geologic structure maps presented in those reports have been revised, and a potentiometric-surface map of the A1 aquifer has been constructed for the northern part of the NSA Mid-South area for February and March 2000 water-level conditions. Additional hydraulic-conductivity data also have been collected for the alluvial-fluvial deposits aquifer beneath the airfield area from a multiple-well, 24-hour, constant-rate-withdrawal aquifer test conducted by EnSafe, Inc., in 1999 as part of the RFI at AOC A (EnSafe, Inc., written commun., 2000). The implications of these new data to this study are discussed later in this report.

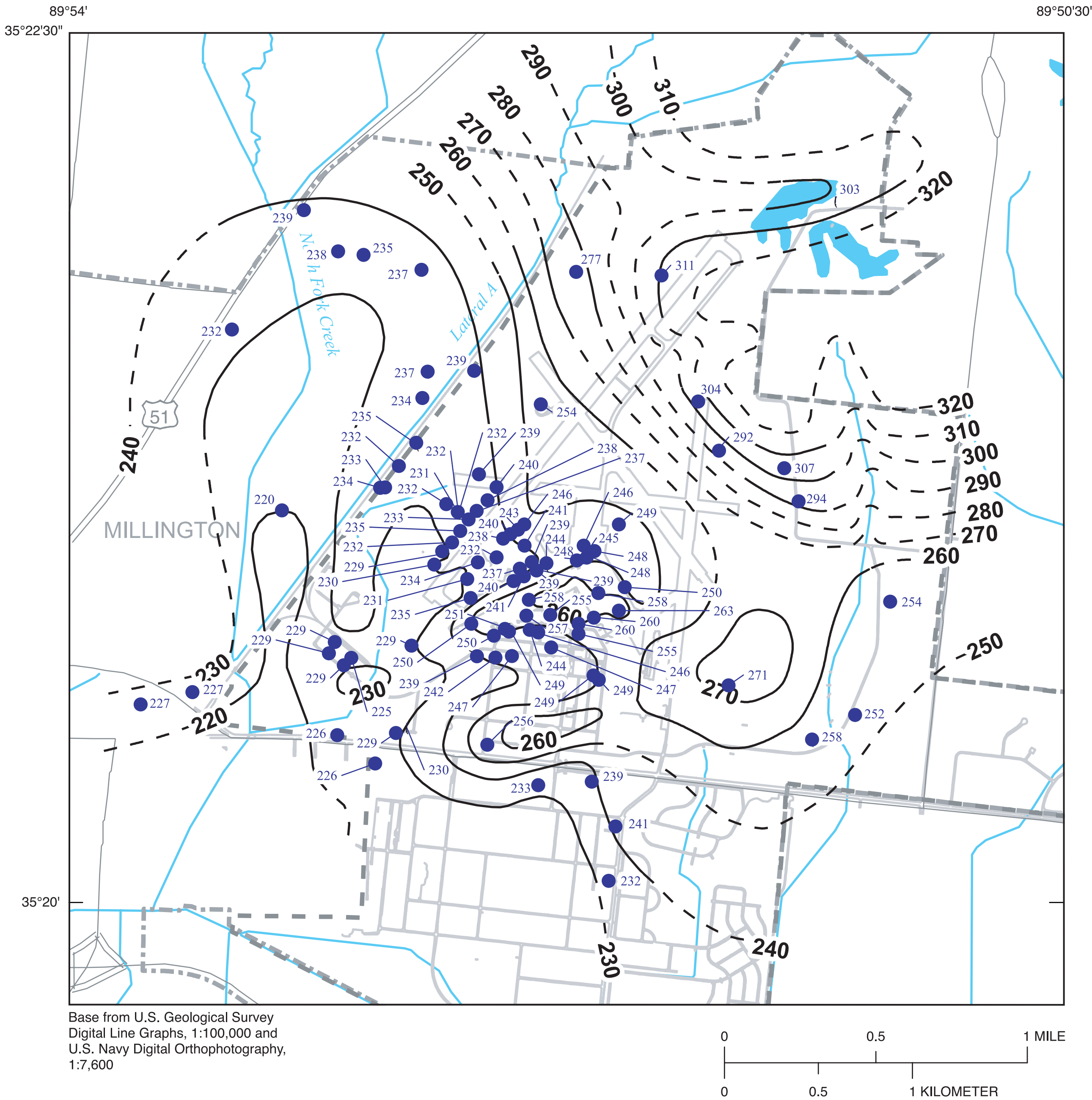
Structure

Since publication of Carmichael and others (1997) and Robinson and others (1997), hydrogeologic data collected from several new monitoring and existing domestic wells screened in the alluvial-fluvial deposits aquifer or the underlying Cockfield Formation in the NSA Mid-South area, along with data from a new production well screened in the Memphis aquifer in the southeastern part of the NSA Mid-South Northside, were used to revise two of the geologic structure maps presented in those reports. Revisions were made to the map that shows the altitude of the base of the loess or silt and clay in the upper alluvium and the map that shows the altitude of the base of sand and gravel in the lower alluvium or fluvial deposits. The revised maps were prepared at the same scale as those shown in the 1997 reports, including all of NSA Mid-South and the surrounding area. For this report, maps are presented that show revisions made within the smaller AOC A study area only (figs. 4 and 5). The revised map of the altitude of the base of the loess or silt and clay in the upper alluvium for the AOC A study area shows minor adjustments for this area, mostly as a result of additional geologic control points (fig. 4). The most significant change in the map of the altitude of the base of sand and gravel in the lower alluvium or fluvial deposits for the AOC A study area is a linear depression in this surface located in the northwestern part of the study area between Lateral A and North Fork Creek (figs. 5 and 6a). This depression defines an area where the alluvial-fluvial deposits aquifer thickens and the Cockfield confining unit appears to thin. These revised maps were used to define the top and bottom altitudes and thickness of the alluvial-fluvial deposits aquifer for that part of the area covered by the AOC A ground-water-flow model.

Shallow Aquifer

The shallow or A1 aquifer, as defined by Robinson and others (1997) for their "basewide" ground-water-flow model, is the primary hydrogeologic unit of interest for this study. Southwest of the erosional scarp in the Cockfield Formation located beneath the north-central part of the former NSA Mid-South Northside (fig. 5) , the A1 aquifer consists of the alluvial-fluvial deposits aquifer; northeast of the erosional scarp, the A1 aquifer consists of the upper part of the Cockfield aquifer (fig. 6). As described previously, the alluvial-fluvial deposits and upper part of the Cockfield aquifers are interpreted to be hydraulically connected across the scarp because the fluvial deposits thin and the basal altitude of this unit rises from about 220 feet above NGVD 29 to about 300 feet above NGVD 29 from southwest to northeast across this feature. Because of the rise in basal altitude across the scarp, the upper-level fluvial deposits commonly are dry or contain only a thin perched water zone in the area northeast of the scarp; thus, the water table in this area is in the upper part of the Cockfield aquifer. For this study, the top of that part of the A1 aquifer that consists of the alluvial-fluvial deposits aquifer was defined by the revised structure map of the base of the loess or silt and clay in the upper alluvium (fig. 4). The bottom of that part of the A1 aquifer that consists of the alluvial-fluvial deposits aquifer was defined by the revised structure map of the base of sand and gravel in the lower alluvium or fluvial deposits (fig. 5). The bottom of that part of the A1 aquifer that consists of the upper part of the Cockfield aquifer has been defined by the altitude of the top of a clay unit in the Cockfield Formation, designated the Cockfield confining unit by Robinson and others (1997). The top of the A1 aquifer in this area is the water table as defined by water levels measured in a couple of wells screened in the upper part of the Cockfield Formation in February and March 2000. Ground water in the A1 aquifer in the study area exists under artesian conditions in most of the part consisting of the alluvial-fluvial deposits aquifer, and under water-table conditions in the section consisting of the upper part of the Cockfield aquifer where water levels are below the base of the loess, with the transition in conditions occurring near the erosional scarp.

The basewide flow model presented in Robinson and others (1997) was constructed using data from the investigation described by Carmichael and others (1997). A horizontal hydraulic-conductivity value of 5.3 feet per day (ft/d) was used as input to the basewide model for that part of the A1 aquifer that consists of the alluvial-fluvial deposits aquifer, and a value of 1 ft/d was used as input for that section of the A1 aquifer that consists of the upper part of the Cockfield aquifer. The value of hydraulic conductivity used for the alluvial-fluvial deposits aquifer was obtained from a multiple-well, 24-hour constant-rate-withdrawal aquifer test conducted by the USGS in 1995 at a location south of the western end of the airfield apron and was thought at the time to be the most reliable value available for calibrating the model. The value of hydraulic conductivity used for the upper part of the Cockfield aquifer was estimated from the results of specific-capacity tests conducted by EnSafe, Inc., in wells screened in this unit (Robinson and others, 1997). In 1999, as part of the AOC A RFI, EnSafe, Inc., conducted a multiple-well, 24-hour constant-rate-withdrawal aquifer test in the alluvial-fluvial deposits aquifer within AOC A, at a location about 2,500 feet north of the USGS aquifer-test site. This test resulted in horizontal hydraulic conductivities for the pumping and for selected observation wells that range from 44.6 to 68.4 ft/d, with a geometric mean of 59.1 ft/d (EnSafe, Inc., written commun., 2000). These horizontal hydraulic conductivity values are about an order of magnitude greater than the value from the USGS test and show that the hydraulic conductivity of the alluvial-fluvial deposits aquifer in the airfield area is variable and higher in some areas than the value of 5.3 ft/d used uniformly for this aquifer in the basewide flow model. In addition to spatial variations in horizontal hydraulic conductivity, quantitative hydraulic data from slug tests and borehole-flowmeter measurements made in selected wells, as well as qualitative data from pumping rates, drawdown, and water-level recovery during well sampling, also indicate that horizontal hydraulic conductivities generally are lowest in the upper part of the fluvial deposits and increase with depth.



EXPLANATION

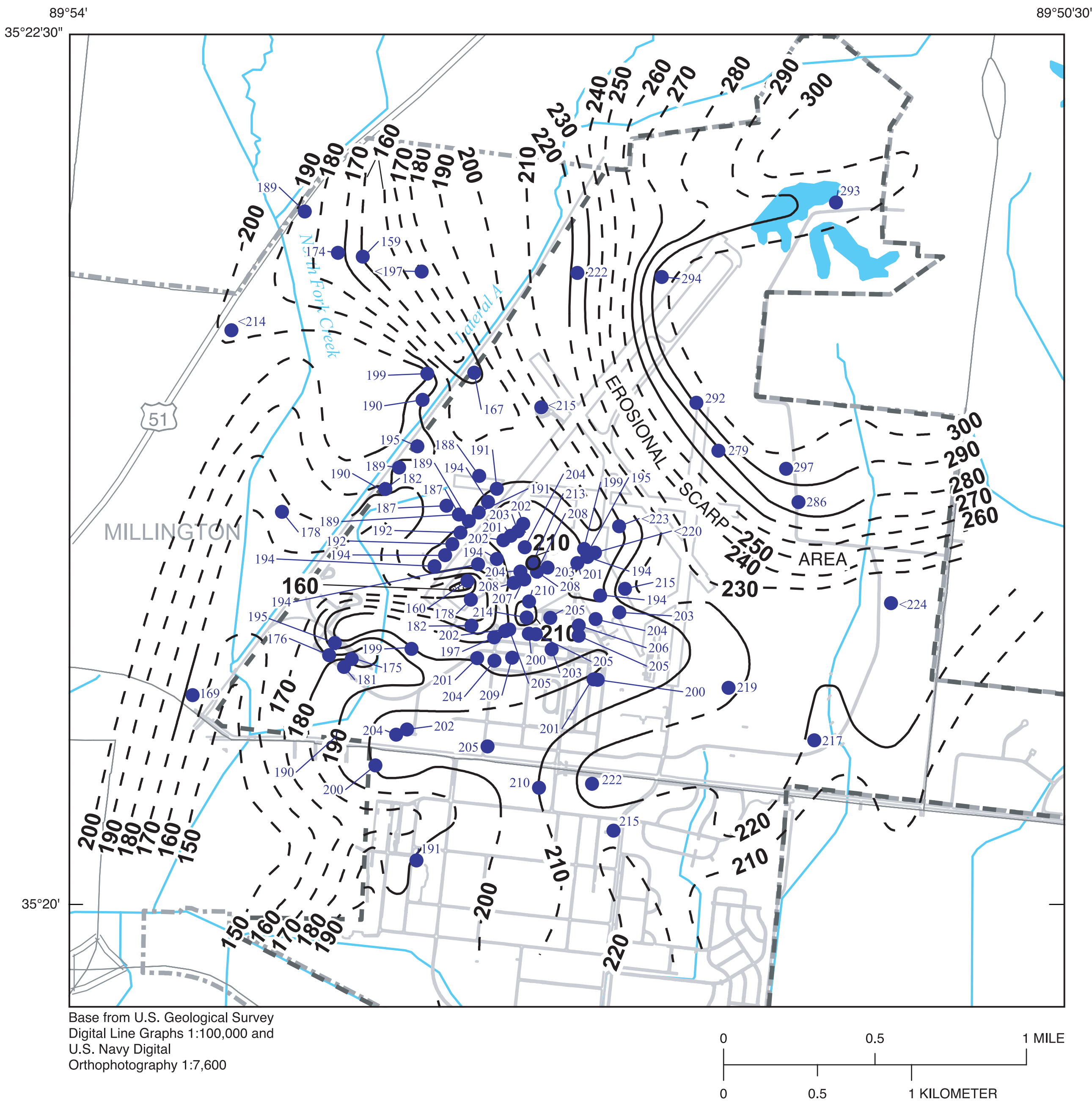
NAVAL SUPPORT ACTIVITY MID-SOUTH BOUNDARY

MILLINGTON CITY BOUNDARY

—230— — SUBSURFACE CONTOUR—Shows altitude of base of loess or silt and clay in the upper alluvium. Dashed where approximate. Contour interval 10 feet. Datum is NGVD 29

● 232 WELL—Number is altitude of base of loess or silt and clay in the upper alluvium, in feet. Datum is NGVD 29

Figure 4. Altitude of the base of the loess or silt and clay in the upper alluvium at Area of Concern (AOC) A, Naval Support Activity Mid-South, Millington, Tennessee.



EXPLANATION

NAVAL SUPPORT ACTIVITY MID-SOUTH BOUNDARY

MILLINGTON CITY BOUNDARY

190 — SUBSURFACE CONTOUR -- Shows altitude of base of sand and gravel in the alluvial-fluvial deposits aquifer. Dashed where approximate. Hachures indicate closed depression. Contour interval 10 feet. Datum is NGVD 29

215 — WELL -- Number is altitude of base of sand and gravel in the alluvial-fluvial deposits aquifer, in feet. Datum is NGVD 29

Figure 5. Altitude of the base of sand and gravel in the lower alluvium or fluvial deposits at Area of Concern (AOC) A, Naval Support Activity Mid-South, Millington, Tennessee.

Water-level data were collected from wells in the AOC A study area in February and March 2000 and a potentiometric-surface map of the A1 aquifer was constructed (fig. 7). The potentiometric-surface map of the A1 aquifer for February and March 2000 is similar to the previous potentiometric-surface maps of the alluvial-fluvial deposits aquifer for April and October 1996 (Carmichael and others, 1997). Overall, water-levels for the February and March 2000 map are about 3 feet lower than the average water levels for April and October 1996. The February and March 2000 map also shows steep gradients and highest water-levels in the scarp area located in the northeastern part of the study area where the A1 aquifer transitions from the alluvial-fluvial deposits aquifer to the upper part of the Cockfield aquifer. This transition occurs near the 260-foot potentiometric contour (fig. 7). A ground-water divide occurs southeast of the airfield area. Ground-water flow directions generally are to the northwest in most of the model area. A depression in the potentiometric surface occurs in an off-base location in the northwestern part of the area where water levels in the A1 aquifer are at an altitude of less than 225 feet. This depression coincides with an area where data collected during monitoring-well installations show that the alluvial-fluvial deposits aquifer thickens and, on the basis of relatively flat topography in the area, the Cockfield Formation consequently thins. Downward leakage of water locally through the Cockfield and Cook Mountain confining units is indicated by observed water levels in the A1 aquifer in this depression that are approximately equal in altitude to water levels in the Memphis aquifer in the area (Robinson and others, 1997, fig. 13). Downward leakage of water from the alluvial-fluvial deposits aquifer to the Memphis aquifer has been identified on the basis of depressed water levels in the alluvial-fluvial deposits aquifer at various locations in the Memphis area (Parks, 1990).

Continuous water-level data are available for about 9 years (1995 to 2004) at well Sh:U-101 screened in the fluvial deposits located south of the western end of the airfield apron (fig. 7) at the site of the aquifer test conducted by the USGS in 1995 (Carmichael and others, 1997). These data are indicative of the timing and magnitude of water-level fluctuations in the alluvial-fluvial deposits aquifer, the primary part of the A1 aquifer in the AOC A study area. The hydrograph for well Sh:U-101 (fig. 8) shows short- and long-term water-level fluctuations in response to seasonal and annual changes in recharge. Water levels have fluctuated between 3 and 8 feet annually in this well during the period of record (1995-2004). On the basis of periodic measurements, water levels throughout the A1 aquifer in the study area generally fluctuate by about 1 to 5 feet annually (Robinson and others, 1997). The hydrograph for well Sh:U-101 shows no obvious trends, increasing or decreasing, in water levels, and no significant effects from pumping on the A1 aquifer within the study area are indicated.

Simulation of Ground-Water Flow

The physical system, described in the hydrogeology section of this report, provides the framework for design and calibration of a numerical ground-water-flow model of AOC A. Models that simulate the flow of water through aquifers are useful tools to test the understanding and conceptualization of a flow system. Although a model is necessarily a simplification of the physical system, the model should be consistent with all known hydrogeologic observations. The ground-water-flow model code used in this study, MODFLOW-2000, was developed by McDonald and Harbaugh (1988) and was recently updated (Harbaugh and others, 2000). MODFLOW uses the finite-difference technique to solve the ground-water-flow equation for three-dimensional, steady or non-steady flow in a heterogeneous and anisotropic medium.

A steady-state model of the A1 aquifer in the AOC A study area was constructed and calibrated to conditions of February and March 2000. Following model calibration, a particle-tracking simulation was used to analyze ground-water-flow paths from selected locations within AOC A.

Conceptual Model

The modeled A1 aquifer consists of the alluvial-fluvial deposits aquifer within most of the modeled area and the upper part of the Cockfield aquifer in the scarp area and to the northeast. As described in the hydrogeology section of this report, the alluvial-fluvial deposits are a coarsening downward sequence that generally is composed of silty sand or sandy silt in the upper part, and sand or sand and gravel through the remaining part, but with gravel more common in the lower part. Additionally, hydraulic conductivity generally is lowest in the upper part of the formation and increases with depth. Recharge to the modeled aquifer occurs as leakage from the overlying loess. Ground water does not discharge to streams or springs anywhere within the model area. Ground water leaves the modeled area through a constant-head boundary at the 225-foot potentiometric contour that defines a depression in the potentiometric surface in the alluvial-fluvial deposits aquifer (fig. 7). This constant-head boundary is near an area where the Cockfield confining unit is thought to thin and where water moves downward and out of the A1 aquifer.

Model Assumptions

The following assumptions were made in the development of the flow model of the hydrologic system in the AOC A study area:

1. The A1 aquifer is assumed to be in steady-state conditions because water levels in February-March 2000 were relatively stable (fig. 8).