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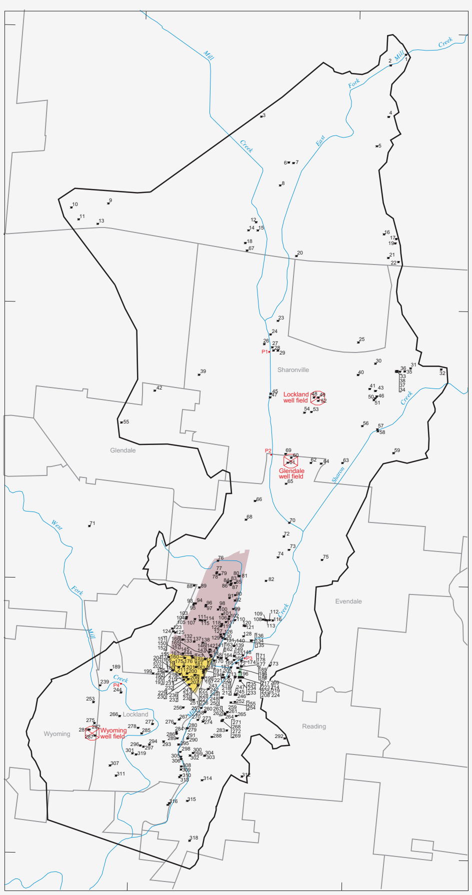
Water-Resources Investigations Report 02–4167



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By Charles W. Schalk and Thomas L. Schumann

ABSTRACT

Withdrawals of ground water in the central Mill Creek Valley near Evendale, Ohio, caused water-level declines of more than 100 feet by the 1950s. Since the 1950s, management practices have changed to reduce the withdrawals of ground water, and recovery of water levels in long-term monitoring wells in the valley has been documented. Changing conditions such as these prompted a survey of water use, streamflow conditions, and water levels in several aquifers in the central Mill Creek Valley, Hamilton and Butler Counties, Ohio. Geohydrologic information, water use, and water levels were compiled from historical records and collected during the regional survey. Data collected during the survey are presented in terms of updated geohydrologic information, water use in the study area, water levels in the aquifers, and interactions between ground water and surface water. Some of the data are concentrated at former Air Force Plant 36 (AFP36), which is collocated with the General Electric Aircraft Engines (GEAE) plant, and these data are used to describe geohydrology and water levels on a more local scale at and near the plant.

A comparison of past and current ground-water use and levels indicates that the demand for ground water is decreasing and water levels are rising. Before 1955, most of the major industrial ground-water users had their own wells, ground water was mined from a confined surficial (lower) aquifer, and water levels were more than 100 feet below their predevelopment level. Since 1955, however, these users have been purchasing their water from the city of Cincinnati or a private water purveyor. The cities of Reading and Lockland, both producers of municipal ground-water supplies in the area, shut down their well fields within their city limits. Because the demand for ground-water supplies in the valley has lessened greatly since the 1950s, withdrawals have decreased, and, consequently, water levels in the lower aquifer are 65 to 105 feet higher than they were in 1955.

During the time of the water-level survey (November 2000), ground water was being pumped from four locations in the lower aquifer, including three municipalities and one remediation site. Effects of pumping in those four areas were evident from the regional water-level data. Overall, the direction of ground-water flow in the lower aquifer is from northeast to southwest along the primary orientation of the Mill Creek Valley in the study area.

Water levels in shallower surficial aquifers were mapped at local scales centered on GEAE. Examination of well logs indicated that these aquifers (called shallow and water-table) are discontinuous and, on a regional scale, few wells were completed in these aquifers. Water levels in the shallow aquifer indicated that flow was from northeast to southwest except in areas where pumping in the lower aquifer or the proximity of Mill Creek may have been affecting water levels in the shallow aquifer. Water levels in the water-table aquifer indicated flow toward Mill Creek from GEAE.

INTRODUCTION

Availability of ground water in the Mill Creek Valley near Cincinnati, Ohio, has been a significant issue in that region for more than 75 years. In the early 1900s, Fuller and Clapp (1912) documented ground-water use for industry, including whiskey distilleries, laundries, slaughterhouses, and manufacturers of asbestos products. Declines in water levels have been documented as a result of industrial and municipal use. Maximum water-level declines in the valley, more than 100 ft (Fidler, 1970), were reached in the 1950s. Because of changes in management practices, however, recovery of water levels, by as much as 105 ft, has been steady since then.

Changing conditions in the valley were important to the U.S. Air Force (USAF) because of current and planned water-management programs at former Air Force Plant 36 (AFP36). Although AFP36 was sold to General Electric Aircraft Engines (GEAE) in 1989, the Air Force retains responsibility for all environmental liability resulting from activities on AFP36 before the date of the sale (U.S. Air Force, 1994). General Electric, as current owner of the property, is operating under a Resource Recovery and Conservation Act (RCRA) Corrective Action permit (O'Brien and Gere Engineers, Inc., 1993). Part of the planned water-management program of GEAE and USAF is a ground-water-flow model intended to focus the characterization and sampling of possible offsite contamination (John Doepker, U.S. Air Force, written commun., 2001); necessary components of such a model are current water-level, water-use, and hydrogeologic information.

The U.S. Geological Survey (USGS), in cooperation with U.S. Air Force Aeronautical Systems Center, measured water levels and streamflow conditions in November 2000 from southern Butler County and northern Hamilton County, Ohio, in the Mill Creek Valley (fig. 1). The USGS also updated the hydrogeologic information presented by Fidler (1970) to incorporate results of investigations since 1970.

Purpose and Scope

The purpose of this report is to present current (2000) use and levels of ground water in the central Mill Creek Valley and compare them with past conditions. A document of this nature will be useful to agencies and groups concerned about the quantity of water resources in the Mill Creek Valley and provide a sense of direction for future studies and practices to improve the availability of water in the valley. The data provided in the report will be used in the ground-water-flow modeling that will help GEAE and USAF in their water-management programs.

The unconsolidated deposits in the study area were mapped to present the water-level and water-use data in their proper geologic framework. The maps of unconsolidated aquifers and confining units were drawn on the basis of 318 well logs and boring logs (Appendix 1). Historical ground-water-level and -use data collected by the USGS, Ohio Department of Natural Resources (ODNR), Ohio Environmental Protection Agency (EPA), and other organizations were examined. Water levels in 182 wells completed at depths as great as 201 ft were measured and interpreted for this report. Pump-discharge records from production wells in the area were obtained and used to aid the interpretation of the ground-water-level data. Streamflow and stream-aquifer data were collected to aid interpretation of surface-water/ground-water interactions.

Geography

The Mill Creek drainage basin, as much as10 mi wide and 21 mi long, encompasses about 164 mi^2 in southwestern Ohio (fig. 1). Mill Creek flows about 28 mi through a 2-mi-wide valley from southern Butler County to its confluence with Ohio River. The valley is generally broad and flat, bounded by glacial and alluvial terraces and relatively steep bedrock walls. The creek and its tributaries flow from the upland areas along the valley walls at altitudes of about 780 ft to the confluence with Ohio River, which is at an altitude of 444 ft. Average gradient of the valley along the course of Mill Creek is 12 ft/mi.

Land Use

Land use in the Mill Creek Valley is about 63 percent urban, 22 percent agricultural, and 12 percent forested. Cincinnati, Ohio, is the major city in the valley. Cities in the valley of population greater than 10,000 include Forest Park, North College Hill, Norwood, Reading, Sharonville, and Springdale. Total population in Mill Creek Valley is approximately 490,000, with population density greater in the southern part of the valley than in the northern part.

Much of the Mill Creek Valley in Hamilton County is dominated by industry. Mill Creek Valley historically provided the best route from agricultural commodities in the north to markets on Ohio River in the south. As settlement in the valley grew, so did industries that were based on the local resources. Completion of the Miami and Erie Canal in 1845 and construction of the railroads a few years later further encouraged industrial development in the valley. Lumber and grain mills, distilleries, slaughterhouses, and stockyards were the first notable industries; other industries based on agriculture included wool and paper mills, wagon factories, and box factories. Each industry historically used Mill Creek as a waste sewer; numerous accounts describe Mill Creek as "foully polluted" by the mid- to late 1800s (Hedeen, 1994). Manufacturing in the valley grew during the war years of 1911-20 and the 1940s. Today, large companies in the Mill Creek Valley include Borden Chemical, Cincinnati Specialties, Ford Motor Company, Formica Corporation, General

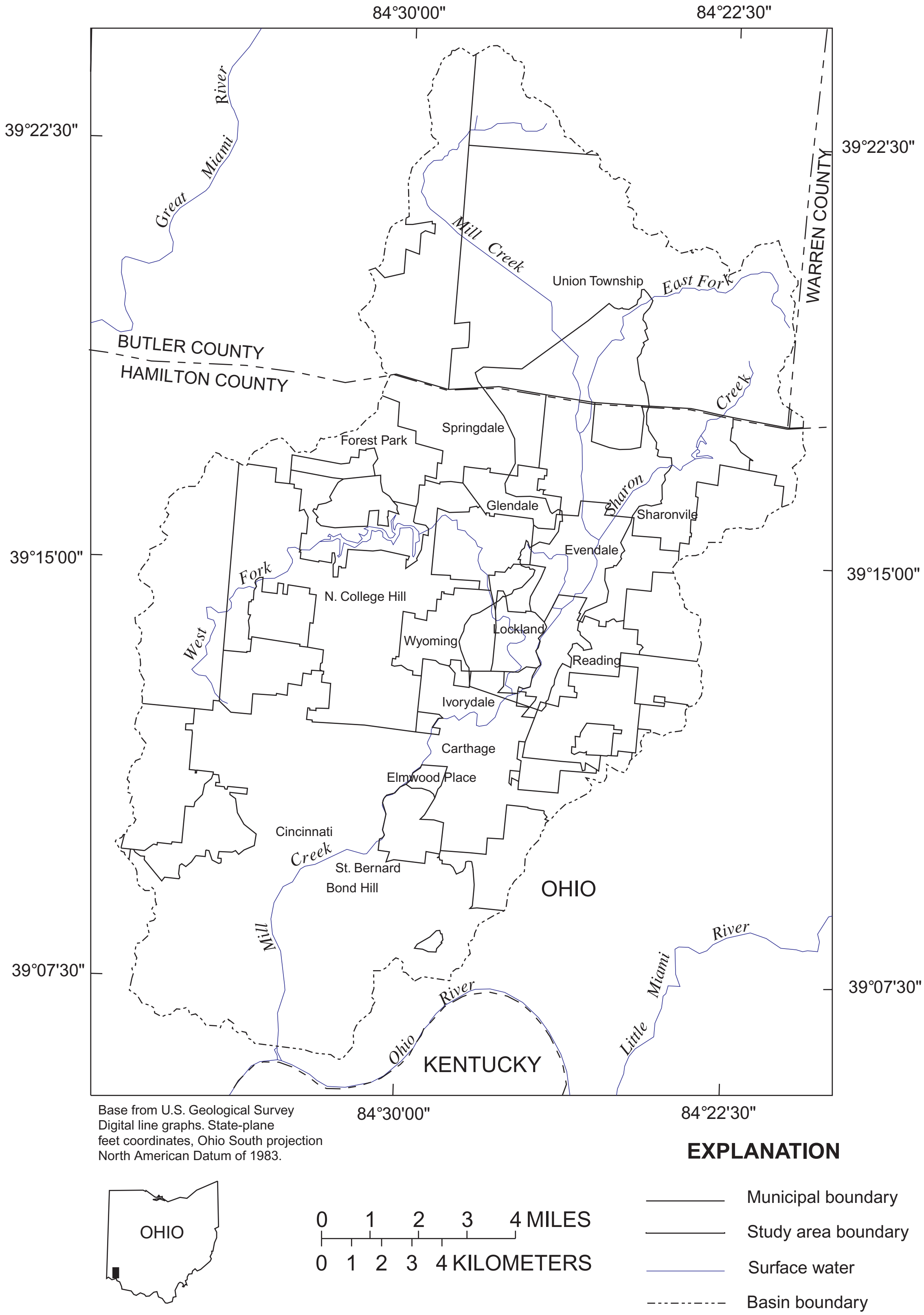

Figure 1. The Mill Creek Valley, Ohio.

Electric Aircraft Engines, Jefferson Smurfit, Procter and Gamble, Shepherd Chemical, and Stearns & Foster.

In 1940, about 90 percent of Butler County and 51 percent of Hamilton County were in agricultural use (Klaer and Thompson, 1948; urban land use not available). By comparison, the 1990 census indicates that 75 percent of Butler County and 16 percent of Hamilton County are now agricultural. The decreasing amount of agricultural land probably is an indication of urban development during the last 50 years in the greater Cincinnati area. Recent urban development in the northern part of the valley, including Butler County, has given rise to emphasis on flood control. The U.S. Army Corps of Engineers is involved in attempts to mitigate flood damage by use of channel improvements and early warning systems.

Climate

Cincinnati's climate is humid and temperate, characterized by hot and humid summers and moderately cold winters. On average, July is the hottest month (76^{o} F) and January the coldest month (30^{o} F) (extremes are for years 1949-2000, whereas averages are for years 1961-1990) (Midwestern Regional Climate Center, 2001). Highest recorded temperature is 105^{o} F, whereas lowest recorded temperature is -22^{o} F. Mean yearly precipitation is 40.7 in. May is the wettest month, averaging 4.4 in., and February is the driest month, averaging 2.5 in. The most rainfall recorded in a 24-hr period was 4.73 in. Rain falls 132 days per year on average. Prevailing winds are 4.5-9.0 mi/hr from the southwest year round.

Acknowledgments

The authors gratefully acknowledge the assistance of David Cashell and Allan Luczyk, ODNR; Henry Cooke, Conestoga-Rovers and Associates; Gregory Jaspers, General Electric Aircraft Engines; Bruce Koehler, Ohio-Kentucky-Indiana Regional Council of Governments; Darcy Riegel, Metropolitan Sewer District of Greater Cincinnati; Randy Welker, Greater Cincinnati Chamber of Commerce; Randy Watterworth and Paul Pardi, Ohio EPA; William Miller, Ohio Department of Transportation (ODOT); representatives of the City of Wyoming and the Villages of Glendale and Lockland; and the many agencies, companies, organizations, and individuals who allowed access to their wells or provided pump-discharge data.

HYDROGEOLOGY

Detailed descriptions of the hydrogeology and geologic history of Mill Creek Valley can be found in Fenneman (1916), Fuller and Clapp (1912), and Klaer and Thompson (1948). In general, the Mill Creek Valley consists of shale and limestone bedrock overlain by unconsolidated glacial outwash (in the lowlands) and (or) till (in the uplands) of variable composition and thickness. Only the more permeable parts of the outwash are significant sources of water. A brief summary of the local hydrogeology is presented here to illustrate its control on ground-water levels and flow directions.

Bedrock

Most rocks underlying the glacial deposits are limestones and interbedded shales of Ordovician age. An exception is the formation known as the St. Peter Sandstone, which is at depths of about 900 ft below land surface and is about 400 ft thick. Beneath the St. Peter Sandstone are undifferentiated dolomites and marbles of Ordovician and Cambrian ages. The St. Peter Sandstone is not in direct contact with the glacial deposits.

Lithologic logs obtained from ODOT indicate that the upper surface of the bedrock is highly weathered and fragmented. One log (location 2, plate 1) describes the upper 4.5 ft of bedrock as "clay shale, gray, soft and crumbly with thick interbeds, very badly broken and jointed." Limestone fragments are common in the near-surface of the bedrock, as described in many logs from ODOT and other agencies. Another log (location 1, plate 1) describes the shale as calcareous, and the ratio of shale to limestone as 72:28. A third log (location 173, plate 1) describes the bedrock as the first two logs did, indicating that the composition of the shale is about the same in the southern part of the study area as in the northern part. The descriptions in the logs suggest that the shale becomes harder (less weathered) with depth.

Contours on the bedrock surface in the study area are shown on plate 2. The most notable feature of the bedrock surface is the north-south valley incised into the bedrock. This bedrock valley is called a buried valley because it has been filled with unconsolidated deposits. The bedrock-valley walls are steep, in many areas falling at slopes of 18 percent or more to the relatively flat bottom of the bedrock valley. Minimum altitudes are in the range of 365-370 ft above sea level in the Wyoming area and about 370 ft above sea level in Sharonville. Minimum altitude in the vicinity of Evendale is about 380 ft above sea level.

The bedrock valley appears to be its narrowest in the vicinity of Evendale, widening to the north and south. A few incised branch valleys are evident, including one from the east in Reading and one from the west near Glendale. In the Wyoming-Lockland area, the main valley widens to incorporate the West Fork Mill Creek Valley. Few data points are available in the northern part of the study area to define the extent of the bedrock valley.

Unconsolidated Deposits

Sands, gravels, and clays of glacial origin are the primary surficial deposits in the Mill Creek area. In upland areas flanking the valley, the unconsolidated deposits are dominated by clayey till about 15 to 25 ft thick. In the vicinity of Reading, Evendale, and Lockland, the unconsolidated deposits are more than 200 ft thick and include sands and gravels that may contain beds of clayey till. Some glacially derived terrace gravels are found in the valley; the best example is in the Norwood trough (Klaer and Thompson, 1948), supposedly an old channel of Ohio River, between Mill Creek and Little Miami River near Norwood, south of the study area.

Two glacial outwash aquifers have been delineated in the study area (plate 3). A confined lower or deep aquifer, also called the fluvioglacial unit by Chem-Nuclear Geotech, Inc. (1993), is the aquifer used historically for water supply by industries and municipalities in the study area. The upper aquifer, also called the fluviolacustrine unit by Chem-Nuclear Geotech, Inc. (1993), historically has not been used for water supply. A fairly homogeneous but leaky confining unit separates the lower and upper aquifers throughout the valley.

Contours on the upper surface of the lower aquifer are presented in plate 4. This productive aquifer, present everywhere in the buried valley, occurs at an altitude of about 490 ft in the central part of the valley, except for an area in Sharonville where the surface is shallower. In the southern part of the study area, the altitude of the top of the lower aquifer varies considerably from 415 to 500 ft. The altitude of the top of the lower aquifer increases near the bedrock walls.

The thickness of the lower aquifer is shown in plate 5. Although the total thickness of the unconsolidated deposits is greatest in the vicinity of Lockland and Wyoming, the lower aquifer is thinner in those areas than in the central part of the valley between Evendale and Sharonville. In the Reading area, the thickness of the lower aquifer is from 20 to 60 ft; in Lockland and Wyoming, about 80 ft; and in Evendale and Sharonville, from 100 to 120 ft.

The lower aquifer south of Sharonville is separated from the upper aquifer by a fairly homogeneous, poorly permeable confining unit of clay and silt. The thickness of this confining unit is shown in plate 6 for areas in which both the upper and lower aquifers exist. The confining unit is from 0 ft to about 35 ft thick in most of the study area, although it is as much as 80 ft thick in a few locations. From Sharonville northward, data points are few and the confining unit is not well defined. In some parts of Lockland and Wyoming where the upper aquifer is absent, the clays and silts overlying the lower aquifer (from land surface to the top of the lower aquifer) are more than 100 ft thick. Because of the presence and thickness of the confining unit, natural recharge to the lower aquifer is less in the Reading-Lockland-Wyoming area than it is north of Evendale (Bernhagen and Schaefer, 1947; Fidler, 1970).

In several parts of the study area, the confining unit between the upper and lower aquifers is absent. Deutsch and Theis (1952) suspected leakage from the upper aquifer to the lower aquifer on the basis of rapid declines in water levels in wells that tap the upper aquifer, and hypothesized the existence of gaps in the confining unit. A well-defined gap in the confining unit is in the southwestern part of GEAE (Chem-Nuclear Geotech, Inc., 1993; Earth Tech, 1997), where a gap in the confining unit of about 150 ft radius, called the “communication area,” includes well clusters AF-9, AF-19, AF-20, and AF-21. The confining unit is about 5 ft thick at AF-11, which is on the west flank of the communication area, but is at least 29 ft thick on the southeastern edge of GEAE. The confining unit also seems to be absent at the Pristine, Inc. (Pristine) site east of Mill Creek in Reading (Camp, Dresser, and McKee, Inc., 1986). Klaer and Thompson (1948) reported that the confining unit was absent in at least one location in the Sharonville area, somewhere near the channel of Mill Creek. In areas where the confining unit is missing, the gaps in the confining unit are thought to be the result of erosional events during glacial melting and recession (Klaer and Thompson, 1948; Deutsch and Theis, 1952; Geraghty & Miller, Inc., 1988). The absence of the confining unit is beneficial for water supply because any gap in the confining unit is conducive to recharging the lower aquifer; however, a gap in the confining unit also is a potential pathway for contaminants from the upper to lower aquifers.

In the upper aquifer throughout most of the study area, clays and silts of variable extent and thickness are present, further dividing the upper aquifer into what are known locally as shallow and perched aquifers (Geraghty & Miller, Inc., 1988) or outwash lenses (Camp, Dresser, and McKee, Inc., 1986). Because the uppermost aquifer rarely exhibits truly perched conditions, however, the aquifer referred to as “perched” in other reports will be called the water-table aquifer in this report upon recommendation by Stanley Norris of Metcalf & Eddy (written commun., 1991).

In parts of the study area, the shallow aquifer is present at depths of 40 to 60 ft below land surface. In several other areas, the shallow aquifer is absent. In most of the area centered on Evendale and Reading, however, the shallow aquifer does exist. The top of the shallow aquifer, which is considered to be a discontinuous layer of silt and clay, is generally higher along the valley wall than in the center of the valley. Altitudes of the top of this aquifer are shown in plate 7. The altitude of the top of the shallow aquifer ranges from 490 to 545 ft above sea level in most of the area that includes Evendale and Reading. Near Sharonville, the altitude of the top of the shallow aquifer ranges from 490 to 540 ft above sea level. The thickness of the shallow aquifer ranges from about 5 ft to more than 40 ft in the vicinities of Evendale and Reading (plate 8). The shallow aquifer is absent in northern Reading, along the western flank of Evendale, and across the center of the buried valley in Sharonville.

The water-table aquifer is distinguished from the shallow aquifer primarily on the basis of depth. Whereas the shallow aquifer is about 40-60 ft below land surface, the water-table aquifer extends from the bottom of surficial till and soil to about 40 ft. The water-table aquifer contains discontinuous layers of outwash as deep as 30 ft in most areas where it exists. This unit is discontinuous enough to be referred to as “lenses” at the Pristine site (Camp, Dresser, and McKee, Inc., 1986). Till and soil overlie the water-table aquifer in most areas. Thickness of the water-table aquifer is calculated as the difference between the bottom of surficial till and soil (upper limit) and the top of the discontinuous clay layer overlying the shallow aquifer (lower limit).

Thickness of the water-table aquifer is shown in plate 9. The aquifer is absent in many places throughout the study area. In particular, the water-table aquifer seems to be absent in much of Lockland, southern Reading, and eastern Sharonville. The aquifer is also absent close to the bedrock walls and in some areas in Evendale. Maximum thickness is in the vicinity of southern Sharonville, where the water-table aquifer is at least 68 ft thick. The aquifer is 40-50 ft thick in northwestern Reading but also is absent in some locations in the same area. Because data in the northern part of the study are few, contours of thickness north of Evendale are estimated.

Aquifer Properties

Horizontal hydraulic conductivity, transmissivity, storativity, and specific yield data reported for the hydrogeologic units in the study area are summarized in table 1. Generally, reported hydraulic conductivities and transmissivities of the lower aquifer are higher than those of the shallow and water-table aquifers. Hydraulic conductivity ranges from about 10 to 460 ft/d in the lower aquifer and from 0.03 to 340 ft/d in the shallow and water-table aquifers. Transmissivity ranges from 331 to 40,000 ft^2/d in the lower aquifer, whereas transmissivity of the shallow aquifer is in the range of 10,500 ft^2/d in Evendale. Lithologic information from boreholes drilled in these aquifers indicates that the lower aquifer contains less clay and silt than do the shallow and water-table aquifers. Klaer and Thompson (1948) estimate that permeability is greater near the center of the buried valley than the edges. Reported values of storativity are relatively consistent and the only reported value of specific yield (0.20) is within the typical range for sands and gravels (Fetter, 1994).

Sources of Ground Water

The St. Peter Sandstone is the only bedrock formation that produces water readily enough for common use, though it is not used in the Mill Creek Valley. Fidler (1970) reported that wells completed in the Ordovician shales and limestones produce generally less than 5 gal/min. Water produced from bedrock, including the St. Peter Sandstone, is generally saline and (or) sulfurous. The only viable aquifers in the vicinity of Mill Creek are the unconsolidated glacial sand and gravel deposits in the buried valley. All municipal and industrial production wells have been completed in the lower aquifer, which is predominantly sand at depths greater than about 80 ft below land surface. Reported yields to wells drilled in this aquifer have been as high as 1,300 gal/min (Klaer and Thompson, 1948).

Natural recharge to the aquifers is principally from precipitation, though infiltration is hindered in many areas by the clay layers separating the aquifers. Most of the recharge to the lower aquifer occurs north of Lockland (Bernhagen and Schaefer, 1947) because confining layers are not present in some areas. Fidler (1970) reported that of the 39 in. of precipitation annually, evapotranspiration accounts for 25 in., runoff 8 in., and recharge 6 in. Klaer and Thompson (1948) estimated natural recharge as 13 Mgal/d valleywide in 1940; Bernhagen and Schaefer (1947) estimated recharge as 10.7 Mgal/d in 1943; and Fidler (1970) estimated recharge as 8.5 Mgal/d. On the basis of these estimates, recharge to the glacial aquifer has decreased over the years, probably in response to urban development in the valley.

Some recharge to the glacial outwash aquifers occurs along the valley walls. Bedding planes, joints, and solution channels have been found in the bedrock along the valley walls (Fuller and Clapp, 1912). These features probably contribute small amounts of water to surface runoff (by way of springs) and the aquifers in the buried valley.

HISTORICAL GROUND-WATER USE AND LEVELS

Ground water has played an important role in the development of the Mill Creek Valley. Fidler (1970) reports that in 1900, about 1.5 Mgal/d was pumped from the aquifers valleywide; by 1919, about 4.6 Mgal/d; and in the 1930s, at least 10 Mgal/d. The pumping in the 1930s, when combined with droughts in 1930, 1934, and 1936, caused notable and alarming declines in water levels in the lower aquifer.

Withdrawals from the lower aquifer in the Mill Creek Valley from 1939 to 1946, based on data from Bernhagen and Schaefer (1947), are listed in table 2. Withdrawals in the current study area, including Sharonville to Wyoming, were between 7 and 11 Mgal/d, representing between 56 and 65 percent of all ground-water withdrawals in the Mill Creek Valley during this time period. The disproportionately large volume of withdrawals is attributed to the productivity of the aquifer and the degree of industrialization of the valley in this area. Lockland withdrawals ranged from 3 to 9 Mgal/d, fluctuating primarily on a seasonal basis (Klaer and Thompson, 1948). Withdrawals south of the current study area, including Carthage to Bond Hill, were between 4 and 7 Mgal/d. Peak withdrawals were in the years 1942-43.

Average daily withdrawal from the aquifer between 1942 and 1952 was about 14.4 Mgal (Fidler, 1970). By 1964, withdrawal from the lower aquifer averaged about 8 Mgal/d,

Table 1. Properties of glacial deposits in the Mill Creek Valley, Ohio

Aquifer	Value	Location	Source
Horizontal hydraulic conductivity (feet per day)			
Lower	225	Evendale	Geraghty & Miller, Inc., 1988
Lower	9.5 to 164	Evendale	O'Brien and Gere Engineers, Inc., 1993
Lower	13 to 458	Reading	Conestoga-Rovers and Associates, 1995, 1996, 1997, 1999
Confining unit	$3.4x10^{-5}$	Reading	Geomatrix Consultants, Inc., 2000
Shallow	71-247	Evendale	Klaer and Thompson, 1948
Shallow	0.14 to 10	Evendale	O'Brien and Gere Engineers, Inc., 1993
Shallow	0.03 to 340	Reading	Geomatrix Consultants, Inc., 2000
Water-table	0.14 to 104	Evendale	O'Brien and Gere Engineers, Inc., 1993
Transmissivity (feet squared per day)			
Lower	13,000 to 40,000	Evendale	Fidler (1970)
Lower	22,725	Evendale	Geraghty & Miller, Inc., 1988
Lower	331 to 8,000	Reading	Conestoga-Rovers and Associates, 1995, 1996, 1997
Lower	22,500	Reading	Howard Consultants, Inc., 1986
Shallow	10,160	Evendale	Chem-Nuclear Geotech, Inc., 1993 (pumping test)
Shallow	11,230	Evendale	Chem-Nuclear Geotech, Inc., 1993 (recovery test)
Storativity (dimensionless)			
Lower	$1.35x10^{-3}$ to $3.81x10^{-1}$	Reading	Conestoga-Rovers and Associates, 1995, 1996, 1997
Lower	$5.7x10^{-3}$	Reading	Howard Consultants, Inc., 1986
Shallow	$4.6x10^{-3}$	Evendale	Chem-Nuclear Geotech, Inc., 1993
Specific yield (dimensionless)			
Water-table	0.2	Evendale	Fidler, 1970

representing about 27 percent of the daily water use in the valley; the rest of the water used daily was supplied from sources outside the Mill Creek Valley. Nearly all of the ground water pumped in the Mill Creek Valley was for industrial or municipal use; by comparison, residential use was insignificant. Consequently, historical residential use will not be discussed.

Industrial Use

Some of the earliest records of ground-water use for industrial purposes concerned Cincinnati's whiskey-distilling industry. Whiskey was one of the primary exports in Cincinnati as early as 1826, and several of the largest distilleries were in the Mill Creek Valley because of the ready access to ground water. Hedeen (1994) reports that in 1913, Mill Creek Distilling Company used 95,000 gal/d, some of which came from its own wells. The Union Distilling Company used 550,000 gal/d in 1913, all of which came from its own wells during spring, summer, and autumn. The pork-packing industry also became important in Cincinnati; slaughterhouses were using more than 12,000 gal/d from wells for cooling and cleaning.

Paper mills were early industries in the Mill Creek Valley. Mills in Lockland and towns further north used ground water in the process of converting rags, old paper, and wood pulp into paper (Hedeen, 1994). In 1913, as much as 3 Mgal/d of waste products from the paper industry was disposed of in Mill Creek. By 1940, paper mills in southern Butler County that once had been moderate users of ground water had been abandoned (Klaer and Thompson, 1948). A company in Lockland that produced pipe coverings used as much as 1.5 Mgal/d of ground water during 1913 and discharged its by-products into Mill Creek.

The years of 1911-20 and the 1940s saw much growth in industry in the Mill Creek Valley. As a result of the pro-

Table 2. Municipal and industrial ground-water use in the Mill Creek Valley, 1939 to 1946 (from Bernhagen and Schaefer, 1947)

Production area (north to south)	Pumpage, in million gallons per day, for given year							
	1939	1940	1941	1942	1943	1944	1945	1946
Sharonville and Evendale	0.99	0.96	0.98	0.96	0.95	0.95	0.80	0.81
Wyoming and Lockland	5.58	6.34	6.98	9.25	8.78	6.94	6.73	6.51
Reading	0.52	0.54	0.66	0.72	0.82	0.89	0.91	1.31
Study area subtotal	7.09	7.84	8.62	10.93	10.55	8.78	8.44	8.63
Carthage	1.16	1.16	1.16	2.56	2.56	2.60	1.79	1.79
Elmwood Place	0.06	0.08	0.12	0.13	0.12	0.10	0.10	0.10
Ivorydale	3.24	3.10	2.91	2.67	2.79	2.03	1.59	1.75
St. Bernard	0.77	0.88	0.96	0.92	0.84	0.84	0.89	0.99
Bond Hill	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
South of study area subtotal	5.45	5.44	5.37	6.50	6.53	5.79	4.59	4.85
Total in valley	12.54	13.28	13.99	17.43	17.08	14.57	13.03	13.48

duction of the 1940s, water levels declined to critical levels. Wright Aeronautical Corporation began using water from the Great Miami River valley in 1944 (Fidler, 1970). Although this action alleviated the stress on the aquifer somewhat, it did not solve the critical-use problem completely. Several alternatives for natural and artificial replenishment of the aquifer were considered. Of these alternatives, only one was adopted—supplying more industries in Mill Creek Valley with water from sources outside the valley (Fidler, 1970). In June 1952, Southwestern Ohio Water Company (SOWC), a private cooperative of industrial users, began to supply 11 Mill Creek industries with unchlorinated water from its well field near Great Miami River, northwest of Mill Creek (Deutsch and Theis, 1952); from 1952 to 1965, SOWC delivered about 13.5 Mgal/d to industries in the Mill Creek Valley. This relief to the aquifer caused recovery of water levels in the areas of Carthage and Ivorydale, but declines were still noticed in some wells in the Lockland-Reading area (Fidler, 1970).

The Ohio-Kentucky-Indiana Regional Council of Governments (OKI) surveyed industries in Hamilton, Butler, Clermont, and Warren Counties, Ohio, in 1990 to estimate ground-water withdrawals in the region (Ohio-Kentucky-Indiana Regional Council of Governments, 1990). Of the 157 industries surveyed, only a few were in the study area. Withdrawals in the study area varied somewhat on a daily basis but amounted to more than 1.2 Mgal/d, not including water supplied by SOWC.

Municipal Use

The municipalities that have produced ground water in the study area include Glendale, Lockland, Reading, and Wyoming. Until March 1949, the city of Lockland bought water from the village of Wyoming; thereafter, Lockland began pumping from its well field north of Sharon Road. The original well field in Reading was south of Columbia Avenue; by 1952, a new well field along Mill Creek in northern Reading began producing about 85 percent of Reading's water supply (Deutsch and Theis, 1952).

Wyoming's daily average pumpage in 1939 was 740,000 gal; Reading's was 350,000 gal (Klaer and Thompson, 1948). In July 1952, Lockland pumped 852,000 gal/d; Glendale, 350,000 gal/d; Reading, 1,128,000 gal/d; and Wyoming, 685,000 gal/d (Deutsch and Theis, 1952). Lockland's production was all from the well field north of Sharon Road; Glendale's was from its well field on Sharon Road. Municipal pumpage records from other years up to 1990 are not available.

Reading's well fields ceased operation on or before March 2, 1994 (Conestoga-Rovers and Associates, 1996) because of contamination problems (Ohio Environmental Protection Agency, 2000).

Historical Water Levels

Prior to the 1980s, most discussions of water levels in the central Mill Creek Valley were fairly general and focused primarily on water-level declines in response to pumping. Bernhagen and Schaefer (1947) reported that water-level declines of almost 30 ft were recorded during the 8 years from 1939 to 1946 in Wyoming and Lockland and at the Glendale Water Works. On average, from Kemper Road on the north to Ivorydale on the south, water-level declines were 1.9 ft/yr during that timespan. Klaer and Thompson (1948) reported that as of 1948, water levels had declined about 100 ft since 1891 (considered the predevelopment date) near Lockland, which was the center of the area of greatest declines (Fidler, 1970). The effect of industrial water use on water levels is reported by Klaer and Thompson (1948); at one plant in Lockland, pumpage decreased from 1.43 Mgal/d to 0.29 Mgal/d during November-December 1939, resulting in a water-level rise of 10 ft during those 2 months.

Hydrographs of water levels in six wells in the study area are shown in Deutsch and Theis (1952). The periods of record for these hydrographs are between 11 and 13 years during the span 1938 to 1950. Of these six wells, five were completed in the lower aquifer and one was completed in the shallow aquifer. Characteristics of the wells are listed in table 3. Water levels in the shallow aquifer fluctuated annually but did not show the effects of pumping in the lower aquifer. Water levels in the lower aquifer, however, decreased steadily from 1938 to 1950. Water-level declines in the lower aquifer ranged from 30 to 41 ft during these years. Greatest declines were near Glendale-Milford Road north of GEAE and at the Wyoming well field. Water levels were lowest near Lockland and Wyoming. No regional synoptic water-level surveys of the lower aquifer have been reported prior to 2000. Fidler (1970), however, was able to estimate water-level declines in the lower aquifer on the basis of pumping records, continuously monitored water levels in several wells, and analog modeling. The reader is referred to his report for details. In general, Fidler (1970) simulated drawdowns of 25 ft as early as 1920, 70 ft in 1942, and more than 90 ft after 1952. In all cases, the cone of depression was centered on Lockland; by 1965, the cone of depression had moved slightly north and east of Lockland, probably in response to simulated pumping in the Reading area.

Long-term monitoring wells were established by ODNR at seven locations in the Mill Creek Valley as early as 1938. Of these monitoring wells, five are in the study area (located in plate 1 and cross-listed in Appendix 1). Characteristics of the five wells are listed in table 4. Four of the wells are completed in the lower aquifer and one well is completed in the shallow aquifer. Water levels in two of the wells, BU-9 and H-9 (fig. 2), were measured periodically after 1982. Water levels in the other three wells have been measured continuously for their entire period of record.

The hydrographs in figure 2 show the depths to which water levels declined in these five wells in the central valley of Mill Creek. Assuming that the predevelopment water table was within a few feet of land surface throughout the valley, as Fidler (1970) did, water levels had declined more than 20 ft in H-6 and nearly 100 ft in H-8 by 1938. Maximum daily low water levels in the wells completed in the lower aquifer range from 84.10 ft at Glendale's well field (H-6) to 148.86 ft at Wyoming's well field (H-8). This spatial distribution of declines was simulated by Fidler (1970).

Water levels in wells H-8 and H-9 began recovering in the early 1950s, whereas water levels in H-6 and H-7 began recovering around 1964. Fidler (1970) suggests that industries in the Lockland and Wyoming area began exclusive use of water supplied by SOWC before industries in the Evendale and Sharonville area. No records concerning the rapidity of declines are available; recoveries, however, have

Table 3. Characteristics of wells in the Mill Creek Valley, Ohio, as described in Deutsch and Theis (1952)

Well	Aquifer of completion	Period of record	Proximity	Minimum and maximum water-levels (feet)
T-8	Shallow	1939-50	Evendale north of General Electric	4-20
212-1	Lower	1938-50	Evendale north of General Electric	21-62
216-E	Lower	1941-50	General Electric	44-77
236-4	Lower	1941-50	West Fork Mill Creek in Wyoming	99-129
237-3	Lower	1938-50	Wyoming well field	113-149
241-3	Lower	1938-50	Central Lockland	106-137

Table 4. Characteristics of long-term monitoring wells in central Mill Creek Valley, Ohio

Well	Period of record	Depth (feet below land surface)	Aquifer of completion	Proximity	Comments
BU-9	7/38 - present	85	Shallow	Southern Butler County	Continuous 7/38 - 9/82, periodic thereafter.
H-6	7/38 - present	167	Lower	Glendale well field (Sharonville)	Maximum daily low was 84.10 ft on 10/14/60.
H-7	4/41 - present	180	Lower	Evendale	Maximum daily low was 101.09 ft on 1/29/64.
H-8	6/38 - present	194	Lower	Wyoming well field	Maximum daily low was 148.86 ft on 12/1/48.
H-9	7/38 - 1997	163	Lower	Lockland	Maximum daily low was 136.80 ft on 2/15/48; periodic since 9/82; abandoned in 1997.

averaged about 1.9 ft/yr since 1964 in H-6, 2.8 ft/yr since 1964 in H-7, 2.0 ft/yr since 1952 in H-8, and 2.3 ft/yr since 1952 in H-9.

The hydrographs of wells H-6 and H-7 are similar in most respects. Annual cycles in water-level increases and declines can be seen in both hydrographs from the years 1945 to 1952, and water-level peaks can be seen in both hydrographs for the years 1959, 1975, and 1980. Since about 1990, water levels in H-7 were higher than those in H-6, probably because pumping in Evendale had nearly ceased whereas pumping at the Glendale well field continued (data presented later in this report). Water levels in H-7, H-8, and H-9 appear to be declining since about 1996, though the reason for this is unknown.

Well BU-9 is in Butler County north of the industries and municipalities that mined most of the ground water. This well is reported to be an artesian (confined) well 85 ft deep (Shindel and others, 2001); the driller's log reports clay and

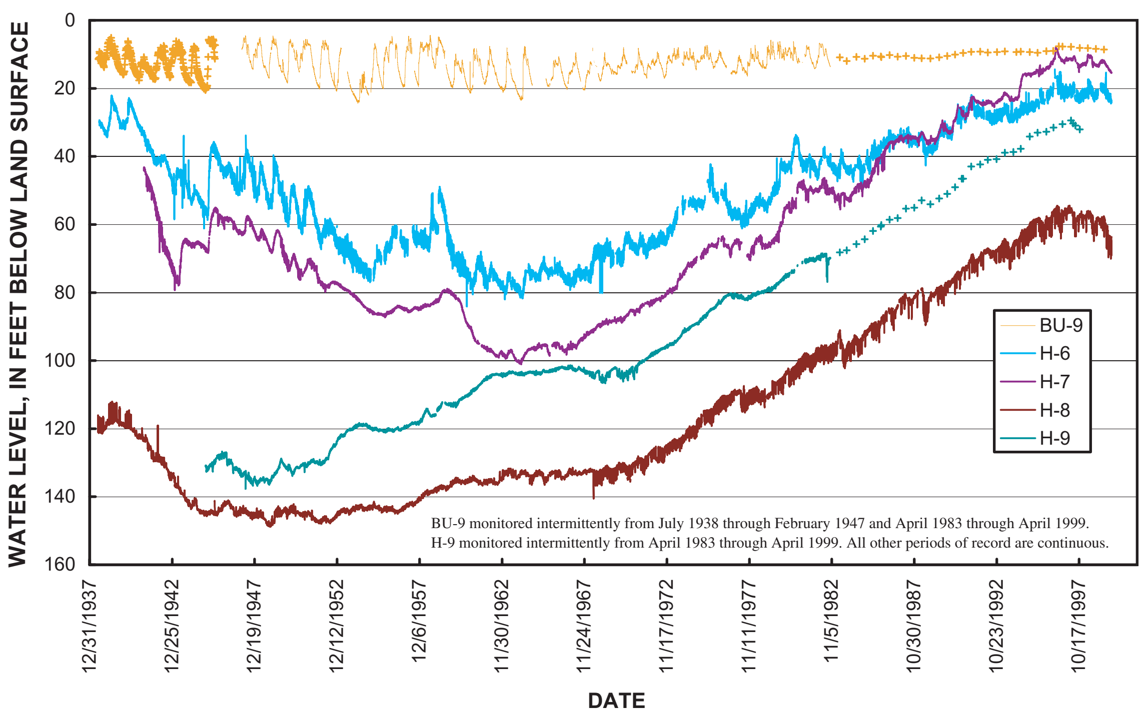

Figure 2. Water levels in long-term monitoring

hardpan to 53 ft and sand and gravel to 90 ft (David Cashell, Ohio Department of Natural Resources, oral commun., 2001; data on file with ODNR). Because BU-9 is screened in the shallow aquifer, water levels were relatively unaffected by ground-water pumping in the valley; maximum depth to water was 24.40 ft below land surface. Annual cycles are evident in the hydrograph of BU-9 until 1982, when periodic measurements began. BU-9 was originally a 26-in.-diameter well; in May 1965, a new 8-in. screen was installed through detritus at the bottom of the well. Water-level fluctuations decreased after the new screen was installed; average depth to water before May 1965 was 13.33 ft with a standard deviation of 4.94 ft, whereas average depth to water after May 1965 was 12.51 with a standard deviation of 2.77 ft.

Water levels in the lower, shallow, and water-table aquifers have been measured periodically since 1987 at GEAE and AFP36 (O'Brien and Gere Engineers, Inc., 1993; Earth Tech, 1999). Rises in water levels since 1987 at these facilities are related to the decrease in pumping throughout the valley. From March 1987 to October 1992 at GEAE, water levels rose an average of 12.4 ft at six locations in the lower aquifer, 11.1 ft at nine locations in the shallow aquifer, and 4.1 ft at two locations in the water-table aquifer. From June 1988 to April 1997 at former AFP36, water levels rose an average of 26.2 ft at 8 locations in the lower aquifer and 23.4 ft at 14 locations in the shallow aquifer. From October 1992 to April 1997 at former AFP36, water levels rose an average of 4.5 ft in the water-table aquifer.

Greatest rises in water levels in the lower aquifer from October 1992 to April 1997 at AFP36 were on the eastern edge of the plant (wells AF-1D, AF-5D, and AF-7D), probably in response to the cessation of pumping at Reading's well field east of Mill Creek from AFP36. Greatest rises in water levels in the shallow aquifer during the same time period were in the vicinity of the communication area (wells AF-9S through AF-13S) in the southeastern part of the plant. Rises in water levels in the shallow aquifer were about 10 percent less than rises in water levels in the lower aquifer from 1987 to 1997, indicating that water levels in the shallow aquifer also had been affected by pumping in the lower aquifer. The effects on water levels in the shallow aquifer are further indication that the confining unit overlying the lower aquifer is somewhat leaky (Deutsch and Theis, 1952; Geraghty & Miller, Inc., 1988). Additionally, these trends in water levels in the two aquifers indicate that the rate of recharge to the aquifers is about the same.

Whether historical pumping in the lower aquifer affected water levels in the water-table aquifer is uncertain. If pumping in the lower aquifer affected the water table, then the effects probably would have been lessened by recharge during rainfall events and the presence of any confining units in the unconsolidated aquifers. The rise in water levels during the timespan described above may have depended as much on climatic effects as on the decrease of pumping in the lower aquifer. From 1987 to 1996, the average annual precipitation at Cincinnati Lunken Airport was 42.1 in. (National Oceanic and Atmospheric Administration, 2000), which is greater than the 40.7-in. long-term average; the rise in water levels may have resulted from increased recharge during the same timespan. If increased recharge had been the primary factor, however, the distribution of water-level rises in the water-table aquifer would have been spatially consistent across all of AFP36. Geologic evidence indicates that at least some of the increases in water levels resulted from the decrease of pumping in the lower aquifer. Water-level rises from 1987 to 1996 in the water-table aquifer at former AFP36 averaged 6.5 ft in wells on the east and north sides of the plant (AF-1P through AF-6P, AF-16P, and AF-17P), whereas water-level rises averaged 0.7 ft in wells on the west and south sides of the plant (AF-7P, -10P, -12P, -13P) (fig. 3). If water levels rose in response to the decrease of pumping in the lower aquifer, then the communication between the lower and water-table aquifers must be stronger on the northeast side of the plant than the southwest side of the plant. This is in fact the case, according to the current knowledge of unconsolidated units presented in Earth Tech (1999). An intermediate-depth clay layer separating the water-table and shallow aquifers acts as only a partial barrier to vertical flow on the eastern side of the plant, whereas it acts as a significant barrier to vertical flow on the central and western side of the plant.

Water levels were measured in the lower aquifer at Reading's well field and Pristine before and after closure of the well field (Conestoga-Rovers and Associates, 1996). In March 1993, water levels in Reading municipal wells 9 and 15 were 415 and 469 ft above sea level, respectively, and potentiometric gradients at Pristine were northwestward, toward the municipal wells. By March 9, 1994, a week after wells 9 and 15 were shut down, water levels in both wells had risen to 534 ft. Water levels in several monitoring wells at and near Pristine rose between 4 and 7 ft from December 1, 1993 to March 9, 1994, in response to the cessation of pumping at the Reading well field (fig. 4). Water levels in March 1995 indicated that flow in the lower aquifer east of Mill Creek was northeast to southwest.

CURRENT (2000) GROUND-WATER USE

Surveys of water use are now part of routine ground-water management in the Mill Creek Valley. ODNR keeps an annual registry of all ground-water users who are capable of producing at least 100,000 gal/d. After the extensive mining that led to the drawdown issues of the 1950s, managers are more proactive in monitoring the use of ground water.

Industrial

Much of the burden on the aquifer has been relieved because of increased reliance on municipal sources of water from

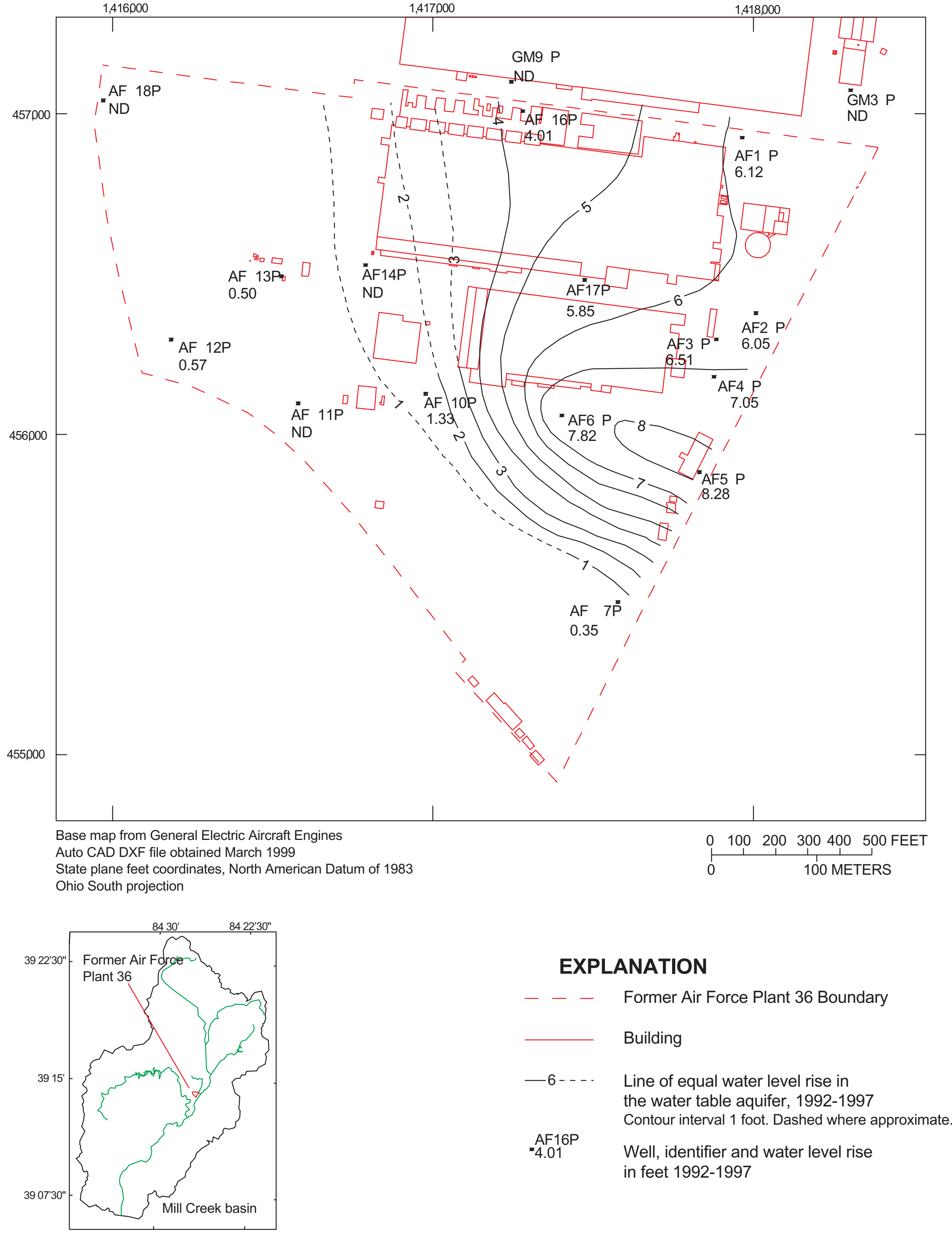

Figure 3. Water-table rise at former Air Force Plant 36, 1992-1997.

outside the valley. Most industries reported during the 2000 survey that they use municipal water exclusively. SOWC withdraws about 20 Mgal/d from Great Miami River valley (Ohio-Kentucky-Indiana Regional Council of Governments, 1990) and provides that water to industries in the Mill Creek Valley. GEAE, for example, purchases between 4 and 5 Mgal/d from SOWC (Gregory Jaspers, General Electric Aircraft Engines, oral commun., 2000,.) and discharges the process water to Mill Creek. Discharge from GEAE's outfall to Mill Creek on November 28, 2000, was measured at 3.1 Mgal/d (4.75 ft^3/s). Data from ODNR's water-use registry (Allan Luczyk, Ohio Department of Natural Resources, written commun., 2001) indicate that GEAE's production of ground water has been decreasing steadily in the latter half of the 1990s (fig. 5). Formica Corporation also purchases water for industrial purposes (Michael End, Formica Corporation, oral commun., 2001); discharge from Formica Corporation through a flume to Mill Creek on November 27, 2000, was about 1.37 Mgal/d (2.1 ft^3/s). In recent times, Formica Corporation has pumped some ground water during the summer to help cool the industrial process water that is stored in a lagoon onsite so that the discharge water meets temperature requirements (Robert Fremont, Pristine Facility Trust, oral commun., 2001).

Ground water is pumped for remedial purposes at at least one site, the Pristine site (currently in remedial action), withdraws contaminated ground water from five wells in the lower aquifer in Reading, processes it onsite, and discharges the treated water into Mill Creek. The remedial system is designed to process 450 gal/min (648,000 gal/d) (Henry Cooke, Conestoga-Rovers and Associates, oral commun., 2000), but the actual volume of water treated on a given day is less than the design rate because of routine system maintenance and rate-limiting treatment processes. Pumping records are reported for subsets of the five wells and discharges of the treated ground water are reported monthly to Ohio EPA. If line leakages can be considered negligible, then pumping volumes and discharge volumes are equivalent. On November 27-28, 2000, discharge from Pristine averaged 545,000 gal/d. Monthly averages of daily discharge from

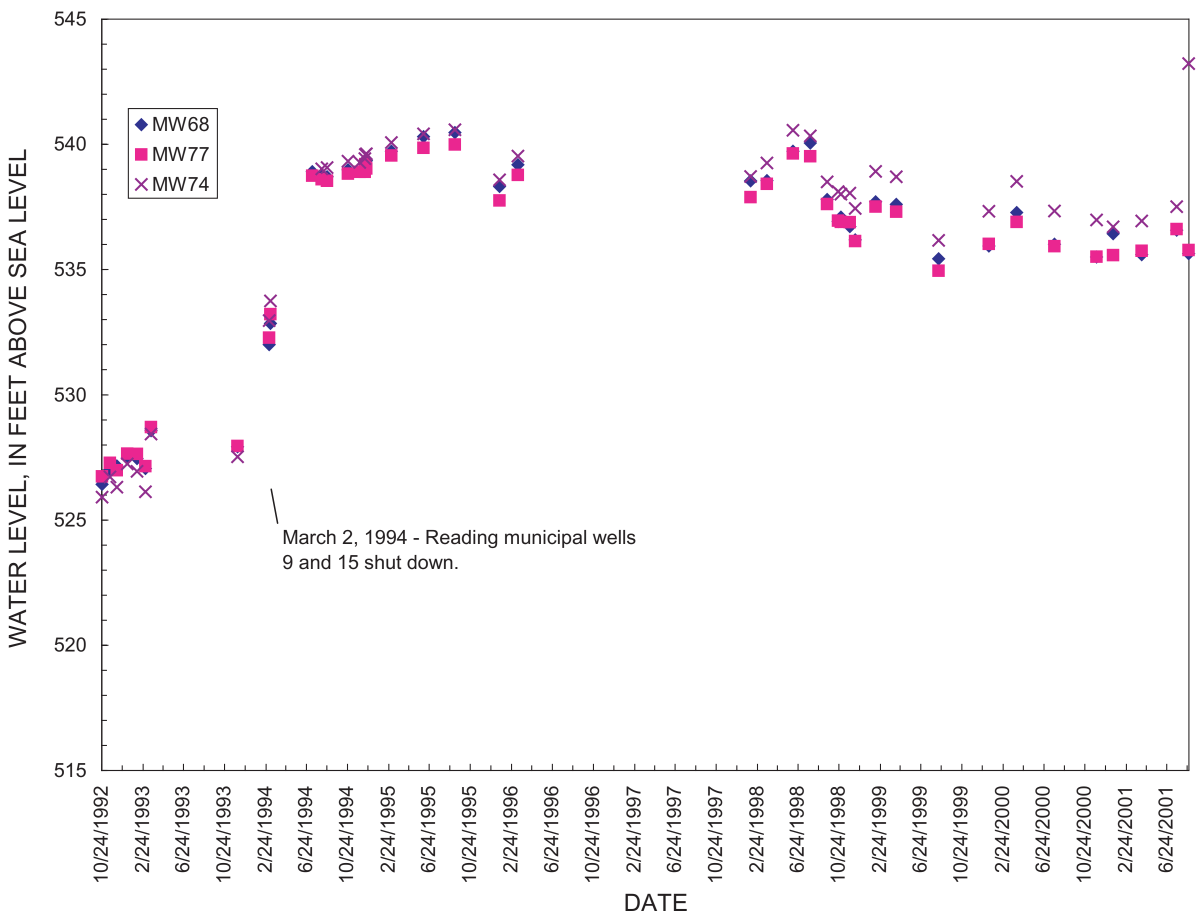

Figure 4. Water levels in three wells in the lower aquifer at the Pristine, Inc., site, 1992-2001.

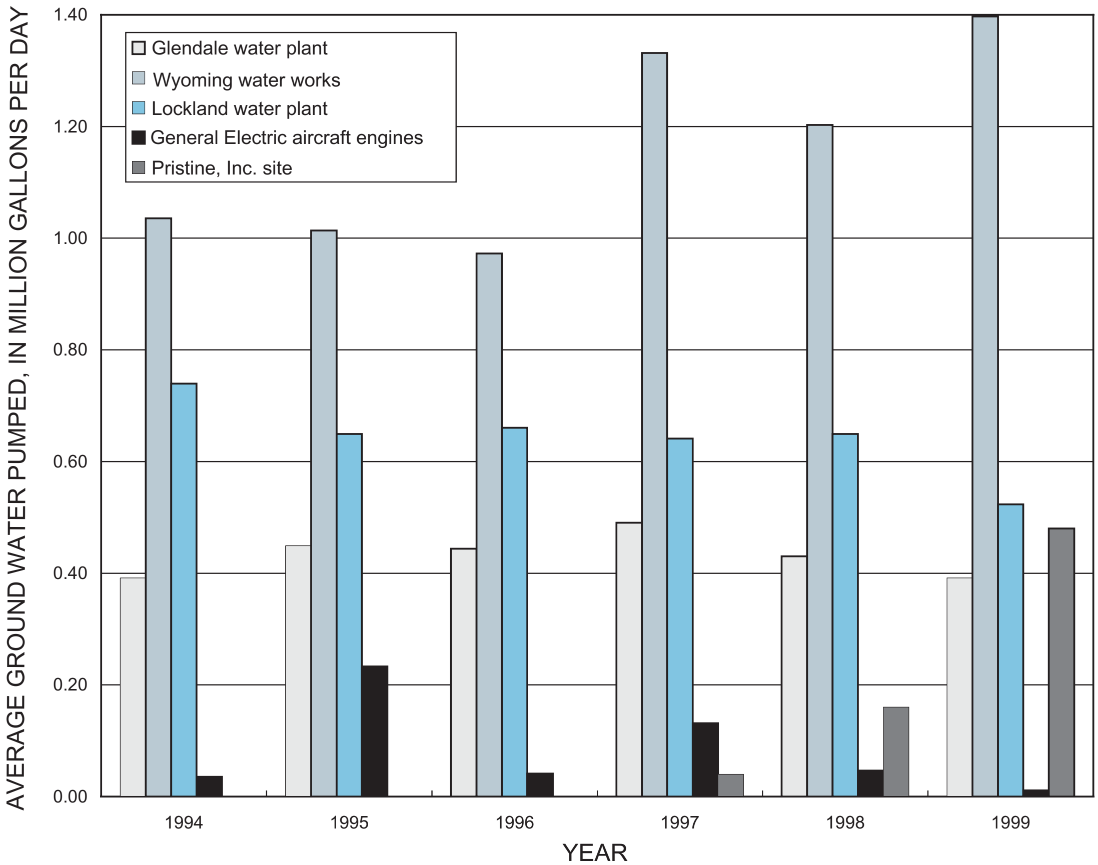

Figure 5. Industrial and municipal ground-water use, 1994-99, central Mill Creek Valley.

Pristine for November 1997 to January 2001 are shown in figure 6. The system became fully operational in November 1998. Low volumes of discharge shown in figure 6 correspond to an annual 2-week shutdown in June for maintenance.

At least one industry, Continental Mineral in Sharonville, withdraws ground water from one well and injects the water into the aquifer through another well. Continental Minerals is a sand-and-gravel mining operation and uses the ground water for washing.

Municipal

Most of the municipalities in the Mill Creek Valley purchase water from Cincinnati Water Works, all of which is produced in the Great Miami River valley. Three cities–Glendale, Lockland, and Wyoming–still produce municipal water from the central Mill Creek Valley (plate 1, fig. 5). Lockland and Glendale produce water from wells in Sharonville, whereas Wyoming produces water in its city limits.

Municipal withdrawals in the Sharonville area (well fields of Glendale and Lockland) average about 1.1 Mgal/d, which is more than the combined (industrial plus municipal) withdrawals in this vicinity between 1939 and 1946 (table 2). Ground-water use from this area has not increased much in the past 60 years. The amount of ground water withdrawn in the Wyoming-Lockland area, however, decreased from more than 10 Mgal/d in 1942 to about 1.5 Mgal/d in 1999, a decrease of about 85 percent. Much of the decline in water use may be a result of decreased industrial, rather than municipal, pumpage.

Residential

Few homeowners in the study area produce their own water for domestic purposes. OKI estimated that about 1 Mgal/d is withdrawn from domestic wells in the entire southwestern Ohio area, which includes the Great and Little Miami River valleys as well as the Mill Creek Valley (Ohio-Kentucky-Indiana Regional Council of Governments, 1990); this amount is relatively small in comparison with industrial and

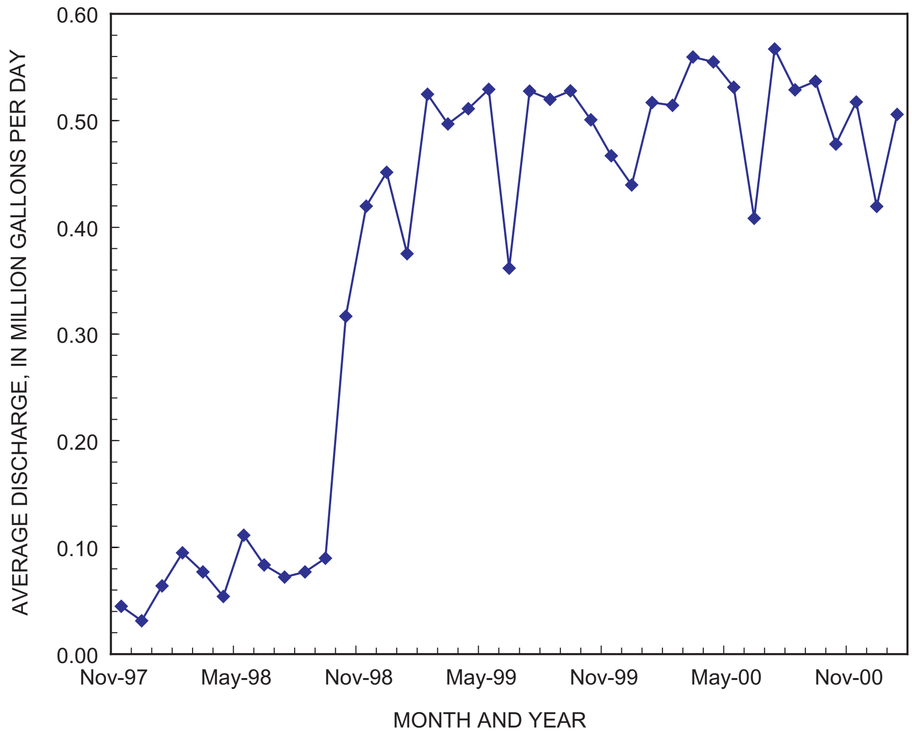

Figure 6. Average daily discharge of treated effluent, by month, from the Pristine, Inc., site.

municipal use, which is estimated at 110 Mgal/d (Ohio-Kentucky-Indiana Regional Council of Governments, 1990). Most wells in the valley are owned by industries; of the few homeowner wells on record at ODNR, most have been destroyed or abandoned as land use converted from residential or agricultural to industrial and commercial. Few residential wells exist in the study area. Of all 318 well logs examined for this study, only 16 (about 5 percent) were at residences, and no residential wells were drilled more recently than 1986. Probably this dearth of records is because nearly all of the study area in Hamilton County has been developed since the 1950s, when well logs were first filed at ODNR. Of the residential wells surveyed, most were in Butler County, where development is more recent than in Hamilton County.

CURRENT (2000) GROUND-WATER LEVELS

Water levels were measured in 182 wells from November 27-29, 2000, and are reported in Appendix 1. Wells or clusters of wells that are discussed by name can be located on plate 1 by cross-referencing names and numbers listed in Appendix 1. Most water levels were measured by USGS personnel; water levels in wells owned by the Pristine Facility Trust were measured by representatives of Conestoga-Rovers and Associates. Only three of the wells were completed in bedrock; the rest were completed in unconsolidated deposits. On the bases of the apparent productivity of the aquifers and historical records, we expected a broad distribution of wells in which water levels could be measured; this was not the case, however, as more than 86 percent of wells in which water levels were measured are owned by GEAE and the Pristine Facility Trust. As previously mentioned, nearly all homeowners and most businesses are on city water, and many wells that had once served industry have been abandoned or destroyed.

Lower Aquifer

Water levels were measured in 87 wells and piezometers that penetrate the lower aquifer. Of these wells, 50 were owned by the Pristine Facility Trust and 28 were owned by GEAE.

The potentiometric surface in the lower aquifer is shown on plate 10. Flow is generally from northeast to southwest in the study area, following the orientation of the buried valley. Exceptions to the regional flow pattern were observed at the municipal well fields (Glendale, Lockland, and Wyoming) and in the vicinity of the Pristine extraction wells.

Pristine's remedial design includes a line of five extraction wells (plate 10) in Reading. Wells EW1, EW2, and EW3 produce as much as 150 gal/min (combined) for treatment, whereas EW4 and EW5 produce up to 300 gal/min (combined). On November 27-28, 2000, about 378 gal/min was being discharged to Mill Creek from the treatment system (Henry Cooke, written commun., 2000), indicating that the system was operating at about 84 percent of capacity. Prepumping water levels in the area of the Pristine extraction wells were between 539 and 534 ft above sea level (Conestoga-Rovers and Associates, 1997); since the remedial system began operating, water levels at the extraction wells are between 529 and 507 ft above sea level (Conestoga-Rovers and Associates, 2000), a decline of 10 to 27 ft. The western edge of this cone of depression affects water levels on the west side of Mill Creek.

A cone of depression in the vicinity of the Glendale and Lockland well fields also is shown on plate 10. Most of the production wells for these cities were completely enclosed at land surface, having no access port for measurement of water levels. As a result, few measurements could be made at the well fields, and contour lines on the potentiometric surface in those areas are estimated. Contours on the potentiometric surface near the Wyoming well field also are estimated because of few measuring points.

Although search was made for wells south of Evendale between Reading and Wyoming, only one accessible well was found; consequently, the orientation of the flow field south of Evendale cannot be determined from available data. The data collected during this study are insufficient to determine whether pumping at Wyoming's well field influences water levels as far away as Evendale.

Overall, water levels in the lower aquifer in Evendale at GEAE are similar to water levels in the shallow aquifer at the same locations (table 5), with head differences between -0.62 and 3.46 ft. Historically, pumping from the lower aquifer was much greater than at the present time, and the resultant drawdowns in the lower aquifer created significantly higher vertical gradients than exist currently between the shallow and lower aquifers. These historical vertical gradients increased the potential for movement of water from the shallow aquifer to the lower aquifer through the confining unit and at those locations where the confining unit is absent. In areas where contamination was present in the shallow aquifer and the confining unit between the aquifers was absent or compromised, the lower aquifer was highly vulnerable to advectively driven contamination from above. Because the gradient between the shallow and lower aquifers is much smaller now than previously, the potential for flow from the shallow aquifer to the lower aquifer is reduced.

Water levels in the lower aquifer in Evendale are more than 70 ft higher than the 1965 water levels simulated by Fidler (1970), indicating that water levels have recovered substantially. The water level recorded in H-7 on November

Table 5. Ground-water gradients between wells in the shallow and lower aquifers, Evendale and Reading, Ohio, November 27-29, 2000

Well cluster	Well depth (feet)		Head (feet)		Vertical gradient (foot/foot)	Head difference (feet)
	Shallow	Lower	Shallow	Lower		
AF-1	51.5	118	537.95	535.61	0.04	2.34
AF-5	51	110	537.29	534.12	0.05	3.17
AF-7	56.5	119	536.90	533.44	0.06	3.46
AF-8	61.5	96	533.84	532.92	0.03	0.92
AF-9	60	88	532.81	532.78	0.00	0.03
AF-11	63	102	532.72	532.72	0.00	0.00
AF-12	75	112	532.40	531.24	0.03	1.16
AF-15	56.5	113	534.65	534.21	0.01	0.44
AF-19	62.4	91.1	533.44	533.14	0.01	0.30
AF-20	69	91.1	533.08	533.10	0.00	-0.02
GM-3	56.5	147	539.28	536.78	0.03	2.50
GM-5	61.7	117.9	534.22	534.84	-0.01	-0.62
GM-6	47.4	160	542.54	541.68	0.01	0.86
GM-7	54.4	112	542.66	543.06	-0.01	-0.40
GM-8	70.3	112	536.09	536.13	0.00	-0.04
GM-9	55.2	111.5	538.31	534.86	0.06	3.45

29, 1965, was 96.28 ft; that measured on November 28, 2000, was 21.73 ft, for an increase of 74.55 ft. Fidler's prediction of water levels in the year 2000 was based on water-use trends in the 1960s; he predicted drawdowns of 140-150 ft in the lower aquifer in Evendale without the addition of artificial recharge. Because water has since been obtained from sources other than the lower aquifer, the predicted drawdowns have not occurred. Water levels have recovered enough to restore the natural artesian (confined) condition to the lower aquifer in the study area.

Shallow Aquifer

Twenty-six measurements of water levels were made in the shallow aquifer, 25 of which were at GEAE and none at Pristine. The water from this aquifer is not used for municipal or industrial purposes and typically is not associated with near-surface monitoring. Because nearly all of the water levels obtained from this aquifer were at GEAE, only conditions in the shallow aquifer at GEAE are described in this report.

Flow in the shallow aquifer on GEAE is generally from northeast to southwest (plate 11), roughly parallel to the flow direction of Mill Creek. Available data are insufficient to determine whether Mill Creek acts as a discharge area to water in the shallow aquifer or whether pumping at the Pristine site affects water levels in the shallow aquifer; not enough monitoring wells in the shallow aquifer near those areas are available.

In most of the shallow aquifer, gradients are downward toward the lower aquifer, indicating the possibility of recharge in areas where the confining unit does not prohibit flow. Significant upward gradients were observed at clusters GM-5 and GM-7. Previous measurements of water levels (1987-92) indicate consistently downward gradients at GM-7 and mostly downward gradients at GM-5 (O'Brien and Gere Engineers, Inc., 1993). No activities or natural discharge areas in the vicinities of GM-5 and GM-7 would suggest that an upward component of flow should exist. Vertical hydraulic gradients at clusters AF-9, AF-11, AF-19, and AF-20, each of which has wells screened in the shallow and lower aquifers, are small. Previous measurements of water levels (1987-92) indicate consistently downward gradients at AF-9 and variable (upward and downward) gradients at AF-11 (O'Brien and Gere Engineers, Inc., 1993). The confining unit between the shallow and lower aquifers is absent in the area centered on these well clusters (Earth Tech, 1997).

Water-table Aquifer

Water levels were measured in 69 wells completed in the water-table aquifer or at depths consistent with those of the water-table aquifer. Of these 69 wells, 52 were at GEAE and none were at Pristine. Altitude and configuration of the water table in the vicinity of GEAE are shown on plate 12. Although water levels in the water-table aquifer were measured elsewhere in the study area, this aquifer is too discontinuous and the distances between measuring points too great to allow plotting of a regional water table.

The water-table surface at GEAE is depicted as continuous on plate 12, but some doubt exists as to whether the water-table aquifer itself is continuous, especially in the area bounded by well clusters AF-18, AF-14, and AF-12. Most vertical hydraulic gradients (table 6) are in the range of 0.05-0.12 ft/ft. Hydraulic gradients at clusters AF-12, AF-13, and AF-14, however, are in the range of 0.28-0.56 ft/ft. A shallow well was not installed at AF-18, but the gradient between the water-table and lower aquifers at AF-18 is 0.57 ft/ft. The relatively high gradients at AF-12, -13, -14, and -18 compared to those in nested wells in the rest of the area suggest that the water-table aquifer at GEAE is not continuous. Hydraulic gradients between nested wells in the water-table and underlying shallow aquifers are downward in all cases.

Water levels indicate that flow in the water-table aquifer is lateral to the central part of GEAE, then southward toward Mill Creek. Evidence of this flow pattern is provided by Earth Tech (1999), who traced a plume of volatile organic contaminants in the water-table aquifer at GEAE from north to south. The plume delineated by Earth Tech is consistent with the flow directions indicated on plate 12. Further relations between the water-table aquifer and Mill Creek were characterized by use of piezometers and streamflow measurements. Three piezometers were driven into the streambed of Mill Creek and one into the streambed of West Fork Mill Creek to estimate directions of flow between the creeks and the underlying sediments (table 7). Locations of the piezometers are shown on plate 1. All of the piezometers were installed near one of the banks of the creeks rather than in the center of the channels. Attempts to install piezometers south of Evendale were thwarted by the numerous cobbles in the streambed of Mill Creek between piezometer 3 (table 7) and the stage-only gage on Mill Creek in Reading (USGS station 03255500). Heads in the piezometers and streams were measured six times from September 25, 2000, through February 22, 2001, including November 27-28, 2000 (table 8). The measurements of November 27, 2000, probably were affected by rainfall the previous night.

Heads in the piezometer at Kemper Road were influenced by a dewatering operation in conjunction with sewer work between Mill Creek and Mosteller Road north of Kemper Road (Les Eihorn, Kelley Dewatering, Inc., oral commun., 2000); the dewatering operation artificially lowered the heads in the aquifer to produce gradients that do not reflect normal conditions. The piezometer at Sharon Road was installed in a tight clay and never equilibrated adequately; the presence and consistency of the clay, however, indicate that the aquifer and the stream are in poor hydraulic connection at that location.

Most of the head gradients measured in Mill Creek at the railroad bridge (piezometer 3) and West Fork Mill Creek (piezometer 4) were within the 0.01-ft error of measurement.

Table 6. Ground-water gradients between wells in water-table and shallow aquifers on GEAE, November 27-29, 2000

Well cluster	Well depth (feet)		Head (feet)		Gradient (foot per foot)	Head difference (feet)
	Water-table	Shallow	Water-table	Shallow		
AF-1	29	51.5	540.22	537.95	0.10	2.27
AF-2	33	51.5	539.31	537.76	0.08	1.55
AF-3	31	52	539.12	537.70	0.07	1.42
AF-4	34.5	56.5	538.84	537.56	0.06	1.28
AF-5	33	51	538.22	537.29	0.05	0.93
AF-6	33	51.5	538.44	537.40	0.06	1.04
AF-7	36.5	56.5	537.08	536.90	0.01	0.18
AF-10	22.4	71.5	539.16	533.32	0.12	5.84
AF-12	19.5	75	562.28	532.40	0.54	29.88
AF-13	15.4	61	559.07	533.61	0.56	25.46
AF-14	27.5	66.5	544.19	533.39	0.28	10.80
GM-1	24.1	57	544.51	541.46	0.09	3.05
GM-3	29.3	56.5	539.44	539.28	0.01	0.16
GM-6	20.1	47.4	548.34	542.54	0.21	5.80
GM-9	28	55.2	540.56	538.31	0.08	2.25
GM-11	30.8	60.9	541.47	538.38	0.10	3.09

Two of the measurements in Mill Creek at the railroad bridge and one at West Fork Mill Creek, however, indicated potential for upward flow from the underlying sediments, or a gaining stream. Discharge measurements at two points on West Fork Mill Creek were made to verify the gaining nature of the stream; stream gain or loss, however, was indeterminate on the basis of measurement error.

USGS has been recording water levels and temperature in wells AF-5P and AF-5S since November 1997 (fig. 7). Water levels in these wells were plotted with stage in Mill Creek (station 03255500, about 1 mi south of AF-5) to estimate relations between the water-table aquifer, the shallow aquifer, and Mill Creek. A pump-and-treat system was operating until March 1998 in the shallow aquifer adjacent to AF-5; water levels in AF-5S and AF-5P were affected by the pumping, though the greater effect was in AF-5S. Since about August 1998, water levels in AF-5S and AF-5P have mimicked one another, with water levels in AF-5S normally being between 0.24 and 1.25 ft lower than those in AF-5P.

Flooding occurs in the Mill Creek Valley fairly regularly. Since 1998, flood stage exceeded about 10 ft above datum five times. Little effect on water levels was observed

Table 7. Characteristics of piezometers installed in Mill Creek and West Fork Mill Creek, Ohio

Number	Name	Latitude	Longitude	Screen length (inches)	Depth to top of screen (feet below streambed)
1	Mill Creek at Kemper Road	39° 17’ 05”	84° 25’ 58”	14	2.8
2	Mill Creek at Sharon Road	39° 16’ 09”	84° 25’ 56”	18	1.7
3	Mill Creek at railroad bridge	39° 14’ 19”	84° 26’ 11”	18	2.8
4	West Fork Mill Creek at Wayne Avenue	39° 14’ 03”	84° 27’ 37”	24	2.5

Table 8. Depths to water measured in piezometers, October 2000 to February 2001, Mill Creek Valley, Ohio [NM, not measured; --, no data. Piezometer number described in Table 7. All depths were measured from the tops of the piezometers and are not related to any established datum.]

Piezometer number	Date	Time	Depth to water, sediments (feet)	Depth to water, stream (feet)	Comment
1	10/25/2000	1500	DRY	1.61	Dewatering
1	11/15/2000	1130	4.40	1.62	Dewatering
1	11/24/2000	1326	5.84	1.68	Dewatering
1	11/27/2000	1045	4.69	1.50	Dewatering
1	11/28/2000	0830	4.79	1.65	Dewatering
1	2/22/2001	0950	1.78	1.55	Dewatering
2	10/25/2000	NM	--	--	Not equilibrated
2	11/15/2000	1140	2.91	1.92	Not equilibrated
2	11/24/2000	1333	3.10	2.05	Not equilibrated
2	11/27/2000	1400	3.04	1.82	Not equilibrated
2	2/22/2001	1000	2.91	1.81	Not equilibrated
3	10/25/2000	1115	2.77	2.80	Gaining stream
3	11/15/2000	1200	1.75	1.75	Within measurement error
3	11/24/2000	1348	1.93	1.92	Within measurement error
3	11/27/2000	1455	1.63	1.62	Within measurement error
3	11/28/2000	830	1.71	1.74	Gaining stream
3	2/22/2001	NM	--	--	Inaccessible
4	10/25/2000	1230	2.04	2.03	Within measurement error
4	11/15/2000	1220	1.09	1.10	Within measurement error
4	11/24/2000	1400	1.18	1.19	Within measurement error
4	11/28/2000	1442	1.10	1.11	Within measurement error
4	2/22/2001	1015	0.99	1.01	Gaining stream

during the three winter floods because the ground was frozen and infiltration was impeded. During spring and summer floods, however, water levels in the water-table aquifer responded quickly to flood events. The flood of July 2001, for example, caused a sharp rise in water levels and temperature in the water-table aquifer. Water-level data in AF-5S were lost during the flood of July 2001, probably because the instrument was wetted or fouled. Temperature data in AF-5S, however, do not show a response to the July 2001 flood, indicating that Mill Creek and the shallow aquifer at AF-5S are not as well connected as Mill Creek and the water-table aquifer at AF-5P.

SUMMARY AND CONCLUSIONS

The unconsolidated deposits in the central Mill Creek Valley, Butler and Hamilton Counties, Ohio, have been used as a source of water supply since before 1900. Documentation of water use showed increasing pumpage of water from the lower confined aquifer through the early 1950s, when resulting water levels reached critical levels and inspired changes to the management of the water supply. Because of the changes in water management, which included the importation of industrial supply water from a source outside the Mill Creek Valley, water levels in the lower aquifer have risen between 65 and 105 ft throughout the study area, restoring the aquifer to a confined state.

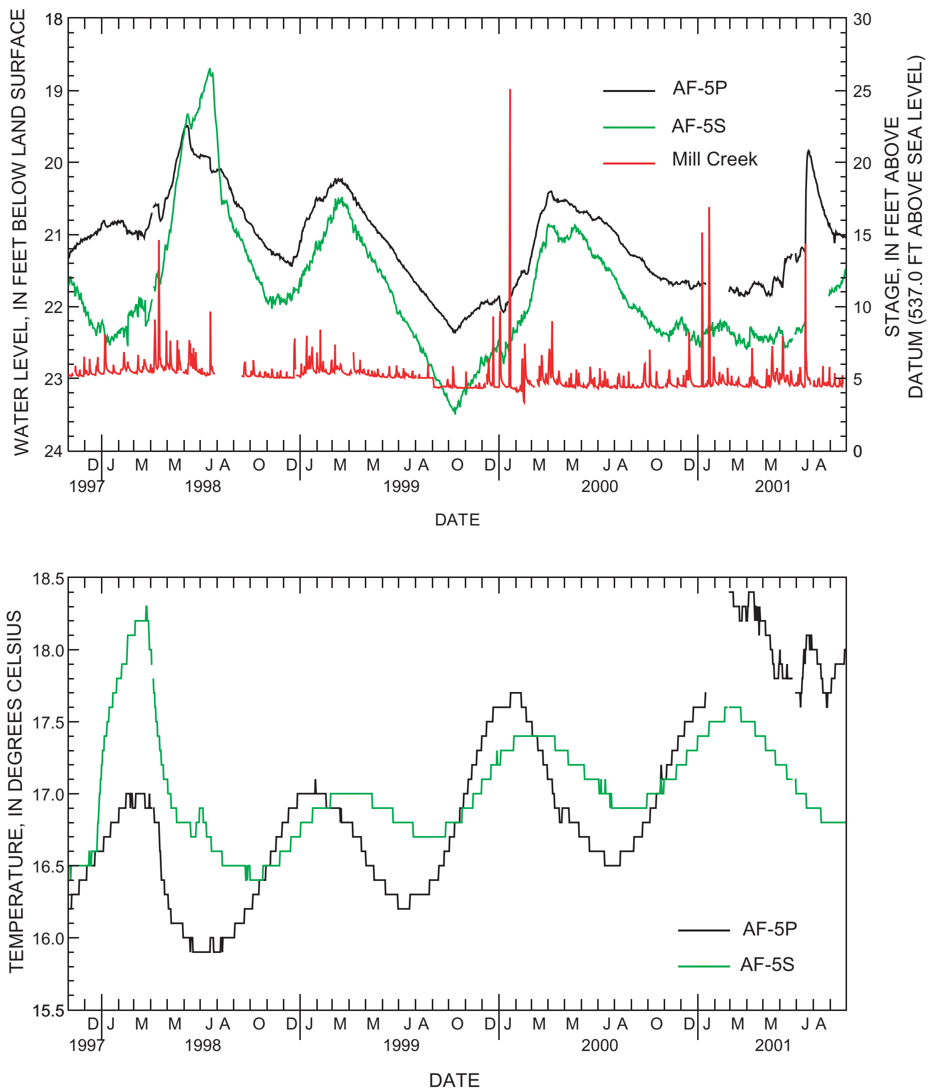

Figure 7. Ground-water levels and temperature in wells AF-5P and AF-5S, 1997-2001.

The most recent study of ground-water conditions in the study area was completed in 1970. Since 1970, new hydrogeologic information has become available as part of remedial investigations at several industrial sites in the valley. The hydrogeologic data were used to update maps of regional aquifers, bedrock boundaries, and confining units. The hydrogeologic data indicate that (1) the lower aquifer is continuous in the buried valley throughout the study area, whereas the shallow and water-table aquifers are not; and (2) the confining unit overlying the lower aquifer is absent in several places. The updated maps can be used by planners and scientists who wish to investigate ground-water flow in the region.

Historical and current water-use and water-level data were compiled and analyzed to quantify the changes in the status of ground water since the 1940s. About 85 percent less water is pumped today near Lockland and Wyoming than was pumped in 1942. The amount of water pumped in the Sharonville area today is about the same as or slightly greater than the amount pumped during the 1940s. Two municipal well fields, one in Lockland and one in Reading, have been closed since the 1980s, and a remedial pump-and-treat system at the Pristine Superfund site has been operating since 1997. Water levels have increased steadily in the lower aquifer since about 1950 in response to the decrease in ground-water use. Although long-term water-level data are not available for the shallow and water-table aquifers, data from 1987 through 1997 indicate that water levels in these shallower aquifers also increased in response to the decrease in pumping in the lower aquifer. From 1988 through 1997 in Evendale, water levels rose about 26 ft in the lower aquifer and 23 ft in the semiconfined shallow aquifer. Water levels in the water-table aquifer rose 4.5 ft between 1992 and 1997, at least partly in response to decreased pumping in the lower aquifer. The response of water levels in the shallower aquifers is an indication of the leaky nature of the underlying confining unit, at least in some parts of the study area.

Water levels were measured in 182 wells, of which 155 were at the industrial sites of General Electric Aircraft Engines (GEAE) and the Pristine, Inc., Superfund site. Most of the wells were completed in the lower and water-table aquifers. Water levels in the lower aquifer were plotted regionally, but water levels in the shallower aquifers were plotted only in the vicinity of GEAE because of the discontinuity of the aquifers and the sparseness of available data. Despite the extent and productivity of the aquifers, not many wells other than those at GEAE and Pristine are in the study area.

The primary flow direction in the lower aquifer is northeast to southwest, following the orientation of the buried valley except where influenced by pumping in the lower aquifer, such as at the municipal well fields and the Pristine remediation site. In the vicinity of GEAE, the primary flow direction in the shallow aquifer also is northeast to southwest, though some variation to the pattern is evident on the eastern part of GEAE, possibly in response to the influences of either Mill Creek or pumping at the Pristine site. Flow in the water-table aquifer at GEAE converges from the eastern and western parts of the facility, then turns southward toward Mill Creek south of GEAE. Limited piezometer, discharge, and continuous water-level data indicate that the streams in the southern part of the study area are in connection with and can be gaining water from the water table.

The lower aquifer is recharged primarily in areas where the overlying confining unit is absent, which include locations at GEAE and Pristine. Where the confining unit is absent or leaky, the effect of pumping in the lower aquifer on water levels in the shallow and water-table aquifers has been observed; recharge to the lower aquifer is increased; and advective transport to the lower aquifer is possible. Although vertical gradients in areas where the confining unit is absent may be small under normal conditions, they would undoubtedly increase, and percolation of water to the lower aquifer occur, during significant recharge events and (or) pumping in the lower aquifer.

SUGGESTIONS FOR FUTURE STUDY

Because of the proximity of industrial sites to municipal well fields (those of Glendale, Lockland, and Wyoming), the ground-water-flow paths in the lower aquifer, and the scarcity of monitoring wells throughout the valley, installation of more wells in the Sharonville, Reading, and Lockland areas would be useful. With the addition of new monitoring points, another survey of water levels would provide a clearer overall picture of ground-water flow in the area.

The extent and continuity of the shallow and water-table aquifers between Evendale and Wyoming are unknown. The potentiometric surfaces of both aquifers indicate gradients to the southwest or south, and the terminal locations of flow in these aquifers is important from a water-quality perspective. To define these terminal locations more clearly, the extents of and water levels in these aquifers should be mapped in more detail than currently exists.

To clarify interactions among the aquifers and with Mill Creek, water levels and temperature in the water-table, shallow, and lower aquifers need to be monitored continuously at several locations, especially near Mill Creek and in areas where the confining unit is absent. Stresses on the aquifers, such as pumping and recharge during rainfall events, can increase the vertical hydraulic gradients between the aquifers. Continuously recorded data will provide information on how the aquifers respond to stresses and interact with each other and Mill Creek.

Although Mill Creek does not seem to influence flow in the lower aquifer in this area, it may be influencing recharge to and flow directions in the shallow aquifers. Studies are needed to ascertain the relation of Mill Creek and the underlying aquifer, especially near Evendale and Reading. Gaining and losing reaches of Mill Creek between Evendale and Reading could be mapped by use of piezometers and seepage meters during low flow so that relations between the creek and the underlying aquifer can be estimated. New, shallow wells could be installed near Mill Creek so that vertical gradients between the creek and the water table can be monitored and estimates of discharge to the creek can be made. A water-quality study would help to address whether Mill Creek is a receptor of flow from the water-table aquifer south of Evendale.

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APPENDIX 1

Well and Borehole Data

Appendix 1. Well and borehole data, central Mill Creek Valley, Ohio

[Well number referenced in plate 1; fbls, feet below land surface; fals, feet above land surface; msl, feet above sea level; alt, altitude; coord, coordinate; --, no data. WT (water table), shallow, and lower aquifers described in the report. State-plane feet coordinates, Ohio South zone, North American datum of 1983.]

Well number	East coord (feet)	North coord (feet)	Well name	Top WT (fbls)	Bottom WT (fbls)	Top shallow (fbls)	Bottom shallow (fbls)	Top lower (fbls)	Bottom lower (fbls)	Top bedrock (fbls)	Land altitude (sl)	Altitude accuracy (feet)	Measure point alt (fals)	Water level (sl)	Well depth (feet)	Measure point alt (sl)
1	1429014	490144	ODOT26	--	--	--	--	--	--	33	611	.1	--	--	40	--
2	1428172	489563	ODOT27	--	--	--	--	--	--	53	635	.1	--	--	58	--
3	1421063	486744	999-177	--	--	--	--	160	--	--	599	1	--	--	165	--
4	1428061	486730	ODOT22	--	--	--	--	--	--	--	632	.1	--	--	40	--
5	1427413	485116	BU-30	--	--	40	45	--	--	--	632	5	-0.48	610.78	45	631.52
6	1422565	484227	530991	0	30	--	--	100	133	--	595	1	--	--	133	--
7	1422828	484190	566409	5	20	50	55	--	--	--	596	1	--	--	60	--
8	1422097	482967	483135	--	--	--	--	100	104	--	591	1	--	--	104	--
9	1412654	481975	78739	--	--	--	--	--	--	--	690	1	--	--	55	--
10	1410617	481753	366567	--	--	--	--	75	160	--	675	1	--	--	160	--
11	1411017	481101	247767	--	--	--	--	141	155	--	675	1	--	--	155	--
12	1420775	480941	277611	--	--	--	--	90	91	--	595	1	--	--	91	--
13	1412066	480853	58821	--	--	--	--	--	--	47	680	1	--	--	65	--
14	1420359	480496	634865	--	--	45	51	53	90	--	595	1	--	--	90	--
15	1420866	480492	624387	9	27	--	--	46	87	--	595	1	--	--	88	--
16	1427807	480277	189863	8	52	--	--	--	--	--	630	1	--	--	52	--
17	1428478	480014	145213	--	--	--	--	--	--	63	660	1	--	--	95	--
18	1420179	479796	999-180	--	--	--	--	53	90	90	588.6	0.1	--	--	90	--
19	1428421	479779	100473	--	--	--	--	--	--	34	660	1	--	--	65	--
20	1422990	479078	175766	10	50	--	--	--	--	--	590	1	--	--	60	--
21	1428042	478975	999-183	--	--	--	--	60	--	--	635	1	--	--	120	--
22	1428597	478751	BU-31	2	70	--	--	--	--	70	695	5	1.08	654.37	100	696.08
23	1421976	475521	865244	4	39	--	--	--	--	--	585	1	2.9	568.82	50	587.9
24	1421568	474775	999-204.4	--	--	--	--	98	108	108	576	1	--	--	108	--
25	1426396	474330	834555	8	30	--	--	--	--	--	605	1	--	--	30	--
26	1421221	474238	999-204.6	--	--	--	--	69	101	101	576	1	--	--	112	--
27	1421662	474066	151055	--	--	--	--	208	218	--	582	1	--	--	218	--
28	1421730	473887	794703	--	--	--	--	--	--	--	579.9	0.1	-0.35	569.11	25	579.65
29	1421966	473882	794704	--	--	--	--	--	--	--	579.9	0.1	-0.35	561.85	24	579.65
30	1427331	473163	819528	--	--	--	--	78	120	--	602	1	--	--	127	--
31	1429265	472907	GREEN4	4	18	--	--	--	--	29	631	5	2.0	626.21	30	633.00
32	1430947	472839	94122	--	--	--	--	--	--	6	700	1	--	--	77	--
33	1428519	472759	GREEN8029	--	--	--	--	--	--	100	615	5	--	--	117	--
34	1428487	472756	GREEN1	18	22	--	--	--	--	--	615	5	2.5	606.53	24	617.50

Appendix 1. Well and borehole data, central Mill Creek Valley, Ohio

[Well number referenced in plate 1; fbls, feet below land surface; fals, feet above land surface; msl, feet above sea level; alt, altitude; coord, coordinate; --, no data. WT (water table), shallow, and lower aquifers described in the report. State-plane feet coordinates, Ohio South zone, North American datum of 1983.]

Well number	East coord (feet)	North coord (feet)	Well name	Top WT (fbls)	Bottom WT (fbls)	Top shallow (fbls)	Bottom shallow (fbls)	Top lower (fbls)	Bottom lower (fbls)	Top bedrock (fbls)	Land altitude (sl)	Altitude accuracy (feet)	Measure point alt (fals)	Water level (sl)	Well depth (feet)	Measure point alt (sl)
35	1428941	472736	GREEN7	17	18	--	--	--	--	--	620	5	-0.35	607.26	25	619.65
36	1428681	472723	GREEN3	8	27	--	--	--	--	--	615	5	2.87	601.94	30	617.87
37	1428542	472721	GREEN5	--	--	--	--	--	--	--	615	5	2.2	602.06	30	617.20
38	1428483	472716	GREEN2	--	--	--	--	--	--	--	615	5	2.4	602.11	30	617.40
39	1417636	472556	699582	--	--	--	--	--	--	7	630	1	--	--	47	--
40	1426381	472539	142790	40	43	74	80	100	140	--	588	1	--	--	140	--
41	1427020	471774	XTEK8	--	--	--	--	--	--	--	588.64	0.01	-0.31	582.81	13	588.33
42	1415202	471681	276469	--	--	--	--	--	--	78	642	1	--	--	108	--
43	1427332	471666	358256	--	--	--	--	90	185	--	590	1	--	--	185	--
45	1421572	471513	9931175	20	30	--	--	98	201	201	573	5	--	--	202	--
46	1427404	471361	XTEK4	--	--	--	--	--	--	--	590.01	0.01	-0.28	584.02	13	589.73
47	1421541	471314	9931174	--	--	--	--	90	201	201	573	5	--	--	201	--
48	1423954	471309	279262	17	22	--	--	85	200	--	578	1	--	--	200	--
49	1424192	471304	lockland7	--	--	--	--	--	--	--	578	1	3.9	552.58	198	581.90
50	1427324	471261	XTEK1	14	15	--	--	--	--	--	587.45	0.01	-0.41	582.60	19	587.04
51	1427243	471162	XTEK5	--	--	--	--	--	--	--	586.10	0.01	-0.21	581.61	13	585.89
52	1424190	471124	lockland6	6	36	--	--	70	196	196	578	1	3.9	550.00	196	581.90
53	1423810	470514	FORD3	6	14	--	--	--	--	--	573.34	0.01	1.9	565.32	19	575.24
54	1423430	470471	FORD1	6	16	--	--	--	--	--	573.16	0.01	2.44	563.66	17	575.60
55	1413372	469931	696967	--	--	26	30	--	--	30	650	1	1.28	631.19	50	651.28
56	1426611	469732	174657	18	30	30	60	60	118	--	591	1	--	--	118	--
57	1427436	469556	ODOT19	--	--	30	--	--	--	--	597	.1	--	--	50	--
58	1427463	469451	ODOT18	--	--	30	--	--	--	--	597	.1	--	--	50	--
59	1428330	468244	145239	--	--	--	--	--	--	20	625	1	--	--	82	--
60	1422705	467997	51743	6	74	--	--	85	194	--	572	1	9.53	536.53	194	581.53
61	1422515	467721	9931159	6	52	62	69	82	181	--	571	5	--	--	181	--
62	1423783	467710	9931141	5	37	55	70	81	185	--	571	5	--	--	185	--
63	1425522	467700	9931140	18	41	57	82	88	202	202	581	5	--	--	202	--
64	1424347	467669	999-208	--	--	--	--	90	194	194	575	5	--	--	194	--
65	1422421	466564	999-209	--	--	--	--	77	--	--	570	5	--	--	170	--
66	1420716	465617	999-210	--	--	--	--	--	--	--	590	5	--	--	120	--
67	1420276	479383	BU-9	--	--	53	90	--	--	--	586.89	.01	4.66	--	85	591.55

Appendix 1. Well and borehole data, central Mill Creek Valley, Ohio

[Well number referenced in plate 1; fbls, feet below land surface; fals, feet above land surface; msl, feet above sea level; alt, altitude; coord, coordinate; --, no data. WT (water table), shallow, and lower aquifers described in the report. State-plane feet coordinates, Ohio South zone, North American datum of 1983.]

Well number	East coord (feet)	North coord (feet)	Well name	Top WT (fbls)	Bottom WT (fbls)	Top shallow (fbls)	Bottom shallow (fbls)	Top lower (fbls)	Bottom lower (fbls)	Top bedrock (fbls)	Land altitude (sl)	Altitude accuracy (feet)	Measure point alt (fals)	Water level (sl)	Well depth (feet)	Measure point alt (sl)
68	1420221	464588	9931143	--	--	--	--	90	192	--	578	5	--	--	192	--
69	1422396	468206	H-6	--	--	--	--	--	--	--	570.65	0.01	4.05	--	167	574.70
70	1422599	464420	406	0	33	44	47	76	101	--	570	1	--	--	101	--
71	1411605	464236	999-235	--	--	--	--	70	--	--	610	1	--	--	80	--
72	1422295	463659	999-212	--	--	--	--	--	--	--	572.7	0.1	--	--	181	--
73	1422579	462932	999-213	--	--	--	--	--	--	--	565	1	--	--	178	--
74	1421979	462522	999-214	--	--	--	--	--	--	--	570	1	--	--	176	--
75	1424397	462375	835861	0	25	--	--	--	--	--	583	1	--	--	25	--
76	1418674	462331	NWBG-MW1S	9	15	--	--	--	--	--	569.0	0.1	2.10	556.29	22	571.10
77	1418617	461702	20-MW3S	6	20	--	--	--	--	--	567.5	0.1	1.80	553.45	22	569.30
78	1418599	461643	20-MW3D	10	25	45	85	100	135	--	567.6	0.1	1.47	545.06	131	569.07
79	1418761	461569	20-MW1S	7	25	--	--	--	--	--	565.8	0.1	-0.23	551.07	24	565.57
80	1419811	461485	NEBG-MW1S	4	22	--	--	--	--	--	565.5	0.1	2.21	550.26	28	567.71
81	1419854	461481	NEBG-MW1D	10	40	65	70	80	150	--	565.8	0.1	1.20	546.19	132	567.00
82	1421316	461227	999-215	--	--	--	--	--	--	--	557.8	0.1	--	--	104	--
83	1419376	461218	AOCL-MW1S	1	27	--	--	--	--	--	565	0.1	-0.25	549.18	26	564.75
84	1419209	461133	32-MW1S	7	28	--	--	--	--	--	565.4	0.1	1.99	548.51	28	567.39
85	1419620	461111	MW-306-6	6	24	--	--	--	--	--	565.2	0.1	-0.32	548.94	25	564.88
86	1419409	461084	61_67-MW3S	5	28	--	--	--	--	--	564.7	0.1	-0.23	548.68	25	564.47
87	1419376	460997	61_67-MW1S	--	--	--	--	--	--	--	564.2	0.1	2.05	548.23	28	566.25
88	1417366	460967	ODOT24	5	7	--	--	--	--	--	584	0.1	--	--	55	--
89	1417650	460861	ODOT23	2	20	63	68	--	--	--	570	0.1	--	--	71	--
90	1419626	460440	70-MW1S	--	--	--	--	--	--	--	561.8	0.1	-0.45	546.74	25	561.35
91	1419310	460287	MW-301-8	0	25	--	--	--	--	--	561.6	0.1	-0.21	545.50	25	561.39
92	1419609	460143	86-MW4S	7	27	--	--	--	--	--	560.7	0.1	-0.28	545.96	26	560.42
93	1417356	459992	9931147	--	--	--	--	--	--	--	568	5	--	--	60	--
94	1417444	459981	436	--	--	--	--	105	170	170	570	1	--	--	170	--
95	1417329	459915	9931144	--	--	--	--	--	--	--	568	5	--	--	50	--
96	1418014	459900	435	--	--	27	40	75	182	182	560	1	--	--	182	--
97	1418000	459828	GM-2	10	29	--	--	--	--	--	561.94	0.01	1.17	543.50	31	563.11
98	1418784	459798	9931149	4	28	40	68	80	176	--	559	5	--	--	176	--
99	1419522	459681	433	--	--	25	45	75	183	183	560	1	--	--	184	--

Appendix 1. Well and borehole data, central Mill Creek Valley, Ohio

[Well number referenced in plate 1; fbls, feet below land surface; fals, feet above land surface; msl, feet above sea level; alt, altitude; coord, coordinate; --, no data. WT (water table), shallow, and lower aquifers described in the report. State-plane feet coordinates, Ohio South zone, North American datum of 1983.]

Well number	East coord (feet)	North coord (feet)	Well name	Top WT (fbls)	Bottom WT (fbls)	Top shallow (fbls)	Bottom shallow (fbls)	Top lower (fbls)	Bottom lower (fbls)	Top bedrock (fbls)	Land altitude (sl)	Altitude accuracy (feet)	Measure point alt (fals)	Water level (sl)	Well depth (feet)	Measure point alt (sl)
100	1418682	459652	9931156	6	32	42	54	62	82	--	559	5	--	--	82	--
101	1418915	459391	H-7	--	--	--	--	--	180	--	559.78	0.01	3.4	541.45	180	563.18
102	1419299	459261	9931158	4	30	42	54	62	180	--	560	5	--	--	180	--
103	1416948	459240	9931154	10	14	29	64	79	171	171	562	5	--	--	171	--
104	1416931	459160	WBG-MW2S	--	--	--	--	--	--	--	569.4	0.1	1.88	554.24	28	571.28
105	1416931	459156	WBG-MW2D	--	--	55	70	90	125	--	569.3	0.1	1.50	537.75	121	570.80
106	1419266	459124	64_68-MW1S	--	--	--	--	--	--	--	562.18	0.01	-0.28	542.19	24	561.90
107	1417408	459119	9931155	10	25	50	55	90	158	158	559	5	--	--	158	--
108	1421157	459098	142775	15	30	--	--	110	161	--	580	1	--	544.27	161	580.48
109	1421285	459073	250804	23	28	34	73	76	178	178	572	1	--	--	178	--
110	1419614	459067	EBG-MW4D	10	35	55	65	70	112	--	556.4	0.1	1.72	542.08	102	558.12
111	1417684	459065	AOCPST-MW3S	--	--	--	--	--	--	--	558.2	0.1	-0.32	541.53	26	557.88
112	1421510	459061	250803	--	--	30	70	96	169	169	572	1	--	--	170	--
113	1421371	459057	101817	--	--	60	83	118	191	--	580	1	1.45	539.25	191	581.45
114	1417960	459057	AOCPST-MW2S	8	26	--	--	--	--	--	559.9	0.1	-0.20	541.42	26	559.70
115	1417797	459053	AOCPST-MW1S	--	--	--	--	--	--	--	556.73	0.01	-0.45	541.52	20	556.28
116	1421686	459050	358267	24	31	--	--	86	168	--	580	1	1.66	543.87	168	581.66
117	1419112	458959	93_94-MW2S	16	17	--	--	--	--	--	560.7	0.1	2.00	540.70	30	562.70
118	1418890	458856	9931146	16	21	--	--	--	--	--	560	5	--	--	25	--
119	1418874	458770	GM-4	10	36	--	--	--	--	--	558.82	0.01	2.00	540.73	37	561.07
120	1420096	458766	GM-7D	15	19	43	53	85	110	--	568.18	0.01	1.00	543.06	112	569.18
121	1420167	458741	GM-7S	--	--	43	52	--	--	--	568.24	0.01	1.67	542.66	54	569.91
122	1418835	458728	9931150	6	32	39	67	79	178	--	560	5	--	--	178	--
123	1416167	458602	ODOT17	--	--	--	--	--	--	--	583	0.1	--	--	61	--
124	1416221	458451	ODOT16	8	24	45	61	--	--	--	575	0.1	--	--	61	--
125	1416328	458380	ODOT15	10	12	--	--	--	--	--	569	0.1	--	--	51	--
126	1419007	458309	9931145	13	25	--	--	--	--	--	558	5	--	--	25	--
127	1418822	458282	AOCW6-MW1S	2	25	--	--	--	--	--	560.0	0.1	-0.24	541.01	29	559.76
128	1420084	458182	EBG-MW4S	7	16	--	--	--	--	--	561.2	0.1	2.02	551.52	18	563.22
129	1418845	458161	98_99-MW1S	--	--	--	--	--	--	--	560.2	0.1	-0.19	541.11	27	560.01
130	1418919	458092	123-MW1S	11	27	--	--	--	--	--	560.1	0.1	-0.23	541.14	27	559.87
131	1419068	458029	EBG-MW1S	5	20	--	--	--	--	--	556.3	0.1	1.93	542.17	21	558.23

Appendix 1. Well and borehole data, central Mill Creek Valley, Ohio

[Well number referenced in plate 1; fbls, feet below land surface; fals, feet above land surface; msl, feet above sea level; alt, altitude; coord, coordinate; --, no data. WT (water table), shallow, and lower aquifers described in the report. State-plane feet coordinates, Ohio South zone, North American datum of 1983.]

Well number	East coord (feet)	North coord (feet)	Well name	Top WT (fbls)	Bottom WT (fbls)	Top shallow (fbls)	Bottom shallow (fbls)	Top lower (fbls)	Bottom lower (fbls)	Top bedrock (fbls)	Land altitude (sl)	Altitude accuracy (feet)	Measure point alt (fals)	Water level (sl)	Well depth (feet)	Measure point alt (sl)
132	1416733	457998	GM-8D	--	--	41	44	57	110	--	561.80	0.01	0.75	536.13	112	562.55
133	1416733	457989	GM-8S	10	16	39	66	--	--	--	561.72	0.01	0.83	536.09	70	562.55
134	1420504	457945	GM-6P	3	18	--	--	--	--	--	560.70	0.01	2.10	548.38	20	562.80
135	1420520	457934	GM-6D	6	17	42	44	116	160	--	561.11	0.01	1.71	541.68	160	562.82
136	1420510	457932	GM-6S	5	7	38	44	--	--	--	561.34	0.01	2.25	542.54	47	563.59
137	1417368	457884	AOCLD-MW3S	2	25	--	--	--	--	--	556.5	0.1	0.29	541.97	22	556.79
138	1417836	457826	AOCLD-MW2S	16	27	--	--	--	--	--	556.4	0.1	-0.26	541.05	25	556.14
139	1419572	457657	27_28-MW1D	11	20	41	79	135	153	--	561.4	0.1	1.82	539.02	151	563.22
140	1419566	457643	27_28-MW1S	12	22	--	--	--	--	--	561.7	0.1	1.97	544.77	23	563.67
141	1418587	457529	62_63-MW4S	14	30	--	--	--	--	--	561.7	0.1	-0.23	541.71	29	561.47
142	1418222	457451	9931153	6	32	--	--	57	163	163	552	5	--	--	163	--
143	1418207	457323	9931152	5	50	61	68	83	167	--	552	5	--	--	167	--
144	1416754	457241	GM-5D	6	21	45	72	100	116	--	562.53	0.01	1.54	534.84	118	564.07
145	1416752	457229	GM-5S	10	17	46	62	--	--	--	562.49	0.01	1.83	534.22	62	564.32
146	1418266	457163	GM-3D	14	25	50	57	128	147	--	560.80	0.01	1.67	536.78	147	562.47
147	1418264	457152	GM-3S	5	7	15	57	--	--	--	560.67	0.01	2.19	539.28	57	562.86
148	1420054	457134	EBG-MW3S	6	16	--	--	--	--	--	557.6	0.1	2.00	545.68	18	559.60
149	1419566	457106	GM-1P	--	--	--	--	--	--	--	562.50	0.01	2.11	544.51	24	564.61
150	1417244	457101	GM-9P	6	28	--	--	--	--	--	560.30	0.01	-0.35	540.56	28	559.95
151	1417254	457100	GM-9D	16	29	42	53	80	111	--	561.02	0.01	-0.96	534.86	112	560.06
152	1417249	457094	GM-9S	10	31	41	52	--	--	--	560.95	0.01	-0.82	538.31	55	560.13
153	1419574	457082	GM-1	15	17	35	56	--	--	--	562.33	0.01	2.08	541.46	57	564.41
154	1418304	457075	GM-3P	--	--	--	--	--	--	--	559.50	0.01	-0.26	539.44	29	559.24
155	1415971	457043	AF-18P	--	--	--	--	--	--	--	577.08	0.01	0.89	564.45	24	577.97
156	1415971	457037	AF-18D	--	--	--	--	61	80	--	577.25	0.01	1.24	532.75	80	578.49
157	1417281	457009	AF-16P	9	30	--	--	--	--	--	560.40	0.01	1.53	540.38	31	561.93
158	1418666	457009	27_28-MW2D	10	35	50	65	125	130	--	564.1	0.1	1.71	536.28	123	565.81
159	1417281	457004	AF-16D	5	32	40	72	90	101	--	560.40	0.01	1.43	534.82	101	561.83
160	1416852	456992	AF-15D	10	20	47	70	84	115	--	559.80	0.01	1.15	534.21	113	560.95
161	1416851	456990	AF-15S	0	22	44	57	--	--	--	559.90	0.01	1.49	534.65	57	561.39
162	1418869	456983	GM-11S	20	31	51	59	--	--	--	565.8	0.1	2.81	538.38	61	568.61
163	1418810	456978	GM-11P	17	29	--	--	--	--	--	564.4	0.1	2.32	541.47	31	566.72
164	1419129	456972	GM-10P	11	23	--	--	--	--	--	559.0	0.1	1.62	543.46	24	560.62

Appendix 1. Well and borehole data, central Mill Creek Valley, Ohio

[Well number referenced in plate 1; fbls, feet below land surface; fals, feet above land surface; msl, feet above sea level; alt, altitude; coord, coordinate; --, no data. WT (water table), shallow, and lower aquifers described in the report. State-plane feet coordinates, Ohio South zone, North American datum of 1983.]

Well number	East coord (feet)	North coord (feet)	Well name	Top WT (fbls)	Bottom WT (fbls)	Top shallow (fbls)	Bottom shallow (fbls)	Top lower (fbls)	Bottom lower (fbls)	Top bedrock (fbls)	Land altitude (sl)	Altitude accuracy (feet)	Measure point alt (fals)	Water level (sl)	Well depth (feet)	Measure point alt (sl)
165	1417966	456927	AF-1P	4	29	--	--	--	--	--	559.38	0.01	0	540.22	29	559.38
166	1417978	456927	AF-1D	6	35	--	--	103	118	--	559.66	0.01	0	535.61	118	559.66
167	1417977	456921	AF-1S	6	31	40	52	--	--	--	559.45	0.01	0	537.95	52	559.45
168	1419200	456884	27_31-MW5D	20	35	50	85	95	150	--	558.7	0.1	1.41	536.75	111	560.11
169	1419561	456875	18-MW1S	27	32	--	--	--	--	--	557.6	0.1	1.92	540.46	34	559.52
170	1418466	456843	EBG-MW5S	6	20	--	--	--	--	--	553.7	0.1	1.96	540.47	21	555.66
171	1419958	456835	142780	2	20	35	45	83	160	--	551	1	--	--	160	--
172	1419684	456704	142795	--	--	--	--	84	163	--	551	1	--	--	163	--
173	1421525	456563	ODOT25	5	15	-	--	--	--	30	577	0.1	--	--	45	--
174	1419962	456531	MW71	23	24	--	--	55	65	--	562.1	0.1	1.67	537.49	65	563.77
175	1416791	456529	AF-14P	16	27	--	--	--	--	--	559.32	0.01	-0.89	544.19	28	558.43
176	1416789	456526	AF-14S	12	19	54	67	--	--	--	559.37	0.01	-0.92	533.39	67	558.45
177	1419959	456521	MW73	23	24	--	--	52	145	145	562.0	0.1	2.04	537.35	145	564.04
178	1419962	456510	MW72	23	24	--	--	52	94	145	562.3	0.1	1.96	537.30	94	564.26
179	1416527	456495	AF-13P	0	16	--	--	--	--	--	565.40	0.01	1.42	559.07	15	566.82
180	1416524	456490	AF-13S	1	9	50	57	--	--	--	565.50	0.01	2.76	533.61	61	568.26
181	1417468	456484	AF-17D	8	34	41	75	89	100	--	561.16	0.01	0	534.38	100	561.16
182	1417474	456483	AF-17P	9	33	--	--	--	--	--	560.96	0.01	0	539.32	32	560.96
183	1419390	456469	51741	--	--	--	--	59	172	--	551	1	--	--	172	--
184	1419777	456447	MW75	28	30	40	46	58	97	160	567.0	0.1	2.03	536.91	97	569.03
185	1419755	456445	MW74	28	30	40	46	58	66	--	565.8	0.1	2.32	536.89	66	568.12
186	1419767	456445	MW76	28	30	40	46	58	160	160	566.5	0.1	1.74	536.96	159	568.24
187	1418009	456379	AF-2P	15	33	--	--	--	--	--	561.45	0.01	1.76	539.31	33	563.21
188	1418006	456374	AF-2S	12	28	32	52	--	--	--	561.57	0.01	0.90	537.76	52	562.47
189	1412801	456335	747653	--	--	--	--	81	103	--	565	1	--	--	103	--
190	1416192	456298	AF-12D	--	--	53	84	94	115	--	573.00	0.01	2.14	531.24	112	575.14
191	1417884	456297	AF-3P	5	32	--	--	--	--	--	559.69	0.01	1.93	539.12	31	561.62
192	1416186	456297	AF-12S	--	--	49	75	--	--	--	573.74	0.01	1.38	532.40	75	575.12
193	1416183	456296	AF-12P	14	16	--	--	--	--	--	573.52	0.01	1.25	562.28	20	574.77
194	1417880	456296	AF-3S	4	32	43	57	--	--	--	559.85	0.01	1.94	537.70	52	561.79
195	1415852	456249	ODOT13	--	--	30	35	--	--	--	586	0.1	--	--	61	--
196	1419851	456220	MW80	33	35	54	57	70	81	--	578.4	0.1	1.78	536.48	81	580.18

Appendix 1. Well and borehole data, central Mill Creek Valley, Ohio

[Well number referenced in plate 1; fbls, feet below land surface; fals, feet above land surface; msl, feet above sea level; alt, altitude; coord, coordinate; --, no data. WT (water table), shallow, and lower aquifers described in the report. State-plane feet coordinates, Ohio South zone, North American datum of 1983.]

Well number	East coord (feet)	North coord (feet)	Well name	Top WT (fbls)	Bottom WT (fbls)	Top shallow (fbls)	Bottom shallow (fbls)	Top lower (fbls)	Bottom lower (fbls)	Top bedrock (fbls)	Land altitude (sl)	Altitude accuracy (feet)	Measure point alt (fals)	Water level (sl)	Well depth (feet)	Measure point alt (sl)
197	1417880	456183	AF-4S	14	35	42	57	--	--	--	560.10	0.01	1.97	537.56	57	562.07
198	1417878	456181	AF-4P	14	35	--	--	--	--	--	560.18	0.01	1.54	538.84	35	561.72
199	1415104	456142	ODOT14	--	--	--	--	--	--	--	580	0.1	--	--	66	--
200	1416979	456134	AF-10S	0	24	63	72	--	--	--	559.74	0.01	2.16	533.32	72	561.90
201	1416978	456128	AF-10P	3	22	--	--	--	--	--	559.46	0.01	1.95	539.16	22	561.41
202	1416580	456098	AF-11P	15	22	--	--	--	--	--	564.52	0.01	1.63	--	22	566.15
203	1416578	456095	AF-11S	20	39	45	62	--	--	--	564.55	0.01	0.44	532.72	63	564.99
204	1416584	456088	AF-11D	23	40	46	71	76	106	--	564.71	0.01	1.37	532.72	102	566.08
205	1418955	456061	999-217	9	16	33	69	86	--	--	550	1	--	--	173	--
206	1417403	456060	AF-6P	4	34	--	--	--	--	--	559.55	0.01	2.05	538.44	33	561.60
207	1417403	456056	AF-6S	12	52	--	--	--	--	--	560.00	0.01	2.59	537.40	52	562.59
208	1419853	455949	MW81	8	12	28	74	81	89	--	581.0	0.1	-0.74	534.99	89	580.26
209	1419955	455943	MW68	--	--	24	78	85	99	158	581.2	0.1	0.11	535.50	99	581.31
210	1419623	455941	MW77	18	29	--	--	54	66	--	558.6	0.1	2.21	535.51	66	560.81
211	1416777	455941	AF-21D	15	33	37	--	--	90	--	559.99	0.01	-0.38	533.01	90	559.61
212	1419616	455935	MW79	18	29	--	--	53	125	125	558.6	0.1	2.28	535.71	124	560.88
213	1419257	455934	201948	9	13	33	48	50	156	--	550	1	--	--	156	--
214	1419957	455934	MW69	--	--	24	77	85	121	158	581.0	0.1	-0.45	535.63	121	580.55
215	1416941	455934	AF-20D	14	21	55	--	--	90	--	559.80	0.01	2.62	533.10	91	562.42
216	1416941	455928	AF-20S	32	38	54	--	--	69	--	559.78	0.01	2.60	533.08	69	562.38
217	1419848	455927	PZ-S-1	--	--	--	--	--	--	--	578.54	0.01	1.50	--	--	580.04
218	1419614	455926	MW78	18	29	--	--	53	108	125	558.6	0.1	2.04	535.49	105	560.64
219	1419959	455925	MW70	--	--	23	73	84	149	158	580.5	0.1	0.07	534.65	149	580.57
220	1418995	455924	58819	0	52	--	--	104	175	--	551	1	--	--	175	--
221	1418893	455921	999-218	--	--	--	--	98	--	--	553	1	--	--	162	--
222	1417839	455917	AF-INT1	15	35	42	59	--	--	--	553	1	--	--	63	--
223	1419840	455913	PZ-D-1	--	--	--	--	--	143	--	577.66	0.01	--	532.61	--	578
224	1420047	455912	MW82	19	23	64	83	91	101	--	580.8	0.1	2.04	536.12	101	582.84
225	1419858	455912	EW1	8	34	35	70	75	148	163	579.6	0.1	1.92	529.31	154	581.52
226	1417835	455889	AF-5D	2	34	41	62	91	111	--	559.47	0.01	2.18	534.12	110	561.65
227	1417833	455887	AF-5S	2	39	41	51	--	--	--	559.47	0.01	2.09	537.29	51	561.56
228	1417832	455883	AF-5P	4	34	--	--	--	--	--	559.89	0.01	1.34	538.22	33	561.23
229	1417038	455823	AF-19S	14	23	53	--	--	62	--	561.50	0.01	2.29	533.44	62	563.79

Appendix 1. Well and borehole data, central Mill Creek Valley, Ohio

[Well number referenced in plate 1; fbls, feet below land surface; fals, feet above land surface; msl, feet above sea level; alt, altitude; coord, coordinate; --, no data. WT (water table), shallow, and lower aquifers described in the report. State-plane feet coordinates, Ohio South zone, North American datum of 1983.]

Well number	East coord (feet)	North coord (feet)	Well name	Top WT (fbls)	Bottom WT (fbls)	Top shallow (fbls)	Bottom shallow (fbls)	Top lower (fbls)	Bottom lower (fbls)	Top bedrock (fbls)	Land altitude (sl)	Altitude accuracy (feet)	Measure point alt (fals)	Water level (sl)	Well depth (feet)	Measure point alt (sl)
230	1417039	455818	AF-19D	12	21	48	--	--	92	--	561.65	0.01	2.37	533.14	91	564.02
231	1416787	455794	AF-9D	--	--	39	--	--	91	--	562.10	0.01	1.71	532.78	88	563.81
232	1416793	455791	AF-9S	--	--	35	--	--	52	--	561.83	0.01	2.25	532.81	60	564.08
233	1419897	455736	MW85	--	--	47	58	89	136	137	579.4	0.1	-0.16	530.47	126	579.24
234	1419903	455736	MW84	--	--	46	58	89	114	137	579.3	0.1	-0.01	530.91	114	579.29
235	1419900	455735	MW83	--	--	46	50	88	102	137	579.0	0.1	-0.19	--	102	578.81
236	1417088	455525	AF-8S	6	20	49	62	--	--	--	559.17	0.01	1.90	533.84	62	561.07
237	1417092	455518	AF-8D	8	22	49	66	77	101	--	558.95	0.01	1.81	532.92	96	560.76
238	1417579	455489	AF-7D	3	38	44	60	92	120	--	559.63	0.01	1.47	533.44	119	561.10
239	1412197	455485	999-236	--	--	--	--	96	182	182	550	1	--	--	182	--
240	1417578	455482	AF-7S	3	35	40	57	--	--	--	559.58	0.01	2.32	536.90	57	561.90
241	1417577	455478	AF-7P	5	38	--	--	--	--	--	559.38	0.01	1.70	537.08	37	561.08
242	1418151	455289	MW93	8	25	34	73	75	154	154	551.8	0.1	-0.17	533.51	153	551.63
243	1418154	455286	MW92	8	25	34	73	75	92	154	552.0	0.1	-0.25	533.79	92	551.75
244	1413346	455090	lockland4	--	--	--	--	--	--	--	555	1	--	--	160	--
245	1419606	454972	PZ2	7	13	58	71	116	127	129	563.0	0.1	0.03	513.24	127	563.03
246	1419672	454966	MW86	16	35	65	66	111	130	136	564.1	0.1	-0.23	511.39	128	563.87
247	1419662	454966	EW2	--	--	--	--	114	133	133	564.1	0.1	--	510.36	133	564
248	1418898	454812	MW88	5	49	64	72	100	145	163	564.1	0.1	-0.23	513.05	136	563.87
249	1418895	454806	MW87	5	49	64	72	100	110	163	564.1	0.1	-0.37	513.03	110	563.73
250	1418892	454799	MW89	5	49	64	72	100	163	163	563.9	0.1	-0.24	513.02	160	563.66
251	1417336	454691	999-219	--	--	--	--	--	--	--	545	1	--	--	165	--
252	1419605	454574	198166	9	18	57	64	90	143	143	565	1	--	--	145	--
253	1411829	454562	250805	--	--	--	--	105	194	194	575	1	--	--	194	--
254	1419395	454537	PZ3	6	39	52	62	97	140	141	563.4	0.1	-0.01	510.20	141	563.39
255	1419381	454533	EW3	--	--	--	--	97	143	143	563.4	0.1	--	507.83	143	563
256	1416763	454266	Sawbrook	14	20	38	47	126	174	174	554.85	0.01	1.92	531.45	174	556.77
257	1417757	454241	230003	--	--	58	76	85	153	--	550	1	--	--	153	--
258	1417968	454029	MW100	6	50	57	88	92	151	151	548.5	0.1	-0.20	515.56	148	548.30
259	1419193	454010	MW94	5	41	49	55	75	90	140	563.9	0.1	-0.23	508.76	90	563.67
260	1417966	454006	9931161	31	47	72	81	94	152	--	565	5	--	--	152	--
261	1419189	454003	MW95	5	42	49	55	75	140	140	563.9	0.1	-0.24	512.26	141	563.66

Appendix 1. Well and borehole data, central Mill Creek Valley, Ohio

[Well number referenced in plate 1; fbls, feet below land surface; fals, feet above land surface; msl, feet above sea level; alt, altitude; coord, coordinate; --, no data. WT (water table), shallow, and lower aquifers described in the report. State-plane feet coordinates, Ohio South zone, North American datum of 1983.]

Well number	East coord (feet)	North coord (feet)	Well name	Top WT (fbls)	Bottom WT (fbls)	Top shallow (fbls)	Bottom shallow (fbls)	Top lower (fbls)	Bottom lower (fbls)	Top bedrock (fbls)	Land altitude (sl)	Altitude accuracy (feet)	Measure point alt (fals)	Water level (sl)	Well depth (feet)	Measure point alt (sl)
262	1419071	453932	PZ4	--	--	62	77	85	150	151	563.5	0.1	0.07	510.16	150	563.57
263	1419064	453916	EW4	--	--	--	--	70	152	152	563.5	0.1	--	501.58	152	563
264	1419046	453882	PZ5	13	29	--	--	72	145	146	564.5	0.1	0.07	507.54	145	564.57
265	1419678	453796	PB7-94	23	25	--	--	--	--	55	567	1	--	--	64	--
266	1413268	453791	710927	0	20	--	--	--	--	--	575	1	--	--	20	--
267	1416541	453601	999-221	--	--	--	--	--	--	--	550	1	--	--	135	--
268	1418937	453588	PZ-S-7	14	19	42	44	61	100	147	562.6	0.1	0.03	512.01	96	562.63
269	1418936	453588	PZ-D-7	14	19	42	44	61	147	147	562.6	0.1	0.03	511.91	145	562.63
270	1417569	453585	999-220.3	--	--	--	--	101	156	156	555	1	--	--	156	--
271	1418893	453538	EW5	--	--	--	--	58	149	149	562.5	0.1	--	504.59	149	562
272	1418888	453525	PZ6	7	10	43	45	54	148	148	562.5	0.1	0.02	511.44	145	562.52
273	1417853	453498	MW90	3	20	28	56	72	148	148	548.6	0.1	-0.30	511.59	135	548.30
274	1417854	453494	MW91	3	20	27	56	72	148	148	548.3	0.1	-0.17	511.95	149	548.13
275	1411884	453405	H-8	--	--	--	--	180	200	--	570.65	0.01	4.35	512.57	200	575
276	1416303	453379	ODOT9	12	14	44	67	--	--	--	569	0.1	--	--	71	--
277	1415078	453352	999-240.T	--	--	--	--	112	175	175	540	1	--	--	176	--
278	1414284	453149	999-238	--	--	--	--	131	--	--	546	1	--	--	139	--
279	1416985	453128	MW104	12	55	57	71	85	148	148	552.0	0.1	-0.18	510.92	146	551.82
280	1416981	453120	MW105	12	55	57	71	85	107	148	551.7	0.1	-0.21	524.32	107	551.49
281	1411556	453053	342965	--	--	19	72	131	195	--	578	1	--	--	197	--
282	1411598	453043	250801	--	--	45	85	120	196	196	578	1	--	--	196	--
283	1419158	453001	727418	1	7	14	50	--	--	--	570	1	--	--	50	--
284	1416392	452911	ODOT8	24	33	41	64	87	--	--	559	0.1	--	--	86	--
285	1414479	452844	9931134	--	--	55	60	96	178	178	552	5	--	--	181	--
286	1416402	452822	ODOT7	7	10	41	59	--	--	--	560	0.1	--	--	71	--
287	1411906	452720	819525	--	--	--	--	110	180	--	575	1	2.75	518.37	180	577.75
288	1418337	452649	MW101	5	12	29	55	117	147	147	560.0	0.1	-0.06	519.04	144	559.94
289	1416442	452573	ODOT6	14	17	40	59	--	--	--	558	0.1	--	--	70	--
290	1417000	452570	MW98	5	14	26	69	83	148	150	549.4	0.1	0.12	524.16	146	549.52
291	1417012	452569	MW99	13	14	26	69	83	104	150	549.6	0.1	0.07	524.17	104	549.67
292	1422349	452562	258873	--	--	37	42	--	--	42	680	1	--	--	100	--
293	1415685	452402	999-222	--	--	40	55	85	170	170	560	1	--	--	170	--
294	1414906	452230	999-241	--	--	--	--	115	175	175	560	1	--	--	175	--

Appendix 1. Well and borehole data, central Mill Creek Valley, Ohio

[Well number referenced in plate 1; fbls, feet below land surface; fals, feet above land surface; msl, feet above sea level; alt, altitude; coord, coordinate; --, no data. WT (water table), shallow, and lower aquifers described in the report. State-plane feet coordinates, Ohio South zone, North American datum of 1983.]

Well number	East coord (feet)	North coord (feet)	Well name	Top WT (fbls)	Bottom WT (fbls)	Top shallow (fbls)	Bottom shallow (fbls)	Top lower (fbls)	Bottom lower (fbls)	Top bedrock (fbls)	Land altitude (sl)	Altitude accuracy (feet)	Measure point alt (fals)	Water level (sl)	Well depth (feet)	Measure point alt (sl)
295	1416512	452225	ODOT5	--	--	31	54	--	--	--	552	0.1	--	--	76	--
296	1414406	452173	9931135	--	--	25	--	--	175	--	559	5	--	--	175	--
297	1414574	452110	9931139	--	--	65	69	86	175	175	558	5	--	--	175	--
298	1416601	451827	ODOT4	2	18	28	52	91	--	--	552	0.1	--	--	95	--
299	1417308	451769	MW103	16	48	61	63	75	96	150	552.0	0.1	-0.23	520.29	96	551.77
300	1417314	451768	MW102	16	48	61	63	75	150	150	552.0	0.1	-0.21	524.12	150	551.79
301	1413972	451748	999-240.1	--	--	--	--	95	170	170	552	1	--	--	170	--
302	1417133	451623	999-223	--	--	--	--	--	--	--	550.6	0.1	--	--	147	--
303	1417940	451616	MW96	13	17	53	68	75	135	142	556.9	0.1	-0.32	520.49	135	556.58
304	1417947	451614	MW97	13	17	53	71	75	85	142	557.0	0.1	-0.11	520.46	85	556.89
305	1416641	451558	ODOT3	7	18	24	44	80	91	--	544	0.1	--	--	91	--
306	1416651	451429	ODOT2	8	14	21	44	80	90	--	544	0.1	--	--	90	--
307	1412742	451078	999-243	--	--	--	--	--	--	--	587	1	--	--	163	--
308	1416658	451017	ODOT10	--	--	36	64	--	--	--	562	0.1	--	--	66	--
309	1416641	450852	ODOT1	--	--	36	55	--	--	--	556	0.1	--	--	71	--
310	1416633	450525	ODOT21	--	--	33	51	--	--	--	554	0.1	--	--	66	--
311	1413069	450517	999-242	--	--	--	--	105	185	185	550	1	--	--	185	--
312	1419993	450467	33682	--	--	44	65	89	141	141	650	1	--	--	141	--
313	1416555	450437	ODOT20	--	--	30	47	--	--	--	552	0.1	--	--	66	--
314	1417803	450268	999-224	--	--	--	--	--	118	118	545	1	--	--	118	--
315	1416994	449133	142762	--	--	36	46	87	141	--	550	1	--	--	141	--
316	1415994	449002	ODOT12	16	46	--	--	--	--	--	544	0.1	--	--	81	--
317	1415917	448915	ODOT11	5	41	--	--	85	91	--	543	0.1	--	--	91	--
318	1417113	446940	ODOT28	18	30	--	--	--	--	50	570	0.1	--	--	56	--
319	1414172	451686	H-9	--	--	--	--	--	--	--	555.30	0.01	2.76	--	168	558.06

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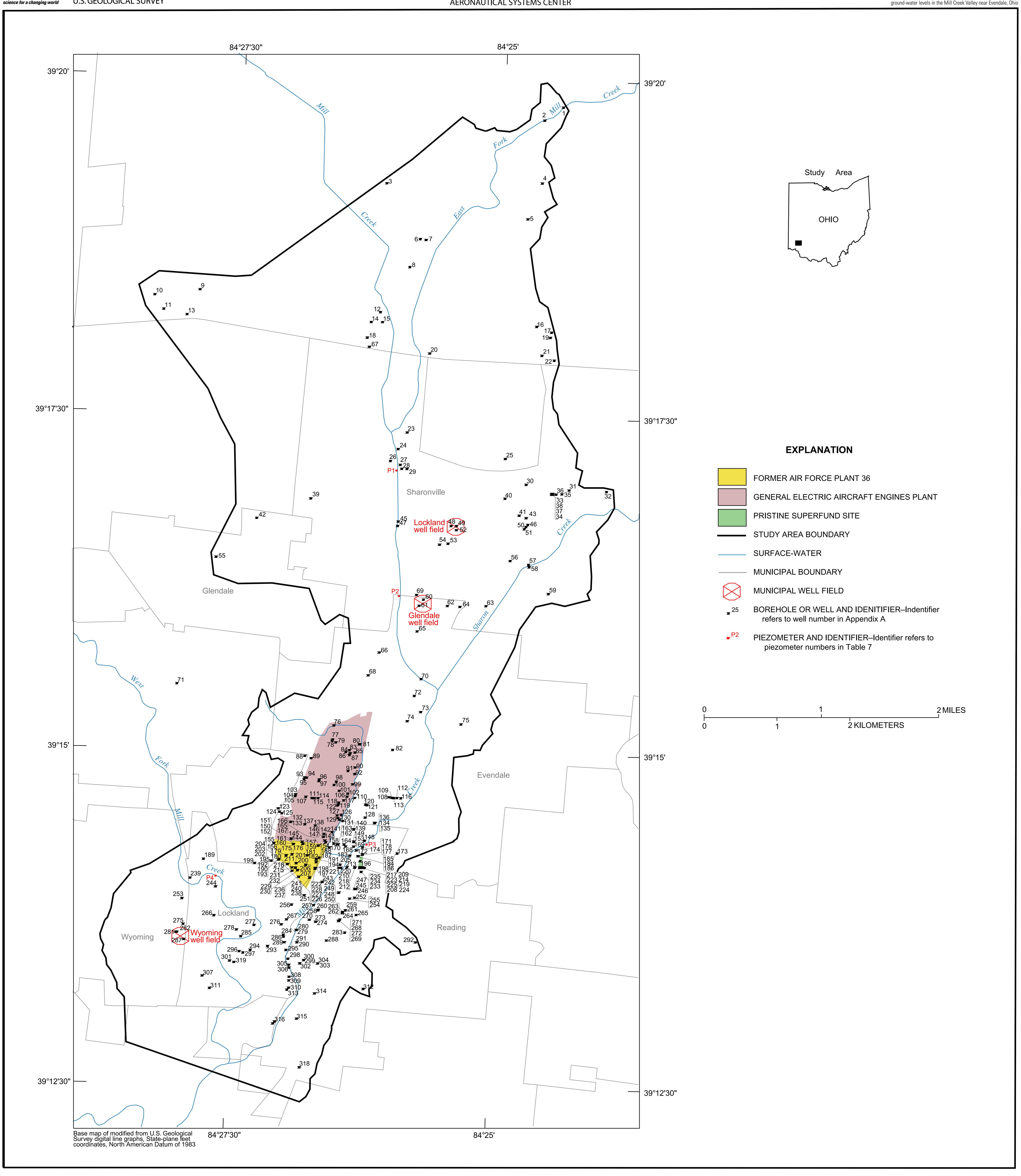
WATER-RESOURCES INVESTIGATIONS REPORT 02–4167
Wells, well fields, boreholes, and piezometers–PLATE 1
C.W. Schalk, T.L. Schumann, 2002. Hydrogeology, ground-water use, and ground-water levels in the Mill Creek Valley near Evendale, Ohio



MAP SHOWING LOCATION OF WELLS, WELL FIELDS, BOREHOLES, AND PIEZOMETERS, CENTRAL MILL CREEK VALLEY, OHIO

By
C.W. Schalk and T.L. Schumann

2002

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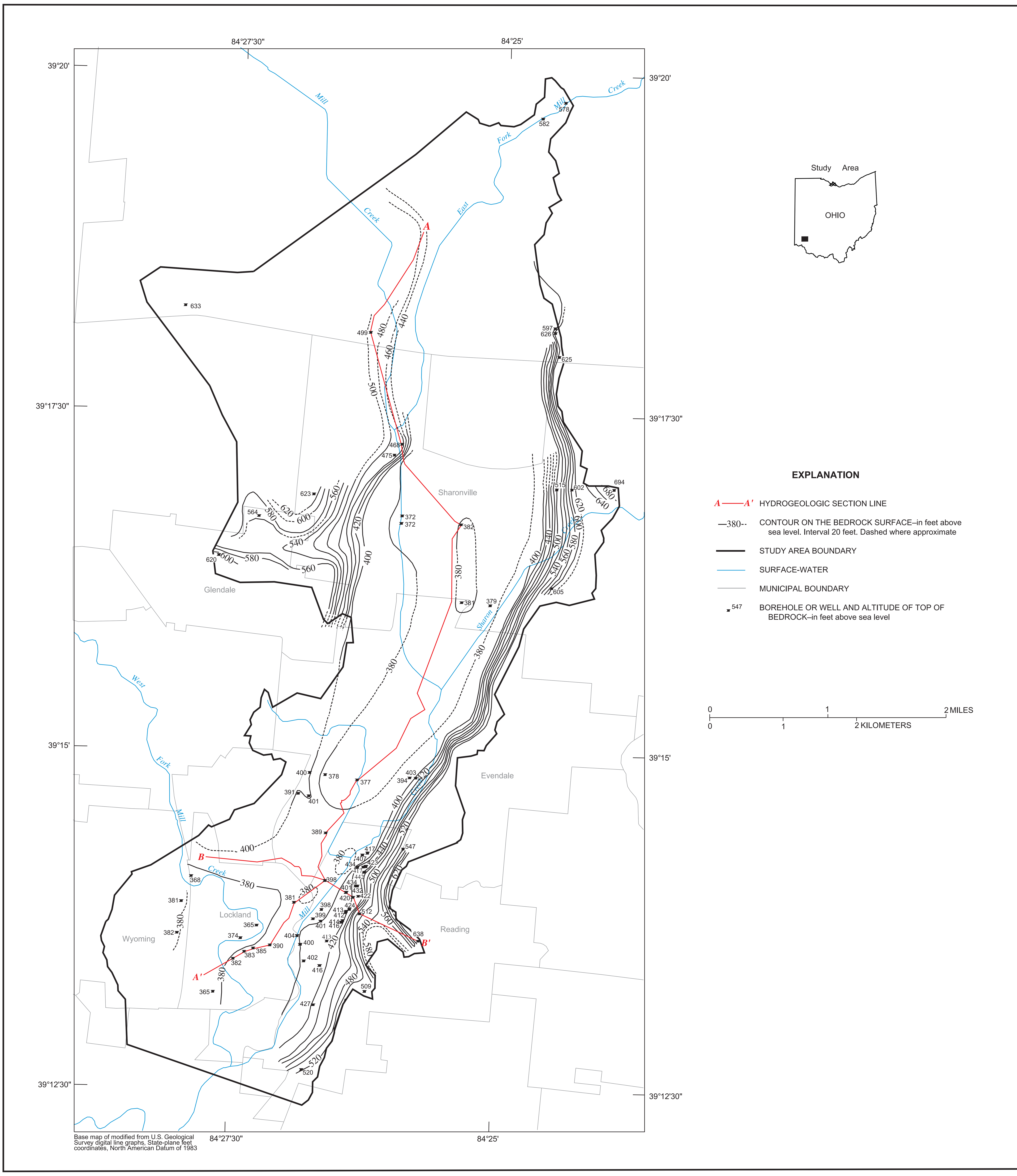
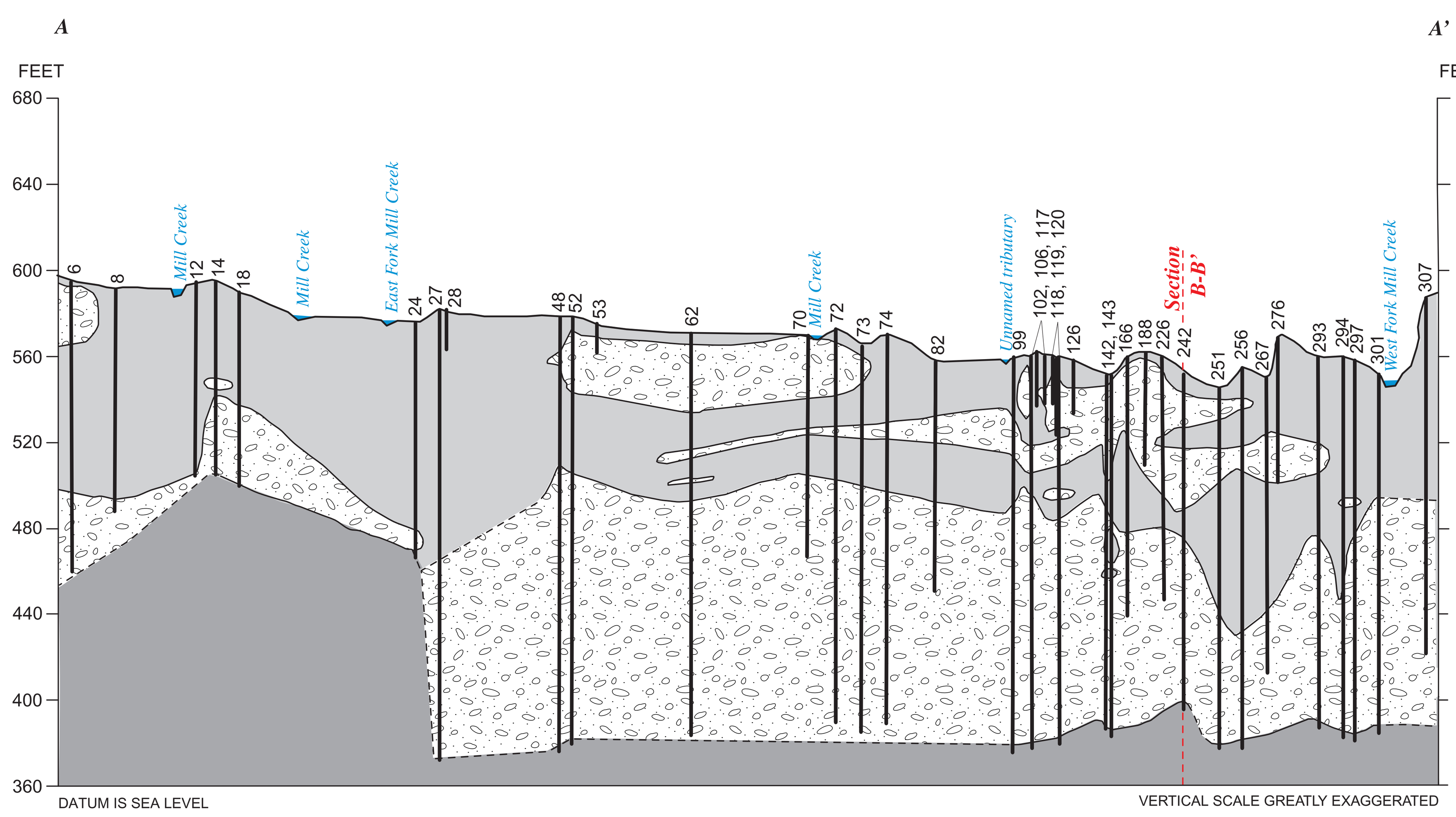
WATER-RESOURCES INVESTIGATIONS REPORT 02–4167
Altitude and configuration of top of bedrock–PLATE 2
C.W. Schalk, T.L. Schumann, 2002, Hydrogeology, ground-water use, and ground-water levels in the Mill Creek Valley near Evendale, Ohio

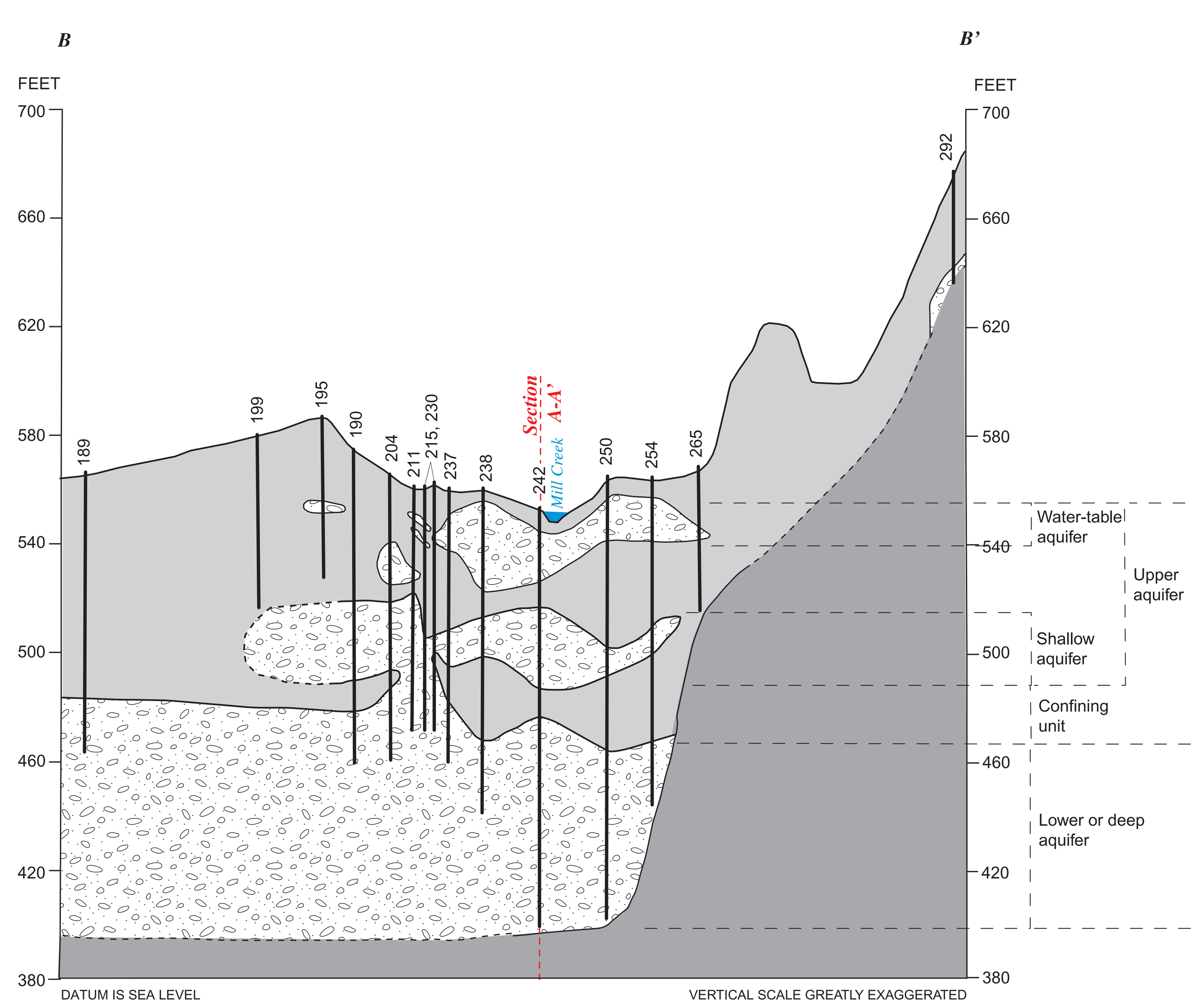


MAP SHOWING ALTITUDE AND CONFIGURATION OF THE TOP OF BEDROCK, CENTRAL MILL CREEK VALLEY, OHIO

By
C.W. Schalk and T.L. Schumann

2002





EXPLANATION

- FINE-GRAINED UNCONSOLIDATED DEPOSITS (silt and clay confining units)
- COARSE-GRAINED UNCONSOLIDATED DEPOSIT (sand and gravel aquifers)
- BEDROCK
- LAND SURFACE
- CONTACT BOUNDARY–approximately located. Dashed where inferred
- *A* — *A'* LINE OF SECTION–shown in plate 2
- 12 BOREHOLE OR WELL AND IDENTIFIER–bends in section correspond to well locations

NOTE: Horizontal scale is varied, owing to numerous bends in section

HYDROGEOLOGIC SECTIONS, CENTRAL MILL CREEK VALLEY, OHIO

By

C.W. Schalk and T.L. Schumann

2002

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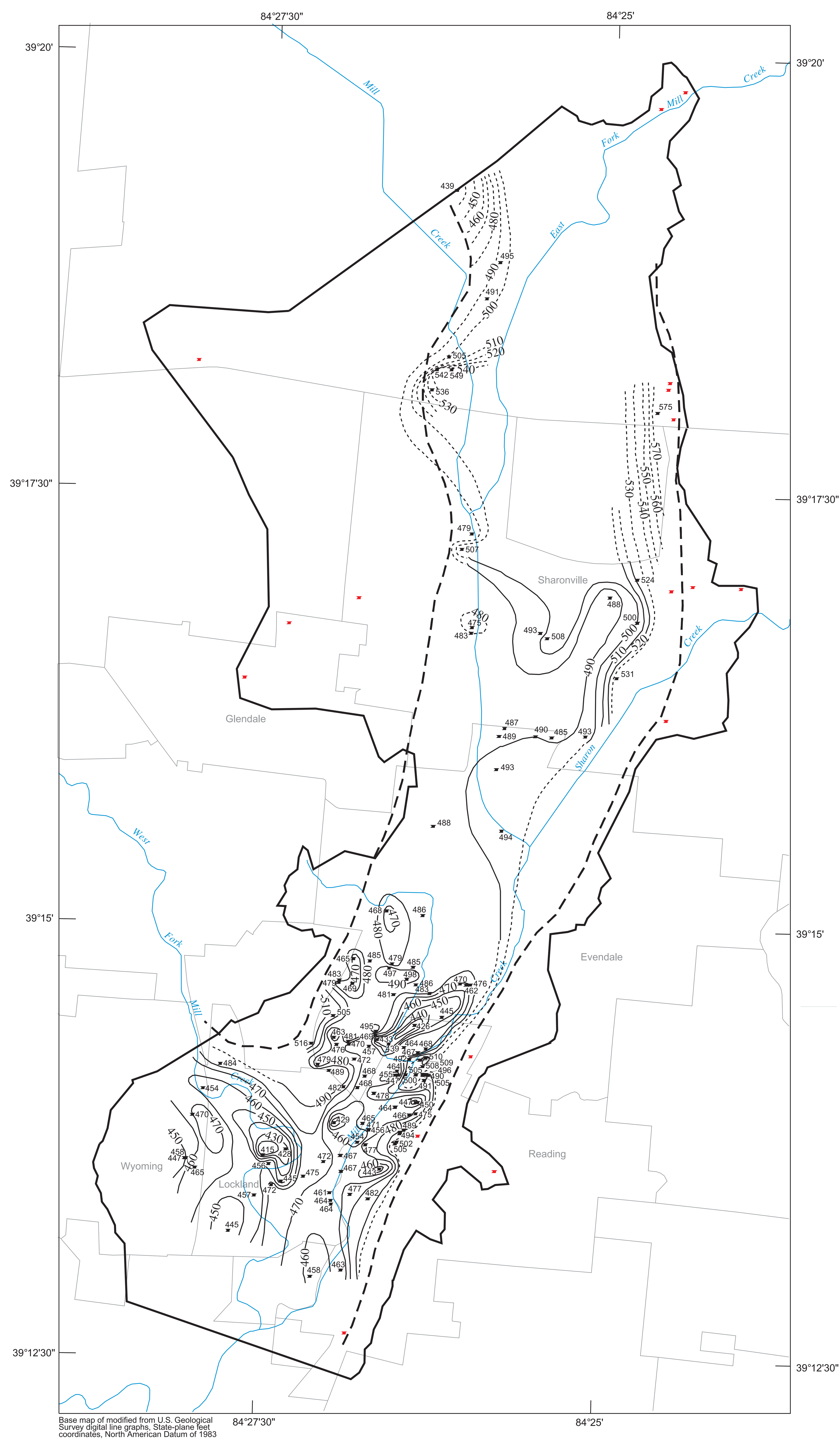
WATER-RESOURCES INVESTIGATIONS REPORT 02–4167
Altitude and configuration of the surface of lower aquifer–PLATE 4
C.W. Schalk, T.L. Schumann, 2002. Hydrogeology, ground-water use, and
ground-water levels in the Mill Creek Valley near Evendale, Ohio



EXPLANATION

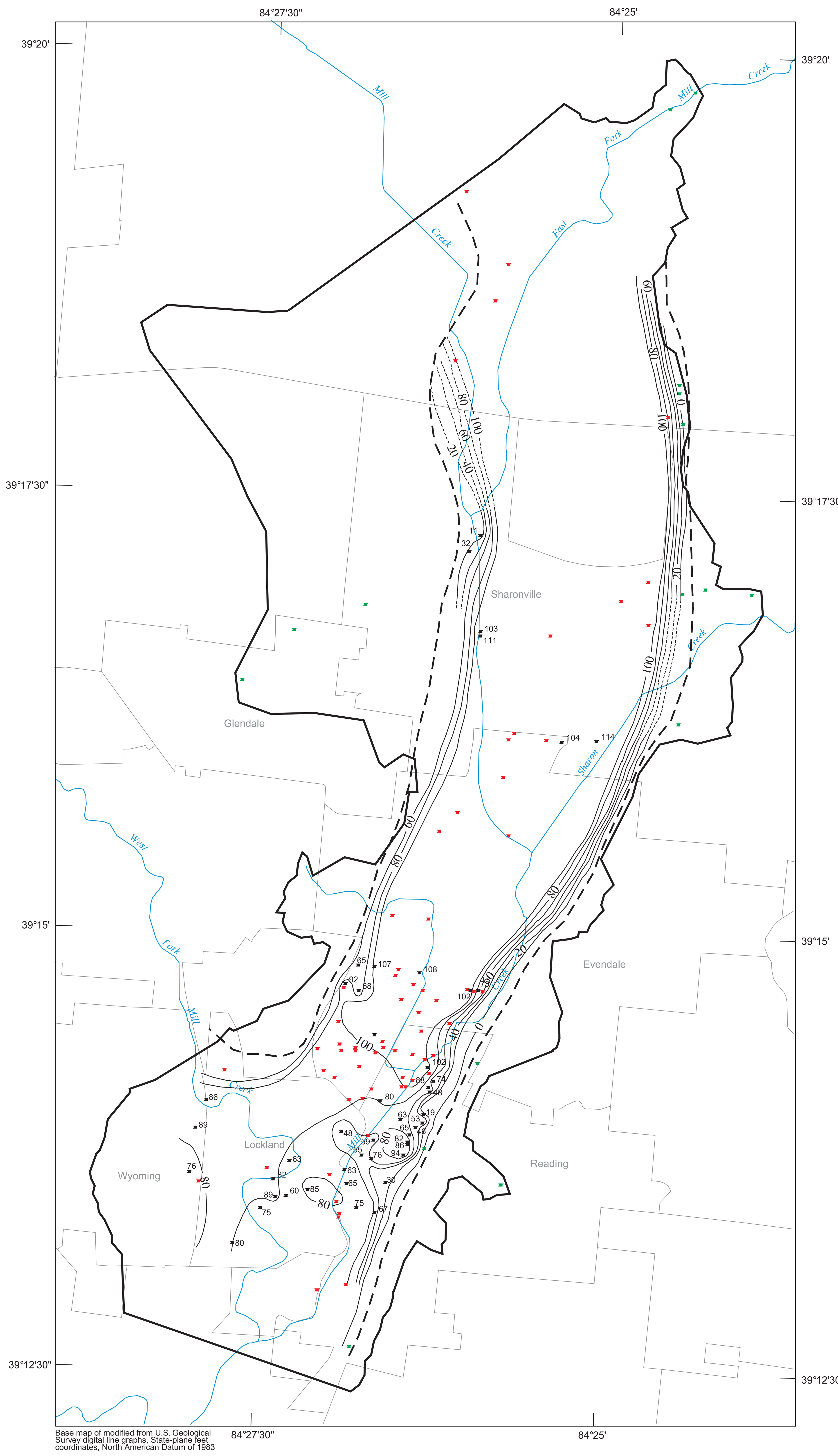
- APPROXIMATE EXTENT OF LOWER AQUIFER
- —470-- CONTOUR ON THE SURFACE OF THE LOWER AQUIFER–in feet above sea level. Interval 10 feet. Dashed where approximate
- STUDY AREA BOUNDARY
- SURFACE-WATER
- MUNICIPAL BOUNDARY
- 547 BOREHOLE OR WELL AND ALTITUDE OF TOP OF LOWER AQUIFER–in feet above sea level
- LOCATION WHERE LOWER AQUIFER IS ABSENT

0 1 2 MILES
0 1 2 KILOMETERS

MAP SHOWING ALTITUDE AND CONFIGURATION OF THE SURFACE OF THE LOWER AQUIFER, CENTRAL MILL CREEK VALLEY, OHIO

By
C.W. Schalk and T.L. Schumann

2002



EXPLANATION

- STUDY AREA BOUNDARY
- SURFACE-WATER
- MUNICIPAL BOUNDARY
- APPROXIMATE EXTENT OF LOWER AQUIFER
- 80 LINE OF EQUAL THICKNESS OF LOWER AQUIFER–in feet. Interval 20 feet. Dashed where approximate
- 103 BOREHOLE OR WELL AND THICKNESS OF LOWER AQUIFER–in feet
- BOREHOLE OR WELL AT WHICH LOWER AQUIFER IS PRESENT, THICKNESS UNKNOWN
- BOREHOLE OR WELL AT WHICH LOWER AQUIFER IS ABSENT

0 1 2 MILES
0 1 2 KILOMETERS

MAP SHOWING THICKNESS OF THE LOWER AQUIFER, CENTRAL MILL CREEK VALLEY, OHIO

By
C.W. Schalk and T.L. Schumann

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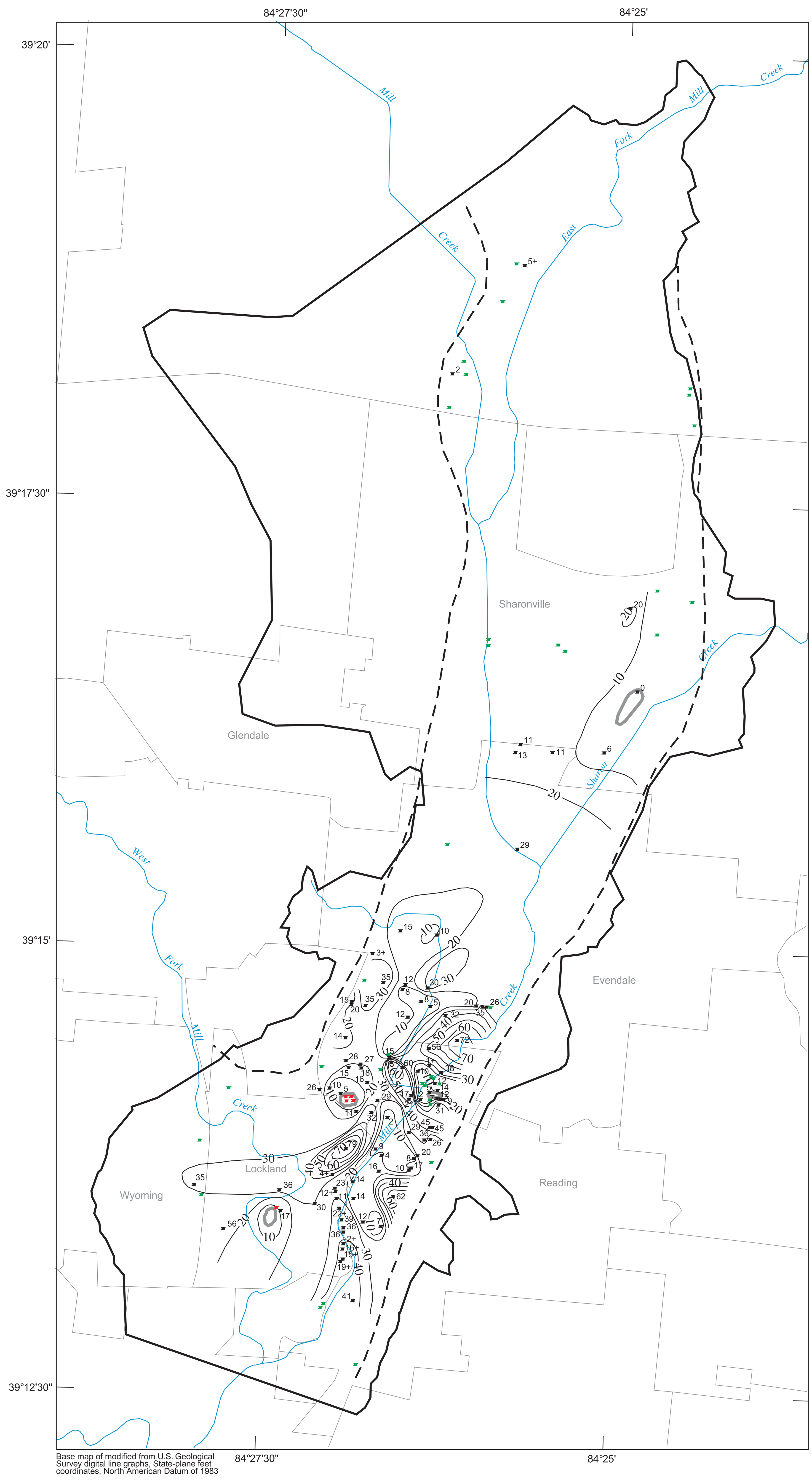
WATER-RESOURCES INVESTIGATIONS REPORT 02–4167
Thickness of confining unit–PLATE 6
C.W. Schalk, T.L. Schumann, 2002. Hydrogeology, ground-water use, and ground-water levels in the Mill Creek Valley near Evendale, Ohio



Base map of modified from U.S. Geological Survey digital line graphs, State-plane feet coordinates, North American Datum of 1983

EXPLANATION

- STUDY AREA BOUNDARY
- SURFACE-WATER
- MUNICIPAL BOUNDARY
- APPROXIMATE EXTENT OF LOWER AQUIFER
- AREA IN WHICH CONFINING UNIT IS ABSENT
- 40 LINE OF EQUAL THICKNESS OF LOWER CONFINING UNIT SEPARATING UPPER AND LOWER AQUIFERS–in feet. Interval 10 feet
- 56 LOCATION AND THICKNESS OF CONFINING UNIT–in feet. Plus symbol (+) indicates thickness is greater than indicated value
- LOCATION AT WHICH CONFINING UNIT IS ABSENT
- LOCATION AT WHICH UPPER OR LOWER AQUIFER IS ABSENT

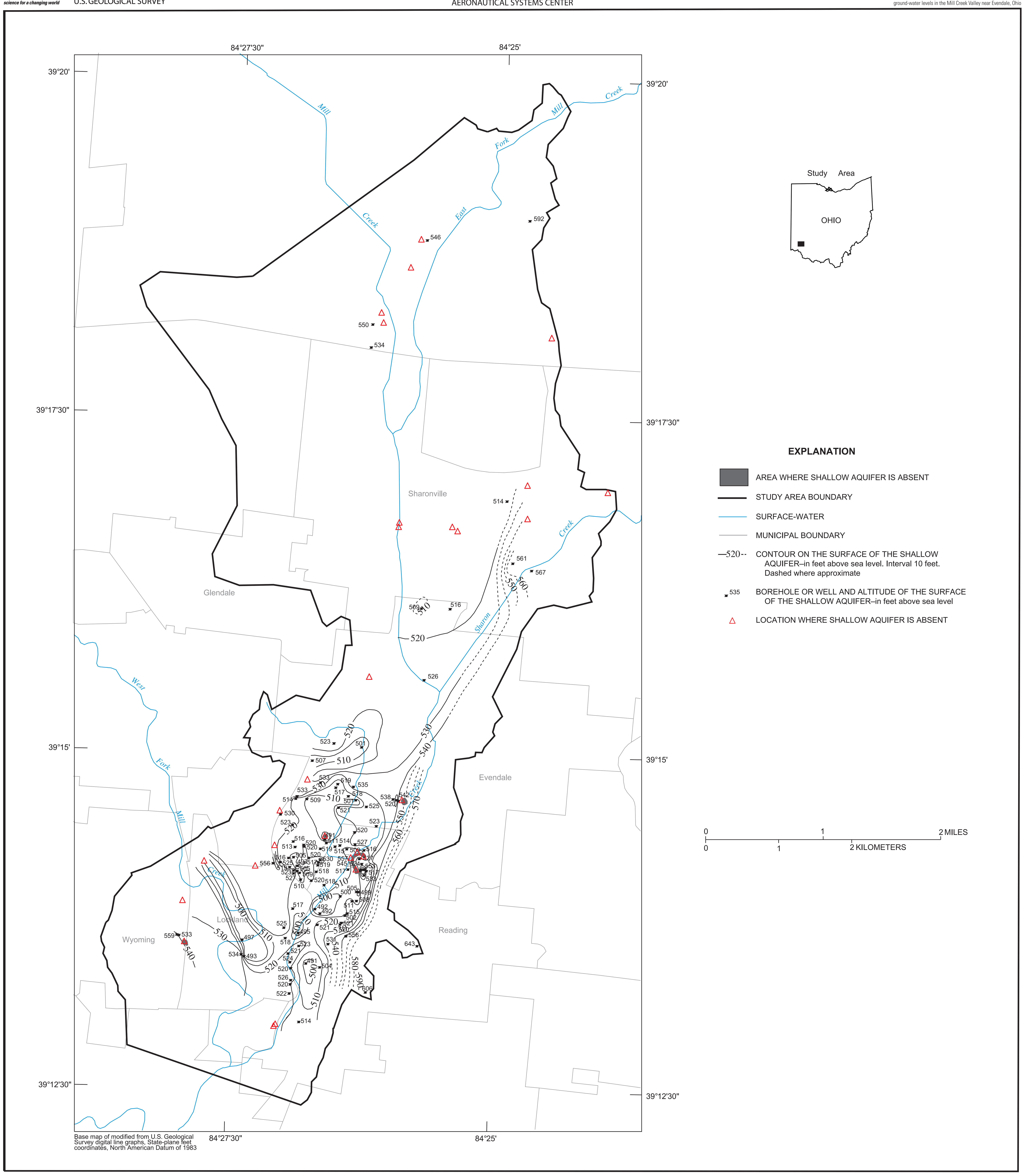
NOTE: For the purpose of this map, thickness of the confining unit is relevant only in those areas where the upper and lower aquifers are present

0 1 2 MILES
0 1 2 KILOMETERS

MAP SHOWING THICKNESS OF THE CONFINING UNIT BETWEEN SHALLOW AND LOWER AQUIFERS, CENTRAL MILL CREEK VALLEY, OHIO

By
C.W. Schalk and T.L. Schumann

2002



MAP SHOWING ALTITUDE AND CONFIGURATION OF THE SURFACE OF THE SHALLOW AQUIFER, CENTRAL MILL CREEK VALLEY, OHIO

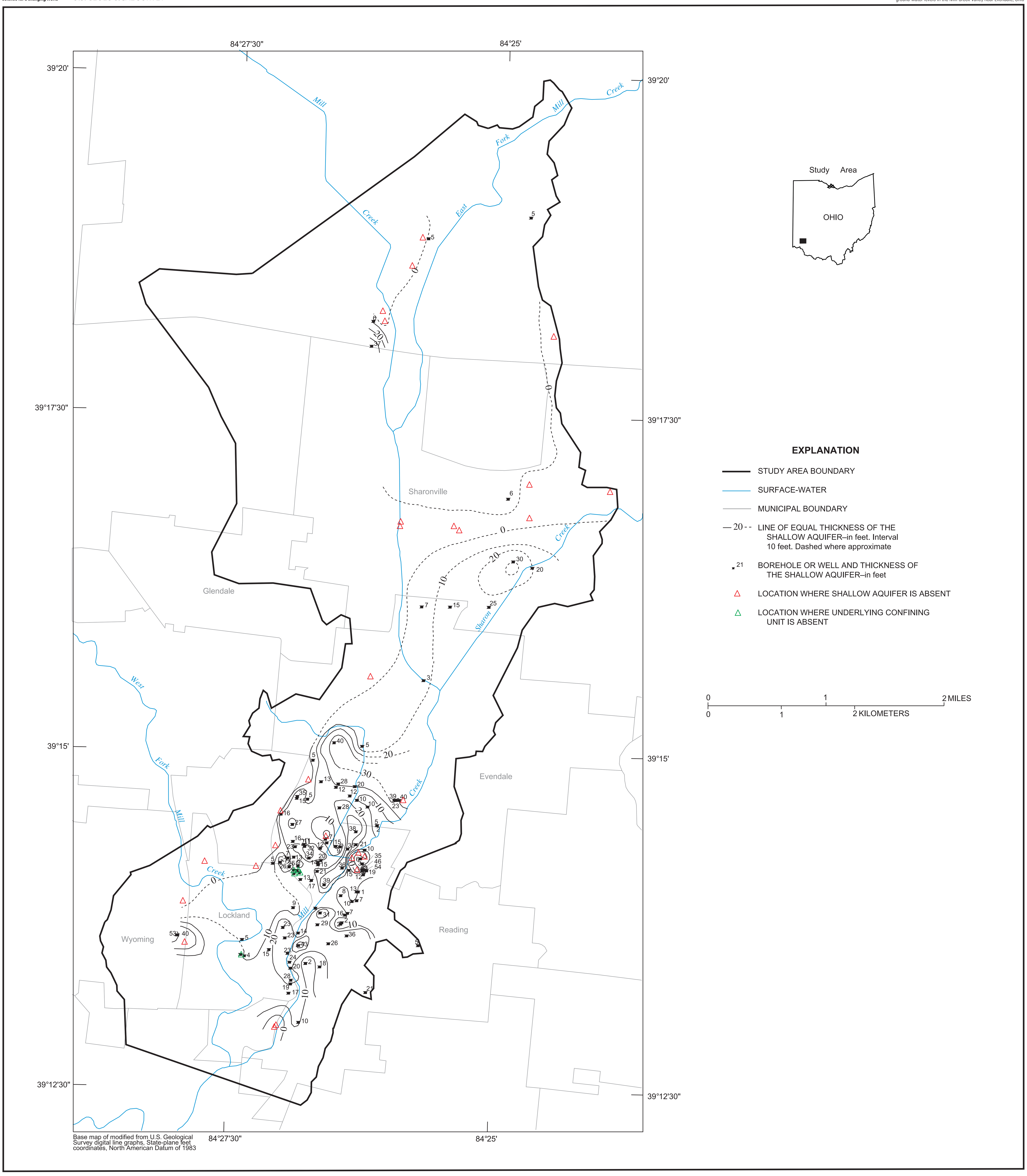
By
C.W. Schalk and T.L. Schumann

2002

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
UNITED STATES AIR FORCE
AERONAUTICAL SYSTEMS CENTER

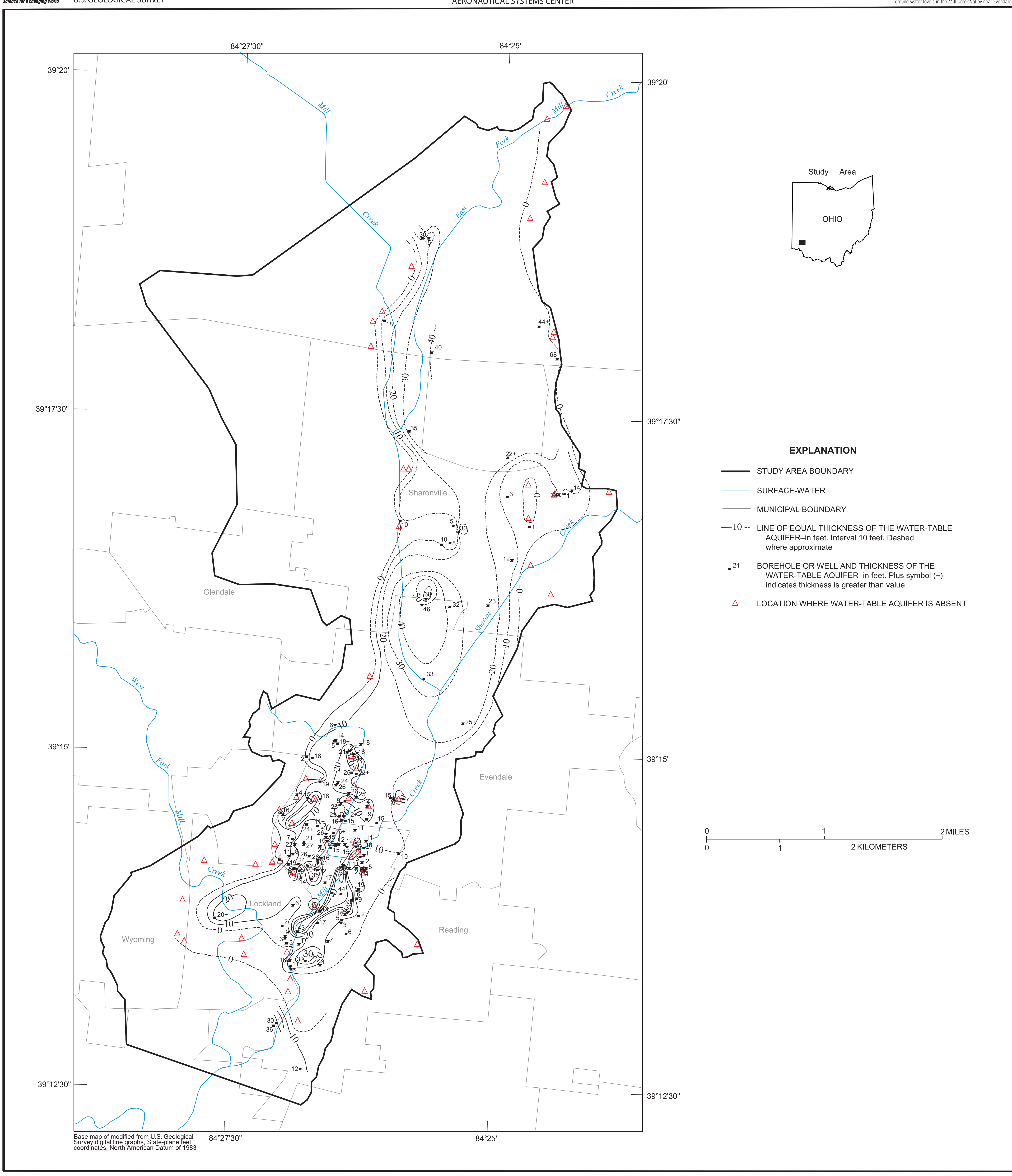
WATER-RESOURCES INVESTIGATIONS REPORT 02–4167
Thickness of shallow aquifer–PLATE 8
C.W. Schalk, T.L. Schumann, 2002. Hydrogeology, ground-water use, and ground-water levels in the Mill Creek Valley near Evendale, Ohio



MAP SHOWING THICKNESS OF THE SHALLOW AQUIFER, CENTRAL MILL CREEK VALLEY, OHIO

By
C.W. Schalk and T.L. Schumann

2002



MAP SHOWING THICKNESS OF THE WATER-TABLE AQUIFER, CENTRAL MILL CREEK VALLEY, OHIO

By
C.W. Schalk and T.L. Schumann

2002

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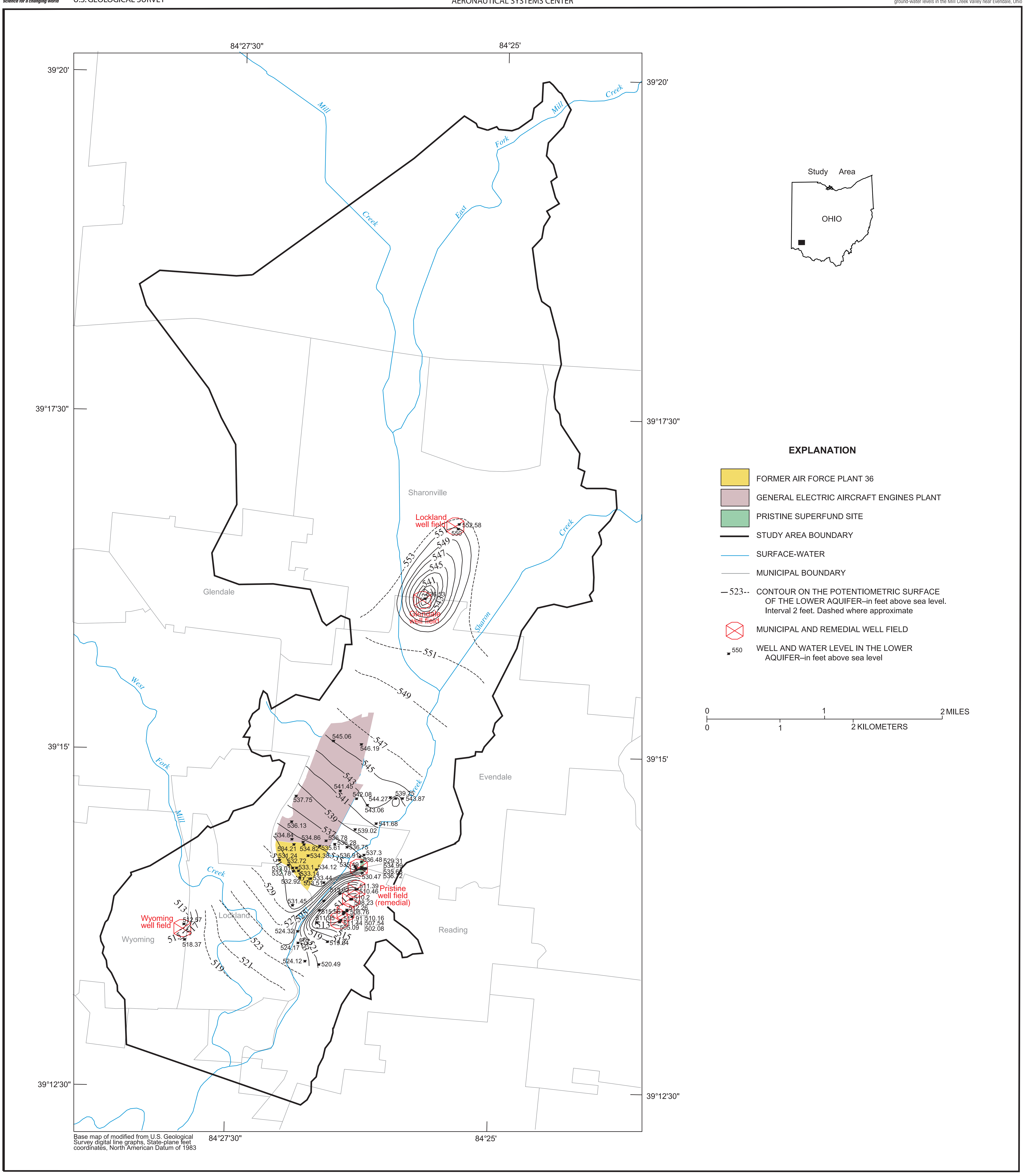
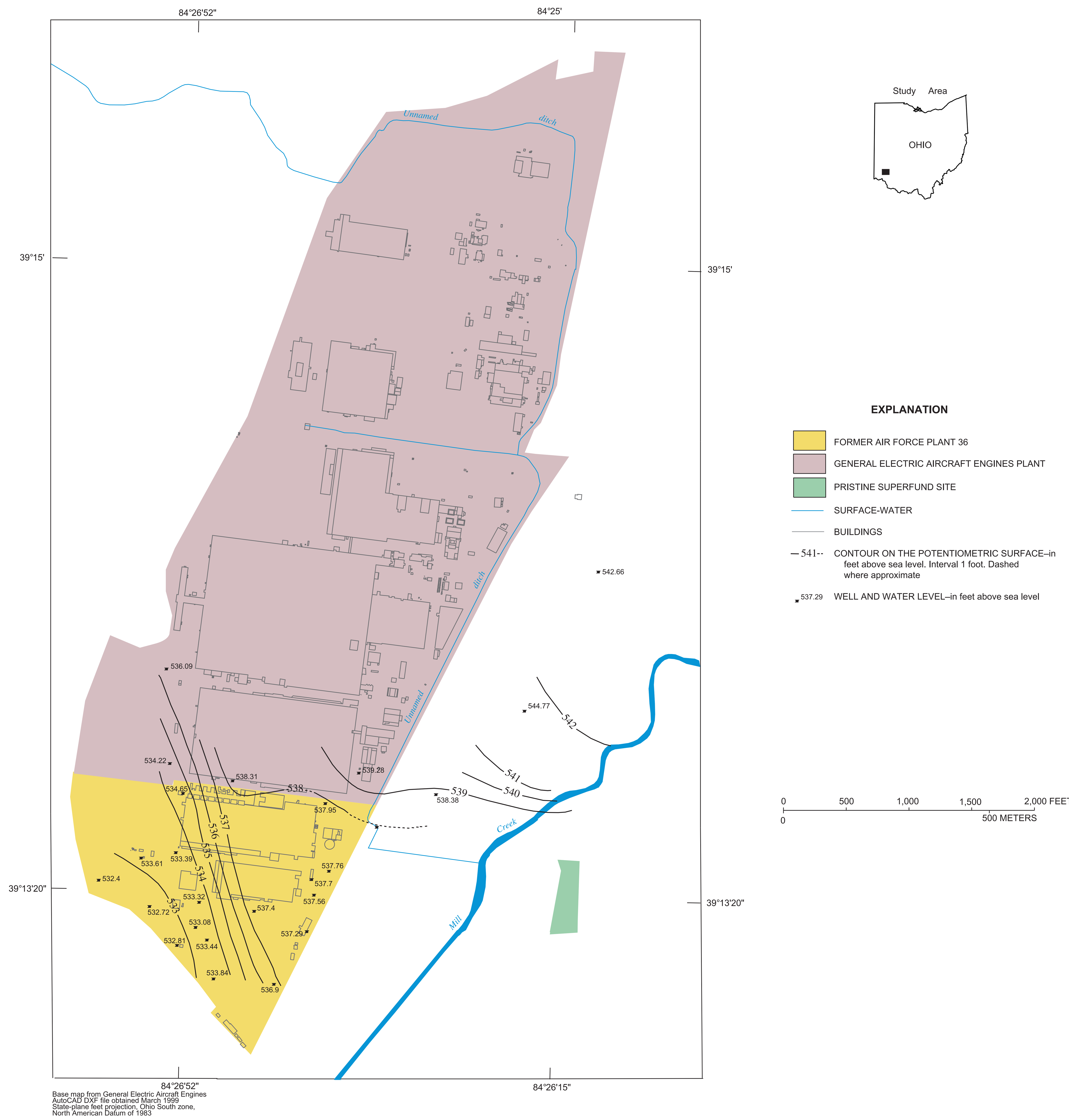
WATER-RESOURCES INVESTIGATIONS REPORT 02–4167
Water levels in lower aquifer–PLATE 10
C.W. Schalk, T.L. Schumann, 2002. Hydrogeology, ground-water use, and ground-water levels in the Mill Creek Valley near Evendale, Ohio



MAP SHOWING WATER LEVELS IN THE LOWER AQUIFER IN CENTRAL MILL CREEK VALLEY, OHIO, NOVEMBER 27-29, 2000

By
C.W. Schalk and T.L. Schumann

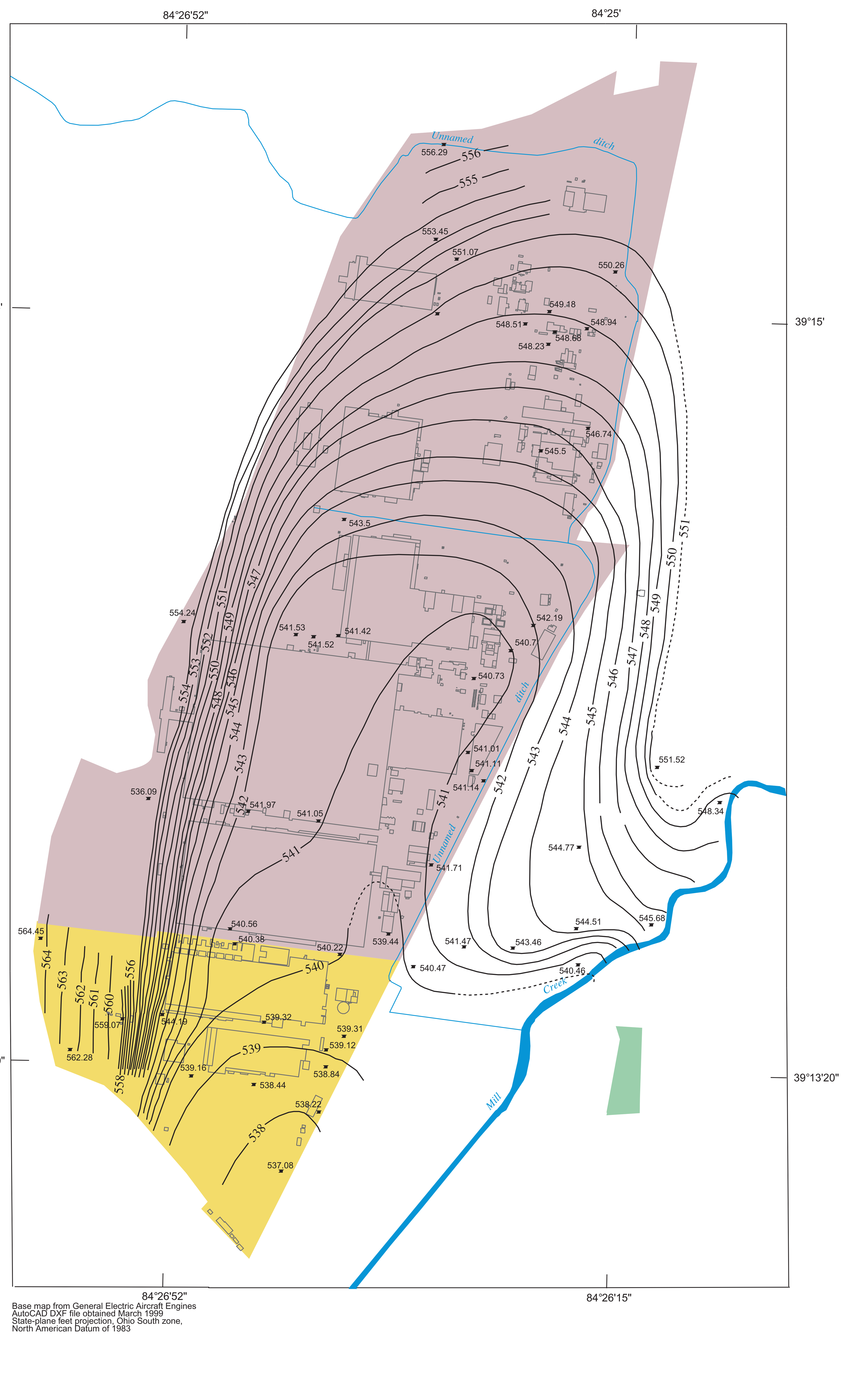
2002



MAP SHOWING WATER LEVELS IN THE SHALLOW AQUIFER AT GENERAL ELECTRIC, CENTRAL MILL CREEK VALLEY, OHIO, NOVEMBER 27-29, 2000

By
C.W. Schalk and T.L. Schumann

2002



Base map from General Electric Aircraft Engines
AutoCAD DXF file obtained March 1999
State-plane feet projection, Ohio South zone,
North American Datum of 1983

EXPLANATION

- FORMER AIR FORCE PLANT 36
- GENERAL ELECTRIC AIRCRAFT ENGINES PLANT
- PRISTINE SUPERFUND SITE
- SURFACE-WATER
- BUILDINGS
- 541-- CONTOUR ON THE POTENTIOMETRIC SURFACE–in feet above sea level. Interval 1 foot. Dashed where approximate
- 537.29 WELL AND WATER LEVEL–in feet above sea level

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

MAP SHOWING WATER LEVELS IN THE WATER-TABLE AQUIFER AT GENERAL ELECTRIC, CENTRAL MILL CREEK VALLEY, OHIO, NOVEMBER 27-29, 2000

By
C.W. Schalk and T.L. Schumann

2002

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Water-Resources Investigations Report 02–4167