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Scientific Investigations Report 2006–5172

U.S. Department of the Interior
U.S. Geological Survey

Cover. Photograph of the direct-push drill rig used to collect sediment cores and construct piezometers and a photograph of flowing well MW6 at the U.S. Army Atterbury Joint Maneuver Training Center, near Edinburgh, Indiana.

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DIRK KEMPTHORNE, Secretary

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P. Patrick Leahy, Acting Director

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Conversion Factors

Multiply	By	To obtain
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	2.590	square kilometer (km^2)
foot per minute (ft/min)	0.3048	meter per minute (m/min)
foot per foot (ft/ft)	1	meter per meter (m/m)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8$$

Vertical coordinate information is referenced to North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

Hydrogeologic Framework and Ground-Water Flow in Quaternary Deposits at the U.S. Army Atterbury Joint Maneuver Training Center near Edinburgh, Indiana, 2002–2003

By Bret A. Robinson and Martin R. Risch

Abstract

A hydrogeologic framework was developed for unconsolidated Quaternary deposits at the U.S. Army Atterbury Joint Maneuver Training Center. The framework describes the potential for the occurrence of ground water on the basis of physiography and the distribution of geologic materials within the study area. Four geologic units—the Jessup, Trafalgar, Atherton, and Martinsville Formations—were identified, and their distribution was mapped as four hydrogeologic regions. The Jessup and Trafalgar Formations are fine-grained, poorly sorted tills. At least two facies of the Atherton Formation, the lacustrine and outwash facies, are in the study area. The Martinsville Formation includes materials deposited or reworked since the glacial period. With the exception of the Atherton Formation outwash facies, the Quaternary deposits are primarily fine-grained, silt- and clay-rich sediments that function as confining layers or aquitards. The Atherton Formation outwash facies includes sand and gravel deposits that constitute the primary aquifers in the study area. The four hydrogeologic regions mapped in this investigation are designated as the Bedrock, Jessup Till, Trafalgar Till, and Atherton Outwash Regions. Each region represents an area with a distinctive physiographic expression and vertical sequence of Quaternary deposits.

The Bedrock Region in the western and southwestern part of the study area commonly is underlain by 0 to 15 feet of Martinsville Formation resting directly on bedrock. Potential ground-water yields are limited. The Jessup Till Region in the southeastern part of the study area includes the uplands on either side of the stream valleys. Sediments commonly range from 30 to 90 feet in thickness. This region includes clay-rich till of the Jessup Formation and sand and gravel deposits of the Atherton Formation outwash facies; the Atherton Formation outwash facies tends to be thin, and ground-water yields will be moderate. The Trafalgar Till Region in the north and northwest-central part of the study area commonly is underlain by 10 to 30 feet of Trafalgar till or Trafalgar till over 25 to 50 feet of Jessup till. Within, separating, and beneath these tills are deposits of the Atherton Formation outwash facies—the sand and gravel deposits with the best potential to support a water-supply well. Generally, the outwash facies in this region are thin sand and gravel lenses, except in a few locations that are in excess of 30 feet thick. The Atherton Outwash Region is the lowland area associated with the major valleys in all but the far southwestern part of the study area. This region has the greatest thickness of outwash facies sands and gravels (often in excess of 20 feet), which are the primary aquifers.

In the Atterbury Joint Maneuver Training Center, the combined Atherton Outwash Region and the Trafalgar Till Region have the greatest potential as infiltration areas because of low topographic relief and(or) sandy soils. From water-level data collected in July and August 2003, horizontal ground-water flow was determined generally to be toward the Atherton Outwash Region and the valley of the Driftwood River to the east. Vertical hydraulic gradients were documented at nested well pairs. At two sites, upwardly directed gradients are reflected by flowing wells.

Ground-water discharge to surface water is likely in some eastern reaches of the valleys of Nineveh and Lick Creeks. In the valley of Nineveh Creek, potential for ground-water discharge is indicated by the presence of a flowing well, upwardly directed vertical hydraulic gradients, and ground-water heads that were higher than surface-water elevations. In the valley of Lick Creek, ground-water discharge also is indicated by the presence of flowing wells and ground-water heads that were higher than surface-water elevations.

Introduction

Through a variety of programs, the U.S. military has been obtaining environmental data, including information about water resources, at its facilities nationwide (U.S. Department of Defense, 2006). Information about ground-water resources is necessary for compliance with Federal water-pollution-control regulations and for water-quality-management programs. Facility-specific knowledge of the occurrence of ground water and an understanding of local ground-water-flow systems are required for development and protection of water supplies and for evaluation of potential or known environmental-quality concerns. The U.S. Geological Survey (USGS) has been assisting Department of Defense agencies on earth-science issues through the Department of

Defense Earth Science Program (2006). The USGS provides support for facility restoration, water management, geographical information, geologic assessments, and biological resources.

The U.S. Army Atterbury Joint Maneuver Training Center (referred to as Camp Atterbury) in central Indiana near Edinburgh (fig. 1) primarily has been a training facility for the U.S. Army and Indiana Army National Guard for more than 50 years. The Guard needed information about ground-water resources at Camp Atterbury to plan water supplies to support training and for environmental-management programs. The USGS previously had completed investigations of surface-water quality at Camp Atterbury (Risch, 2004; Robinson, 2004). The Guard requested the USGS complete an initial assessment of ground water sufficient to delineate a hydrogeologic framework for Camp Atterbury. The framework would provide a basis for evaluating environmental concerns and help focus future data collection.

During 2002 and 2003, the USGS collected geologic data and made hydrologic measurements to delineate the hydrogeologic framework for ground water beneath much of Camp Atterbury. The investigation was focused on the Quaternary deposits. Quaternary deposits are defined as all of the unconsolidated geologic materials above bedrock, including Pleistocene deposits, which are predominantly glacially derived, and Holocene deposits, which are from the postglacial epoch. Ground water within the Quaternary deposits has the greatest potential for contamination from activities at Camp Atterbury and for use as a potable-water supply. The data-collection network designed and installed for this investigation resulted in a permanent network of monitoring wells for use in any future investigations.

Purpose and Scope

This report documents the results of a hydrogeologic investigation of the Quaternary deposits at Camp Atterbury based on previously published information and additional data collection during 2002 and 2003. The investigation resulted in delineation of a hydrogeologic framework for the approximate northern two-thirds of the military facility that describes the potential for the occurrence of ground water, based on characterization of unconsolidated sediments in relation to their capability to store and transmit ground water. The report describes the hydrogeologic framework, defines areas of expected infiltration, and interprets directions of ground-water flow and ground-water/surface-water interactions. In addition, methods of data collection and interpretation are described.

The scope of work included collection and description of 12 sediment cores to refine the distribution of Quaternary sediments at Camp Atterbury, installation of 9 monitoring wells and 11 piezometers, and measurement of ground-water levels to interpret directions of flow. Measurements of surface-water levels at three locations were used to determine potential ground-water/surface-water interactions. Previously published information about the geology, physiography, topography, and soils of the area were consulted to aid in development of the hydrogeologic framework.

Description of Study Area

This description of the Camp Atterbury region is based on previously published information that describes facility history, hydrology, water use, physiography, topography, soils, and climate. The study area for the hydrogeologic-framework investigation comprised the approximate northern two-thirds of the Camp Atterbury property (fig. 2).

Site History

Camp Atterbury was established in 1942 as a 40,320-acre U.S. Army installation, and operations continued through 1968. The installation was a troop-training, military-hospital, and prisoner-of-war facility during World War II. Camp Atterbury was deactivated from 1948 through 1950 and again in 1954 after the Korean Conflict. In 1968 and 1969, approximately 7,000 acres were sold and the remaining U.S. Army property was redesignated the Atterbury Reserve Forces Training Area. At that time, the installation was placed under the control of the Indiana Army National Guard (Indiana Army National Guard, 1995). The facility is named the U.S. Army Atterbury Joint Maneuver Training Center.

The current mission of Camp Atterbury is to support training of the Army and Air National Guard; Army and Air Force Reserve; specialized units of the U.S. military; and emergency, public-safety, and law-enforcement personnel. In 2002, the year-round facilities and operations provided an expanded role as a mobilization site for processing and preparing soldiers and equipment to serve overseas.

Physical Setting

Camp Atterbury is in central Indiana about 30 mi south of Indianapolis (fig. 1). Nearby cities and towns include Edinburgh (population 4,505), less than 3 mi to the east of Camp Atterbury; Nineveh (population 4,133), less than 1 mi to the northwest; Franklin (population 19,463), about 8 mi to the north; and Columbus (population 39,059), about 6 mi to the southeast (Indiana Business Research Center, 2000).

In 2006, Camp Atterbury encompasses approximately 33,760 acres[1], spanning 4 to 6.5 mi by 9.5 mi (fig. 1). Most of the property is within northwestern Bartholomew County, with smaller parts in northeastern Brown and southern Johnson Counties. Nearby transportation routes include State Road 252 to the north, I-65 and U.S. Highway 31 to the east, State Road 46 to the south, and State Road 135 to the west. The study area for this investigation included the northern two thirds of the property, approximately 22,820 acres[1] north

[1]Area computed from maps of Camp Atterbury training areas and installation boundary (unpublished data, Indiana Army National Guard, 2002, Geographic Information System for Camp Atterbury), converted from square meters to acres by multiplying with a conversion factor of 0.0002471 acres per square meter.

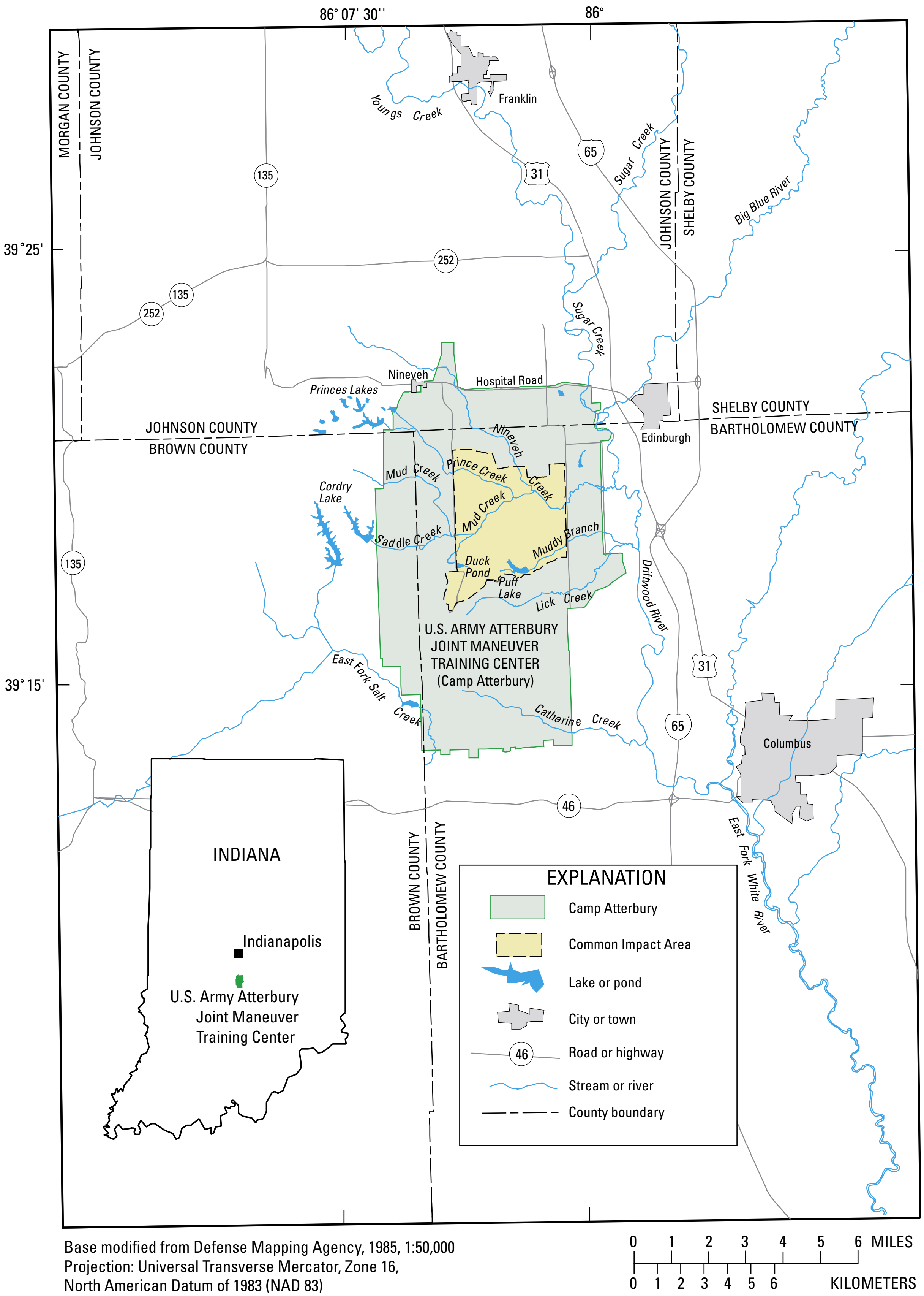


Figure 1. U.S. Army Atterbury Joint Maneuver Training Center and surrounding region near Edinburgh, Indiana.

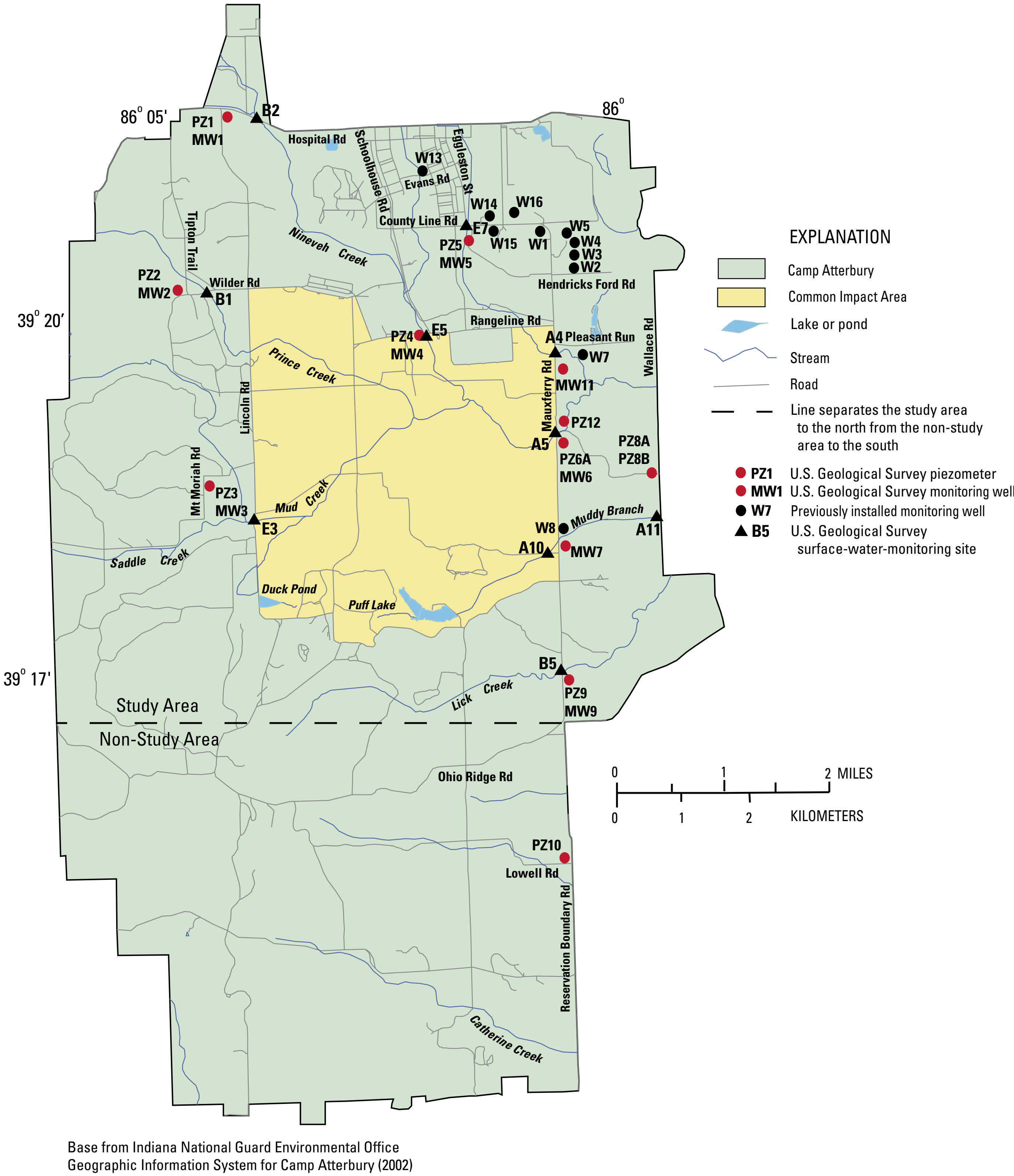


Figure 2. Locations of U.S. Geological Survey monitoring wells, piezometers, and selected surface-water-monitoring sites, and existing monitoring wells at the U.S. Army Atterbury Joint Maneuver Training Center near Edinburgh, Indiana.

of Ohio Ridge Road (fig. 2). Within the study area is the approximately 6,000-acre Common Impact Area for the weapons-training, aerial-gunnery, and bombing ranges. For safety reasons, the Common Impact Area was not directly investigated in this study.

Camp Atterbury (fig. 1) is in the East Fork White River Basin; more than 90 percent of surface water at the property drains eastward to the Driftwood River (Risch, 2004), a tributary of the East Fork White River. The largest stream draining the property is Nineveh Creek, with a drainage area of approximately 44 mi^2 (fig. 2). Nineveh Creek originates upstream from the northern property boundary and, within the boundaries of Camp Atterbury, receives drainage from Prince Creek, Mud Creek, Saddle Creek, and unnamed tributaries. Muddy Branch, Lick Creek, and Catherine Creek (with drainage areas of 2 to 6 mi^2) are headwater streams that originate inside the property boundary. Less than 10 percent of surface water at Camp Atterbury drains southwest to East Fork Salt Creek. The study area for the hydrogeologic-framework investigation includes all surface-water-drainage areas, with the exception of Catherine Creek and East Fork Salt Creek. Several manmade lakes, including Puff Lake, are within Camp Atterbury's boundaries. A number of large manmade lakes with residential communities—Princes Lakes and Cordry Lake—are upstream from Camp Atterbury (fig. 1).

Camp Atterbury, along with many private residences in the vicinity, is served by the Princes Lakes public-water-supply system that obtains water from wells in the Big Blue River Valley northwest of Edinburgh. In the area from the Camp Atterbury boundary east and southeast to the Driftwood River (fig. 1), at least 50 private water-supply wells serve individual residences, according to the Indiana water-well database (Indiana Department of Natural Resources, 2003). The median depth of these wells is approximately 50 ft, and most wells are completed in unconsolidated Quaternary deposits.

Physiography, Topography, and Soils

Camp Atterbury falls within three of the physiographic divisions (fig. 3) described by Gray (2000). The northern part—in southern Johnson County, northeastern Brown County, and northwestern Bartholomew County—is within the New Castle Till Plains and Drainageways division, a till plain of low relief crossed by many major tunnel valleys. The southwestern part of Camp Atterbury—in eastern Brown County and western Bartholomew County—is within the Norman Upland division, an area of high local relief that has bedrock at or near the land surface. The central and southeastern part—in Bartholomew County—is within the Scottsburg Lowland division, an area of low relief where glacial deposits as much as 150 ft thick cover bedrock.

The surface topography of Camp Atterbury includes flat to rolling terrain in the north and northeast to steep, hilly terrain in the south and southwest. Terrain along Nineveh Creek and the Driftwood River (fig. 1) to the east is lowland flanked by terraces. Land-surface elevations range from about 645 ft where Nineveh Creek crosses the eastern property boundary to approximately 960 ft at the drainage divide between the Lick Creek and East Fork Salt Creek Watersheds. Elevation in the central part of Camp Atterbury ranges from 740 to 820 ft (Defense Mapping Agency, 1985).

Numerous soil associations (table 1) are recognized at Camp Atterbury (Noble and others, 1990; Sturm, 1979). Their slopes, drainage characteristics, and position on the landscape influence infiltration capacity and the potential for recharge to underlying aquifers.

Climate

Camp Atterbury has a humid continental climate, characterized by distinct winter and summer seasons with large annual temperature ranges. Mean monthly temperatures at Columbus, Indiana, about 6 mi southeast of the study area, range from about 28°F in January to about 76°F in July. At Columbus, normal annual precipitation is 42 in.; normal monthly precipitation ranges from about 2.6 in. during February to about 4.6 in. during May (Midwestern Regional Climate Center, 2004).

Previous Studies

Previous studies at Camp Atterbury provided information about geology and water resources that was used in the 2002 and 2003 hydrogeologic-framework investigation. A general understanding of the geology of the Camp Atterbury region was derived from Schneider and Gray (1966), who describe the geology of the upper East Fork White River drainage basin in south-central Indiana. Maps from that report had a coarse scale for the study area in Camp Atterbury; additional hydrogeologic data were collected and evaluated during the 2002 and 2003 investigation.

A total of 16 monitoring wells had been constructed at Camp Atterbury prior to 2002. In the vicinity of a closed sanitary landfill at Mauxferry Road and County Line Road, five monitoring wells were constructed by the U.S. Army Environmental Hygiene Agency (1981) to evaluate shallow ground-water quality. In the vicinity of several former waste-disposal sites in the northeastern part of Camp Atterbury, the Military Department of Indiana constructed 11 monitoring wells to evaluate shallow ground-water quality (Military Department of Indiana, 1997). Geologic logs from these wells were consulted when locations for hydrogeologic-data collection were selected for this investigation.

A network of 27 surface-water stations was established for a base-wide assessment of chemical and biological quality of surface water at Camp Atterbury by the USGS in 2000 and 2001 (Risch, 2004). An inventory of aquatic macroinvertebrates in the streams of Camp Atterbury in 2003 was based on

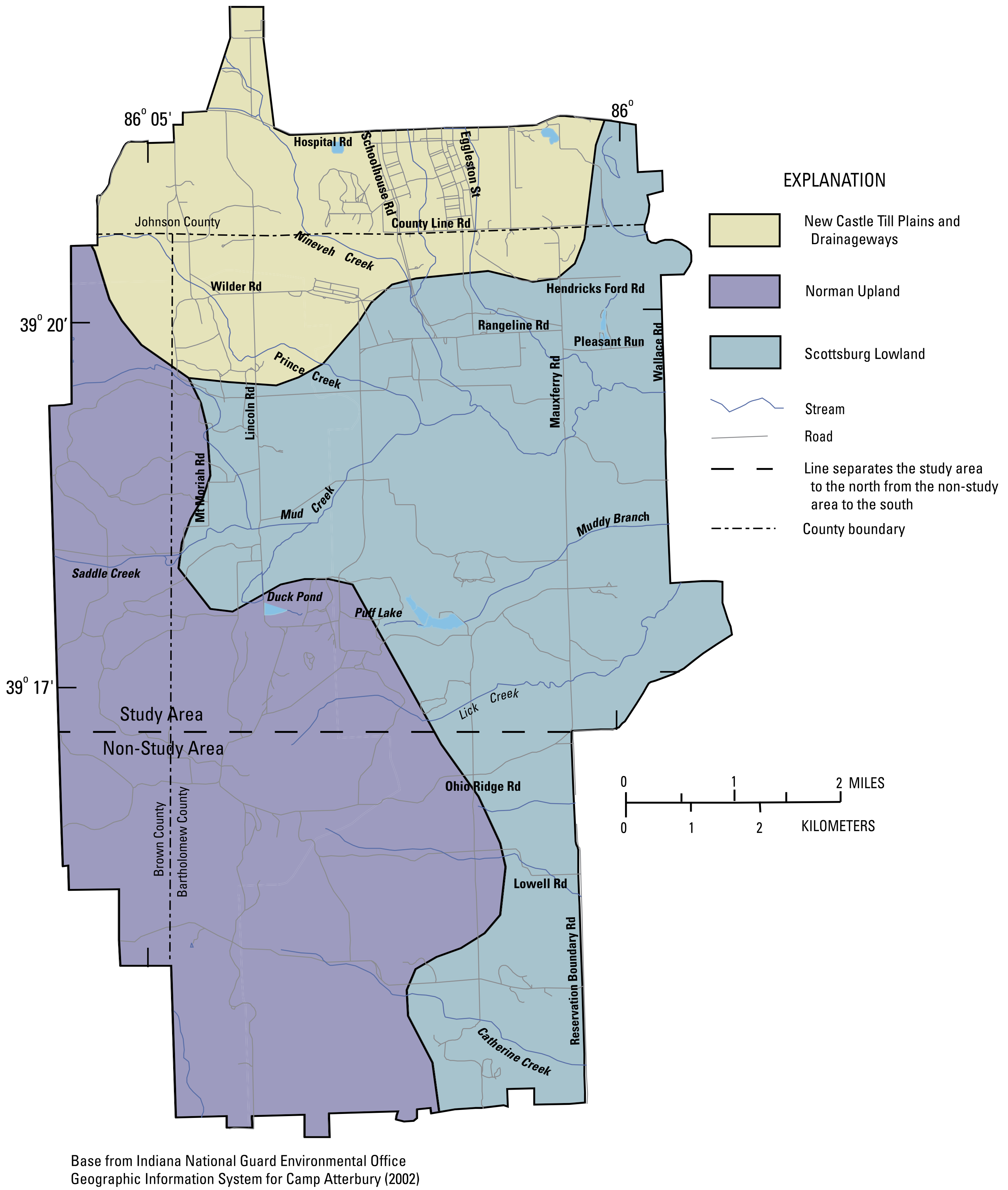


Figure 3. Physiographic divisions at the U.S. Army Atterbury Joint Maneuver Training Center near Edinburgh, Indiana.

Table 1. Soil associations at the U.S. Army Atterbury Joint Maneuver Training Center near Edinburgh, Indiana.

Soil association	Description	Landscape position
Berks-Wellston-Trevlac	Moderately deep and deep, moderately sloping to very steep, well-drained soils formed in loess and in material weathered from shale, siltstone, and sandstone	Uplands.
Hickory-Cincinnati-Rossmoyne	Deep, gently sloping to very steep, well-drained and moderately well-drained soils formed in loess and in underlying loamy and silty glacial drift and till	Uplands.
Miami-Hennepin	Well drained, deep, gently sloping to very steep soils formed in a thin silty layer and underlying glacial till	Uplands.
Crosby-Miami-Rensselaer	Deep, nearly level to strongly sloping, somewhat poorly drained, well-drained, and very poorly drained soils formed in loess and underlying loamy glacial till, in glacial till, and in stratified loamy sediments	Uplands and terraces.
Pekin-Chetwynd-Bartle	Deep, nearly level to very steep, somewhat poorly drained to well-drained soils formed in silty and loamy deposits	Terraces.
Rensselaer-Whitaker	Deep, very poorly drained and somewhat poorly drained, moderately fine-textured and medium-textured, nearly level and gently sloping soils formed in loess and underlying glacial till, in glacial till, or in outwash	Terraces.
Stonelick-Chagrin	Deep, nearly level, well-drained soils formed in loamy alluvial deposits	Flood plains.
Genesee-Ross-Shoals	Deep, well-drained and somewhat poorly drained, nearly level soils formed in loamy alluvium	Bottom lands.

this network (Robinson, 2004). These surface-water stations were included in the design of the data-collection network for the hydrogeologic-framework investigation.

Methods of Study

Methods used for the investigation included design of a data-collection network, collection and description of sediment cores, installation of monitoring wells and piezometers, and measurement of ground-water and surface-water levels. Data collection was completed during 2002 and 2003. The data-collection network designed and installed for this investigation resulted in a permanent network of monitoring wells for use in future investigations.

Design of the Monitoring Network

The monitoring network developed for this investigation consisted of 11 monitoring wells previously constructed for environmental investigations at Camp Atterbury (U.S. Army Environmental Hygiene Agency, 1982; Military Department of Indiana, 1977), 10 surface-water stations from a previous investigation of water quality (Risch, 2004), and 9 monitoring wells and 11 piezometers installed for this investigation. In this report, the term “monitoring well” is used to describe wells with a diameter of 2 in. or more that were constructed to permit sampling for water quality. The term “piezometer” is used to describe 1-in.-diameter wells that were installed for measurement of water levels only.

Previously constructed monitoring wells were installed for investigations at specific sites in northeastern Camp Atterbury and, therefore, did not provide information for other parts of the facility. Locations for monitoring wells and piezometers installed for the hydrogeologic-framework investigation were selected to provide areal coverage and target areas where water-bearing sediments (sand and gravel) were expected. Locations were selected to be accessible by the drill rigs and to avoid buried utilities and unexploded ordnance. In some cases, hydrogeologic information gathered from drilling was used to select the next location for drilling.

Monitoring wells and piezometers installed by the USGS were named, using a combination of letters and numbers (fig. 2 and table 2). The letters designate a monitoring well (MW) or piezometer (PZ), and the number designates each of the 12 monitoring locations. For locations where shallow and deep piezometers were installed, the deep one has the suffix A and the shallow one has the suffix B. Previously installed monitoring wells were designated with the prefix W and the

Table 2. Selected characteristics of monitoring wells, piezometers, and water-supply wells at the U.S. Army Atterbury Joint Maneuver Training Center near Edinburgh, Indiana.

[USGS, U.S. Geological Survey; ft, feet; in., inch; MW, monitoring well; PZ, piezometer; W, existing monitoring well; WS, water-supply well; --, unknown or not listed]

Name	USGS site identification	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Screened interval (ft below land surface)	Land-surface elevation (ft)	Height of measuring point above land surface (ft)	Screen length (ft)	Casing diameter (in.)
MW1	392145086041401	39° 21’ 45”	86° 04’ 14”	42 - 46	728.3	3.7	4	2
PZ1	392145086041501	39° 21’ 45”	86° 04’ 15”	12.5 - 22.5	731.6	4.2	10	1
MW2	392011086044301	39° 20’ 10”	86° 04’ 43”	22 - 26	732.6	3.4	4	2
PZ2	392011086044302	39° 20’ 11”	86° 04’ 43”	20 - 25	732.7	-.4	5	1
MW3	391824086042901	39° 18’ 24”	86° 04’ 29”	18 - 22	692.4	2.6	4	2
PZ3	391824086042902	39° 18’ 24”	86° 04’ 29”	18 - 23	693.3	-.5	5	1
MW4	391948086020501	39° 19’ 48”	86° 02’ 05”	32 - 40	679.5	3.2	8	2
PZ4	391948086020502	39° 19’ 48”	86° 02’ 05”	12.5 - 22.5	679.3	4.0	10	1
MW5	392037086013301	39° 20’ 36”	86° 01’ 33”	24 - 28	689.4	3.6	4	2
PZ5	392037086013302	39° 20’ 37”	86° 01’ 33”	16.5 - 21.5	689.1	3.9	5	1
MW6	391855086003301	39° 18’ 55”	86° 00’ 33”	26 - 34	657.1	2.3	8	2
PZ6A	391856086003001	39° 18’ 57”	86° 00’ 30”	8.5 - 13.5	657.2	3.8	5	1
MW7	391753086003101	39° 17’ 53”	86° 00’ 31”	20.5 - 25.5	668.8	3.3	5	2
PZ8A	391835085592601	39° 18’ 35”	86° 59’ 26”	24 - 29	647.6	3.9	5	1
PZ8B	391835085592602	39° 18’ 35”	86° 59’ 26”	12 - 17	647.9	3.3	5	1
MW9	391650086003101	39° 16’ 50”	86° 00’ 31”	52 - 62	662.4	3.4	10	2
PZ9	391649086003101	39° 16’ 49”	86° 00’ 31”	37 - 42	662.1	3.1	5	1
PZ10	391513086002801	39° 15’ 13”	86° 00’ 28”	14.5 - 19.5	676.3	4.0	5	1
MW11	391918086003301	39° 19’ 18”	86° 00’ 33”	22 - 30	677.7	3.2	8	2
PZ12	391859086003301	39° 18’ 59”	86° 00’ 33”	10.5 - 15.5	659.2	3.9	5	1
W1	--	39° 20’ 43”	86° 00’ 39”	45 - 55	743.8	1.6	10	2
W2	--	39° 20’ 22”	86° 00’ 22”	13 - 23	689.8	1.2	10	2
W3	--	39° 20’ 28”	86° 00’ 21”	10 - 20	699.8	1.3	10	2
W4	--	39° 20’ 36”	86° 00’ 23”	27 - 37	714.3	1.6	10	2
W5	--	39° 20’ 42”	86° 00’ 28”	36 - 46	716.9	1.7	10	2
W7	--	39° 19’ 39”	86° 00’ 10”	5 - 15	653.1	-.5	10	2
W8	--	39° 18’ 08”	86° 00’ 30”	20 - 30	664.6	-.5	10	2
W13	--	39° 21’ 11”	86° 02’ 03”	22.3 - 32.3	711.2	-.5	10	2
W14	--	39° 20’ 49”	86° 01’ 18”	19.3 - 29.3	708.7	-.4	10	2
W15	--	39° 20’ 44”	86° 01’ 11”	--	716.6	-.6	--	2
W16	--	39° 20’ 46”	86° 01’ 06”	--	727.5	-.5	--	2
WS22	--	--	--	50 - 70	--	--	20	5
WS42	--	--	--	90 -120	--	--	20	5

number assigned when they were constructed in 1981 or 1996. Water-supply wells were designated with the prefix WS. (By USGS policy and Indiana Code IC 5-14-3-4 [Indiana Legislative Services Agency, undated], the location of water-supply wells are identified neither by coordinates nor shown on maps.)

The hydrogeologic data collection associated with this investigation resulted in the construction and rehabilitation of a network of monitoring wells and piezometers coupled with surface-water stations, all surveyed to a common datum. The combination of new and previously constructed wells and piezometers, along with the surface-water stations, provided a network for synoptic water-level measurements sufficient to describe ground-water-flow directions and ground-water/surface-water interactions.

Hydrogeologic-Data Collection

Hydrogeologic information was obtained through a review of previous site-specific and regional studies and additional data collection at Camp Atterbury. Installation of monitoring wells and piezometers included collection of sediment cores and geophysical logging. Water levels were measured in 20 monitoring wells and 11 piezometers and at 10 surface-water stations. The data were compiled and used to interpret generalized hydrogeologic regions, ground-water-flow directions, and vertical hydraulic gradients.

Boreholes

Drilling for this investigation was completed at 12 locations (fig. 2) during October and November 2002, April 2003, and June 2003. At seven locations, a monitoring well and a piezometer were installed. At three locations, only piezometers were installed. At the remaining two locations, only monitoring wells were installed. All the drilling equipment and tools were pressure washed prior to use in each borehole.

A truck-mounted hollow-stem auger drill rig (fig. 4) was used to drill nine boreholes (eight were drilled to bedrock). A nearly continuous core of sediment was collected with a 3-in.-

Figure 4. Photographs of (A) the truck-mounted hollow-stem auger drill rig used to collect sediment cores and construct monitoring wells and (B) an example core collected with this drill rig at the U.S. Army Atterbury Joint Maneuver Training Center, near Edinburgh, Indiana.

diameter, 5-ft-long core barrel advanced inside the lead auger. Occasionally, sediment or borehole conditions interfered with recovery of a continuous core. Sediments that were not cohesive (sand) fell from the bottom of the core barrel when it was removed from the borehole or when subsurface-water pressure forced loose sediments into the bottom of the core barrel.

A truck-mounted direct-push drill rig (fig. 5) was used for drilling boreholes in which piezometers were installed. The direct-push drill rig made a 2-in.-diameter borehole and retrieved a 1.5-in.-diameter sediment core from a hydraulically advanced 4-ft-long coring tube with an acrylic liner. Nearly continuous sediment cores were collected from boreholes that ranged in depth from 13.5 to 42 ft.

Geologic logs were developed from descriptions of the sediment cores and were used to select the depth and screen length for monitoring wells and piezometers. In most cases, monitoring wells were screened in the deepest water-bearing unit and, where paired with a piezometer, the depth of the piezometer was selected to provide water-level data from a different shallow water-bearing unit or from a different depth in the same unit as the monitoring well. Sediment cores were examined and described with methods consistent with those in Storer (1994).

Geophysical logs of natural-gamma activity were made with a portable digital logger at nine of the drilling locations—seven monitoring-well locations and two locations where water-supply wells had been drilled recently. The logging tool was lowered with a cable and winch into the hollow-stem augers or well casing. All geophysical logs were run at a rate of 10 ft/min. The gamma-tool electric signal was logged digitally every 0.2 ft, and the data value and depth were recorded with logging software on a laptop computer. Borehole logs of natural gamma activity are used widely for identifying textural characteristics of subsurface materials (Keys, 1990). Fine-grained sediments that contain abundant clay tend to contain naturally occurring radioisotopes that emit gamma radiation. The intensity of natural-gamma radiation emitted by subsur-

Figure 5. Photographs of (A) the direct-push drill rig used to collect sediment cores and construct piezometers at the U.S. Army Atterbury Joint Maneuver Training Center, near Edinburgh, Indiana, and (B) a core collected with this drill rig.

face layers that contain more clay is larger than the intensity of radiation emitted by strata with less clay.

The geologic and geophysical logs for the boreholes provide a description of the thickness and type of geologic materials in the Quaternary deposits at Camp Atterbury. The geophysical logs were used to confirm and supplement visual descriptions of the geology made from the sediment cores. Geophysical logs collected inside the augers were affected by the change in thickness of the auger wall at joints, which made interpretations difficult. In several cases, the geophysical logs provided a better indication of the bedrock surface than could be obtained from the sediment cores. In general, however, the geophysical logs were of limited quality and geological interpretations were based primarily on data derived from the collected cores. Appendix 1 contains the geologic logs and includes a visual description of the sediment cores from the on-site geologist and the drill-rig operator. Geologic and well-construction data for the USGS-installed monitoring wells and piezometers are stored in the USGS National Water Information System (NWIS) database.

Monitoring Wells and Piezometers

Monitoring wells were constructed in 9 boreholes completed with the hollow-stem auger drill rig, and piezometers were constructed in 11 boreholes completed with the direct-push drill rig. Monitoring wells were constructed to be suitable for water-quality sampling and water-level measurements. Piezometers were constructed only for water-level measurements. At 8 of the 12 monitoring locations, two piezometers or one well and one piezometer were paired so that water levels could be measured at two depths in one aquifer or in two distinct aquifers separated by a confining layer.

Monitoring wells were constructed (fig. 6) with 2-in.-diameter polyvinyl chloride (PVC) casing and well screen. Piezometers were constructed (fig. 6) with 1-in.-diameter PVC casing and well screen. Monitoring well and piezometer screens ranged from 4 to 10 ft in length, with 0.01-in. slot size. A filter pack of clean silica gravel was placed in the borehole around the screen of monitoring wells if native sand did not collapse into the borehole and fill the annular space. The remaining opening around the casing was filled from the top of the filter pack to within a few feet of land surface with high-solids bentonite manufactured specifically for environmental-monitoring applications. For the monitoring wells, powdered bentonite and water were placed in a grout mixer and pumped through a tremie pipe down the annulus. For the piezometers, native sand was allowed to fill in around the screen. Dry granular bentonite chips were poured into the annular space not filled by collapsed natural materials to within 2 ft of the land surface.

Monitoring wells and piezometers were finished with either an above-ground riser that was enclosed with a painted-steel, lockable, protective cover or with a flush-mount well vault. Both enclosures were set in a concrete pad that extended from the top of the grout in the borehole to land surface. Wells and piezometers constructed by the USGS in 2002 and 2003 have a brass tablet set in the concrete pad. Painted steel posts and a red-, yellow-, and white-striped tubular marker surround monitoring-well and piezometer sites (fig. 7).

Selected characteristics (such as site identification, location, land-surface elevation, and screen length) of the monitoring wells and piezometers are presented in table 2. The screened interval for each well and piezometer is diagrammed in appendix 1 or appendix 2 with the geologic description at each monitoring location. Records of the monitoring wells installed by the USGS were filed with the Indiana Department of Natural Resources Division of Water. Well and water-level data were entered into the USGS National Water Information System (NWIS) database.

Monitoring wells and piezometers installed by the USGS were developed by pumping until the water appeared to be clear. The connection of the water level in the well to water in the aquifer in each of the previously installed wells was tested by measuring water-level recovery after displacement by a plastic slug temporarily inserted in each well. Where the connection was found to be poor, water was pumped from the well to improve the connection and the connection between the aquifer and well screen was re-tested. Eleven previously installed monitoring wells were determined to be suitable for water-level measurements and were incorporated into the monitoring network for this investigation.

Water-Level Measurements

Traditional surveying techniques and a high-resolution, survey-grade global positioning system (GPS) were used to determine the geographic coordinates, land-surface, and measuring-point elevations of the monitoring wells, piezometers, and surface-water stations in the monitoring network (table 2). To complete the GPS survey of the monitoring network, a temporary GPS base station was established at Camp Atterbury. Then, a GPS roving unit was taken to eight National Geodetic Survey permanent benchmarks in the surrounding area. With the known location and elevation of the benchmarks, the position and elevation of the temporary base station and reference points at the monitoring sites were determined. The horizontal accuracy of 0.06 ft northing and 0.42 ft easting and vertical accuracy of 0.18 ft was established. The GPS-surveying method allowed the entire monitoring network to be tied to a common reference datum. Traditional surveying with a level and stadia rod was used to determine the relative elevations of the measuring points for the paired wells and piezometers.

A synoptic measurement of water levels in the monitoring network was completed July 31 and August 1, 2003. An electric water-level tape was used to measure depth to water in monitoring wells and piezometers and depth to surface water from surveyed reference points on bridges and culverts above streams. Measurements of water levels were recorded to the nearest 0.01 ft and subtracted from the measuring-point elevation to determine water-level elevations.

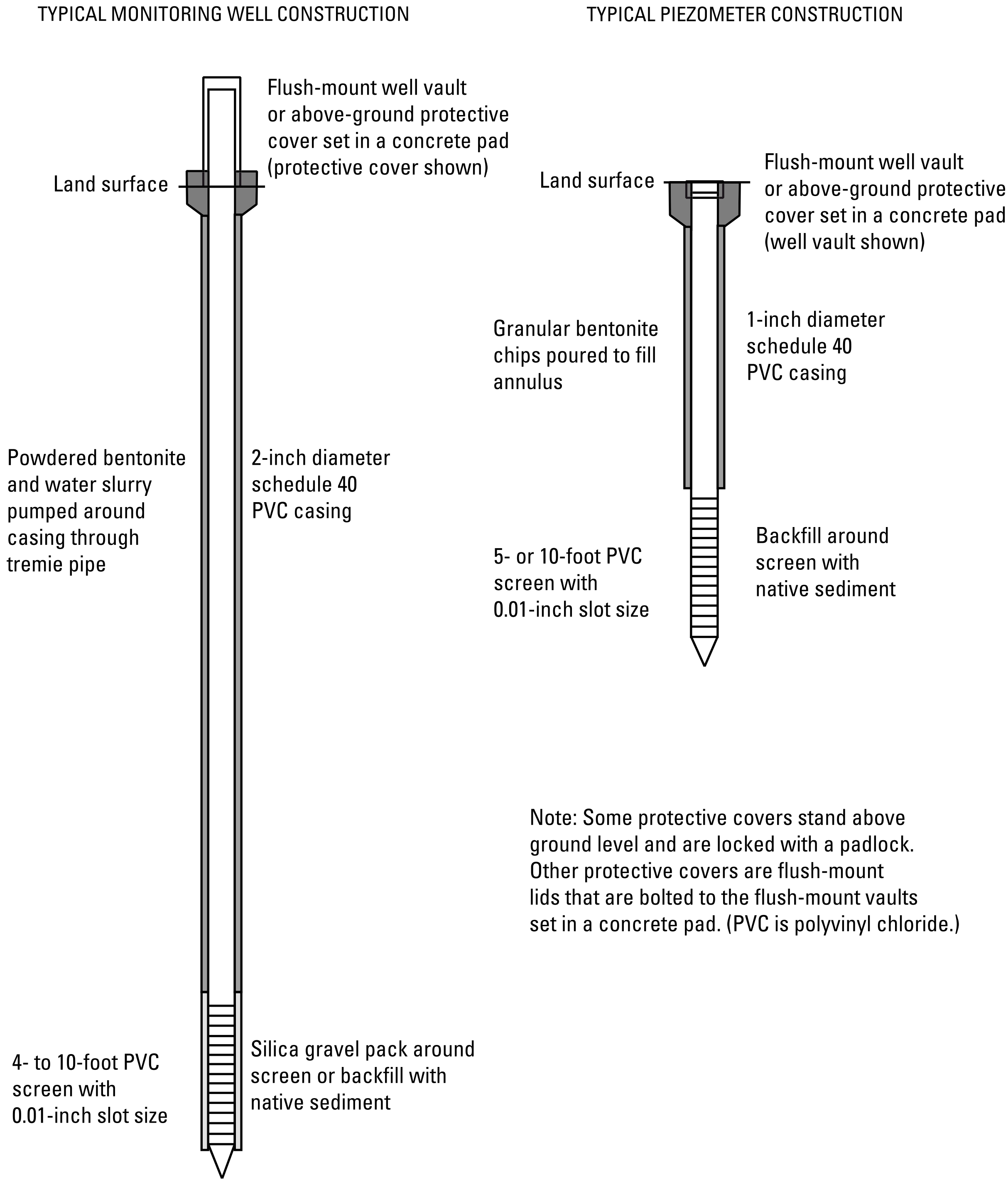


Figure 6. Diagram of monitoring wells and piezometers for investigation of the hydrogeologic framework in Quaternary deposits at the U.S. Army Atterbury Joint Maneuver Training Center near Edinburgh, Indiana.

Figure 7. Photographs of (A) a piezometer with a protective cover and tubular marker and (B) a monitoring well with a flush-mount well vault at the U.S. Army Atterbury Joint Maneuver Training Center near Edinburgh, Indiana.

Hydrogeologic Mapping and Nomenclature

To map the hydrogeologic framework within the Quaternary deposits at Camp Atterbury, geologic and geophysical logs from boreholes and existing well records were combined with geomorphic interpretation of topographic maps. The geologic and geophysical logs provided a description of the subsurface sediments underlying each monitoring location. The geomorphic interpretation of the topographic maps identified basic landforms and determined the area to which each geologic log could be extrapolated.

The names applied to the Quaternary deposits discussed in this report are based on a nomenclature system for Indiana originated by Wayne (1963). In that system, the Quaternary deposits are grouped into formations that are divided into members (for the till formations) or facies (for the non-till formations). Each formation, member, or facies represents a group of sediments that shares some common aspects in their mode of origin or textural characteristics. Five formations/facies are most relevant to the study area—the Martinsville Formation, Jessup Formation, Trafalgar Formation, Atherton Formation lacustrine facies, and the Atherton Formation outwash facies.

Hydrogeologic Framework

The hydrogeologic framework for Camp Atterbury identified five geologic formations/facies within four hydrogeologic regions mapped in the study area. Generalized geologic columns were developed to present the vertical sequences of the formations/facies in each region. Descriptions of the Quaternary deposits in each region determined the potential for water supply related to the presence, thickness, and extent of aquifers and aquitards. Ground-water resources are described in terms of infiltration potential, horizontal and vertical flow, and ground-water/surface-water interactions.

Quaternary Deposits

In this report, the Martinsville Formation includes all materials deposited or reworked in recent time (the past 8,000 to 11,000 years or the post-glacial period). For this investigation, the Martinsville Formation is assumed to include colluvial (slope-wash) deposits and the thin layer of soil that caps the Pleistocene deposits and bedrock. To include colluvium and the modern soils in the Martinsville Formation is to deviate slightly from Wayne's (1963) original definition; including these, however, greatly simplifies the geologic descriptions and does not affect the hydrogeologic interpretation. In the study area, the Martinsville Formation consists predominately of fine-grained and poorly sorted materials and holds little potential as an aquifer.

The Jessup Formation and the Trafalgar Formation are similar in most respects. Both formations are fine-grained till (poorly sorted materials deposited directly from glacial ice). Tills do not transmit water readily; therefore, these formations represent confining layers or aquitards. One characteristic that distinguishes these two formations is age—the older Jessup Formation is pre-Wisconsinan and the younger Trafalgar Formation is Wisconsinan. Some water-deposited and water-bearing sand and gravel lenses either underlie or are interbedded within the tills of the Jessup and Trafalgar Formations. Most of these lenses are thin, are not of significant lateral extent, and do not constitute important aquifers at Camp Atterbury.

The Atherton Formation represents sediments that were deposited extraglacially (not in contact with glacial ice). The Atherton Formation lacustrine facies are very well-sorted silts and clays deposited in lake environments. Within the hydrogeologic framework, the lacustrine facies functions as a confining layer or aquitard because it can be of great thickness and has a uniform fine-grained texture. The Atherton Formation outwash facies contains sand and gravel deposits transported and deposited by flowing water. These deposits tend to be coarse grained, are moderately to well sorted, and can store and transmit substantial quantities of ground water. Within the hydrogeologic framework, the sands and gravels of the outwash facies constitute the primary aquifers of the study area.

Hydrogeologic Regions

The study area was mapped into four hydrogeologic regions (fig. 8), each with a distinct set of Quaternary deposits. The Quaternary deposits underlying each region are illustrated in the corresponding generalized geologic columns in figure 9. Each of the hydrogeologic regions can be characterized by one to four generalized geologic columns; however, natural variation and some deviation from the simplified geology presented in these columns should be expected.

Bedrock Region

The Bedrock Region is mapped as the upland area west of Mt. Moriah Road, west and south of Saddle Creek and Duck Pond, and southwest of Puff Lake (fig. 8). A generalized geologic column (fig. 9, column B) shows that this region is characterized by Martinsville Formation resting directly on bedrock. In this region, the Martinsville Formation is expected to range from 0 to 15 ft in thickness; bedrock is Late Devonian and Mississippian shales and siltstones. Potential ground-water yields are limited because the Quaternary deposits are thin and tend to be fine grained.

Jessup Till Region

The Jessup Till Region is mapped as the uplands on either side of the valleys of Lick Creek and Muddy Branch, the upland area south of Nineveh Creek, and an isolated upland north of Nineveh Creek and west of Mauxferry Road (fig. 8). Two generalized geologic columns (fig. 9, columns J1 and J2) show that the Jessup Formation till is the dominant Quaternary deposit, with some thin deposits of the Atherton Formation lacustrine and outwash facies. The Quaternary deposits in this region typically range from 30 to 90 ft in thickness. Within this region, the Atherton Formation outwash facies holds the best potential to provide a water supply, but it tends to be thin and ground-water yields will be moderate.

Trafalgar Till Region

The Trafalgar Till Region is mapped as the area bordering and north of County Line Road and east of Nineveh Creek and five isolated upland areas in the northwest quarter of Camp Atterbury (fig. 8). This region roughly defines the southward-most advance of Wisconsinan glaciers in the study area. Two generalized geologic columns (fig. 9, columns T1 and T2) show that this region typically is underlain by till of the Trafalgar and Jessup Formations. Of these two till units, Trafalgar Formation till was nearest the land surface and typically ranged from 10 to 30 ft in thickness (well MW2 and well MW5, appendix 1). Where it was recognized, the till of the Jessup Formation was below the Trafalgar Formation and ranged from 25 to 50 ft in thickness. Within, separating, and beneath these till units can be found sediments of the Atherton Formation. The sediments of the Atherton Formation outwash facies have the best potential to support a water-supply well. Generally, the outwash sediments in this region are thin, except in the area bordering and north of County Line Road where the thickness tends to increase (40 ft at well W1 and 42 ft at well W5, appendix 2).

Atherton Outwash Region

The Atherton Outwash Region is mapped as the lowland areas associated with the major valleys of the study area, including the valley bottoms and terraces associated with Lick, Nineveh, Prince, Mud, and Saddle Creeks and Muddy Branch (fig. 8). Within the study area, this region has the greatest thickness of Atherton Formation outwash facies sands and gravels, which are the primary aquifers of the study area.

Four generalized geologic columns (fig. 9, columns A1–A4) show that the depth to bedrock and the thickness of the outwash facies vary greatly. In the western (well MW3, appendix 1) and southern part of the region and in the valleys of Muddy Branch (well MW7, appendix 1) and Lick Creek (well MW9, appendix 1), the depth to bedrock is approximately 45 to 60 ft and the sands and gravels range from 4 to 25 ft in thickness. An example of the aquifer in the valley of Lick Creek of this region is at monitoring location 9 where sand and gravel are present between 39.5 to 64.5 ft below land surface. In the northern part of the region (wells MW1 and MW4, appendix 1), depth to bedrock is 105.5 to 126 ft and sands and gravels exceed 25 ft in thickness. In the eastern part of the region (well MW11 and piezometer PZ8A), the depth to bedrock is 44 to 96 ft; approaching the valley of the Driftwood River (fig. 1), the coarse-grained outwash sediments can be in excess of 30 ft in thickness.

In this region, more than one potential aquifer may be present in a vertical sequence separated by aquitards. For example, at monitoring location 1 (well MW1, appendix 1), potential aquifers include sand from 8 to 20.5 ft; sand and gravel from 24.5 to 52 ft; sand and gravel from 59 to 61 ft; and sand from 83.5 ft to an unknown lower contact.

Within the Atherton Outwash Region, the Atherton Formation lacustrine facies also exhibits its greatest thickness. The silts and clays of this formation were deposited as lake sediments when former tributaries to the ancestral Driftwood River were blocked by meltwater and outwash. The best examples are in the valleys of Muddy Branch and Lick Creek (wells MW7 and MW9, appendix 1) where lacustrine deposits can exceed 20 ft in thickness.

Ground-Water Flow

Recognizing the areas with greatest infiltration potential and the directions of ground-water flow is important for the protection and management of water resources. In this investigation, the topography and soil characteristics of the study area served as guides to mapping the areas with greatest infiltration potential. Synoptic measurements of ground-water levels were used to interpret horizontal ground-water-flow directions on a water-level-contour map. Calculated vertical hydraulic gradients between paired wells were used to interpret potential vertical ground-water-flow directions.

Infiltration Areas

Precipitation falling on the land surface can follow one of several potential pathways. It can be returned to the atmosphere through evapotranspiration (the combined processes of evaporation from the land surface and transpiration from plants); it can flow over the land surface as runoff and eventually become incorporated in surface-water bodies; or it can infiltrate through soils and percolate into underlying geologic materials to become part of the ground-water system. This final pathway of infiltration and percolation as ground water describes the process of recharge to aquifers.

Topography and soil texture are two factors that influence infiltration and the potential for recharge to an underlying aquifer. In areas of low topographic relief, precipitation tends to puddle on the land surface, allowing the time required for infiltration. In areas of high topographic relief, precipitation quickly is translated into runoff and infiltration is reduced. Infiltration rates tend to be greatest in areas with coarse-grained soils (soils developed in sand- and gravel-rich materials). In areas with fine-grained soils (soils developed in silt- and clay-rich materials), infiltration—and therefore recharge—tends to be limited. Therefore, with other factors being equal, infiltration is most likely in an area with low topographic relief and coarse-grained soils.

In Camp Atterbury, the combined Atherton Outwash Region and the Trafalgar Till Region have the greatest potential as infiltration areas (fig. 10). The Atherton Outwash Region exhibits low topographic relief and sandy soils, the characteristics discussed above that promote infiltration. Although the Trafalgar Till Region lacks sandy soils, its topographic relief is low enough to allow puddling of precipitation and consequent infiltration.

Horizontal Flow

Horizontal ground-water flow directions can be interpreted from a water-level-contour map (fig. 11). Water-level elevations (table 3) measured July 31 to August 1, 2003, in wells and piezometers were plotted on a map, and contour lines were drawn to connect areas of equal water-level elevations. The general directions of ground-water flow (shown by arrows) are perpendicular to the contour lines.

From the water-level-elevation data collected, the regional direction of horizontal ground-water flow in the Camp Atterbury study area is east toward the valley of the Driftwood River (fig. 1). Within the valleys of the study area, local horizontal ground-water flow tends to be away from the areas mapped as the Bedrock, Jessup Till, and Trafalgar Till Regions and toward the Atherton Outwash Region. In the valleys of Lick Creek and Muddy Branch, ground-water flow follows the slope of the land surface from the ridge tops into the valley bottoms and then east toward the Driftwood River. In the northern half of the study area, horizontal ground-water flow generally is from the north and west toward the sand

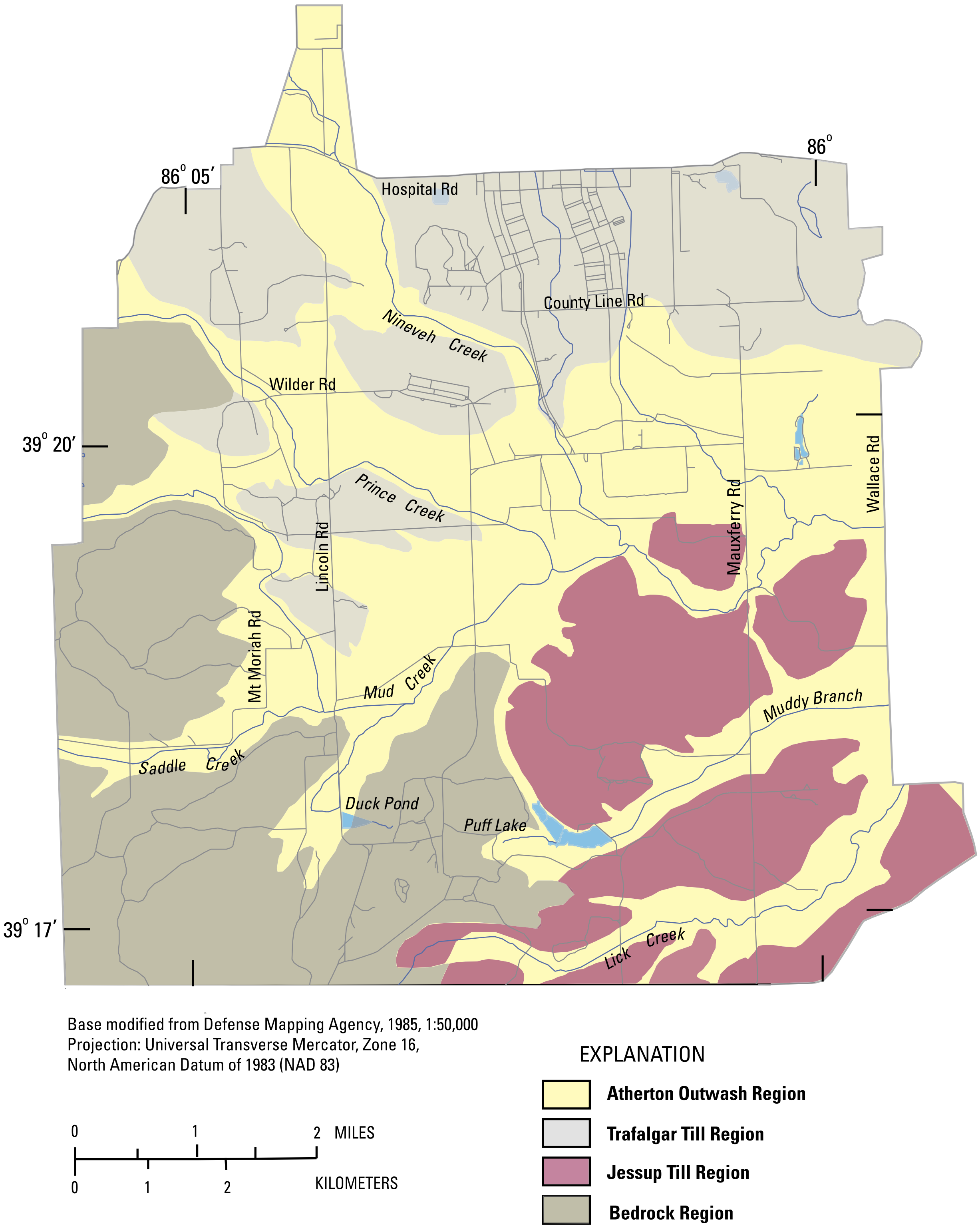


Figure 8. Hydrogeologic regions in the study area at the U.S. Army Atterbury Joint Maneuver Training Center near Edinburgh, Indiana.

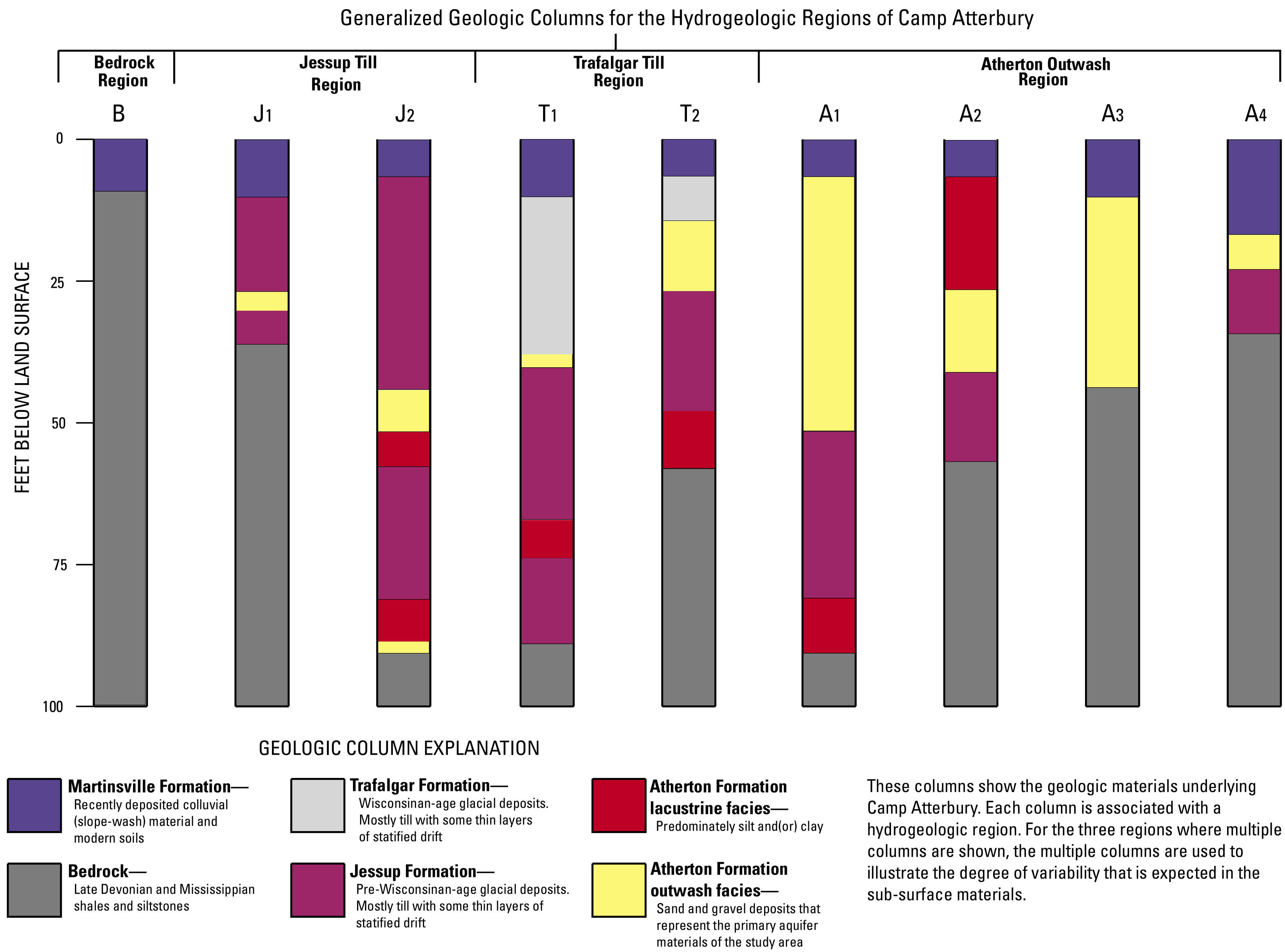


Figure 9. Gene raining Center near Edinburgh, Indiana.

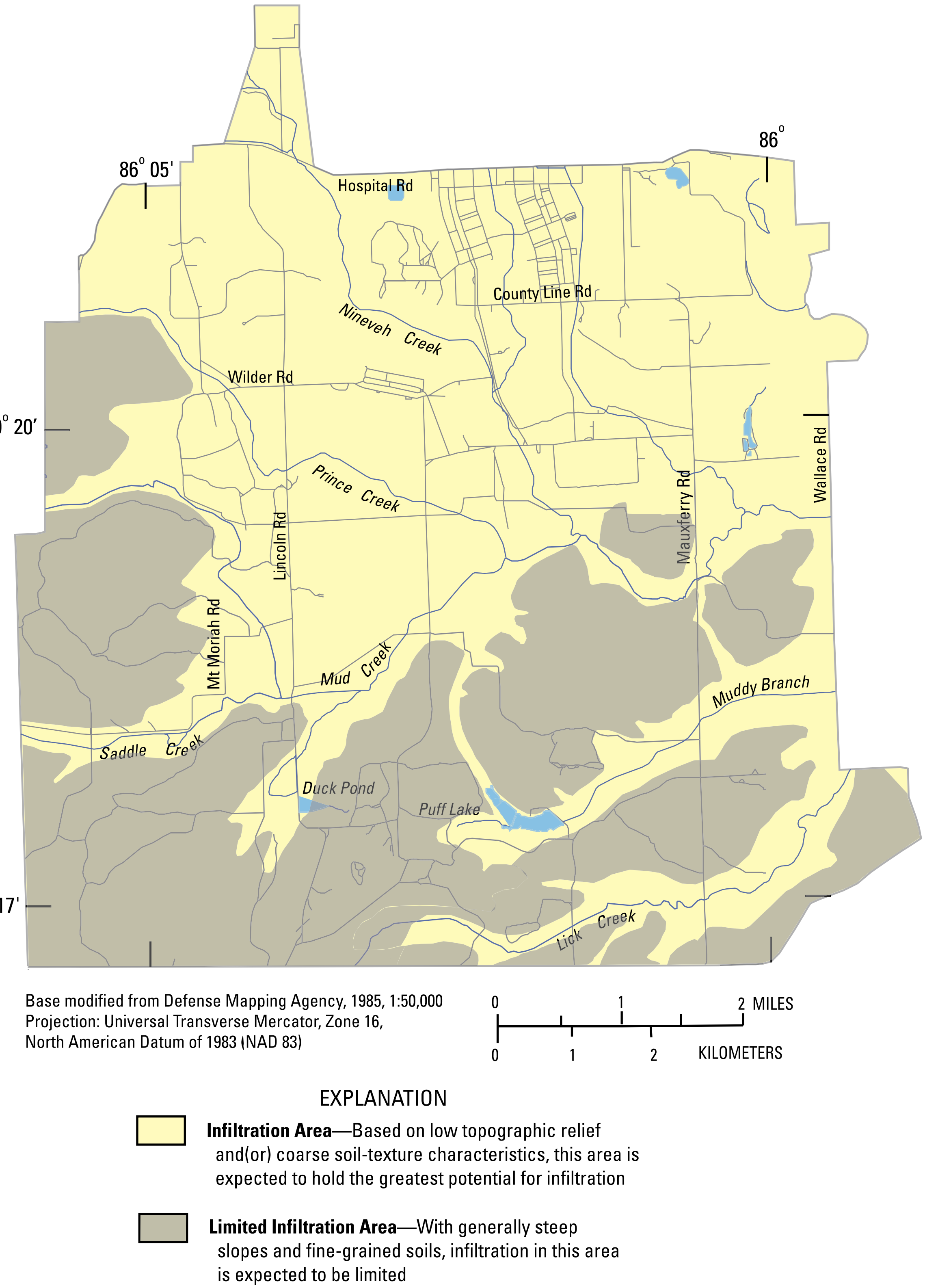


Figure 10. Infiltration areas determined by low topographic relief and(or) coarse-grained soil texture in the hydrogeologic-framework study area at the U.S. Army Atterbury Joint Maneuver Training Center near Edinburgh, Indiana.

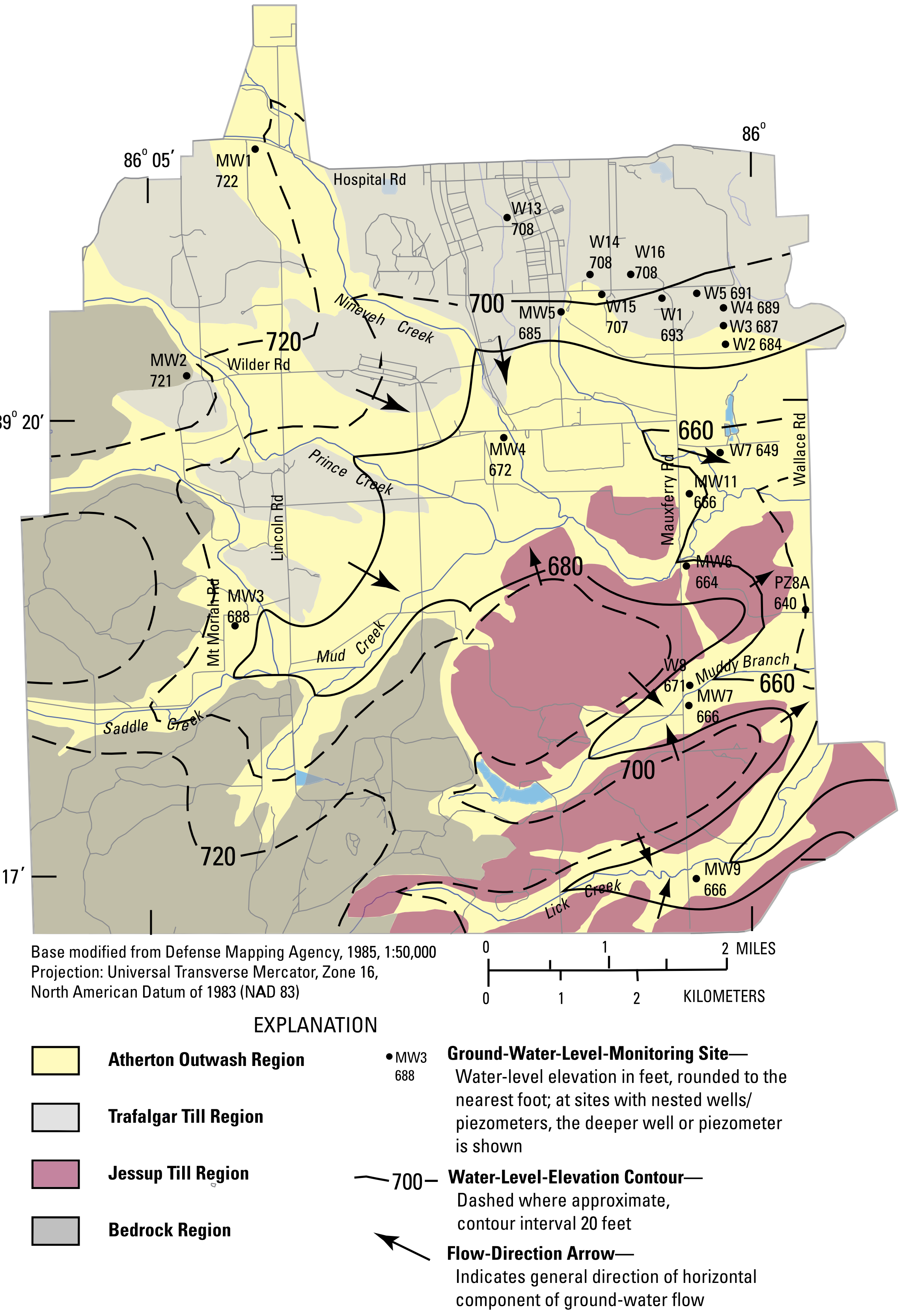


Figure 11. Ground-water elevations at selected monitoring locations, generalized ground-water elevation contours, and generalized directions of horizontal ground-water flow on July 31 and August 1, 2003, in the hydrogeologic-framework study area at the U.S. Army Atterbury Joint Maneuver Training Center near Edinburgh, Indiana.

Table 3. Measuring-point elevation, screen-midpoint elevation, and water-level elevation measured July 31 to August 1, 2003, in monitoring wells and piezometers at the U.S. Army Atterbury Joint Maneuver Training Center near Edinburgh, Indiana.

[USGS, U.S. Geological Survey; ft, feet; MW, monitoring well; Rd, Road; PZ, piezometer; St, Street; W, previously installed well; --, no data]

USGS site name	Location	Measuring-point elevation[a] (ft)	Screen-midpoint elevation (ft)	Water- level elevation (ft)
MW1	East of Lincoln Rd, south of Hospital Rd	732.0	684.3	722.1
PZ1	East of Lincoln Rd, south of Hospital Rd	735.8	714.1	721.9
MW2	North of Wilder Rd, west of Tipton Trail	736.0	708.6	721.5
PZ2	North of Wilder Rd, west of Tipton Trail	732.3	710.2	721.5
MW3	East of Mt. Moriah Rd, west of Lincoln Rd	695.0	672.4	688.4
PZ3	East of Mt. Moriah Rd, west of Lincoln Rd	692.8	672.8	688.6
MW4	South of Rangeline Rd, west of Schoolhouse Rd	682.7	643.5	672.1
PZ4	South of Rangeline Rd, west of Schoolhouse Rd	683.3	661.8	668.6
MW5	South of County Line Rd, east of Eggleston St	693.0	663.4	685.4
PZ5	South of County Line Rd, east of Eggleston St	693.0	670.1	685.5
MW6[b]	East of Mauxferry Rd, south of Nineveh Creek	659.4	625.1	664.1
PZ6	East of Mauxferry Rd, south of Nineveh Creek	661.0	646.2	652.2
MW7	East of Mauxferry Rd, south of Muddy Branch	672.1	645.8	666.0
PZ8A	West of Wallace Rd, north of Muddy Branch	651.5	621.1	640.3
PZ8B	West of Wallace Rd, north of Muddy Branch	651.2	633.4	642.3
MW9[b]	East of Mauxferry Rd, south of Lick Creek	665.8	605.4	665.8
PZ9[b]	East of Mauxferry Rd, south of Lick Creek	665.2	622.6	665.6
PZ10	West of Reservation Boundary Rd, at Lowell Rd	680.3	659.3	671.7
MW11	East of Mauxferry Rd, south of Pleasant Run	680.9	651.7	666.0
PZ12	East of Mauxferry Rd, north of Nineveh Creek	663.1	646.2	653.1
W1	West of Mauxferry Rd, south of County Line Rd	745.4	693.8	693.5
W2	North of Hendricks Ford Rd, east of Mauxferry Rd	691.0	671.8	684.2
W3	North of Hendricks Ford Rd, east of Mauxferry Rd	701.1	684.8	687.0
W4	North of Hendricks Ford Rd, east of Mauxferry Rd	715.9	682.3	688.8
W5	South of County Line Rd, east of Mauxferry Rd	718.6	675.9	691.4
W7	South of Pleasant Run, east of Mauxferry Rd	652.6	643.1	648.9
W8[b]	East of Mauxferry Rd, north of Muddy Branch	664.1	639.6	671.0
W13	North of Evans Rd, west of Eggleston St	710.7	683.9	708.4
W14	West of Mauxferry Rd, north of County Line Rd	708.3	684.4	707.7
W15	South of County Line Rd, west of Mauxferry Rd	716.0	--	707.2
W16	East of Mauxferry Rd, north of County Line Rd	727.0	--	708.3

[a]For all wells and piezometers, the measuring point was a reference mark on the top of the well and piezometer casing.

[b]Flowing well.

and gravel of the Atherton Outwash Region in the valley of Nineveh Creek and then east toward the valley of the Driftwood River.

Precipitation data for Columbus, Indiana (6 mi southeast of Camp Atterbury), reveals that July 2003 was wetter than normal. For 1971 through 2000, the July precipitation normal was 4.02 in. (National Climatic Data Center, 2002). In July 2003, the Columbus, Indiana, climatic-data-collection site received 8.4 in. (National Climatic Data Center, undated), more the twice the monthly normal.

The horizontal-flow directions described above are derived from only one set of water-level measurements. Additional water-level measurements could establish the consistency of the relations demonstrated with the July and August 2003 water levels. The directions of ground-water flow may vary seasonally or in years with below- or above-nomal precipitation.

Vertical Flow

The potential for vertical ground-water flow was interpreted by calculating vertical hydraulic gradients between pairs of nested wells/piezometers. In this case, vertical hydraulic gradient is the difference in water-level elevation, in feet, for every foot of elevation difference in the midpoints of the screens of two nested wells (two or more wells drilled in proximity to each other and screened at different depths). A measured gradient implies the potential for flow, but it does not necessarily indicate actual flow. Large-magnitude gradients may develop where effective aquitards (confining layers) prevent ground-water movement between water-bearing layers.

Vertical hydraulic gradients were calculated for eight well pairs (table 4) from one set of water-level measurements collected July 31 to August 1, 2003. For well pairs MW1–PZ1, MW2–PZ2, MW5–PZ5, and MW9–PZ9, the magnitude of the calculated gradients were small (0.0 to 0.015 ft/ft), indicating an absence of aquitards separating the midpoint of the well screens in these well pairs.

Well pairs PZ8A–PZ8B and MW3–PZ3 showed downward gradients of 0.16 ft/ft and 0.5 ft/ft, respectively. Well pairs MW4–PZ4 and MW6–PZ6 showed upward gradients, indicating a potential for ground water to flow toward the land surface under hydrostatic pressure. Two field observations also indicate an upward gradient in the vicinity of well MW6: (1) an area of wetland west of Mauxferry Road and north of piezometer PZ12 appears to be sustained by ground-water discharge, and (2) well MW6 is a flowing well (this well, when observed during periodic field visits, consistently had water levels several feet above the land surface).

Although the vertical gradient calculated for well pair MW9–PZ9 was slight, the fact that these wells flow indicates an upwardly directed gradient (and flow) in the vicinity of this monitoring site. Monitoring well W8 is a flowing well, indicating an upwardly directed gradient at that location.

Table 4. Vertical hydraulic gradients on July 31 and August 1, 2003, between selected pairs of monitoring wells/piezometers at the U.S. Army Atterbury Joint Maneuver Training Center near Edinburgh, Indiana.

[ft/ft, foot per foot; MW, monitoring well; PZ, piezometer]

Well pair[a]	Vertical gradient[b] (ft/ft)	Direction of potential vertical flow
MW1–PZ1	0.007	Up.
MW2–PZ2	.0	(No gradient.)
MW3–PZ3	-.5	Down.
MW4–PZ4	.19	Up.
MW5–PZ5	-.015	Down.
MW6–PZ6	.56	Up.
PZ8A–PZ8B	-.16	Down.
MW9–PZ9	.012	Up.

[a]Locations of well pairs are shown on figure 2.

[b]Vertical hydraulic gradient was calculated by dividing the difference in ground-water elevations between the two wells by the difference in the elevations of the midpoint of the screens.

Ground-Water/Surface-Water Interaction

The monitoring network in the hydrogeologic-framework study area includes locations where ground-water and surface-water elevations (table 5) were measured. These elevations, along with calculated vertical hydraulic gradients, can be used to evaluate the potential for ground-water/surface-water interactions. Such interactions include ground-water discharge from the aquifer through the streambed into the stream, which is important for providing base flow to the stream during periods without precipitation. One area likely to have ground-water discharge to surface water is the valley of Nineveh Creek. This is indicated by the presence of a flowing well (MW6), upwardly directed vertical hydraulic gradients at well pairs MW4–PZ4 and MW6–PZ6, and ground-water elevations that were higher than surface-water elevations (for example, 668.6 ft at piezometer PZ4 and 667.6 ft at surface-water-monitoring site E5; 652.2 ft at piezometer PZ6 and 648.6 ft at surface-water-monitoring site A5). Another area likely to have ground-water discharge to surface water is the valley of Lick Creek, indicated by the presence of flowing wells (MW9 and PZ9) and ground-water elevations that were higher than surface-water elevations (for example, 665.6 ft at piezometer PZ9 and 653.4 ft at surface-water-monitoring site B5).

During the investigation of surface-water quality at Camp Atterbury in 2000 (Risch, 2004), base flow sustained by ground-water discharge was documented in Nineveh Creek and Lick Creek in periods of low flow and no precipitation.

Table 5. Surface-water-level elevations and ground-water-level elevations measured at adjacent sites on July 31 and August 1, 2003, at the U.S. Army Atterbury Joint Maneuver Training Center near Edinburgh, Indiana.

[USGS, U.S. Geological Survey; ft, foot; --, no data]

USGS surface-water-monitoring site	USGS site identification	Surface-water-level elevation (ft)	Adjacent ground-water-level-monitoring site	Ground-water-level elevation (ft)
B1	392012086042901	703.2	--	--
E3	391813086035601	671.8	--	--
E7	392046086013101	685.8	--	--
A4	391937086003401	657.5	--	--
B2	392142086035301	707.5	--	--
E5	391949086020401	667.6	PZ4	668.6
A5	391857086003401	648.6	PZ6	652.2
A10	391804086003201	663.1	--	--
A11	391814085592401	642.8	--	--
B5	391652086003001	653.4	PZ9	665.6

Under the same conditions, some reaches of Saddle Creek and Prince Creek in the western part of the study area were dry or held only isolated pools, indicating that not all stream reaches are sustained by ground-water discharge throughout the year.

Summary and Conclusions

A hydrogeologic framework was developed for unconsolidated Quaternary deposits at the U.S. Army Atterbury Joint Maneuver Training Center (Camp Atterbury) near Edinburgh, Indiana. The framework describes the potential for the occurrence of ground water on the basis of physiography and the distribution of geologic materials within the study area. The hydrogeologic framework, coupled with information about surface-water hydrology, land-surface topography, and water-level measurements, enables estimates of the directions of horizontal and vertical ground-water flow.

Four geologic units—the Jessup, Trafalgar, Atherton, and Martinsville Formations—were identified, and their distribution was mapped as four hydrogeologic regions. The Jessup and Trafalgar Formations are fine-grained, poorly sorted tills. At least two facies of the Atherton Formation, the lacustrine and outwash facies, are in the study area. The Martinsville Formation includes materials deposited or reworked since the glacial period. With the exception of the Atherton Formation outwash facies, the Quaternary deposits primarily are fine-grained, silt- and clay-rich sediments that function as confining layers or aquitards. The Atherton Formation outwash facies includes sand and gravel deposits that constitute the primary aquifers in the study area. The four hydrogeologic regions mapped in this investigation are designated as the Bedrock, Jessup Till, Trafalgar Till, and Atherton Outwash Regions. Each region represents an area with a distinctive physiographic expression and vertical sequence of Quaternary deposits.

The Bedrock Region in the western and southwestern part of the study area commonly is underlain by 0 to 15 ft of Martinsville Formation resting directly on bedrock. Potential ground-water yields are limited because the Quaternary deposits are thin and tend to be fine grained. The Jessup Till Region in the southeastern part of the study area includes the uplands on either side of the stream valleys. Sediments commonly range from 30 to 90 ft in thickness. This region includes clay-rich till of the Jessup Formation and sand and gravel deposits of the Atherton Formation outwash facies; the Atherton Formation outwash facies tends to be thin, and ground-water yields will be moderate. The Trafalgar Till Region in the north and northwest-central part of the study area commonly is underlain by 10 to 30 ft of Trafalgar till or Trafalgar till over 25 to 50 ft of Jessup till. Within, separating, and beneath these tills are deposits of the Atherton Formation outwash facies—the sand and gravel deposits with the best potential to support a water-supply well. Generally, the outwash facies in this region are thin sand and gravel lenses, except in a few locations that are in excess of 30 ft thick. The Atherton Outwash Region is the lowland area associated with the major valleys in all but the far southwestern part of the study area. This region has the greatest thickness of outwash facies sands and gravels (often in excess of 20 ft), which are the primary aquifers at Camp Atterbury. Within the Atherton Outwash Region, the Atherton Formation lacustrine facies also exhibits its greatest thickness, at some locations exceeding 20 ft in thickness.

At Camp Atterbury, the combined Atherton Outwash Region and the Trafalgar Till Region have the greatest potential as infiltration areas because of low topographic relief and(or) sandy soils. The Atherton Outwash Region exhibits low topographic relief and sandy soils. Although the Trafalgar Till Region lacks sandy soils, its topographic relief is low enough to allow for infiltration.

From water-level-elevation data, horizontal ground-water flow was determined generally to be toward the Atherton Outwash Region and the valley of the Driftwood River to the east. Within the valleys of the study area, local horizontal ground-water flow tends to be away from the areas mapped as the Bedrock, Jessup Till, and Trafalgar Till Regions and toward the Atherton Outwash Region. In the northern half of the study area, horizontal ground-water flow generally is from the north and west and toward the valley of Nineveh Creek and the Driftwood River to the east.

Vertical hydraulic gradients were documented for eight nested well pairs. At four sites, calculated gradients were small, indicating an absence of aquitards separating the well screens. At two sites, downward gradients were calculated. At the remaining two sites, upwardly directed gradients have resulted in flowing wells.

Ground-water discharge to surface water is likely in some eastern reaches of the valleys of Nineveh and Lick Creeks. In the valley of Nineveh Creek, potential for ground-water discharge is indicated by the presence of a flowing well, upwardly directed vertical hydraulic gradients, and ground-water heads that were higher than surface-water elevations. In the valley of Lick Creek, ground-water discharge is indicated by the presence of flowing wells and ground-water heads that were higher than surface-water elevations.

Acknowledgments

The authors gratefully acknowledge the contributions of Lieutenant Colonel Richard Jones, Supervisory Environmental Protection Specialist with the Indiana Army National Guard, who provided technical guidance for design and implementation of the investigation described in this report. The authors and USGS field personnel greatly appreciate the assistance of Master Sergeant Russell Reichart, Camp Atterbury Range Control Officer, who coordinated scheduling and safety for the drilling and hydrogeologic-data-collection activities. The USGS drill-rig operators, Patrick Mills and Stephen Grant, along with the licensed well drillers of the USGS, Lee Watson and Mark Hopkins, were essential to the successful completion of drilling and well construction, while providing considerable technical input. Thanks also are extended to Walter Anderson, Camp Atterbury Environmental Protection Coordinator and Nancy McWhorter, Camp Atterbury Geographic Information Specialist, who helped with logistical arrangements and access to maps and historical records.

References Cited

Defense Mapping Agency, 1985, Installation map of Indiana Atterbury Reserve Forces Training Area, ed. 1-DMA, series V751S: Washington, D.C., Defense Mapping Agency Hydrographic/Topographic Center, scale 1:50,000.

Department of Defense Earth Science Program, 2006, USGS–DOD publications, accessed February 7, 2006, at http://dodesp.er.usgs.gov/publications.html

Gray, H.H., 2000, Physiographic divisions of Indiana: Indiana University, Indiana Geological Survey Special Report 61, 15 p.

Indiana Business Research Center, 2000, Bartholomew County IN Depth Profile: STATS Indiana; Indiana University Kelley School of Business, accessed November 2, 2001, at http://www.stats.indiana.edu/profiles/pr18081.html

Indiana Business Research Center, 2000, Johnson County IN Depth Profile: STATS Indiana; Indiana University Kelley School of Business, accessed November 2, 2001, at http://www.stats.indiana.edu.profiles/pr18081.html

Indiana Department of Natural Resources, 2003, Water well record database: Division of Water, accessed April 1, 2003, at http://www.in.gov/dnr/water/groun_water/well_database/.

Indiana Legislative Services Agency, undated, Indiana Code IC 5-14-3-4: accessed March 23, 2006, at http://www.in.gov/legislative/ic/code/title5/ar14/ch3.html

Indiana National Guard, 1995, Atterbury News: Edinburgh, Ind., Indiana National Guard, v. 1, no. 1, 19 p.

Keys, W.S., 1990, Borehole geophysics applied to ground-water investigations: Techniques of Water-Resources Investigations of the United States Geological Survey, book 2, chap. E2, p. 66.

Midwestern Regional Climate Center, 2004, Historical climate summaries online date: accessed February 10, 2004, at http://mcc.sws.uiuc.edu/html/MWclimate_data_summaries.htm

Military Department of Indiana, 1997, Final site investigation report, Atterbury Reserve Forces Training Area, Edinburgh, Indiana, v. 1: Novi, Mich: Montgomery Watson, File no. 4162.0200, 75 p.

National Climatic Data Center, undated, Hourly precipitation data, Indiana, July 2003: accessed March 30, 2006, at http://www1.ncdc.noaa.gov/pub/orders/0E338C94-930E-D078-8FA2-35F78AB08C66.PDF

National Climatic Data Center, 2002, Monthly station normals of temperature, precipitation, and heating and cooling degree days 1971–2000: accessed March 30, 2006, at http://www5.ncdc.noaa.gov/climatenormals/clim81/INnorm.pdf

Noble, R.A., Wingard, Jr., R.C., and Ziegler, T.R., 1990, Soil survey of Brown County and part of Bartholomew County, Indiana: U.S. Department of Agriculture Soil Conservation Service, 135 p.

Risch, M.R., 2004, Chemical and biological quality of surface water at the U.S. Army Atterbury Reserve Forces Training Area near Edinburgh, Indiana, September 2000 through July 2001: U.S. Geological Survey Water-Resources Investigations Report 03-4149, 87 p.

Robinson, B.A., 2004, An inventory of aquatic macroinvertebrates and calculation of selected biotic indices for the U.S. Army Atterbury Reserve Forces Training Area near Edinburgh, Indiana, September 2000–August 2002: U.S. Geological Survey Scientific Investigations Report 2004-5010, 19 p.

Schneider, A.F., and Gray, H.H., 1966, Geology of the Upper East Fork Drainage Basin, Indiana: Department of Natural Resources, Geological Survey, Special Report 3, 55 p.

Storer, R.A., dr. ed. services, 1994, ASTM standards on environmental sampling: Scranton, Penn.: American Society for Testing and Materials, 975 p.

Sturm, R.H., 1979, Soil Survey of Johnson County, Indiana: U.S. Department of Agriculture Soil Conservation Service, 76 p.

U.S. Army Environmental Hygiene Agency, 1981, Solid waste management study no. 38-26-0146-81, Atterbury Reserve Forces Training Area, Edinburgh, Indiana: Aberdeen Proving Ground, Md., 50 p.

U.S. Department of Defense, 2006, Defense Environmental Programs annual report to Congress Fiscal Year 2005 : accessed June 1, 2006, at https://www.denix.osd.mil/denix/Public/News/OSD/DEP2005/deparc2005.html

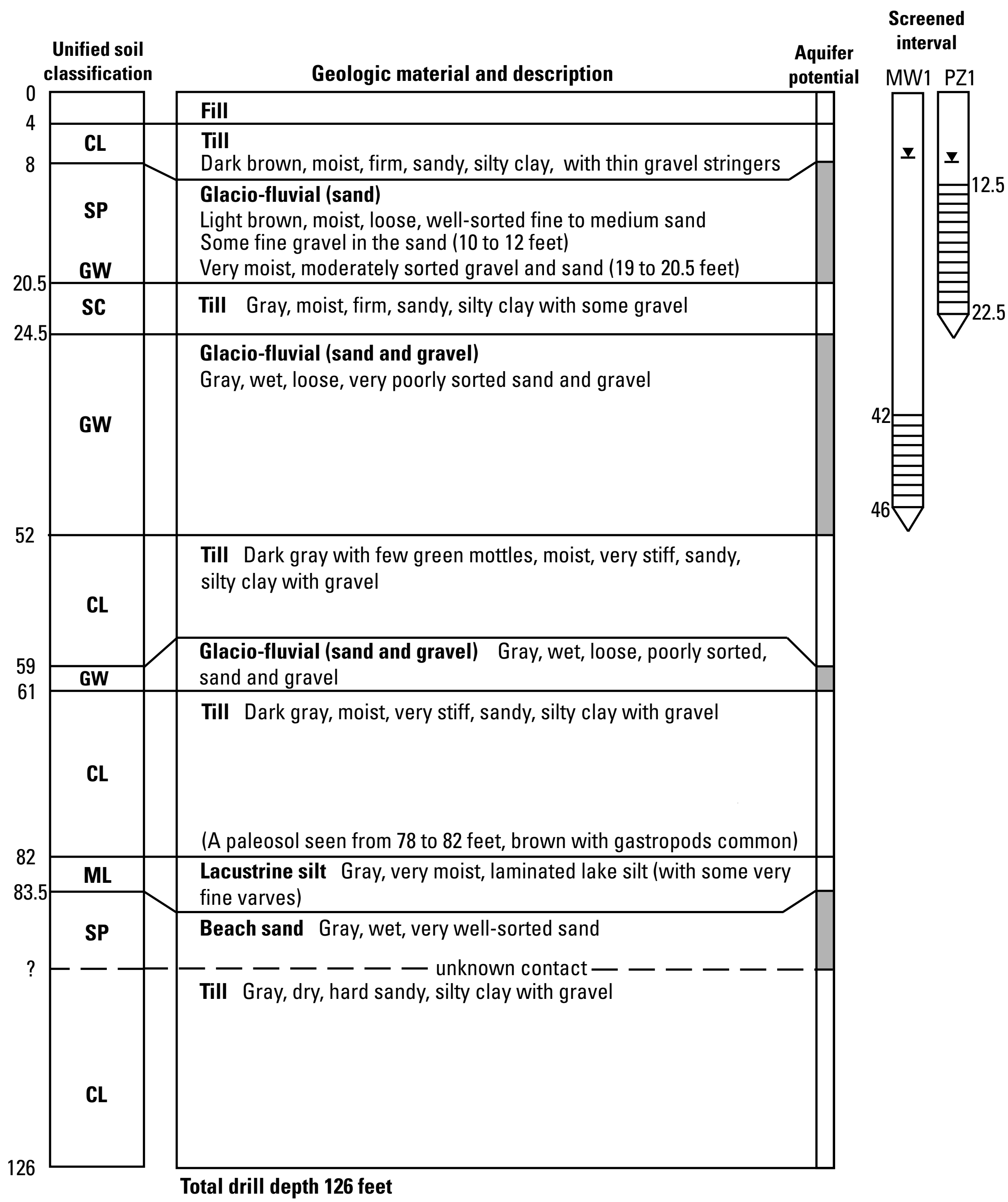
Wayne, W.J., 1963, Pleistocene formations in Indiana: Indiana Department of Conservation, Geological Survey, Bulletin No. 25, 85 p.

Appendixes 1–2

Appendix 1. Geologic logs and diagrams for monitoring wells and piezometers constructed by the U.S. Geological Survey for the hydrogeologic-framework investigation at the U.S. Army Atterbury Joint Maneuver Training Center near Edinburgh, Indiana, 2002–2003

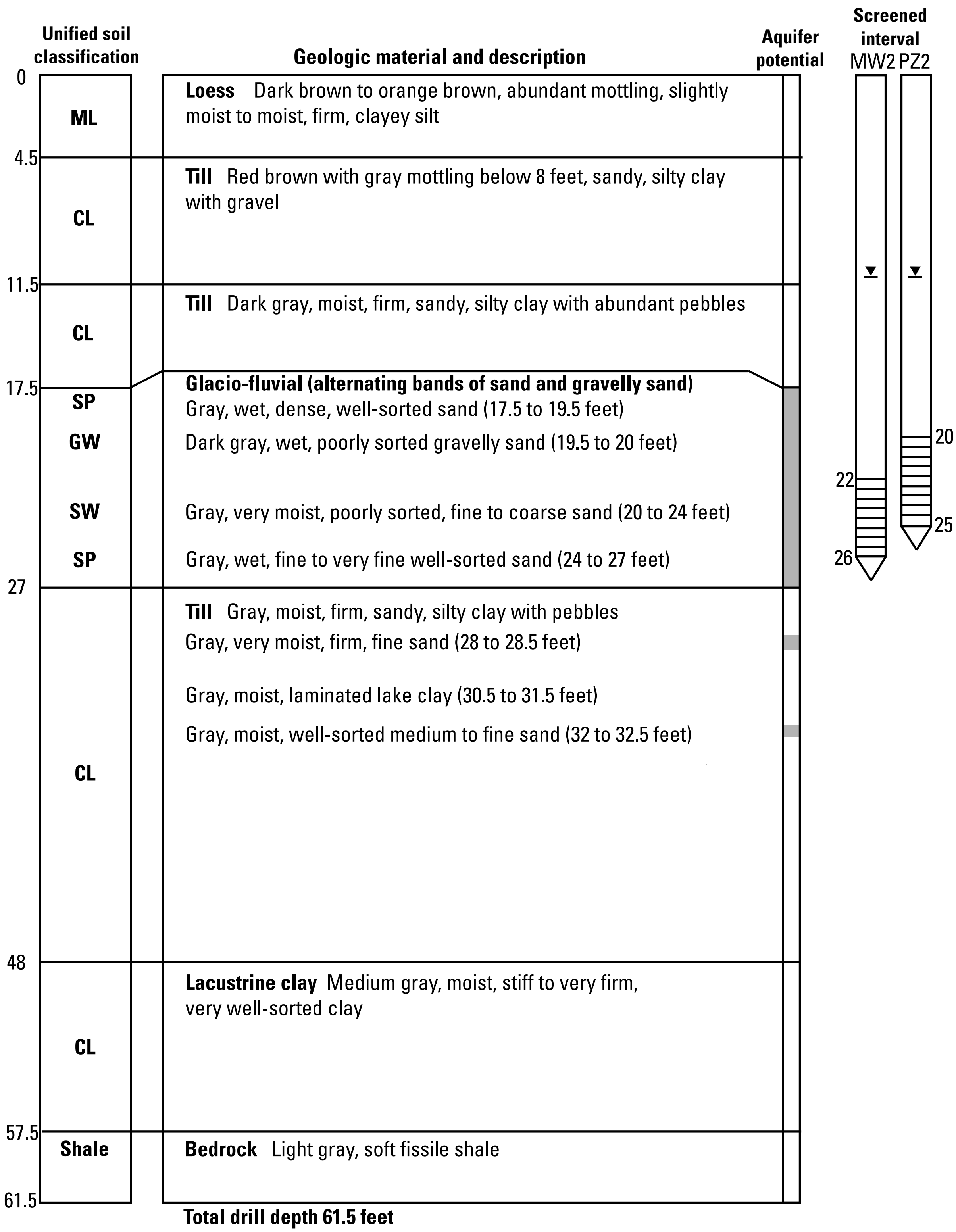
Monitoring Site 1

Located at north end of Lincoln Rd, south of Hospital Rd, inside gate E12, 30 feet east of Lincoln Rd, 35 feet south of gate E12, at edge of grassed area. U.S. Geological Survey, 1962, 7.5-min topographic map, Nineveh quadrangle, T11N, R4E, Section 27, NW1/4, SE1/4, SE1/4. Water level [▼] measured 7/31/2003. Unit contacts and screened intervals are shown in feet below land surface (dashed where approximate). Shaded gray bar identifies geologic materials with the greatest potential to function as aquifers.



Monitoring Site 2

Located north side of Wilder Rd (gravel extension), south of Prince Ck, west of metal bridge over Prince Ck on Wilder Rd, west of gravel road across Prince Ck, 30 feet inside woods. U.S. Geological Survey, 1962, 7.5-min topographic map, Nineveh quadrangle, T10N, R4E, Section 3, NW1/4, NE1/4, SW1/4. Water level [▼] measured 7/31/2003. Unit contacts and screened intervals are shown in feet below land surface. Shaded gray bar identifies geologic materials with the greatest potential to function as aquifers.

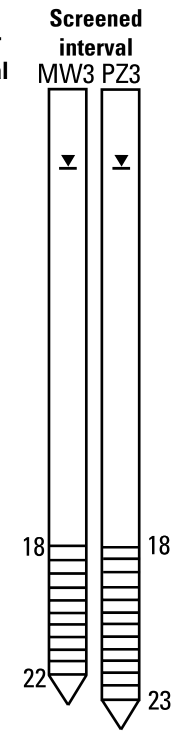


Monitoring Site 3

East of Mt Moriah Rd, north of Saddle Ck, south and west of Mud Ck, east of first north-south section of Mt Moriah Rd after Mud Ck bridge, in weed field 25 feet from road. U.S. Geological Survey, 1962, 7.5-min topographic map, Nineveh quadrangle, T10N, R4E, Section 15, SW1/4, NW1/4, SE1/4. Water level [▼] measured 7/31/2003. Unit contacts and screened intervals are shown in feet below land surface. Shaded gray bar identifies geologic materials with the greatest potential to function as aquifers.

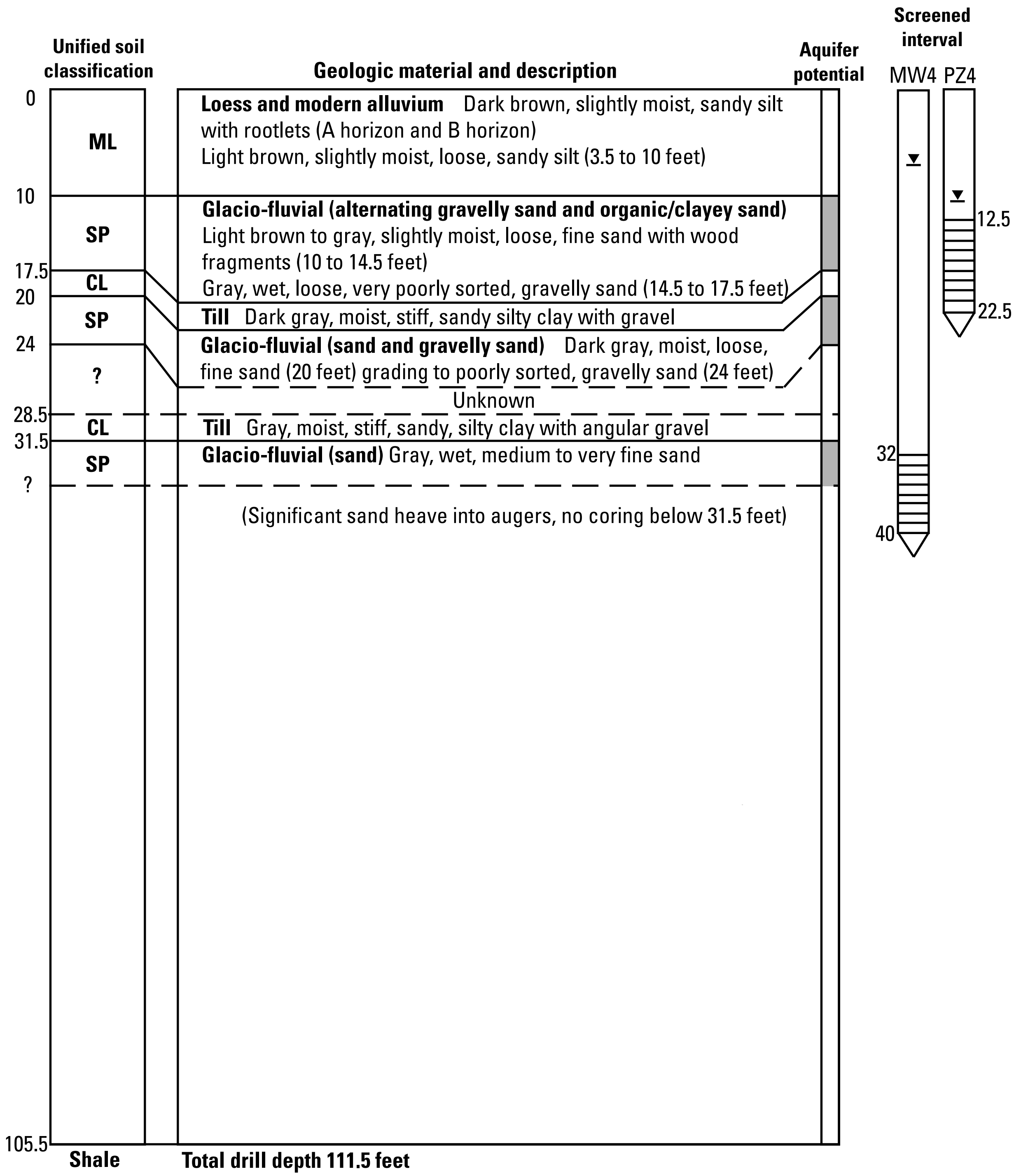
Depth (feet)	Unified soil classification	Geologic material and description	Aquifer potential
0–7.5	ML	**Loess and modern alluvium** Light brown with abundant orange, gray, and dark brown mottling; moist, firm, sandy silt with few rootlets	
7.5–16.5	ML	**Lacustrine silt** Light gray with abundant mottling, very well-sorted clayey silt	
16.5–20.5	SW	**Glacio-fluvial (sand and gravel)** Light to medium brown, moist, loose, poorly sorted gravelly sand with a few clay-rich bands	Shaded
20.5–23	CL	**Till** Brown, moist, firm, sandy, silty clay with pebbles grades to medium gray (22 to 23 feet)	
23–35	CL	**Till** Gray, moist, very stiff, sandy, silty clay with gravel Wood fragments (27.5 to 35 feet)	
35–48	CL	**Interbedded till and lacustrine deposits** Blue, moist, firm, clay and silty clay (lake deposits) Dark gray silty, sandy clay with fine gravel (till) Some woody debris and thin gravel lenses (44 to 48 feet)	
48–52	Shale	**Bedrock** Blue/gray weathered shale	

Total drill depth 52 feet



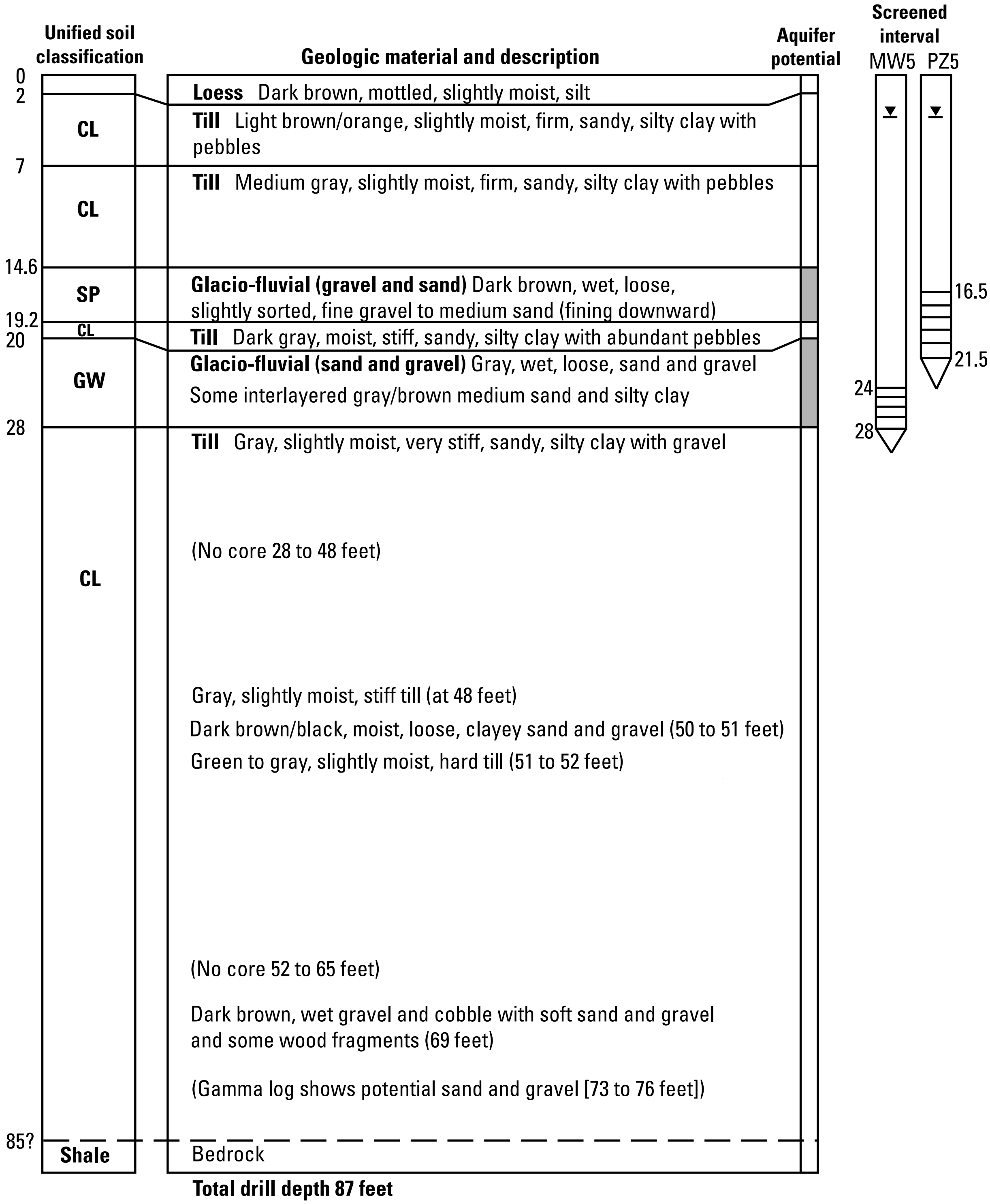
Monitoring Site 4

South of Rangeline Rd, west of Nineveh Ck, edge of grassed area south of guardrail and 35 feet south of centerline of Rangeline Rd, by Range 9. U.S. Geological Survey, 1962, 7.5-min topographic map, Nineveh quadrangle, T10N, R4E, Section 12, NW1/4, NW1/4, NE1/4. Water level [▼] measured 7/31/2003. Unit contacts and screened intervals are shown in feet below land surface (dashed where approximate). Shaded gray bar identifies geologic materials with the greatest potential to function as aquifers.



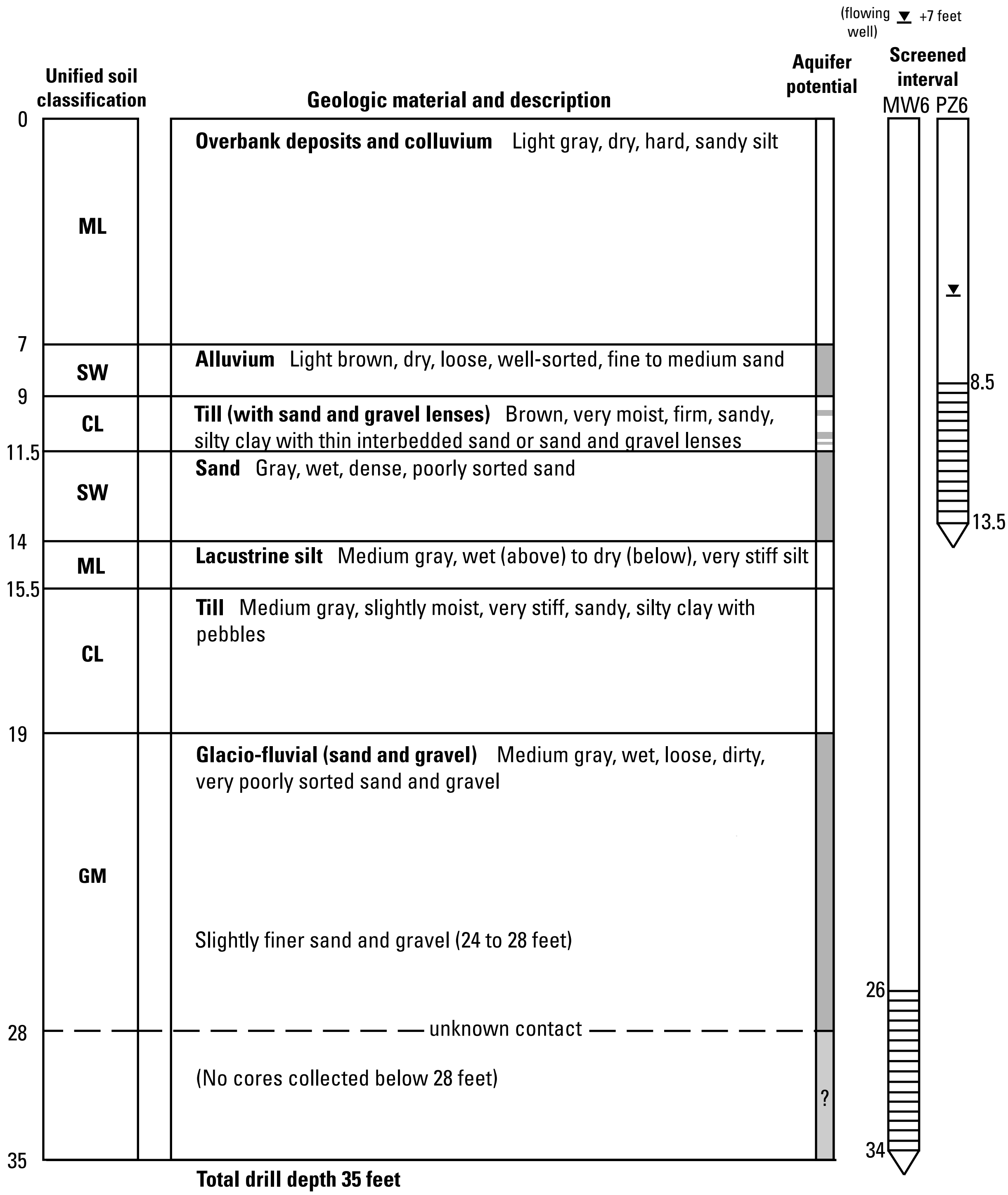
Monitoring Site 5

South of County Line Rd, 125 feet west of center of gravel drive to Rapelling Tower (Bldg 40164), east of unnamed tributary of Nineveh Ck, west of Bldg 40164, west of metal shed, inside weed field. U.S. Geological Survey, 1962, 7.5-min topographic map, Nineveh quadrangle, T10N, R5E, Section 6, NW1/4, NW1/4, NW1/4. Water level [▼] measured 7/31/2003. Unit contacts and screened intervals are shown in feet below land surface (dashed where approximate). Shaded gray bar identifies geologic materials with the greatest potential to function as aquifers.



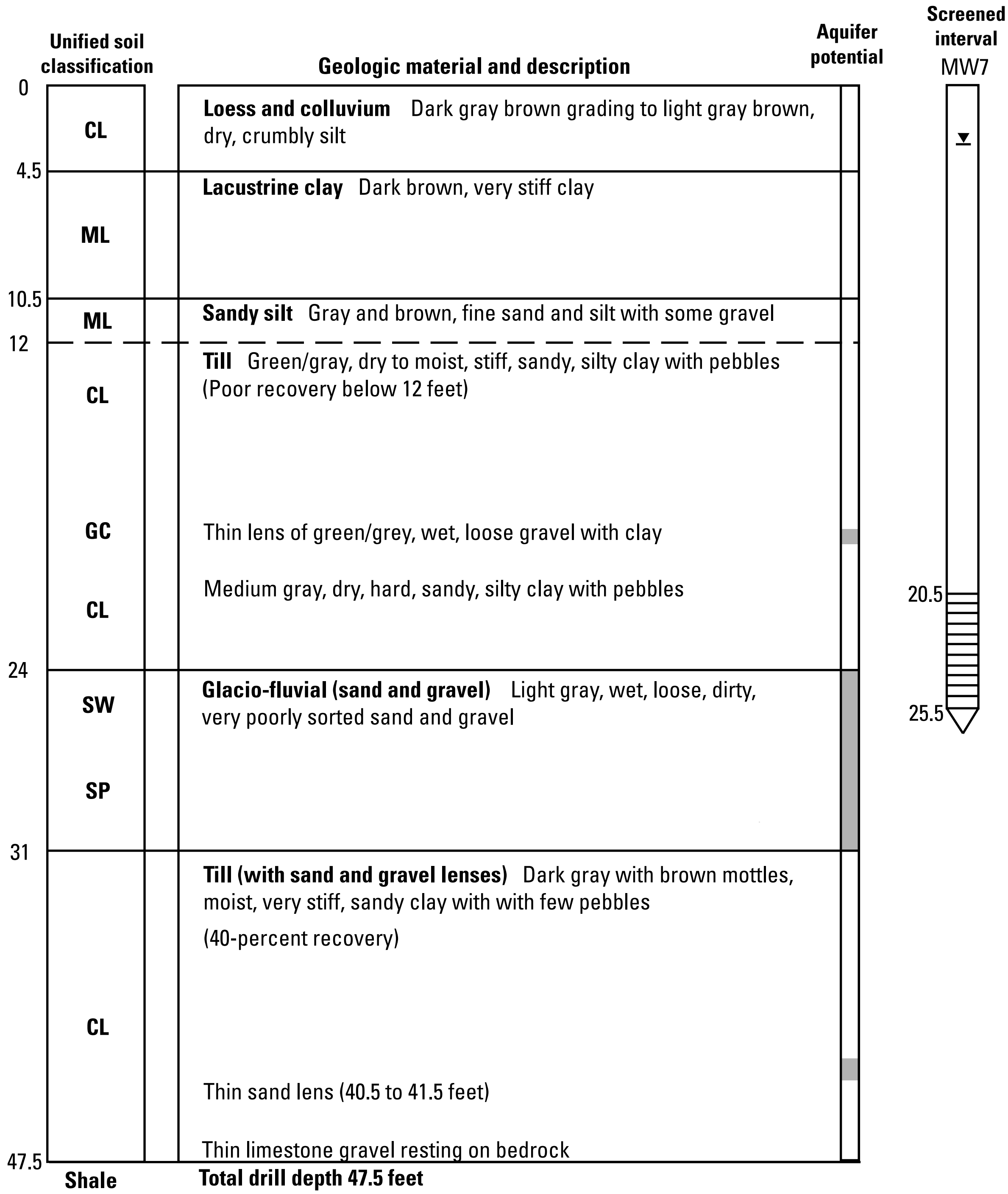
Monitoring Site 6

East of Mauxferry Rd, south of Nineveh Ck, MW6 is 100 feet east of Mauxferry Rd and 25 feet south of dirt trail. PZ6 is 360 feet east of Mauxferry Rd, 38 feet north of dirt trail. U.S. Geological Survey, 1962, 7.5-min topographic map, Nineveh quadrangle, T10N, R5E, Section 17, NW1/4, NW1/4, NW1/4. Water level [▼] measured 8/1/2003. Unit contacts and screened intervals are shown in feet below land surface (dashed where approximate). Shaded gray bar identifies geologic materials with the greatest potential to function as aquifers.



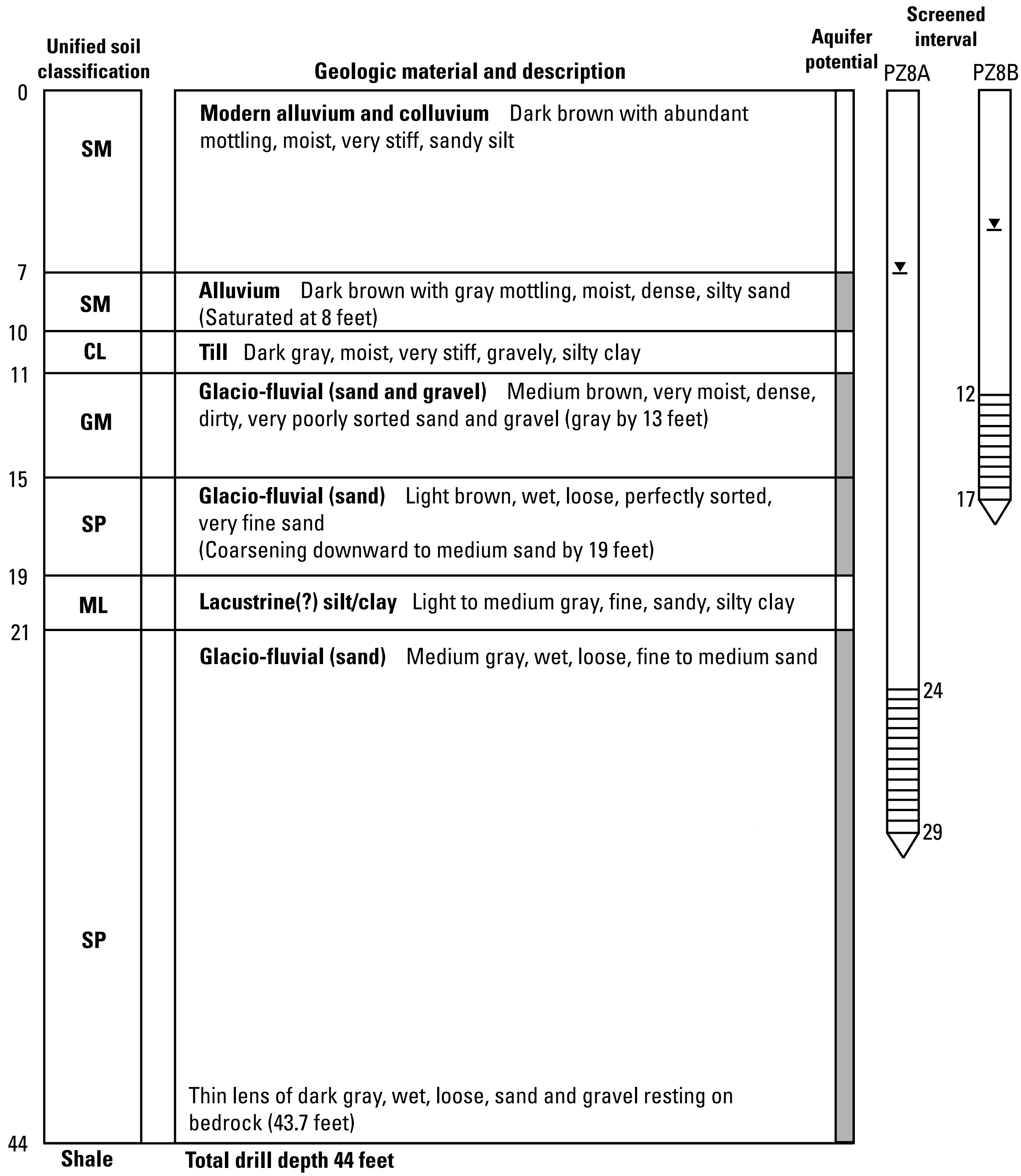
Monitoring Site 7

East of Mauxferry Rd, south of Muddy Branch. MW7 is 135 feet east of Mauxferry Rd, 105 feet south of Bearrs Rd. U.S. Geological Survey, 1962, 7.5-min topographic map, Nineveh quadrangle, T10N, R5E, Section 20, SW1/4, NW1/4, NW1/4. Water level [▼] measured 7/31/2003. Unit contacts and screened intervals are shown in feet below land surface (dashed where approximate). Shaded gray bar identifies geologic materials with the greatest potential to function as aquifers.



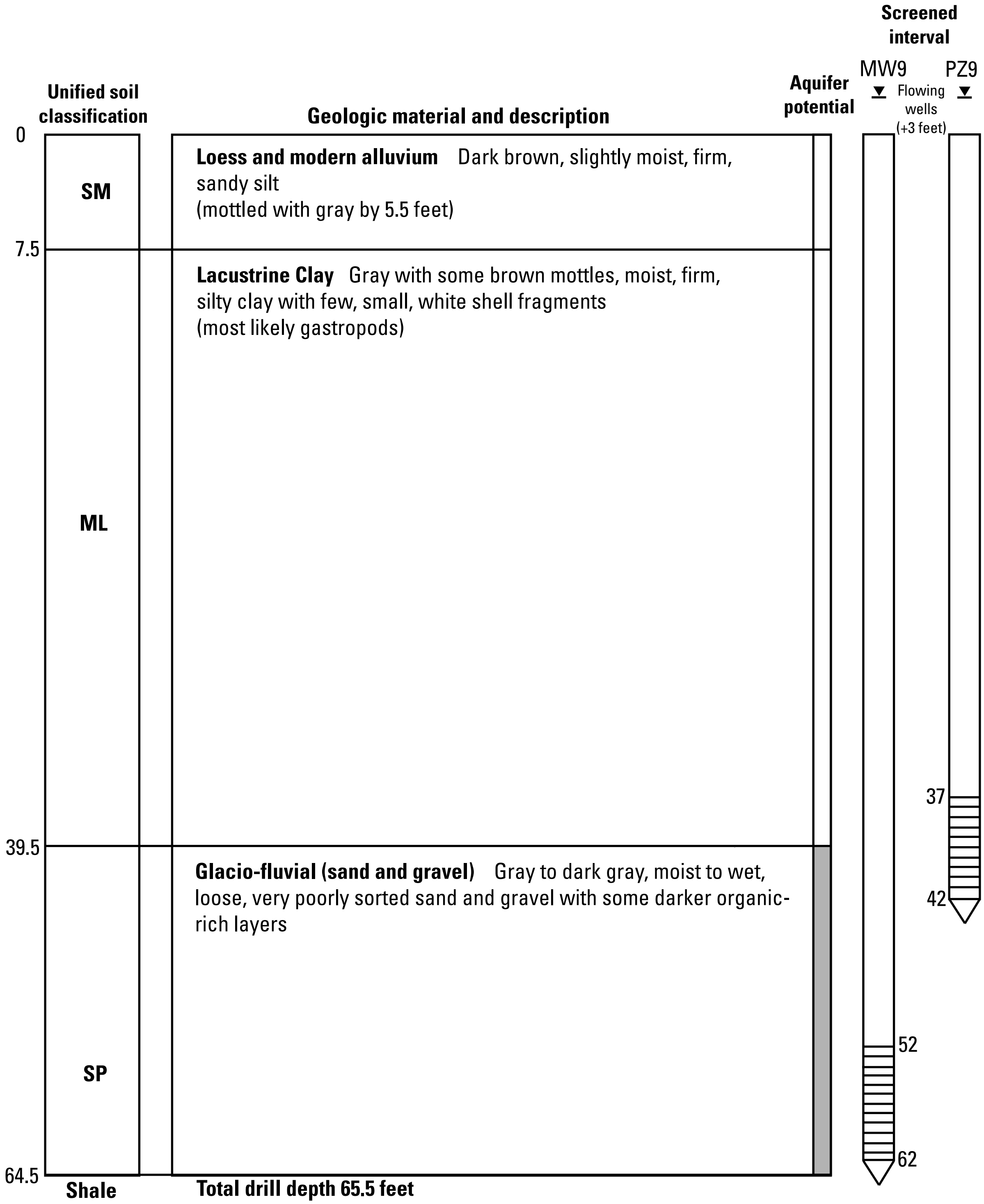
Monitoring Site 8

65 feet west of Wallace Rd, 2,700 feet north of 700N, 3,640 feet south of Nineveh Creek. U.S. Geological Survey, 1961, 7.5-min topographic map, Edinburgh quadrangle, T10N, R5E, Section 17, SE1/4, SE1/4, NE1/4. Water level [▼] measured 8/1/2003. Unit contacts and screened intervals are shown in feet below land surface. Shaded gray bar identifies geologic materials with the greatest potential to function as aquifers.



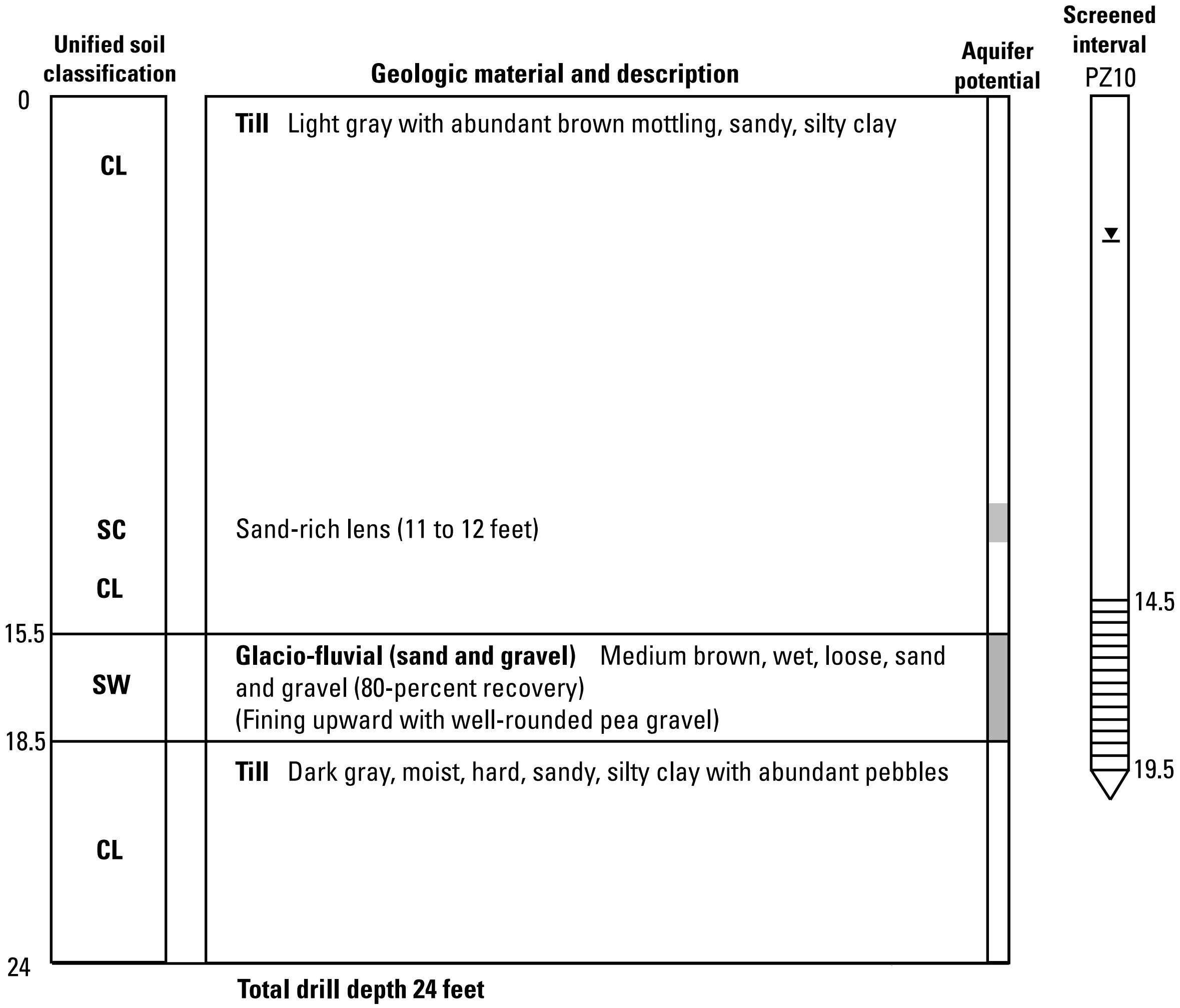
Monitoring Site 9

Southeast of the Mauxferry Rd bridge over Lick Ck, 40 feet east of Mauxferry Rd, 225 feet south of Lick Ck. U.S. Geological Survey, 1962, 7.5-min topographic map, Nineveh quadrangle, T10N, R5E, Section 29, SW1/4, SW1/4, NW1/4. Water level [▼] measured 8/1/2003. Unit contacts and screened intervals are shown in feet below land surface. Shaded gray bar identifies geologic materials with the greatest potential to function as aquifers.



Monitoring Site 10

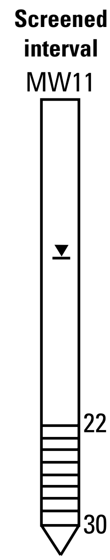
110 feet west of Reservation Boundary Rd, 70 feet south of Lowell Rd. U.S. Geological Survey, 1962, 7.5-min topographic map, Nineveh quadrangle, T10N, R5E, Section 29, SW1/4, SW1/4, NW1/4. Water level [▼] measured 8/1/2003. Unit contacts and screened intervals are shown in feet below land surface. Shaded gray bar identifies geologic materials with the greatest potential to function as aquifers.



Monitoring Site 11

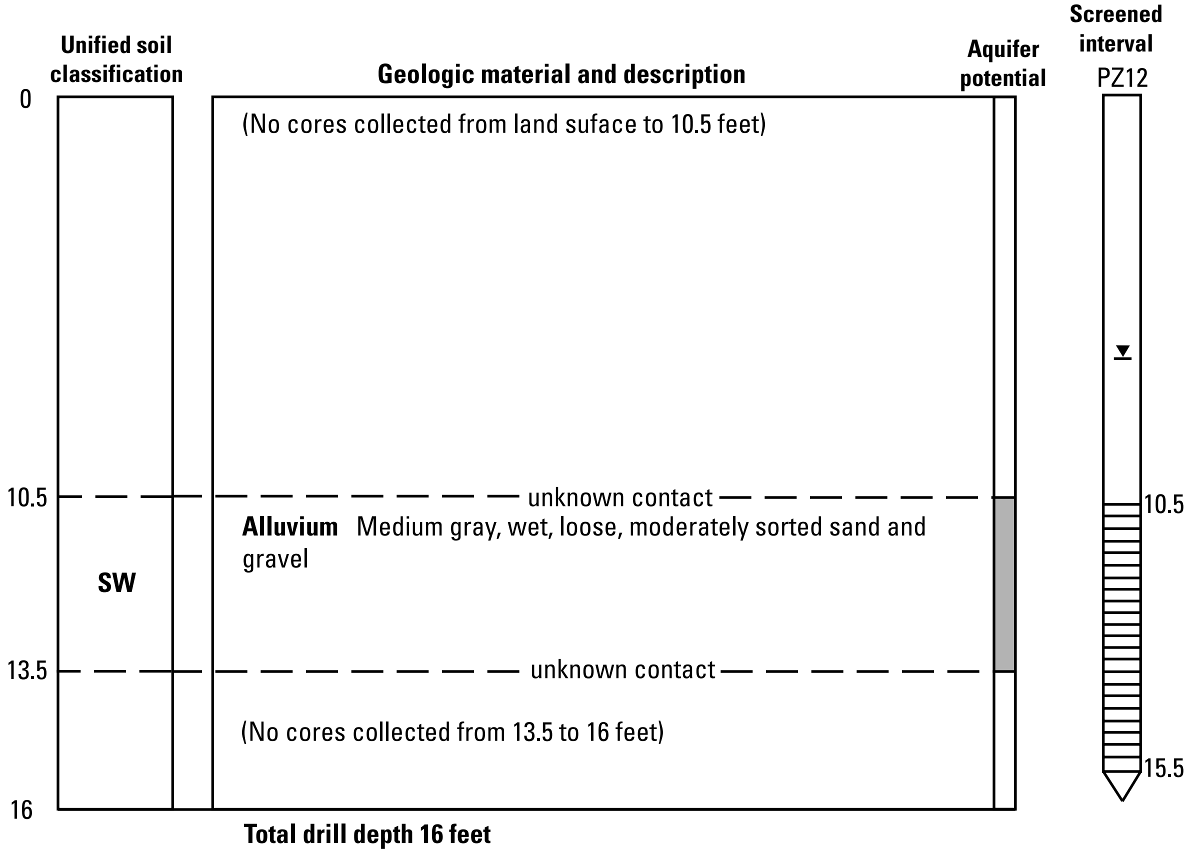
65 feet east of the center line of Mauxferry Rd and 2,150 feet north of Nineveh Ck. U.S. Geological Survey, 1962, 7.5-min topographic map, Nineveh quadrangle, T10N, R5E, Section 29, SW1/4, SW1/4, NW1/4. Water level [▼] measured 8/1/2003. Unit contacts and screened intervals are shown in feet below land surface. Shaded gray bar identifies geologic materials with the greatest potential to function as aquifers.

Depth	Unified soil classification	Geologic material and description	Aquifer potential
0	CL	**Till** Brown, moist, very stiff, sandy, silty clay with gravel	
8	SP	**Glacio-fluvial (sand)** Brown, moist, soft to loose sand	
11.5	CL	**Till** Gray, slightly moist to dry, very stiff to hard, sandy, silty clay with gravel	
20	SW	**Glacio-fluvial (sand and gravel)** Gray, wet, loose sand and gravel (Up to 2-inch gravel resulted in poor recovery)	
40.5	CL	**Till** Gray, dry, hard, sandy, silty clay with pebbles (No cores collected 44.5 to 53 feet)	
58	SP	**Glacio-fluvial (sand and gravel)** Dark brown, wet, soft, fine sand	
59.5	CL	**Till** Dark gray, dry, sandy, silty clay with pebbles (No cores collected 61.5 to 68.5 feet) Clay-rich sand stringer 68.5 to 69 feet (No cores collected 71.5 to 96 feet)	
96	Shale	**Total drill depth 96 feet**	



Monitoring Site 12

50 feet east of Mauxferry Rd, 135 feet north of Nineveh Ck, in woods. U.S. Geological Survey, 1962, 7.5-min topographic map, Nineveh quadrangle, T10N, R5E, Section 17, NW1/4, NW1/4, NW1/4. Water level [▼] measured 8/1/2003. Unit contacts and screened intervals are shown in feet below land surface (dashed where approximate). Shaded gray bar identifies geologic materials with the greatest potential to function as aquifers.

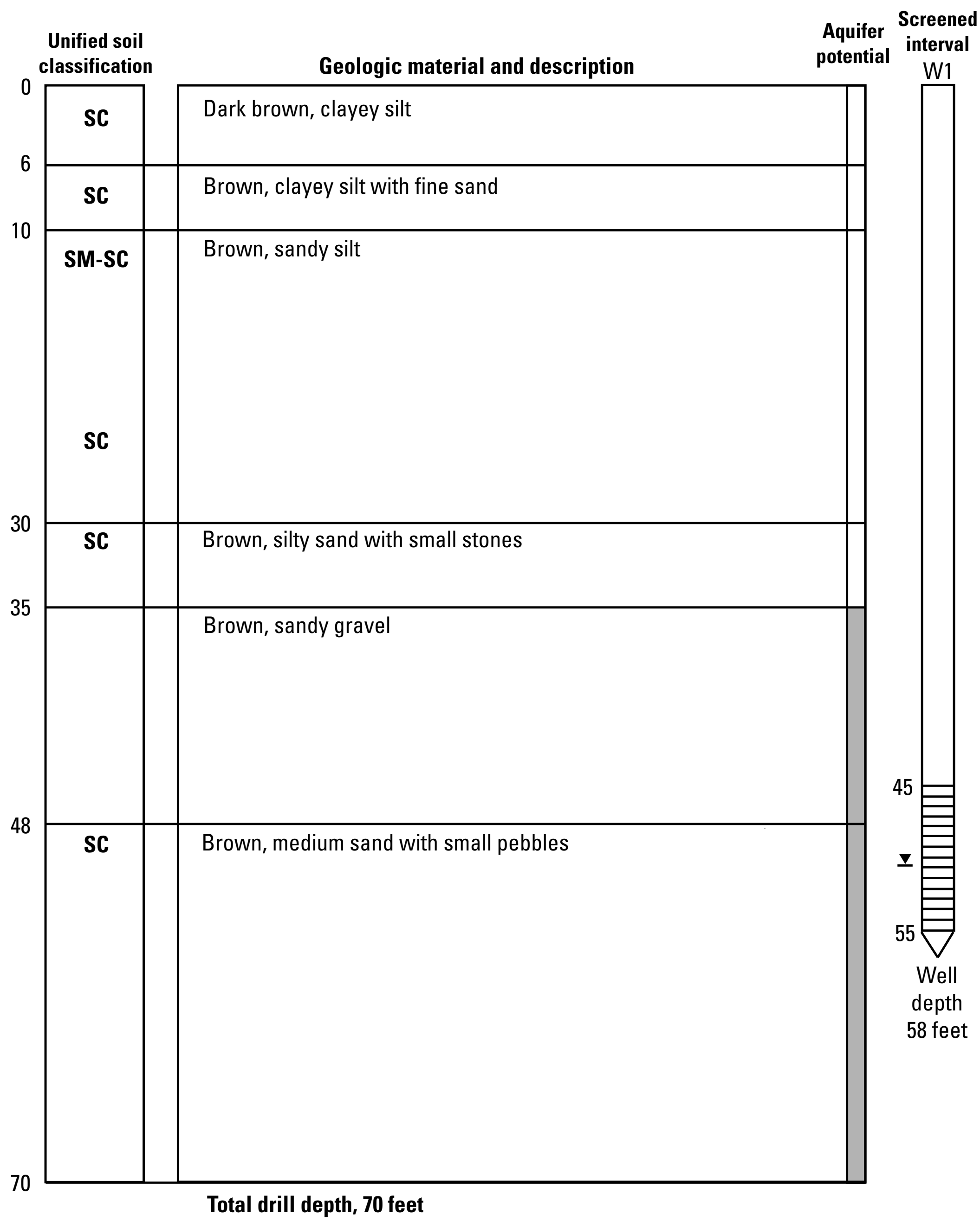


Appendix 2. Geologic logs and diagrams for monitoring wells constructed in 1981 and 1996 and water-supply wells constructed in 2003 at the U.S. Army Atterbury Joint Maneuver Training Center near Edinburgh, Indiana

Data for these well logs were obtained from: U.S. Army Environmental Hygiene Agency, 1981; Military Department of Indiana, 1997; and Walter Anderson, written commun., 2004.

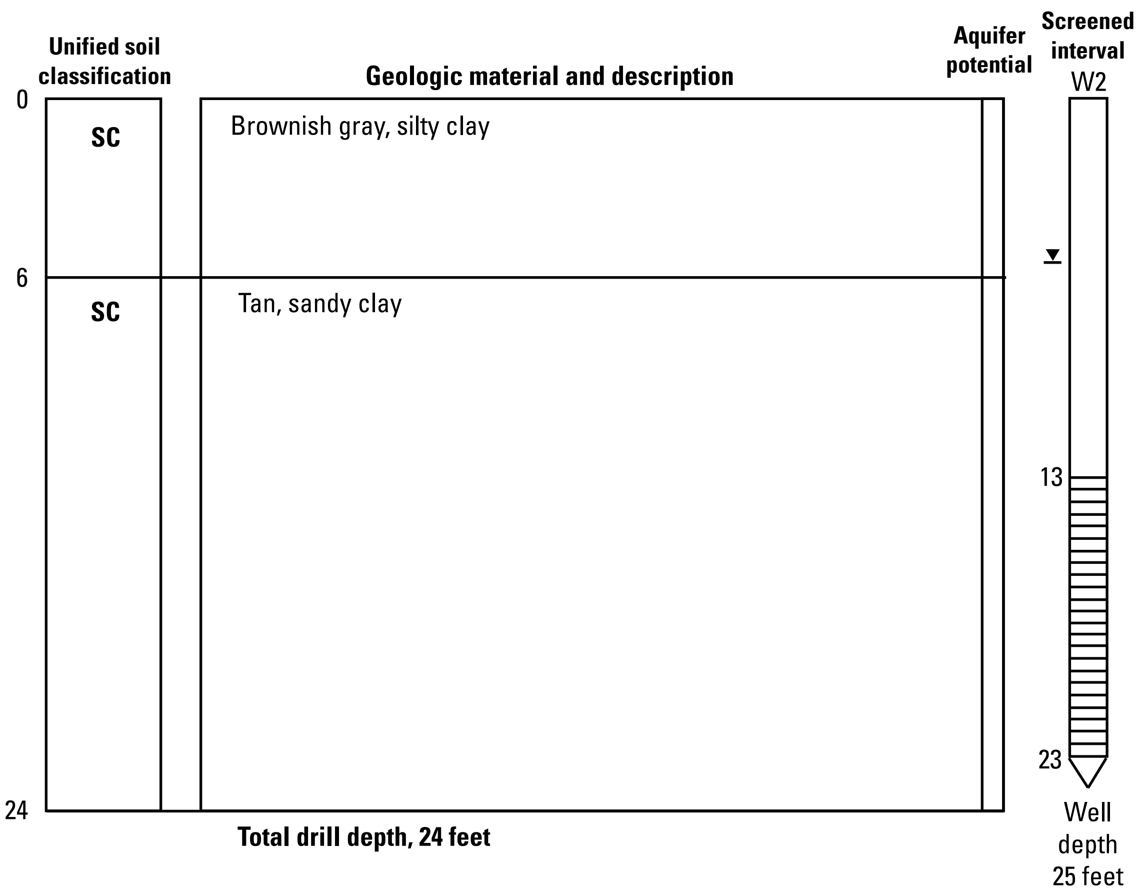
Monitoring Well W1

West of Mauxferry Rd, south of County Line Rd. Land-surface elevation, 744 feet, U.S. Geological Survey, 1962, 7.5-min topographic map, Nineveh quadrangle, T10N, R5E, Section 6, NE1/4, NE1/4, NE 1/4. Water level [▼] measured 7/31/2003. Unit contacts and screened intervals are shown in feet below land surface. Shaded gray bar identifies geologic materials with the greatest potential to function as aquifers.



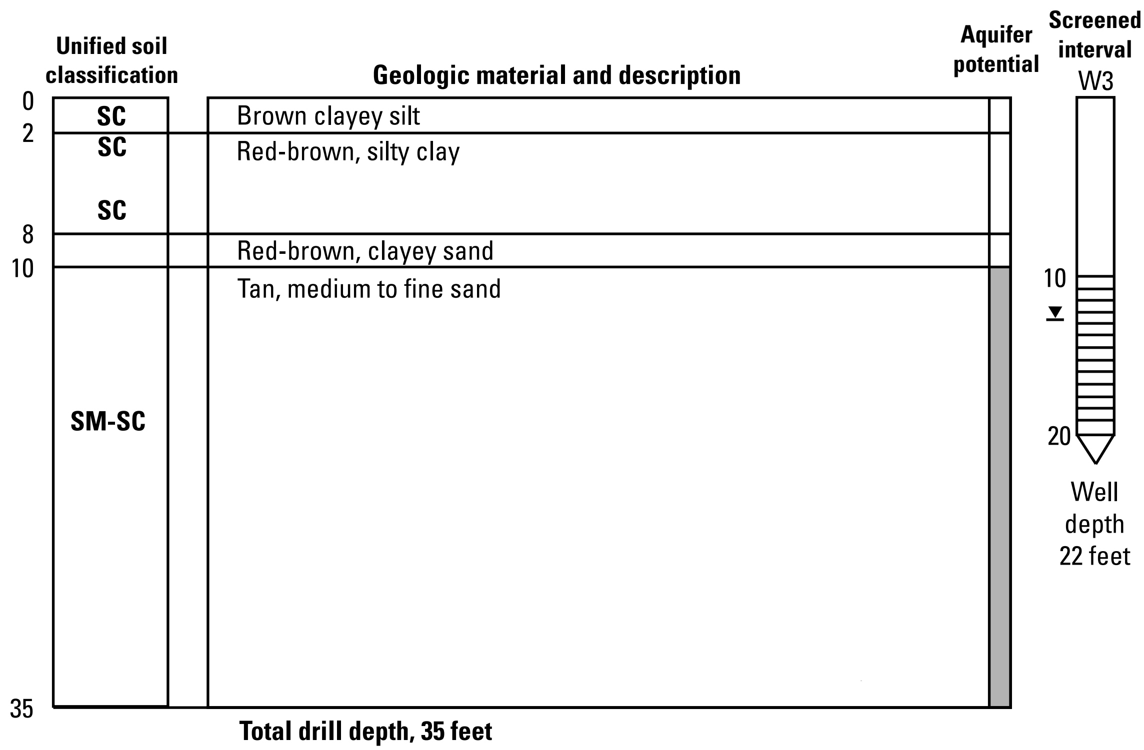
Monitoring Well W2

East of Mauxferry Rd, north of Hendricks Ford Rd. Land-surface elevation, 690 feet. U.S. Geological Survey, 1962, 7.5-min topographic map, Nineveh quadrangle, T10N, R5E, Section 5, SE1/4, SW1/4, NW 1/4. Water level [▼] measured 7/31/2003. Unit contacts and screened intervals are shown in feet below land surface. Shaded gray bar identifies geologic materials with the greatest potential to function as aquifers.



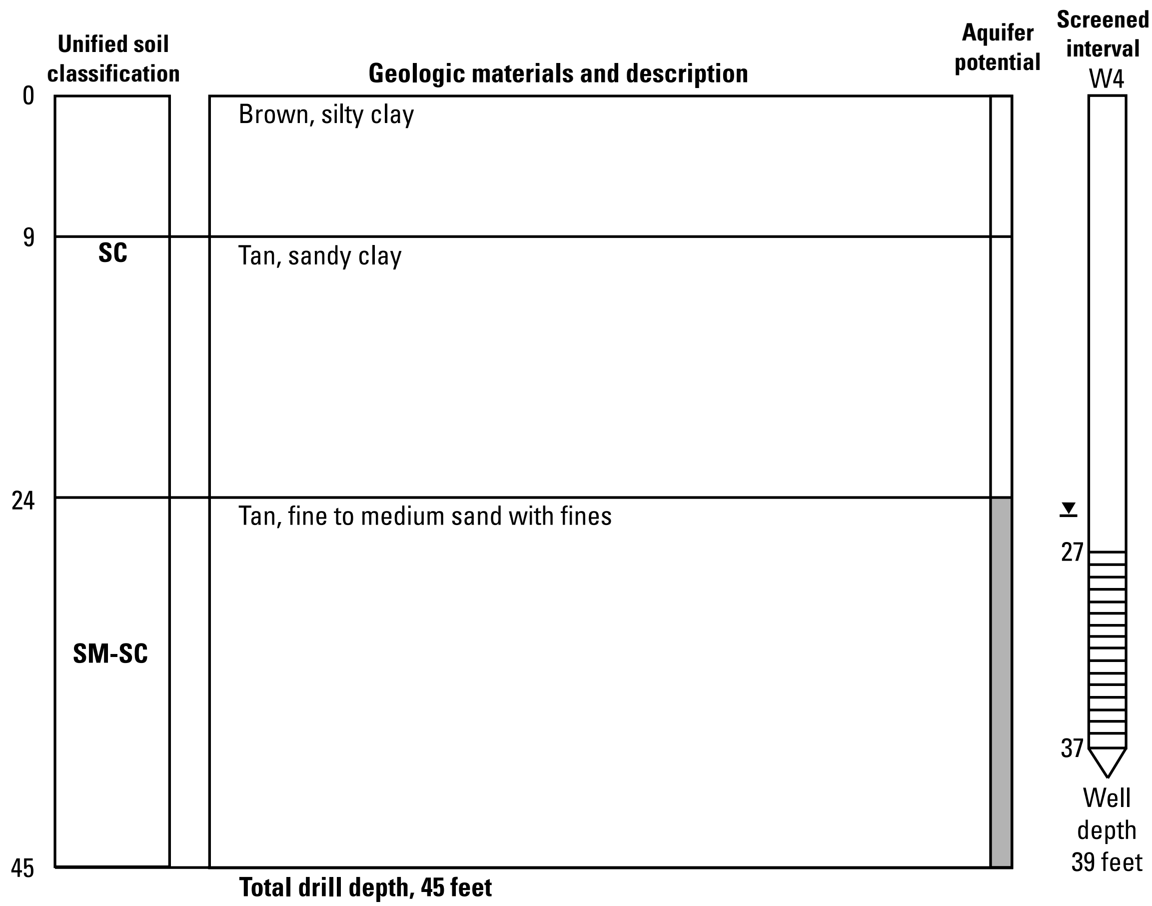
Monitoring Well W3

East of Mauxferry Rd, north of Hendricks Ford Rd. Land-surface elevation, 700 feet. U.S. Geological Survey, 1962, 7.5-min topographic map, Nineveh quadrangle, T10N, R5E, Section 5, NE1/4, SW1/4, NW 1/4. Water level [▼] measured 7/31/2003. Unit contacts are shown in feet below land surface. Shaded gray bar identifies geologic materials with the greatest potential to function as aquifers.



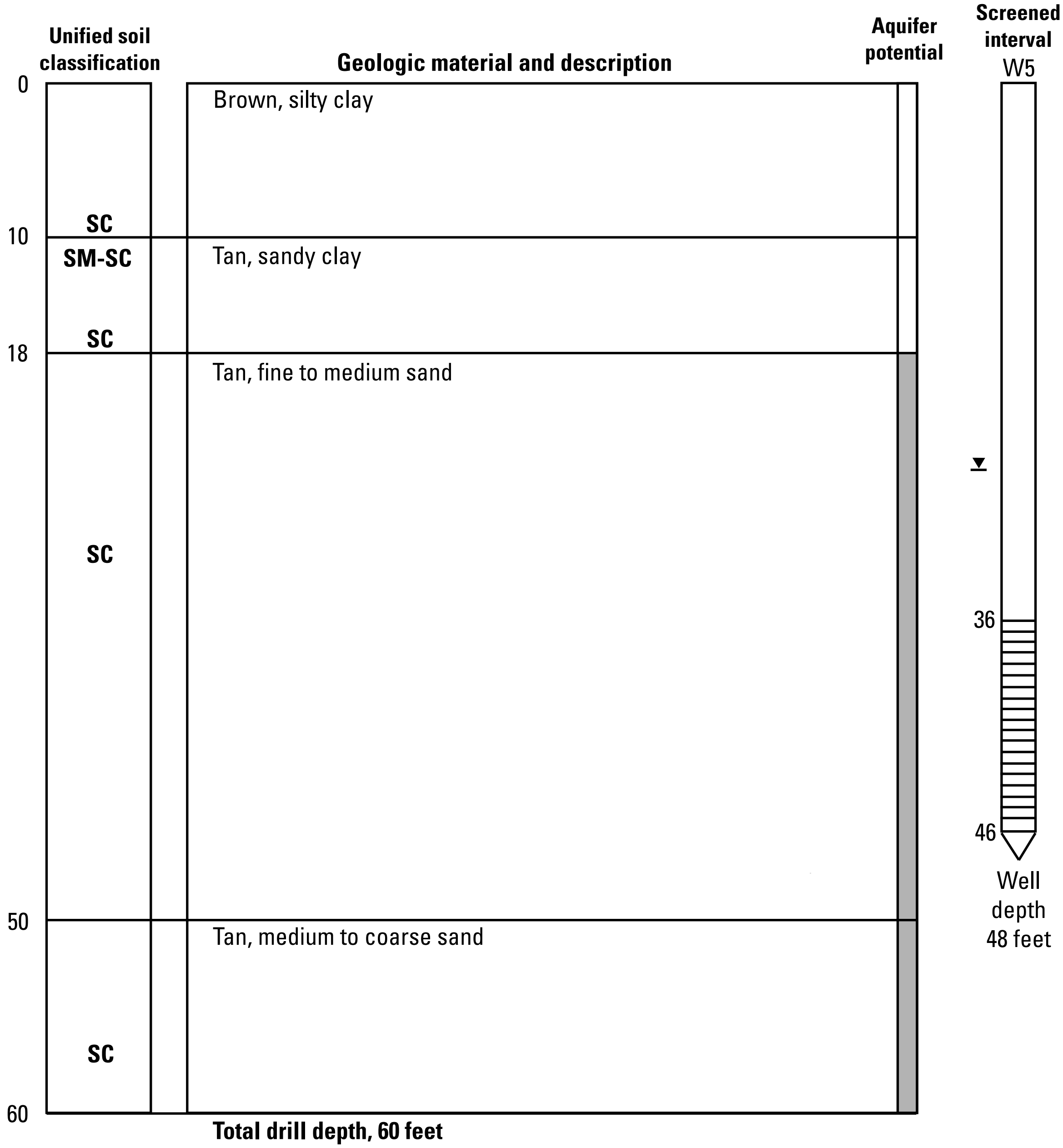
Monitoring Well W4

East of Mauxferry Rd, north of Hendricks Ford Rd. Land-surface elevation, 714 feet. U.S. Geological Survey, 1962, 7.5-min topographic map, Nineveh quadrangle, T10N, R5E, Section 5, SE1/4, NW1/4, NW 1/4. Water level [▼] measured 7/31/2003. Unit contacts and screened intervals are shown in feet below land surface. Shaded gray bar identifies geologic materials with the greatest potential to function as aquifers.



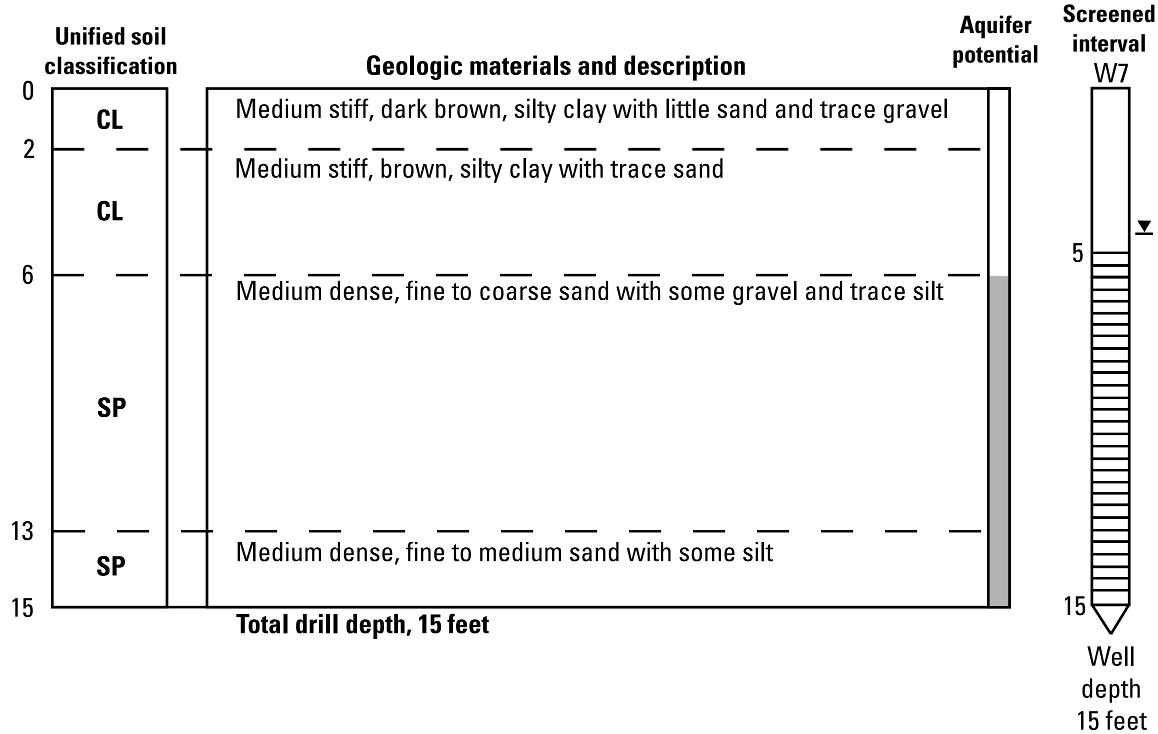
Monitoring Well W5

South of County Line Rd, east of Mauxferry Rd. Land-surface elevation, 717 feet. U.S. Geological Survey, 1962, 7.5-min topographic map, Nineveh quadrangle, T10N, R5E, Section 5, NE1/4, NW1/4, NW 1/4. Water level [▼] measured 7/31/2003. Unit contacts and screened intervals are shown in feet below land surface. Shaded gray bar identifies geologic materials with the greatest potential to function as aquifers.



Monitoring Well W7

South of Pleasant Run, east of Mauxferry Rd. Land-surface elevation, 653 feet. U.S. Geological Survey, 1962, 7.5-min topographic map, Nineveh quadrangle, T10N, R5E, Section 7, NW1/4, SE1/4, NW 1/4, Water level [▼] measured 8/1/2003. Unit contacts and screened intervals are shown in feet below land surface (dashed where approximate). Shaded gray bar identifies geologic materials with the greatest potential to function as aquifers.



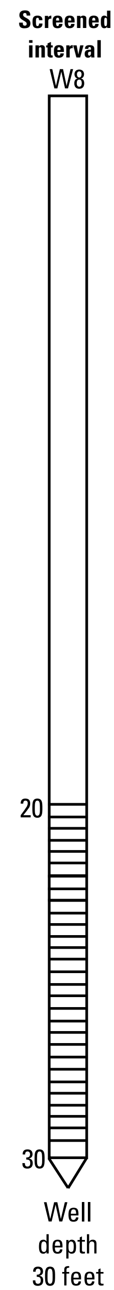
Monitoring Well W8

East of Mauxferry Rd, north of Muddy Branch. Land-surface elevation, 665 feet. U.S. Geological Survey, 1962, 7.5-min topographic map, Nineveh quadrangle, T10N, R5E, Section 17, SW1/4, SW1/4, SW 1/4. Water level [▼] measured 8/1/2003. Unit contacts and screened intervals are shown in feet below land surface (dashed where approximate). Shaded gray bar identifies geologic materials with the greatest potential to function as aquifers.

(flowing well +6.4 ft) ▼

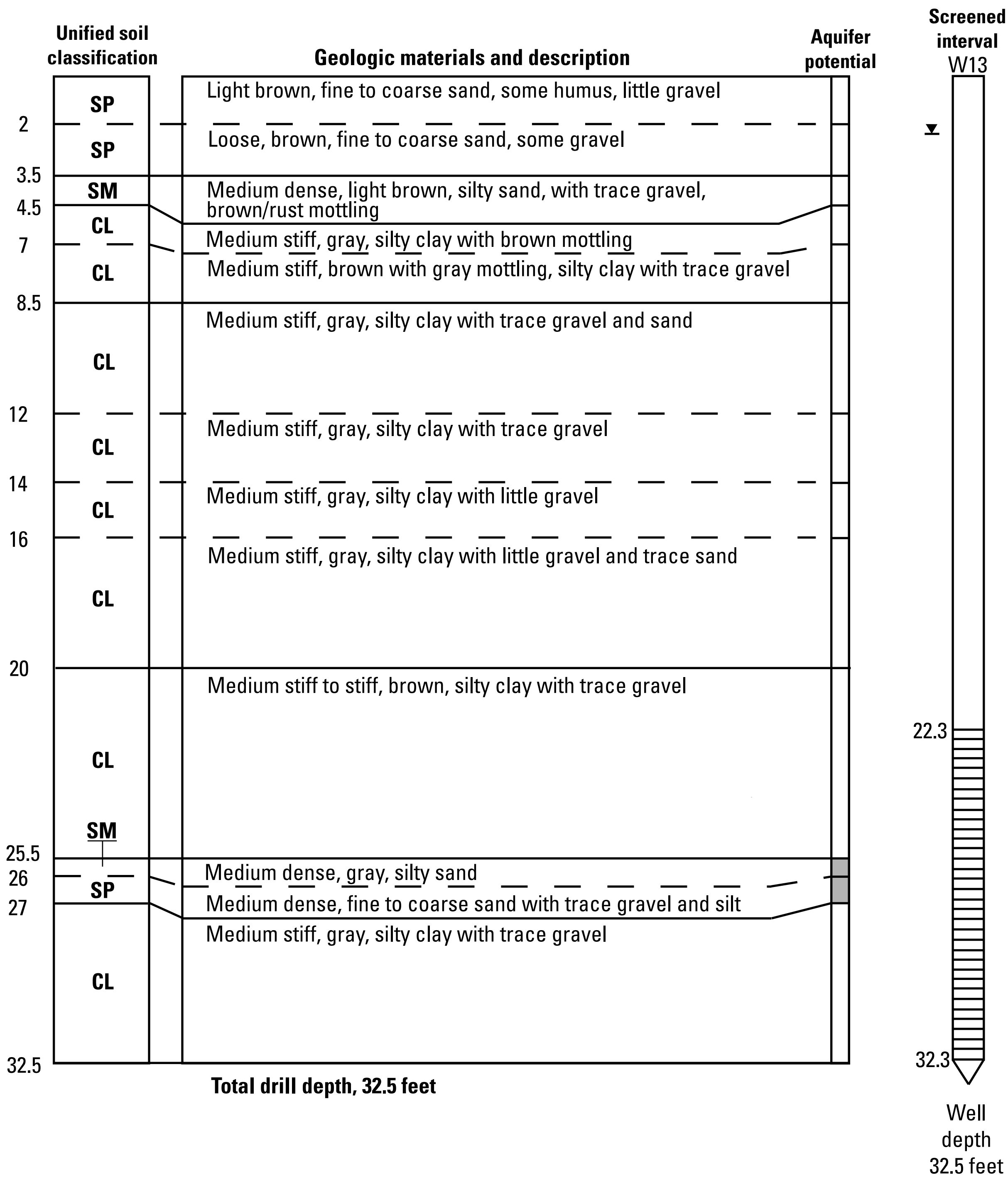
Depth (feet)	Unified soil classification	Geologic materials and description	Aquifer potential
0–0.5	CL	Soft, medium brown/gray, silty clay, with little fine (sic) and humus	
0.5–8.5	CL	Soft, yellow-brown with little light gray and reddish-brown mottling, silty clay with little fine sand	
8.5–11	CL	Medium stiff, gray, little reddish-brown mottling, silty clay with little to some fine sand	
11–12.5	CL	Medium stiff, gray, little reddish-brown mottling, silty clay with little to some fine sand (plastic)	
12.5–15	CL	Very soft, gray with brown mottling, silty clay with little sand	
15–17	CL	Medium stiff, gray, silty clay with little fine to medium sand	
17–20.5	CL	Stiff, gray with no mottling, silty clay with trace to little fine sand	
20.5–22	CL	Stiff, gray with no mottling, silty clay	
22–24	CL	Soft, gray with no mottling, silty clay	
24–24.5	CL	Soft, gray, silty clay with some sand and gravel	
24.5–30	GP	Medium dense, gravel with some sand	Shaded

Total drill depth, 30 feet



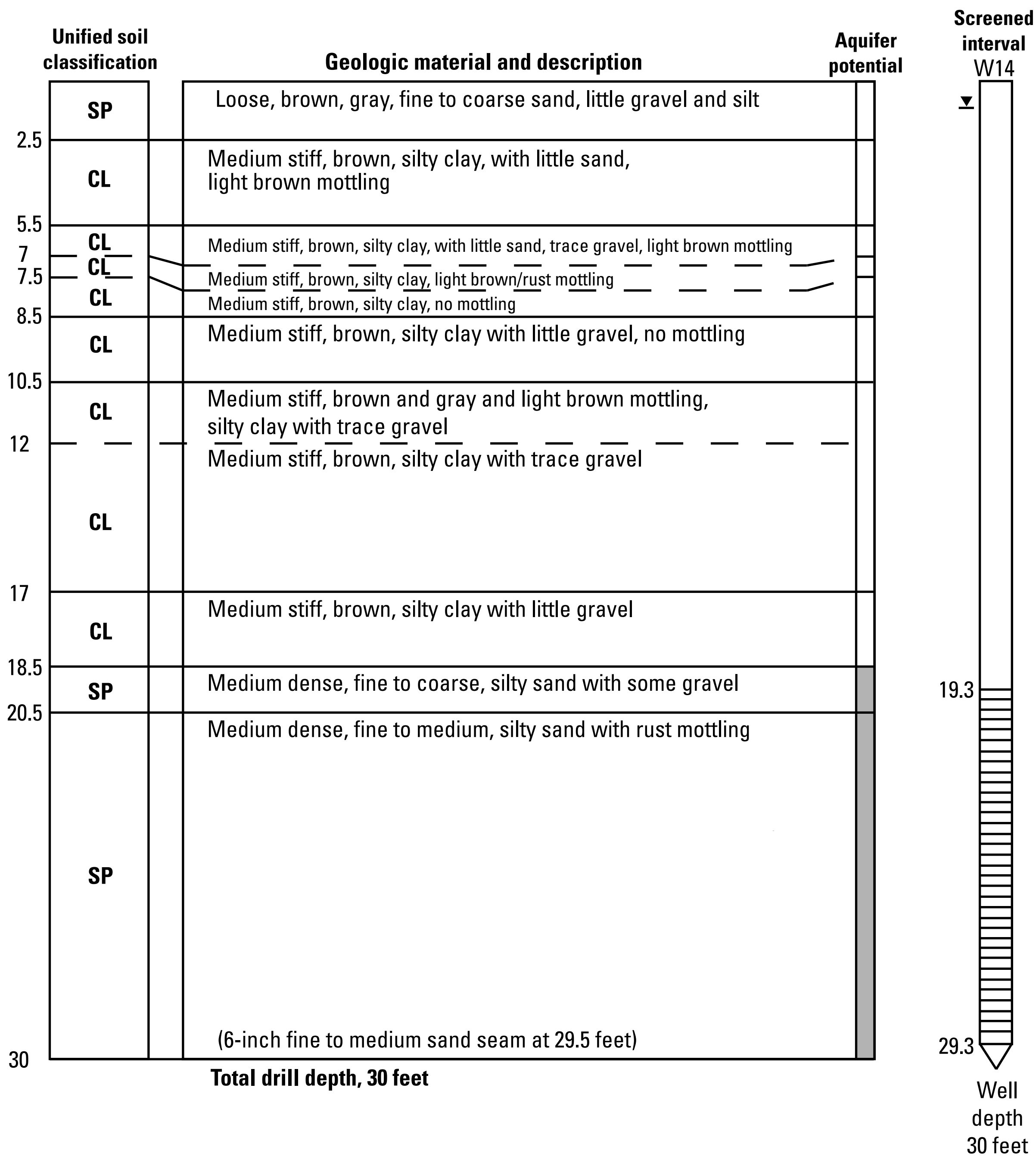
Monitoring Well W13

North of Evans Rd, west of Eggleston St. Land-surface elevation, 711 feet. U.S. Geological Survey, 1962, 7.5-min topographic map, Nineveh quadrangle, T11N, R4E, Section 36, SE1/4, SW1/4, NE 1/4. Water level [▼] measured 8/1/2003. Unit contacts and screened interval are shown in feet below land surface (dashed where approximate). Shaded gray bar identifies geologic materials with the greatest potential to function as aquifers.



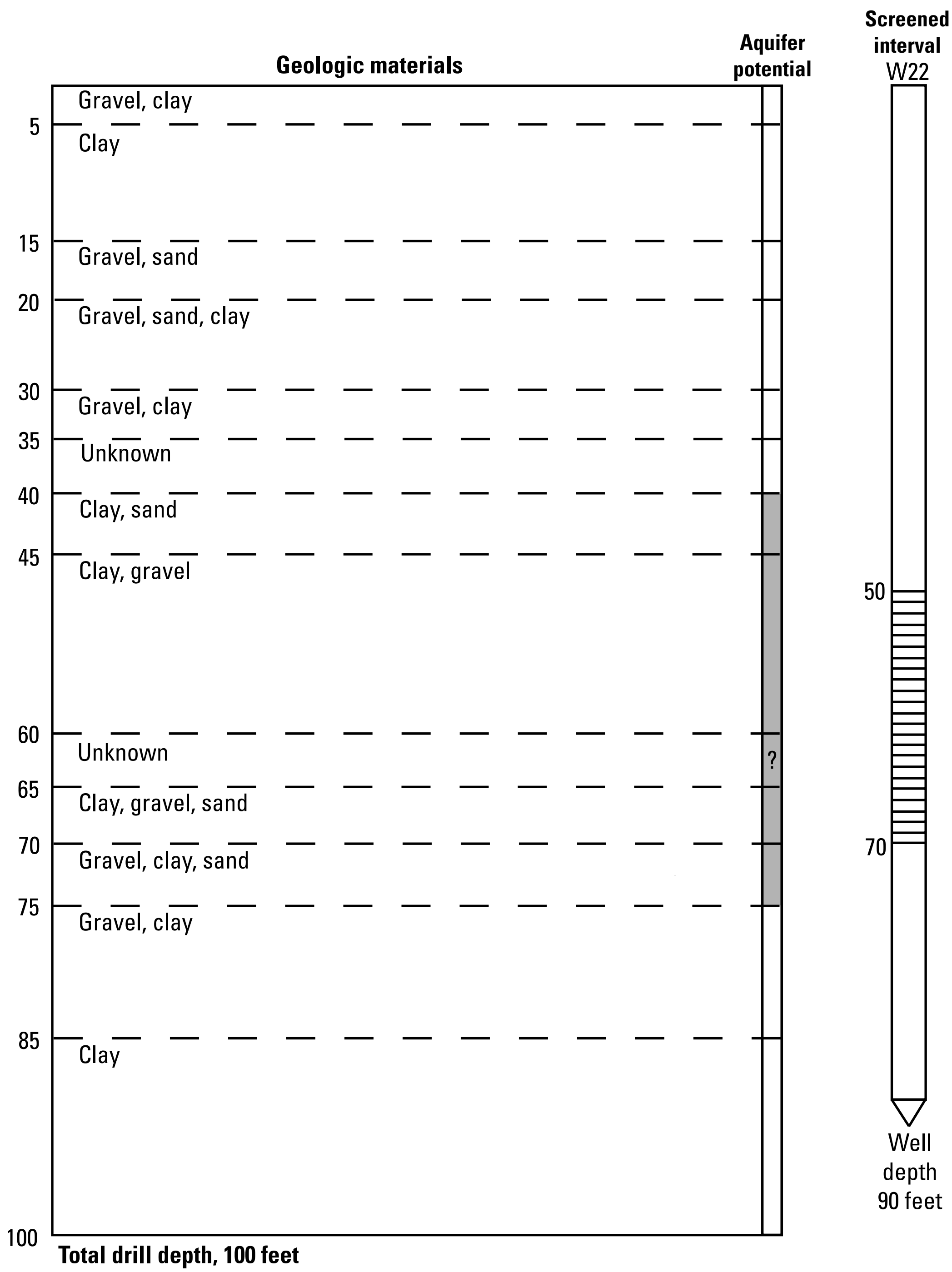
Monitoring Well W14

West of Mauxferry Rd, north of County Line Rd. Land-surface elevation, 709 feet. U.S. Geological Survey, 1962, 7.5-min topographic map, Nineveh quadrangle, T11N, R5E, Section 31, SE1/4, SE1/4, SW 1/4. Water level [▼] measured 7/31/2003. Unit contacts and screened intervals are shown in feet below land surface (dashed where approximate). Shaded gray bar identifies geologic materials with the greatest potential to function as aquifers.



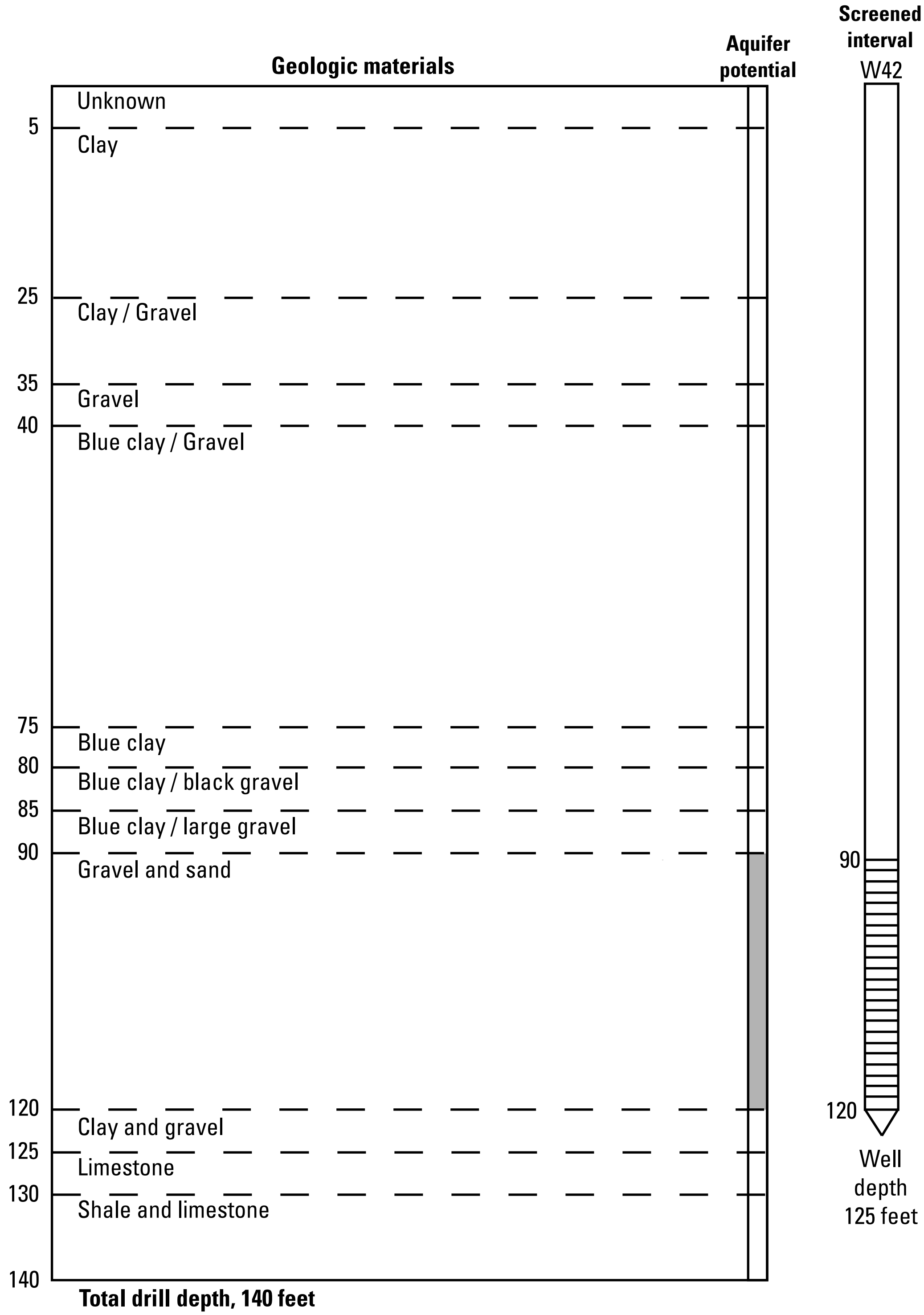
Water-Supply Well WS22

Unit contacts and screened interval are shown in feet below land surface (dashed where approximate). Shaded gray bar identifies geologic materials with the greatest potential to function as aquifers.



Water-Supply Well WS42

Unit contacts and screened interval are shown in feet below land surface (dashed where approximate). Shaded gray bar identifies geologic materials with the greatest potential to function as aquifers.



Robinson, Risch—**Hydrogeologic Framework, U.S. Army Atterbury Training Center, Edinburgh, Indiana, 2002–2003—Scientific Investigations Report 2006–5172**