Prepared in cooperation with the
UNITED STATES AIR FORCE,
ARNOLD AIR FORCE BASE

Introduction

Arnold Air Force Base (AAFB) occupies about 40,000 acres in Coffee and Franklin Counties, Tennessee (fig. 1). The primary mission of AAFB is to support the development of aerospace systems. This mission is accomplished in part through test facilities at Arnold Engineering Development Center (AEDC), which occupies about 4,000 acres in the center of AAFB. The AAFB is underlain by gravel and limestone aquifers, the most productive of which is the Manchester aquifer. The Manchester aquifer is the primary source of domestic drinking water in the area. Ground-water contamination in this aquifer in and near the AAFB has been well documented in numerous investigations (CH2M HILL, 1999; 2001; Williams, 2003). Several synthetic volatile organic compounds (VOCs), primarily chlorinated solvents, have been identified in ground-water samples collected at several solid waste management units (SWMUs) at AAFB.

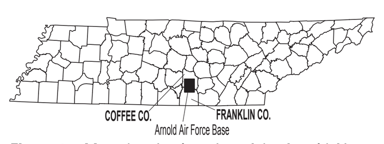

Figure 1. Map showing location of the Arnold Air Force Base area in Coffee and Franklin Counties, Tennessee.

The occurrence of VOC contamination and domestic drinking-water wells raised the concern that the private ground-water supplies that are hydraulically downgradient from AEDC could be affected by transport of VOCs in the ground water. Although the towns of Manchester and Tullahoma no longer use the Manchester aquifer for their water needs, rural wells in the area still are sources of water for domestic and agricultural use, and a need exists for a better understanding of the ground-water flow system within the Manchester aquifer in and near the AAFB. To address this need, the U.S. Geological Survey (USGS), in cooperation with the U.S. Air Force, AAFB, conducted a comprehensive study of the ground-water resources in the AAFB area. As part of the investigation, water-level measurements were collected from 452 wells in May 2002 and from 473 wells in October 2002. The water-level measurements were used to map the potentiometric surface and to determine the general direction of the ground-water flow in the aquifer. This map report, which is based on those measurements, shows the altitude of the potentiometric surface of the Manchester aquifer at AAFB and in surrounding areas. These potentiometric maps of the Manchester aquifer provide useful information to aid in understanding ground-water and contamination flow paths in and near AAFB. The area of investigation extends outward to nearby major hydrologic and physiographic features that are important boundaries to the regional ground-water system. These features include the Highland Rim escarpment, Bradley Creek, Woods Reservoir, Elk River, and Rock Creek (fig. 2).

Hydrologic Setting

The AAFB area is located in the eastern part of the Highland Rim physiographic section (Fenneman, 1938). Topography in the AAFB area ranges from relatively flat, poorly drained uplands to well-dissected, sloping escarpments. A broad topographic high transects the AAFB area. Surface drainage to the north and west of this terrain feature flows toward the Duck River, and is impounded at Normandy Lake, whereas drainage to the east and south flows toward the Elk River, and is impounded at Woods Reservoir.

The AAFB area is located in a fractured carbonate terrane covered by regolith derived from the weathering of carbonates of Mississippian age (fig. 3). These units compose (in descending order): the St. Louis Limestone, the Warsaw Limestone, and the Fort Payne Formation (Wilson, 1976). Regolith in the AAFB area is typically 10 to 100 feet thick and consists primarily of clayey chert rubble with some silt and sand. Typically, the regolith grades upward from gravel-size chert rubble at the top of bedrock to clay-size chert particles with silt, sand, and clay at land surface (Burchett, 1977). Bedrock underlying the regolith consists of the Fort Payne Formation, which is an indurated siliceous limestone containing many chert nodules and platy chert stringers. The Fort Payne bedrock in the AAFB area is generally 20 to 230 feet thick. The upper part of the Fort Payne bedrock contains many fractures and solution openings. Underlying the Fort Payne Formation is the Chattanooga Shale, which consists of 20 to 30 feet of fissile, black, carbonaceous shale. The Chattanooga Shale is considered to be the base of the fresh ground-water system in the study area (Haugh and Mahoney, 1994; Haugh, 1996).

The ground-water system above the Chattanooga Shale can be divided into three different zones or aquifers (Haugh and Mahoney, 1994): the shallow aquifer, the Manchester aquifer, and the Fort Payne aquifer (fig. 3). The aquifers differ from one another in degree of weathering, amount of chert, and type of weathering product. The aquifers are not separated by confining units of any significant lateral extent; therefore, water is free to flow between these zones at most locations. The shallow aquifer is described as alluvial, residual silt, clay, sand, and clay-size chert particles of the upper part of the regolith; is not continuous throughout the AAFB area; and is perched at some locations. The Manchester aquifer, the primary drinking-water aquifer in the area, consists of chert rubble at the base of the regolith and solution openings in the upper part of the bedrock (Burchett and Hollyday, 1974). The Fort Payne aquifer consists of dense, cherty limestone in the Fort Payne Formation where solution openings are less developed. The base of the Fort Payne aquifer is the Chattanooga Shale (Haugh and Mahoney, 1994; Haugh, 1996).

AEDC is located on the top of a local dome-shaped geologic structure that trends southwest to northeast through the industrial area (Haugh and Mahoney, 1994; Haugh, 1996). Regionally the geologic formations dip to the east and southeast. The primary set of fracture traces in these formations is oriented northwest to southeast. A secondary set of fracture traces is oriented northeast to southwest. These fracture traces, particularly where they are oriented parallel to the geologic dip, potentially provide preferential pathways for ground-water flow through the bedrock. The dome structure and fractures in the bedrock influence surface-water and ground-water flow directions in the AAFB area (Haugh and Mahoney, 1994; Haugh, 1996).

Stratigraphy	Thickness, in feet	Lithology	Hydrogeologic unit	AEDC unit designation	Natural character of aquifer
Regolith derived from in-situ weathering of the St. Louis Limestone, Warsaw Limestone, and Fort Payne Formation	10-100	Clay, silt, and sand with some chert and rock fragments.	Shallow aquifer	Shallow aquifer	Low producing wells, shallow ground-water circulation, low dissolved solids, and bicarbonate dominant anion.
		Rock fragments, chert gravel, and rubble with some clay.	Manchester aquifer, upper part	Intermediate aquifer	Good producing wells, rapid ground-water circulation, low dissolved solids, and bicarbonate dominant anion.
Fort Payne Formation	20-230	Fractured and dissolutional cherty limestone and siltstone.	Manchester aquifer, lower part	Deep aquifer, upper part	
		Dark gray siltstone; dense, cherty limestone; and bedded chert. Few fractures.	Fort Payne aquifer	Deep aquifer, lower part	Low well yield, slow ground-water circulation, high dissolved solids, and high sulfate.
Chattanooga Shale	20-30	Dark grayish black, carbonaceous shale.	Chattanooga confining unit	Chattanooga confining unit	Confining unit.

Figure 3. Stratigraphy, lithology, and hydrogeologic units for the Arnold Air Force Base area, Tennessee. (Modified from Haugh and Mahoney, 1994.)

Explanation of Potentiometric Surface Maps

The ground-water flow system was investigated by measuring base flow in streams (Robinson and Haugh, 2004), measuring water levels in wells, and by constructing two potentiometric-surface maps (figs. 2 and 4) of the Manchester aquifer in the area. During May 2002, water-level data were collected from 176 private wells and 276 monitoring wells. These measurements were made when water levels were near seasonal highs (fig. 5). Water-level altitudes in the wells ranged from 931 to 1,113 feet above NGVD 29 in May 2002. During October 2002, water-level data were collected from 193 private wells and 280 monitoring wells. These measurements were made when water levels were near seasonal lows (fig. 5). Water-level altitude in the wells ranged from 928 to 1,104 feet above NGVD 29 in October 2002. Potentiometric surfaces were mapped by contouring altitudes of water levels measured in wells completed in the Manchester aquifer and at 13 springs.

Topography and surface drainage patterns influence the shape of the potentiometric-surface map. The AEDC facility is on the ground-water divide, which runs northeast to southwest and generally coincides with the Duck River-Elk River surface-water divide. A broad saddle in the main ground-water divide separates a ground-water high southwest of AEDC from a larger, broader ground-water high north of AEDC. Overall, ground water generally flows from the main ground-water divide area toward the northwest or toward the south or southeast, and discharges to the principal streams and reservoirs. Several troughs are present in the potentiometric surface. The most prominent trough trends northwest to southeast in the Crumpton Creek Basin (figs. 2 and 4). The trough parallels the main axis of Crumpton Creek, but generally is not coincident with Crumpton Creek. During seasonal water-level lows in October 2002, this trough extends upgradient and toward the northeast to the Sinking Pond area (fig. 4). Sinking Pond is a karst wetland that fills and drains seasonally with pond-stage levels essentially identical to nearby ground-water levels (Wolfe, 1996).

The major human-induced stress on the ground-water system at AEDC is dewatering of the aquifers at the J4 test cell (a deep excavation in which rocket engines are tested) where a cone of depression has formed within the potentiometric surface of the Manchester aquifer (figs. 2 and 4). Approximately 105 gal/min of ground water are pumped from a collection system which surrounds the J4 test cell and extends to a depth of about 250 feet below land surface (Haugh, 1996). Dewatering also occurs, in lesser amounts and at shallower depths, at several other test facilities at AEDC.

Natural seasonal fluctuations of the potentiometric surface are related to seasonal changes in ground-water recharge. Ground-water levels are normally highest during the spring months following the winter period of high precipitation and low evapotranspiration. Water levels recede during the summer in response to diminishing precipitation and high evapotranspiration, and are lowest in the fall. The average difference in water levels from wells measured in both May 2002 and October 2002 is about 9 feet. The largest seasonal changes in water level occur in the northern part of AAFB where seasonal changes of 20 feet or more are typical (MW-177 and MW-359, fig. 5).

The hydrograph in figure 5 shows ground-water-level trends in three wells completed in the lower part of the Manchester aquifer. The gradient between wells MW-359 and MW-551 reverses seasonally. Water-level altitudes in well MW-359 were at higher altitudes than levels in well MW-551 in spring 2002. However, water-level altitudes in well MW-359 were lower than levels in well MW-551 in fall 2002. The seasonal change in ground-water gradient between wells MW-551 and MW-359 is the result of the Crumpton Creek ground-water trough extending farther to the northeast toward the Sinking Pond area during seasonally low water times. This seasonal change in the potentiometric-surface map and ground-water gradients may affect the movement and shape of the SWMU 74 “northwest plume” (CH2M HILL, 2001; Williams, 2003). Additionally, near the ground-water divides in the northern part of AAFB where the potentiometric surface is relatively flat, the gradients, implied directions of flow, and ground-water divides for May 2002 (fig. 2) and October 2002 (fig. 4) may not be representative of all conditions that occur. For example, well MW-177 has higher water- level altitudes than well MW-359 in both the spring and fall when the regional water levels were measured, but well MW-177 has a lower water-level altitude than well MW-359 in June and July during part of the seasonal recession.

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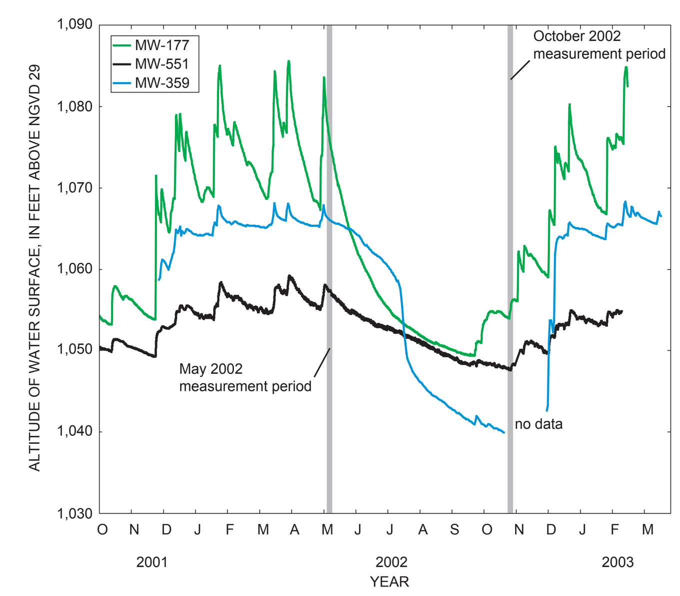


Figure 5. Water-level trends in wells MW-177, MW-551, and MW-359 from October 2001 through March 2003.

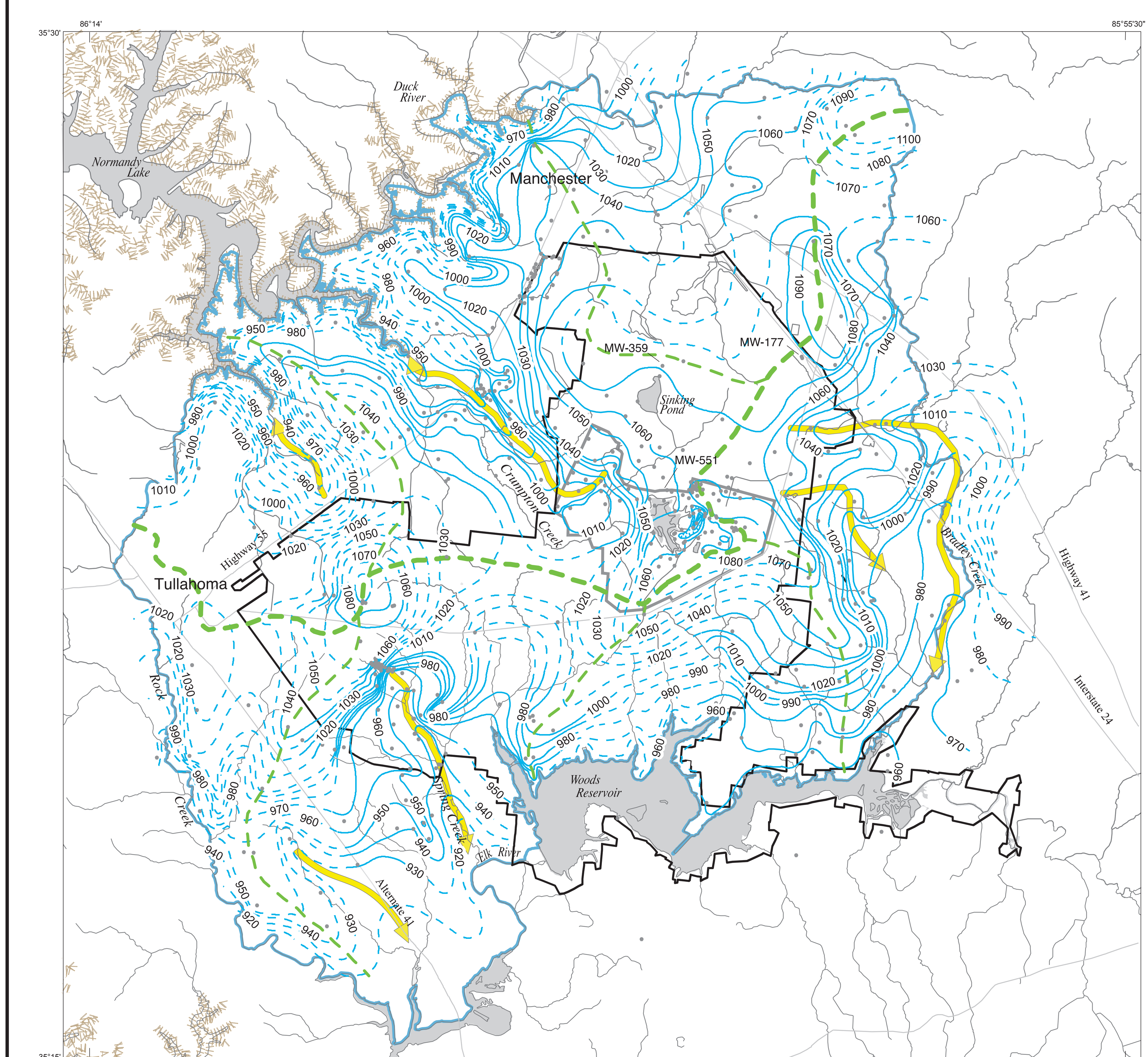
CONVERSION FACTORS AND DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	4,047	square kilometer
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
gallon per minute (gal/min)	0.06308	liter per second

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C), and temperature in °C to °F, as follows:

°F = (1.8 °C) + 32
°C = 5/9 (°F – 32)

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29); horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).



Base from U.S. Geological Survey topographic quadrangles, 1:24,000 Lambert Conformal Conic Projection, Standard parallels 35°15'N and 36°25'N, central meridian 86°W and USGS digital data, 1:100,000; final map, Conformal Conic projection Standard parallels 35°15'N and 36°25'N. central meridian 86°W

0 1 2 MILES
0 1 2 KILOMETERS

Figure 2. Altitude of the potentiometric surface of the Manchester aquifer in the Arnold Air Force Base area, Coffee and Franklin Counties, Tennessee, May 2002.

EXPLANATION

HYDROLOGIC BOUNDARY—Delineation of regional ground-water-flow system underlying Arnold Air Force Base

BOUNDARY OF ARNOLD AIR FORCE BASE

BOUNDARY OF ARNOLD ENGINEERING DEVELOPMENT CENTER (AEDC)

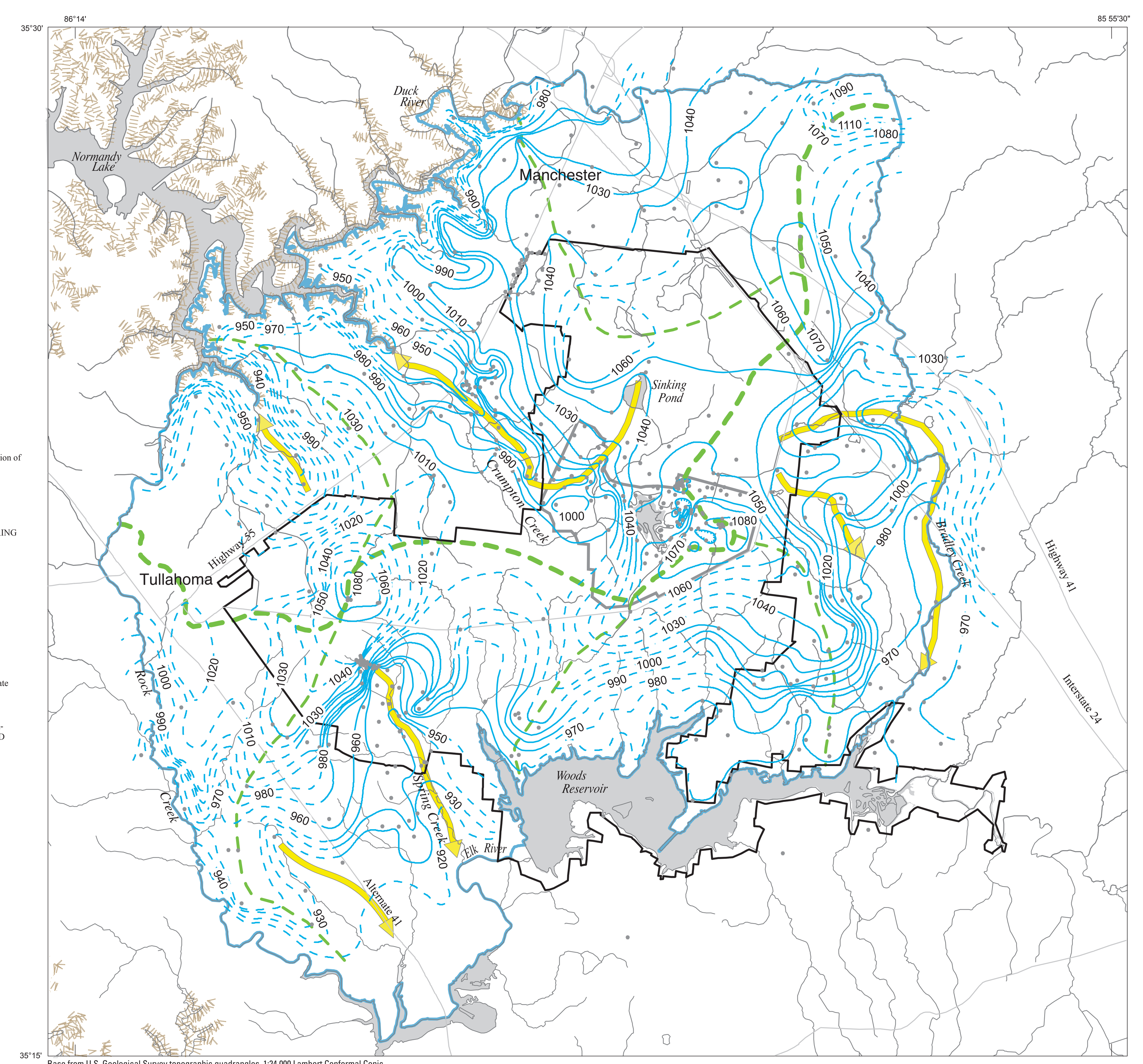
GROUND-WATER DIVIDE—Thin line represents subdivide

GROUND-WATER TROUGH

HIGHLAND RIM ESCARPMENT

960 POTENTIOMETRIC-SURFACE CONTOUR—Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Hachures indicate depression. Contour interval 10 feet. Datum is NGVD 29

WELL OR SPRING IN WHICH WATER-LEVEL MEASUREMENT WAS USED AS CONTROL



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0 1 2 MILES
0 1 2 KILOMETERS

Figure 4. Altitude of the potentiometric surface of the Manchester aquifer in the Arnold Air Force Base area, Coffee and Franklin Counties, Tennessee, October 2002.

POTENTIOMETRIC SURFACE OF THE MANCHESTER AQUIFER, ARNOLD AIR FORCE BASE, TENNESSEE, 2002

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2005