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Geohydrology of Southeastern Pennsylvania

by Dennis J. Low, Daniel J. Hippe, and Dawna Yannacci

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CONVERSION FACTORS, ABBREVIATED WATER-QUALITY UNITS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
	Flow	
gallons per minute (gal/min)	0.06308	liters per second per meter
	Hydraulic conductivity	
feet per day (ft/d)	0.305	meters per day
	Transmissivity	
square feet per day (ft^2/d)	0.0929	square meters per day

Temperature

Temperature conversions for degrees Fahrenheit (°F) and degrees Celsius (°C) are given in the following equations:

$$°C=5/9\ (°F-32)$$

$$°F=1.8\ \text{temp}\ °C+32$$

Other Abbreviations

Abbreviated water-quality units used in this report:

- microsiemens per centimeter (µS/cm)
- milligrams per liter (mg/L)
- picoCuries per liter (pCi/L)

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

GEOHYDROLOGY OF SOUTHEASTERN PENNSYLVANIA

by Dennis J. Low, Daniel J. Hippe, and Dawna Yannacci

ABSTRACT

Rapid population growth in southeastern Pennsylvania has increased the demand for ground water. In an effort to address the increased ground-water needs, a ground-water investigation in a 5,200-square-mile area of southeastern Pennsylvania was initiated. Information on the geohydrologic system of the area and the water-bearing capabilities of 51 geohydrologic units in six physiographic provinces or sections (Coastal Plain, Piedmont Upland, Piedmont Lowland, Gettysburg-Newark Lowland, South Mountain, and Reading Prong) has been summarized. Also included are statistical summaries by geohydrologic unit for well construction and discharge data (according to water use), as well as inorganic and radiochemical ground-water-quality data.

Characteristics of the ground-water-flow system in the study area, as well as aquifer hydrologic properties, are related to geology, but can be modified by human development. Ground-water flow in the Coastal Plain Physiographic Province, is through intergranular or primary openings under either unconfined or confined aquifer conditions. Historically, ground-water flowed toward the Delaware and Schuylkill Rivers, but the original flow paths and water quality have been altered significantly by urbanization. In igneous and metamorphic rocks (Piedmont Upland, South Mountain, and Reading Prong), ground-water flows through a network of interconnected secondary openings (fractures, joints, cleavage planes). Ground water in the carbonate rocks (Piedmont Lowland) also flows through a network of secondary openings, but these openings have been enlarged by solution. In the Triassic sedimentary rocks (Gettysburg-Newark Lowland), thin tabular aquifers are separated by much thicker, strata-bound aquitards. The fractured Triassic bedrock forms a very complex, anisotropic, and heterogeneous aquifer with horizontal permeability much greater than vertical permeability.

In general, ground-water flow in southeastern Pennsylvania takes place within local flow systems that discharge within days or weeks to adjacent stream valleys or surface-water bodies. Intermediate (South Mountain) and regional (Gettysburg-Newark Lowland) scale systems, however, in which residence times have been measured in months or years discharge to major streams or rivers that are located in different physiographic provinces or sections or tens of miles distant.

Well depths, casing lengths, reported yields, and specific capacities can vary significantly by geohydrologic unit, use of well, and topographic setting. Wells drilled in the Weverton and Loudon Formations, undivided, and the Montalto Quartzite Member (South Mountain) have median well and casing lengths of 374 and 130 feet, respectively, significantly greater than in almost every other geohydrologic unit in the study area. Wells drilled in the Peach Bottom Slate and Cardiff Conglomerate, undivided (Piedmont Upland) are typically shallow, with a median well depth of 90 feet. Wells in the Marburg Schist (Piedmont Upland) have the lowest median casing length—5.5 feet. Wells in the Stonehenge Formation (Piedmont Lowland), the most productive unit in the study area, have a median reported yield of 200 gallons per minute and a median specific capacity of 27 gallons per minute per foot. The Cocalico Formation (Piedmont Lowland) is the least productive unit with a median reported well yield of 2.5 gallons per minute and a median specific capacity of 0.01 gallons per minute per foot. In general, high-demand wells are significantly deeper, use significantly more casing, and have significantly greater yields than domestic wells drilled in the same unit. Commonly, wells drilled in valleys will have greater reported yields and specific capacities than wells drilled in the same unit on slopes or hilltops.

Except where adversely affected by human activities, the quality of ground water in southeastern Pennsylvania is suitable for most purposes. Yet several water-quality criteria are exceeded in many wells throughout the area. Water from 51 percent of 2,075 wells sampled had a pH higher or lower than the range specified in the U.S. Environmental Protection Agency (USEPA) secondary maximum contaminant

level (SMCL). Of water samples analyzed, about 1 percent of 1,623 wells contained concentrations of chloride and 27 percent of 1,624 wells sampled contained concentrations of iron that exceeded the USEPA SMCL. Twenty-seven percent of 1,397 wells sampled contained water with manganese concentrations greater than the USEPA SMCL. Sulfate concentrations in the water of 3 percent of 1,699 wells sampled and total dissolved solids in the water from 10 percent of 1,590 wells sampled exceeded the USEPA SMCL. Concentrations of cadmium, chromium, cyanide, mercury, nickel, radium-226, selenium, and zinc in the water exceeded the USEPA maximum contaminant level (MCL) in less than 5 percent of the 183 to 620 wells sampled. Nine percent of 625 wells sampled contained water with lead concentrations that exceeded the USEPA MCL. Radon concentrations in the water of 92 percent of the 285 wells sampled exceeded the proposed USEPA MCL. Radium-228 in the water of 10 percent of the 240 wells sampled and nitrate in the water of 13 percent of 1,413 wells sampled exceeded the USEPA MCL. Gross-alpha activity in the water was measured only in the Chickies and Harpers Formations of the Piedmont Upland, with 23 percent of the 168 wells sampled exceeding the USEPA MCL.

INTRODUCTION

Rapid population growth has increased southeastern Pennsylvania's reliance on ground water as a source of water supply. To address the capacity of ground water to meet the increased demand, the U.S. Geological Survey (USGS) and the Pennsylvania Bureau of Topographic and Geologic Survey (PaGS), in 1987, began a cooperative investigation of ground water in southeastern Pennsylvania. Through the use of the two agencies' data bases, and reconnaissance work by Piper (1933), Hall (1934), Leggette (1936), Lohman (1938; 1939), regional work by Taylor (1984), Taylor and others (1982; 1983), and Taylor and Werkheiser (1984), and many county, quadrangle, and geologic formational studies, it was possible to evaluate the geohydrology and ground-water quality by geologic formation or geologic unit and physiographic province.

Purpose and Scope

This report provides a comprehensive guide to the geohydrology of four physiographic provinces in southeastern Pennsylvania, by geologic formation or geohydrologic unit. Almost all of the units discussed are shown on the Geologic Map of Pennsylvania (Berg and others, 1980); the exceptions are Cretaceous and Holocene age sediments in the Coastal Plain Physiographic Province. Here, these sediments are either buried by younger sediments or are too thin to support much ground-water development.

The report is based on published and unpublished studies and other available information, including the Ground Water Site Inventory (GWSI) data base of the USGS and the PaGS's Water Well Inventory (WWI) data base. Data analysis is based on more than 12,000 wells and on 5,830 chemical analyses of ground water made during 1900-92. This report describes the geohydrologic system and the water-bearing and water-transmitting properties, and the chemistry of water in the units, and presents statistical summaries of well depth, casing length, well yield, specific capacity, hydraulic conductivity, transmissivity, depth of water-bearing zones, and inorganic water-quality data. The report provides a description for many geohydrologic units and summarizes relevant geologic literature through 1996. The bibliography, although extensive, does not include all relevant references on the geology and hydrology of the study area.

Methods of Investigation and Analysis

Records of 11,021 wells from the GWSI data base, a nationwide ground-water data storage and retrieval system, were used to characterize the hydrology of the geohydrologic units. Records of 563 wells from the WWI data base supplemented data from GWSI for the Blue Ridge Physiographic Province at South Mountain. An additional 467 well records from the WWI data base were used to supplement the available information for several selected geohydrologic units in the Piedmont Lowland and Upland Sections of the Piedmont Physiographic Province.

Water Use

Wells were first grouped according to the geohydrologic unit (geologic unit) each well was open to and obtained the greatest amount of water from. These wells were then grouped into three main water-use categories: (1) all wells, (2) high-demand wells, and (3) domestic wells. All wells represented the largest data set and comprised high-demand and domestic wells and wells not easily categorized, such as those used for aquaculture, commercial, fire control, irrigation, recreation, and stock-watering purposes. High-demand wells were defined as wells in which the dominant water use was identified as air conditioning, water bottling, industrial, public supply, or institutional. High-demand wells usually represented the smallest data set. Domestic wells were defined as wells used to supply household needs (up to four families), turnpike gates, and similar low water-use installations.

Well Depth and Casing Length

Well depth and casing length can vary significantly by geohydrologic unit, water use, lithology, and topographic setting. Well drilling is usually terminated when a sufficient yield (dependent on the proposed use) is obtained. Dug and trenched wells and wells 50 ft or less in depth with no recorded method of construction were not used in the analysis of construction data. These wells generally are no longer constructed, and therefore, do not reflect current well-construction techniques.

Casing lengths are generally related to the resistance to weathering of the geohydrologic unit and the thickness of surficial deposits. Casing usually is installed through the weathered over-burden and any surficial deposits into competent bedrock. Because casing is generally set only a few feet into competent bedrock, casing length can be used as a rough approximation of regolith thickness. In Chester County, however, regulations since 1983 require a minimum of 20 ft of casing in newly constructed wells. Most wells, however, have casing lengths longer that 20 ft; therefore, no corrective measures were undertaken to evaluate or correct the impact of minimum casing lengths.

Depth to Water

Depth to water depends on many factors, including geology, topography, and proximity to pumped wells and quarries. Sloto and Schreffler (1994) report encountering wells that have penetrated more than one formation. If the upper formation had a different hydraulic head than the lower formation, the water level in the well would be a composite of heads from both formations. Under natural conditions, water levels generally are closest (shallowest) to land surface in valleys and greatest (deepest) below land surface on hilltops. Lloyd and Growitz (1977, p. 38) estimated that water levels in the area near Thomasville, York County, may have been lowered at least 100 ft by dewatering operations at a nearby quarry.

Depth to water also fluctuates in response to ground-water recharge or ground-water discharge. Precipitation is the principal source of water that enters the ground-water flow systems, although surface-water bodies such as large lakes can be major, local sources of ground-water recharge. Much of the recharge to ground water takes place from late fall to early spring, resulting in a rising water table. During the remainder of the year, rapid plant growth contributes to high evapotranspiration rates, creating soil-moisture deficits that greatly reduce the amount of recharge reaching ground-water systems, thereby lowering the water table.

In this report, if a well was flowing (artesian) and no estimate of static head was available, the depth to water was assumed to be zero. The standard datum of depth to water for wells in Pennsylvania is zero at land surface.

Well Yield

The majority of reported well yields are from short-term driller completion tests during which the driller bailed or blew water from the well. Although these methods are not as accurate as those conducted using high-capacity pumps, they provide a basis for estimating and comparing the yield capacity of individual geohydrologic units. If a well had more than one discharge record, each with a different reported yield, the record with the largest reported yield was retained for analysis. However, many USGS specific-capacity tests were conducted with low-yield submersible pumps that did not pump the well at a rate near its capacity. As these yields (pumping rates) were usually below the yields reported by drillers, the yields were excluded from the data analysis because such yields would tend to bias the data towards lower reported yields.

Reported yields for high-demand and other nondomestic wells provide a better estimate of the maximum sustainable yield of a geohydrologic unit than reported yields for domestic wells. Part of the difference is because nondomestic wells generally are completed at greater depths, and thus they penetrate more water-bearing zones. Nondomestic wells also have larger borehole diameters than domestic wells. Nondomestic wells commonly are drilled in valleys, which is a favorable topographic setting for better yields.

Specific Capacity

Specific capacity is a better measure of a geohydrologic unit's productivity than well yield. Specific capacity is calculated by dividing the pumping rate of a well by the drawdown. Specific capacity for a well pumped at a constant yield decreases with time. For example, the specific capacity of one high-demand well pumped 1 hour at a constant discharge was 4.3 (gal / min) / ft (gallons per minute per foot) of drawdown. After 2 hours the specific capacity was 2.6 (gal / min) / ft, a reduction of 40 percent. At another high-demand well, specific capacity was 0.44 (gal / min) / ft after pumping 1 hour at a constant discharge rate, and, after 24 hours, the specific capacity was 0.29 (gal / min) / ft, a reduction of 34 percent.

Specific capacities associated with a reported yield and a pumping duration of 1 hour or longer were retained for analysis. Specific-capacity tests 8 hours or longer in duration were analyzed separately. If there were two or more specific-capacity tests, the test with the greatest production volume (discharge multiplied by duration) was used in the analysis.

Storage Coefficient

The storage coefficient (S) is defined as the volume of water released from or taken into storage by an aquifer per unit surface area per unit change in head (Heath, 1983, p. 28). As seen in the equation below, the storage coefficient is a dimensionless unit.

$$S = \text{volume of water} / [(\text{unit area}) \times (\text{unit head change})] = ft^3 / [(ft^2) \times (ft)] = ft^3 / ft^3 \qquad (1)$$

The magnitude of the storage coefficient is dependent upon whether the aquifer is confined or unconfined. In confined aquifers, water released from storage comes from expansion of the water and from compression of the aquifer. Typically, the storage coefficient (or storativity) of confined aquifers ranges from about 0.00001 to 0.001. In unconfined aquifers, the primary source of water is from gravity drainage of the saturated rock or soil. Typically, the storage coefficient (or specific yield) of unconfined aquifers ranges from about 0.1 to 0.3.

The storativity and specific yield values used in this report to determine hydraulic conductivity and transmissivity are estimates. These estimates were derived from published data, most commonly from single and multiple-well aquifer tests.

Hydraulic Conductivity and Transmissivity

Hydraulic conductivity and transmissivity give an indication of the ability or capacity of an aquifer to transmit water. Hydraulic conductivity is defined as the volume of water that will move in a unit time under a unit hydraulic gradient through a unit area, at the prevailing temperature (Heath, 1983, p. 12). The transmissivity of an aquifer is equal to the hydraulic conductivity of the aquifer multiplied by the saturated thickness of the aquifer. For this report, the saturated thickness of an aquifer was the length of the well's borehole minus the depth to water.

Hydraulic conductivities and transmissivities were calculated from 1 hour or longer, single-well aquifer tests or specific capacity tests by use of a modified Theis formula (Theis and others, 1963). Because borehole storage can affect transmissivity, borehole storage was calculated utilizing a program written by S.S. Papadopulos (Reed, 1980, p. 96-97) based on Papadopulos and Cooper's (1967) solution for drawdown in a well of large diameter. It should be noted, however, the ideal hydrogeological conditions and theoretical assumptions used by Theis and others (1963) are rarely encountered at a well site. Some of the major assumptions used to determine hydraulic conductivity and transmissivity in this report are that (1) ground-water flow to the open interval of the well is radial, (2) vertical flow is excluded from consideration, (3) there is no well loss due to turbulence, and (4) the water-producing unit is of infinite areal extent.

Water-Bearing Zones and Borehole Flow

The distribution of 8,975 water-bearing zones in 4,413 wells up to 1,000-ft deep was analyzed. The density of the water-bearing zones was determined as follows:

$$N \text{ x } 50\text{-ft} / F, \qquad (2)$$

where N is equal to the number of reported water-bearing zones per 50 feet of hole depth, and F is equal to penetrated footage by full, 50-ft increments (if a well encountered one water-bearing zone at a depth of 45 ft and the well was completed at 49 ft, neither the water-bearing zone or the footage would be included in the calculation of water-bearing zone density). Water-bearing zones penetrated above the depth to water in a well's borehole were excluded. Water-bearing zones that were cased off but below the water level were included in the analysis.

Ninety-six borehole geophysical logs, from wells at least 200 ft in depth, were examined to determine the geothermal gradient and the maximum depth of ground-water flow. Vertical borehole flow was determined by reviewing geophysical logs including brine-trace and fluid-temperature logs. Depths to water-bearing zones were determined by examining fluid-temperature, caliper, and fluid-resistivity logs and driller logs.

Ground-Water Quality

A total of 8,845 field measurements of specific conductance, hardness, and pH from 3,716 wells in the GWSI data base and 5,830 water-quality analyses from 1,784 wells in the quality of water (QW) data base of the USGS were analyzed to characterize ground-water quality. Principal analytical components from the QW data base included alkalinity, total and dissolved cations, anions, trace metals, nitrogen species, and silica. Information on radionuclides were included where possible. Components from the QW database with nondetect or less than (<) values were assigned the reporting limit value.

Statistical Methods of Analysis

Nonparametric statistical techniques were used to determine whether statistically significant differences in well depth, casing length, yield, specific capacity, and in field-measured pH, specific conductance, and hardness (if the sample population contained at least 10 observations) could be identified between different geohydrologic units and within each geohydrologic unit. The data also were analyzed to determine whether statistically significant differences existed by topographic setting, lithology, and spatially (by county) within each geohydrologic unit.

Nonparametric tests were used because the data are not normally distributed. Data were ranked in ascending order. The ranked values were used to compute the test statistic; an average rank was assigned to equal values. The Kruskal-Wallis test was used to test for statistically significant differences among the groups' median values at the 95-percent level of confidence. The null hypothesis tested by Kruskal-Wallis is that the medians of the different groups (population) are identical. If the null hypothesis is rejected, the alternative hypothesis is that at least one median differs from the others. The Kruskal-Wallis test, however, does not indicate which group is different.

Multiple comparison tests (MCT) were performed if the null hypothesis of the Kruskal-Wallis test was rejected (r greater than or equal to 0.05) as MCT's compare all possible pairs of group medians. Because sample size was generally unequal, Tukey's studentized range test, honestly significant difference procedure, Statistical Analysis System's[1] (SAS) version 6.03 for personal computers, was the MCT used on the rank-transformed data to make multiple comparisons and test for significant differences at the 95-percent confidence level.

Populations with two to four samples are presented in tables showing minimum, maximum, and median. Populations of five to nine samples are presented in tables showing quartiles, minimum, and maximum. Populations of 10 or more samples are presented in tables showing quartiles, 10th and 90th percentiles, minimum, and maximum. In illustrations, populations of nine samples or less are shown as individual observations. Populations with 10 or more samples are shown with quartiles and 10th and 90th percentiles.

Description of Study Area

The area of investigation (fig. 1) encompasses all of Adams, Chester, Delaware, Lancaster, Montgomery, Philadelphia, and York Counties, and parts of Berks, Bucks, Cumberland, Dauphin, Franklin, Lebanon, Lehigh, and Northampton Counties. All segments of the Coastal Plain, Piedmont, Blue Ridge, and New England Physiographic Provinces in Pennsylvania are included. Topography ranges from flat terraces and floodplains along the Susquehanna and Delaware Rivers and major tributaries to steep, wooded slopes of mountain ridges. Altitudes range from near sea level along the Coastal Plain to 2,080 ft at South Mountain in the Blue Ridge Physiographic Province.

The Coastal Plain Physiographic Province is nearly flat with unconsolidated sediments of Cretaceous to Recent age overlying metamorphic and igneous rocks of Precambrian and early Paleozoic age. The Piedmont Physiographic Province includes three distinct sections or physiographic settings: (1) Piedmont Upland Section, (2) Piedmont Lowland Section, and (3) Gettysburg-Newark Lowland Section. The Piedmont Upland is characterized by rolling hills and valleys underlain by structually deformed igneous and metamorphic rocks of Precambrian and early Paleozoic age. The Piedmont Lowland generally has low to moderate relief and is underlain by folded and faulted sedimentary and metasedimentary rocks of early Paleozoic age. The Gettysburg-Newark Lowland has low to moderate relief and is underlain by monoclinally dipping Triassic and Jurassic age sedimentary rocks and diabase sills and dikes. The Blue Ridge Physiographic Province in Pennsylvania is represented by the South Mountain Section. It is characterized by steep ridges and deep narrow valleys underlain by folded igneous and metamorphic rocks of Precambrian age and graywackes and quartzites of Cambrian age. The New England Physiographic Province in Pennsylvania is known as the Reading Prong Section. This physiographic section has high rolling hills underlain by thrust faulted igneous and metasedimentary rocks of Precambrian age and by quartzites of Cambrian age.

Most of the study area is within the Susquehanna or Delaware River Basins; the western and southwestern flanks of South Mountain, the very southern part of the Gettysburg-Newark Lowland, and the southwestern corner of the Piedmont Upland are in the Potomac River Basin. Also, a small segment of the Piedmont Upland near the Pennsylvania-Maryland-Delaware borders drains directly into the Chesapeake Bay. The major tributaries to the Susquehanna River draining the report area include the Yellow Breeches, Conewago, and Conestoga Creeks. The major tributaries to the Delaware River draining the report area include the Schuylkill and Lehigh Rivers.

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[1] The use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

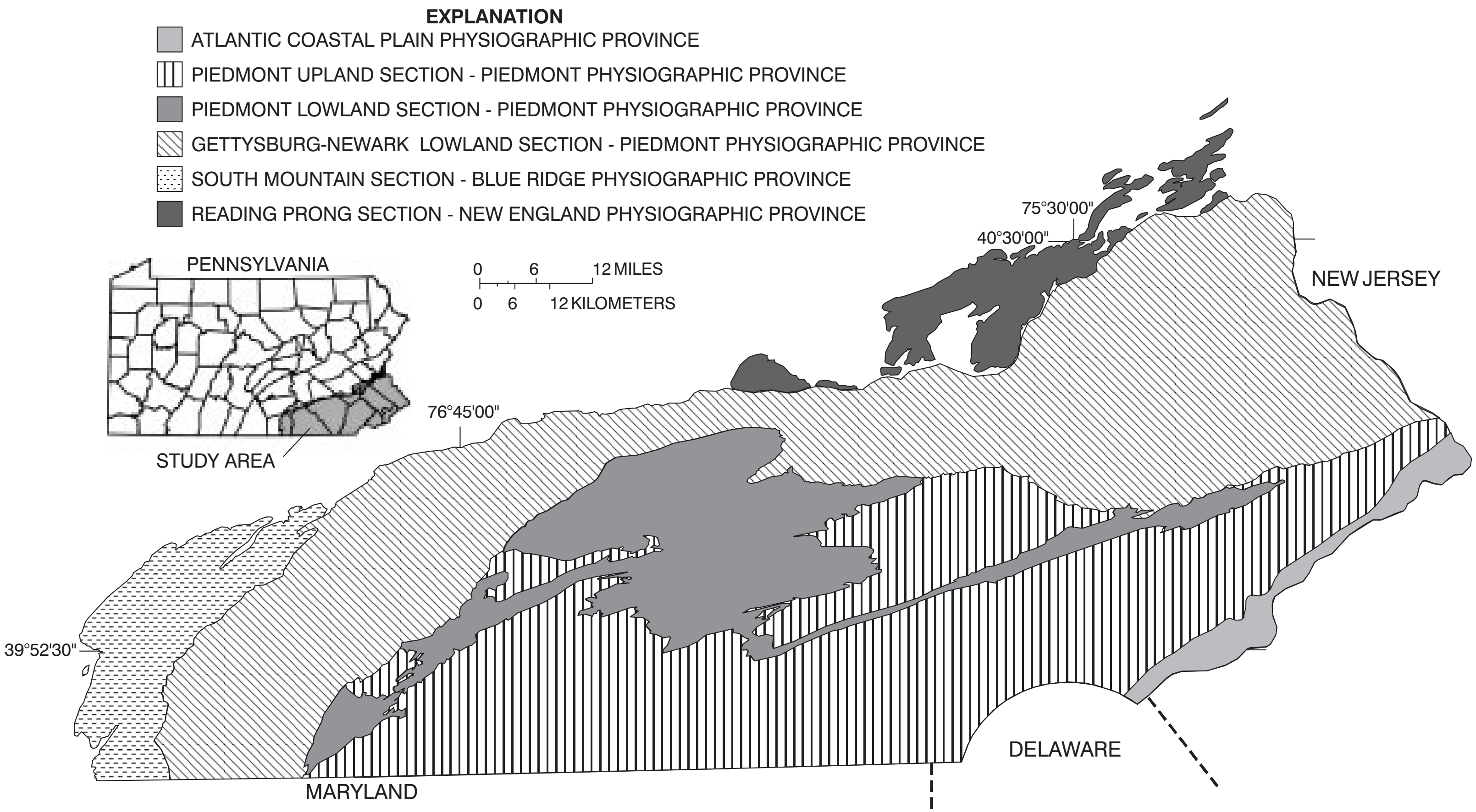


Figure 1. Location of study area, physiographic provinces, and sections.

Population density is greatest east of the Schuylkill River in the Coastal Plain and lowest west of the Susquehanna River near South Mountain. Major population centers in the eastern third of the study area include Philadelphia, Norristown, Pottstown, Chester, Drexel Hill, and Springfield; in the central third, major population centers include Lancaster, Millersville, New Holland, and Middletown; in the western third, major population centers include York, Hanover, and Gettysburg.

GEOHYDROLOGY OF THE COASTAL PLAIN PHYSIOGRAPHIC PROVINCE

Location and Geographic Setting

In Pennsylvania, the Coastal Plain Physiographic Province (figs. 1 and 2), as described by Fenneman (1938), is in the southeastern part of the Commonwealth. This province covers about 95 mi^2 and is adjacent to the lower Delaware River between Morrisville, Pa., and the Delaware State line. It is bounded on the south and east by the Delaware River and on the north by the Fall Line, which marks the transition from the rolling hills of the Piedmont Upland to the flat lowlands of the Coastal Plain (Berg and others, 1980) (fig. 2). Altitudes range from near sea level along the river to a maximum of 100 ft above sea level at the Fall Line.

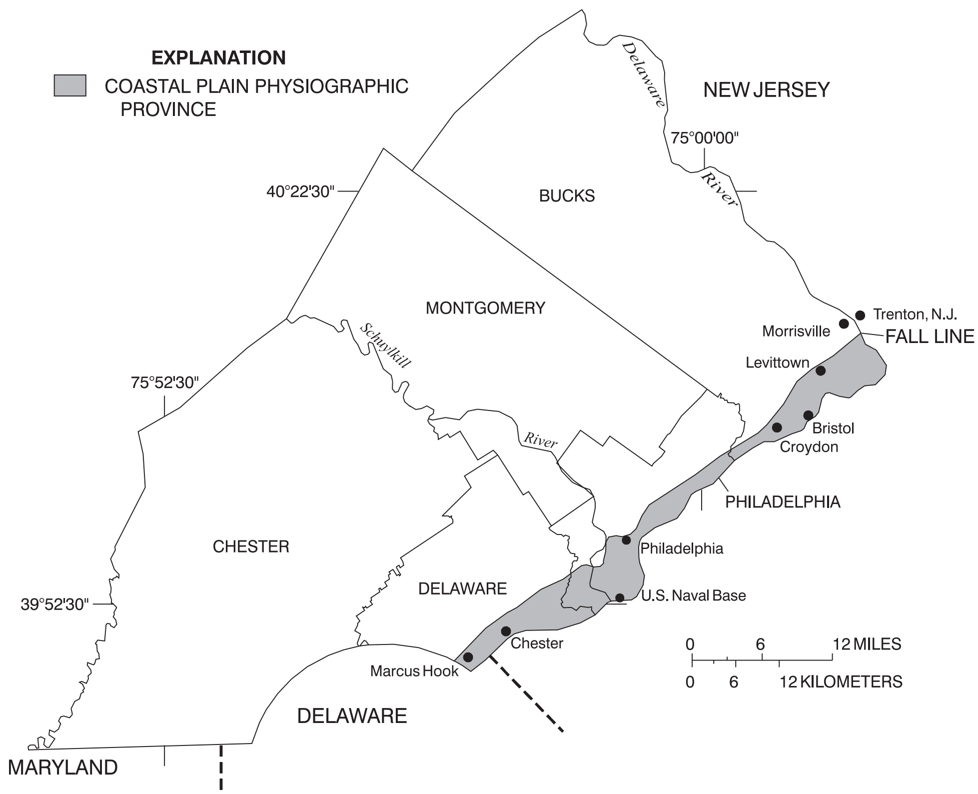


Figure 2. Coastal Plain Physiographic Province, major streams, counties, and major population centers.

Major population centers within the Coastal Plain of Pennsylvania include Philadelphia, Levittown, Bristol, Morrisville, Croydon, Chester, and Marcus Hook. Numerous smaller communities are present outside these larger cities throughout the length of the Coastal Plain (fig. 2) (Berg and others, 1980).

The climate in the Coastal Plain area is humid continental; precipitation averages about 45 in. per year. Summer and winter mean temperatures are 25 and -1°C, respectively (Pennsylvania Department of Environmental Resources, 1983b, p. 13). Prevailing winds are westerly during the winter and southerly during the summer. The dominant land use is urban; agricultural and park land use is minor.

Water-Well Density

The records of 482 wells completed in the Coastal Plain were analyzed (fig. 3). Because the study area covers about 95 mi^2, the well density is 5.1 wells per square mile. Of the 482 wells analyzed, 112 were in Bucks County (3.0 wells per square mile), 21 were in Delaware County (1.0 wells per square mile), and 349 were in Philadelphia County (8.5 wells per square mile). Most wells in Bucks and Philadelphia Counties are evenly distributed along the Delaware River. In Delaware County, however, the wells are concentrated near the Philadelphia County Line.

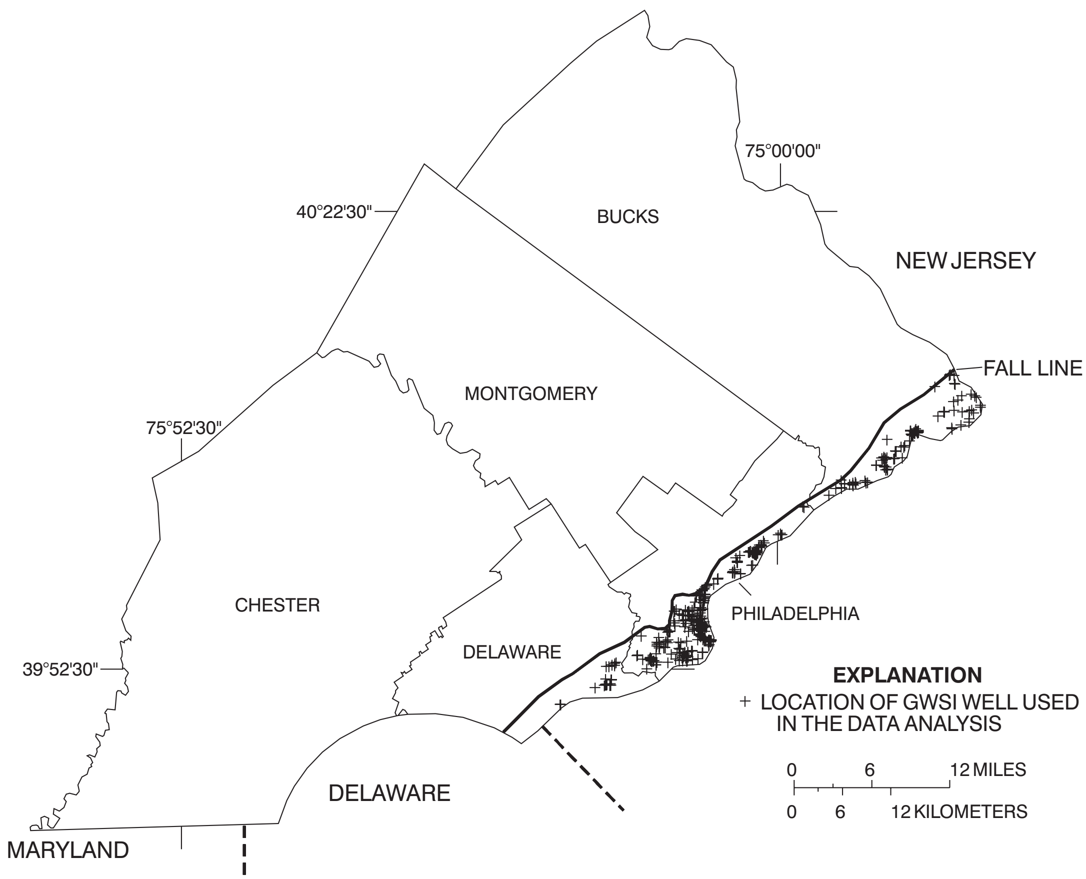


Figure 3. Location of wells in the Coastal Plain Physiographic Province.

Previous Work

One of the earliest workers in Pennsylvania's Coastal Plain was Bascom (1904), who summarized the water resources of the Philadelphia district, including parts of Pennsylvania, New Jersey, and Delaware. Her report includes a section on deep and artesian wells and some information on ground-water quality. She also described the geology of the Coastal Plain and the adjacent Piedmont Physiographic Province. The next major investigator of the hydrogeology of Pennsylvania's Coastal Plain was Hall (1934), who collected most of his well data in 1925 and 1927. Hall described the ground water by formation, water use, and county; he also provided the results of two chemical analyses. Graham and others (1951) and Greenman (1955) described the hydrogeology of Bucks County, including parts of the Coastal Plain and list the results of 31 chemical analyses of water samples from wells completed in the unconsolidated deposits. Graham and Kammerer (1952) discuss the ground water and water quality at the U.S. Naval Base in Philadelphia, Pa. (fig. 2). Barksdale and others (1958) evaluated the ground-water resources of the Philadelphia Tri-State District, which also includes parts of Delaware and New Jersey.

Greenman and others (1961) described the ground-water resources and water quality of the Coastal Plain and its underlying crystalline rocks in Philadelphia and Bucks Counties and documented the effects of human activities on water quality. The report contains records of 679 wells and lists 752 chemical analyses of water samples from some of those wells. Interpretation of drillers' logs of wells, borings, and well-cutting samples from 301 sites in Philadelphia and Bucks Counties and 11 from New Jersey also are included. Paulachok and others (1984) present records of 828 wells and three drainage sumps, and 1,467 chemical analyses of water samples from 205 sites; an index of 51 geophysical logs also is included. Paulachok and Wood (1984) constructed a water-table map of Philadelphia, Pa. Sloto (1988) simulated ground-water flow in the lower sand unit of the Potomac-Raritan-Magothy aquifer system in Philadelphia, Pa., and parts of New Jersey. Paulachok (1991) also evaluated the occurrence, availability, and quality of ground water in Philadelphia, Pa.

Although the study area of this report is confined to the Coastal Plain of Pennsylvania, important and related work in the Coastal Plain of New Jersey and (or) surrounding areas also should be mentioned. Those investigators who confined their studies to the areas or counties immediately adjacent to the Pennsylvania state line include Vecchioli and Palmer (1962), Rush (1962; 1968), Hardt and Hilton (1969), and Farlekas and others (1976). Zapecza (1984) provides information on the framework of the Coastal Plain for all of New Jersey. Langmuir (1969a; 1969b) discussed the occurrence of iron in the ground water of Camden County, N.J. Ervin and others (1991) provided information on the water quality of the Potomac-Raritan-Magothy aquifer system in the four counties immediately south of the Delaware River. Luzier (1980) modeled the Potomac-Raritan-Magothy aquifer system in the Coastal Plain of New Jersey. Martin (1998) also developed a computer model that simulates the ground-water flow in the Coastal Plain of New Jersey. Investigators of the Coastal Plain on a broader scale include Parker and others (1964), who studied the water resources of the Delaware River Basin, Back (1966), who studied the hydrochemical facies and ground-water flow in the northern part of the Atlantic Coastal Plain, and Meisler (1986), who studied the aquifer-system of the northern Atlantic Coastal Plain.

Geohydrologic Setting

The Coastal Plain rests on a bedrock assemblage of metamorphic and igneous rocks whose buried and weathered surface is marked by a residual clay. The crystalline rocks and residual clay are overlain by unconsolidated Cretaceous through Quaternary sediments. The poorly exposed Cretaceous and Tertiary sediments (Berg and others, 1980) consist of a sequence of interlayered, generally fluvial sands, clays, and gravels ranging in thickness from zero feet near the Fall Line to over 200 ft near the Delaware River (Greenman and others, 1961). Quaternary sediments, which overlie most Cretaceous and Tertiary sediments, consist of Pleistocene and Holocene deposits. The Pleistocene deposits are a sequence of interlayered, generally fluvial sands, gravels, and clays ranging in thickness from zero feet near the Fall Line and along the Delaware and Schuylkill Rivers to about 80 ft in former channels of the ancestral Schuylkill and Delaware Rivers. Holocene deposits consist of organic rich mud, silt, and fine sand. These sediments underlie the channels and tidal flats of the present-day streams and range in thickness from less than 10 ft where removed by erosion to about 80 ft near the confluence of the Delaware and Schuylkill Rivers (Greenman and others, 1961; Owens and Minard, 1979).

The unconsolidated sediments form low, nearly-flat plains and broad shallow valleys covered by tidal marsh and swamp deposits. The unconsolidated sediments form a wedge that dips and thickens southeast from the Fall Line (fig. 2) toward and under the Delaware River. This wedge continues to thicken across New Jersey and continues out beneath the Atlantic Ocean.

The Piedmont Physiographic Province to the north and west of the Coastal Plain consists of a complex assemblage of metamorphic schists of the Wissahickon Formation, metagabbros, gneisses, and granites; all of Precambrian to early Paleozoic age (Bascom and Stose, 1932; 1938). These crystalline rocks plunge beneath the Coastal Plain at the Fall Line (Berg and others, 1980). To the north, the Gettysburg-Newark Lowland broadens into the New Jersey Basin. This basin contains thick sequences of arkosic sands and gravel of the Stockton Formation and the red shale and sandstone of the Brunswick Formation.

The ground-water system is recharged by precipitation and infiltration, primarily through undeveloped areas near the Fall Line. Induced infiltration occurs along streams and rivers, and locally, from man-made lakes. Ground-water flow, however, has been altered significantly by urbanization. Impervious surfaces have replaced vegetative cover, increasing direct runoff and decreasing evapotranspiration and infiltration. Sewers now represent a major flow path in the hydrologic cycle, serving as ground-water drains or sources of recharge (Paulachok, 1991, p. 10).

The crystalline rocks and overlying residual clay are the lower confining unit of the Coastal Plain. The unconsolidated Cretaceous through Pleistocene deposits comprise the principal water-bearing units. Greenman and others (1961) described the Coastal Plain in Pennsylvania as consisting of two distinct but locally interconnected aquifers—artesian and water table. Because the unconsolidated sediments thicken seaward, workers in New Jersey (Barksdale and others, 1958; Gill and Farlekas, 1976; Luzier, 1980; Zapecza, 1984) have been able to identify additional aquifers and aquifer systems. However, because many of the geohydrologic units present in New Jersey can not be traced into Pennsylvania (Owens and Sohl, 1969, p. 239-242), informal names are used to describe the Potomac-Raritan-Magothy aquifer system in Pennsylvania. A generalized stratigraphic section of the Coastal Plain in Pennsylvania showing the names of the geohydrologic units used in this report and those used by Greenman and others (1961) is presented in table 1. Important topographic, geologic, and hydrologic features of the Coastal Plain Physiographic Province are shown in figure 4.

Table 1. *Generalized stratigraphic section of the Coastal Plain Physiographic Province*

[Modified from Greenman and others, 1961; Sloto, 1988.]

<table>
<tr><th rowspan="2">Age</th><th colspan="4">Geohydrologic unit</th></tr>
<tr><th colspan="2">This report</th><th colspan="2">Greenman and others (1961)</th></tr>
<tr><td rowspan="3">Quaternary</td><td colspan="2">Holocene deposits</td><td colspan="2">Alluvium</td></tr>
<tr><td colspan="2" rowspan="2">Trenton gravel</td><td colspan="2">Cape May Formation</td></tr>
<tr><td colspan="2">Pensauken Formation</td></tr>
<tr><td>Tertiary</td><td colspan="2">Bridgeton Formation</td><td colspan="2"></td></tr>
<tr><td rowspan="7">Upper Cretaceous</td><td rowspan="8">Potomac-Raritan-Magothy Aquifer System</td><td rowspan="2">Upper Clay unit</td><td colspan="2">Magothy Formation</td></tr>
<tr><td colspan="2">Upper Clay member</td></tr>
<tr><td>Upper Sand unit</td><td rowspan="6">Raritan Formation</td><td>Old Bridge Sand member</td></tr>
<tr><td>Middle Clay unit</td><td>Middle Clay member</td></tr>
<tr><td>Middle Sand unit</td><td>Sayreville Sand member</td></tr>
<tr><td>Lower Clay unit</td><td>Lower Clay member</td></tr>
<tr><td rowspan="2">Lower Sand unit</td><td>Farmington Sand member</td></tr>
<tr><td>Lower Cretaceous</td><td></td></tr>
<tr><td>Pre-Cretaceous</td><td colspan="4">Unconformity</td></tr>
</table>

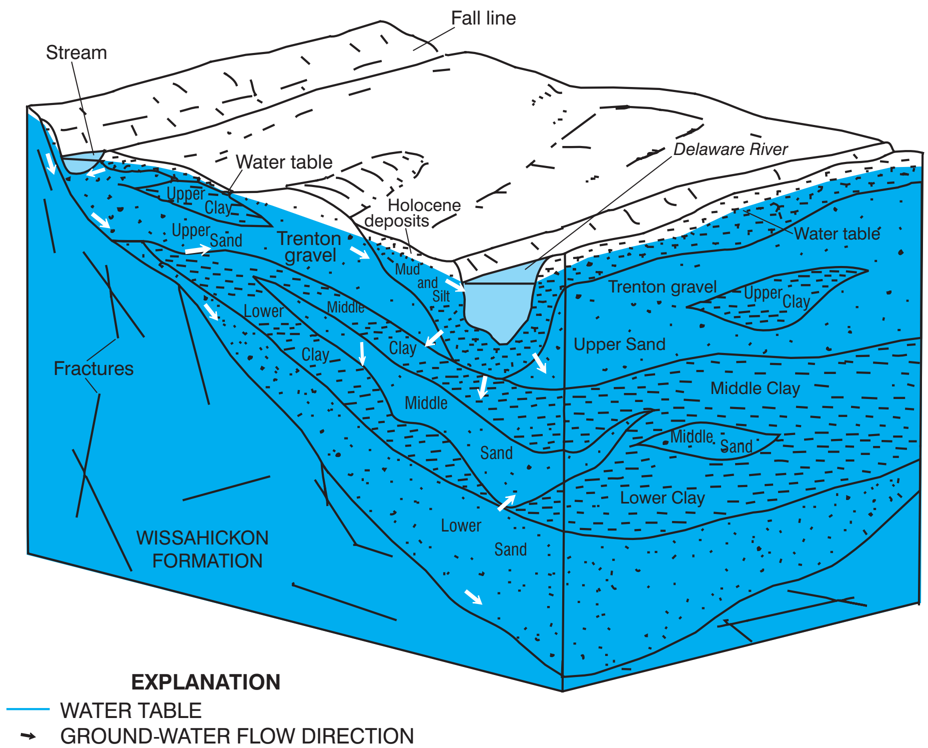


Figure 4. Topographic, geologic, and hydrologic features of the Coastal Plain Physiographic Province.

Ground-water flow in the Coastal Plain Physiographic Province has been altered significantly by urbanization. Impervious surfaces have replaced vegetative cover, increasing direct runoff and decreasing evapotranspiration and infiltration. Sewers now represent a major flow path in the hydrologic cycle, serving as ground-water drains or sources of recharge (Paulachok, 1991, p. 10).

Unconfined Ground-Water System

The unconfined ground-water system includes all depositional units or parts of such units exposed at the surface and recharged directly from (1) local precipitation, (2) surface sources, or (3) leaking sewers and water pipes. Depositional units comprising the unconfined ground-water system include most of the Trenton gravel and Upper Sand unit and parts of the Lower and Middle Sand units where confining clays are absent near the Fall Line.

Prior to extensive development by wells and drainage works, water in the unconfined ground-water system flowed from upland recharge areas near the Fall Line toward lowland discharge areas of the Delaware and Schuylkill Rivers. According to Greenman and others (1961, p. 51), the natural hydraulic gradient was about 10 ft or less per mile. The water table of this system generally resembled the land-surface profile; the altitude of the water table is usually highest under hilltops and ridges and lowest in valleys. Seepage from the unconfined system discharged not only to streams but also by evaporation from the contiguous soil zone and transpiration from plants. Evapotranspiration was areally extensive and greatest in low lying areas such as marshes (Greenman and others, 1951, p. 54).

After development of high-demand wells and water-distribution and sewer systems, the ground-water flow pattern and altitude of the water table changed considerably (Paulachok, 1991, fig. 45). Extensive withdrawals from the Lower Sand unit of the confined ground-water system produced significant vertical differences in head between the confined and unconfined ground-water systems. Because of these head differences, water flowed downward from the unconfined ground-water system through the confining clays to the Lower Sand unit, causing heads to decline locally below sea level in the unconfined ground-water system. Cones of depression around pumping wells were established. The pumping of wells immediately adjacent to the Schuylkill and Delaware Rivers reversed the natural gradient in those areas and induced river water to recharge the unconfined aquifer and flow downward through the confining unit and into the Lower Sand unit (Sloto, 1988, p. 12). Wells remote from the river were dependent on other sources of recharge such as precipitation and infiltration from water-distribution and sewer systems. After about 1960, ground-water withdrawals from the Lower Sand unit declined and head in the unconfined system began to increase (Paulachok, 1991, fig. 46).

Confined Ground-Water System

The confined ground-water system includes (1) the Lower Sand unit, where it is confined at its base by the pre-Cretaceous bedrock or, where present, the layer of residual clay formed from the bedrock, and an overlying, confining clay; (2) the Middle Sand unit, where it is confined at its base by the Lower Clay unit and is overlain by a confining clay; (3) the Upper Sand unit, where it is confined at its base by the Middle Clay unit and is overlain by a confining clay; and (4) the Trenton gravel, where it is confined at its base by a confining clay and overlain by alluvial silt and clay of Holocene age.

The pattern of ground-water movement in the confined ground-water system under pre-development conditions was more uniform than that in the unconfined ground-water system because of the reduced influence of topography on the hydraulic gradient. The principal direction of ground-water flow was east to southeast toward points of natural discharge (Delaware and Schuylkill Rivers) (Barksdale and others, 1958; Greenman and others, 1961; Back, 1966; Paulachok, 1991, fig. 39). The rate of ground-water flow varied according to local conditions of recharge and discharge. Greenman and others (1961, p. 54) estimated the natural hydraulic gradient in the Lower Sand unit at southern Philadelphia was about 2.5 ft / mi. Most water from the Lower Sand unit was discharged to rivers, streams, other surface water bodies, and to the overlying unconfined ground-water system.

The hydraulic gradient of the confined ground-water system began to change after the development and completion of high-demand wells (Paulachok, 1991, figs. 40-43). Cones of depression formed around pumping wells. Additional withdrawals steepened the local hydraulic gradient and lowered water levels. Also, differences in head between water in the Lower Sand unit and water in overlying units became established. After about 1960, ground-water withdrawals from the Lower Sand unit in Pennsylvania decreased and the water table began to rise, but downward leakage into the Lower Sand unit continues today (1999). Hydrographs of wells Ph-12 and Ph-20 (Paulachok, 1991, fig. 52) indicate by 1973 cones of depression beneath the U.S. Naval Base had dissipated and the potentiometric contours in this area closely paralleled the channel of the Delaware River (Paulachok, 1991, fig. 44). Since the early 1970’s, ground water in the Lower Sand unit under south Philadelphia has flowed toward pumping wells in New Jersey. This is confirmed by the map of the potentiometric surface in 1978 given by Sloto (1988, fig. 25). Greenman and others (1961) and Paulachok (1991) present additional information on the altitude and configuration of the potentiometric surface of the Lower Sand unit during 1915-80.

Cretaceous Sediments

Cretaceous sediments do not crop out in Pennsylvania's Coastal Plain Physiographic Province (Berg and others, 1980) but are exposed at the surface in New Jersey, Delaware, and Maryland (Parker and others, 1964). These sediments unconformably overlie crystalline rocks and residual clay and are regionally known as the Potomac-Raritan-Magothy aquifer system. The Cretaceous sediments are fluvial-deltaic in origin (Owens and others, 1968) and are considered to be chiefly non-marine in Pennsylvania. The sediments consist of highly permeable beds of sand and gravel separated by less permeable beds of clay and silt. In Pennsylvania, the Potomac-Raritan-Magothy aquifer system has been divided into three informal sand and clay units: Lower Sand and Clay, Middle Sand and Clay, and Upper Sand and Clay (table 1). In New Jersey, the Potomac-Raritan-Magothy aquifer system also has been divided into three units (Farlekas and others, 1976, p. 22; Zapecza, 1984, p. 14-19; Sloto, 1988, p. 8-9; Paulachok, 1991, table 3). However, Blickwedel and Wood (1989) stated the three sand and three clay units recognized in Pennsylvania are not equivalent to those recognized in New Jersey. The lower sand of Pennsylvania is equivalent to at least part of the lower sand of New Jersey. The middle sand of Pennsylvania is equivalent to either the upper part of the lower sand of New Jersey or part of the middle sand of New Jersey. The upper sand of New Jersey probably is absent in Pennsylvania.

Lower Sand and Clay

The Lower Sand unit is directly overlain by the Lower or Middle Clay unit and is part of the artesian aquifer or confined ground-water system. Where the clays are absent, the Lower Sand unit becomes part of the water-table aquifer or unconfined ground-water system. Recharge to the Lower Sand unit is estimated by Farlekas (1979, p. 32) to be 5 in / year. About 55 to 77 percent of the recharge comes from downward vertical leakage through the overlying Lower Clay unit. Other water sources include induced recharge from the Delaware and Schuylkill Rivers, recharge on unconfined parts of the Lower Sand unit near the Fall Line, and flow from pre-Cretaceous rocks (Sloto, 1988). From 1957 to 1978, most of the water (93 percent) discharged from the Lower Sand unit was removed by pumpage (Sloto, 1988, p. 35). Prior to 1950, the Lower Sand unit was an important source of ground water for public, industrial, and other high-demand wells in Pennsylvania. Today, however, more than 90 percent of the wells completed in the Lower Sand unit have been abandoned or destroyed because of excessive concentrations of iron and manganese in the ground water (Charles R. Wood, U.S. Geological Survey, oral commun., 1997).

Geologic description.—The Lower Sand unit is the lowermost unit of the Potomac-Raritan-Magothy aquifer system in the study area. It consists of yellowish gray to yellowish brown, generally well-sorted coarse sand and fine gravel that grade upward into fine- to medium-grained sand containing a few beds of white clay. Thickness of the Lower Sand unit ranges from less than 1 ft at the Fall Line to about 90 ft in pre-Cretaceous channels carved into the underlying crystalline rocks near the U.S. Naval Base. In Pennsylvania, however, the Lower Sand unit rarely exceeds a thickness of 60 ft (Greenman and others, 1961).

The Lower Clay unit unconformably overlies the Lower Sand unit or the residual clay of the crystalline bedrock. The Lower Clay unit is composed mainly of a tough clay containing beds of softer, well-stratified clay and thin lenses of fine-grained sand. Thickness of the Lower Clay unit ranges from 0 to over 60 ft but generally is 20 to 40 ft thick.

Well depths and casing lengths.—Depths of wells completed in the Lower Sand unit are presented in the table below. All but three of the wells are in Philadelphia, and 90 percent of the wells were drilled by 1953. Most wells are screened, but a few are perforated or slotted. The length of open interval ranges from 5 to 45 ft; the median is 20 ft. In general, the deeper a well is drilled, the greater the length of open interval.

Reported well depth, Lower Sand unit

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	178	62	82	132	165	194	36	270
High-demand	175	63	82	133	165	192	36	270

Casing lengths for wells in the Lower Sand unit are presented in the table below. Increased casing length is almost always directly related to increased well depth.

Reported casing length, Lower Sand unit

[Casing length in feet; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	120	42	67	113	148	187	24	242
High-demand	117	45	67	117	148	188	24	242

Hydrologic properties.—Depths to water in 155 wells range from 6 to 93 ft below land surface; the median is 24 ft below land surface. During the period 1979-81, water levels were measured monthly on seven selected wells in the Philadelphia area by Paulachok and others (1984). These wells had static water levels ranging from about 7 to 38 ft below land surface and had seasonal fluctuations of as much as 7 ft. According to Greenman and others (1961, p. 59), the ratio between the amplitude of water-level fluctuations observed in wells (0.005 ft to about 2 ft) and the amplitude of corresponding tidal fluctuations in the Delaware River (about 6 ft) for eight wells completed in the Lower Sand unit ranged from 0.009 to 0.383. For two of the eight wells, the lag in time between the arrival of high or low tides in the river and maximum or minimum water levels in wells was 0.47 and 2.35 hours and corresponded to the highest and lowest amplitude ratio of 0.383 and 0.009, respectively. This effect of river tides on the fluctuations of water levels in wells was measured up to 3,000 ft from the shoreline (Greenman and others, 1961, table 9).

Reported yields in the Lower Sand unit are presented in the table below. Only one well had a reported yield less than 5.0 gal/min. Such a low yield probably is the result of an undersized pump producing minimal drawdown in the well. In general, the best yielding wells are those near the Delaware River (Paulachok, 1991, fig. 28).

Reported well yield, Lower Sand unit

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	157	50	115	275	550	754	3.3	1,350
High-demand	151	60	120	287	560	766	6.0	1,350

Specific capacities for wells completed in the Lower Sand unit are presented in the table below. Specific capacities of wells with a pumping duration of 8 hours or longer (seven wells) range from 2.5 to 36 (gal / min) / ft; the median is 11 (gal / min) / ft. In general, the thicker the Lower Sand unit, the greater the specific capacity.

Reported specific capacity, Lower Sand unit

[Specific capacity in gallons per minute per foot of drawdown; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
High-demand	17	2.2	9.5	17	26	45	1.2	50

Values for hydraulic conductivity and transmissivity for the Lower Sand unit are presented below. A storativity of 0.0002 was used in estimating these hydrologic properties.

Hydraulic conductivity and transmissivity of single-well aquifer tests, Lower Sand unit

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	16	28	88	150	260	390	16	1,300
Transmissivity (ft^2 / d)	16	2,400	3,000	4,400	7,200	12,000	700	15,000

Greenman and others (1961, table 6) conducted seven aquifer tests on the Lower Sand unit in the vicinity of Philadelphia, Pa., to estimate the storage coefficient, transmissivity, and hydraulic conductivity. Storage coefficients ranged from 0.00007 to 0.0008; the median was 0.00015. Transmissivity ranged from 2,800 to 9,100 ft^2 / d; the median was 7,700 ft^2 / d. Hydraulic conductivity ranged from 123 to 151 ft / d; the median was 135 ft / d. According to Greenman and others (1961), the wide range in the storage coefficient and transmissivity is chiefly the result of variation in lithology and thickness of the Lower Sand unit.

Sloto (1988) analyzed 15 aquifer tests from the Lower Sand unit in Philadelphia, Pa., and Camden and Gloucester Counties, N.J. The hydraulic conductivities ranged from 95.0 to 207 ft / d and averaged 138 ft / d. In his computer model, Sloto determined simulated heads were very sensitive to changes in hydraulic conductivity but not to changes in the storage coefficient. Sloto produced a 20-ft head change at one node by varying the hydraulic conductivity from 95.0 to 207 ft / d.

Paulachok (1991, fig. 31) conducted short-duration (1- to 3-hour) single-well aquifer tests at 10 sites; however, only the results of 1 test could be interpreted reliably. He estimated the storativity as 0.0008 and a transmissivity of 2,800 ft^2 / d. On the basis of these and other test results, Paulachok considered the Lower Sand unit to be a moderately permeable confined aquifer.

Water quality.—As seen in the table below, wells completed in the Lower Sand unit generally yield water that is moderately high to high in dissolved solids, acidic, and very hard. Calcium and magnesium are the dominant cations; bicarbonate and sulfate are the dominant anions. Elevated concentrations of iron, manganese, nitrate, and sulfate, and low pH are the most common water-quality problems in the Lower Sand unit. Elevated concentrations of cadmium, cyanide, lead, mercury, and selenium may be related to past industrial practices (Paulachok, 1991, p. 62). Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of chemical constituents and properties analyzed for the Lower Sand unit

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	14	—	—	—	640	810	1,000	520	1,600
Field hardness	2	—	—	—	—	360	—	350	370
Field pH (standard units)	16	—	<6.5 >8.5	12	6.0	6.3	6.5	5.7	7.4
Bicarbonate	77	—	—	—	73	92	110	21	610
Cadmium	22	0.005	—	5	.001	.010	.020	.000	<.048
Calcium	65	—	—	—	15	26	39	2.0	270
Chloride	76	—	250	0	22	31	44	8.0	230
Cyanide	15	.2	—	2	.002	.10	.14	.000	.40
Iron	69	—	.3	54	.28	.98	2.9	.000	100
Lead	24	.015	—	7	.005	.010	.013	.000	.10
Magnesium	65	—	—	—	6.0	11	20	.6	200
Manganese	52	—	.05	35	.005	.25	2.1	.000	8.6
Mercury	13	.002	—	1	.010	.010	.014	.000	.035
Nitrate (as N)	75	10	—	22	.02	.05	1.7	.00	29
Potassium	53	—	—	—	3.4	4.9	8.0	.70	37
Selenium	15	.050	—	6	.001	.001	.20	<.001	.20
Silica	65	—	—	—	10	13	16	2.0	61
Sodium	53	—	—	—	26	37	51	3.3	280
Sulfate	78	—	250	10	15	29	84	2.0	1,300
Total dissolved solids	61	—	500	30	170	220	280	77	4,100

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.

The quality of water in the Lower Sand unit has changed dramatically since ground-water withdrawals from the confined ground-water system began around 1904 (Bascom, 1904; Barksdale and others, 1958; Greenman and others, 1961; Ervin and others, 1991). By 1980, ground water that originally had only trace amounts of iron and nitrate (Greenman and others, 1961, p. 96) had as much as 100 mg/L of dissolved iron and 15.0 mg/L of dissolved nitrate (Paulachok and others, 1984). The quality of water in the Lower Sand unit at the U.S. Naval Base has been documented from early 1943 through early 1957 by Greenman and others (1961, p. 93-104) and through 1982 by Paulachok (1991, fig. 55). Those investigators noted the water had undergone extensive degradation and attributed the contamination to human activities; wells at the Naval Base were abandoned by 1966 because of excessive concentrations of dissolved iron (Sloto, 1988; Paulachok, 1991).

Middle Sand and Clay

The Middle Sand unit lies stratigraphically between the underlying Lower Clay unit and the overlying Middle Clay unit. Where it is confined between persistent clay beds that isolate the sand from other water-bearing units, the Middle Sand unit becomes a distinct hydrologic unit. The Middle Sand unit is a minor aquifer with only 25 nondomestic water-supply wells inventoried; most were completed prior to 1950.

Geologic description.—The Middle Sand unit consists of a sequence of light-colored, very fine- to coarse-grained sand beds and a few beds of light-gray clay. Most sediments are fairly well sorted and were deposited in lens-shaped masses, probably by shifting currents. It is present in shallow channels cut into the lower clay. In southeastern Bucks County, the sand is present as valley-fill deposits separated by narrow bedrock divides and, in a few places, is in contact with younger sand and channel-fill deposits. Thickness of this sand unit ranges from 0 to 49 ft but commonly is less than 20 ft. In the Philadelphia area, the Middle Sand unit has a maximum thickness of about 25 ft (Greenman and others, 1961).

The Middle Clay unit is the most extensive clay unit of the Potomac-Raritan-Magothy aquifer system in Pennsylvania. The Middle Clay unit is composed of a tough, red and white clay with a uniformly massive texture that contains several thin lenses of fine-grained sand. The clay ranges in thickness from 0 to about 60 ft and commonly exceeds a thickness of 20 ft. Where the Middle Clay unit lies on top of the Lower Clay unit, it is impossible to differentiate the two clays.

Well depths and casing lengths.—Depths of wells completed in the Middle Sand unit are presented in the table below; data were available only for high-demand wells. The length of open interval ranges from 5 to 41 ft; the median is 16 ft. In general, the deeper a well is drilled the greater is the length of open interval. Wells generally are drilled deeper in Philadelphia (7 wells) than in Bucks County (18 wells); the median depths are 125 and 74 ft, respectively.

Reported well depth, Middle Sand unit

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
High-demand	25	56	66	82	103	129	55	140

Casing lengths for wells in the Middle Sand unit are presented in the table below. Increased casing length is almost always directly associated with increased well depth.

Reported casing length, Middle Sand unit

[Casing length in feet; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
High-demand	17	36	42	55	97	127	36	133

Hydrologic properties.—Depths to water in 23 wells range from 4 to 29 ft below land surface; the median is 15 ft below land surface. Most static water levels have shown strong seasonal and tidal influence. At one well in Philadelphia, water levels in the Middle Sand unit have been measured continuously since 1975. From 1979 through 1981, the static water level in this well ranged from about 15 to 21 ft below land surface (Paulachok and others, 1984, p. 8). Greenman and others (1961, p. 59) determined the ratio between the amplitude of water-level fluctuations observed in a well completed in the Middle Sand unit (about 0.03 ft) and the amplitude of corresponding tidal fluctuations in the Delaware River as 0.005. This well is about 4,400 ft from the shoreline.

Reported yields in the Middle Sand unit are presented in the table below. Four of the five wells with yields of 750 gal / min or greater are within 1,500 ft of the Delaware River. Wells drilled to a depth of more than 100 ft (five wells) have a median reported yield of 350 gal / min, whereas wells drilled less than 100 ft deep (13 wells) have a median reported yield of 300 gal / min.

Reported well yield, Middle Sand unit

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
High-demand	18	94	150	350	690	900	50	1,020

Specific capacities for wells completed in the Middle Sand unit are presented in the table below. Specific capacities of six wells with pumping durations of 8 hours or longer range from 6.7 to 39 (gal / min) / ft; the median is 19 (gal / min) / ft.

Reported specific capacity, Middle Sand unit

[Specific capacity in gallons per minute per foot of drawdown; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Well type	Number of wells	P25	Median	P75	Minimum	Maximum
High-demand	7	6.7	10	32	4.7	39

Values of hydraulic conductivity and transmissivity for the confined Middle Sand unit are presented below; a storativity of 0.0002 was used in estimating these hydrologic properties. Hydraulic conductivity and transmissivity for two wells completed in the unconfined Middle Sand unit are 39 and 310 ft / d and 1,100 and 6,100 ft^2 / d, respectively. A specific yield of 0.2 was used in estimating these hydrologic properties.

Hydraulic conductivity and transmissivity of single-well aquifer tests, Middle Sand unit

[ft/d, feet per day; ft^2/d, feet squared per day; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Hydrologic property	Number of wells	P25	Median	P75	Minimum	Maximum
Hydraulic conductivity (ft / d)	5	33	290	680	7.4	470
Transmissivity (ft^2 / d)	5	1,600	2,900	9,700	1,200	12,000

Water quality.—As seen in the following table, wells completed in the Middle Sand unit generally yield water that contains moderate amounts of dissolved solids and may be some what acidic. Sodium plus potassium are the dominant cations, and chloride is the dominant anion. Elevated concentrations of iron and manganese appear to be the most common water-quality problems. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water is presented in the appendix.

Summary of chemical constituents and properties analyzed for the Middle Sand unit

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	1	—	—	—	—	690	—	690	—
Field hardness	0	—	—	—	—	—	—	—	—
Field pH (standard units)	1	—	<6.5 >8.5	0	—	7.0	—	7.0	—
Bicarbonate	8	—	—	—	20	25	180	11	330
Cadmium	2	0.005	—	1	—	.010	—	.001	<.020
Calcium	8	—	—	—	11	15	33	7.9	39
Chloride	8	—	250	0	10	14	31	5.1	160
Iron	8	—	.3	6	.58	6.1	42	.000	53
Lead	2	.015	—	2	.010	.015	.040	.010	.046
Magnesium	8	—	—	—	4.7	8.9	14	3.9	20
Manganese	7	—	.05	2	.000	.003	.89	.000	1.7
Nitrate (as N)	8	10	—	0	.14	1.2	3.4	.01	7.7
Potassium	6	—	—	—	1.5	3.4	5.0	.9	7.0
Silica	8	—	—	—	12	13	13	6.2	19
Sodium	6	—	—	—	7.3	19	27	3.1	40
Sulfate	8	—	250	0	5.4	23	35	.9	66
Total dissolved solids	8	—	500	1	110	170	260	68	540

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.

Upper Sand and Clay

Throughout much of the Coastal Plain, the Upper Sand unit is part of the water-table aquifer and is recharged by precipitation, leakage from sewers and water pipes, and contact with surface-water bodies (Greenman and others, 1961; Paulachok, 1991). Most of the 14 wells inventoried in this unit are industrial wells; all have been either abandoned or destroyed because of poor water quality.

Geologic description.—The Upper Sand unit consists principally of light gray to yellowish brown, well sorted, medium- to coarse-grained sand with minor amounts of fine to very fine sand and gravel. Gravel beds are common, especially at the base. In south Philadelphia, the Upper Sand unit has a maximum thickness of 50 ft and locally in Bucks County it may be as thick as 100 ft, but elsewhere it seldom exceeds 35 ft in thickness (Greenman and others, 1961; Greenman, 1955). The Upper Sand unit unconformably overlies the Middle Clay unit where it occupies erosional depressions or scour channels. Locally, the Middle Clay unit has been removed by erosion and the Upper Sand unit was deposited on the Middle Sand unit or older deposits.

The Upper Clay unit consists of light-gray sandy clays; dark-gray carbonaceous clays; and massive, red, white, and yellow clays. It is 35 ft thick in south Philadelphia and 25 ft thick in Bucks County. The Upper Clay unit is not areally extensive, but where present it overlies the Upper Sand unit separating it from the overlying Tertiary and Quaternary sediments.

Well depths and casing lengths.—Depths of wells completed in the Upper Sand unit are presented in the table below. Wells in this unit are finished with either screens or perforated pipe. The screens or perforated pipe have lengths ranging from 5 to 34 ft; the median is 10 ft.

Reported well depth, Upper Sand unit

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
High-demand	14	61	62	74	83	105	61	105

Casing lengths for drilled wells in the Upper Sand unit are presented in the table below. Increased casing length is almost always directly related to increased well depth.

Reported casing length, Upper Sand unit

[Casing length in feet; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
High-demand	14	40	52	61	73	100	39	100

Hydrologic properties.—Depths to water in 12 wells range from 14 to 34 ft below land surface; the median is 18 ft below land surface. Water levels in wells within several hundred feet of the Delaware River can be influenced by the tide.

Reported yields in the Upper Sand unit are presented in the table below. The largest reported yields are from wells with a water column of 45 ft or less in height.

Reported well yield, Upper Sand unit

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
High-demand	11	22	30	54	310	760	20	850

Specific capacities of five wells, irregardless of pumping duration, range from 0.30 to 22 (gal / min) / ft; the median is 13 (gal / min) / ft. The specific capacities of three wells pumped 8 hours or longer are 0.30, 13, and 17 (gal / min) / ft. The largest specific capacity is from a well with a water column less than 20 ft in length.

Values for hydraulic conductivity and transmissivity for the Upper Sand unit are limited to four wells. A storativity of 0.0002 was used in estimating these hydrologic properties. Hydraulic conductivities in the Upper Sand unit are 7.2, 37, 140, and 270 ft / d; transmissivities are 72, 560, 4,000 and 4,900 ft^2 / d.

Water quality.—As seen in the following table, wells completed in the Upper Sand unit yield water that contains moderate amounts of dissolved solids. Calcium and sodium plus potassium are the dominant cations; bicarbonate is the dominant anion. Elevated concentrations of iron and manganese are the most common water-quality problems. High concentrations of sulfate and total dissolved solids also are reported. The high lead and cadmium concentrations reported may be the result of leaks or spills of industrial chemicals and waste products (Paulachok, 1991, fig. 64).

Summary of chemical constituents and properties analyzed for the Upper Sand unit

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum	Maximum
Laboratory specific conductance (µS/cm)	6	—	—	—	280	490	600	130	3,500
Field hardness	1	—	—	—	—	390	—	390	—
Field pH (standard units)	1	—	<6.5 >8.5	1	—	5.6	—	5.6	—
Bicarbonate	6	—	—	—	42	120	230	16	300
Cadmium	3	0.005	—	2	—	.007	—	.004	<.010
Calcium	6	—	—	—	18	33	57	13	230
Chloride	6	—	250	0	11	29	34	3.0	44
Iron	6	—	.3	3	.012	.33	.140	.11	.220
Lead	3	.015	—	2	—	.010	—	.000	.020
Magnesium	6	—	—	—	9.3	14	17	9.0	150
Manganese	5	—	.05	3		.57	.65	.000	31
Nitrate (as N)	5	10	—	0	.10	.78	3.1	.09	6.9
Potassium	4	—	—	—	4.8	15	33	2.7	34
Silica	6	—	—	—	9.6	12	19	7.5	25
Sodium	4	—	—	—	—	24	—	20	54
Sulfate	6	—	250	1	5.2	9.8	80	3.4	1,700
Total dissolved solids	6	—	500	1	160	270	380	66	4,500

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.

Post-Cretaceous Sediments

Tertiary- and Quaternary-age clays, silts, sands, and gravels completely cover the Cretaceous sediments (Berg and others, 1980). The thickness of these terrace and valley-fill deposits ranges from zero along the Schuylkill and Delaware Rivers to about 80 ft in Philadelphia and about 60 ft in Bucks County but typically are about half the maximum thickness reported (Greenman and others, 1961). The post-Cretaceous deposits, which are areally extensive and form most of the water-table aquifer, consist of the Bridgeton Formation, the Trenton gravel, and Holocene sediments.

The overlying sediments are part of the unconfined ground-water system. Near the Schuylkill River and at a few other localities, the Pleistocene gravels (Greenman and others, 1961) are overlain by a veneer of alluvium of Holocene age. Prior to 1950, the gravels were an important source of ground water in the Coastal Plain, capable of supplying numerous industrial and other high-demand wells. Today, however, the gravels are important only in areas adjacent to rivers where induced recharge can provide water of acceptable quality.

Bridgeton Formation

The Bridgeton Formation is composed of stratified, feldspathic quartz sand with local beds of fine gravel; clay and silt beds are rarely present (Owens and Minard, 1979). Owens and Minard (1979, p. 18) tentatively assigned a Miocene age to the Bridgeton Formation on the basis of its stratigraphic relation with younger sediments. Because the Bridgeton Formation is widely scattered and generally present only as topographic highs, it is not considered an important geohydrologic unit in the Coastal Plain of Pennsylvania.

Trenton Gravel

The name "Trenton gravel" was first proposed by Lewis (1880) to "* * * the newest and last gravels found in the lower Delaware valley." In the Coastal Plain of Pennsylvania, only the Trenton gravel (informal usage) is presently exposed at land surface (Berg and others, 1980).

Geologic description.—The Trenton gravel was informally subdivided, primarily on the basis of lithology, by Owens and Minard (1979, p. 29) into the stratigraphically higher Spring Lake beds and the stratigraphically lower Van Sciver Lake beds. The Spring Lake beds can exceed 75 ft in thickness and consist of silt, clay, sand, and gravel. The Van Sciver Lake beds are as thick as 55 ft and consist primarily of clay, silt, and sand. Where they have not been removed by erosion, the Spring and Van Sciver Lake beds generally form small terraces and scarps; altitudes rarely exceed 70 ft above sea level. Both units have been dated radiologically and palynologically as Sangamonian in age (Owens and Minard, 1979, p. 38 and 42). The Trenton gravel overlies the Bridgeton Formation where it is present, although generally the Trenton gravel lies directly on Cretaceous sediments. Near the Schuylkill River and at a few other localities, the Trenton gravel is overlain by a veneer of alluvium of Holocene age. According to Paulachok (1991), the Trenton gravel is equivalent to the Pleistocene sediments of Wisconsin age of Greenman and others (1961).

Well depths and casing lengths.—Depths of wells completed in the Trenton gravel are presented in the table below. Most wells in the Trenton gravel are finished with screens; a few wells are completed with perforated pipe. Six wells are completed as well points. The open length for screened and perforated wells ranges from 4 to 34 ft; the median is 10 ft.

Reported well depth, Trenton gravel

[Depth in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	186	26	33	43	62	85	17	107
Domestic	4	—	—	38	—	—	35	55
High-demand	121	26	35	50	71	89	17	107

Well depths vary considerably by county. Wells drilled in Bucks County (58 wells) are completed at shallower depths than wells drilled in Delaware County (10 wells) and Philadelphia County (118 wells). The median depths of wells drilled in the Trenton gravels of Bucks, Delaware, and Philadelphia Counties are 35, 57, and 51 ft, respectively.

Casing lengths for wells in the Trenton gravel are presented in the table below. In general, the deeper the well the more casing is used. Wells drilled in Bucks County (32 wells) use considerably less casing than wells drilled in Delaware County (8 wells) or Philadelphia County (77 wells). The median casing lengths of wells drilled in Bucks, Delaware, and Philadelphia Counties are 25, 39, and 41 ft, respectively.

Reported casing length, Trenton gravel

[Casing length in feet; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	117	10	19	33	51	65	10	87
High-demand	75	12	19	38	57	67	10	87

Hydrologic properties.—Depths to water in 176 wells range from flowing at land surface to 48 ft below land surface; the median is 13 ft below land surface. As seen in the table below, water levels appear to be deeper (farther from land surface) in valleys than on slopes. However, this may be because of the small sample size for wells on slopes. In general, water levels show strong seasonal fluctuation, but in wells near the Delaware River these seasonal fluctuations are moderated because the river is a tidewater body with a relatively constant mean stage. These wells may show tidal fluctuations in response to the 6-ft tidal impulse of the Delaware River (Blickwedel and Linn, 1987).

Water levels, Trenton gravel

[Water levels in feet below land surface; F, flowing well; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Slope	6	—	5	12	18	—	4	22
Valley	167	4	8	13	23	32	F	48

Reported yields in the Trenton gravel are presented in the table below. Yields of 5.0 gal / min or less are reported from three wells. High-demand wells drilled in Bucks County (32 wells) generally have greater yields than high-demand wells in Delaware (5 wells) or Philadelphia (70 wells) Counties. The median reported yields of high-demand wells in Bucks, Delaware, and Philadelphia Counties are 203, 85, and 108 gal / min, respectively. The three wells with yields of 1,000 gal / min or greater are 75 ft or deeper. Paulachok (1991, fig. 17) shows the approximate distribution of well yields in the Trenton gravel. In general, wells close to the Delaware River and open to a large saturated thickness will have high yields.

Reported well yield, Trenton gravel

[Yield in gallons per minute; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	157	6.7	43	105	257	600	0.0	1,370
Domestic	1	—	—	50	—	—	50	—
High-demand	107	44	80	150	300	600	3.5	1,370

Specific capacities for wells completed in the Trenton gravel are presented in the table below. Specific capacities of wells (15 wells) with pumping durations of 8 hours or longer range from 1.3 to 80 (gal / min) / ft; the median is 15 (gal / min) / ft. Specific capacities of high-demand wells in Bucks County (11 wells) are considerably greater than in Philadelphia County (7 wells); the medians are 20 and 7.8 (gal / min) / ft, respectively.

Reported specific capacity, Trenton gravel

[Specific capacity in gallons per minute per foot of drawdown; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	32	0.38	1.1	6.6	31	56	0.01	80
High-demand	20	.71	4.8	11	37	57	.58	80

Values of hydraulic conductivity and transmissivity for the Trenton gravel are presented below. A specific yield of 0.2 was used in estimating the hydrologic properties of the unconfined Trenton gravel, and a storativity of 0.0002 was used for the confined Trenton gravel.

Hydraulic conductivity and transmissivity from single-well aquifer tests, unconfined Trenton gravel

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	14	16	63	430	990	2,300	15	2,900
Transmissivity (ft^2 / d)	14	140	280	5,700	8,300	14,000	61	18,000

Hydraulic conductivity and transmissivity from single-well aquifer tests, confined Trenton gravel

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	18	3.9	15	98	180	650	0.40	1,600
Transmissivity (ft^2 / d)	18	54	130	1,400	2,300	9,700	2.0	12,000

Paulachok (1991) conducted 10 short-duration (less than 3-hour), single-well aquifer tests in the unconfined aquifers; however, the test data for only two wells completed in the Trenton gravel could be interpreted reliably. Greenman and others (1961, p. 47) conducted a long-duration test in the Trenton gravel. The transmissivities from these three tests are 3,800, 4,200, and 4,900 ft^2 / d. From the long-duration test, Greenman and others (1961) estimated storativity as 0.00059 and hydraulic conductivity as 142 ft / d. According to Paulachok (1991, p. 18), the data for the long-duration test indicate the Trenton gravel may be in direct hydraulic contact with the Delaware River.

Water quality.—As seen in the following table, wells completed in the Trenton gravel generally yield water that contains moderately high amounts of dissolved solids and is acidic. Calcium is the dominant cation, and, after 1967, bicarbonate is the dominant anion. Elevated concentrations of iron, manganese, nitrate, sulfate, and total dissolved solids and low pH are the most common water-quality problems. Elevated concentrations of lead and mercury may be related to past industrial practices (Paulachok, 1991, p. 62). Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of chemical constituents and properties analyzed for the Trenton gravel

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	20	—	—	—	410	720	1,100	280	3,000
Field hardness	2	—	—	—	—	61	—	1	120
Field pH (standard units)	20	—	<6.5 >8.5	11	5.7	6.4	6.6	5.2	7.2
Bicarbonate	67	—	—	—	35	57	130	.0	460
Cadmium	24	0.005	—	2	<.001	.002	.009	<.0001	<.060
Calcium	56	—	—	—	19	26	46	5.7	740
Chloride	66	—	250	4	12	18	46	.0	2,200
Iron	62	—	.3	47	.57	3.0	9.3	.020	430
Lead	15	.015	—	2	.001	.003	.006	.000	.081
Magnesium	56	—	—	—	11	13	16	5.1	140
Manganese	54	—	.05	23	.025	1.6	12	.000	15
Mercury	21	.002	—	4	<.0001	<.0001	.0001	<.0001	.055
Nitrate (as N)	67	10	—	11	.25	.81	2.9	.0	39
Potassium	44	—	—	—	2.2	4.4	7.7	.0	20
Silica	58	—	—	—	8.2	11	16	5.1	83
Sodium	44	—	—	—	9.1	19	47	3.3	420
Sulfate	67	—	250	9	29	66	110	.4	2,200
Total dissolved solids	60	—	500	20	190	230	400	95	4,300

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.

The quality of ground water in the Trenton gravel has declined since intensive industrial development began in the 1920's. This degradation of the ground water can be traced to the dumping of industrial and municipal wastes, leaking wells and sanitary sewers, cesspools, dumps, and landfills. Greenman and others (1961) attempted to trace this degradation on the basis of numerous wells whose waters were analyzed over a period of several years. They noted a wide range in the composition of the ground water from site to site. This variation was believed to be the result of different sources of contamination, and "* * * the effects of blending of recharge from multiple sources in response to pumping." (Greenman and others, 1961, p. 70).

Holocene Deposits

Holocene Deposits consisting of richly organic, dark gray mud, silt, and fine sand underlie the channels and tidal flats of the Delaware River and its principal tributaries. These sediments can be as thick as 78 ft in south Philadelphia where the channels of the Delaware and Schuylkill Rivers merge, but elsewhere, the thickness is generally about 30 ft and commonly less than 10 ft (Greenman and others, 1961). Because these sediments form a veneer, are very fine grained, and are less permeable than the Trenton gravel or the other sand units, the Holocene Deposits are not considered an important geohydrologic unit in the Coastal Plain of Pennsylvania.

Summary Characteristics of Unconsolidated Aquifers in the Coastal Plain Physiographic Province

Data evaluated for most units in the Coastal Plain Physiographic Province are summarized in figures 5 to 9. Well depths range from 17 to 270 ft below land surface and casing lengths from 10 to 242 ft. Well depths and casing lengths are generally greatest in the Lower Sand unit (oldest and stratigraphically lowest unit) and least in the Trenton gravel (youngest and stratigraphically highest unit).

Reported yields range from essentially 0 to 1,370 gal / min and specific capacities from 0.01 to 80 (gal / min) / ft. In general, wells in close proximity to surface water bodies such as the Schuylkill or Delaware Rivers have the greatest reported yields and specific capacities.

The quality of water has decreased as a result of heavy pumping and intense industrial development. Elevated concentrations of iron, manganese, nitrate, sulfate, total dissolved solids, and low pH are the most common water-quality problems. Elevated concentrations of metals (cadmium, cyanide, lead, mercury, selenium) may be the result of leaks or spills of industrial chemicals and waste products.

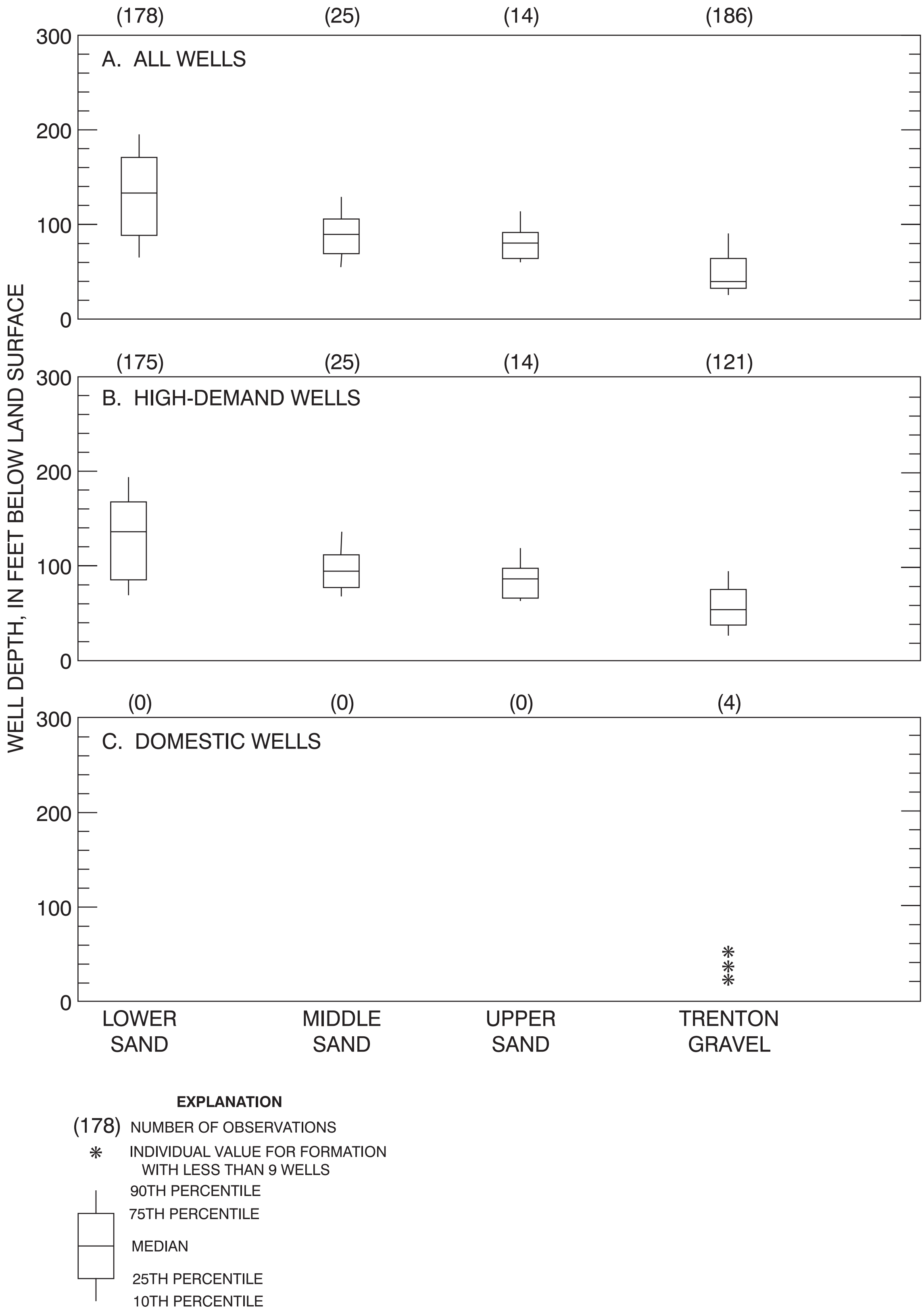


Figure 5. Depths of wells in the Coastal Plain Physiographic Province.

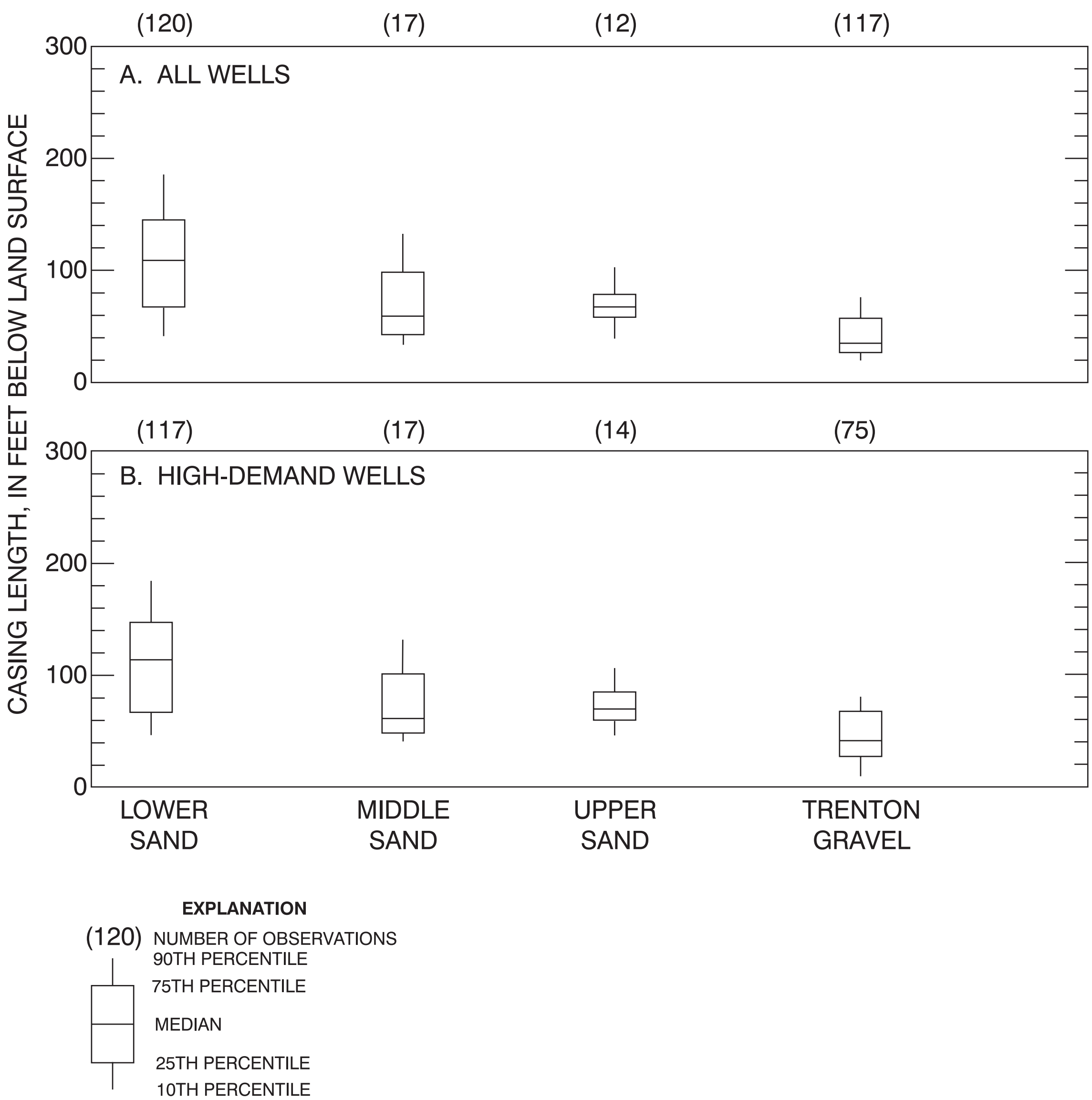


Figure 6. Casing lengths of wells in the Coastal Plain Physiographic Province.

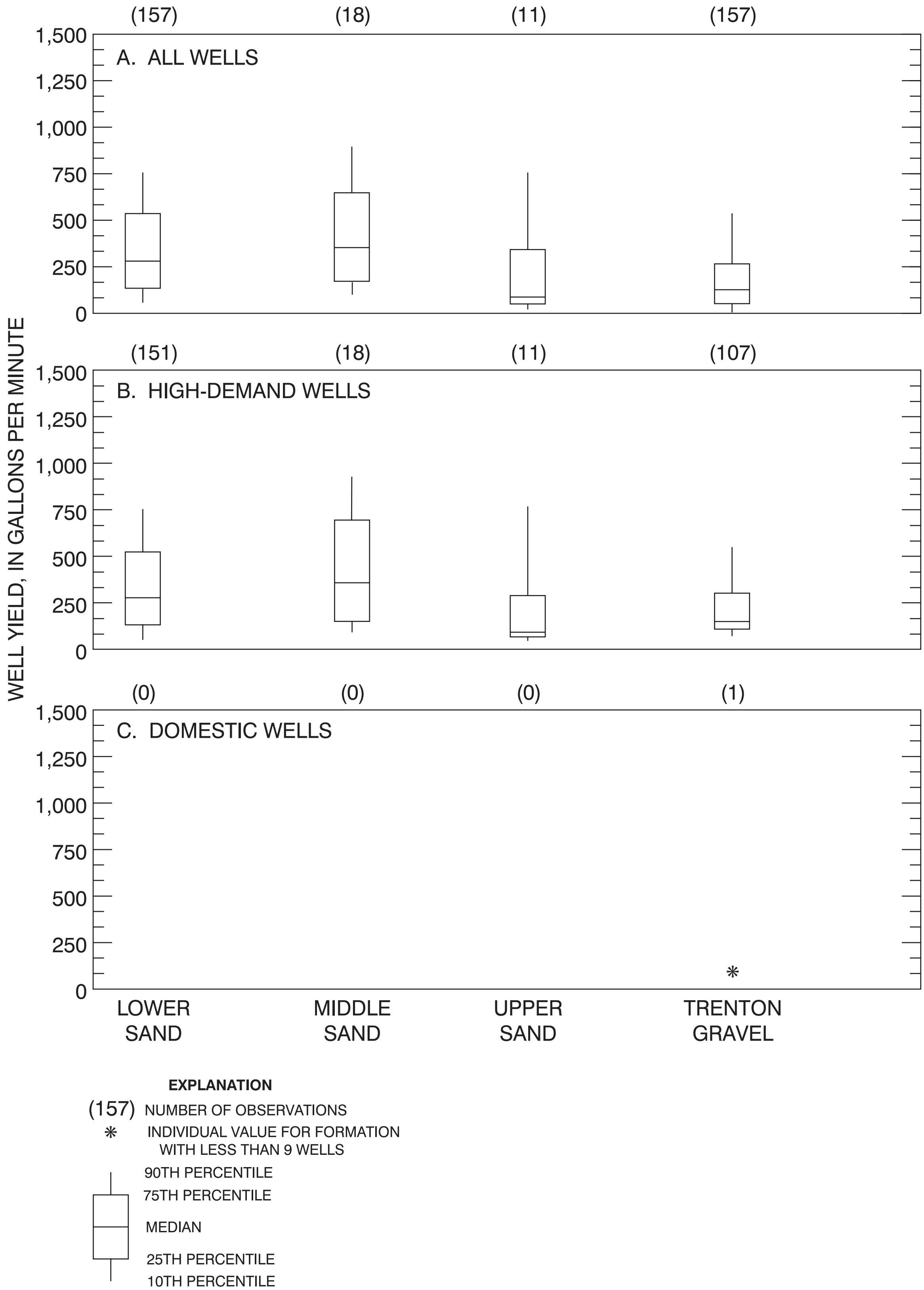


Figure 7. Reported yields of wells in the Coastal Plain Physiographic Province.

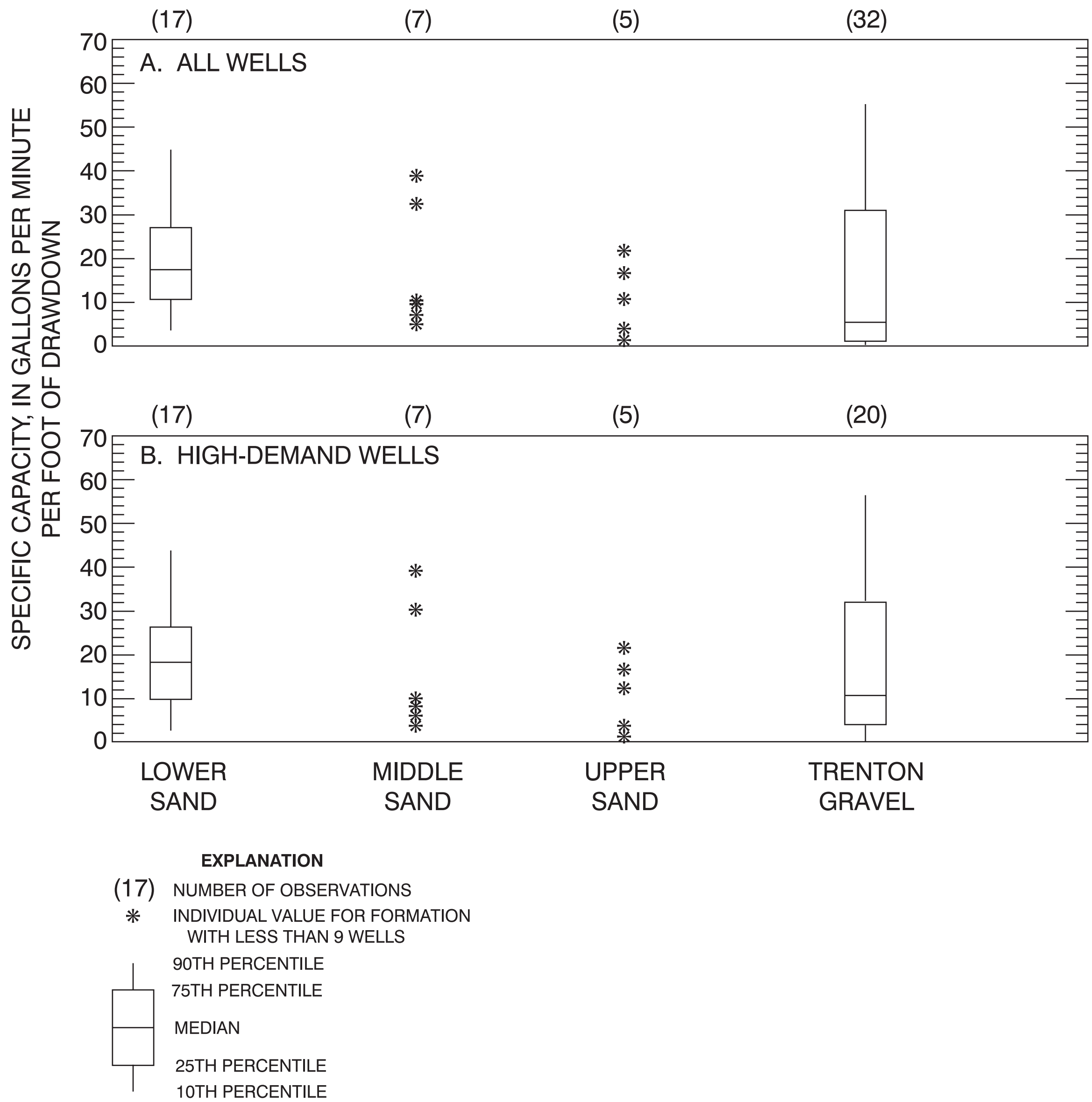


Figure 8. Specific capacities of wells in the Coastal Plain Physiographic Province.

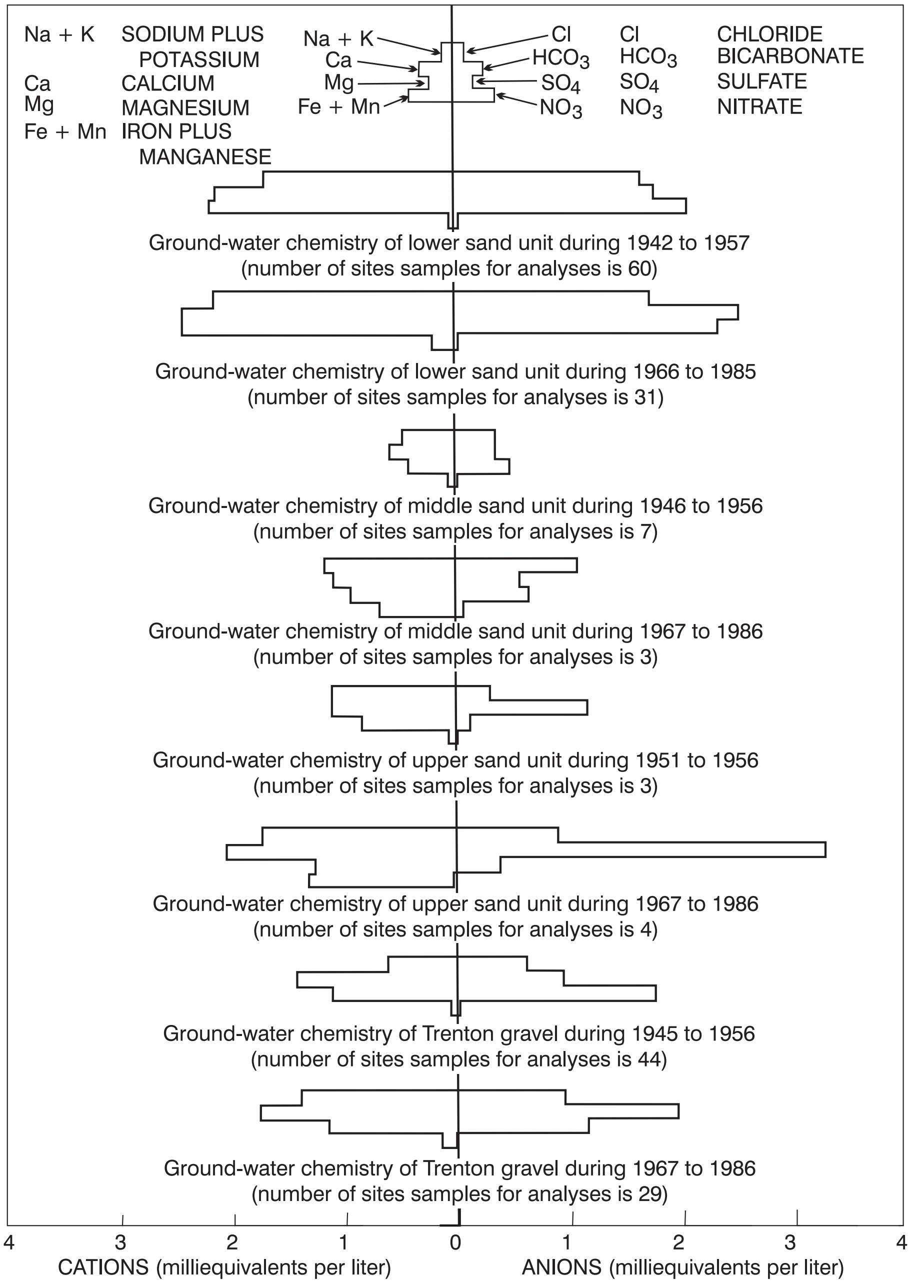


Figure 9. Median values of results of chemical analyses of selected chemical constituents in water from the geohydrologic units in the Coastal Plain Physiographic Province.

GEOHYDROLOGY OF THE PIEDMONT PHYSIOGRAPHIC PROVINCE, PIEDMONT UPLAND SECTION

Location and Geographic Setting

The Piedmont Upland Section is part of the Piedmont Physiographic Province as originally described by Fenneman (1938). Berg and others (1989) have recently redefined the Piedmont Upland Section in Pennsylvania and their delineation will be used throughout this report (figs. 1 and 10). In Pennsylvania, the Piedmont Upland Section occupies about 1,800 mi^2 of the southeastern part of the Commonwealth. The part of the Piedmont Upland Section under study for this report is bounded on the south by the border of Pennsylvania with Maryland and Delaware and on the east by the Fall Line that separates the Piedmont and Coastal Plain Physiographic Provinces. The northern and western boundaries coincide with the contact between mostly noncarbonate metamorphic rocks that are a part of the Piedmont Upland, carbonate rocks of the Piedmont Lowland, and siliciclastic rocks of the Gettysburg-Newark Lowland.

The Piedmont Upland is characterized by rolling hills and valleys, generally with gentle to moderately steep slopes. However, steeper slopes with narrow valley bottoms dominate near the Susquehanna River. Many higher ridges are underlain by more resistant bedrock such as quartzite. Altitudes range from about 100 ft above sea level near the Fall Line to between 1,000 and 1,200 ft on the highest ridges. For much of the area, altitudes range from 100 to 300 ft above sea level.

The eastern third of the Piedmont Upland is densely populated, including part of Philadelphia as well as numerous outlying communities such as Drexel Hill, Springfield, Chester, and parts of Levittown. The central part of the Piedmont Upland is less densely populated but contains several communities including West Chester, Malvern, and Wayne. The western part is the least densely populated area of the Piedmont Upland; population centers include Red Lion and Stewartstown (fig. 10). Urban and suburban land use predominates in the eastern part of the Piedmont Upland but gives way to a greater percentage of rural agricultural and forested land use toward the west. Parts of the physiographic region with more rugged terrain are commonly forested and sparsely populated.

The Piedmont Upland of Pennsylvania has a humid continental climate. Average yearly precipitation is about 43 in. (Pennsylvania Department of Environmental Resources, 1980). Summer and winter mean temperatures are about 24 and 0°C, respectively. Prevailing winds are westerly during the winter and southerly during the summer. Weather systems that affect the area generally originate in the central United States and move eastward over the Appalachians. Periodically, moist northward moving weather systems bring moderate and heavy precipitation to the area.

Water-Well Density

The location of wells in the analysis of the Piedmont Upland is shown in figure 11. The uneven distribution of analyzed wells is partly related to the location of historical studies, population density, the presence of springs, and the abundance of surface water. The highest density of recorded wells are from Chester (3.8 wells per square mile), Philadelphia (2.7 wells per square mile), and Delaware (2.5 wells per square mile) Counties. Records from high-demand wells comprise a larger part of all well records for these counties than for the counties located further west in the Piedmont Upland. Areas with the least dense well data are Lancaster (0.46 wells per square mile), Montgomery (0.58 wells per square mile), and Bucks (0.66 wells per square mile) Counties and include relatively few high-demand wells.

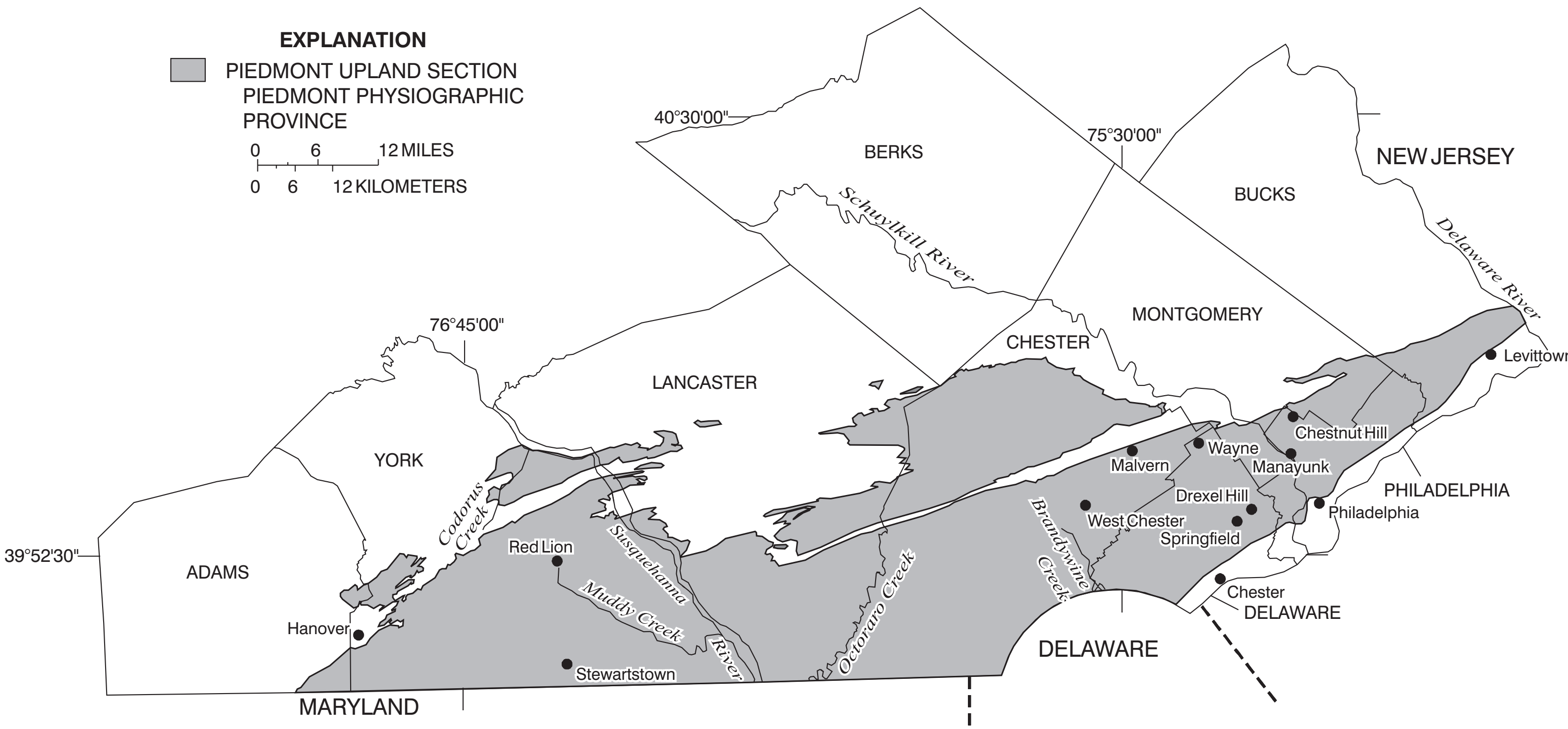


Figure 10. Piedmont Physiographic Province, Piedmont Upland Section, major streams, counties, and major population centers.

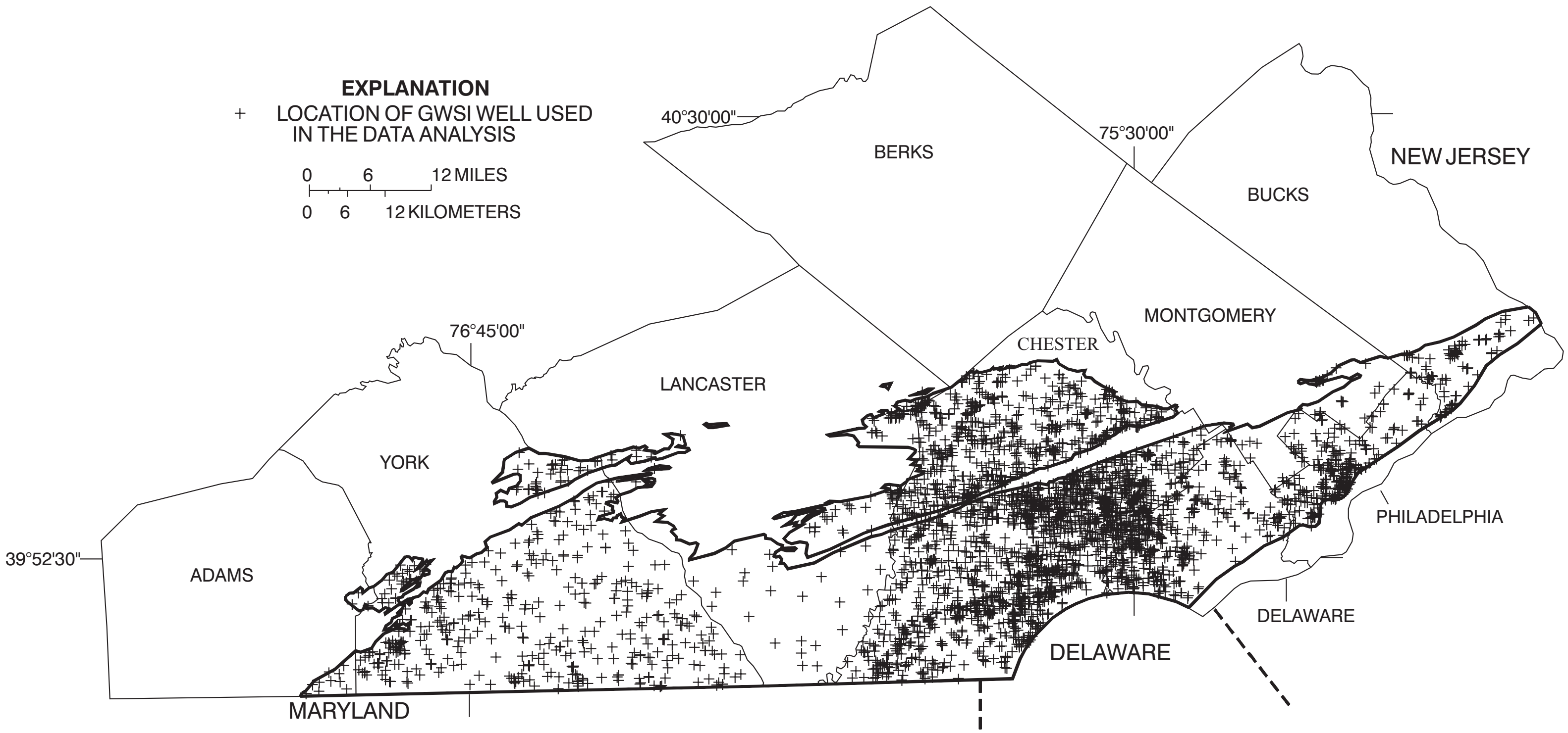


Figure 11. Locations of wells in the Piedmont Physiographic Province, Piedmont Upland Section.

Previous Work

Initial efforts to map and describe the geology of the Piedmont Upland were undertaken by Bascom and others (1909), Bascom and Miller (1920), Jonas and Stose (1926; 1930), Knopf and Jonas (1922; 1923), Bascom and Stose (1932; 1938), Stose (1932), and Stose and Jonas (1939). The most controversial aspect of the earlier investigations was the Martic Overthrust, proposed by Knopf and Jonas (1929). The arguments regarding the overthrust and Martic Line culminated in the detailed study by Cloos and Hietanen (1941). Other more recent studies on the geology of the Piedmont Upland include Agron (1950), Bromery and Griscomb (1967), Higgins (1972), Crawford and Crawford (1980), Lyttle and Epstein (1987), Wagner and Srogi (1987), Drake and others (1989), Gates and Valentino (1991), Faill and Sevon (1994), and Faill (1997).

Hall (1934) presented some of the earliest ground-water data and briefly discussed the water-bearing characteristics of the principal geological formations of southeastern Pennsylvania. Water-resource reports for Bucks (Greenman, 1955), Chester (Poth, 1968; McGreevy and Sloto, 1976, 1977; Sloto, 1987, 1989, 1990), Delaware (Balmer and Davis, 1996), Lancaster, (Meisler and Becher, 1971; Poth, 1977), Montgomery (Newport, 1971), Philadelphia (Paulachok, Wood, and Norton, 1984), and York Counties (Lloyd and Growitz, 1977) have been published. Water resources of several drainage basins have been studied or modeled by Olmstead and Hely (1962), Miller and others (1971), McGreevy and Sloto (1980), Gerhart and Lazorchick (1984b) and Sloto (1990). The ground-water resources for the Delaware River were studied by Parker and others (1964) and for the Schuylkill River by Biesecker and others (1968).

Geohydrologic Setting

The Piedmont Upland (Berg and others, 1980) is generally underlain by Precambrian to Early Paleozoic age metamorphic and igneous rocks (table 2). Recent work (Wagner and Srogi, 1987) suggests this area was the site of a collision between a magmatic arc and the Precambrian North American continent along an east-dipping subduction zone. Lithologies include felsic to mafic gneiss; felsic to mafic plutonic rocks; serpentinite; schistose rocks of the Wissahickon Formation, Marburg Schist, and Peters Creek Schist; slaty rocks of the Peach Bottom Slate; siliciclastic sedimentary rocks of the Chickies, Harpers, and Antietam Formations; and carbonate rocks of the Cockeysville and Wakefield Marble (Bascom and Stose, 1932; 1938; Stose and Jonas, 1939; McKinstry, 1961; Freedman and others, 1964; Crawford and Crawford, 1980; and Faill and Valentino, 1989). These rocks have been repeatedly metamorphosed, intruded, folded, and thrust faulted (Stose and Jonas, 1923; Hopson, 1964). Much of the Piedmont Upland consists of the Glenarm Terrace and several less extensive outlying areas, the largest of which includes the Honey Brook Upland and adjoining Mine Ridge area (fig. 12). The Glenarm Terrane consists primarily of the Wissahickon Formation and other metasedimentary rocks. The Honey Brook Upland and Mine Ridge area are underlain for the most part by mafic and felsic gneisses and plutonic igneous rocks. These metamorphic and igneous rocks form numerous, discordant bodies (Berg and others, 1980). The Glenarm Terrane and the Honey Brook Upland and Mine Ridge area have undergone repeated periods of metamorphism beginning as early as 1 billion years ago and ending about 320 million years ago (Tilton and others, 1960; Grauert and others, 1973; Lapham and Bassett, 1964).

Recent work by Lyttle and Epstein (1987) indicates the Piedmont may be divided into northern and southern parts (table 2). The boundary between the two on the 1980 Geologic Map of Berg and others (1980) is essentially the contact between the Albite-Chlorite Schist and the Oligoclase-Mica Schist of the Wissahickon Formation. According to Lyttle and Epstein (1987), this contact may represent an important suture that joined, probably before the late Proterozoic or earliest Paleozoic, two distinctly different terranes.

Table 2. *Generalized stratigraphic section of the Piedmont Physiographic Province, Piedmont Upland Section in Pennsylvania*

[Modified from Berg and others, 1983; Lyttle and Epstein, 1987]

Age	Geohydrologic unit						
	Northern Piedmont Upland			Southern Piedmont Upland			
Upper Ordovician	Unconformity Wakefield Marble					Peach Bottom Slate and Cardiff Conglomerate	
Middle Ordovician	Wakefield Marble					Peach Bottom Slate and Cardiff Conglomerate	
Lower Ordovician		Unconformity		Unconformity Plutonic Rocks			
Upper Cambrian		Albite-Chorite Schist		Oligoclase-Mica Schist Gneissic Rocks		Peters Creek Schist	Serpentinite
Middle Cambrian	Unconformity	Albite-Chorite Schist		Oligoclase-Mica Schist	Unconformity Cockeysville Marble	Peters Creek Schist	Serpentinite
Lower Cambrian	Marburg Schist	Albite-Chorite Schist Metavolcanics Albite-Chlorite Schist	Antietam Formation Harpers Formation Chickies Formation	Oligoclase-Mica Schist	Cockeysville Marble Setters Quartzite	Peters Creek Schist	Serpentinite
Precambrian	Unconformity Gneissic and Plutonic Rocks	Fault Gneissic and Plutonic Rocks	Unconformity Gneissic and Plutonic Rocks	Unconformity Gneissic and Plutonic Rocks	Setters Quartzite Unconformity Gneissic and Plutonic Rocks	Unconformity Gneissic and Plutonic Rocks	Unconformity Gneissic and Plutonic Rocks

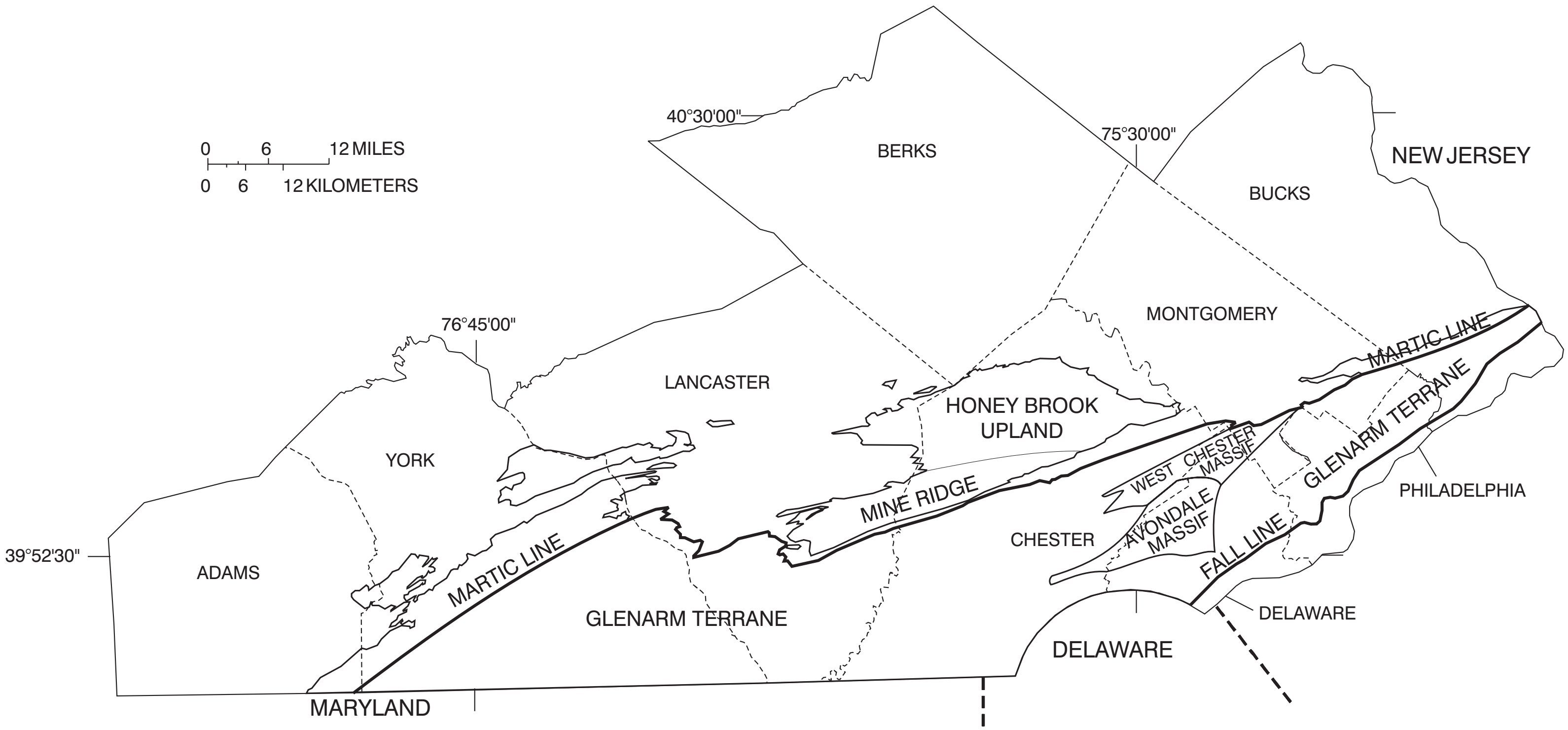


Figure 12. Major geologic terranes of the Piedmont Upland Section (modified from Faill, 1997, fig. 4).

Although the Piedmont Upland receives nearly uniform precipitation throughout the year, much of the recharge to ground water takes place from late fall to early spring. During the remainder of the year, rapid plant growth, high evapotranspiration rates, and soil-moisture deficits greatly reduce the amount of recharge that reaches the ground-water system. Much of the precipitation returns to the atmosphere or reaches streams as overland runoff. The precipitation that is not lost to evapotranspiration, soil saturation, or overland runoff infiltrates into the regolith and the underlying bedrock. After reaching the saturated zone, ground water moves from areas of high hydraulic head to areas of lower hydraulic head and eventually returns to land surface through wells, springs, or streams. Ground water discharged to streams as base flow is important to maintain adequate streamflow and to dilute effluents discharged during periods of little precipitation. Lloyd and Growitz (1977, p. 27) estimated that (in central and southern York County) about two-thirds of the water that constitutes streamflow is ground water. Gerhart and Lazorchick (1988, p. 27-28), using annual precipitation, base flow, and lithologies, determined that 28 percent of annual precipitation became ground-water recharge for Paleozoic sedimentary rocks and 22 percent of annual precipitation recharged ground water in the crystalline rocks.

The most important regional bedrock aquifer in the Piedmont Upland is the Oligoclase-Mica Schist. It underlies about 30 percent of the entire Piedmont Upland, including the more populated areas. Important, highly productive, local bedrock aquifers include the Cockeysville Marble and the Peach Bottom Slate and Cardiff Conglomerate. Less productive units include the Plutonic Rocks and Albite-Chlorite Schist; the least productive unit is the Marburg Schist.

Ground-water flow in the Piedmont Upland is dominated by local flow with ridges or hilltops commonly serving as water-table divides (fig. 13). According to LeGrand (1988, p. 205), the small, numerous, ground-water systems that comprise local flow closely correspond to small surface-water drainage systems in which a perennial stream is present.

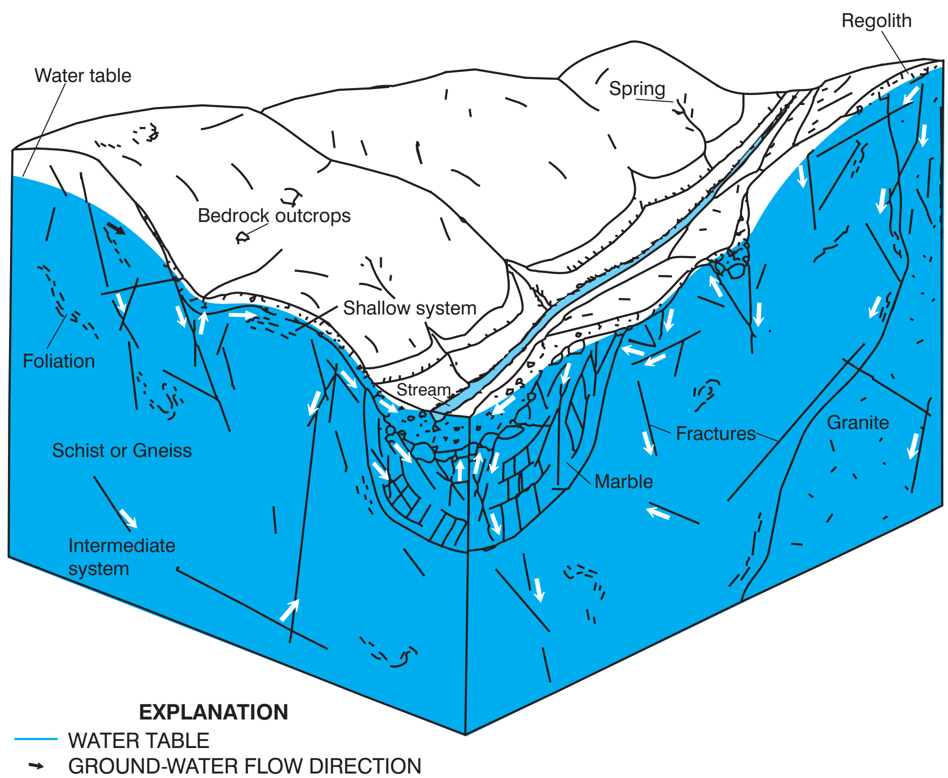


Figure 13. Topographic, geologic, and hydrologic features of the Piedmont Physiographic Province, Piedmont Upland Section.

Regolith

In the Piedmont Upland, regolith is composed of granular to clayey soil and saprolite, and disaggregated bedrock. The regolith also may include deposits of colluvium on slopes and alluvium in valley bottoms. Regolith permits infiltration of precipitation and stores large quantities of water in intergranular pores. These pores then slowly release water to the underlying, fractured bedrock. The porosity of regolith typically far exceeds that of the underlying fractured bedrock, but the saturated regolith by itself commonly is not thick enough (fig. 13) to support sustained yields to wells (Stewart, 1962, p. B106-107).

In the regolith, ground water generally flows downslope; however, the direction and rate of flow can be affected by the amount of bedrock weathering, mineral composition of the parent rock, orientation of mineral grains (especially micas), the presence of shear zones, quartz veins, and fractures. Stewart (1962, p. B-106) found that ground-water movement parallel to foliation of mica crystals can be 25 to 100 times greater than that of water moving normal to or at an angle to the schistosity.

Thickness of regolith and saturated (casing depth – static water level) regolith varies according to the underlying geohydrologic unit and topographic setting. The median thickness of regolith, estimated from the depth of casing in 1,740 domestic wells completed in the Piedmont Upland, is 40 ft. Regolith thickness is least in the Marburg Schist and greatest in the Cockeysville Marble. Geohydrologic units that have some of the thinnest saturated regolith are the Albite-Chlorite Schist, Peach Bottom Slate and Cardiff Conglomerate, and the Antietam Formation. The Cockeysville Marble has the greatest thickness of saturated regolith. Valleys have a greater thickness of saturated regolith than slopes or hilltops.

The exact amount of ground water stored in saturated regolith is unknown. However, its approximate magnitude can be determined from estimates of specific yield. McGreevy and Sloto (1977, p. 33) estimated a specific yield of 0.08 in saturated regolith for noncarbonate and non-Triassic rocks in Chester County, Pa. Olmstead and Hely (1962, p. 18) estimated the specific yield of saturated regolith for crystalline rocks in the Brandywine Creek Basin, Pa., as 0.075 to 0.10.

Fractured Bedrock

Ground water is stored in and moves through consolidated bedrock in networks of cleavage planes, joints, faults, or solution openings (fig. 13). The consolidated bedrock has negligible intergranular porosity; fracturing and chemical weathering provide most of the available porosity. Although fractured bedrock may have a low porosity, the permeability of individual fractures can be quite high. Fractured bedrock yields usable quantities of water to wells nearly everywhere. The quantity of water stored in fractured bedrock may be insufficient to sustain high well yields for long periods of time. However, fractures may be replenished by seepage if the overlying regolith is saturated.

Although it is not possible to determine an exact thickness or maximum depth of the fresh ground-water system, several methods can provide useful estimates. These methods include borehole temperature logs, borehole velocity measurements (R.W. Conger, U.S. Geological Survey, 1996, written commun.), and depth distributions of water-bearing zones reported by well drillers.

In the Oligoclase-Mica Schist, the USGS logged a well completed at a depth of 651 ft. Analysis of the borehole temperature log indicated no geothermal gradient was present. The absence of a geothermal gradient suggests ground water was entering the well near the final depth and moving upwards to an area of lower hydraulic pressure.

Depth distributions of water-bearing zones are varied and appear to be somewhat dependent on the bedrock lithology. Quartz-rich rocks such as the Setters Quartzite, Chickies Formation, or Antietam Formation have median water-bearing zone depths of 100, 110, and 112 ft below land surface, respectively. Quartz-poor rocks, such as the Cockeysville Marble and Marburg Schist, have median water-bearing zone depths of 77 and 81 ft, respectively. The deepest water-bearing zone was encountered in the Gneissic Rocks at a depth of 650 ft.

Gneissic Rocks (g)

The Gneissic Rocks are regionally metamorphosed rocks that exhibit textural and compositional banding; the layers are more widely spaced than those in schistose rocks. Ten different gneissic lithologies are mapped in the Piedmont Upland of Pennsylvania (Berg and others, 1980)—granite gneiss (gn), granodiorite gneiss (ggd), quartz monzonite gneiss (gqm), hornblende- (fgh) and pyroxene-bearing (fgp) felsic gneisses, graphitic gneiss (gg), hornblende gneiss (hg), hornblende- (mgh) and pyroxene-bearing (mgp) mafic gneisses, and gabbroic gneiss (gga).

Gneissic Rocks underlie about 285 mi^2 of the Piedmont Upland and are present in parts of Lancaster, Chester, Delaware, Montgomery, Bucks, and Philadelphia Counties (Berg and others, 1980). Data from wells completed in these rocks are evaluated together because each lithology has similar water-bearing properties and water quality.

Geologic description.—The Gneissic Rocks (table 2) include a wide range of colors, texture, and mineral content. Colors range from dark gray to light gray, buff, pink, or tan. Grain size ranges from one thirty-second to one-fourth inch. The gneissic texture generally is defined by layers of platy or elongated minerals, usually biotite, muscovite, or hornblende, between layers of more equigranular minerals such as quartz, feldspar, amphibole, or pyroxene. Quartz and potassium feldspar are the dominant minerals; hornblende, biotite, and pyroxene are the most common secondary minerals.

The Gneissic Rocks form hills of medium to high relief with fairly steep and stable slopes. These rocks are moderately to highly resistant to weathering. Joints are the most common fractures and are commonly open.

Thicknesses of the Gneissic Rocks are not known in the Piedmont Upland. Originally, these rocks constituted part of the gneissic basement (Crawford and Crawford, 1980). The basement gneisses are dated as Precambrian by Tilton and others (1960) and Grauert and others (1973).

Well depths and casing lengths.—Depths of wells completed in the Gneissis Rocks are presented in the table below. All but two of eight wells completed at depths of 500 ft or greater are high-demand wells.

Reported well depth, Gneissic Rocks

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	833	63	85	125	200	300	30	916
Drilled, domestic	553	60	80	120	174	250	30	900
Drilled, high-demand	120	79	113	190	300	400	40	916

Topographic setting can affect well depth. Domestic wells on hilltops are completed at significantly greater depths than in valleys. The median depths of domestic wells on hilltops (104 wells), slopes (350 wells), and in valleys (33 wells) are 120, 120, and 95 ft, respectively.

Casing lengths for wells completed in the Gneissic Rocks are presented in the table below.

Reported casing length, Gneissic Rocks

[Casing length in feet; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	628	22	30	40	58	75	6	318
Drilled, domestic	434	21	30	40	56	75	6	245
Drilled, high-demand	83	26	39	48	60	138	20	286

Casing length can vary spatially. Casing lengths of wells completed in the Gneissic Rocks in Bucks County (14 wells) are significantly greater than the casing lengths of wells in Chester (367 wells) and Delaware Counties (228 wells). The casing lengths of wells in Chester County also are significantly greater than in Delaware County. The median casing lengths in Bucks, Chester, and Delaware Counties are 63, 41, and 40 ft, respectively.

Hydrologic properties.—Water levels for wells completed in the Gneissic Rocks are presented in the table below. Depths to water in 782 wells range from flowing at land surface to 250 ft below land surface; the median is 25 ft below land surface. Of the nine flowing wells, four are in valleys and three are on slopes.

Water levels, Gneissic Rocks

[Water levels in feet below land surface; F, flowing well; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	123	15	21	32	45	73	3	250
Slope	436	10	17	27	37	51	F	250
Valley	86	3	5	12	19	39	F	60

Reported yields in the Gneissic Rocks are presented in the table below. Yields of 5.0 gal / min or less are reported from 155 wells, and 60 wells have reported yields of 100 gal / min or greater. Of these 60 high yielding wells, 25 are completed at depths greater than 200 ft.

Reported well yield, Gneissic Rocks

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	760	3.0	6.0	15	30	75	0.0	650
Domestic	509	3.0	5.5	12	20	40	.3	270
High-demand	122	10	20	47	107	242	2.0	650

Topographic setting can affect yield. Wells on hilltops (136 wells) or slopes (423 wells) have significantly lower reported yields than wells in valleys (110 wells). The median reported yields of wells on hilltops, slopes, and in valleys are 12, 12, and 41 gal / min, respectively. High-demand and domestic wells also follow this pattern of significantly more productive wells being in valleys. The median reported yield of high-demand wells on hilltops (15 wells) is 19 gal / min, on slopes (48 wells) 40 gal / min, and in valleys (40 wells) 100 gal / min. For domestic wells, hilltops (101 wells) and slopes (321 wells) have a median reported yield of 10 gal / min; in valleys (32 wells), the median reported yield is 22 gal / min.

Specific capacities for wells completed in the Gneissic Rocks are presented in the following table. Fifty-six wells (drilled from 93 to 900 ft below land surface) have specific capacities of 0.04 (gal / min) / ft or less and are incapable of meeting most domestic or other water-use demands. Sixty-five wells have specific capacities of 1.0 (gal / min) / ft or greater; 9 are deeper than 200 ft. Specific capacities of wells with pumping durations of 8 hours or longer (38 wells) range from 0.04 to 62 (gal / min) / ft; the median is 1.4 (gal / min) / ft.

Reported specific capacity, Gneissic Rocks

[Specific capacity in gallons per minute per foot of drawdown; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	322	0.01	0.05	0.20	0.67	3.3	0.00	62
Domestic	219	.01	.04	.14	.42	1.6	.00	50
High-demand	59	.04	.20	.94	4.0	8.4	.01	62

Topographic setting also can affect specific capacity. Wells in valleys (54 wells) have significantly greater specific capacities than wells on hilltops (40 wells) or slopes (191 wells); the median specific capacities of wells in hilltops, slopes, and valleys are 0.12, 0.16, and 0.63 (gal / min) / ft, respectively.

Values of hydraulic conductivity and transmissivity for the Gneissic Rocks are presented below; a specific yield of 0.02 was used in estimating these hydrologic properties. Hydraulic conductivity and transmissivity are generally lower on hilltops and slopes than in valleys. The median hydraulic conductivities of wells on hilltops (30 wells), slopes (151 wells), and valleys (51 wells) are 0.40, 0.51, and 1.5 ft / d, respectively. The median transmissivities of wells on hilltops, slopes, and valleys are 34, 25, and 99 ft^2 / d, respectively.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Gneissic Rocks

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	261	0.03	0.14	0.66	2.9	14	0.00	730
Transmissivity (ft^2 / d)	261	4.0	11	35	130	760	.40	14,800

In other work, Dingman and others (1956) used one well completed in the Baltimore Gneiss of the Maryland Piedmont to estimate transmissivities of 307 to 709 ft^2 / d. Gerhart and Lazorchick (1988, p. 22) estimated hydraulic conductivities of 0.67 to 1.34 ft / d for the upper 200 ft of their Lower Susquehanna River Basin digital model and hydraulic conductivities of 0.067 to 0.134 ft / d for the lower 200 ft of their model. Olmsted and Hely (1962, p. 20) estimated a transmissivity of about 134 ft^2 / d for the Brandywine Creek Basin. In their model of the Red Clay Creek Basin, Vogel and Reif (1993, table 10) estimated horizontal hydraulic conductivity. For hilltops, horizontal hydraulic conductivity ranged from 0.01 to 0.22 ft / d; for slopes, from 0.01 to 22.92 ft / d; and for valleys, from 0.32 to 36.14 ft / d. The calibrated slope values for aquifer horizontal hydraulic conductivity in the mafic and felsic gneisses were 0.15 and 0.19 ft / d, respectively.

The depths of water-bearing zones in 486 wells drilled as deep as 900 ft range from near land surface to 650 ft below land surface. Fifty percent of the 1,072 water-bearing zones reported are penetrated by a depth of 79 ft and 90 percent by a depth of 190 ft. The greatest density of water-bearing zones (0.92 per 50-ft of well depth) is from 51 to 100 ft below land surface (fig. 14); the density of water-bearing zones at depths of 351 ft or greater are based on the presence of only one water-bearing zone per 50-ft interval. The overall density of water-bearing zones in the Gneissic Rocks is 0.57 per 50 ft of well depth.

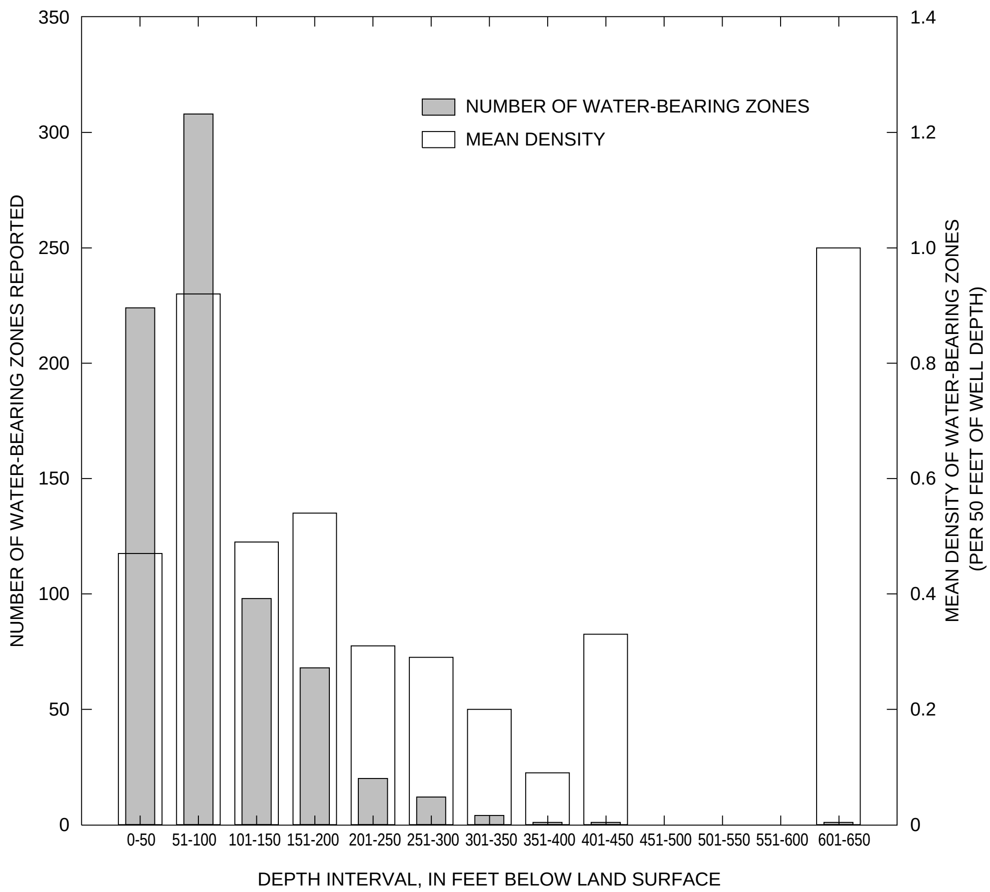


Figure 14. Number and density of water-bearing zones per 50 feet of well depth in the Gneissic Rocks of the Piedmont Physiographic Province, Piedmont Upland Section.

Water quality.—As seen in the following table, wells completed in the Gneissic Rocks generally yield water that is low in dissolved solids, soft to moderately hard, and slightly acidic. Calcium is the dominant cation, and bicarbonate is the dominant anion. Elevated concentrations of iron, manganese, nitrate, and radon and low pH are common water-quality problems.

In the Red Clay Creek Basin of Pennsylvania and Delaware, Senior (1996, table 13) found that the median concentration or value for pH, specific conductance, dissolved oxygen, alkalinity, chloride, sulfate, and nitrate plus nitrite were significantly lower in the Gneissic Rocks than in the Cockeysville Marble. Significant differences in other physical and chemical properties and selected dissolved constituents were also noted between the Gneissic Rocks and other lithologic units (Oligoclase-Mica Schist, Serpentinite, and Setters Quartzite) studied.

The pH of water from wells in Delaware County (122 wells) ranges from 5.4 to 7.9 and is significantly greater than the pH of water (133 wells) in Chester County, which ranges from 4.1 to 7.7; the medians are 6.5 and 6.4, respectively. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Gneissic Rocks

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; pCi/L, picoCurie per liter; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	318	—	—	—	130	190	260	34	1,500
Field hardness	320	—	—	—	51	68	100	7	430
Field pH (standard units)	284	—	<6.5 >8.5	155	6.1	6.4	6.7	4.0	7.9
Bicarbonate	94	—	—	—	26	41	57	4.0	140
Calcium	61	—	—	—	13	20	29	1.5	140
Chloride	90	—	250	3	5.2	12	28	1.0	1,800
Iron	85	—	.3	29	.010	.050	.72	.000	7.5
Magnesium	61	—	—	—	4.7	6.4	11	.10	41
Manganese	70	—	.05	15	.002	.009	.020	.000	1.0
Nickel	52	0.1	—	0	.002	.003	.006	.001	.10
Nitrate (as N)	86	10	—	13	1.1	3.0	6.2	.01	38
Potassium	59	—	—	—	1.3	2.0	2.8	.20	19
Radon (pCi/L)	8	[3] 300	—	5	190	560	1,700	71	4,000
Silica	57	—	—	—	18	24	28	.30	40
Sodium	59	—	—	—	6.0	7.1	11	1.6	110
Sulfate	80	—	250	0	13	23	36	.30	110
Total dissolved solids	78	—	500	2	113	145	227	20	929

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.
[3] U.S. Environmental Protection Agency, 1994, proposed maximum contaminant level.

Plutonic Rocks (p)

The Plutonic Rocks consist primarily of quartz monzonite (gqm), granodiorite (ggd), anorthosite (a, Xa), and related gneisses, gabbro and gabbroic gneiss (gga); metadiabase (md), metagabbro (Xmg), and pegmatite (Xpg) are minor (Berg and others, 1980). These rocks underlie about 150 mi^2 of the Piedmont Upland and are present in parts of Chester, Delaware, Lancaster, Philadelphia, and York Counties. The Plutonic Rocks comprise a large part of the Honey Brook Uplift. In the Glenarm Terrane and Mine Ridge areas, however, the Plutonic Rocks are limited to numerous small exposures (fig. 10). Data from wells completed in these rocks are evaluated together because each lithology has similar water-bearing properties and water quality.

Geologic description.—The Plutonic Rocks (table 2) include a wide range of colors, texture, and mineral content. Colors range from dark gray to light gray, buff, pink, green, or tan. Grain size ranges from one thirty-second to several inches in the pegmatite and from one thirty-second to one-half inch in the other rock types. Quartz, plagioclase, and feldspar are the most common minerals; biotite and muscovite are fairly common in the gneisses; hypersthene or augite are common secondary minerals in the gabbro. In places, the Plutonic Rocks may possess metamorphic textures and mineral phases and are commonly associated with and grade into metamorphic gneisses.

Plutonic rocks generally underlie hills of moderate to high relief with narrow valleys. Areas underlain by the pegmatite are commonly more deeply weathered than for other rock types. Large boulders should be expected in most areas. The abundance of joints will vary from rock type to rock type, but joints generally are moderately abundant and open.

The basement gneisses in the Honey Brook Uplift have been dated as upper middle Precambrian. A charnockite associated with the anorthosite near the Delaware-Pennsylvania state line has been dated as Cambrian to Ordovician in age (Tilton and others, 1960; Grauert and others, 1973; Foland and Muessig, 1978).

Well depths and casing lengths.—Depths of wells completed in the Plutonic Rocks are presented in the table below. Twenty wells are deeper than 300 ft; 5 are high-demand wells and 14 are domestic wells.

Reported well depth, Plutonic Rocks

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	314	62	82	100	176	280	28	562
Drilled, domestic	246	60	78	100	150	245	42	550
Drilled, high-demand	27	95	125	200	260	324	65	562

Topographic setting can affect well depth. Domestic wells on hilltops are completed at significantly greater depths than wells in valleys. The median depths of domestic wells on hilltops (26 wells), slopes (180 wells), and in valleys (33 wells) are 130, 95, and 93 ft, respectively.

Casing lengths for wells completed in the Plutonic Rocks are presented in the table below. The four wells in the Plutonic Rocks with casing lengths greater than 100 ft consist of a high-demand well and three domestic wells. Casing lengths for high-demand and domestic wells are not significantly different.

Reported casing length, Plutonic Rocks

[Casing length in feet; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	291	21	32	41	54	68	7	186
Drilled, domestic	233	22	32	40	54	67	7	186
Drilled, high-demand	24	20	35	43	53	79	15	141

Hydrologic properties.—Water levels for wells completed in the Plutonic Rocks are presented in the table below. Depths to water in 248 wells range from flowing 3 ft above land surface to 87 ft below land surface; the median depth to water is 22 ft below land surface. The two flowing wells are in valleys.

Water levels, Plutonic Rocks

[Water levels in feet below land surface except for flowing well; -, flowing well; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	27	11	20	35	43	46	2	55
Slope	175	9	15	24	34	42	1	87
Valley	40	2	5	9	18	36	- 3	50

Reported yields for wells completed in the Plutonic Rocks are presented in the table below. Yields of 5.0 gal / min or less are reported from 51 wells; 19 wells reported yields of 100 gal / min or greater. Of the 19 high-yielding wells, only 5 are deeper than 200 ft.

Reported well yield, Plutonic Rocks

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	90	75	Median	25	10	Minimum	Maximum
All	304	3.0	8.2	20	37	75	0.00	234
Domestic	237	4.0	8.0	20	35	52	.50	100
High-demand	30	12	30	60	102	198	4.0	234

Topographic setting can affect yield. Wells in valleys (47 wells) and on slopes (221 wells) have significantly greater reported yields than wells on hilltops (30 wells); the median reported yields are 30, 20, and 12 gal / min, respectively. Domestic wells also follow this pattern. The median reported yield of domestic wells on hilltops (24 wells) is 8.5 gal / min, on slopes (175 wells) 20 gal / min, and in valleys (34 wells) 30 gal / min.

Specific capacities for wells completed in the Plutonic Rocks are presented in the table below. Twenty-one wells (drilled from 100 to 562 ft below land surface) have specific capacities of 0.04 (gal / min) / ft or less and are incapable of meeting most domestic or other water-use demands. None of the wells with specific capacities of 3.5 (gal / min) / ft or greater are deeper than 200 ft. Specific capacities of wells with pumping durations of 8 hours or longer (11 wells) range from 0.12 to 3.5 (gal / min) / ft; the median is 0.57 (gal / min) / ft.

Reported specific capacity, Plutonic Rocks

[Specific capacity in gallons per minute per foot of drawdown; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	123	0.03	0.12	0.37	0.90	2.6	0.00	15
Domestic	86	.03	.12	.34	.84	2.5	.00	15
High-demand	18	.04	.19	.42	1.8	2.1	.04	3.5

Values of hydraulic conductivity and transmissivity for the Plutonic Rocks are presented below; a specific yield of 0.02 was used in estimating these hydrologic properties. The median hydraulic conductivities of wells on hilltops (8 wells), slopes (84 wells), and valleys (16 wells) are 0.70, 0.95, and 1.4 ft / d, respectively. The median transmissivities of wells on hilltops, slopes, and valleys are 51, 61, and 79 ft^2 / d, respectively.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Plutonic Rocks

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	110	0.02	0.17	0.87	4.3	18	0.00	190
Transmissivity (ft^2 / d)	110	1.7	16	61	140	410	.18	2,800

The depths of water-bearing zones in 245 wells drilled as deep as 420 ft range from 20 to 360 ft below land surface. Fifty percent of the 526 water-bearing zones reported are penetrated by a depth of 70 ft and 90 percent by a depth of 158 ft. The greatest density of water-bearing zones (1.12 per 50 ft of well depth) is from 51 to 100 ft below land surface (fig. 15); the density of water-bearing zones at depths of 251 ft or greater are based on the presence of three or less zones per 50-ft interval. The overall density of water-bearing zones in this unit is 0.61 per 50 ft of well depth.

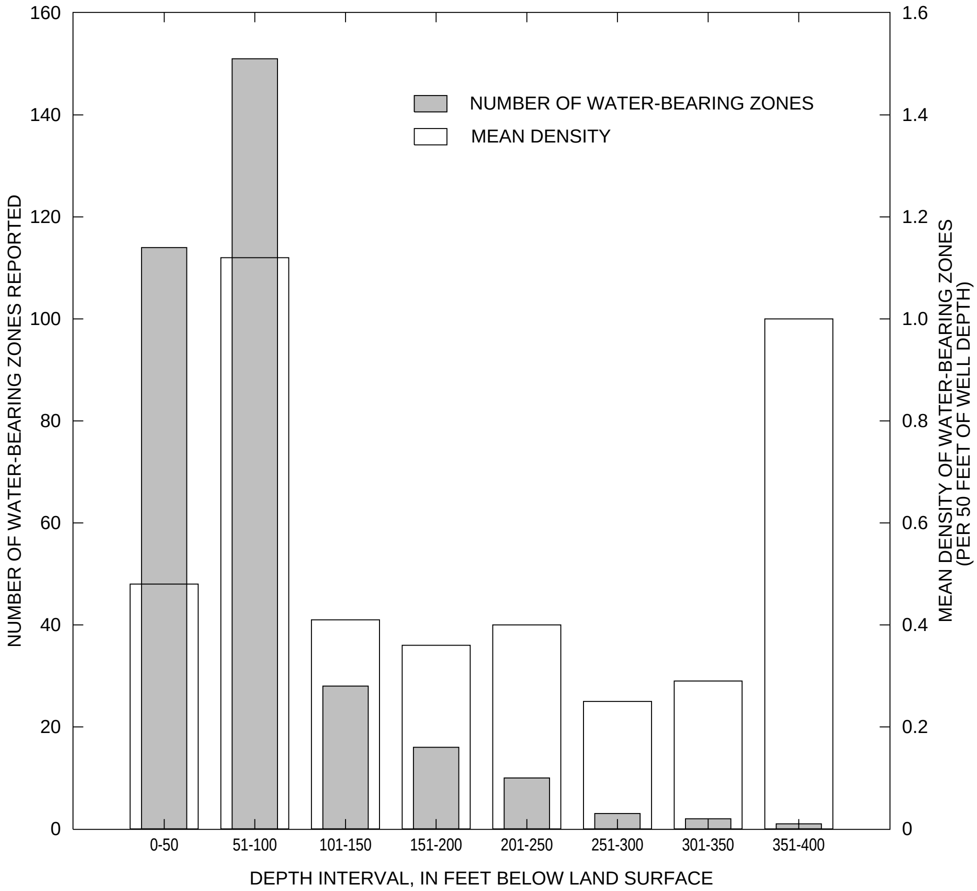


Figure 15. The number and density of water-bearing zones per 50 feet of well depth in the Plutonic Rocks of the Piedmont Physiographic Province, Piedmont Upland Section.

Water quality.—As seen in the following table, wells completed in the Plutonic Rocks generally yield water that is low in dissolved solids, soft to moderately hard, and slightly acidic; calcium is the dominant cation, and bicarbonate is the dominant anion. Elevated concentrations of iron, manganese and radon and low pH are common water-quality problems.

The specific conductance of water from wells in valleys is significantly greater than wells on slopes. The median specific conductance of water in wells located in valleys (23 wells), slopes (83 wells), and hilltops (11 wells) are 180, 120, and 135 μS/cm, respectively. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Plutonic Rocks

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; pCi/L, picoCurie per liter; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	123	—	—	—	100	140	190	25	810
Field hardness	122	—	—	—	34	51	85	6	270
Field pH (standard units)	124	—	<6.5 >8.5	100	6.0	6.2	6.4	4.0	7.9
Bicarbonate	52	—	—	—	16	28	40	2.0	400
Calcium	48	—	—	—	7.3	12	20	3.6	46
Chloride	48	—	250	0	4.0	8.2	13	1.0	60
Iron	48	—	.3	6	.010	.020	.053	<.003	85
Magnesium	38	—	—	—	2.6	4.0	6.1	.80	12
Manganese	46	—	.05	9	.006	.010	.020	.000	4.8
Nitrate (as N)	34	10	—	1	.51	2.2	3.8	.08	11
Potassium	35	—	—	—	1.0	1.6	2.2	.20	5.0
Radon (pCi/L)	6	[3]300	—	6	320	420	6,200	310	8,200
Silica	35	—	—	—	17	21	24	8.0	38
Sodium	36	—	—	—	4.5	5.9	8.2	2.7	16
Sulfate	48	—	250	0	4.1	15	26	.10	45
Total dissolved solids	48	—	500	0	79	106	167	32	298

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.
[3] U.S. Environmental Protection Agency, 1994, proposed maximum contaminant level.

Serpentinite (Xs)

Serpentinite underlies relatively small parts of the Piedmont Upland of Pennsylvania in Chester, Delaware, Lancaster, Philadelphia, and York Counties. The bodies of serpentinite are commonly elongate; the total outcrop area is about 20 mi^2 (Berg and others, 1980). All of the Serpentinite data presented in this report are from wells in Chester and Delaware Counties.

Geologic description.—Serpentinite (table 2) is massive, green, greenish-yellow, or greenish-gray rock that is commonly veined or spotted. It is composed primarily of serpentine-group minerals such as antigorite or chrysotile. Chlorite, talc, and magnetite are common secondary minerals; at some localities in the Piedmont Upland, serpentinites host commercial deposits of chrysotile and chromite.

Areas underlain by Serpentinite generally form rolling hills with moderate slopes that for the most part remain uncultivated and possess only sparse vegetation lending to the term “Serpentinite Barrens.” Soils formed over serpentinite “* * * are rich in magnesia and correspondingly poor in lime and potash; they are typically thin and therefore unable to retain moisture.” (Pearre and Heyl, 1960, p. 710). The Serpentinite is moderately resistant to weathering, with abundant, closely spaced and irregular open joints (Geyer and Wilshusen, 1982, p. 256).

Serpentinite is associated with and is a product of retrograde metamorphism of mafic plutonic rocks. Lyttle and Epstein (1987, pl. 2) considered the Serpentinite to be Cambrian and Late Proterozoic in age (table 2).

Well depths and casing lengths.—Depths of wells and reported casing lengths for wells completed in the Serpentinite are presented in the following tables. Only seven wells in the Serpentinite are completed at depths greater than 150 ft; five wells use more than 80 ft of casing.

Reported well depth, Serpentinite

[Depth in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	40	63	82	102	130	242	40	340
Drilled, domestic	33	65	82	100	126	220	40	340
Drilled, high-demand	4	—	—	222	—	—	72	310

Reported casing length, Serpentinite

[Casing length in feet; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	35	13	23	43	63	93	9	108
Drilled, domestic	30	15	23	41	63	90	9	98
Drilled, high-demand	4	—	—	52	—	—	9	108

Hydrologic properties.—Water levels for wells completed in the Serpentinite are presented in the table below. Depths to water in 35 wells range from 5 to 60 ft below land surface; the median is 20 ft below land surface.

Water levels, Serpentinite

[Water levels in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	3	—	—	11	—	—	10	20
Slope	21	6	14	24	35	40	5	60
Valley	5	—	9	12	15	—	7	18

Reported yields in the Serpentinite are presented in the following table. Yields of 5.0 gal / min or less are reported from 10 domestic wells. Of the 11 wells with reported yields of 20 gal / min or greater, only 4 are shallower than 200 ft.

Reported well yield, Serpentinite

[Yield in gallons per minute; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	40	3.1	5.5	12	25	50	2.0	80
Domestic	34	2.5	5.0	12	23	40	2.0	75
High-demand	4	—	—	55	—	—	10	80

Specific capacities for wells completed in the Serpentinite are presented in the table below. Five domestic wells (drilled from 117 to 340 ft below land surface) have specific capacities of 0.04 (gal / min) / ft or less and are incapable of meeting most domestic water-use demands. None of the wells with specific capacities of 1.0 (gal / min) / ft or greater are deeper than 103 ft.

Reported specific capacity, Serpentinite

[Specific capacity in gallons per minute per foot of drawdown; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	26	0.02	0.10	0.22	1.1	5.8	0.01	38
Domestic	23	.01	.10	.23	1.2	9.7	.01	38
High-demand	2	—	—	.28	—	—	.21	.36

Values of hydraulic conductivity and transmissivity for the Serpentinite are presented below; a specific yield of 0.02 was used in estimating these hydrologic properties. Hydraulic conductivity and transmissivity are generally lower on hilltops and slopes than in valleys. The median hydraulic conductivities of wells on hilltops (3 wells), slopes (15 wells), and valleys (4 wells) are 1.0, 0.64, and 6.3 ft / d, respectively. The median transmissivities of wells on hilltops, slopes, and valleys are 45, 26, and 180 ft^2 / d, respectively.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Serpentinite

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	23	0.11	0.20	1.0	4.6	54	0.00	250
Transmissivity (ft^2 / d)	23	5.3	14	45	170	1,800	.40	7,600

In other work, Geyer and Wilshusen (1982, p. 257) reported rock-test data on the Serpentinite. The reported permeability of weathered Serpentinite ranged from 1 to 615 ft / d and from 0 to 0.5 ft / d on unweathered Serpentinite.

The depths of water-bearing zones in 29 wells drilled as deep as 340 ft range from 25 to 340 ft below land surface. Fifty percent of the 59 water-bearing zones reported are penetrated by a depth of 80 ft and 90 percent by a depth of 170 ft. The greatest density of water-bearing zones (0.89 per 50 ft of well depth) is from 51 to 100 ft below land surface (fig. 16). The overall density of water-bearing zones in this unit is 0.55 per 50 ft of well depth.

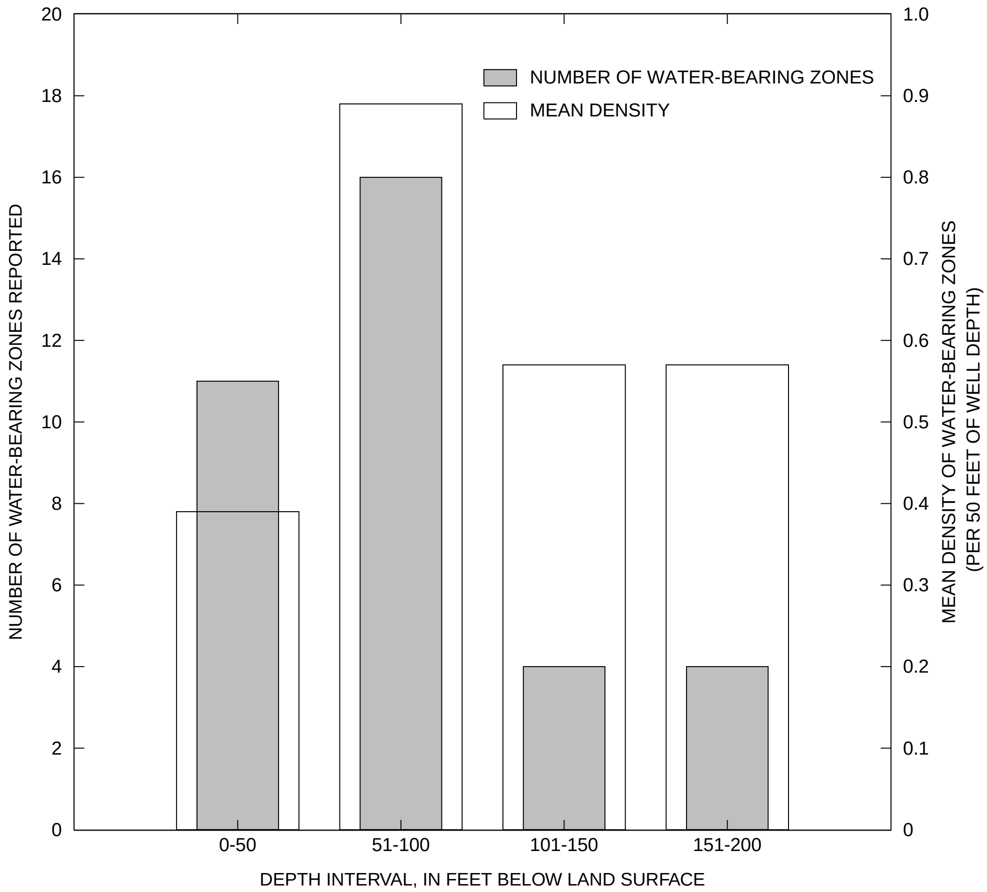


Figure 16. The number and density of water-bearing zones per 50 feet of well depth in the Serpentinite of the Piedmont Physiographic Province, Piedmont Upland Section.

Water quality.—As seen in the following table, wells completed in the Serpentinite generally yield water that contains low to moderate amounts of dissolved solids, is moderately hard to very hard, and is alkaline; magnesium is the dominant cation, and bicarbonate is the dominant anion. Elevated concentrations of alkalinity, iron, and manganese are common water-quality problems. The high levels of bicarbonate, magnesium, and silica may cause scaling on hot water pipes or interfere with potential industrial uses. The pH of water in four wells is below the USEPA secondary maximum contaminant level (SMCL); one well contains water with a pH greater than the USEPA SMCL. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Serpentinite

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	18	—	—	—	195	309	365	105	1,300
Field hardness	20	—	—	—	105	150	205	51	750
Field pH (standard units)	18	—	<6.5 >8.5	5	6.9	7.4	8.0	6.1	9.1
Bicarbonate	9	—	—	—	77	120	160	48	270
Calcium	9	—	—	—	2.1	4.3	7.2	1.7	20
Chloride	9	—	250	0	7.3	8.5	11	2.4	30
Iron	11	—	.3	2	.010	.015	.23	<.003	5.4
Magnesium	9	—	—	—	22	29	46	16	76
Manganese	8	—	.05	1	.001	.010	.010	.000	.080
Nitrate (as N)	8	10	—	0	1.2	23	6.0	.61	7.9
Potassium	9	—	—	—	.40	.90	1.4	.30	3.0
Silica	9	—	—	—	9.9	24	32	8.3	40
Sodium	9	—	—	—	2.3	3.1	5.0	1.6	17
Sulfate	9	—	250	0	3.2	7.2	14	1.7	36
Total dissolved solids	9	—	500	0	127	150	199	111	333

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.

Setters Quartzite (Xsq)

The Setters Quartzite underlies about 12 mi^2 of Chester County along the flanks of the Woodville and Avondale massifs (Berg and others, 1980). The reference section is in a small quarry near Avondale, Chester County, Pa.

Geologic description.—The Setters Quartzite (table 2) is coarse grained, white to gray, quartzite, quartzose schist, and feldspathic schist that includes biotite and muscovite. Accessory minerals include hornblende, magnetite, apatite, garnet, zircon, titanite, and schorl. According to Higgins (1972, p. 1,017), the detrital zircons originated in the Baltimore Gneiss. In the lower part of the Setters Quartzite, mica (chiefly biotite) constitutes about 50 percent of the rock (Poth, 1968, p. 56; Sloto, 1994, p. 11).

The Setters Quartzite is very resistant to weathering, forming rolling slopes and hills. Joints are well formed, moderately abundant, and open (Geyer and Wilshusen, p. 257).

Reported thickness of this formation varies markedly from 150 ft (Geyer and Wilshusen, 1982, p. 257) to about 1,000 ft (Bascom and Stose, 1932). The Setters Quartzite is considered by Higgins (1972, p. 1,017) to be latest Precambrian or Early Cambrian in age and comprises the lowest formation in the Glenarm Series (Knopf and Jonas, 1923, p. 45). The formation is bounded by unconformities, with gneisses below and the Cockeysville Marble above (table 2). Poth (1968, p. 57) considered the Setters Quartzite to be correlative to the Chickies Formation and Higgins (1972, p. 1,017) to the lower-most Chilhowee rocks. According to Wagner and Srogi (1987, p. 115), the Setters Quartzite was probably a continental margin deposit formed during a period of collision between a magmatic arc and the North American continent.

Well depths and casing lengths.—Depths of wells completed in the Setters Quartzite are presented in the table below.

Reported well depth, Setters Quartzite

[Depth in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	50	73	93	124	226	300	55	408
Drilled, domestic	29	69	87	115	216	280	55	300
Drilled, high-demand	8	—	125	174	—	343	90	343

Casing lengths for wells in the Setters Quartzite are presented in the table below. Three wells contain more than 200 ft of casing; all three are in valleys and are deeper than 300 ft. Poth (1968, p. 57) noted some unusually deep casings in wells completed in the Setters Quartzite. The reason for these deep casings is not known but may be the result of caving in of weathered rock or intensely fractured zones at unusually great depths.

Reported casing length, Setters Quartzite

[Casing length in feet; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	31	26	40	60	118	209	20	394
Drilled, domestic	14	23	30	51	105	174	21	198
Drilled, high-demand	8	—	42	63	116	—	38	298

Hydrologic properties.—Water levels for wells completed in the Setters Quartzite are presented in the table below. Depths to water in 49 wells range from flowing at land surface to 98 ft below land surface; the median is 20 ft below land surface.

Water levels, Setters Quartzite

[Water levels in feet below land surface; F, flowing well; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	6	—	19	25	37	—	17	56
Slope	35	6	9	18	30	45	F	98
Valley	6	—	2	10	32	—	F	69

Reported yields of wells completed in the Setters Quartzite are presented in the table below. Yields of 5.0 gal / min or less are reported from eight wells. Only 4 of the 20 wells with yields of 20 gal / min or greater are deeper than 200 ft.

Reported well yield, Setters Quartzite

[Yield in gallons per minute; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	44	3.5	10	15	35	85	1.0	110
Domestic	24	2.5	9.2	14	20	42	1.0	50
High-demand	9	—	17.5	50	105	—	2.0	110

Specific capacities for wells completed in the Setters Quartzite are presented in the table below. Three wells (with well depths of 165, 266, and 300 ft below land surface) have specific capacities of 0.04 (gal / min) / ft or less and are incapable of meeting most domestic or other water-use demands. Four wells, however, have specific capacities of 1.0 (gal / min) / ft or greater and should be able to meet all domestic and many high-demand water-use requirements. The specific capacity of one well pumped 8 hours or longer is 1.5 (gal / min) / ft.

Reported specific capacity, Setters Quartzite

[Specific capacity in gallons per minute per foot of drawdown; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	13	0.00	0.08	0.33	1.0	1.8	0.00	2.0
Domestic	9	—	.06	.18	1.0	—	.00	2.0
High-demand	2	—	—	1.1	—	—	.70	1.5

Values of hydraulic conductivity and transmissivity for the Setters Quartzite are presented in the following table; a specific yield of 0.02 was used in estimating these hydrologic properties. Hydraulic conductivity and transmissivity are generally lower on hilltops and slopes than in valleys. The median hydraulic conductivities of wells on hilltops (1 well), slopes (8 wells), and valleys (1 well) are 0.03, 1.6, and 2.9 ft / d, respectively. The median transmissivities on hilltops, slopes, and valleys are 3.2, 79, and 310 ft^2 / d, respectively.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Setters Quartzite

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydraulic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	11	0.06	0.23	1.5	2.9	190	0.03	240
Transmissivity (ft^2 / d)	11	5.3	15	55	190	310	3.2	310

In other work, Vogel and Reif (1993, table 10) estimated horizontal hydraulic conductivity for their Red Clay Creek model. For hilltops, horizontal hydraulic conductivity was 0.02 ft / d. For slopes, the horizontal hydraulic conductivity ranged from 0.15 to 266 ft / d; the median was 0.43 ft / d. The calibrated slope for aquifer horizontal hydraulic conductivity was 0.24 ft / d. Vogel and Reif (1993, table 11) also presented the results from a single-well, long term (35 hour), high-discharge (110 gal / min) aquifer test. The transmissivity was estimated as 305 ft^2 / d, coefficient of storage as 0.10, and hydraulic conductivity as 2.8 ft / d.

The depths of water-bearing zones in 20 wells drilled as deep as 336 ft range from 15 to 260 ft below land surface. Fifty percent of the 38 water-bearing zones are penetrated by a depth of 100 ft and 90 percent by a depth of 213 ft. The greatest density of water-bearing zones (0.76 per 50 ft of well depth) is from 51 to 100 ft below land surface (fig. 17). The density of water-bearing zones at depths of 151 ft or greater are based on the presence of three or fewer water-bearing zones per 50-ft interval. The overall density of water-bearing zones in this unit is 0.46 per 50 ft of well depth.

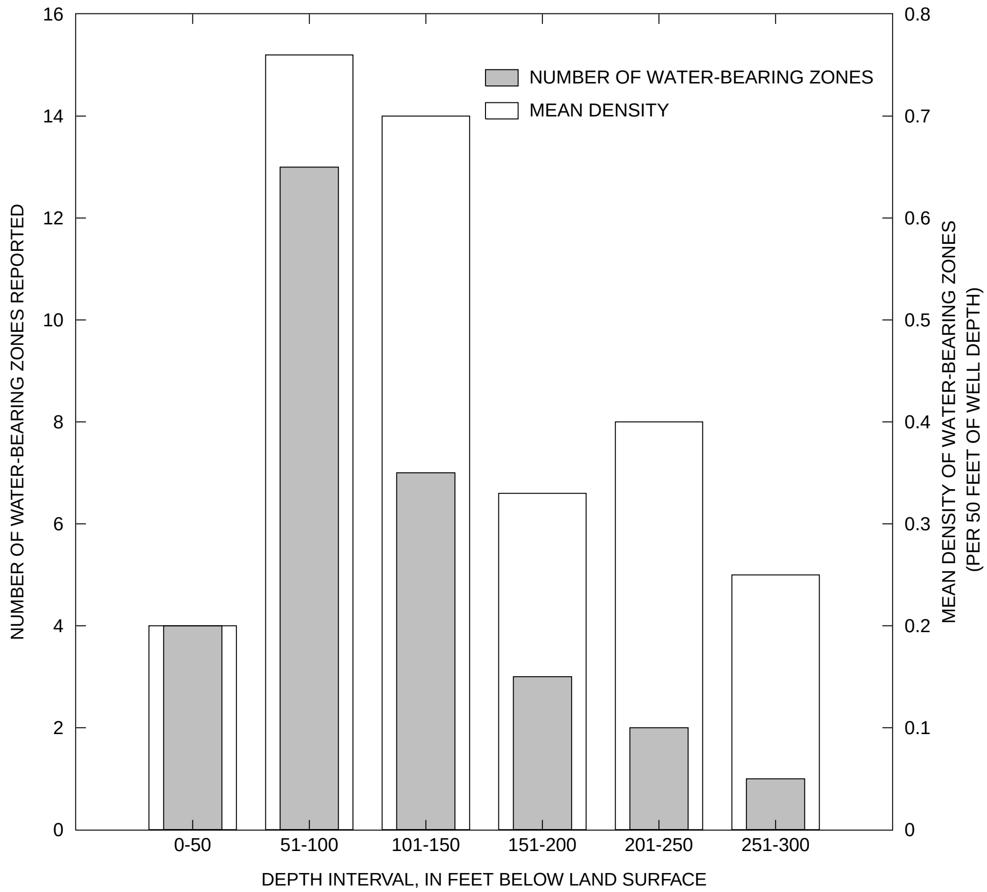


Figure 17. The number and density of water-bearing zones per 50 feet of well depth in the Setters Quartzite of the Piedmont Physiographic Province, Piedmont Upland Section.

Water quality.—As seen in the following table, wells completed in the Setters Quartzite generally yield water that is low in dissolved solids, soft to moderately hard, and slightly acidic; calcium is the dominant cation; chloride, bicarbonate, and sulfate anions are present in about equal amounts. Elevated concentrations of nitrate and radon and low pH are common water-quality problems. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

In the Red Clay Creek Basin of Pennsylvania and Delaware, Senior (1996, table 13) found the median concentration for calcium and barium in the Setters Quartzite was significantly greater than in the Oligoclase-Mica Schist and Serpentinite. Significant differences in other physical and chemical properties and selected dissolved constituents also were noted between the Setters Quartzite and the other lithologic units (Cockeysville Marble, Oligoclase-Mica Schist, Serpentinite, and Gneissic Rocks) studied.

Summary of selected chemical constituents and properties analyzed for the Setters Quartzite

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; pCi/L, picoCurie per liter; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	15	—	—	—	125	185	265	100	410
Field hardness	13	—	—	—	51	68	130	34	170
Field pH (standard units)	10	—	<6.5 >8.5	7	6.0	6.3	6.9	5.4	7.1
Bicarbonate	10	—	—	—	15	18	35	13	64
Calcium	8	—	—	—	7.4	22	31	4.7	36
Chloride	10	—	250	0	3.6	17	32	2.0	85
Iron	8	—	.3	1	.008	.020	.15	.004	.31
Magnesium	8	—	—	—	3.6	7.7	11	2.3	13
Manganese	7	—	.05	0	.001	.002	.005	.000	.013
Nitrate (as N)	5	10	—	2	2.5	11	18	.34	19
Potassium	7	—	—	—	1.0	1.7	2.7	.90	2.7
Radon (pCi/L)	5	[3] 300	—	5	630	1,600	3,400	370	3,800
Silica	7	—	—	—	18	25	31	16	41
Sodium	8	—	—	—	4.2	8.6	14	3.5	15
Sulfate	10	—	250	0	3.7	13	58	.20	100
Total dissolved solids	8	—	500	0	67	175	246	66	302

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.
[3] U.S. Environmental Protection Agency, 1994, proposed maximum contaminant level.

Cockeysville Marble (Xc)

The Cockeysville Marble underlies about 12 mi^2 in central and southern Chester County, cropping out adjacent to the Setters Quartzite and in an area near the Maryland and Delaware state lines (Berg and others, 1980). The reference section is in a quarry near the village of Chatham, Chester County, Pa.

Geologic description.—The Cockeysville Marble (table 2) is typically white to light bluish-gray, medium- to coarse-grained, granular marble, commonly banded with brown phlogopite mica (Poth, 1968, p. 59). It is thickly bedded and tightly folded; vertical jointing is well developed.

The Cockeysville Marble generally forms narrow, elongate valleys that are situated along the flanks of the Woodville and Avondale massifs. The Cockeysville Marble is moderately resistant to weathering. Joint and solution channels, bedrock pinnacles, and sinkholes are common in this unit (Geyer and Wilshusen, 1982, p. 94-95).

Thickness of the Cockeysville Marble is variable; maximum thickness estimates range from 100 to 500 ft (Bascom and Stose, 1932, p. 4) to 1,700 ft (McKinstry, 1961, p. 559). The Cockeysville Marble is part of the Glenarm Series (Knopf and Jonas, 1923, p. 45) and has a suggested age of latest Precambrian or Early Cambrian (Higgins, 1972, p. 1,017). It unconformably overlies the Setters Quartzite and unconformably underlies the Wissahickon Formation (table 2). Poth (1968, p. 59) considered the Cockeysville Marble to be correlative to the limestones of the Chester Valley (Vintage, Kinzers, Ledger, and Elbrook Formations). The Cockeysville Marble was probably a shallow-water shelf or bank deposit (Crowley and others, 1970, p. 44) or a continental margin deposit formed during a period of collision between a magmatic arc and the North American continent (Wagner and Srogi, 1987, p. 115).

Well depths and casing lengths.—Depths of wells and casing lengths for wells completed in the Cockeysville Marble are presented in the tables below. Of the 20 wells drilled to depths of 150 ft or greater, only 2 are domestic wells. The casing lengths of high-demand wells are not significantly greater than domestic wells.

Reported well depth, Cockeysville Marble

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	87	63	75	100	149	226	34	437
Drilled, domestic	29	60	68	85	113	175	50	260
Drilled, high-demand	40	69	81	105	166	259	63	437

Reported casing length, Cockeysville Marble

[Casing length in feet; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	56	31	45	60	80	98	10	229
Drilled, domestic	18	30	41	58	80	98	10	100
Drilled, high-demand	26	21	50	61	75	102	20	229

Hydrologic properties.—Water levels for wells completed in the Cockeysville Marble are presented in the table below. Depths to water in 86 wells range from flowing at land surface to 55 ft below land surface; the median is 15 ft below land surface. The two flowing wells are on slopes.

Water levels, Cockeysville Marble

[Water levels in feet below land surface; F, flowing well; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	2	—	—	41	—	—	28	55
Slope	29	3	11	19	27	37	F	54
Valley	55	4	8	13	18	24	1	42

Reported yields for wells completed in the Cockeysville Marble are presented in the table below. Yields of 5.0 gal/min or less are reported from three domestic wells. Only 2 of the 36 wells with yields of 100 gal/min or greater are deeper than 200 ft.

Reported well yield, Cockeysville Marble

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	81	10	22	75	163	390	4.0	1,800
Domestic	23	5.0	10	20	35	76	4.0	240
High-demand	44	14	71	123	244	450	10	620

Specific capacities for wells completed in the Cockeysville Marble are presented in the table below. Only one of the eight wells with specific capacities of 1.0 (gal / min) / ft or greater is deeper than 200 ft. Specific capacities of 15 wells with pumping durations of 8 hours or longer range from 1.9 to 200 (gal / min) / ft; the median is 6.3 (gal / min) / ft.

Reported specific capacity, Cockeysville Marble

[Specific capacity in gallons per minute per foot of drawdown; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	29	0.40	1.7	4.9	14	56	0.08	200
Domestic	5	—	.70	1.1	4.1	—	.40	5.0
High-demand	20	.55	2.4	6.1	22	64	.08	200

Values of hydraulic conductivity and transmissivity for the Cockeysville Marble are presented in the table below; a specific yield of 0.02 was used in estimating these hydrologic properties. The median hydraulic conductivities of wells on hilltops (1 well), slopes (3 wells), and valleys (23 wells) are 1.4, 41, and 22 ft / d, respectively. The median transmissivities of wells on hilltops, slopes, and valleys are 55, 1,100, and 1,100 ft^2 / d, respectively.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Cockeysville Marble

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	27	0.87	5.9	22	69	320	0.05	810
Transmissivity (ft^2 / d)	27	47	210	1,100	1,900	14,000	11	51,000

In other work, Stewart and others (1964), using five wells completed in saprolite over the Cockeysville Marble near Texas, Md., estimated hydraulic conductivities of 63 to 106 ft / d. Dingman and others (1956) used one well completed in weathered Cockeysville Marble in the Maryland Piedmont to estimate a transmissivity of 4,680 ft^2 / d. Werkheiser (Woodruff and others, 1995, table 7) evaluated several aquifer tests of the Cockeysville Formation in and around Hockessin, New Castle County, Del. In this investigation, storage coefficients ranged from 0.00008 to 0.04; the median was 0.0006. Transmissivity ranged from 940 to 6,820 ft^2 / d; the median was 1,600 ft^2 / d. Olmsted and Hely (1962, p. 20) estimated a transmissivity of about 134 ft^2 / d for the Brandywine Creek Basin. In their model of the Red Clay Creek Basin, Vogel and Reif (1993, table 10) estimated horizontal hydraulic conductivity. For slopes, horizontal hydraulic conductivity was 26.28 ft / d, and for valleys, it ranged from 0.98 to 325 ft / d; the median was 27.69 ft / d. The calibrated slope for aquifer horizontal hydraulic conductivity was 1.52 ft / d. Vogel and Reif (1993, table 11) also presented the results from a single-well, long term (48 hour), high-discharge (245 gal / min) aquifer test. The transmissivity was estimated as 1,270 ft^2 / d and hydraulic conductivity as 91 ft / d.

The depths of water-bearing zones in 25 wells drilled as deep as 262 ft range from 28 to 200 ft below land surface. Fifty percent of the 56 water-bearing zones reported are penetrated by a depth of 77 ft and 90 percent by a depth of 150 ft. The greatest density of water-bearing zones (1.43 per 50 ft of well depth) is from 101 to 150 ft below land surface (fig. 18); the density of water-bearing zones at depths of 151-200 ft are based on the presence of only three water-bearing zones. The overall density of water-bearing zones in this unit is 0.72 per 50 ft of well depth.

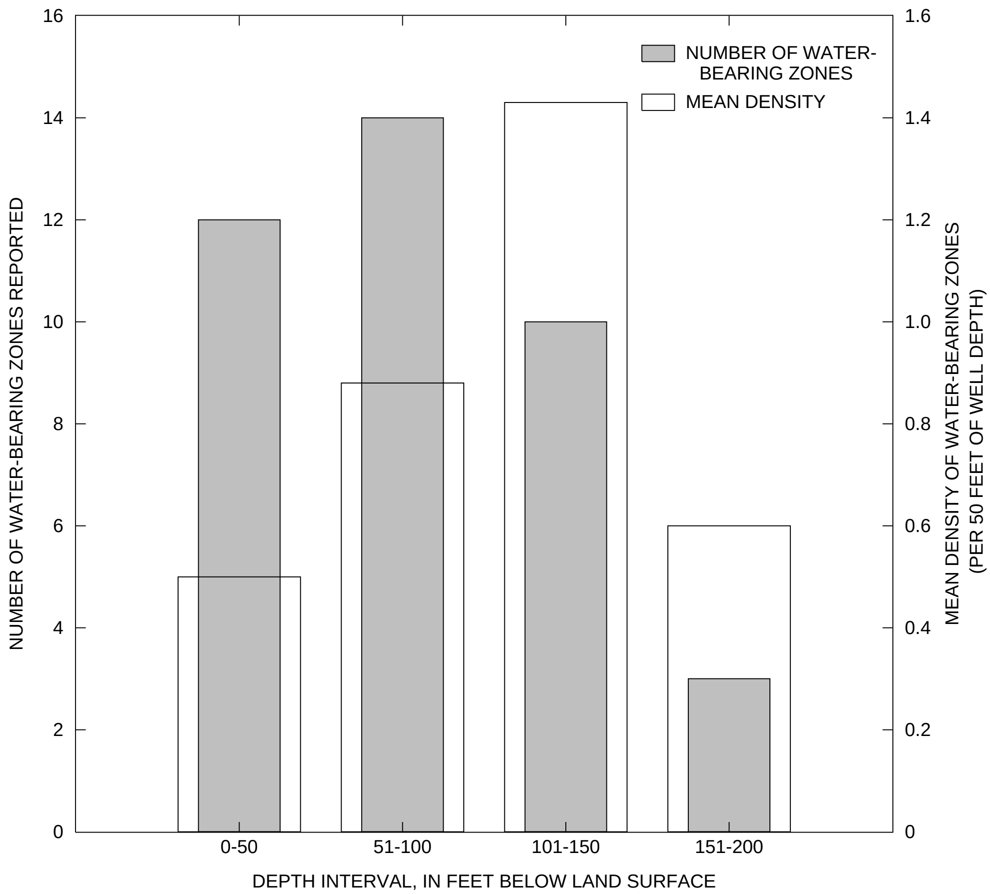


Figure 18. The number and density of water-bearing zones per 50 feet of well depth in the Cockeysville Marble of the Piedmont Physiographic Province, Piedmont Upland Section.

Water quality.—As seen in the following table, wells completed in the Cockeysville Marble generally yield water that contains low to moderate amounts of dissolved solids, is soft to very hard, and slightly alkaline. Calcium and magnesium are the dominant cations, and bicarbonate is the dominant anion. Elevated concentrations of nitrate and radon may be the most common water-quality problems. Of the 18 wells sampled for nitrate, only 1 well contains water with nitrate concentrations greater than the USEPA MCL of 10 mg/L. However, four other wells contain water with nitrate concentrations within 2 mg/L of the USEPA MCL. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

In the Red Clay Creek Basin of Pennsylvania and Delaware, Senior (1996, table 13) found that the Cockeysville Marble had the chemical composition that most differed from that of ground water from the other lithologic groups studied. The median concentration or value for pH, specific conductance, dissolved oxygen, alkalinity, calcium, magnesium, chloride, and nitrate plus nitrite were significantly greater than in the Oligoclase-Mica Schist, Gneissic Rocks, Setters Quartzite, and Serpentinite.

Summary of selected chemical constituents and properties analyzed for the Cockeysville Marble

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; pCi/L, picoCuries per liter; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	13	—	—	—	215	310	413	120	600
Field hardness	17	—	—	—	57	85	203	8	250
Field pH (standard units)	13	—	<6.5 >8.5	3	6.6	7.2	7.6	6.3	8.3
Bicarbonate	26	—	—	—	110	160	200	42	290
Calcium	11	—	—	—	18	40	52	15	110
Chloride	24	—	250	0	10	15	27	4.0	100
Iron	21	—	.3	0	.008	.020	.045	.000	.21
Magnesium	11	—	—	—	9.7	15	23	6.0	58
Manganese	17	—	.05	2	.001	.010	.010	.000	.070
Nitrate (as N)	27	10	—	1	3.4	5.2	7.7	.70	16
Potassium	9	—	—	—	1.3	1.6	1.9	1.0	4.5
Radon (pCi/L)	4	[3] 300	—	4	—	1,900	—	530	3,400
Silica	10	—	—	—	13	17	19	11	22
Sodium	10	—	—	—	3.5	6.8	9.9	3.0	21
Sulfate	24	—	250	0	11	20	39	1.4	70
Total dissolved solids	21	—	500	2	189	234	378	109	659

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.
[3] U.S. Environmental Protection Agency, 1994, proposed maximum contaminant level.

Wissahickon Formation

The Wissahickon Formation (Berg and others, 1980) is the most widespread lithologic unit in the Piedmont Upland Section of Pennsylvania, underlying about 50 percent of the total area. The formation consists of rocks of sedimentary and volcanic origin that exhibit varying degrees of regional metamorphism. The Wissahickon Formation as used in this report includes the following members: Wakefield Marble (Xww), Metavolcanics (Xwv), Oligoclase-Mica Schist (Xw), Albite-Chlorite Schist (Xwc), and Marburg Schist (Xwm).

Higgins (1972, p. 989) believed that the Wissahickon Formation is part of the Glenarm Series (Knopf and Jonas, 1923, p. 45) and is correlative with part of the Chilhowee Group of the Blue Ridge Physiographic Province. Crowley (1976), working in Maryland, raised the Glenarm to a supergroup and the Wissahickon to a group by subdividing the Wissahickon into six geologic units. More recent work in Virginia and Maryland (Gates and others, 1991) have identified a series of tectonostratigraphic terranes. Horton and others (1991) placed the Wissahickon in Pennsylvania within the Potomac terrane, stating that the Potomac terrane is an allochthonous thrust sheet containing basement and a cover sequence of turbidites and ophiolitic melange. Wagner and Srogi (1987, p. 115) no longer considered the Wissahickon part of the Glenarm Supergroup. Lyttle and Epstein (1987) suggested the name “Wissahickon Formation” should be applied only to those rocks included in the original definition of the Wissahickon mica gneiss of Bascom and others (1909), including the type section in the Philadelphia area.

A small part of the Wissahickon Formation is believed by Higgins (1972, p. 1,018) to be Precambrian; most rocks, however, are Cambrian in age, and some are as young as Ordovician. Thickness of the Wissahickon Formation was estimated by Geyer and Wilshusen (1982, p. 288) to be 8,000 to 10,000 ft and by Higgins (1972, p. 990) to be at least 10,000 ft thick.

Wakefield Marble (Xwm)

The Wakefield Marble (Stose and Jonas, 1939; Berg and others, 1980) underlies about 1 mi^2 of south-central York County. This unit crops out in several small, scattered valleys and quarries within the Albite-Chlorite Schist and the Marburg Schist. The Wakefield Marble is named after Wakefield Valley in western Carroll County, Md., where fresh exposures were present (Stose and Jonas, 1939, p. 84).

Geologic description.—The Wakefield Marble (table 2) may be an impure grayish-white marble; a blue, thin-bedded, crystalline limestone with argillaceous bands; or a greenish medium-grained calcareous schist composed of calcite, epidote, zoisite, chlorite, and albite. It is closely folded with the Albite-Chlorite Schist and Marburg Schist and contains quartz lenses (Stose and Jonas, 1939, p. 84). According to Stose and Jonas (1939, p. 84), the Wakefield Marble in Carroll County, Md., grades upward into the Wissahickon Formation (Oligoclase-Mica Schist of this report).

Thickness of the Wakefield Marble is estimated at 100 ft and this unit may be correlative with the Cockeysville Marble (Stose and Jonas, 1939, p. 84). Stose and Jonas (1939, p. 83) suggested a Precambrian age for the Wakefield Marble. However, recent work in Maryland suggests the Wakefield Marble may actually be Ordovician in age (David MacLachlan, Pennsylvania Topographic and Geologic Survey, oral commun., 1994).

Well depths and casing lengths.—Only one well is known to be completed in the Wakefield Marble. This well is 125 ft deep and has about 50 ft of 6-in. casing.

Hydrologic properties.—The static water level in October 1970 was 42.7 ft below land surface. The specific capacity of this well is 2.6 (gal/min)/ft.

Meyer and Beall (1958), using two wells completed in the Wakefield Marble in Maryland, estimated a specific yield of 0.004; the transmissivity was 6,952 ft^2/d.

Water quality.—Calcium is the dominant cation, and bicarbonate is the dominant anion. The field values of specific conductance, hardness, and pH of water from the single well are 350 µS/cm, 120 mg/L, and 7.0, respectively. Concentrations of total iron and manganese are 150 and 20 µg/L, respectively. The concentration of nitrate (as N) is 47 mg/L. A possible reason for the high nitrate concentration is that the well is next to a barn where animals may be kept.

Metavolcanics (Xwv)

The Metavolcanics (Berg and others, 1980) underlie about 10 mi^2 of south-central York County in narrow, elongate bands that trend northeast-southwest within the Albite-Chlorite Schist. Smith and Barnes (1994, p.70), however, indicated that the outcrop area shown is too great and that much of the exposures may represent chaotic fragments in a melange.

Geologic description.—The Metavolcanics (table 2) are described as altered basaltic flows with some being amygdaloidal (Berg and others, 1980). According to Stose and Jonas (1939, p. 85) these metabasalts are a green schistose rock composed of albite, uralitic hornblende, and epidote; veins and amygdules of quartz and epidote are present. Albite, zoisite, and epidote are secondary minerals to a lime-soda feldspar, and uralite and chlorite derived from pyroxene.

The Metavolcanics are less resistant to erosion than the surrounding schist and occupy narrow valleys between ridges of the schist. No estimate of thickness exists for the Metavolcanics. Stose and Jonas (1939, p. 85) have tentatively assigned a Precambrian age.

Smith and Barnes (1994, p. 70), using known sections in Maryland for comparison and the extensional mapping into Pennsylvania from Maryland by Stose and Jonas (1939, pl. 1), proposed the name “Sams Creek Metabasalt” for the Metavolcanics. Smith and Barnes (1994, p. 70) believed the Metavolcanics are representative of ocean floor basalts that originated near a spreading center.

Well depths and casing lengths.—Depths of wells and reported casing lengths for wells completed in the Metavolcanics are presented in the tables below. Only four wells are completed at depths greater than 300 ft; two wells have casing lengths that exceed 81 ft of casing.

Reported well depth, Metavolcanics

[Depth in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	36	94	125	153	220	388	44	600
Drilled, domestic	25	76	110	140	160	278	44	300
Drilled, high-demand	6	—	200	224	387	—	200	408

Reported casing length, Metavolcanics

[Casing length in feet; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	31	20	27	46	60	80	13	190
Drilled, domestic	23	20	27	44	60	76	19	81
Drilled, high-demand	5	—	35	60	183	—	20	190

Hydrologic properties.—Water levels for wells completed in the Metavolcanics are presented in the table below. Depths to water in 27 wells range from flowing at land surface to 90 ft below land surface; the median is 35 ft below land surface.

Water levels, Metavolcanics

[Water levels in feet below land surface; F, flowing well; —, insufficient data available; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	4	—	—	52	—	—	35	60
Slope	17	11	22	35	56	70	5	80
Valley	4	—	—	5	—	—	F	90

Reported yields for wells completed in the Metavolcanics are presented in the table below. Yields of 5.0 gal / min or less are reported from nine wells, of which eight are domestic. Four of the 12 wells with yields of 20 gal / min or greater are deeper than 200 ft.

Reported well yield, Metavolcanics

[Yield in gallons per minute; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	34	3.5	5.0	12	30	86	1.0	150
Domestic	25	3.6	4.5	7.0	18	32	1.0	40
High-demand	6	—	29	86	116	—	25	150

Specific capacities for wells completed in the Metavolcanics are presented in the table below. Three wells (drilled to depths of 145, 280, and 300 ft below land surface) have specific capacities of 0.04 (gal / min) / ft or less and are incapable of meeting most domestic or other water-use demands. Seven wells have specific capacities of 1.0 (gal / min) / ft or greater, three of which are deeper than 200 ft. Specific capacities of three wells with pumping durations of 8 hours or longer are 0.57, 1.3, and 12 (gal / min) / ft.

Reported specific capacity, Metavolcanics

[Specific capacity in gallons per minute per foot of drawdown; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	18	0.01	0.06	0.58	2.2	5.5	0.01	12
Domestic	10	.01	.03	.06	.77	2.0	.01	2.1
High-demand	6	—	1.1	2.5	6.5	—	.57	12

Values of hydraulic conductivity and transmissivity for the Metavolcanics are presented below; a specific yield of 0.02 was used in estimating these hydrologic properties. The median hydraulic conductivities of wells on hilltops (3 wells), slopes (9 wells), and valleys (2 wells) are 1.1, 0.30, and 2.6 ft / d, respectively. The median transmissivities of wells on hilltops, slopes, and valleys are 250, 10, and 260 ft^2 / d, respectively.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Metavolcanics

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	16	0.05	0.10	1.0	2.8	8.7	0.02	18
Transmissivity (ft^2 / d)	16	4.5	6.8	110	360	1,400	3.2	2,700

The depths of water-bearing zones in 22 wells drilled as deep as 500 ft range from 52 to 265 ft below land surface. Fifty percent of 35 water-bearing zones reported are penetrated by a depth of 96 ft and 90 percent by a depth of 180 ft. The greatest density of water-bearing zones (0.90 per 50 ft of well depth) is from 51 to 100 ft below land surface (fig. 19). The overall density of water-bearing zones in this unit is 0.38 per 50 ft of well depth.

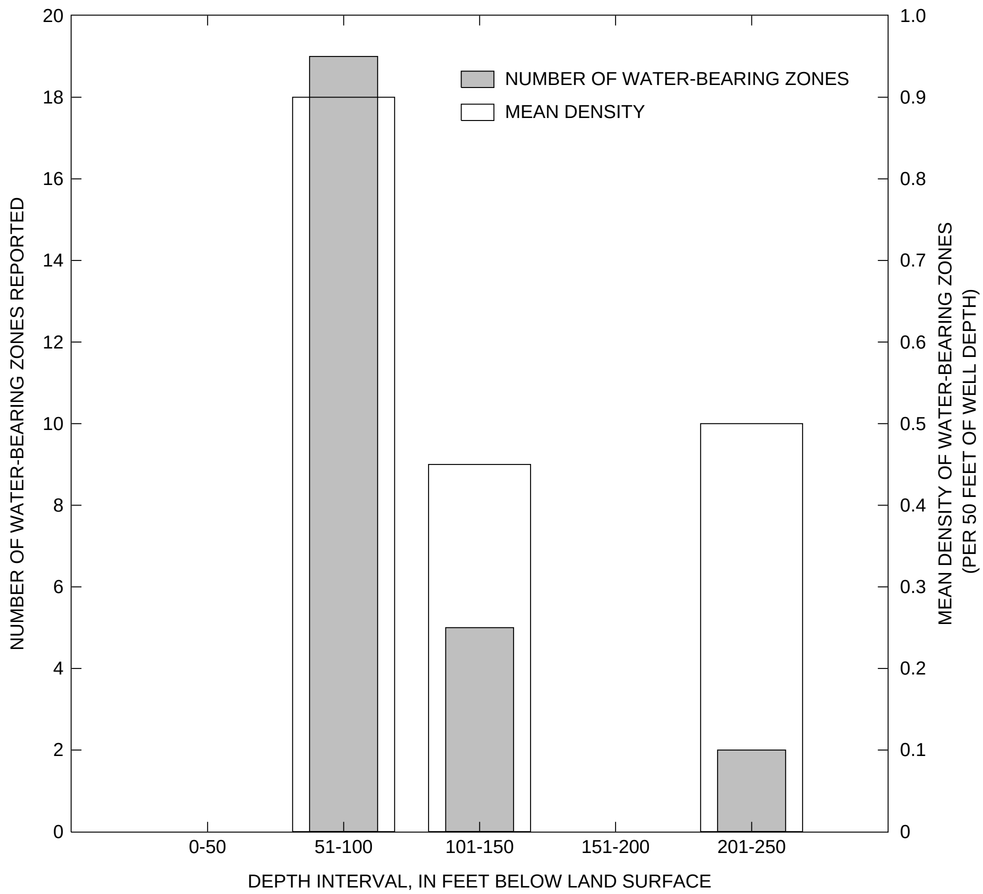


Figure 19. The number and density of water-bearing zones per 50 feet of well depth in the Metavolcanics of the Piedmont Physiographic Province, Piedmont Upland Section.

Water quality.—As seen in the following table, wells completed in the Metavolcanics generally yield water that is low in dissolved solids, soft to moderately hard, and slightly acidic. Calcium is the dominant cation, and bicarbonate is the dominant anion. Elevated concentrations of manganese and nitrate may be common water-quality problems. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Metavolcanics

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	8	—	—	—	94	178	293	62	385
Field hardness	7	—	—	—	34	68	85	34	140
Field pH (standard units)	5	—	<6.5 >8.5	2	6.1	6.5	6.8	5.9	6.9
Bicarbonate	5	—	—	—	9.8	36	74	9	110
Calcium	5	—	—	—	6.4	19	35	3.8	48
Chloride	5	—	250	0	4.5	8.5	14	3.0	22
Iron	5	—	.3	0	.018	.090	.22	.010	.22
Lead	3	0.015	—	1	—	.003	—	.000	.030
Magnesium	5	—	—	—	3.0	3.6	9.0	3.0	11
Manganese	5	—	.05	1	.008	.015	.030	.000	.060
Nitrate (as N)	5	10	—	1	1.7	4.3	9.5	1.2	15
Potassium	5	—	—	—	.50	.85	3.5	.50	8.0
Silica	5	—	—	—	3.0	9.9	15	1.0	17
Sodium	5	—	—	—	2.3	3.6	6.6	2.3	6.6
Sulfate	5	—	250	0	2.4	9.5	22	1.2	23
Total dissolved solids	5	—	500	0	75	107	161	67	225

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.

Oligoclase-Mica Schist (Xw)

The Oligoclase-Mica Schist (Berg and others, 1980) underlies about 90 mi^2 of the Piedmont Upland in Chester, Delaware, Montgomery, and Philadelphia Counties. Lyttle and Epstein (1987) reinstated the name “Wissahickon Formation” for the rocks included in the original definition of the Wissahickon mica gneiss of Bascom and others (1909). This name would apply to the rocks described in this report as Oligoclase-Mica Schist. The type section of the reinstated Wissahickon Formation lies in the Philadelphia area between Chestnut Hill and Manayunk, as well as the narrow, fault-bounded, slivers south of Berwyn and Devon, Pa.

Geologic description.—The Oligoclase-Mica Schist (table 2) is fine- to medium-grained, light to dark gray to black, quartzo-aluminous pelitic schist and gneiss.This unit also contains feldspathic metagraywacke, amphibolites, and altered ultramafic rocks. Dominant minerals include quartz, orthoclase, biotite, muscovite, and plagioclase. Garnet, sillimanite, ilmenite, staurolite, kyanite, and cordierite are common secondary minerals or are locally abundant. Foliation is generally very well developed. Southeast towards the type section, the metamorphic grade increases as well as the percentage of feldspathic metagraywacke (Lyttle and Epstein, 1987, pl. 2). Overall, the rocks range in metamorphic grade from greenschist through upper amphibolite facies. Near the Wilmington Complex, the Oligoclase-Mica Schist locally reached the temperature of incipient melting of at least 650-700°C (Wagner and Srogi, 1987, p. 119).

The Oligoclase-Mica Schist forms undulating hills of medium relief that have moderately steep but stable slopes. These rocks are relatively soft to moderately resistant to weathering. Joints are irregular and widely spaced.

The intense folding and lack of recognizable recurrent beds prevent any determination of thickness. The Oligoclase-Mica Schist is intruded by or in fault contact with the Plutonic Rocks, Gneissic Rocks, and Serpentinites but conformably overlies the Cockeysville Marble (Sloto, 1994, p. 11). According to Wagner and Srogi (1987, p. 122-224), the Oligoclase-Mica Schist "* * *should ideally contain sedimentary rocks that were deposited in at least three different tectonic settings: (1) oceanic sediments that had been deposited on the down going plate that eventually accumulated in an accretionary prism; (2) sediments originally deposited in a forearc basin on the overriding plate that later become involved in deformation; and (3) syntectonic flysch, the result of plate collision." Drake and others (1989, p. 116) believed the Wissahickon Formation of the Philadelphia area consists of at least two rock types—turbidite or submarine fan deposits and an interlayered felsic gneiss-granofels and amphibolite. A potassium-argon date of 353 million years was obtained on muscovite close to the Huntingdon Valley fault near Neshaminy Creek (Long and Kulp, 1962). Drake and others (1989, p. 116) believed that the Oligoclase-Mica Schist is Ordovician or older.

Well depths and casing lengths.—Depths of wells completed in the Oligoclase-Mica Schist are presented in the table below. All of the 10 wells in the Oligoclase-Mica Schist that are 1,000 ft or deeper are high-demand wells.

Reported well depth, Oligoclase-Mica Schist

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	1,204	80	110	190	302	500	20	2,030
Drilled, domestic	461	72	90	120	161	221	28	600
Drilled, high-demand	426	111	200	300	450	566	40	2,030

Well depths can vary spatially. Depths of drilled wells completed in the Oligoclase-Mica Schist in Delaware (145 wells), Montgomery (16 wells), and Philadelphia Counties (439 wells) are significantly greater than wells in Chester County (536 wells). The respective median county well depths are 190, 246, 300, and 125 ft. A similar pattern exists for high-demand and domestic wells. Almost 75 percent of the 94 wells completed at depths greater than 500 ft are in Philadelphia County.

Casing lengths for wells completed in the Oligoclase-Mica Schist are presented in the table below. Casing lengths of 100 ft or greater are reported in 56 wells. Domestic wells in Chester County (276 wells) use significantly more casing than wells in Delaware County (71 wells); the medians are 50 and 40 ft, respectively.

Reported casing length, Oligoclase-Mica Schist

[Casing length in feet; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	854	20	28	41	61	89	4	261
Drilled, domestic	354	24	35	46	63	85	10	157
Drilled, high-demand	296	15	23	40	65	96	7	260

Topographic setting can affect casing length. High-demand wells in valleys (159 wells) use significantly more casing than on slopes (95 wells) or hilltops (28 wells). The median casing lengths in valleys is 49 ft, on slopes 31 ft, and 28 ft on hilltops.

Hydrologic properties.—Water levels for wells completed in the Oligoclase-Mica Schist are presented in the table below. Depths to water in 1,028 wells range from flowing 3 ft above land surface to 124 ft below land surface; the median is 20 ft below land surface. Of the 10 flowing wells, 2 are on hilltops, 5 on slopes, and 3 in valleys.

Water levels, Oligoclase-Mica Schist

[Water levels in feet below land surface; F and -, flowing well; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	149	12	18	25	38	55	F	120
Slope	502	10	15	24	34	45	- 3	97
Valley	273	4	9	15	22	37	F	95

Reported yields for wells completed in the Oligoclase-Mica Schist are presented in the table below. Yields of 5.0 gal / min or less are reported from 122 wells of which 69 are domestic. Yields of 100 gal / min or greater are reported from 104 wells; 78 of these high-yield wells are deeper than 200 ft.

Reported well yield, Oligoclase-Mica Schist

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	1,077	5.0	10	20	50	100	0.00	450
Domestic	418	5.0	7.0	12	20	30	.00	400
High-demand	385	10	20	50	80	126	1.0	450

Specific capacities for wells completed in the Oligoclase-Mica Schist are presented in the table below. Twenty-seven wells (drilled from 100 to 600 ft below land surface) have specific capacities of 0.04 (gal / min) / ft or less and are incapable of meeting most domestic or other water-use demands. Seventy-one wells have specific capacities of 1.0 (gal / min) / ft or greater, and 24 of the wells are deeper than 200 ft. Specific capacities of wells with pumping durations of 8 hours or longer (59 wells) range from 0.08 to 11 (gal / min) / ft; the median is 0.73 (gal / min) / ft. High-demand wells have significantly greater specific capacities than domestic wells.

Reported specific capacity, Oligoclase-Mica Schist

[Specific capacity in gallons per minute per foot of drawdown; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	337	0.05	0.1	0.27	0.76	1.6	0.00	15
Domestic	211	.05	.09	.21	.57	1.4	.00	15
High-demand	80	.10	.27	.65	1.5	3.7	.02	11

Values of hydraulic conductivity and transmissivity for the Oligoclase-Mica Schist are presented in the following table; a specific yield of 0.02 was used in estimating these hydrologic properties. Hydraulic conductivity and transmissivity are generally lower on hilltops or slopes than in valleys. The median hydraulic conductivities of wells on hilltops (34 wells), slopes (205 wells), and valleys (61 wells) are 0.43, 0.56, and 0.60 ft / d, respectively. The median transmissivities of wells on hilltops, slopes, and valleys are 32, 33, and 81 ft^2 / d, respectively.

Hydraulic conductivity and transmissivity of single-well aquifer tests, Oligoclase-Mica Schist

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	317	0.04	0.15	0.55	2.1	6.2	0.00	190
Transmissivity (ft^2 / d)	317	5.7	12	39	120	310	.18	2,900

In other work, Geyer and Wilshusen (1982, p. 257) reported, from rock test data, the permeability of the Oligoclase-Mica Schist ranged from 0.2 to 3 ft / d. Stewart and others (1964) in Dawsonville, Ga., used two wells in saprolite over quartz-mica schist to estimate hydraulic conductivities of 0.001 to 1.2 ft / d. Meyer and Beall (1958) used multiple-well aquifer tests involving 10 wells in Maryland to estimate a specific yield of 0.03 and transmissivity of 668 ft^2 / d. In their model of the Red Clay Creek Basin, Vogel and Reif (1993, table 10) estimated horizontal hydraulic conductivity. For hilltops, horizontal hydraulic conductivity ranged from <0.01 to 6.39 ft / d; for slopes, from 0.01 to 7.89 ft / d; and for valleys, from 0.02 to 4.20 ft / d. The calibrated slope values for aquifer horizontal hydraulic conductivity of their Wissahickon Formation, northern and southern were 0.27 and 0.15 ft / d, respectively. Vogel and Reif (1993, table 11) also presented the results from four single-well aquifer tests. The transmissivities were estimated as 24, 35, 35, 0.38 ft^2 / d, and hydraulic conductivities were 0.10, 0.10, 0.12, and 0.16 ft / d.

The depths of water-bearing zones in 416 wells drilled as deep as 1,000 ft range from near land surface to 500 ft below land surface. Fifty percent of the 932 water-bearing zones reported were penetrated by a depth of 95 ft and 90 percent by a depth of 198 ft. The greatest density of water-bearing zones (0.82 per 50 ft of well depth) is from 51 to 100 ft below land surface (fig. 20); the density of water-bearing zones

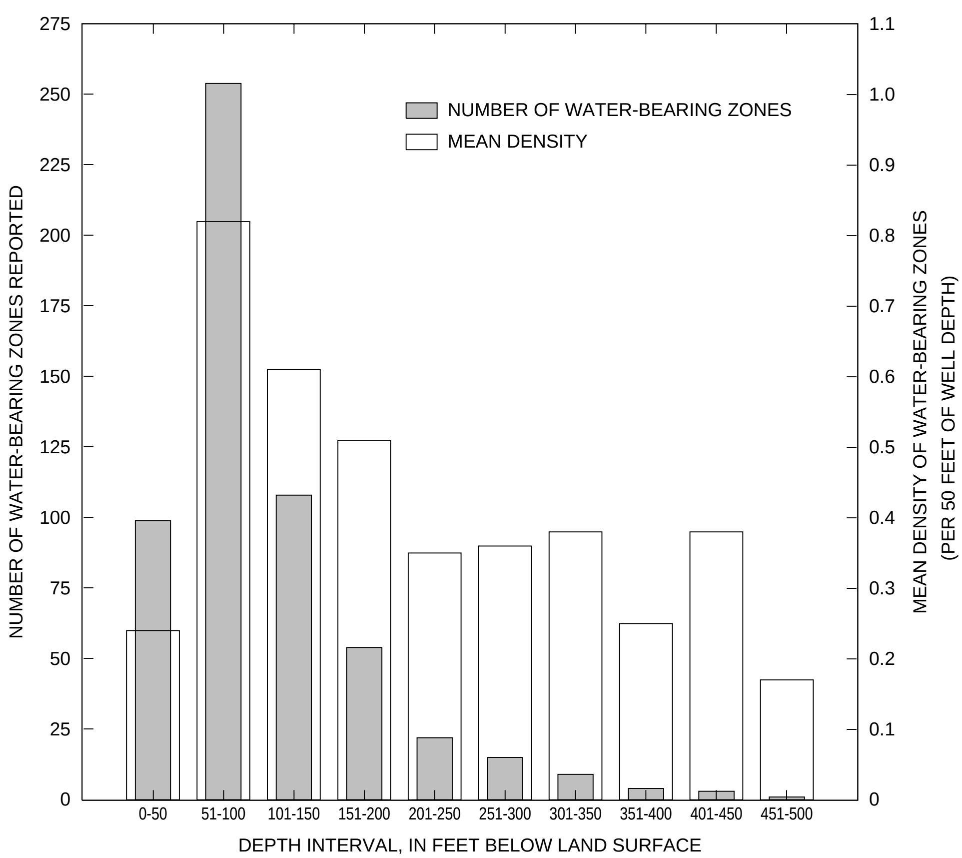


Figure 20. The number and density of water-bearing zones per 50 feet of well depth in the Oligoclase-Mica Schist of the Piedmont Physiographic Province, Piedmont Upland Section.

at depths of 351 ft or greater are based on the presence of four or less water-bearing zones per 50-ft interval. The overall density of water-bearing zones in this unit is 0.48 per 50 ft of well depth.

Water quality.—As seen in the following table, wells completed in the Oligoclase-Mica Schist generally yield water that contains low to moderate amounts of dissolved solids, is soft to moderately hard, and slightly acidic. Calcium is the dominant cation, whereas chloride, bicarbonate, and sulfate anions are present in about equal amounts. Elevated concentrations of iron, manganese, silica, dissolved solids, and radon and low pH are the most common water-quality problems. The concentrations of cadmium and selenium reported in the table are severely restrained by high detection limits. Thirty-eight of the cadmium analyses and 32 of the selenium analyses had detection limits greater than the USEPA MCL. Nine of 53 wells contain water with aluminum concentrations of 200 µg/L or greater. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Oligoclase-Mica Schist

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; pCi/L, picoCurie per liter; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	264	—	—	—	100	150	240	25	1,850
Field hardness	248	—	—	—	34	51	68	1	460
Field pH (standard units)	248	—	<6.5 >8.5	173	6.0	6.2	6.6	5.1	8.0
Bicarbonate	153	—	—	—	25	50	92	.0	420
Cadmium	80	0.005	—	4	<.001	<.002	<.010	<.001	.030
Calcium	105	—	—	—	14	31	55	1.9	230
Chloride	147	—	250	9	12	33	65	1.8	940
Chromium	69	.1	—	1	<.001	<.010	.010	.000	3.7
Cyanide	57	.2	—	2	.000	.010	.010	.000	.31
Iron	152	—	.3	78	.065	1.0	5.8	.000	120
Lead	74	.015	—	1	.000	.002	.004	.000	.037
Magnesium	105	—	—	—	5.6	11	21	.0	110
Manganese	110	—	.05	52	.010	.050	.24	.000	13
Mercury	62	.002	—	4	<.0001	<.0001	.0005	.0000	.012
Nitrate (as N)	134	10	—	4	.11	.41	3.0	.00	16
Potassium	97	—	—	—	2.4	3.8	5.9	.40	18
Radon (piC/L)	4	[3] 300	—	3	—	1,900	—	200	4,200
Selenium	59	.05	—	—	.001	<.20	<.20	.001	<.20
Silica	106	—	—	—	17	21	26	.42	50
Sodium	99	—	—	—	8.3	19	41	2.2	330
Sulfate	148	—	250	9	22	64	130	.50	1,300
Total dissolved solids	123	—	500	24	108	223	455	33	3,390

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.
[3] U.S. Environmental Protection Agency, 1994, proposed maximum contaminant level.

In the Red Clay Creek Basin of Pennsylvania and Delaware, Senior (1996, table 13) found that the median concentrations or value for pH, specific conductance, alkalinity, calcium, chloride, sulfate, nitrate plus nitrite, and barium were significantly lower in the Oligoclase-Mica Schist than in the Cockeysville Marble. Significant differences in other physical and chemical properties and selected dissolved constituents also were noted between the Oligoclase-Mica Schist and the other lithologic units (Gneissic Rocks, Serpentinite, and Setters Quartzite) studied.

The specific conductance of water from wells in valleys (31 wells) is significantly greater than on slopes (148 wells) or hilltops (38 wells); the medians are 260, 140, and 163 µS / cm, respectively. The specific conductance of water from wells in Philadelphia County (16 wells) is significantly greater than the specific conductance of water from wells in Delaware County (57 wells) and Chester County (190 wells); the medians are 600, 180, and 128 µS / cm, respectively. The high specific conductance of the Oligoclase-Mica Schist in Philadelphia County may be the result of greater urbanization. Sloto (1987, p. 73) noted that sodium and chloride concentrations were greater in areas of higher population density and greater amounts of paved areas. Sloto attributed an increase in sodium and chloride concentrations to deicing salt (sodium chloride).

The pH of water from wells in Delaware County (53 wells) is significantly greater than the pH of water from wells in Chester County (190 wells). The pH of water in the Delaware County wells ranges from 5.7 to 8.0; the median is 6.5. For the Chester County wells, pH of the well water ranges from 5.1 to 7.9; the median is 6.2.

Albite-Chlorite Schist (Xwc)

The Albite-Chlorite Schist (Berg and others, 1980) underlies about 420 mi^2 of the Piedmont Upland in Chester, Delaware, Lancaster, Montgomery, Philadelphia, and York Counties. Lyttle and Epstein (1987, pl. 2) reinstated the “Octoraro Schist” of Bascom and others (1909) and renamed it the “Octoraro Phyllite.” Valentino (1994, p. 25) suggested the name “Octoraro Formation” because it contains considerably less phyllite than schist.

Geologic description.—The Albite-Chlorite Schist (table 2) is generally fine- to coarse-grained, grayish- to bluish-gray, green, or black, schist or phyllite. The dominant minerals are albite, chlorite, muscovite, and quartz. Common secondary minerals include garnet, ilmenite, magnetite, and biotite. Along the northern edge of the outcrop area where it is thrust over the Conestoga Formation, the Albite-Chlorite Schist is finer grained; ilmenite is the dominant oxide mineral. To the south, the albite, muscovite, and chlorite increase in size, and magnetite is the dominant oxide mineral. Numerous lithologies or “schist facies” have been identified in York County (Stose and Jonas, 1939, p. 87-90) and in Lancaster and Chester Counties (Valentino, 1994, p. 25-34). Valentino (1994, p. 28-29) also identified a metasandstone member and a metabasalt member, which he believed is the Sams Creek Metabasalt as recognized in Maryland.

The Albite-Chlorite Schist is moderately resistant to weathering. It forms high, undulating hills that have moderate to steep and stable slopes. Tight folds are common, and joints tend to be open, irregular, and widely spaced.

Because of shearing, at least two periods of metamorphism and recumbent folding, no estimated stratigraphic thickness is available. According to Faill and Wiswall (1994, p. 74), the Albite-Chlorite Schist was originally laid down on a continental slope or basin and reached a thickness of at least 3 mi. Lyttle and Epstein (1987, Plate 2), Valentino (1994, p. 25), and Valentino and others (1994) indicate the Albite-Chlorite Schist is bounded by major thrust faults (Martic Line to the north and east and the Drumore tectonite of the Pleasant Grove-Huntingdon Valley shear zone on the south). Lyttle and Epstein (1987), who used regional correlations with similar rocks in Massachusetts and the structural contact on the underlying Conestoga Formation of probable Ordovician-Cambrian age, believed the Albite-Chlorite Schist to be Early Cambrian or Late Proterozoic in age. Using information from age dating of the Metabasalt at South Mountain and chemical affinities with exposures of metabasalts in the Piedmont Uplands, Smith and others (1991, p. 10) believed the Albite-Chlorite Schist to be at least as old as latest Precambrian.

Well depths and casing lengths.—Depths of wells completed in the Albite-Chlorite Schist are presented in the table below. Of the six wells completed at depths of 500 ft or greater, only one is a high-demand well.

Reported well depth, Albite-Chlorite Schist

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	367	70	95	123	200	305	15	1,000
Drilled, domestic	226	70	88	110	154	230	30	550
Drilled, high-demand	60	112	180	260	315	398	80	1,000

Topographic setting can affect well depth. Drilled wells on hilltops (92 wells) and slopes (182 wells) are significantly shallower than wells drilled in valleys (40 wells). The median depths of drilled wells on hilltops, slopes, and valleys are 120, 114, and 265 ft, respectively.

Depths of drilled wells in Chester County (196 wells) are significantly greater than in York County (158 wells); the medians are 150 and 110 ft, respectively. More than 70 percent of the 95 wells completed at depths of 200 ft or greater are in Chester County.

Casing lengths for wells completed in the Albite-Chlorite Schist are presented in the table below. Ten of 16 wells with casing lengths of 100 ft or greater are in Chester County.

Reported casing length, Albite-Chlorite Schist

[Casing length in feet; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	244	18	22	35	54	80	6	400
Drilled, domestic	159	18	21	30	44	74	6	275
Drilled, high-demand	43	21	28	46	62	100	18	400

Hydrologic properties.—Water levels for wells completed in the Albite-Chlorite Schist are preneted in the table below. Depths to water in 343 wells range from 1 to 110 ft below land surface; the median is 33 ft below land surface.

Water levels, Albite-Chlorite Schist

[Water levels in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	79	25	35	44	58	69	14	87
Slope	169	11	20	34	49	66	1	110
Valley	28	3	5	10	18	31	2	90

Reported yields for wells completed in the Albite-Chlorite Schist are presented in the table below. Yields of 5.0 gal / min or less are reported from 90 wells; 13 wells have yields of 100 gal / min or greater. Of the 13 high-yielding wells, 8 are deeper than 200 ft.

Reported well yield, Albite-Chlorite Schist

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	302	2.3	5.0	10	25	50	0.0	300
Domestic	186	2.0	5.0	7.5	15	29	.3	300
High-demand	59	15	21	37	75	100	6.0	230

Topographic position can affect well yields. Domestic wells on slopes (100 wells) have significantly greater reported yields than domestic wells on hilltops (46 wells); the medians are 9.0 and 5.0 gal / min, respectively.

Specific capacities for wells completed in the Albite-Chlorite Schist are presented in the table below. Nine wells (drilled from 140 to 380 ft below land surface) have specific capacities of 0.04 (gal / min) / ft or less and are incapable of meeting most domestic or other water-use demands. Specific capacities of 1.0 (gal / min) / ft or greater are reported from 40 wells, 14 of which are completed by a depth of 200 ft. Specific capacities of wells with pumping durations of 8 hours or longer (10 wells) range from 0.15 to 3.0 (gal / min) / ft; the median is 1.2 (gal / min) / ft. High-demand wells have specific capacities significantly greater than domestic wells.

Reported specific capacity, Albite-Chlorite Schist

[Specific capacity in gallons per minute per foot of drawdown; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	107	0.06	0.17	0.49	1.8	3.9	0.00	28
Domestic	64	.03	.07	.34	1.3	4.5	.00	28
High-demand	32	.16	.29	1.2	2.6	4.2	.11	7.6

Specific capacity can vary by county. Wells in York County (60 wells) have specific capacities significantly greater than the specific capacities of wells in Chester County (47 wells); the medians are 0.92 and 0.31 (gal / min) / ft, respectively. This pattern also holds for domestic wells. The median specific capacity of domestic wells in York County (34 wells) is 0.86 (gal / min) / ft and for Chester County (30 wells) is 0.24 (gal / min) / ft. Only 1 of 11 wells with specific capacities of 4.0 (gal / min) / ft or greater are in Chester County; the other 10 are in York County.

Values of hydraulic conductivity and transmissivity for the Albite-Chlorite Schist are presented in the table below; a specific yield of 0.02 was used in estimating these hydrologic properties. Hydraulic conductivity and transmissivity are generally greater on slopes than on hilltops or in valleys. The median hydraulic conductivities of wells on hilltops (22 wells), slopes (57 wells), and valleys (10 wells) are 0.54, 1.2, and 0.22 ft / d, respectively. The median transmissivities of wells on hilltops, slopes, and valleys are 45, 86, and 49 ft^2 / d, respectively.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Albite-Chlorite Schist

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	103	0.05	0.22	1.0	3.8	20	0.00	390
Transmissivity (ft^2 / d)	103	5.2	21	80	290	710	.40	5,500

In other work, Dingman and others (1956, p. 25-28) used one pumped well and two observation wells in weathered Albite-Chlorite Schist of the Maryland Piedmont to estimate specific yields of 0.002 to 0.01 and transmissivities of 401 to 1,340 ft^2 / d. On the basis of their streamflow study of Muddy Creek Basin in York County, Lloyd and Growitz (1977, p. 27-30) estimated that (1) about 70 percent of the streamflow was ground-water discharge; (2) the specific yield of the zone of water-table fluctuation, which consisted mostly of regolith, was 0.08; and (3) the average transmissivity of the basin using base flow was 98 ft^2 / d, whereas from 72 specific-capacity tests, the transmissivity of the Albite-Chlorite Schist was 104 ft^2 / d.

Gerhart and Lazorchick (1984b, tables 6 and 14), in their digital model of parts of Lancaster and Berks Counties, used a specific yield of 0.02 and a hydraulic conductivity of 0.5 ft / d. In their Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, table 16 and table 8) used a specific yield of 0.020 and a hydraulic conductivity of 1.34 ft / d. Sloto (1990, p. 39), using a specific yield of 0.08 for his model in the Valley Creek Basin of eastern Chester County, estimated a hydraulic conductivity of 5.0 ft / d.

The depths of water-bearing zones in 81 wells drilled as deep as 460 ft range from 9 ft below land surface to 375 ft below land surface. Fifty percent of the 176 water-bearing zones reported are penetrated by a depth of 80 ft and 90 percent by a depth of 191 ft. The greatest density of water-bearing zones (0.93 per 50 ft of well depth) is from 51 to 100 ft below land surface (fig. 21); the density of water-bearing zones at depths of 201 ft or greater are based on the presence of five or fewer water-bearing zones per 50-ft interval. The overall density of water-bearing zones in the Albite-Chlorite Schist is 0.53 per 50 ft of well depth.

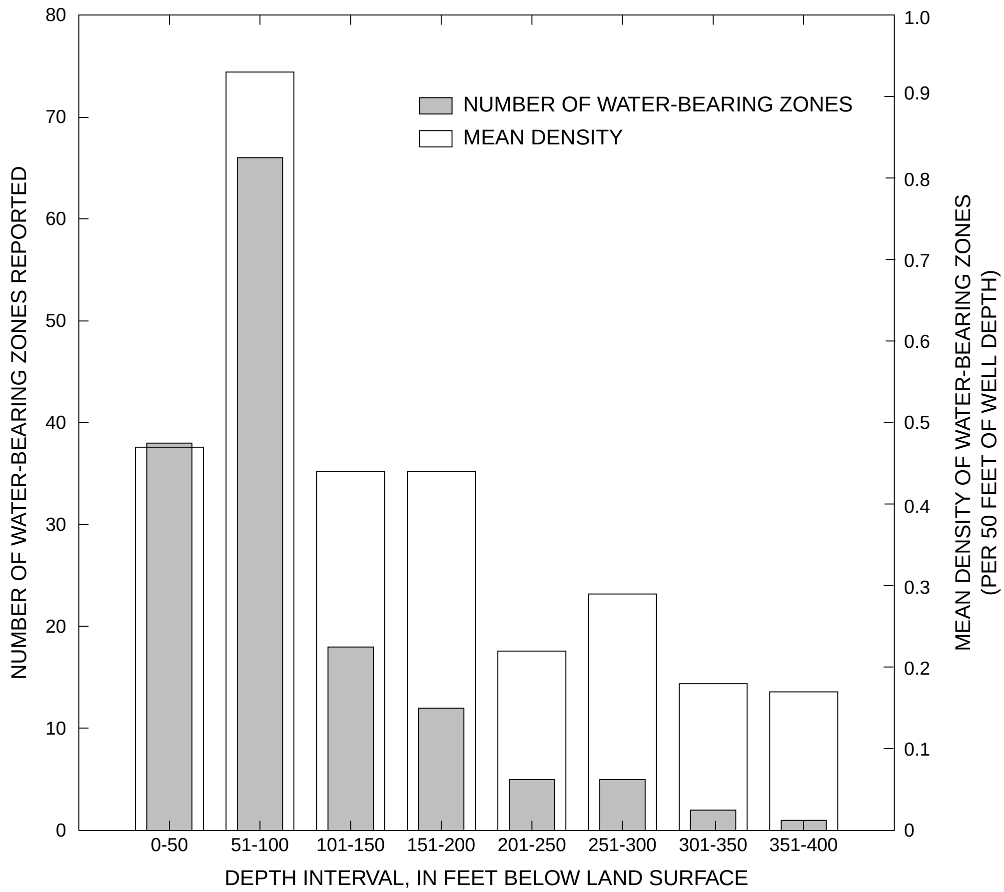


Figure 21. Number and density of water-bearing zones per 50 feet of well depth in the Albite-Chlorite Schist of the Piedmont Physiographic Province, Piedmont Upland Section.

Water quality.—As seen in the following table, wells completed in the Albite-Chlorite Schist generally yield water that is low in dissolved solids, soft to moderately hard, and slightly acidic. Calcium and magnesium are the dominant cations, and chloride and bicarbonate are the dominant anions. Elevated concentrations of iron, lead, manganese, nitrate, and radon and low pH are common water-quality problems. Three wells contain water with aluminum concentrations of 0.35, 0.37, and 3.7 mg/L—far in excess of typical ground-water concentrations of 0.01 to 0.06 mg/L (Cook and Miles, 1980, p. 5). The well containing water with the highest aluminum concentration also has a zinc concentration 10 times the USEPA SMCL of 5 mg/L. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Albite-Chlorite Schist

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; pCi/L, picoCurie per liter; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	178	—	—	—	82	120	220	20	725
Field hardness	155	—	—	—	34	51	68	17	310
Field pH (standard units)	101	—	<6.5 >8.5	173	5.7	6.0	6.5	5.0	7.6
Bicarbonate	83	—	—	—	10	23	31	3.0	160
Calcium	68	—	—	—	5.2	12	18	.20	38
Chloride	80	—	250	0	7.0	12	18	.50	88
Iron	85	—	.3	19	.020	.060	.14	.000	4.1
Lead	52	0.015	—	10	.002	.005	.010	.001	.074
Magnesium	68	—	—	—	2.8	5.4	6.8	.30	24
Manganese	82	—	.05	27	.010	.020	.063	.000	3.1
Nickel	50	.1	—	1	.004	.010	.030	.000	.14
Nitrate (as N)	70	10	—	13	3.0	6.0	9.4	.04	22
Potassium	63	—	—	—	.60	1.0	2.4	.10	41
Radon (pCi/L)	4	[3] 300	—	3	—	2,800	—	220	4,400
Silica	45	—	—	—	5.6	7.4	12	.10	27
Sodium	63	—	—	—	3.3	5.1	10	1.0	41
Sulfate	80	—	250	0	4.0	7.0	15	.00	58
Total dissolved solids	78	—	500	0	84	120	157	22	474
Zinc	48	—	5	1	.030	.050	.090	.000	50

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.
[3] U.S. Environmental Protection Agency, 1994, proposed maximum contaminant level.

The pH of water in Chester County (68 wells) is significantly greater than the pH of water in York County (31 wells). The pH in Chester County ranges from 5.0 to 7.6; the median is 6.1. For York County, pH ranges from 5.0 to 7.0; the median is 5.6. The water in Chester County (67 wells) is significantly harder than the water in York County (79 wells). The hardness of water in Chester County ranges from 17 to 310 mg/L; the median is 51 mg/L. In York County, the hardness of water ranges from 17 to 170 mg/L; median is 34 mg/L.

Marburg Schist (Xwm)

The Marburg Schist (Berg and others, 1980) underlies about 120 mi^2 of the Piedmont Upland in Adams and York Counties. Valentino (1994, p. 29) included the Marburg Schist in the Octoraro Formation. Valentino (1994, p. 26) and Stose and Jonas (1939, p. 90) recognized the Marburg Schist in Lancaster County. The Marburg Schist is named after the village of Marburg, 5 mi southeast of Hanover, Pa. (Stose and Jonas, 1939, p. 90).

Geologic description.—The Marburg Schist (table 2) is typically bluish-gray to silvery green, fine-grained schist with well-developed platy cleavage. The dominant minerals are muscovite, chlorite, albite, chloritoid, and quartz; pyrite is a minor secondary mineral. The northeastern part of the Marburg Schist is coarser grained than the southwestern part. Part of the Marburg Schist contains volcanic tuff, with beds of quartzite and coarse, pebbly, quartz conglomerate forming the upper part of the formation (Stose and Jonas, 1939, p. 90-92). The quartzites are closely folded and interbedded with slate and schist.

Much of the area underlain by the Marburg Schist is in the form of slopes with rolling hills dissected by numerous upland draws and narrow valleys. The quartzites, interbedded with slate and schist, form the higher hills; the ridges are underlain by quartzite and quartz conglomerate. Thickness of the regolith is highly variable and averages about 45 ft near the Keystone Sanitation Superfund Site, south of Littlestown, Adams County, Pa. (Conger, 1997, p. 2).

Thickness of the Marburg Schist is not known. Originally, the schist was deposited in a continental or slope environment (Faill and Wiswall, 1994, p. 74). Wise (1970, p. 319) believed the Marburg Schist was an Antietam-Chickies equivalent. Work by Valentino (1994, p. 29) and Lyttle and Epstein (1987) suggested the Marburg Schist is Cambrian and Late Proterozoic in age. The Marburg Schist may be in gradational contact with the Albite-Chlorite Schist (Stose and Jonas, 1939, p. 90-91; Valentino, 1994, p. 29). Wise (1970, p. 318), however, pointed out the contact between the Marburg Schist and the Albite-Chlorite Schist is the location of a sharp break on aeromagnetic maps. To the north is the Martic Line or Martic Overthrust (Stose and Jonas, 1939, p. 80-83) where the Marburg Schist is in structural contact with the Antietam and Harpers Formations.

Well depths and casing lengths.—Depths of wells completed in the Marburg Schist are presented in the table below. Only six wells are completed at depths of 300 ft or greater. High-demand wells are not completed at significantly greater depths than domestic wells.

Reported well depth, Marburg Schist

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	96	75	100	140	169	223	41	1,030
Drilled, domestic	78	75	100	138	162	207	41	500
Drilled, high-demand	10	110	117	135	285	970	110	1,030

Casing lengths for wells completed in the Marburg Schist are presented in the table below. Casing lengths of 50 ft or greater are reported from eight wells.

Reported casing length, Marburg Schist

[Casing length in feet; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	74	19	21	27	40	50	12	80
Drilled, domestic	66	19	21	29	40	50	13	80
Drilled, high-demand	5	—	16	20	24	—	12	28

Hydrologic properties.—Water levels for wells completed in the Marburg Schist are presented in the table below. Depths to water in 83 wells range from 2 to 69 ft below land surface; the median is 30 ft below land surface.

Water levels, Marburg Schist

[Water levels in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	27	23	28	38	46	50	20	51
Slope	43	12	19	30	38	46	5	69
Valley	8	—	6	11	16	—	2	18

Lloyd and Growitz (1977, p. 45) have shown that schistosity in the Marburg Schist can have a considerable effect on water levels. York County well number Yo-253 was pumped at 12 gal/min for 1 hour with a drawdown of 9.5 ft. The greatest water-level drawdown of 2.2 ft was in observation well Yo-254, which is along a line parallel with the pumping well and the strike of schistosity. In the two observation wells perpendicular to schistosity, the drawdowns were 0.06 and 0.02 ft.

Reported yields for wells completed in the Marburg Schist are presented in the table below. Yields of 5.0 gal/min or less are reported from 42 wells. None of the four wells with reported yields of 20 gal/min or greater are deeper than 200 ft. High-demand wells do not yield significantly more water than domestic wells.

Reported well yield, Marburg Schist

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	84	1.0	3.0	5.5	10	13	0.5	70
Domestic	69	1.0	3.0	6.0	10	12	1.0	20
High-demand	10	.80	4.0	9.5	28	66	.5	70

Specific capacities for wells completed in the Marburg Schist are presented in the table below. Seven wells (drilled from 120 to 1,030 ft below land surface) have specific capacities of 0.04 (gal / min) / ft or less and are incapable of meeting most domestic or other water-use demands. Specific capacities of 1.0 (gal / min) / ft or greater are reported from seven wells, but none are deeper than 150 ft. Specific capacities of wells with pumping durations of 8 hours or longer are 0.04, 0.16, and 0.18 (gal / min) / ft.

Reported specific capacity, Marburg Schist

[Specific capacity in gallons per minute per foot of drawdown; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	36	0.04	0.08	0.21	0.88	1.3	0.00	2.3
Domestic	32	.04	.08	.21	.79	1.3	.03	2.3
High-demand	3	—	—	.90	—	—	.00	1.1

Values of hydraulic conductivity and transmissivity for the Marburg Schist are presented in the table below; a specific yield of 0.02 was used in estimating these hydrologic properties. Hydraulic conductivity and transmissivity are generally greater on hilltops than on slopes. The median hydraulic conductivities of wells on hilltops (12 wells), slopes (18 wells), and in valleys (1 well) are 0.71, 0.19, and 0.06 ft / d, respectively. The median transmissivities of wells on hilltops is 50 ft^2 / d, on slopes 22 ft^2 / d and in valleys 11 ft^2 / d.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Marburg Schist

[ft/d, feet per day; ft^2/d, feet squared per day P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	35	0.01	0.06	0.25	1.8	2.8	0.01	9.6
Transmissivity (ft^2 / d)	35	1.5	6.4	30	130	200	.46	370

In other work, Meyer and Beall (1958) used multiple-well aquifer tests involving six wells in Maryland to estimate a specific yield of 0.02 and transmissivity of 976 ft^2 / d. In their Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, tables 8 and 16) used a specific yield of 0.02 and a hydraulic conductivity of 1.34 ft / d for a hydrogeologic unit that included the Marburg Schist.

The depths of water-bearing zones in 48 wells drilled as deep as 500 ft range from 15 to 395 ft below land surface. Fifty percent of the 83 water-bearing zones reported were penetrated by a depth of 78 ft and 90 percent by a depth of 133 ft. The greatest density of water-bearing zones (1.02 per 50 ft of well depth) is from 51 to 100 ft below land surface (fig. 22); only three water-bearing zones are reported at depths greater than 150 ft. The overall density of water-bearing zones in the Marburg Schist is 0.48 per 50 ft of well depth.

Near the Keystone Sanitation Superfund Site, Adams County, Pa., the USGS conducted borehole-geophysical logging on eight monitor wells that ranged in depth from 146 to 397.9 ft below land surface (Conger, 1997). Driller and borehole geophysical logs indicate water-bearing zones are present in the regolith and to a depth of 215 ft below land surface. However, most water-bearing zones are shallow and are typically penetrated by a depth of 96 ft or less. The heatpulse flowmeter measured vertical flow under ambient conditions in three wells. The water entered the boreholes through fractures between 82-139 ft below land surface, moved upward, and exited the borehole through fractures between 50-75 ft below land surface. In general, water is more available in the regolith and decreases with depth.

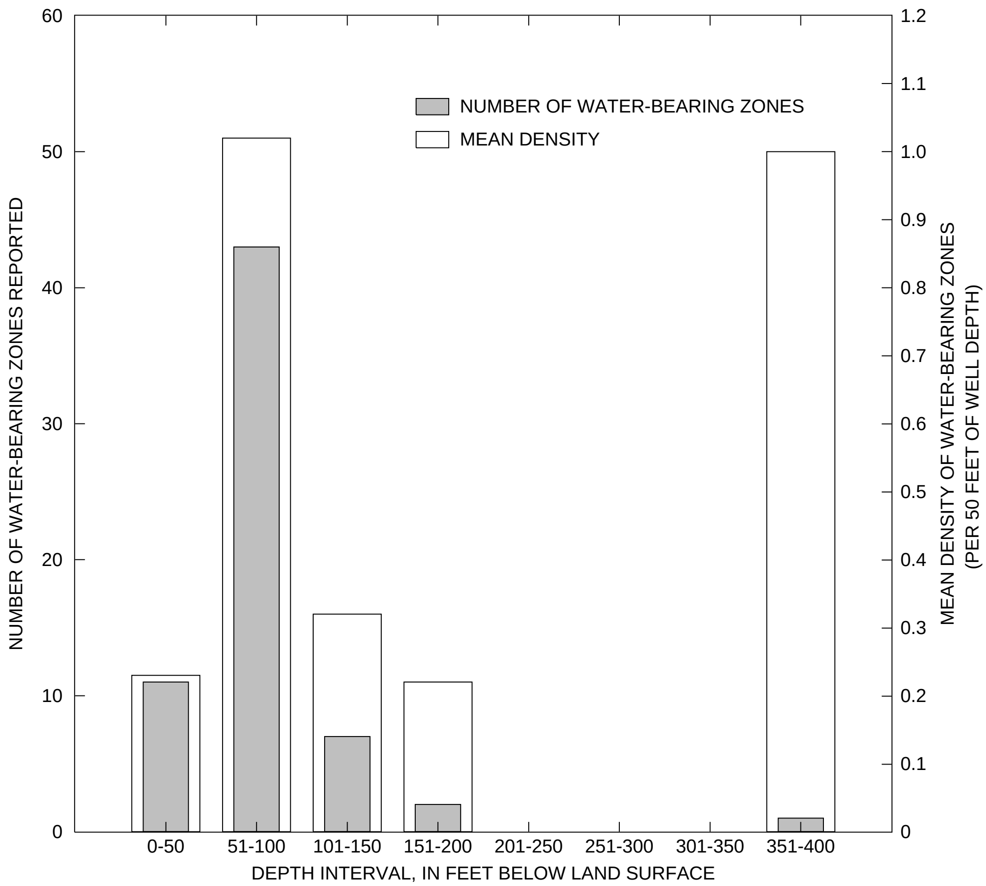


Figure 22. The number and density of water-bearing zones per 50 feet of well depth in the Marburg Schist of the Piedmont Physiographic Province, Piedmont Upland Section.

Water quality.—As seen in the following table, wells completed in the Marburg Schist generally yield water that is low in dissolved solids, soft to moderately hard, and slightly acidic. Calcium is the dominant cation, and bicarbonate is the dominant anion. Low pH and elevated concentrations of iron and manganese are the most common water-quality problems. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Marburg Schist

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	40	—	—	—	100	123	179	20	430
Field hardness	40	—	—	—	34	51	68	17	190
Field pH (standard units)	16	—	<6.5 >8.5	7	5.8	6.5	6.6	5.4	7.8
Bicarbonate	15	—	—	—	7.0	16	31	4.0	55
Calcium	15	—	—	—	3.7	9.8	16	3.2	21
Chloride	15	—	250	0	4.0	6.5	9.4	1.6	29
Iron	14	—	.3	3	.058	.10	.34	.020	8.4
Magnesium	15	—	—	—	2.7	3.5	4.8	1.5	8.3
Manganese	14	—	.05	4	.020	.025	.083	.010	.18
Nitrate (as N)	15	10	—	1	1.2	3.2	7.0	.02	12
Potassium	14	—	—	—	.50	.85	.92	.30	2.0
Silica	10	—	—	—	7.1	8.2	11	4.7	14
Sodium	15	—	—	—	3.2	4.1	6.5	1.0	25
Sulfate	15	—	250	0	3.5	7.0	10	.00	28
Total dissolved solids	14	—	500	0	52	92	124	42	180

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.

Peters Creek Schist (Xpc)

The Peters Creek Schist (Berg and others, 1980) underlies about 180 mi^2 of Chester, Lancaster, and York Counties in a northeast trending belt from the Maryland-Pennsylvania state line into northeastern Chester County. Lyttle and Epstein (1987) extended the Peters Creek Schist eastward to the Schuylkill River.

Stose and Jonas (1939, p. 93) named the Peters Creek Schist (Peters Creek quartzite) for its exposures along Peters Creek in Lancaster County. More recently, this unit has been referred to as the Peters Creek Formation (Valentino and Gates, 1994, p. 35-43).

Geologic description.—Lyttle and Epstein (1987) and Valentino and Gates (1994, p. 35-43) identified at least three sequences or lithologies in the Peters Creek Schist (table 2). In general, the Peters Creek Schist is fine- to medium-grained, light to medium gray or greenish-gray, yellowish- to reddish-brown weathering, finely laminated, nonfissile muscovite, chlorite, quartz schist or gneiss. It is interbedded with quartzites that contain thin layers of muscovite and chlorite on the parting planes. In the schist, albite is abundant; magnetite and titanite are abundant accessory minerals; apatite, pyrite, and tourmaline are common. The quartzitic layers contain quartz grains and pebbles that have been stressed (Stose and Jonas, 1939, p. 93); original crossbedding has been observed in Maryland (Dingman and others, 1956, p. 28). The Peters Creek Schist has a well developed platy cleavage, steeply dipping bedding, and has been intensely folded. It also contains tectonic slivers of altered ultramafic rocks (Lyttle and Epstein, 1987) and mafic tuffs or volcaniclastic sediments (Valentino and Gates, 1994, p. 38).

The Peters Creek Schist is moderately resistant to weathering, forming undulating hills of medium relief with moderately steep and stable slopes; joints are irregular, poorly formed, widely spaced, steeply dipping, and open (Geyer and Wilshusen, 1982, p. 221-223).

Bascom and Stose (1932, p. 6) estimated a thickness of 2,000 ft for the Peters Creek Schist; however, other workers (Stose and Jonas, 1939, p. 94; Lyttle and Epstein, 1987) citing the extensive faulting and folding have not been able to estimate a total thickness. Berg and others (1983) considered this unit to be Ordovician in age, whereas Lyttle and Epstein (1987) believed the Peters Creek Schist is Cambrian and Late Proterozoic in age. According to Valentino and Gates (1994, p. 35), the Peters Creek Schist represents turbidite-fan deposits laid down in a rift basin. The Peters Creek Schist is largely bounded by faults or shear zones, but in parts of southern Chester County, it is in strike-parallel gradational contact with the Oligoclase-Mica Schist (Valentino and Gates, 1994, p. 36).

Well depths and casing lengths.—Depths of wells completed in the Peters Creek Schist are presented in the table below. In general, wells drilled on hilltops (42 wells) are deeper than wells on slopes (63 wells) or in valleys (16 wells); the median well depths are 120, 100, and 102 ft, respectively. Of 13 wells drilled to depths of 300 ft or greater, 7 are on slopes and 5 are on hilltops.

Reported well depth, Peters Creek Schist

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	166	62	80	102	157	254	29	575
Drilled, domestic	130	65	80	100	140	216	42	575
Drilled, high-demand	11	64	114	188	247	326	60	334

Casing lengths for wells completed in the Peters Creek Schist are presented in the table below. Five of the six wells with casing lengths of 100 ft or greater are on hilltops; one is on a slope. Typically, drilled wells on hilltops (24 wells) use considerably more casing than drilled wells on slopes (63 wells) or in valleys (12 wells); the median casing lengths are 59, 36, and 32 ft, respectively.

Reported casing length, Peters Creek Schist

[Casing length in feet; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	112	20	22	36	55	83	6	224
Drilled, domestic	98	19	22	34	52	76	6	224
Drilled, high-demand	7	—	42	56	90	—	20	200

Hydrologic properties.—Water levels for wells completed in the Peters Creek Schist are presented in the table below. Depths to water in 163 wells range from 3 to 250 ft below land surface; the median is 33 ft below land surface.

Water levels, Peters Creek Schist

[Water levels in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	41	27	32	48	58	85	10	250
Slope	86	15	22	32	44	54	3	80
Valley	16	6	8	12	17	32	5	38

Reported yields of wells completed in the Peters Creek Schist are presented in the table below. Yields of 5.0 gal / min or less are reported from 34 wells completed in the Peters Creek Schist; 29 of these wells are domestic wells. None of the 21 wells completed at depths greater than 200 ft have reported yields that exceed 35 gal / min.

Reported well yield, Peters Creek Schist

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	137	3.0	5.0	10	20	30	0.0	312
Domestic	109	3.0	5.0	9.0	15	25	.2	60
High-demand	12	5.9	16	22	31	239	5.0	312

Specific capacities of wells completed in the Peters Creek Schist are presented in the table below. Nine wells (drilled from 166 to 330 ft below land surface) have specific capacities of 0.04 (gal / min) / ft or less and are incapable of meeting most domestic or other water-use demands. Specific capacities of 1.0 (gal / min) / ft or greater are reported from 13 wells; only 2 of these wells exceed a depth of 100 ft. The specific capacities of four wells with a pumping duration of 8 hours or longer range from 0.03 to 0.16 (gal / min) / ft; the median is 0.14 (gal / min) / ft.

Reported specific capacity, Peters Creek Schist

[Specific capacity in gallons per minute per foot of drawdown; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	57	0.03	0.07	0.37	0.89	3.0	0.00	9.0
Domestic	48	.02	.07	.38	.85	3.1	.00	9.0
High-demand	8	—	.13	.21	2.1	—	.03	2.5

Values of hydraulic conductivity and transmissivity for the Peters Creek Schist are presented in the table below; a specific yield of 0.02 was used in estimating these hydrologic properties. Hydraulic conductivity and transmissivity are generally lower on hilltops than on slopes or in valleys. The median hydraulic conductivity of wells on hilltops (4 wells), slopes (32 wells), and valleys (5 wells) are 0.48, 1.2, and 1.4 ft / d, respectively. The median transmissivity on hilltops is 41 ft^2 / d, on slopes 57 ft^2 / d, and in valleys 50 ft^2 / d.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Peters Creek Schist

[ft/d, feet per day; ft^2/d, feet squared per day P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	52	0.04	0.14	1.1	5.1	18	0.01	110
Transmissivity (ft^2 / d)	52	4.1	16	51	160	480	2.0	1,800

In other work, Geyer and Wilshusen (1982, p. 223) used rock-test data from Dames and Moore, Inc., to estimate the permeability of unweathered Peters Creek Schist as 0.1 ft / d. For highly weathered and fractured rock, the permeability of Peters Creek Schist was 20 ft / d. In the Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, tables 8 and 16) used a specific yield of 0.020 and a hydraulic conductivity of 1.34 ft / d for a hydrogeologic unit that included the Peters Creek Schist.

The depths of water-bearing zones in 70 wells drilled as deep as 400 ft range from 8 to 270 ft below land surface. Fifty percent of the 140 water-bearing zones reported are penetrated by a depth of 81 ft and 90 percent by a depth of 160 ft. The greatest density of water-bearing zones (0.84 per 50 ft of well depth) is from 51 to 100 ft below land surface (fig. 23); the density of water-bearing zones at depths of 151 ft or greater are based on the presence of four or less water-bearing zones per 50-ft interval. The overall density of water-bearing zones in this unit is 0.47 per 50 ft of well depth.

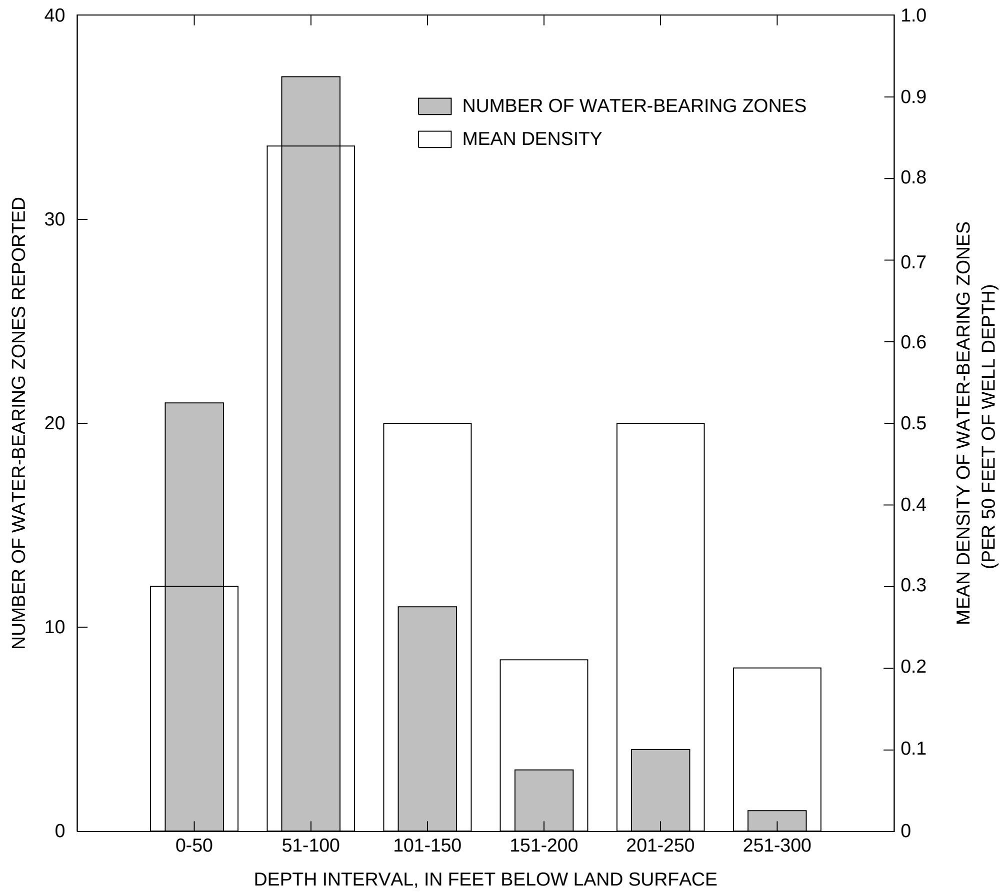


Figure 23. The number and density of water-bearing zones per 50 feet of well depth in the Peters Creek Schist of the Piedmont Physiographic Province, Piedmont Upland Section.

Water quality.—As seen in the following table, wells completed in the Peters Creek Schist generally yield water that is low in dissolved solids, soft to moderately hard, and slightly acidic. Calcium is the dominant cation, and bicarbonate is the dominant anion. Elevated concentrations of iron, manganese, nitrate, and radon are the most common water-quality problems. Water in one well has an aluminum concentration of 80 µg/L; another well contains water with a zinc concentration of 3.8 mg/L. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Peters Creek Schist

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; pCi/L, picoCurie per liter; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	103	—	—	—	95	120	200	30	500
Field hardness	101	—	—	—	34	51	85	17	140
Field pH (standard units)	94	—	<6.5 >8.5	70	5.8	6.1	6.5	4.8	8.2
Bicarbonate	39	—	—	—	14	20	34	4.0	90
Calcium	33	—	—	—	5.9	12	24	1.7	35
Chloride	37	—	250	0	5.1	8.4	28	1.4	110
Iron	39	—	.3	8	.012	.080	.19	.003	5.4
Lead	22	0.015	—	2	.002	.004	.007	.000	6.9
Magnesium	33	—	—	—	3.5	4.6	8.9	.90	24
Manganese	33	—	.05	8	.010	.013	.060	.000	.32
Nickel	21	.1	—	1	.002	.006	.018	.000	.20
Nitrate (as N)	32	10	—	10	1.4	5.1	13	.04	40
Potassium	29	—	—	—	.47	.85	1.3	.20	7.4
Radon (pCi/L)	6	[3] 300	—	6	2,800	5,200	7,700	2,500	9,100
Silica	23	—	—	—	9.5	11	14	.80	16
Sodium	29	—	—	—	4.2	5.7	11	2.4	39
Sulfate	37	—	250	0	3.1	6.3	15	.30	54
Total dissolved solids	36	—	500	0	75	108	197	24	470

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.
[3] U.S. Environmental Protection Agency, 1994, proposed maximum contaminant level.

Peach Bottom Slate and Cardiff Conglomerate, Undivided (Xpb)

These two geologic units are mapped as one on the State Geologic Map (Berg and others, 1980) and underlie about 4 mi^2 of the Piedmont Upland. The Peach Bottom Slate and Cardiff Conglomerate form a thin, very narrow band that trends northeast from the Maryland-Pennsylvania state line within the Peters Creek Schist in Lancaster and York Counties.

The Peach Bottom Slate was named for Peach Bottom Station, Lancaster County (Knopf and Jonas, 1929, p. 39-41); more recently, this unit has been referred to as the Peach Bottom Formation (Valentino, 1994, p. 88).

The Cardiff Conglomerate was named by the Maryland Geological Survey for exposures near the village of Cardiff, Md., on the Pennsylvania-Maryland state line. More recently, this unit has been referred to as the Cardiff Formation (Valentino, 1994, p. 89).

Geologic description.—The Peach Bottom Slate (table 2) is deep blue-black to dark-gray phyllitic slate and slate that has a finely lustrous sheen on cleavage surfaces; quartzitic interbeds are very thin. This unit may contain up to 90 percent very fine muscovite and sericite with accessory quartz, chlorite, chloritoid, and ilmenite. Folding and folded slaty cleavage is common; joints are vertical and open (Stose and Jonas, 1939, p. 96-102).

The Peach Bottom Slate is moderately resistant to weathering, forming local ridges or uplands with steep and stable slopes. This unit has been quarried for slate near Delta, Pa., and south into Maryland. Geyer and Wilshusen (1982, p. 218) estimated the Peach Bottom Slate to be about 1,000 ft thick.

The Cardiff Conglomerate is greenish-gray on a fresh surface, weathering to a mottled red. The Cardiff Conglomerate consists of alternating layers of conglomerate and quartzite with muscovite partings. Quartz pebbles up to 3 in. in length are present in the conglomerate and are elongated parallel to the cleavage. The conglomerate is schistose in texture and is composed of a matrix of fine quartz and plates of muscovite and chlorite; magnetite and titanite also are present. Joints are closely spaced locally, abundant, and open; tight folds and associated shearing are common.

The Cardiff Conglomerate is moderately to highly resistant to weathering forming dissected uplands, and readily breaks into slabs parallel to the muscovite partings (Stose and Jonas, 1939, p. 95). The Cardiff Conglomerate is estimated to have a thickness of about 200 ft (Geyer and Wilshusen,1982, p. 57). According to Higgins (1972, p. 992), the contact with the Peters Creek Schist is gradational.

Stose and Jonas (1939, p. 95-96) believed the Cardiff Conglomerate was Ordovician in age and overlain by a younger Peach Bottom Slate. Higgins (1972, p. 1,017) believed the Peach Bottom was older than the Cardiff Conglomerate and these two units are correlative with the Hellam Member of the Chickies Formation. Valentino (1994, p. 85-100) did not believe in the existence of the Peach Bottom syncline or anticline as proposed by earlier workers. Instead, Valentino proposed that the Peach Bottom structure was a large splay off the Pleasant Grove—Huntingdon Valley dextral shear zone.

According to Valentino (1994, p. 100), the Peach Bottom Slate was originally a pelitic shale and siltstone that was deposited in a restricted basin, either deep water or lacustrine, and the Cardiff Conglomerate in an environment similar to the Peters Creek Schist. Valentino (1994, p. 85) believed also that the Peach Bottom Slate and Cardiff Conglomerate were the structurally lowest units in a monoclinal sequence containing the Peters Creek Schist and may be stratigraphically lower than the Peters Creek Schist; hence, eliminating correlation of the Peach Bottom Slate or Cardiff Conglomerate to any part of the Chickies Formation.

Well depths and casing lengths.—Depths of wells and casing lengths from wells completed in the Peach Bottom Slate and Cardiff Conglomerate are presented in the tables below. Data for the Peach Bottom Slate and Cardiff Conglomerate are from York County. Only two wells in the Peach Bottom Slate and Cardiff Conglomerate are deeper than 200 ft. The casing lengths in eight wells are less than 100 ft.

Reported well depth, Peach Bottom Slate and Cardiff Conglomerate, undivided

[Depth in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	15	65	70	90	150	217	65	225
Drilled, domestic	12	66	71	87	150	214	65	225
Drilled, high-demand	2	—	—	161	—	—	110	210

Reported casing length, Peach Bottom Slate and Cardiff Conglomerate, undivided

[Casing length in feet; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	15	21	24	40	60	66	20	70
Drilled, domestic	12	20	25	40	61	68	20	70
Drilled, high-demand	2	—	—	41	—	—	22	60

Hydrologic properties.—Water levels for wells completed in the Peach Bottom Slate and Cardiff Conglomerate are presented in the table below. Depths to water in 14 wells range from 9 to 75 ft below land surface; the median is 40 ft below land surface. Water levels are strongly influenced by seasonal changes.

Water levels, Peach Bottom Slate and Cardiff Conglomerate, undivided

[Water levels in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	3	—	—	45	—	—	40	50
Slope	11	13	30	40	60	73	9	75

Reported yields for wells completed in the Peach Bottom Slate and Cardiff Conglomerate are presented in the table below. Yields of 5.0 gal / min or less are reported from one well. Eight wells have reported yields of 20 gal / min or greater; however, only one is deeper than 200 ft.

Reported well yield, Peach Bottom Slate and Cardiff Conglomerate, undivided

[Yield in gallons per minute; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	15	5.0	10	20	30	63	2.0	85
Domestic	12	3.2	8.5	18	20	74	2.0	85
High-demand	2	—	—	37	—	—	33	41

Specific capacities for wells completed in the Peach Bottom Slate and Cardiff Conglomerate are presented in the table below. Only one well (well depth 150 ft) has a specific capacity of 0.04 (gal / min) / ft or less. The low specific capacity makes this well incapable of meeting most domestic or other water-use demands. Specific capacities of 1.0 (gal / min) / ft or greater are reported from seven wells; only one of these wells is deeper than 200 ft. The specific capacity of one well with a pumping duration of 8 hours or longer is 2.8 (gal / min) / ft.

Reported specific capacity, Peach Bottom Slate and Cardiff Conglomerate, undivided

[Specific capacity in gallons per minute per foot of drawdown; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	12	0.14	0.62	1.2	2.1	5.6	0.03	6.8
Domestic	10	.07	.49	.95	2.0	2.7	.03	2.8
High-demand	2	—	—	4.1	—	—	1.4	6.8

Values of hydraulic conductivity and transmissivity for the Peach Bottom Slate and Cardiff Conglomerate are presented in the table below; a specific yield of 0.02 was used in estimating these hydrologic properties. Hydraulic conductivity and transmissivity are generally lower on hilltops than on slopes. The median hydraulic conductivity of wells in the Peach Bottom Slate and Cardiff Conglomerate on hilltops (2 wells) is 0.84 ft / d and on slopes (10 wells) is 6.2 ft / d. The median transmissivities on hilltops and slopes are 35 and 210 ft^2 / d, respectively.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Peach Bottom Slate and Cardiff Conglomerate, undivided

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	12	0.10	1.9	5.9	8.2	13	0.02	15
Transmissivity (ft^2 / d)	12	15	83	180	360	1,000	2.2	1,200

Gerhart and Lazorchick (1988) created a digital model of the Lower Susquehanna River Basin. In this digital model, Gerhart and Lazorchick (1988, tables 8 and 16) used a specific yield of 0.02 and a hydraulic conductivity of 1.34 ft / d for a hydrogeologic unit that included the Peach Bottom Slate and Cardiff Conglomerate.

The depths of water-bearing zones in 12 wells drilled as deep as 225 ft range from 42 to 207 ft below land surface. Fifty percent of the 30 water-bearing zones reported are penetrated by a depth of 80 ft and 90 percent by a depth of 197 ft. The greatest density of water-bearing zones (2.0 per 50 ft of well depth) is from 151 to 200 ft below land surface (fig. 24). The overall density of water-bearing zones in this unit is 0.79 per 50 ft of well depth.

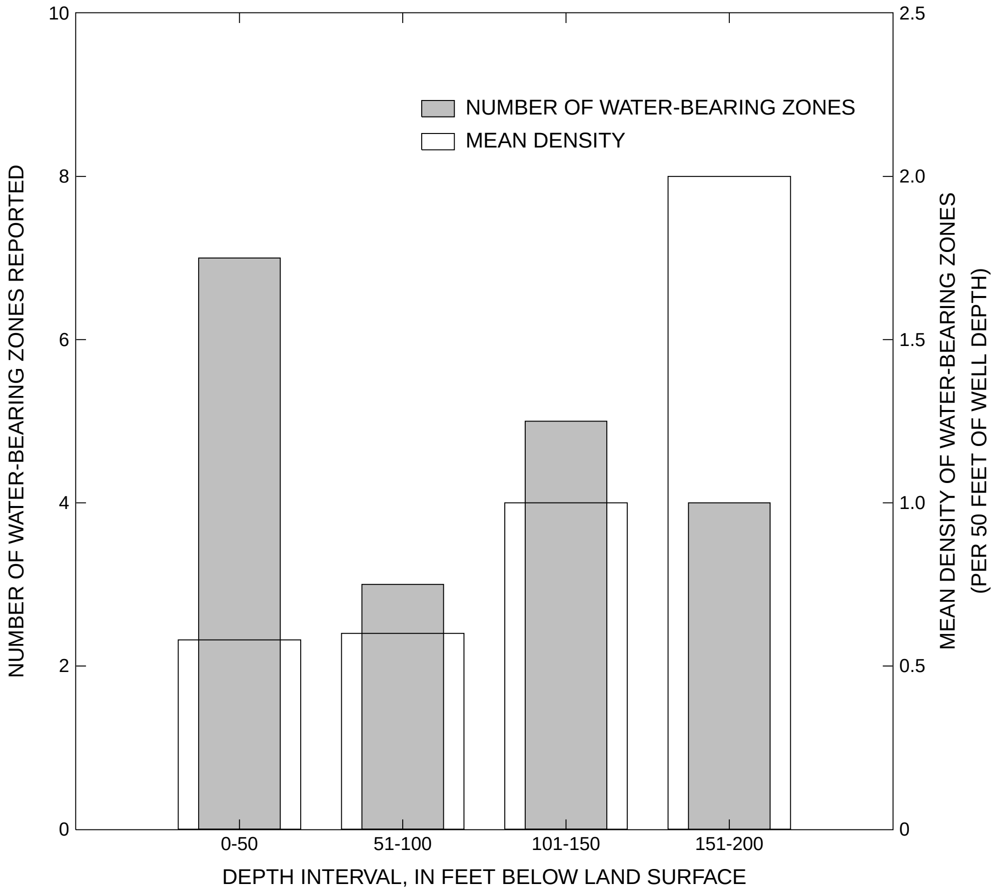


Figure 24. The number and density of water-bearing zones per 50 feet of well depth in the Peach Bottom Slate and Cardiff Conglomerate of the Piedmont Physiographic Province, Piedmont Upland Section.

Water quality.—As seen in the following table, wells completed in the Peach Bottom Slate and Cardiff Conglomerate generally yield water that is low in dissolved solids, very soft, and slightly acidic. Calcium is the dominant cation, and chloride is the dominant anion. Lloyd and Growitz (1977, p. 9) described the water in the Peach Bottom Slate near Delta, Pa., as a calcium sodium nitrate bicarbonate type. Elevated concentrations of iron and manganese may be common water-quality problems. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Peach Bottom Slate and Cardiff Conglomerate, undivided

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	6	—	—	—	48	65	93	40	130
Field hardness	4	—	—	—	—	17	—	17	34
Field pH (standard units)	4	—	<6.5 >8.5	4	—	6.2	—	5.3	6.2
Bicarbonate	3	—	—	—	—	9.0	—	7.0	34
Calcium	3	—	—	—	—	3.7	—	1.6	9.0
Chloride	3	—	250	0	—	5.7	—	3.0	8.2
Iron	3	—	.3	2	—	.35	—	.11	.70
Magnesium	3	—	—	—	—	1.5	—	1.1	2.5
Manganese	3	—	.05	1	—	.020	—	.000	.090
Nitrate (as N)	3	10	—	0	—	3.6	—	.63	7.7
Potassium	2	—	—	—	—	.65	—	.50	.80
Silica	3	—	—	—	—	5.5	—	4.8	6.8
Sodium	2	—	—	—	—	4.2	—	2.5	5.8
Sulfate	3	—	250	0	—	1.9	—	.60	2.0
Total dissolved solids	3	—	500	0	—	57	—	20	94

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.

Chickies Formation (Cch)

The Chickies Formation (Berg and others, 1980) underlies about 110 mi^2 of the Piedmont Upland, where it generally crops out in a series of thin, elongate, fault-truncated belts. The most extensive exposures are in York and Lancaster Counties, but the Chickies also is present in Adams, Bucks, Chester, Montgomery, and Philadelphia Counties.

The type location for the Chickies Formation is at Chickies Rock along the Susquehanna River in Lancaster County, between Marietta and Columbia, Pa. This unit has a prominent basal member, the Hellam Conglomerate, that was named for the Hellam Hills (Stose and Jonas, 1939, p. 42). The Chickies Formation is very resistant to weathering, forming a series of elongated, high ridges with steep and stable slopes.

Geologic description.—The Chickies Formation (table 2) is comprised of three lithologies—conglomerate, quartzite, and slate that have been mapped as three members of the formation, Hellam Conglomerate, Chickies Quartzite, and Chickies Slate (Bascom and Stose, 1938; Stose and Jonas, 1939; Stose and Stose, 1944). The basal member (Hellam Conglomerate) is a pebbly arkosic quartzite to coarse feldspar- and quartz-pebble conglomerate grading into conglomeratic quartzite, with a quartz and sericitic matrix; interbeds or fragments of slate have been reported in York County (Stose and Jonas, 1939). Accessory minerals include zircon, magnetite, hematite, rutile, monazite, titanite, tourmaline, and apatite (Senior and Vogel, 1995, p. 11). The basal member is present everywhere the Chickies Formation has been mapped.

The quartzite member is medium-grained white to gray, massive, medium- to well-bedded, vitreous quartzite with clear to green quartz grains and fine-grained multi-colored, thin-bedded, sericitic quartz schist; Scolithus tubes are relatively common and cross-bedding may be locally observed. Quartz veins are present between and within beds. Accessory minerals include zircon, rutile, apatite, monazite, tourmaline, limonite after pyrite, hematite, magnetite, and other opaque minerals (Senior and Vogel, 1995, p. 11). In some places, the quartzite member is absent, being replaced by the slate member (Stose and Jonas, 1939).

The slate member consists of black slate, green phyllite, and thin-bedded quartzite, with albite, chlorite, muscovite, magnetite, zircon, and tourmaline (Stose and Stose, 1944). In some places, the magnetite is so abundant it has been prospected for iron (Stose and Jonas, 1939, p. 43).

The thickness of the Chickies Formation ranges from about 430 ft in the south to 1,300 ft in the north (Lyttle and Epstein, 1987). The Chickies Formation was deposited in braided streams and the littoral zone along a coastal margin (Hyde, 1971; Goodwin and Anderson, 1974; Adams and Goodwin, 1975). The Chickies Formation unconformably overlies or is in fault contact with the Granitic and Plutonic Rocks and other Precambrian rocks of the Piedmont Upland. It conformably underlies the Harpers Formation and Antietam Formations (Stose and Jonas, 1939; Stose and Stose, 1944).

Well depths and casing lengths.—Depths of wells and casing lengths for wells completed in the Chickies Formation are presented in the tables below. High-demand wells are not significantly deeper nor use significantly more casing than domestic wells.

Reported well depth, Chickies Formation

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	295	80	110	150	230	300	40	600
Drilled, domestic	238	81	118	150	223	280	40	500
Drilled, high-demand	21	90	105	195	303	420	80	504

Reported casing length, Chickies Formation

[Casing length in feet; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	238	20	31	44	74	99	8	282
Drilled, domestic	194	21	33	44	72	97	12	168
Drilled, high-demand	15	21	25	35	60	281	20	282

Hydrologic properties.—Water levels for wells completed in the Chickies Formation are presented in the table below. Depths to water in 241 wells range from flowing at land surface to 202 ft below land surface; the median is 45 ft below land surface. Only two of the wells flow.

Water levels, Chickies Formation

[Water levels in feet below land surface; F, flowing well; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	62	20	36	53	80	96	F	112
Slope	154	14	30	40	60	81	F	140
Valley	10	6	7	14	24	54	6	55

Reported yields for wells completed in the Chickies Formation are presented in the table below. Yields of 5.0 gal / min or less are reported from 76 wells; 64 of these wells are domestic wells. Yields of 100 gal / min or greater are reported from five wells, however, only three are deeper than 200 ft.

Reported well yield, Chickies Formation

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	244	2.7	4.0	9.0	20	34	0.3	125
Domestic	201	2.6	4.0	8.0	15	25	.5	73
High-demand	20	3.1	7.5	35	85	100	.3	100

Yields can vary spatially. Reported yields of domestic wells are significantly greater in Chester County (106 wells) than in York County (50 wells). The median reported yield of domestic wells in Chester County is 10 gal / min and in York County is 6.5 gal / min.

Specific capacities for wells completed in the Chickies Formation are presented in the table below. Thirteen wells (drilled from 94 to 400 ft below land surface) have specific capacities of 0.04 (gal / min) / ft or less and are incapable of meeting most domestic or other water-use demands. Specific capacities of 1.0 (gal / min) / ft or greater are reported from 14 wells; 2 of these wells are deeper than 200 ft, The specific capacities of six wells with pumping durations of 8 hours or longer range from 0.22 to 1.7 (gal / min) / ft; the median is 0.81 (gal / min) / ft.

Reported specific capacity, Chickies Formation

[Specific capacity in gallons per minute per foot of drawdown; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	66	0.02	0.06	0.17	0.57	2.2	0.00	15
Domestic	51	.02	.06	.15	.49	2.4	.00	15
High-demand	11	.01	.17	.43	1.7	2.7	.00	3.0

Values for hydraulic conductivity and transmissivity for the Chickies Formation are presented in the table below; a specific yield of 0.02 was used in estimating these hydrologic properties. Hydraulic conductivity and transmissivity are generally lower on hilltops and slopes, than in valleys. The median hydraulic conductivity of wells on hilltops (15 wells), slopes (36 wells), and valleys (4 wells) are 0.27, 0.30, and 1.8 ft / d, respectively. The median transmissivity on hilltops is 22 ft^2 / d, slopes 18 ft^2 / d, and valleys 80 ft^2 / d.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Chickies Formation

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	58	0.03	0.08	0.32	2.1	25	0.00	140
Transmissivity (ft^2 / d)	58	2.7	8.7	22	88	430	.46	2,800

In other work, Gerhart and Lazorchick (1984b) created a digital model of parts of Lancaster and Berks Counties, Pa. They estimated (Gerhart and Lazorchick, 1984b, tables 8 and 14) a specific yield of 0.20 and a hydraulic conductivity of 0.5 ft / d for a metamorphic rock unit that included the Chickies Formation. For the Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, tables 8 and 16) estimated a specific yield of 0.02 for the upper 200 ft and hydraulic conductivities of 0.67, 1.34 and 2.01 ft / d for different hydrogeologic units that included the Chickies Formation. For his digital model in the Valley Creek Basin of eastern Chester County, Sloto (1990) used a specific yield of 0.08 and estimated a hydraulic conductivity of 3.0 ft / d.

The depths of water-bearing zones in 165 wells drilled as deep as 500 ft range from 9 to 375 ft below land surface. Fifty percent of the 333 water-bearing zones reported are penetrated by a depth of 110 ft and 90 percent by a depth 229 ft. The greatest density of water-bearing zones (0.69 per 50 ft of well depth) is from 251 to 300 ft below land surface (fig. 25); the density of water-bearing zones at depths of 301 ft or greater are based on the presence of two or fewer water-bearing zones per 50-ft interval. The overall density of water-bearing zones in this unit is 0.46 per 50 ft of well depth.

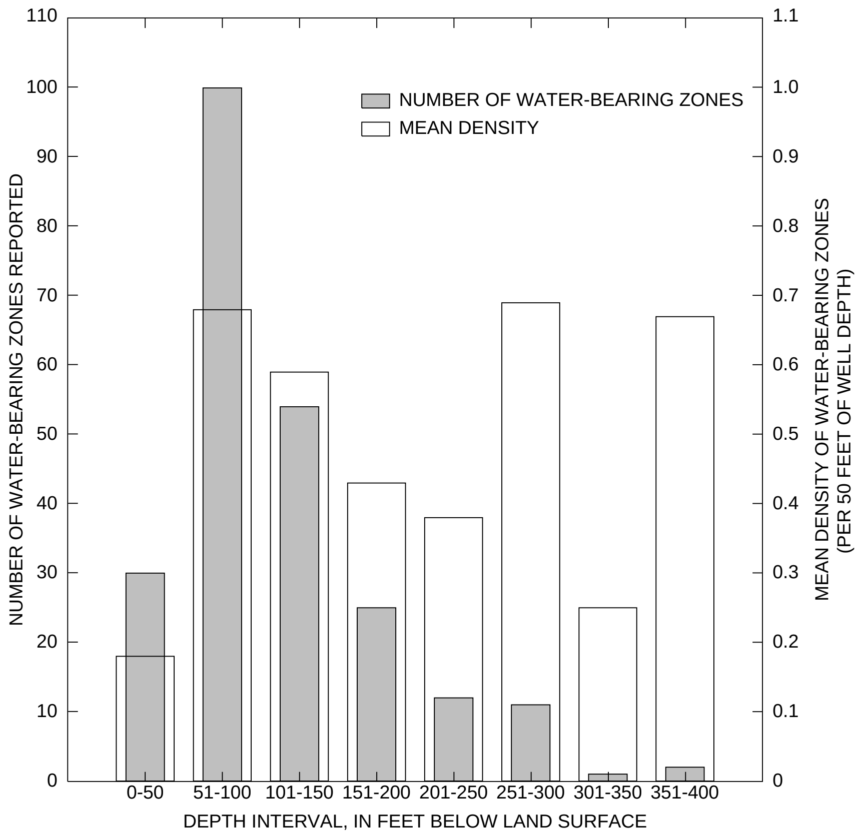


Figure 25. The number and density of water-bearing zones per 50 feet of well depth in the Chickies Formation of the Piedmont Physiographic Province, Piedmont Upland Section.

Water quality.—As seen in the following table, wells completed in the Chickies Formation generally yield water that is low in dissolved solids, soft to moderately hard, and acidic. Magnesium, plus sodium and potassium are the dominant cations, and chloride is the dominant anion. Only one well contains very hard water (specific conductance of 670 µS / cm, hardness of 260 mg / L, pH of 5.9). This well is within 100 ft of the Epler Formation, a crystalline limestone and dolomite unit. The fault, which separates the Chickies from the Epler, may be an area where waters of an acidic and an alkaline nature mix permitting hard, but acid water to be removed during pumping of the well. Wells that contain water with pH of 6.5 or greater also may be in areas where acidic and alkaline waters mix. Elevated concentrations of iron and manganese and low pH are common water-quality problems in the Chickies Formation, however, radon and radium concentrations are of special concern.

Summary of selected chemical constituents and properties analyzed for the Chickies Quartzite

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; pCi/L, picoCurie per liter; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	201	—	—	—	49	77	160	10	900
Field hardness	67	—	—	—	17	34	51	5	260
Field pH (standard units)	193	—	<6.5 >8.5	185	4.8	5.3	5.8	3.8	7.8
Bicarbonate	192	—	—	—	2.8	6.0	18	.00	300
Calcium	192	—	—	—	1.3	3.7	7.6	.10	59
Chloride	198	—	250	0	3.4	8.0	22	.30	120
Gross alpha (pCi/L)	161	15	—	39	1.8	5.5	17	.10	250
Iron	204	—	.3	36	.010	.044	.20	<.003	80
Lead	23	.015	—	1	.002	.003	.009	.000	.038
Magnesium	192	—	—	—	1.4	3.1	5.4	.20	38
Manganese	192	—	.05	74	.01n2	.034	.079	.000	22
Nitrate (as N)	38	10	—	2	.07	.81	2.6	.00	17
Potassium	187	—	—	—	1.2	1.8	3.1	.10	15
Radium-226 (pCi/L)	176	20	—	9	.56	2.0	5.7	.06	200
Radium-228 (pCi/L)	170	20	—	24	1.0	2.7	14	.01	160
Radon (pCi/L)	160	[3] 300	—	155	1,200	2,700	4,900	110	32,000
Silica	191	—	—	—	7.1	8.4	11	3.4	28
Sodium	191	—	—	—	2.2	4.2	8.8	.60	59
Sulfate	198	—	250	0	1.7	8.4	19	.20	62
Total dissolved solids	197	—	500	0	33	62	104	7.0	429

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.
[3] U.S. Environmental Protection Agency, 1994, proposed maximum contaminant level.

Recent work in the Chickies Formation indicates elevated concentrations of radium and associated daughter products are a very common water-quality problem. Senior and Vogel (1995) found that (1) preferential leaching of radium-228 (Ra-228) from aquifer solids may take place; (2) the concentrations of dissolved radium (Ra) are inversely related to pH and directly to total dissolved solids, dissolved organic carbon, barium, and sulfate concentrations; (3) the sources of the radium and radon may be uranium- and thorium-bearing heavy minerals, such as zircon and monazite, in the Chickies Formation; (4) Ra activities were greatest in acidic ground water in the conglomerate and quartzite and least in the more neutral water in the slate; and (5) temporal variations are seasonal.

The pH of water in the Chickies Formation varies spatially. Wells in York County (37 wells) contain water with significantly higher pH than wells in Lancaster County (47 wells). The median pH of water in the Chickies within York County is 5.5 and in Lancaster County 5.1. The more alkaline pH in York County is probably the result of ground water from the adjacent carbonate units such as the Conestoga, Kinzers, and Vintage Formations, flowing towards and mixing with the acidic waters of the Chickies. In Lancaster County, carbonate rocks that are adjacent to the Chickies Formation are sparse except in Chester Valley. This low-lying, carbonate valley probably has ground-water flow directed along its long axis, which is parallel to much of the Chickies, therefore, mixing of alkaline and acidic waters is minimal.

Human activities can greatly affect the quality of water in a well. Chester County well CH-2478 is near the Pennsylvania Turnpike and is on a site where highway deicing salt has been stored (Sloto, 1987, p. 68). The salt leaching into the ground water has resulted in an elevated field specific conductance of 6,000 µS/cm and field hardness of 2,300 mg/L; median laboratory concentrations of calcium, chloride, magnesium, and total dissolved solids are 520, 1,950, 250, and 4,210 mg/L, respectively.

Harpers Formation (Ch)

On the 1980 Geologic Map of Pennsylvania, Berg and others (1980) mapped the Harpers Formation separately and in combination with the Antietam Formation; however, other workers (Bascom and others, 1909; Bascom and Stose, 1932; 1938; Stose and Stose, 1944; Wise, 1970; Wilshusen, 1979) do not combine the two units. Where mapped separately by Berg and others (1980), the Harpers Formation crops out as a scattered series of small, faulted exposures closely associated with the Antietam Formation. The combined unit is more extensively exposed west of the Susquehanna River where it is in contact with the Marburg Schist, sedimentary rocks of the Gettysburg-Newark Lowland, and shale and carbonate rocks of the Piedmont Lowland. East of the Susquehanna River the combined unit crops out as a series of folded and faulted exposures with the shale and carbonate rocks of the Piedmont Lowland. The combined unit underlies about 131 mi^2; where mapped separately, the Harpers Formation underlies about 5 mi^2.

The Harpers Formation derived its name from Harpers Ferry, W.Va., where it was first called a shale and later a slate (Keith, 1894). In Pennsylvania, the Harpers Formation is a phyllite with a reference section east of New Providence, Lancaster County.

Geologic description.—In York County, the Harpers Formation (table 2) is fine- to medium-grained, dark-gray to green quartzose phyllite that locally contains thin quartzose beds (Stose and Jonas, 1939, p. 44). This formation is dark-bluish gray shale that grades laterally into schist in Lancaster County (Poth, 1977, p. 23-24). In central Chester County, this unit is a gray sandy, micaceous schist containing beds of schist quartzite (Poth, 1968, p. 62-63); bedding is generally obscured by cleavage wherever the Harpers Formation crops out.

The Harpers Formation is moderately resistant to weathering, forming hills of low relief with moderately steep and stable slopes (Geyer and Wilshusen, 1982, p. 142-143).The Harpers Formation in the York County area is estimated by Stose and Jonas (1939, p. 44) to be 800 to 1,000 ft thick. Poth (1968, p.62) estimated a thickness of 280 to 1,500 ft for the Harpers in central Chester County.

The Harpers Formation represents nearshore and shallow marine platform sands, and offshore, fine-grained, deep-water turbidite deposits (Schwab, 1970). The Harpers Formation conformably overlies the Chickies Formation and grades into the overlying Antietam Formation (Poth, 1977, p. 23). Although no fossils are known to exist in the Harpers Formation, because it is conformably overlain by the Antietam Formation which contains Lower Cambrian fossils, Stose and Jonas (1939, p. 44) assigned a Lower Cambrian age to the Harpers Formation.

Well depths and casing lengths.—Depths of wells completed in the Harpers Formation are presented in the table below. In general, high-demand wells are deeper than domestic wells.

Reported well depth, Harpers Formation

[Depth in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	118	79	100	120	166	205	27	510
Drilled, domestic	97	71	100	115	150	190	27	300
Drilled, high-demand	7	—	117	164	200	—	109	510

Casing lengths for wells completed in the Harpers Formation are presented in the table below. Only six wells have casing lengths 75 ft or greater.

Reported casing length, Harpers Formation

[Casing length in feet; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	96	20	21	30	43	62	12	146
Drilled, domestic	83	20	21	30	41	59	12	146
Drilled, high-demand	4	—	—	36	—	—	20	48

Casing length can vary spatially. The casing lengths of drilled wells in Chester County (17 wells) are significantly greater than in York County (71 wells); the medians are 48 and 29 ft, respectively.

Hydrologic properties.—Water levels for wells completed in the Harpers Formation are presented in the table below. Depths to water in 110 wells range from land surface to 98 ft below land surface; the median is 30 ft below land surface.

Water levels, Harpers Formation

[Water levels in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	37	20	29	40	49	56	15	98
Slope	57	12	20	30	44	51	4	61
Valley	9	—	7	16	24	—	0	30

Reported yields for wells completed in the Harpers Formation are presented in the table below. Yields of 5.0 gal/min or less are reported from 31 wells. None of the 10 wells reporting yields of 25 gal/min or greater are deeper than 200 ft.

Reported well yield, Harpers Formation

[Yield in gallons per minute; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	106	3.0	5.0	9.0	15	25	1.0	100
Domestic	88	3.0	5.0	9.0	13	20	1.0	100
High-demand	8	—	13	23	32	—	10	75

Specific capacities for wells completed in the Harpers Formation are presented in the table below. One well (well depth 145 ft) has a specific capacity of 0.04 (gal / min) / ft or less and is incapable of meeting most domestic or other water-use demands. Of the four wells with specific capacities of 1.0 (gal / min) / ft or greater, only two are deeper than 100 ft. Specific capacities of wells with pumping durations of 8 hours or longer (6 wells) range from 0.09 to 2.0 (gal / min) / ft; the median is 0.22 (gal / min) / ft.

Reported specific capacity, Harpers Formation

[Specific capacity in gallons per minute per foot of drawdown; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	33	0.08	0.11	0.28	0.60	1.7	0.04	5.3
Domestic	27	.09	.11	.28	.40	1.3	.04	5.3
High-demand	5	—	.08	.61	1.8	—	.08	2.8

Values of hydraulic conductivity and transmissivity for the Harpers Formation are presented in the table below; a specific yield of 0.02 was used in estimating these hydrologic properties. Hydraulic conductivity and transmissivity are generally lower on hilltops and slopes than in valleys,. The median hydraulic conductivity of wells on hilltops (6 wells), slopes (17 wells), and valleys (4 wells) are 0.43, 0.40, and 1.0 ft / d, respectively. The median transmissivity on hilltops is 36 ft^2 / d, on slopes 33 ft^2 / d, and in valleys 56 ft^2 / d.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Harpers Formation

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentil]e

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	32	0.05	0.11	0.52	1.2	5.2	0.03	110
Transmissivity (ft^2 / d)	32	6.4	10	36	75	340	3.2	900

In other work, Gerhart and Lazorchick (1984b) created a digital model of parts of Lancaster and Berks Counties, Pa. They estimated (Gerhart and Lazorchick, 1984b, tables 8 and 14) a specific yield of 0.20 and a hydraulic conductivity of 0.5 ft / d for a metamorphic rock unit that included the Harpers Formation. For the Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, tables 8 and 16) estimated a specific yield of 0.02 for the upper 200 ft and hydraulic conductivities of 0.67, 1.34, and 2.01 ft / d for different hydrogeologic units that included the Harpers Formation. For his digital model in the Valley Creek Basin of eastern Chester County, Sloto (1990) used a specific yield of 0.08 and estimated a hydraulic conductivity of 3.0 ft / d.

The depths of water-bearing zones in 75 wells drilled as deep as 250 ft range from 6 to 220 ft below land surface. Fifty percent of the 144 water-bearing zones reported are penetrated by a depth of 75 ft and 90 percent by a depth of 160 ft. The greatest density of water-bearing zones (1.06 per 50 ft of well depth) is from 51 to 100 ft below land surface (fig. 26); the density of water-bearing zones at depths of 201-250 ft or greater are based on the presence of only one water-bearing zone per 50-ft interval. The overall density of water-bearing zones in the Harpers Formation is 0.64 per 50 ft of well depth.

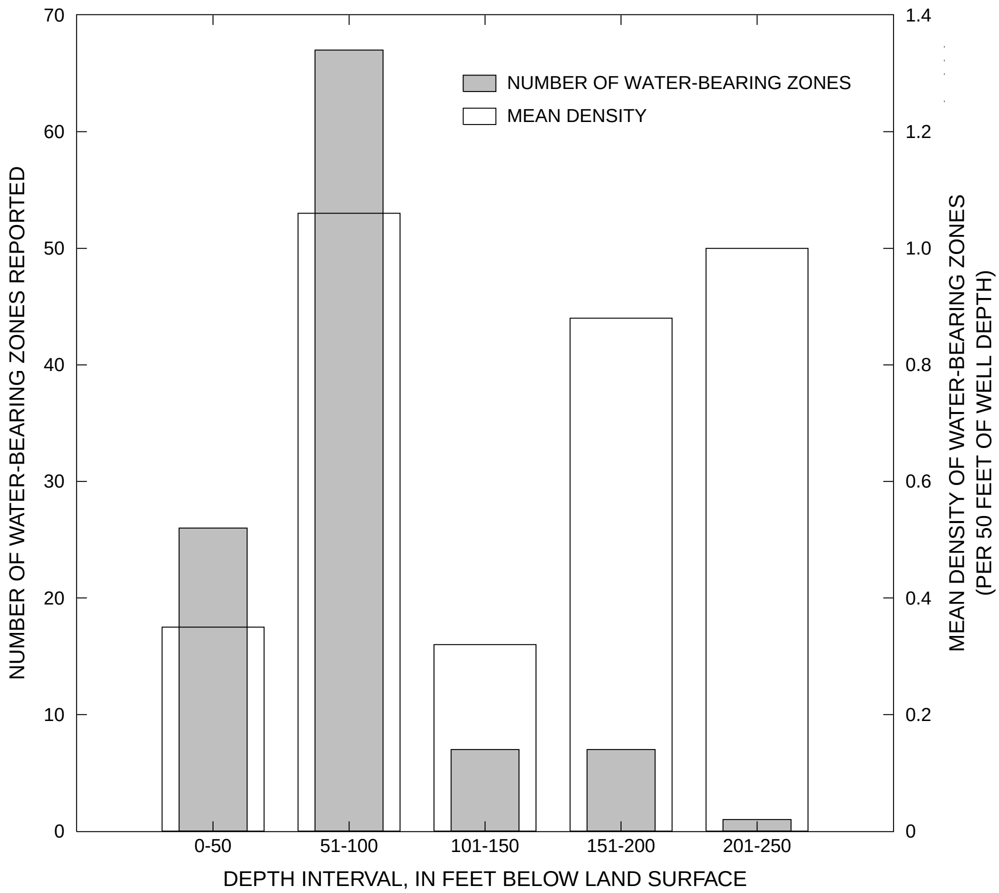


Figure 26. The number and density of water-bearing zones per 50 feet of well depth in the Harpers Formation of the Piedmont Physiographic Province, Piedmont Upland Section.

Water quality.—As seen in the following table, wells completed in the Harpers Formation generally yield water that is low in dissolved solids, is soft to moderately hard, and is acidic. Magnesium, sodium plus potassium, and calcium cations are present in about equal amounts; chloride is the dominant anion. Elevated concentrations of iron, manganese, nitrite, and radon and low pH are common water-quality problems in the Harpers Formation. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Harpers Formation

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; pCi/L, picoCurie per liter; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	58	—	—	—	109	169	276	25	600
Field hardness	51	—	—	—	51	68	100	17	260
Field pH (standard units)	31	—	<6.5 >8.5	21	5.7	6.0	6.5	4.9	7.3
Bicarbonate	23	—	—	—	6.5	16	59	1.0	110
Calcium	24	—	—	—	7.1	10	24	2.6	51
Chloride	24	—	250	0	8.3	16	26	.80	38
Iron	24	—	.3	7	.021	.10	.34	.004	10
Lead	12	0.015	—	1	.000	.003	.005	.000	.050
Magnesium	24	—	—	—	4.7	6.9	8.3	2.0	19
Manganese	22	—	.05	13	.025	.090	.29	.000	1.2
Nitrate (as N)	17	10	—	4	1.6	4.2	10	.00	20
Potassium	22	—	—	—	1.1	2.0	3.0	.70	8.8
Radon (pCi/L)	10	[3] 300	—	9	1,000	2,500	3,600	270	5,300
Silica	18	—	—	—	7.8	9.3	17	6.4	19
Sodium	23	—	—	—	6.6	12	17	2.3	27
Sulfate	24	—	250	1	9.8	16	37	1.8	260
Total dissolved solids	23	—	500	0	88	146	235	54	435

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.
[3] U.S. Environmental Protection Agency, 1994, proposed maximum contaminant level.

Antietam Formation (Ca)

The Antietam Formation in the Piedmont Upland has been mapped separately and in combination with the Harpers Formation in different areas on the Geologic Map of Pennsylvania (Berg and others, 1980); however, other workers (Bascom and others, 1909; Bascom and Stose, 1932; 1938; Stose and Stose, 1944; Wise, 1970; Wilshusen, 1979) do not combine the two units. Where mapped separately, the Antietam Formation crops out as a scattered series of small, generally linear, faulted exposures from Adams County near the Maryland border to western Chester County. The undifferentiated Antietam and Harpers unit is extensively exposed west of the Susquehanna River where it is in contact with the Marburg Schist, sedimentary rocks of the Gettysburg-Newark Lowland, and shale and carbonate rocks of the Piedmont Lowland. East of the Susquehanna River the combined units crop out as a series of folded and faulted exposures with the shale and carbonate rocks of the Piedmont Lowland. The combined Antietam and Harpers unit underlies about 131 mi^2, where mapped separately, the Antietam Formation underlies about 17 mi^2. The Antietam Formation derived its name for exposures along Antietam Creek, Washington County, Md. (Keith, 1892, p. 365; Cloos, 1951, p. 39).

Geologic description.—The Antietam Formation (table 2) is fine- to medium-grained, light gray to grayish-green, quartzite and quartz schist that weathers to a buff or rusty brown. In York County, Stose and Jonas (1939, p. 45) described a lower, fine-grained member that is streaked with argillaceous matter. A middle member is coarser-grained and more resistant than the lower member to erosion. The upper member consists of granular, ferruginous, laminated quartzite beds that produce porous rusty blocks by the solution of calcareous material. In Lancaster County, Poth (1977, p. 23) described the Antietam Formation as a light-gray, quartzitic sandstone with a calcareous cement. In Chester County, the Antietam Formation is generally indistinguishable from the Harpers Formation (Poth, 1968, p. 66).

The Antietam Formation is highly resistant to weathering, forming hills of medium to high relief with moderately steep and stable slopes. Tight folds, faulting, and shearing are fairly common. Joints are moderately developed, abundant, widely spaced, and open. The regolith is relatively thin (Geyer and Wilshusen, 1982, p. 30-31).

Thickness of this unit ranges from less than 100 ft in York County (Stose and Jonas, 1939, p. 46) to 450 ft in Chester County (Lyttle and Epstein, 1987). The Antietam Formation has been interpreted as a line of barrier islands fronting a Cambrian continent (Kauffman and Frey, 1979). It conformably overlies the Harpers Formation and grades into the Vintage Formation of the Piedmont Lowland of Pennsylvania (Stose and Jonas, 1939, p. 46). Based on the presence of trilobite fossils, it has been assigned a Lower Cambrian age (Walcott, 1896).

Well depths and casing lengths.—Depths of wells and casing lengths for wells completed in the Antietam Formation are presented in the tables below. All wells with casing lengths greater than 40 ft are on slopes.

Reported well depth, Antietam Formation

[Depth in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	36	75	93	132	212	328	55	467
Drilled, domestic	30	65	85	128	203	319	55	467
Drilled, high-demand	1	—	—	—	—	—	209	—

Reported casing length, Antietam Formation

[Casing length in feet; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	25	20	25	40	68	92	16	100
Drilled, domestic	22	20	23	33	58	90	16	100

Hydrologic properties.—Water levels for wells completed in the Antietam Formation are presented in the table below. Depths to water in 42 wells range from 3 to 110 ft below land surface; the median is 41 ft.

Water levels, Antietam Formation

[Water levels in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	6	—	32	43	81	—	30	82
Slope	34	14	22	41	59	94	3	110

Reported yields for wells completed in the Antietam Formation are presented in the table below. Yields of 5.0 gal/min or less are reported from 14 wells completed in the Antietam Formation. Only two wells have reported yields of 25 gal/min or greater, both were completed by a depth of 150 ft.

Reported well yield, Antietam Formation

[Yield in gallons per minute; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	31	2.2	4.0	6.0	12	20	1.0	40
Domestic	26	2.0	4.0	6.0	11	20	1.0	40
High-demand	1	—	—	—	—	—	14	—

Specific capacities for wells completed in the Antietam Formation are presented in the table below. Two wells (well depths of 128 and 216 ft) have specific capacities of 0.04 (gal/min)/ft or less and are incapable of meeting most domestic or other water-use demands. Only one well has a specific capacity of 1.0 (gal/min)/ft or greater.

Reported specific capacity, Antietam Formation

[Specific capacity in gallons per minute per foot of drawdown; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Well type	Number of wells	P25	Median	P75	Minimum	Maximum
All	9	0.06	0.40	0.76	0.04	1.0
Domestic	7	.09	.57	.93	.04	1.0

Values of hydraulic conductivity and transmissivity for the Antietam Formation are presented in the table below; a specific yield of 0.02 was used in estimating these hydrologic properties. The median hydraulic conductivity of wells on hilltops (2 wells) is 4.1 ft / d and on slopes (7 wells) the median is 0.31 ft / d. The median transmissivity on hilltops is 110 ft^2 / d and on slopes, 18 ft^2 / d.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Antietam Formation

[ft/d, feet per day; ft^2/d, feet squared per day; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Hydrologic property	Number of wells	P25	Median	P75	Minimum	Maximum
Hydraulic conductivity (ft / d)	9	0.05	0.68	2.3	0.01	6.5
Transmissivity (ft^2 / d)	9	4.9	50	110	1.5	140

In other work, Gerhart and Lazorchick (1984b) created a digital model of parts of Lancaster and Berks Counties, Pa. They estimated (Gerhart and Lazorchick, 1984b, tables 8 and 14) a specific yield of 0.20 and a hydraulic conductivity of 0.5 ft / d for a metamorphic rock unit which included the Antietam Formation. For the Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, tables 8 and 16) estimated a specific yield of 0.02 for the upper 200 ft and hydraulic conductivities of 0.67, 1.34, and 2.01 ft / d for different hydrogeologic units that included the Antietam Formation. For his digital model in the Valley Creek Basin of eastern Chester County, Sloto (1990) used a specific yield of 0.08 and estimated a hydraulic conductivity of 3.0 ft / d.

The depths of water-bearing zones in 17 wells drilled as deep as 467 ft range from 32 to 360 ft below land surface. Fifty percent of the 34 water-bearing zones reported are penetrated by a depth of 112 ft and 90 percent by a depth of 197 ft. The greatest density of water-bearing zones (0.75 per 50 ft of well depth) is from 151 to 200 ft below land surface (fig. 27). The overall density of water-bearing zones in this unit is 0.39 per 50 ft of well depth.

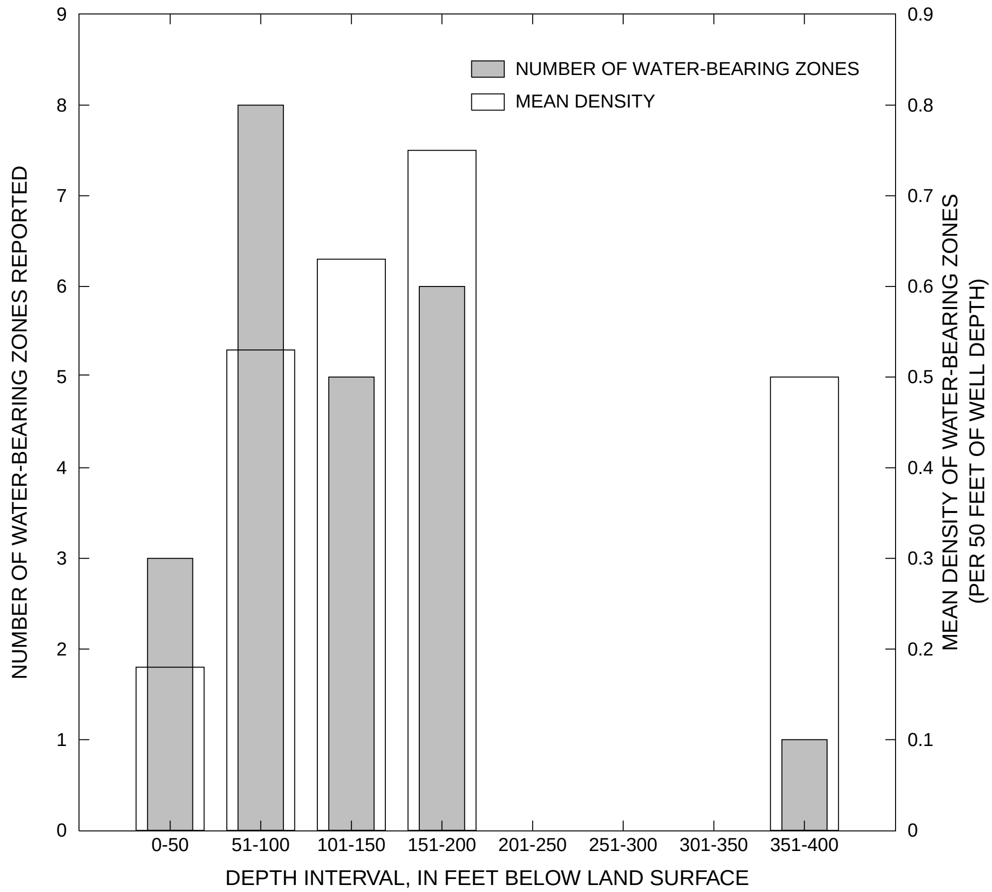


Figure 27. The number and density of water-bearing zones per 50 feet of well depth in the Antietam Formation of the Piedmont Physiographic Province, Piedmont Upland Section.

Water quality.—As seen in the following table, wells completed in the Antietam Formation generally yield water that is low in dissolved solids, soft to moderately hard, and acidic. Calcium is the dominant cation, and bicarbonate and sulfate are the dominant anions. Elevated concentrations of iron, manganese, and radon, and low pH are the most common water-quality problems. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Antietam Formation

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; pCi/L, picoCurie per liter; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	15	—	—	—	70	170	250	46	700
Field hardness	11	—	—	—	34	51	85	17	240
Field pH (standard units)	10	—	<6.5 >8.5	7	5.3	5.7	6.9	4.9	7.6
Bicarbonate	19	—	—	—	9.0	56	88	4.0	150
Calcium	18	—	—	—	7.7	18	25	1.7	76
Chloride	19	—	250	0	3.0	7.5	14	2.0	160
Iron	16	—	.3	3	.010	.075	.25	.004	1.4
Lead	7	0.015	—	1	.002	.004	.007	.001	.046
Magnesium	18	—	—	—	4.5	6.8	9.5	1.0	16
Manganese	16	—	.05	4	.013	.022	.060	.000	.32
Nitrate (as N)	14	10	—	0	.71	3.3	4.2	.16	7.3
Potassium	18	—	—	—	.82	1.7	3.1	.40	11
Radon (pCi/L)	4	[3] 300	—	4	—	2,600	—	1,300	26,000
Silica	9	—	—	—	11	12	15	6.3	17
Sodium	18	—	—	—	2.5	4.7	9.1	.80	21
Sulfate	19	—	250	0	5.6	15	26	.86	50
Total dissolved solids	18	—	500	0	97	142	177	29	447

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.
[3] U.S. Environmental Protection Agency, 1994, proposed maximum contaminant level.

Summary of Characteristics of Bedrock Aquifers in the Piedmont Physiographic Province, Piedmont Upland Section

Data evaluated for most units in the Piedmont Upland Section are summarized in figures 28 to 33 and tables 3 to 7. Well depths range from 15 to 2,000 ft below land surface and casing lengths from 4 to 400 ft. Well depths and casing lengths can vary significantly by water use, topographic setting, and lithology. In general, high-demand wells are completed at significantly greater depths and use significantly more casing than domestic wells (figs. 28 and 29).

Reported yields range from 0 to 1,800 gal/min and specific capacities (1-hour or longer pumping duration) from 0.00 to 200 (gal/min)/ft. Reported yields and specific capacities can vary significantly by water use, topographic setting, and lithology also. Reported yield for high-demand wells (fig. 30b) generally are significantly greater than those for domestic wells (fig. 30c).

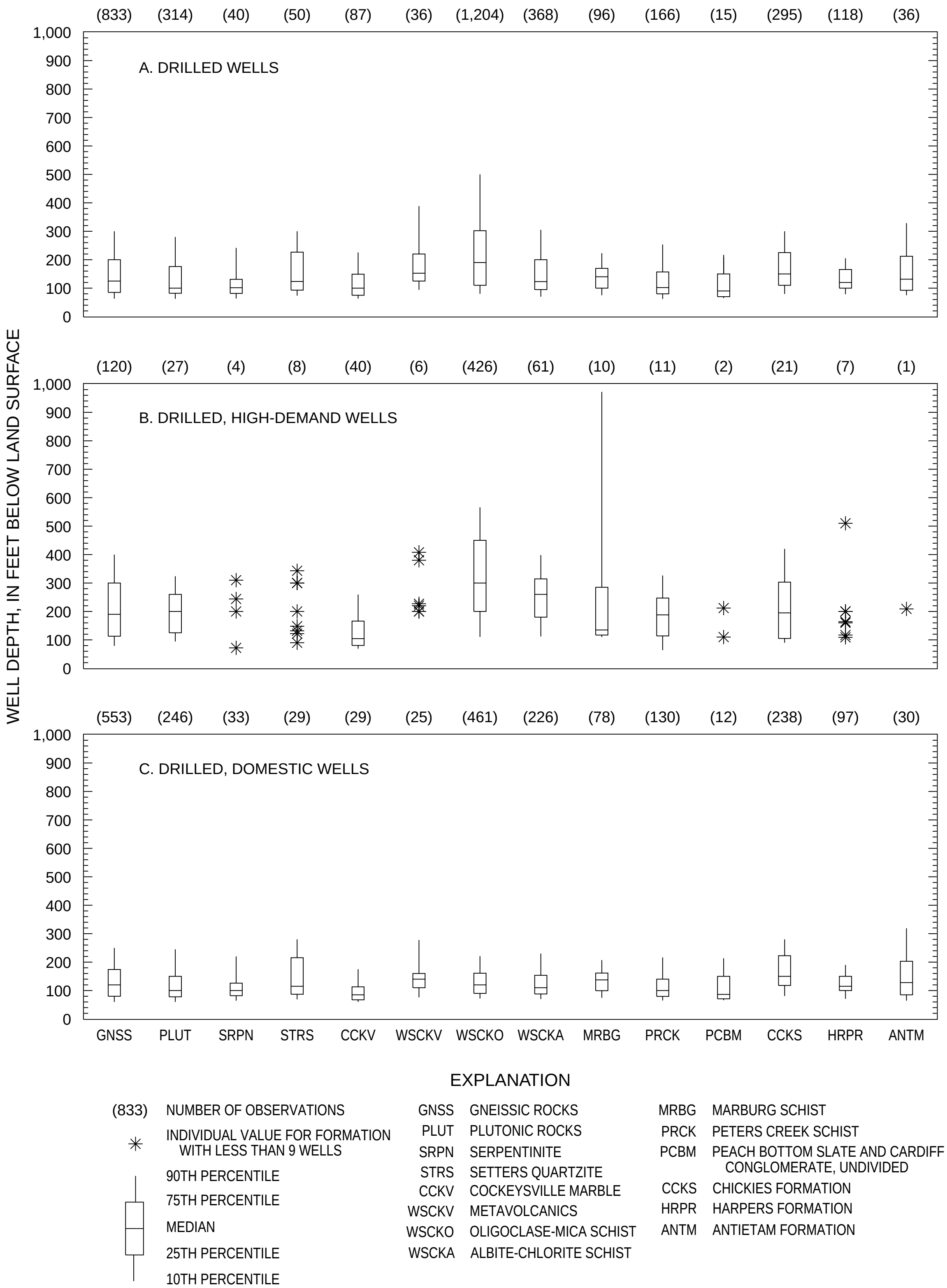


Figure 28. Depths of drilled wells in the Piedmont Physiographic Province, Piedmont Upland Section.

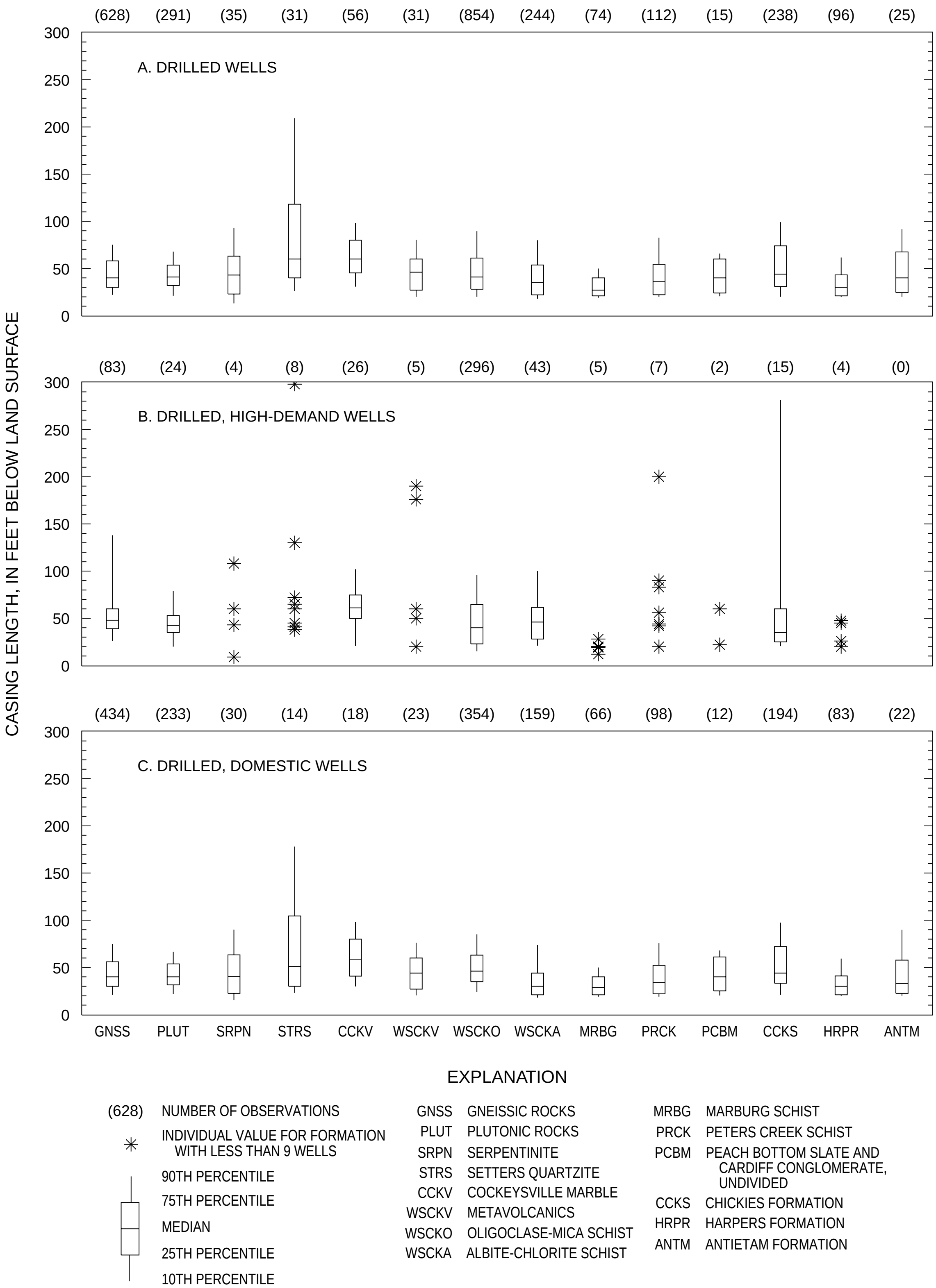


Figure 29. Casing lengths of drilled wells in the Piedmont Physiographic Province, Piedmont Upland Section.

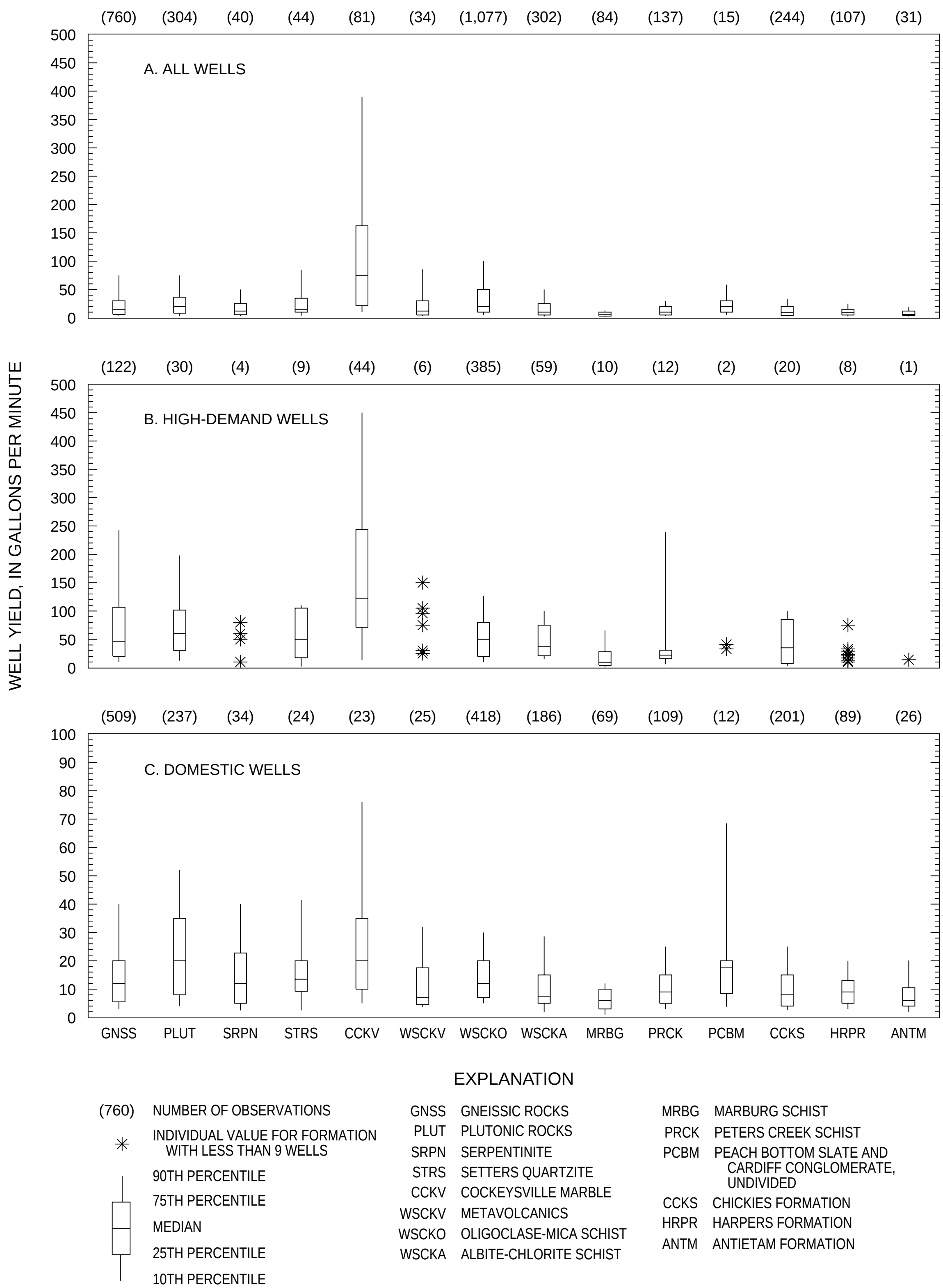
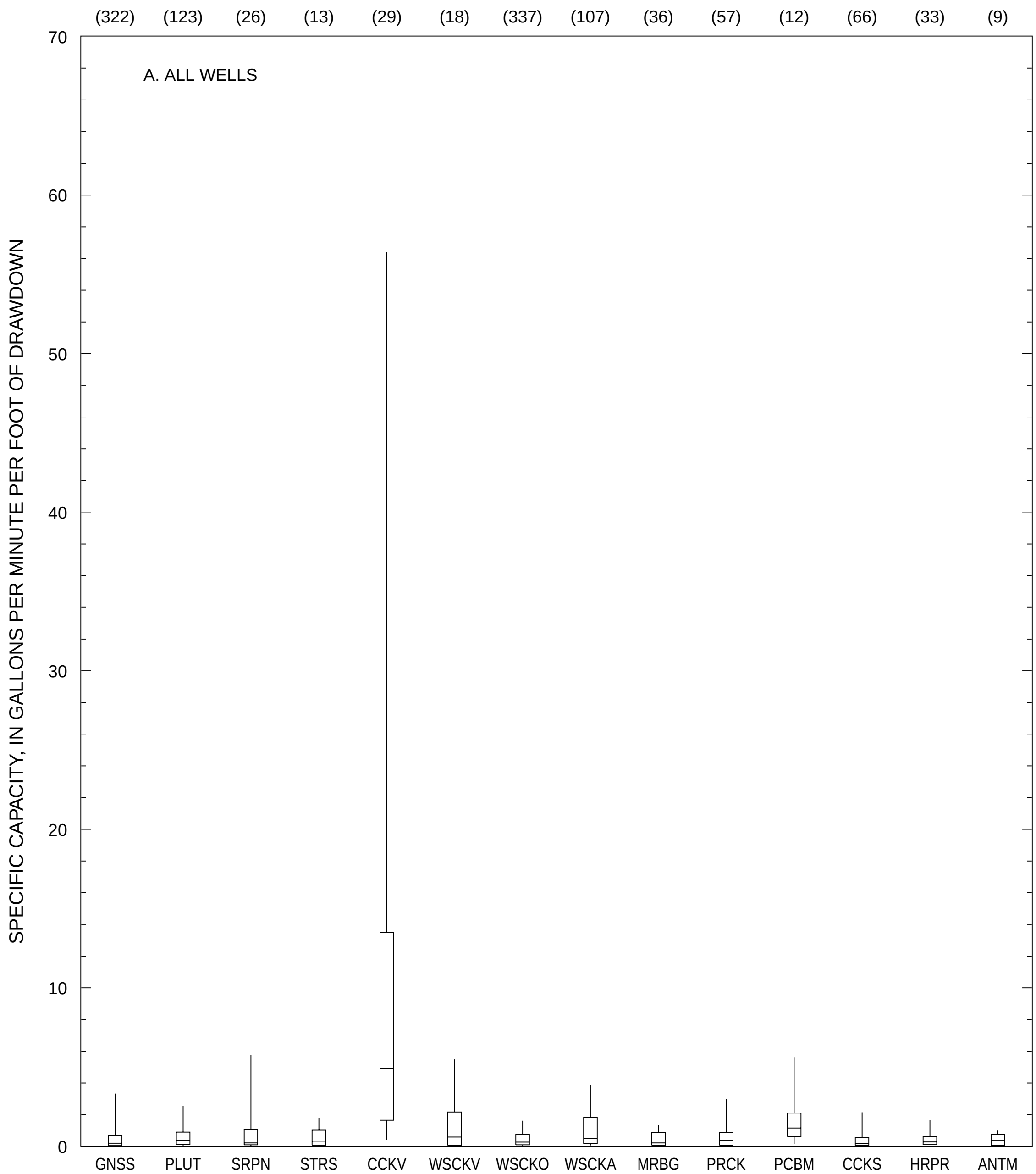


Figure 30. Reported yields of wells in the Piedmont Physiographic Province, Piedmont Upland Section.



EXPLANATION

(322) NUMBER OF OBSERVATIONS

✳ INDIVIDUAL VALUE FOR FORMATION WITH LESS THAN 9 WELLS

90TH PERCENTILE
75TH PERCENTILE
MEDIAN
25TH PERCENTILE
10TH PERCENTILE

GNSS	GNEISSIC ROCKS
PLUT	PLUTONIC ROCKS
SRPN	SERPENTINITE
STRS	SETTERS QUARTZITE
CCKV	COCKEYSVILLE MARBLE
WSCKV	METAVOLCANICS
WSCKO	OLIGOCLASE-MICA SCHIST
WSCKA	ALBITE-CHLORITE SCHIST
MRBG	MARBURG SCHIST
PRCK	PETERS CREEK SCHIST
PCBM	PEACH BOTTOM SLATE AND CARDIFF CONGLOMERATE, UNDIVIDED
CCKS	CHICKIES FORMATION
HRPR	HARPERS FORMATION
ANTM	ANTIETAM FORMATION

Figure 31. Specific capacities of wells in the Piedmont Physiographic Province, Piedmont Upland Section.

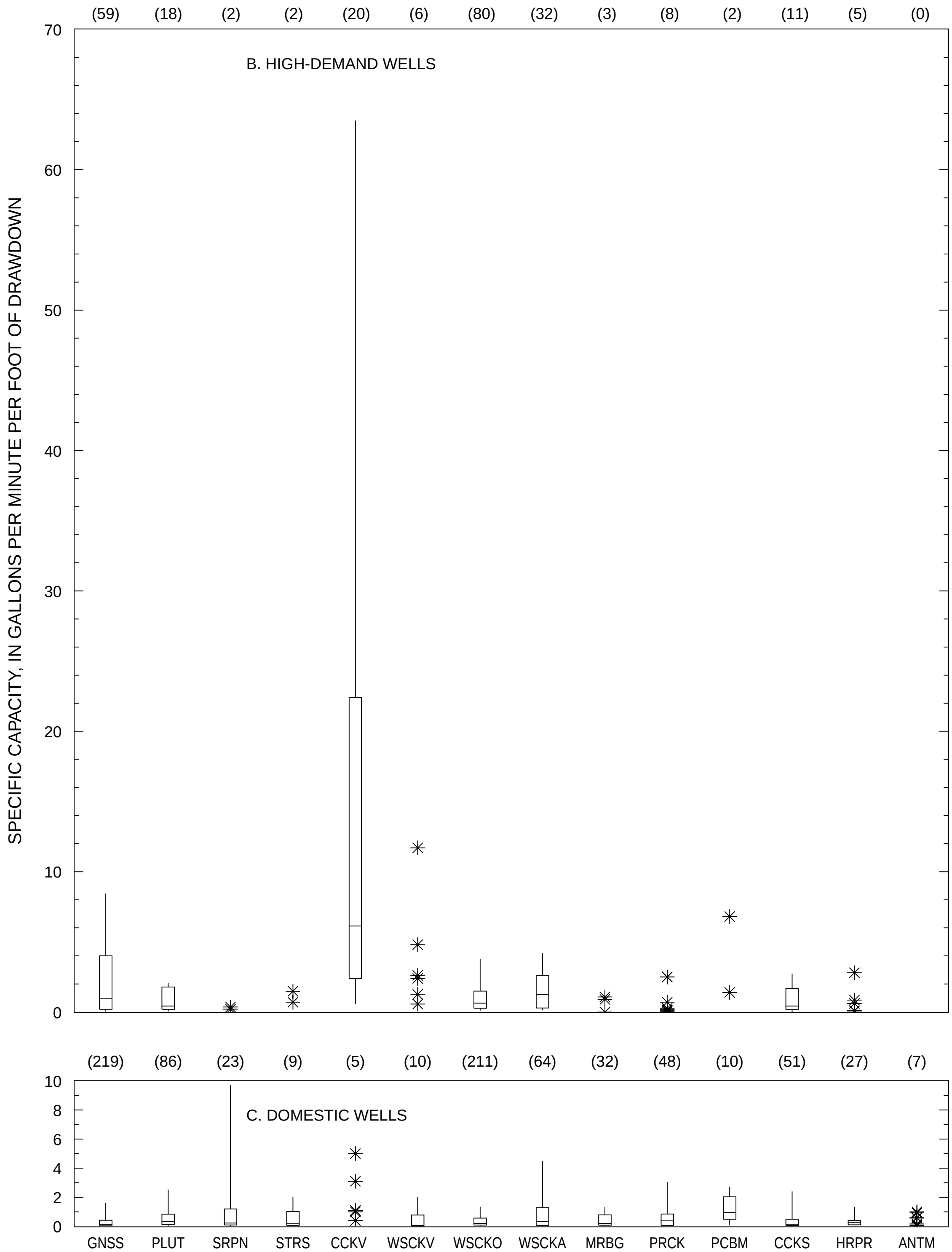
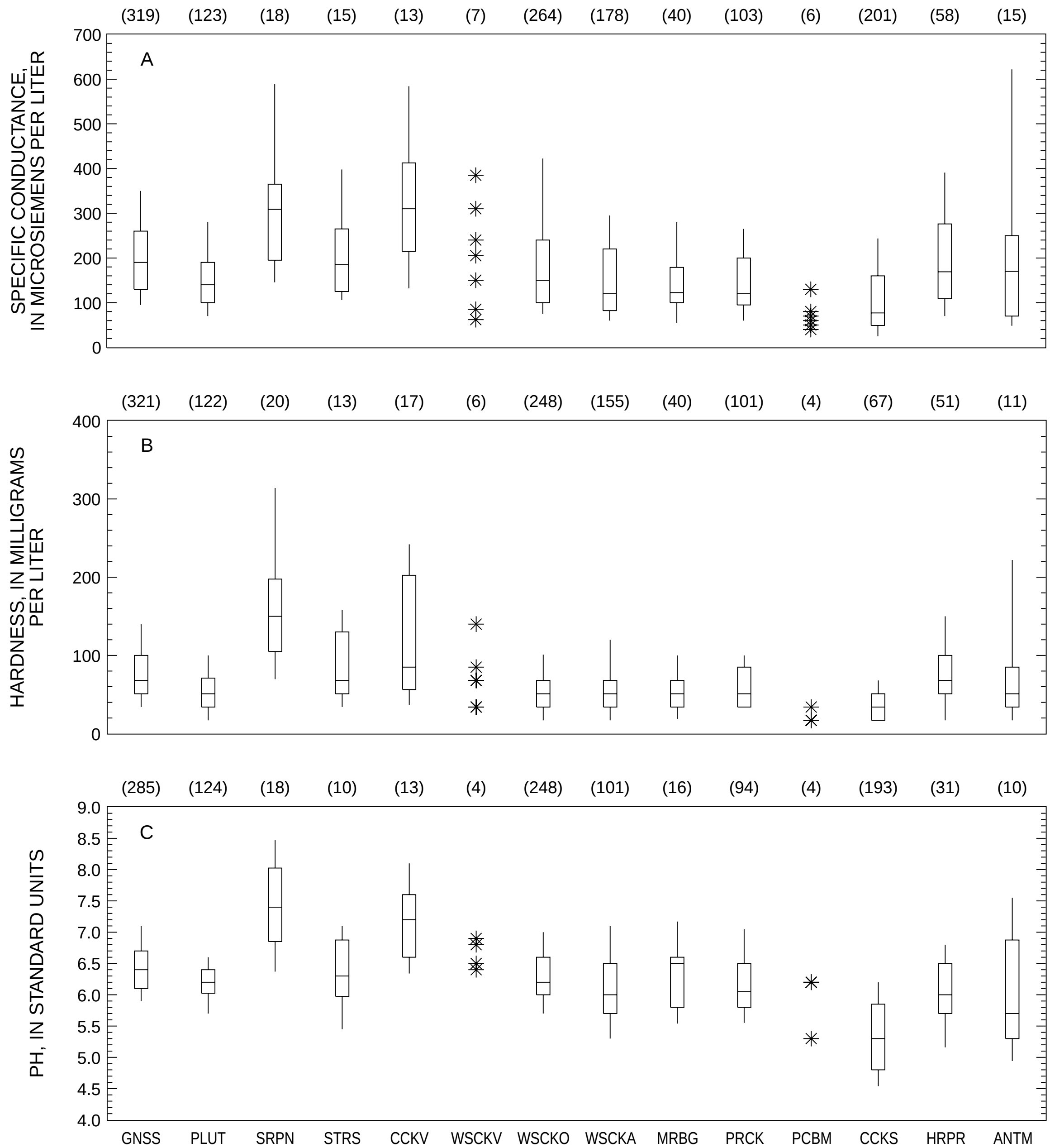


Figure 31. Specific capacities of wells in the Piedmont Physiographic Province, Piedmont Upland Section—Continued.



EXPLANATION

(319)	NUMBER OF OBSERVATIONS	HRPR	GNEISSIC ROCKS	WSCKA	ALBITE-CHLORITE SCHIST
✳	OUTSIDE VALUE	PLUT	PLUTONIC ROCKS	MRBG	MARBURG SCHIST
	90TH PERCENTILE	SRPN	SERPENTINITE	PRCK	PETERS CREEK SCHIST
	75TH PERCENTILE	STRS	SETTERS QUARTZITE	PCBM	PEACH BOTTOM SLATE AND CARDIFF CONGLOMERATE, UNDIVIDED
	MEDIAN	CCKV	COCKEYSVILLE MARBLE	CCKS	CHICKIES FORMATION
	25TH PERCENTILE	WSCKV	METAVOLCANICS	HRPR	HARPERS FORMATION
	10TH PERCENTILE	WSCKO	OLIGOCLASE-MICA SCHIST	ANTM	ANTIETAM FORMATION

Figure 32. Field water-quality characteristics of wells in the Piedmont Physiographic Province, Piedmont Upland Section: A, specific conductance; B, hardness; C, pH.

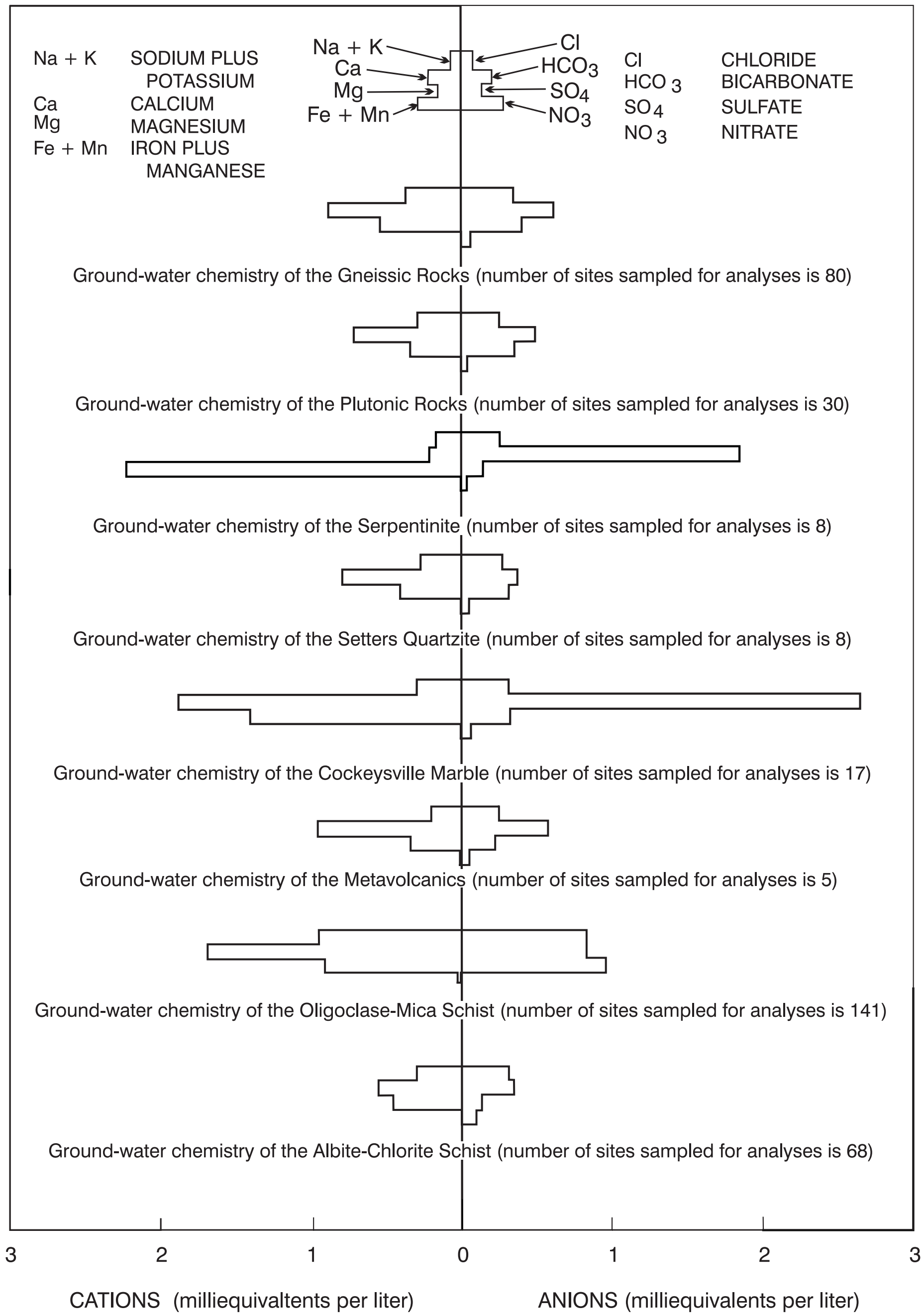


Figure 33. Median chemical analyses of selected chemical constituents from the ground water of geohydrologic units in the Piedmont Physiographic Province, Piedmont Upland Section.

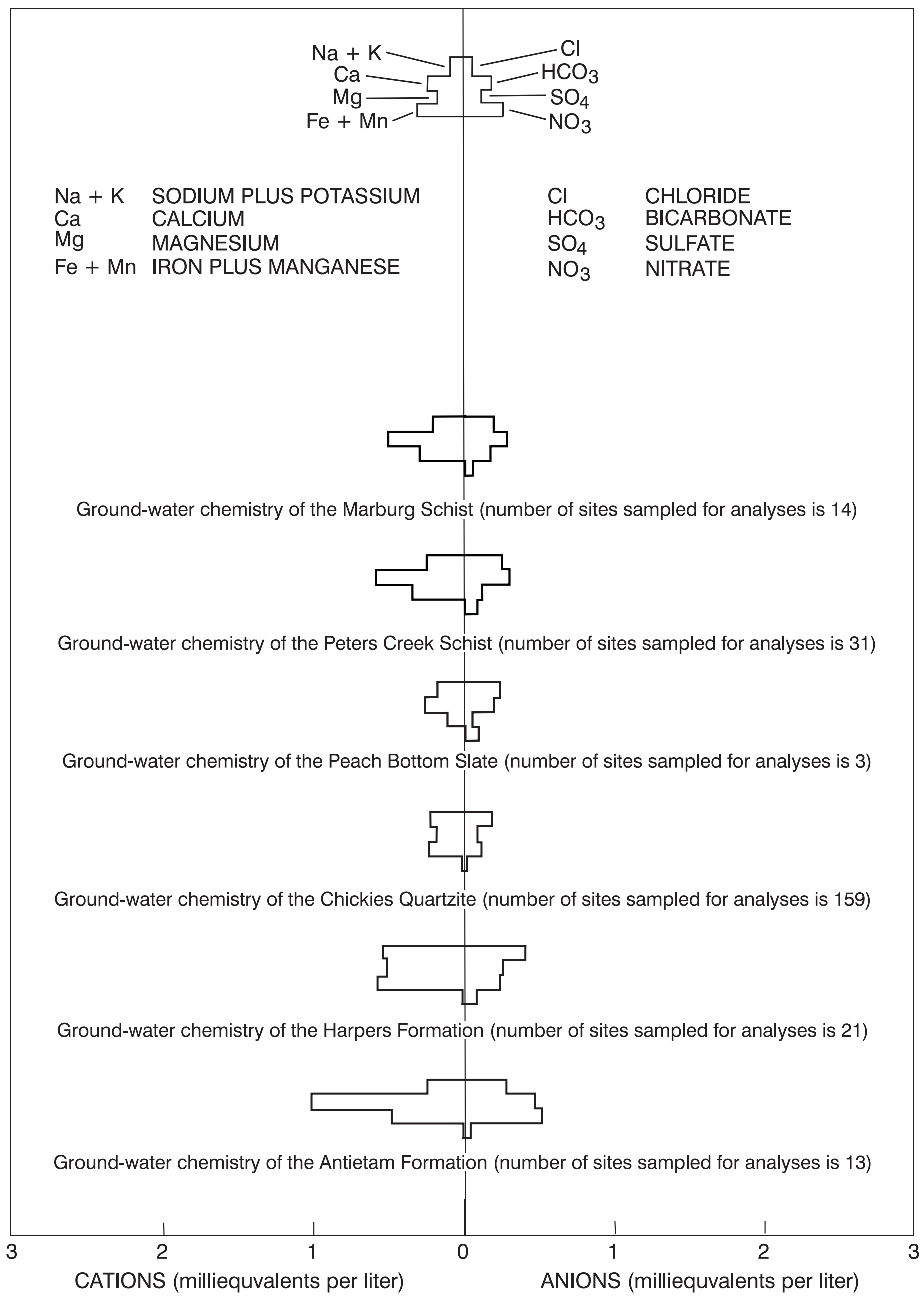


Figure 33. Median chemical analyses of selected chemical constituents from the ground water of geohydrologic units in Piedmont Physiographic Province, Piedmont Upland Section—Continued.

Table 3. *Significant relations for depth of drilled wells among 14 geohydrologic units in the Piedmont Upland Section of the Piedmont Physiographic Province, Pennsylvania*

[Table is read from top down. Example, depths of wells drilled in the Gneissic Rocks are significantly greater than the depths of wells drilled in the Plutonic Rocks but are significantly shallower (less) than in the Oligoclase-Mica Schist. G, greater; L, less; -, insufficient data; blank indicates no significant difference between units]

GNSS, Gneissic Rocks; PLUT, Plutonic Rocks; SRPN, Serpentinite; STRS, Setters Quartzite; CCKV, Cockeysville Marble; WSCKV, Metavolcanics; WSCKO, Oligoclase-Mica Schist; WSCKA, Albite-Chlorite Schist; MRBG, Marburg Schist; PRCK, Peters Creek Schist; PCBM, Peach Bottom Slate and Cardiff Conglomerate, Undivided; CCKS, Chickies Formation; HRPR, Harpers Formation; ANTM, Antietam Formation

	GNSS	PLUT	SRPN	STRS	CCKV	WSCKV	WSCKO	WSCKA	MRBG	PRCK	PCBM	CCKS	HRPR	ANTM
DRILLED WELLS														
GNSS														
PLUT	G													
SRPN														
STRS														
CCKV														
WSCKV		L			L									
WSCKO	L	L	L		L									
WSCKA		L			L		G							
MRBG							G							
PRCK						G	G	G						
PCBM							G							
CCKS	L	L	L		L		G			L				
HRPR							G					G		
ANTM														
DRILLED, HIGH-DEMAND WELLS														
GNSS														
PLUT														
SRPN	-	-												
STRS	-	-	-											
CCKV	G		-	-										
WSCKV	-	-	-	-	-									
WSCKO	L	L	-	-	L	-								
WSCKA			-	-	L	-								
MRBG			-	-		-								
PRCK			-	-		-								
PCBM	-	-	-	-	-	-	-	-	-	-				
CCKS			-	-		-					-			
HRPR	-	-	-	-	-	-	-	-	-	-	-	-		
ANTM	-	-	-	-	-	-	-	-	-	-	-	-	-	
DRILLED, DOMESTIC WELLS														
GNSS														
PLUT														
SRPN														
STRS														
CCKV	G													
WSCKV					L									
WSCKO		L			L									
WSCKA														
MRBG					L									
PRCK														
PCBM														
CCKS	L	L	L		L		L	L		L				
HRPR												G		
ANTM					L									

Table 4. *Significant relations for casing length of drilled wells among 14 geohydrologic units in the Piedmont Upland Section of the Piedmont Physiographic Province, Pennsylvania*

[Table is read from top down. Example, casing lengths of wells drilled in the Gneissic Rocks are significantly greater than casing lengths of wells drilled in the Marburg Schist but are significantly less than in the Setters Quartzite. G, greater; L, less; -, insufficient data; blank indicates no significant difference between units]

GNSS, Gneissic Rocks; PLUT, Plutonic Rocks; SRPN, Serpentinite; STRS, Setters Quartzite; CCKV, Cockeysville Marble; WSCKV, Metavolcanics; WSCKO, Oligoclase-Mica Schist; WSCKA, Albite-Chlorite Schist; MRBG, Marburg Schist; PRCK, Peters Creek Schist; PCBM, Peach Bottom Slate and Cardiff Conglomerate, Undivided; CCKS, Chickies Formation; HRPR, Harpers Formation; ANTM, Antietam Formation

	GNSS	PLUT	SRPN	STRS	CCKV	WSCKV	WSCKO	WSCKA	MRBG	PRCK	PCBM	CCKS	HRPR	ANTM
DRILLED WELLS														
GNSS														
PLUT														
SRPN														
STRS	L	L												
CCKV	L	L												
WSCKV														
WSCKO				G	G									
WSCKA	G				G		G							
MRBG	G	G	G	G	G	G	G	G						
PRCK				G	G									
PCBM														
CCKS								L	L					
HRPR	G	G		G	G	G	G					G		
ANTM														
DRILLED, HIGH-DEMAND WELLS														
GNSS														
PLUT														
SRPN	-	-												
STRS	-	-	-											
CCKV			-	-										
WSCKV	-	-	-	-	-									
WSCKO			-	-	G	-								
WSCKA			-	-		-								
MRBG	-	-	-	-	-	-	-	-						
PRCK	-	-	-	-	-	-	-	-	-					
PCBM	-	-	-	-	-	-	-	-	-	-				
CCKS			-	-		-			-	-	-			
HRPR	-	-	-	-	-	-	-	-	-	-	-	-		
ANTM	-	-	-	-	-	-	-	-	-	-	-	-	-	
DRILLED, DOMESTIC WELLS														
GNSS														
PLUT														
SRPN														
STRS														
CCKV														
WSCKV														
WSCKO	L													
WSCKA	G	G		G	G		G							
MRBG	G	G		G	G	G	G							
PRCK					G		G							
PCBM														
CCKS	L							L	L	L				
HRPR	G	G		G	G		G				G			
ANTM														

Table 5. *Significant relations for reported yield from wells among 14 geohydrologic units in the Piedmont Upland Section of the Piedmont Physiographic Province, Pennsylvania*

[Table is read from top down. Example, reported yields from wells in the Gneissic Rocks are significantly greater than in the Marburg Schist but are significantly less than in the Cockeysville Marble. G, greater; L, less; -, insufficient data; blank indicates no significant difference between units]

GNSS, Gneissic Rocks; PLUT, Plutonic Rocks; SRPN, Serpentinite; STRS, Setters Quartzite; CCKV, Cockeysville Marble; WSCKV, Metavolcanics; WSCKO, Oligoclase-Mica Schist; WSCKA, Albite-Chlorite Schist; MRBG, Marburg Schist; PRCK, Peters Creek Schist; PCBM, Peach Bottom Slate and Cardiff Conglomerate, Undivided; CCKS, Chickies Formation; HRPR, Harpers Formation; ANTM, Antietam Formation

	GNSS	PLUT	SRPN	STRS	CCKV	WSCKV	WSCKO	WSCKA	MRBG	PRCK	PCBM	CCKS	HRPR	ANTM
ALL WELLS														
GNSS														
PLUT														
SRPN														
STRS														
CCKV	L	L	L	L										
WSCKV					G									
WSCKO	L				G									
WSCKA	G	G			G		G							
MRBG	G	G	G	G	G	G	G	G						
PRCK	G	G			G		G		L					
PCBM									L					
CCKS	G	G		G	G		G		L					
HRPR	G	G		G	G		G							
ANTM	G	G		G	G		G							
HIGH-DEMAND WELLS														
GNSS														
PLUT														
SRPN	-	-												
STRS	-	-	-											
CCKV	L		-	-										
WSCKV	-	-	-	-	-									
WSCKO			-	-	G	-								
WSCKA			-	-	G	-								
MRBG	G	G	-	-	G	-	G							
PRCK			-	-	G	-								
PCBM	-	-	-	-	-	-	-	-	-	-				
CCKS			-	-	G	-					-			
HRPR	-	-	-	-	-	-	-	-	-	-	-	-		
ANTM	-	-	-	-	-	-	-	-	-	-	-	-	-	
DOMESTIC WELLS														
GNSS														
PLUT	L													
SRPN														
STRS														
CCKV														
WSCKV		G												
WSCKO		G												
WSCKA	G	G			G		G							
MRBG	G	G	G	G	G		G							
PRCK		G			G				L					
PCBM									L					
CCKS		G			G		G		L					
HRPR		G			G		G							
ANTM		G			G		G							

Table 6. *Significant relations for specific capacity from wells among 14 geohydrologic units in the Piedmont Upland Section of the Piedmont Physiographic Province, Pennsylvania*

[Table is read from top down. Example, specific capacities from wells in the Cockeysville Marble are significantly greater than in the Plutonic Rocks and the Oligoclase-Mica Schist. G, greater; L, less; -, insufficient data; blank indicates no significant difference between units]

GNSS, Gneissic Rocks; PLUT, Plutonic Rocks; SRPN, Serpentinite; STRS, Setters Quartzite; CCKV, Cockeysville Marble; WSCKV, Metavolcanics; WSCKO, Oligoclase-Mica Schist; WSCKA, Albite-Chlorite Schist; MRBG, Marburg Schist; PRCK, Peters Creek Schist; PCBM, Peach Bottom Slate and Cardiff Conglomerate, Undivided; CCKS, Chickies Formation; HRPR, Harpers Formation; ANTM, Antietam Formation

	GNSS	PLUT	SRPN	STRS	CCKV	WSCKV	WSCKO	WSCKA	MRBG	PRCK	PCBM	CCKS	HRPR	ANTM
ALL WELLS														
GNSS														
PLUT														
SRPN														
STRS														
CCKV	L	L	L	L										
WSCKV					G									
WSCKO					G									
WSCKA	L				G									
MRBG					G									
PRCK					G									
PCBM	L													
CCKS					G			G			G			
HRPR					G									
ANTM	-	-	-	-	-	-	-	-	-	-	-	-	-	
HIGH-DEMAND WELLS														
GNSS														
PLUT														
SRPN	-	-												
STRS	-	-	-											
CCKV	L	L	-	-										
WSCKV	-	-	-	-	-									
WSCKO			-	-	G	-								
WSCKA			-	-	G	-								
MRBG	-	-	-	-	-	-	-	-						
PRCK	-	-	-	-	-	-	-	-	-					
PCBM	-	-	-	-	-	-	-	-	-	-				
CCKS			-	-	G	-			-	-	-			
HRPR	-	-	-	-	-	-	-	-	-	-	-	-		
ANTM	-	-	-	-	-	-	-	-	-	-	-	-	-	
DOMESTIC WELLS														
GNSS														
PLUT	L													
SRPN														
STRS	-	-	-											
CCKV	-	-	-	-										
WSCKV				-	-									
WSCKO				-	-									
WSCKA	L			-	-									
MRBG				-	-									
PRCK				-	-									
PCBM	L			-	-									
CCKS				-	-									
HRPR				-	-									
ANTM	-	-	-	-	-	-	-	-	-	-	-	-	-	

Table 7. *Significant relations for field constituents among 14 geohydrologic units in the Piedmont Upland Section of the Piedmont Physiographic Province, Pennsylvania*

[Table is read from top down. Example, field specific conductance in the Chickies Formation is significantly less than in the Harpers Formation and the Oligoclase-Mica Schist. G, greater; L, less; -, insufficient data]

GNSS, Gneissic Rocks; PLUT, Plutonic Rocks; SRPN, Serpentinite; STRS, Setters Quartzite; CCKV, Cockeysville Marble; WSCKV, Metavolcanics; WSCKO, Oligoclase-Mica Schist; WSCKA, Albite-Chlorite Schist; MRBG, Marburg Schist; PRCK, Peters Creek Schist; PCBM, Peach Bottom Slate and Cardiff Conglomerate, Undivided; CCKS, Chickies Formation; HRPR, Harpers Formation; ANTM, Antietam Formation

	GNSS	PLUT	SRPN	STRS	CCKV	WSCKV	WSCKO	WSCKA	MRBG	PRCK	PCBM	CCKS	HRPR	ANTM
SPECIFIC CONDUCTANCE														
GNSS														
PLUT	G													
SRPN		L												
STRS														
CCKV		L												
WSCKV	-	-	-	-	-									
WSCKO	G		G		G	-								
WSCKA	G		G		G	-								
MRBG	G		G		G	-								
PRCK	G		G		G	-								
PCBM	-	-	-	-	-	-	-	-	-	-				
CCKS	G	G	G	G	G	-	G	G		G	-			
HRPR						-					-	L		
ANTM						-					-			
HARDNESS														
GNSS														
PLUT	G													
SRPN	L	L												
STRS														
CCKV		L												
WSCKV	-	-	-	-	-									
WSCKO	G		G		G	-								
WSCKA	G		G		G	-								
MRBG	G		G		G	-								
PRCK	G		G		G	-								
PCBM	-	-	-	-	-	-	-	-	-	-				
CCKS	G	G	G	G	G	-	G	G		G	-			
HRPR			G			-		L			-	L		
ANTM			G			-					-			
pH														
GNSS														
PLUT	G													
SRPN	L	L												
STRS														
CCKV	L	L												
WSCKV	-	-	-	-	-									
WSCKO	G		G		G	-								
WSCKA	G		G		G	-								
MRBG			G			-								
PRCK	G		G		G	-								
PCBM	-	-	-	-	-	-	-	-	-	-				
CCKS	G	G	G	G	G	-	G	G	G	G	-			
HRPR	G		G		G	-					-	L		
ANTM			G		G	-					-			

GEOHYDROLOGY OF THE PIEDMONT PHYSIOGRAPHIC PROVINCE, PIEDMONT LOWLAND SECTION

Location and Geographic Setting

The Piedmont Lowland Section is part of the Piedmont Physiographic Province as originally described by Fenneman (1938). Berg and others (1989) recently redefined the Piedmont Lowland in Pennsylvania and their delineation will be used throughout this report (fig. 1). In Pennsylvania, the Piedmont Lowland occupies about 714 mi^2 in the southeastern part of the Commonwealth. Most of the Piedmont Lowland is present in Lancaster County. In Chester and Montgomery Counties, the Piedmont Lowland is present as a long narrow valley commonly called “Chester Valley” (fig. 34). In Adams and York Counties, the Piedmont Lowland is somewhat discontinuous, forming numerous elongate valleys that generally trend to the northeast (Berg and others, 1980). Only a very small part of the Piedmont Lowland is present in Berks County. The Piedmont Lowland is bounded on the north, east, and west by siliciclastic rocks of the Gettysburg-Newark Lowland. On the south, the Piedmont Lowland is bounded by quartzites and schists of the Piedmont Upland.

The Piedmont Lowland is underlain by folded and faulted sedimentary and metasedimentary rocks that form broad valleys separated by low hills. Solution of the carbonate rocks commonly result in the formation of a karstic terrain with bedrock pinnacles, sinkholes, and sinking springs. Areas underlain by carbonate rocks are 200 to 300 ft lower than the surrounding noncarbonate areas. Altitudes in the Piedmont Lowland range from about 170 to 630 ft above sea level.

Major population centers in or near to Chester Valley include Downingtown, Malvern, Conshohocken, and Coatesville. In Lancaster County, the communities of Ephrata, Millersville, Lancaster, Manheim, Mount Joy, New Holland, and Columbia lie within the Piedmont Lowland. Also, the city of York in York County and the borough of Hanover in Adams County are within the Piedmont Lowland (fig. 34). Much of the Piedmont Lowland is rural and agricultural land use is dominant. Urban and industrial land use dominate the larger metropolitan areas of York and Lancaster, which are surrounded by large suburban areas. The more rugged areas tend to be forested. Rapid urbanization is taking place in the Chester Valley and around the cities of Lancaster and York (Sloto, 1987; State Water Plan, 1980).

The climate in the Piedmont Lowland is characterized as humid continental; precipitation averages about 41 in. per year (State Water Plan, 1980). Summer and winter mean temperatures are 24 and 0°C, respectively. Prevailing winds are westerly in the spring and northwesterly in the winter. The primary source of heavy precipitation is from the Gulf of Mexico; however, storms containing considerable amounts of moisture develop periodically along the southeast Atlantic coast and move into the area.

Water-Well Density

The location of wells used in the analysis of the Piedmont Lowland is shown in figure 35. The uneven distribution of wells is partly related to historical studies, population density, the presence of springs, and the abundance of surface water. The highest density of recorded wells are from Chester (7.6 wells per square mile) and Berks (5.5 wells per square mile) Counties. Of the 1,246 well records analyzed in Lancaster County, about 500 are in the Lancaster 15-minute quadrangle (Meisler and Becher, 1971). Adams (2.0 wells per square mile) and York (1.5 wells per square mile) Counties have the lowest well densities.

Previous Work

Florence Bascom (Bascom and others, 1909; Bascom and Miller, 1920; Bascom and Stose, 1932, 1938) was one of the earliest workers in the study area. The works of Bascom, in conjunction with the works of Stose and Jonas (Stose and Jonas, 1922, 1933, 1939; Jonas and Stose, 1926, 1930; and Stose and Stose, 1944),

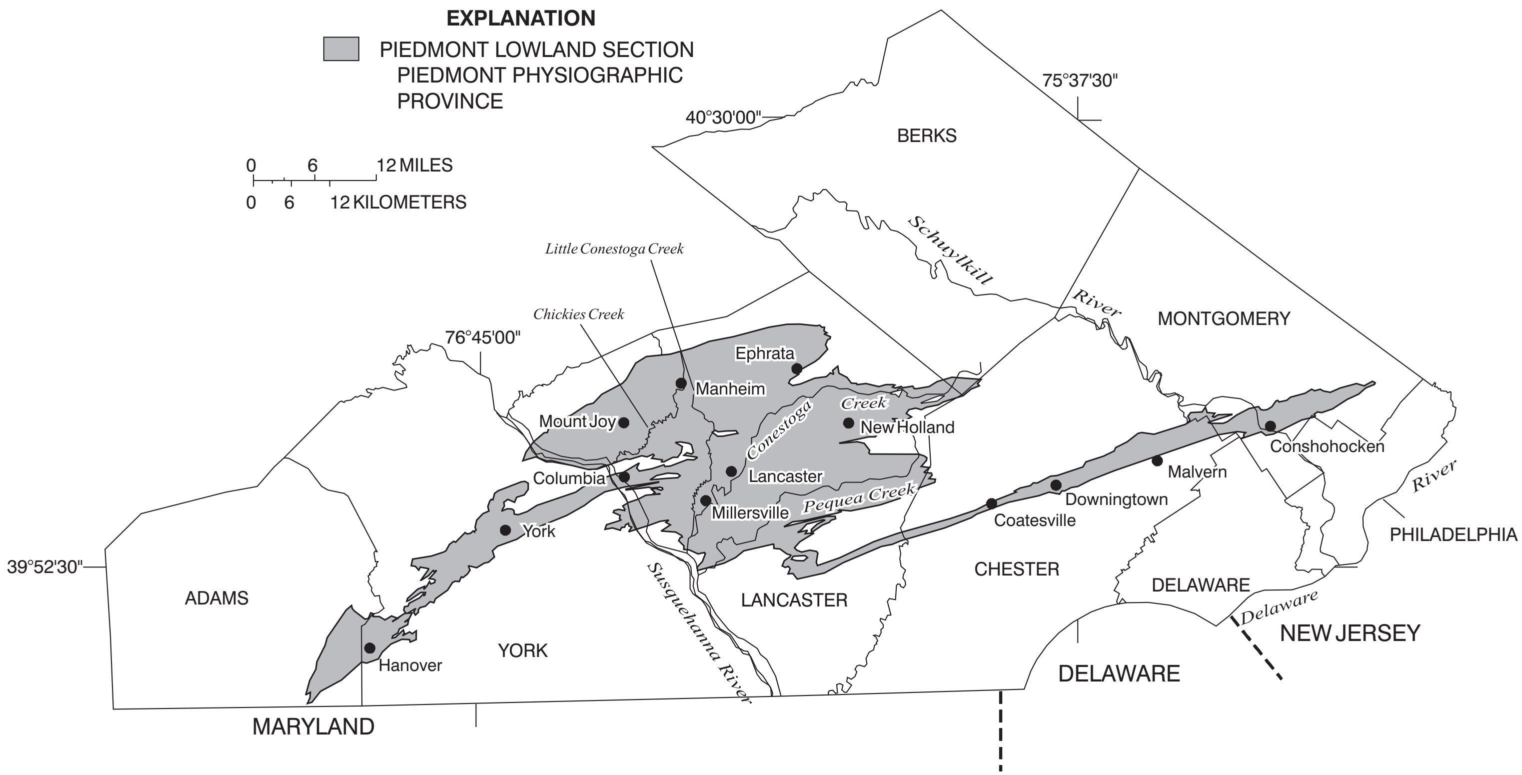


Figure 34. Piedmont Physiographic Province, Piedmont Lowland Section, major streams, counties, and major population centers.

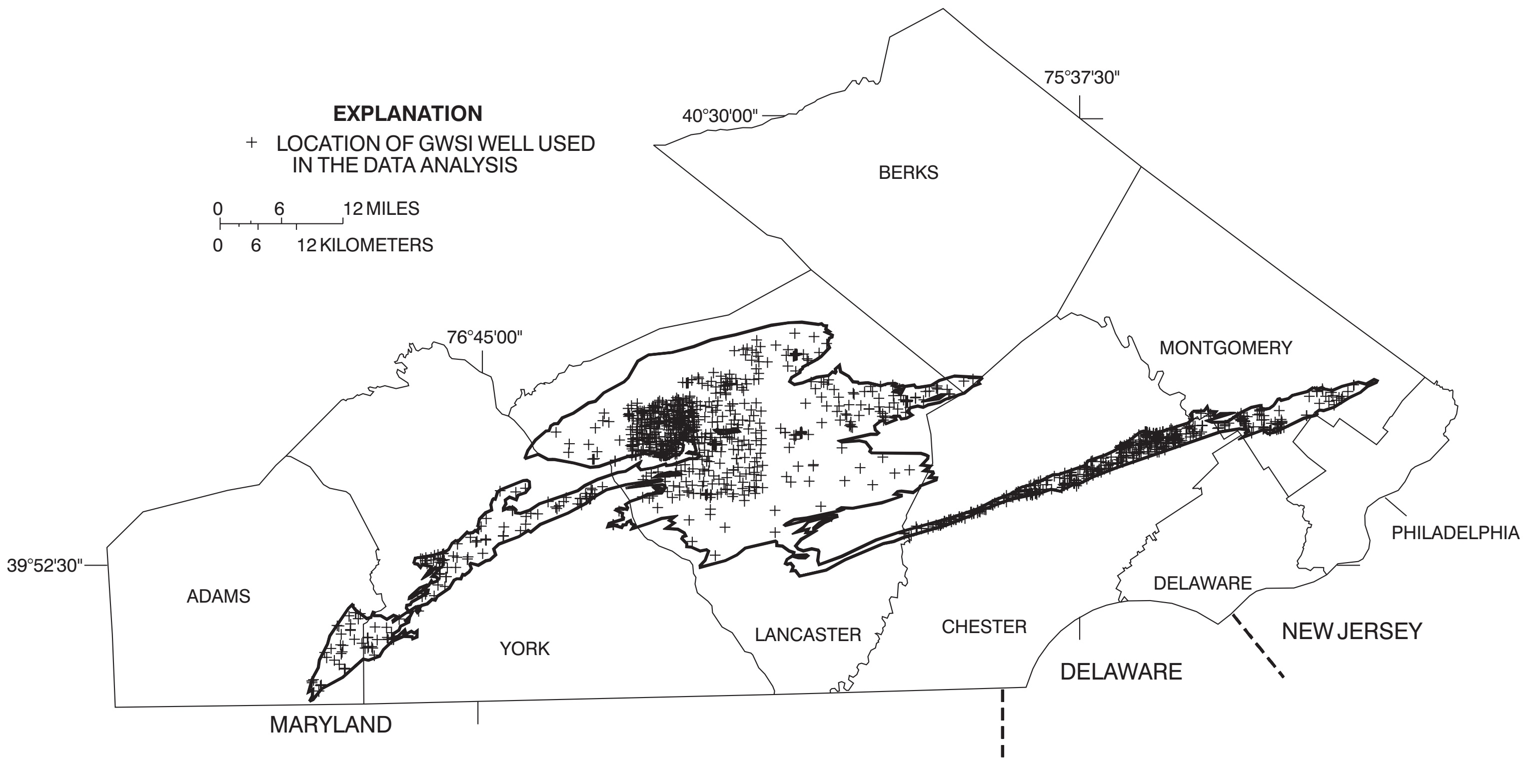


Figure 35. Location of wells in the Piedmont Physiographic Province, Piedmont Lowland Section.

laid the ground work for much of today’s understanding of the geology and structure of the Piedmont Lowlands of Pennsylvania. More recent workers in the Piedmont Lowland include Wise (1970), Meisler and Becher (1971), Wilshusen (1979), Lyttle and Epstein (1987), and Scharnberger (1990).

Although many of the studies by Bascom, Stose, and Jonas were concentrated on geologic quadrangles or districts, their descriptions of the rocks and stratigraphy were important to other workers such as Hall (1934). Hall used the geologic works in his reconnaissance study of the ground water in southeastern Pennsylvania. Some of the more recent workers, such as Meisler and Becher (1966, 1967, 1971), have returned to areas previously studied, such as the Lancaster 15-minute quadrangle. However, their emphasis has been directed more towards the hydrology rather than the geology. Other workers have concentrated on understanding the hydrogeology of counties such as Chester County. These workers include McGreevy (1974), McGreevy and Sloto (1976; 1977), and Sloto (1987; 1990; 1994). Sloto (1990) has simulated and described a simplified ground-water flow model in the Valley Creek Basin of eastern Chester County. On a larger scale, work by Biesecker and others (1968) in the Schuylkill River Basin and Gerhart and Lazorchick (1984a, 1988) in the Lower Susquehanna River Basin have been important in presenting a more unified understanding of the water resources and ground-water flow in southeastern Pennsylvania, including the Piedmont Lowland Section.

Geologic Setting

The area is underlain by a sequence of carbonate and shale rocks of Cambrian and Ordovician age. Thickness of these rocks increases progressively from west to east (Wise, 1970). Sedimentary structures and faunal evidence indicate the carbonate rocks were deposited in nearshore marine and shelf environments, whereas the shales were deposited in an abyssal marine environment (Wise, 1970). The oldest rocks are dominantly dolomite, interbedded with minor amounts of terrigenous clastic rocks and are represented by the Vintage, Kinzers, Ledger, and Zooks Corner Formations. These rocks are overlain in turn by alternating sequences of limestone and dolomite of Cambrian age that are identified as the Elbrook, Buffalo Springs, Snitz Creek, Millbach, and Richland Formations. This sequence of rocks are overlain in turn by limestones of Ordovician age known as the Stonehenge and Epler Formations, and the dolomite of the Ontelaunee Formation. Ordovician age, argillaceous limestones overlie these rocks and are mapped as the Annville, Hershey, and Myerstown Formations. The youngest rocks in the Piedmont Lowland are flysch-like Ordovician shales of the Cocalico Formation. The Conestoga Formation includes schistose carbonate rocks of Middle Cambrian and Lower Ordovician age that are probably correlative with some of the Paleozoic-aged formations (table 8) and unconformably overlie formations older than the Zooks Corner Formation (Meisler and Becher, 1971).

At least two periods of erosion, indicated by regional unconformities beneath the Conestoga and Cocalico Formations (Stose and Jonas, 1939; Meisler and Becher, 1971), punctuate the depositional history. Multiple periods of structural deformation and metamorphism have folded, thrusted, sheared, and recrystallized the rocks (Wise, 1970). Triassic- and Jurassic-age diabase sills and dikes that intruded the Mesozoic siliciclastics extend into rocks of the Piedmont Lowland. The Tertiary history of the region is one of uplift and denudation of the landscape by fluvial erosion.

Hydrologic Setting

The Piedmont Lowland lies within the Susquehanna and Delaware River Basins; however, almost all drainage is to the Susquehanna River. The broad valleys in northern Lancaster County are drained by an elaborate, branched network of meandering streams that include the Chickies, Conestoga, and Pequea Creeks (fig. 34). The elongated valleys in Adams, York, Lancaster, and Chester Counties are bounded by ridges or highlands composed of quartzite, schist, and gneiss. These valleys are drained by a combination of streams that parallel the valley axes and larger streams that cut across the valleys, including the Susquehanna and Schuylkill Rivers (Berg and others, 1980).

Table 8. *Generalized stratigraphic section of the Piedmont Physiographic Province, Piedmont Lowland Section in Pennsylvania*

[Modified from Berg and others, 1983.]

Age	Geohydrologic unit
	This report
Cambrian to Ordovician	Cocalico Formation
Lower Ordovician to Middle Cambrian	Conestoga Formation
Middle Ordovician	Annville Formation; Hershey and Myerstown Formations, undivided
	Ontelaunee Formation
Lower Ordovician	Epler Formation
	Stonehenge Formation
Upper Cambrian	Richland Formation
	Millbach Formation
	Snitz Creek Formation
Middle to Upper Cambrian	Elbrook Formation
Middle Cambrian	Buffalo Springs Formation
Lower to Middle Cambrian	Zooks Corner Formation
Lower Cambrian	Ledger Formation
Lower to Middle Cambrian	Kinzers Formation
Lower Cambrian	Vintage Formation

Surface drainage is dominantly dendritic and only slightly controlled by structure or lithology (Meisler and Becher, 1971, p. 37). Stream densities are lowest in areas underlain by carbonate rocks and where karstic terrain is common, resulting in substantial subsurface drainage (Flippo, 1974, table 2). Stream densities are greatest in areas underlain by the shaley and argillaceous Cocalico Formation.

According to Gerhart and Lazorchick (1988, table 12), 24 to 37 percent of the total annual precipitation recharges the ground water. Areas underlain by carbonate rocks will have higher recharge rates than areas underlain by shale and phyllite. The greater percentage of recharge in areas underlain by carbonate rocks is due to (1) lower relief and greater permeability and (2) the presence of karst features, such as closed depressions, sinkholes, and fissures. In contrast, parts of the Piedmont Lowland underlain by shale and phyllite of the Cocalico Formation, which have higher stream densities and more intricate stream networks, probably have a much lower percentage of recharge derived from annual precipitation. Base flow of perennial streams that include the Chickies, Little Conestoga, and Conestoga Creeks is maintained by ground-water discharge. Approximately 77 percent of the total streamflow of Little Conestoga Creek is base flow (Meisler and Becher, 1971, p. 55). In the Valley Creek Basin of Chester Valley, 76 percent of streamflow is from ground-water discharge (Sloto, 1989, p. 21).

A second source of ground-water recharge is inflow of water from streams as they enter the basin from the adjacent Piedmont Upland and Gettysburg-Newark Lowland. Such streams may lose water to the ground-water system or become perched above the water table as they pass from less permeable rocks of the Piedmont Upland or Gettysburg-Newark Lowland, to more permeable carbonate rocks of the Piedmont Lowland (Sloto, 1990, p. 23). Losses of streamflow have been noted for several streams that enter the Chester Valley from the adjacent Piedmont Upland (McGreevy, 1974). Inflows may be greatest in segments where the streambed is composed of fractured bedrock.

The Cambrian- and Ordovician-age carbonate rocks comprise the most important regional source of water for wells and for sustaining streamflow. Shale and phyllite of the Cambrian Kinzers Formation and the Ordovician Cocalico Formation are minor sources of ground water, mostly for domestic supplies.

Geohydrologic System

In general, most ground-water flow is local and moves in directions of decreasing potential; recharge within each stream basin generally discharges into the adjacent stream valley (Gerhart and Lazorchick, 1984b and 1988). In the Valley Creek Basin of Chester Valley, however, a component of regional ground-water flow has been documented (Sloto, 1990, p. 23) with preferential ground-water flow parallel to the axis of Chester Valley (Sloto, 1990, fig. 13). At the west margin of the basin, there is underflow of ground water into the basin that is induced by dewatering operations at a limestone quarry. At the east margin of the basin, flow is under the basin divide that discharges to the Schuylkill River.

Regional ground-water flow discharging through large springs of 1,000 gal/min or more is limited, confined only to the communities of Elizabethtown, Mount Joy, and Lititz (Flippo, 1974, p. 25). Ground-water and surface-water divides commonly do not coincide with ground water flowing beneath surface-water divides. Although the ground-water system is generally under water-table conditions, ground water is confined locally (Sloto, 1990, p. 18-19).

Although the Piedmont Lowland receives nearly equal amounts of precipitation throughout the year, most of the recharge to ground water is from precipitation during late fall to early spring, which raises the water table. During the remainder of the year, rapid plant growth, high evapotranspiration rates, and soil-moisture deficits greatly reduce precipitation that reaches the ground-water system, lowering the water table. Water levels are shallowest (nearer land surface) in valleys, but deepest (farthest from land surface) on hilltops as the rise in the water table is less than that of land surface.

Regolith

In the Piedmont Lowland, the regolith is comprised of soil and clayey or shaley residuum that are products of weathering of the underlying bedrock. Streambeds and flood plains contain transported fine- to coarse-grained alluvial deposits. The porosity of the regolith typically exceeds that of the underlying fractured bedrock, permitting infiltration of precipitation and storage of large quantities of water. The intergranular pores then slowly release the unconfined water to wells, base flow in streams, and the underlying, fractured bedrock (fig. 36).

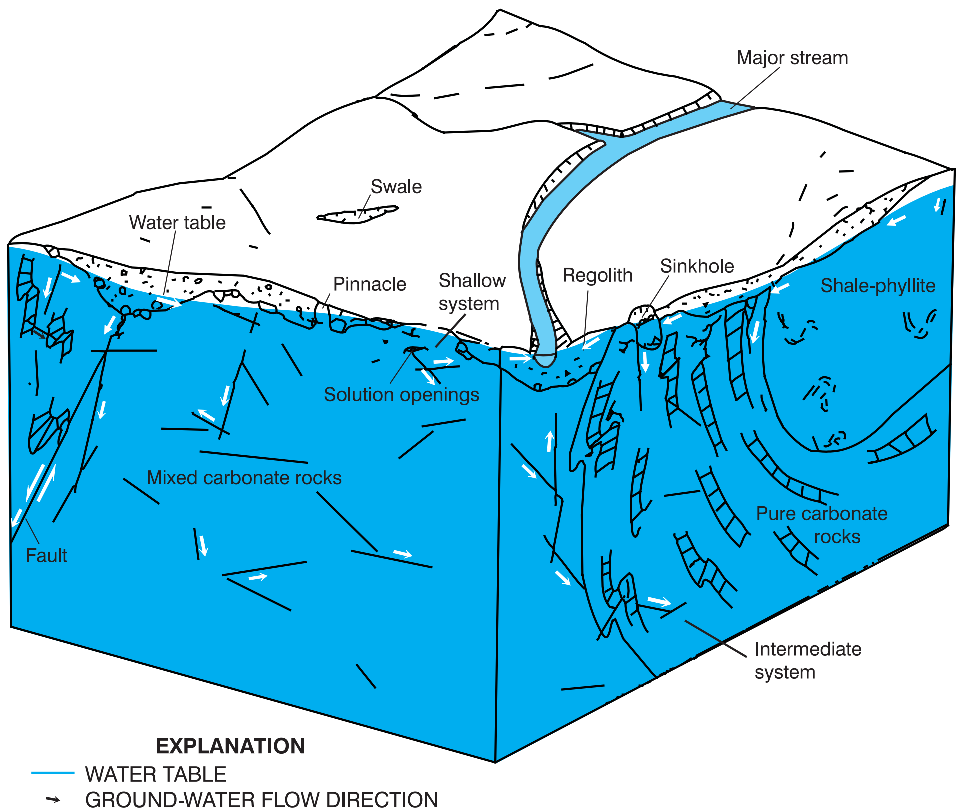


Figure 36. Topographic, geologic, and hydrologic features of the Piedmont Physiographic Province, Piedmont Lowland Section.

In the regolith, ground water generally flows downslope; however, the direction and rate of ground-water flow can be affected by the amount of bedrock weathering, mineral composition of the parent rock, jointing, bedding planes, and structural dip. Differential weathering of carbonate rocks produces substantial local variation in regolith thickness. Dissolution of fractured carbonate rocks can result in the formation of pinnacles and swales. The pinnacles can have 30 or more feet of local relief on the bedrock surface. The swales, which are between the bedrock pinnacles, are infilled with regolith.

Thickness of regolith and saturated regolith (casing depth – static water level) varies according to the underlying geohydrologic unit and topographic setting. Regolith thickness is least in the Zooks Corner Formation and greatest in the Ledger Formation. The median thickness of regolith, estimated from the length of casing in 631 domestic wells completed in the Piedmont Lowland, is 40 ft.

Fractured bedrock

Ground water is stored in and moves through consolidated bedrock in a network of secondary openings such as fractures, bedding planes, joints, faults, and solution openings; primary porosity is negligible. Solution enlargement of these features is concentrated in areas where (1) carbonate material is dominant over noncarbonate (clay, silt, and quartz sand) material and (2) where water movement is relatively rapid and recharge water is acidic. Although the quantity of ground water stored in fractured bedrock is limited, the fractures may be recharged by seepage if the overlying regolith is saturated.

Permeability may be anisotropic within the steeply dipping, folded rocks of the Piedmont Lowland. Bedrock is generally most permeable parallel to bedding and least permeable perpendicular to bedding (Gerhart and Lazorchick, 1984b and 1988; Sloto, 1990, p. 39). At the scale of their regional models, Gerhart (1983), Gerhart and Lazorchick (1984b and 1988), and Sloto (1990) assume that fractured bedrock in the Piedmont Lowland approximates a porous medium.

Although it is not possible to establish an exact thickness or maximum depth of the ground-water system, several methods can provide useful information. These methods include borehole temperature logs, borehole fluid resistivity logs, borehole velocity measurements, and depth distributions of water-bearing zones reported by well drillers.

Borehole temperature or fluid resistivity logs or both are available from 15 wells in the Piedmont Lowland. These wells range in depth from 200 to 600 ft and are completed in the Ledger, Elbrook, or Buffalo Springs Formations. Examination of the temperature logs indicate that the geothermal gradient was not established. This suggests that ground-water circulation can take place at depths greater than 600 ft. Nine water-bearing zones with active flow have been identified on temperature or fluid resistivity logs or both from 7 of the 15 wells. These 9 zones range in depth from 60 to 440 ft with two-thirds of the water-bearing zones occuring at a depth of 180 ft or less.

Depth distributions of water-bearing zones are somewhat dependent upon the bedrock lithology. Wells drilled in shale or phyllite (Cocalico Formation and Kinzers Formation) encounter water-bearing zones at shallower depths than more carbonate rich units. The maximum depths and distributions of water-bearing zones have been used by Sloto (1989) and Gerhart and Lazorchick (1984b, p. 13-14; 1988, table 6) to estimate total aquifer thickness and individual layer thickness for numerical ground-water models. Estimates of total aquifer thickness are 600 ft for the Valley Creek Basin (Sloto, 1990, p. 57) in Chester Valley. In the Lancaster area, estimates of total aquifer thickness is 500 ft for the Cocalico Formation and 550 ft for the carbonate formations (Gerhart and Lazorchick, 1988, table 6). Gerhart and Lazorchick (1984, p. 13) estimate the depth of active ground-water circulation, and therefore, the maximum aquifer thickness, as 150 and 300 ft for the Cocalico Formation and carbonate formations, respectively.

Vintage Formation (Cv)

The Vintage Formation underlies about 50 mi^2 of the Piedmont Lowland in Adams, Berks, Chester, Lancaster, and York Counties (Berg and others, 1980). It crops out as numerous but scattered, folded and faulted rocks that border hills of the Antietam Formation of the Piedmont Upland and the Kinzers and Conestoga Formations of the Piedmont Lowland. The Vintage Formation was named for the town of Vintage, Pa., 13 mi southeast of Lancaster, where it is exposed in a railroad cut.

Geologic description.—Most of the Vintage Formation (table 8) is fine- to medium-grained, mottled or finely banded gray to blue thick-bedded to massive dolomite. However, limestone is common in the upper part and a fine-grained, white to creamy, argillaceous to sandy dolomite or marble commonly represents the lower part.

In York County, the Vintage Formation grades into the ferruginous and calcareous sandstone beds at the top of the underlying Antietam Formation (Stose and Jonas, 1939, p. 49); however, in Lancaster County, the contact is described as sharp, between light-gray granular quartzite and darker gray dolomite (Meisler and Becher, 1971, p. 14). The Vintage Formation is conformably overlain by the Kinzers Formation (Jonas and Stose, 1930); north of the Honey Brook Uplands, the Kinzers grades into the Ledger Formation (Lyttle and Epstein, 1987). The Vintage Formation is considered by Stose and Jonas (1939, p. 59) to be equivalent to the lower part of the Tomstown Formation of the Great Valley. Fossils of Lower Cambrian age have been found in the Vintage Formation by Walcott (1896, p. 19) and by Jonas and Stose (1930, p. 26).

The Vintage Formation is moderately resistant to weathering, forming valleys with slopes of low to moderate relief. Chemical weathering of the Vintage rocks has created a highly irregular contact between regolith and bedrock that forms some shallow bedrock pinnacles. Weathering also has resulted in solution openings along existing joints and fractures (Geyer and Wilshusen, 1982, p. 279-280).

Some variation exists in thickness of the formation; maximum thickness estimates range from 350 to 550 ft in Lancaster County (Meisler and Becher, 1971, p. 14) to about 1,000 ft in York County (Stose and Jonas, 1939, p. 49). The Vintage Formation represents turbidites derived from a carbonate platform (Taylor and Durika, 1990, p. 142).

Well depths and casing lengths.—Depths of wells and casing lengths of wells completed in the Vintage Formation are presented in the tables below.

Reported well depth, Vintage Formation

[Depth in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	72	60	79	113	144	234	35	830
Drilled, domestic	47	59	77	100	144	220	35	442
Drilled, high-demand	7	—	130	139	300	—	101	830

Reported casing length, Vintage Formation

[Casing length in feet; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	50	25	41	65	84	131	10	240
Drilled, domestic	34	23	39	54	77	103	10	144
Drilled, high-demand	5	—	89	129	170	—	72	208

Casing length can vary spatially. Casing lengths of drilled wells in Chester County (12 wells) are significantly greater than in Berks (14 wells) or York (13 wells) Counties; the median casing lengths are 103, 67, and 38 ft, respectively.

Hydrologic properties.—Water levels for wells completed in the Vintage Formation are presented in the table below. Depths to water in 75 wells range from 2 to 106 ft below land surface; the median is 25 ft below land surface. Lloyd and Growitz (1977, p. 38) estimated that water levels in the area near Thomasville, York County, may have been lowered at least 100 ft by dewatering operations at a nearby quarry.

Water levels, Vintage Formation

[Water levels in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	6	—	32	42	60	—	17	76
Slope	33	12	26	42	54	78	8	106
Valley	27	5	8	16	23	66	2	77

Reported yields for wells completed in the Vintage Formation are presented in the table below. Yields of 5.0 gal / min or less are reported from eight wells. Only two of the five wells with reported yields of 100 gal / min or greater are deeper than 200 ft.

Reported well yield, Vintage Formation

[Yield in gallons per minute; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	51	3.2	10	15	30	96	0.0	665
Domestic	33	3.0	9.5	15	20	42	.5	80
High-demand	7	—	30	75	300	—	20	665

Specific capacities for wells completed in the Vintage Formation are presented in the table below. Only two wells (drilled to depths of 184 and 310 ft below land surface) have specific capacities of 0.04 (gal / min) / ft or less and are incapable of meeting most domestic or other water-use demands. Of three wells with specific capacities of 1.0 (gal / min) / ft or greater, only one is deeper than 200 ft. A single well pumped at discharge rates of 280 to 670 gal / min for 8 hours or longer has specific capacities that range from 12 to 29 (gal / min) / ft.

Reported specific capacity, Vintage Formation

[Specific capacity in gallons per minute per foot of drawdown; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	10	0.04	0.09	0.48	7.5	28	0.04	29
Domestic	7	—	.04	.16	.67	—	.04	3.3
High-demand	1	—	—	29	—	—	29	—

Values for hydraulic conductivity and transmissivity for the Vintage Formation are presented in the table below; a specific yield of 0.03 was used in estimating these hydrologic properties. The median hydraulic conductivities of wells on hilltops (1 well), slopes (3 wells), and valleys (6 wells) are 0.00, 15, and 0.46 ft / d, respectively. The median transmissivity of wells on hilltops is 1.4 ft^2 / d; on slopes, 510 ft^2 / d; and in valleys, 51 ft^2 / d.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Vintage Formation

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	10	0.00	0.05	0.93	30	87	0.00	89
Transmissivity (ft^2 / d)	10	1.4	7.4	60	1,300	6,700	1.4	7,100

In other work, Meisler and Becher (1971, p. 56) estimated an average specific yield of 0.04 for the upper part of the Little Conestoga Creek Basin in Lancaster County. In their digital model of parts of Lancaster and Berks Counties, Pa., Gerhart and Lazorchick (1984b, tables 6 and 14) used a specific yield of 0.06 and a hydraulic conductivity of 1.0 ft / d for the Vintage Formation. For the Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, tables 6 and 16) estimated a specific yield of 0.035 for the upper 200 ft and hydraulic conductivities of 1.34, 2.01, and 11.36 ft / d for different carbonate blocks that included the Vintage Formation.

The depths of water-bearing zones in 19 wells drilled as deep as 310 ft below land surface range from 44 to 225 ft below land surface. Fifty percent of the 32 water-bearing zones reported are penetrated by a depth of 80 ft and 90 percent by a depth of 148 ft. The greatest density of water-bearing zones (0.93 per 50 ft of well depth) is from 51 to 100 ft below land surface (fig. 37). The overall density of water-bearing zones in the Vintage Formation is 0.44 per 50 ft of well depth. Lloyd and Growitz (1977, p. 15), in York County, noted that many shallow water-bearing zones in the Vintage Formation have been dewatered by pumping from quarries or mines.

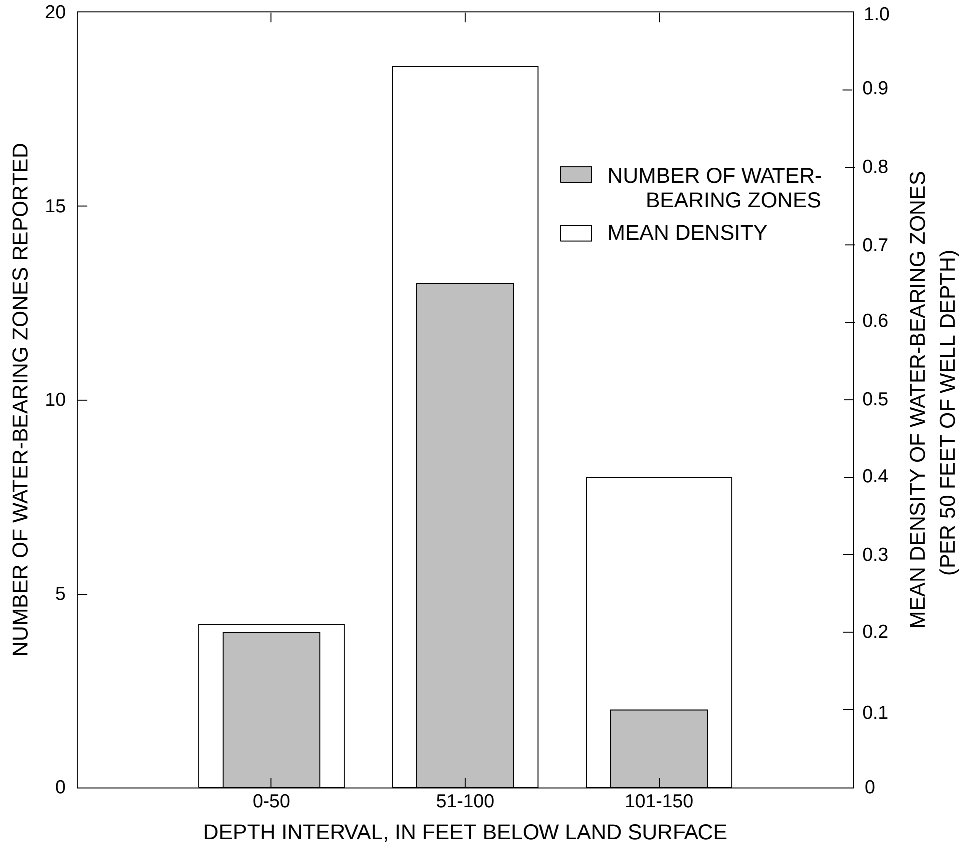


Figure 37. Number and density of water-bearing zones per 50 feet of well depth in the Vintage Formation of the Piedmont Physiographic Province, Piedmont Lowland Section

Water quality.—As seen in the following table, wells completed in the Vintage Formation generally yield water that contains low to moderate amounts of dissolved solids, is moderately soft to very hard, and alkaline. Calcium and magnesium are the dominant cations, and bicarbonate is the dominant anion. Aside from hard water, elevated concentrations of iron, manganese, and total dissolved solids are probably the most common water-quality problems.

Summary of selected chemical constituents and properties analyzed for the Vintage Formation

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; pCi/L, picoCurie per liter; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing waterthat exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	39	—	—	—	320	400	560	100	805
Field hardness	38	—	—	—	135	170	245	51	360
Field pH (standard units)	22	—	<6.5 >8.5	1	7.0	7.3	7.5	6.0	8.2
Bicarbonate	16	—	—	—	120	140	210	25	330
Calcium	15	—	—	—	27	32	53	1.6	87
Chloride	16	—	250	0	4.6	9.0	24	.80	88
Iron	11	—	.3	2	.030	.15	.29	.003	.73
Magnesium	15	—	—	—	15	18	24	.5	41
Manganese	10	—	.05	1	.000	.010	.020	.000	.090
Nitrate (as N)	15	10	—	1	1.8	5.3	6.5	.05	11
Potassium	14	—	—	—	1.2	1.7	2.1	.20	7.3
Radon (pCi/L)	1	[3] 300	—	1	—	460	—	460	460
Silica	8	—	—	—	8.4	9.3	10	6.1	12
Sodium	14	—	—	—	1.6	3.0	15	1.4	42
Sulfate	16	—	250	0	5.0	15	35	.60	65
Total dissolved solids	16	—	500	3	162	222	408	38	620

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.
[3] U.S. Environmental Protection Agency, 1994, proposed maximum contaminant level.

The well with the softest water and lowest specific conductance was drilled with a cable tool drilling rig in the Antietam Formation; after drilling through 35 ft of shale and 54 ft of blue slate (driller’s log), limestone was penetrated. The water-bearing zone at the depth of 89 ft had a reported yield of 12 gal/min.Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Recent work in the Vintage Formation (Durlin and Schaffstall, 1993; 1994) indicates that elevated concentrations of radon also are a common water-quality problem. Concentrations of radon-222 in the water from seven of eight wells exceed the proposed USEPA MCL of 300 pCi/L. Activities up to 5,000 pCi/L of radon-222 are reported; the median is 980 pCi/L. Because of its short half-life (3.8 days) and no chemical affinities, radon-222 is not transported any considerable distance in ground water and its concentration in a well sample is directly controlled by the surrounding lithology (Michel, 1990, p. 90). Radon’s parent (radium-226) is derived from uranium-234, which, however, has a very long half-life and is easily dissolved and transported in ground water (Zapecza and Szabo, 1988, p. 50). Senior and Vogel (1995) found that the concentrations of dissolved radium is inversely related to pH and directly to total dissolved solids, dissolved organic carbon, barium, and sulfate concentrations.

Kinzers Formation (Ck)

The Kinzers Formation underlies about 44 mi^2 of the Piedmont Lowland in Adams, Chester, Lancaster, and York Counties (Berg and others, 1980). The Kinzers Formation crops out as numerous, generally elongate, scattered, folded and faulted exposures. It was named for Kinzers station on the Pennsylvania Railroad, about 13 mi east of Lancaster.

Geologic description.—Stose and Jonas (1939, p. 50-58) identified three members in York County: a basal shale, a middle limestone, and an upper sandy limestone. In many parts of Lancaster County, however, only the basal shale is easily identified.

The basal member (Emigsville Member of Taylor and Durika, 1990) is black to dark gray or dark brown shale to greenish phyllite. It overlies an earthy blue dolomite that weathers to buff or orange-colored tripoli or porous sandstone that grades into the underlying Vintage Formation (Stose and Jonas, 1922; 1939; Jonas and Stose 1926; 1930). Thickness of this member ranges from 42 to 77 ft in Lancaster County (Stose and Stose, 1944) and up to 200 ft in York County (Ganis and Hopkins, 1990, p. 128).

The middle limestone (York Member of Ganis and Hopkins, 1990, p. 129-130) generally is thick-bedded to massive, light to medium-dark-gray, finely crystalline, with argillaceous masses. Some beds of pure limestone have been partially altered to dolomite. Marble, white crystalline limestone, or “leopard rock,” and structures that resemble Archeocyathid reefs are present also (Stose and Jonas, 1939, p. 52). Primary sedimentary features include oolites, burrows, indistinct reefy structure, desiccation features, bioclastic lag deposits, and megaconglomerate; extensive megabreccia development also has been reported (Cloos, 1974; Gohn, 1976). Thickness of this member ranges from about 76 ft in Lancaster County (Stose and Stose, 1944) to 1,000-1,200 ft in York County (Ganis and Hopkins, 1990, p. 128).

The upper member (Greenmount Member of Ganis and Hopkins, 1990, p. 130-131) is fine quartzose limestone banded with dark argillaceous layers. It weathers to a buff tripoli, porous fine sandstone, or dark shale. At some places in the Delta Carbonate quarry in York County, this member has been removed by slumping. Thickness of the upper member ranges from about 45 ft in Lancaster County (Stose and Stose, 1944) and from 0 to 100 ft in York County (Ganis and Hopkins, 1990, p. 128).

In Chester County, Lyttle and Epstein (1987) identified only two members. The lower member is medium-grained, white to light-gray, thin-bedded impure dolomite, which in Chester Valley, weathers to a shaley mica schist. The upper member is fine- to medium-grained, white to light- to bluish-gray, thin- and irregularly bedded argillaceous limestone that resembles the middle member in York County. The formation is much thinner in Chester County, ranging from 130 ft west of the Barren Hills (Honey Brook massif) to less than 30 ft in Chester Valley.

The Kinzers Formation is moderately resistant to weathering. In York County, the middle unit forms narrow valleys between a pair of low ridges underlain by the basal shale unit and by the upper sandy limestone unit (Stose and Jonas, 1939, p. 50). In Lancaster and Chester Counties, the formation underlies mostly valleys, but the shale can form ridges or locally, prominent hills. Joint and cleavage planes are moderately developed, very common, and open (Geyer and Wilshusen, 1982, p. 156-158).

The Kinzers Formation represents off-shelf environments. According to Taylor and Durika (1990, p. 136-156), the Emigsville Member represents turbidites derived from a carbonate platform, the York Member a foreslope facies, and the Greenmount Member off-platform deposition. Most of the Kinzers Formation is considered Lower Cambrian age (Jonas and Stose, 1930, p. 29; Stose and Jonas, 1939, p. 58) with a Middle Cambrian age established for the upper member of the Kinzers Formation (Berg and others, 1983). The Kinzers Formation is gradationally overlain by the Ledger Formation, and, according to Stose and Jonas (1939, p. 59), equivalent to the lower part of the Tomstown Formation of the Great Valley.

Well depths and casing lengths.—Depths of wells completed in the Kinzers Formation are presented in the table below.

Reported well depth, Kinzers Formation

[Depth in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	53	57	74	135	232	357	18	706
Drilled, domestic	39	55	70	103	195	278	50	424
Drilled, high-demand	5	—	192	395	580	—	163	650

Topographic setting can affect well depth. Domestic wells on slopes (22 wells) are completed at significantly greater depths than in valleys (11 wells); the median well depths are 140 and 70 ft, respectively.

Casing lengths for wells completed in the Kinzers Formation are presented in the table below. Large lengths of casing may be required in areas with deep weathering or where shallow water-bearing zones yield water of unacceptable quality. This may be the case of the high-demand well with a casing length of 395 ft as it is within 400 ft of a major fault. Such features can be extremely susceptible to weathering and the abundance of silt and clay dissolved from limestones can cause the formation of turbid water.

Reported casing length, Kinzers Formation

[Casing length in feet; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	24	15	18	39	84	138	4	395
Drilled, domestic	20	—	16	37	81	—	4	150
Drilled, high-demand	2	—	—	260	—	—	126	395

Hydrologic properties.—Water levels for wells completed in the Kinzers Formation are presented in the table below. Depths to water in 64 wells range from 6 to 168 ft below land surface; the median is 26 ft below land surface. In their study of central and southern York County, Lloyd and Growitz (1977, p. 38) reported that water levels near mines or quarries are affected by dewatering operations if the area of excavation is below the natural water table.

Water levels, Kinzers Formation

[Water levels in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	8	—	24	31	40	—	20	57
Slope	33	10	17	31	64	93	7	168
Valley	21	8	13	16	23	31	6	45

Reported yields for wells completed in the Kinzers Formation are presented in the table below. Yields of 5.0 gal / min or less are reported from 10 wells. The yields from 3 of the 10 low-yielding wells may be affected by dewatering operations at quarries and mines near Thomasville, York County (Lloyd and Growitz, 1977, p. 38). Yields of 100 gal / min or greater are reported from four wells, two of which are less than 100 ft deep and the other two are more than 500 ft deep.

Reported well yield, Kinzers Formation

[Yield in gallons per minute; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	34	2.0	5.0	10	21	100	1.0	250
Domestic	24	2.0	5.0	9.5	20	65	1.0	100
High-demand	7	—	17	25	111	—	13	250

Reported yields of wells producing from the basal shale (16 wells) are generally greater than in the limestone units (18 wells); the respective medians are 19 and 7 gal / min. This pattern also holds true if water use is considered. The median reported yield of domestic wells in the basal shale (10 wells) is 14 gal / min, twice the median reported yield of domestic wells (14 wells) completed in the limestone units.

Specific capacities for wells completed in the Kinzers Formation are presented in the table below. Specific capacities of 1.0 (gal / min) / ft or greater are reported from four wells, of which only one is deeper than 200 ft. The specific capacities of three wells pumped 8 hours or longer are 0.09, 0.34, and 2.1 (gal / min) / ft. Specific capacities are generally greater in the basal shale (6 wells) than in the limestone units (11 wells); the medians are 0.43 and 0.18 (gal / min) / ft, respectively.

Reported specific capacity, Kinzers Formation

[Specific capacity in gallons per minute per foot of drawdown; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	17	0.07	0.07	0.34	1.8	14	0.06	31
Domestic	11	.06	.07	.18	.62	27	.06	31
High-demand	5	—	.08	.34	1.9	—	.08	2.1

Values of hydraulic conductivity and transmissivity for the Kinzers Formation are presented in the table below; a specific yield of 0.02 was used in estimating these hydrologic properties. Hydraulic conductivity and transmissivity are generally lower on hilltops and slopes than in valleys. The median hydraulic conductivities of wells on hilltops (2 wells), slopes (9 wells), and in valleys (4 wells) are 0.02, 0.12, and 3.2 ft / d, respectively. The median transmissivity of wells on hilltops is 9.6 ft^2 / d; on slopes, 19 ft^2 / d; and in valleys, 250 ft^2 / d.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Kinzers Formation

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile;

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	15	0.02	0.03	0.12	5.7	62	0.01	87
Transmissivity (ft^2 / d)	15	5.2	5.2	19	83	3,500	5.2	6,100

In other work, Meisler and Becher (1971, p. 56) estimated an average specific yield of 0.04 for the upper part of the Little Conestoga Creek Basin in Lancaster County. In their digital model of parts of Lancaster and Berks Counties, Pa., Gerhart and Lazorchick (1984b, tables 6 and 14) used a specific yield of 0.07 and a hydraulic conductivity of 1.0 ft / d for the Kinzers Formation. For the Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, tables 8 and 16) estimated a specific yield of 0.035 for the upper 200 ft and hydraulic conductivities of 1.34, 2.01, and 11.36 ft / d for different carbonate blocks that included the Kinzers Formation.

The depths of water-bearing zones in 11 wells drilled as deep as 650 ft range from 22 to 366 ft below land surface. Fifty percent of the 16 water-bearing zones reported are penetrated by a depth of 84 ft and 90 percent by a depth of 234 ft. The greatest density of water-bearing zones (0.57 per 50 ft of well depth) is from 51 to 100 ft below land surface (fig. 38). The overall density of water-bearing zones in the Kinzers is 0.28 per 50 ft of well depth.

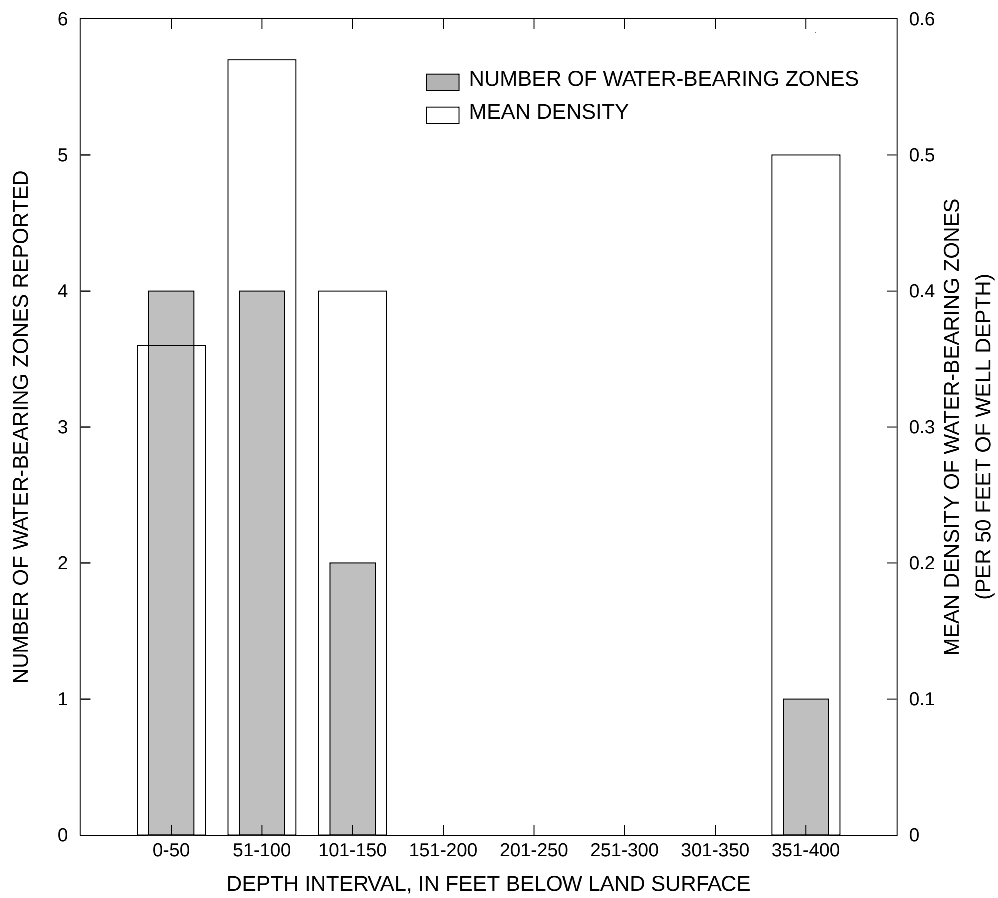


Figure 38. Number and density of water-bearing zones per 50 feet of well depth in the Kinzers Formation of the Piedmont Physiographic Province, Piedmont Lowland Section.

Water quality.—As seen in the following table, wells completed in the Kinzers Formation generally yield water that has moderate to high concentrations of dissolved solids and is hard to very hard. Calcium is the dominant cation, and bicarbonate is the dominant anion. Aside from very hard water, elevated concentrations of nitrite and total dissolved solids are the most common water-quality problems in the Kinzers Formation. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Kinzers Formation

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	47	—	—	—	360	455	640	120	1,150
Field hardness	49	—	—	—	150	190	260	51	410
Field pH (standard units)	23	—	<6.5 >8.5	1	6.9	7.0	7.5	5.5	7.5
Bicarbonate	14	—	—	—	140	180	260	100	320
Calcium	14	—	—	—	39	63	100	30	150
Chloride	14	—	250	0	6.8	21	42	3.6	120
Iron	14	—	.3	1	.040	.050	.10	.030	.40
Lead	7	0.015	—	1	.003	.004	.010	.002	.050
Magnesium	14	—	—	—	12	21	36	6.6	50
Manganese	13	—	.05	0	.000	.010	.010	.000	.020
Nitrate (as N)	14	10	—	2	2.6	3.8	7.3	.02	35
Potassium	12	—	—	—	1.0	1.9	3.5	.40	16
Silica	9	—	—	—	7.4	11	14	6.0	24
Sodium	12	—	—	—	4.6	11	21	2.1	44
Sulfate	14	—	250	0	25	31	54	13	95
Total dissolved solids	13	—	500	3	205	308	522	175	653

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.

The water of wells completed in the basal shale is significantly softer and lower in dissolved solids than in the upper limestone units of the Kinzers Formation. The median specific conductance of water from wells completed in the shale (15 wells) is 360 µS/cm and for wells in the limestone units (32 wells), the median is 523 µS/cm. The median hardness of water from wells in the shale is 150 mg/L (16 wells) and 210 mg/L for water from wells in the limestone units (33 wells). The small number of field pH values prevents any statistical analysis; however, the median pH of water in the shale is 6.5 and 7.0 in the limestones.

Recent work in the Kinzers Formation (Durlin and Schaffstall, 1993; 1994) indicates elevated concentrations of radon are a common water-quality problem also. Concentrations of radon-222 in the water from seven of seven wells sampled exceed the proposed USEPA MCL of 300 pCi/L (U.S. Environmental Protection Agency, 1994). Activities up to 2,600 pCi/L radon-222 are reported in the Kinzers Formation; the median is 1,900 pCi/L. The high radon concentrations in the Kinzers may be related to the presence of the basal shale. The reducing environment produced by a black shale will cause any mobile uranium to precipitate and concentrate in the shale. Radon's parent (radium-226) is most mobile in chloride-rich reducing ground water with high dissolved-solids content (Tanner, 1964, p. 261). Radium's parent (uranium-234) is more soluble in association with carbonate, phosphate, and fluoride ions, or with organic compounds (Langmuir, 1978, p. 556; Turner-Peterson, 1980, p. 163).

Ledger Formation (Cl)

The Ledger Formation underlies about 106 mi^2 of the Piedmont Lowland. It crops out as small, discontinuous, faulted exposures in Adams and York Counties. Eastward, in Lancaster County, this formation is exposed in broad belts repeated by large-scale folding and faulting. In Chester, Montgomery, and Philadelphia Counties, it narrows where it borders small segments of the Gettysburg-Newark Lowland Section or Piedmont Upland Section (Berg and others, 1980). The formation was named for the Village of Ledger in Lancaster County.

Geologic description.—The Ledger Formation is coarse-grained, white to light to dark gray, thick-bedded to massive, medium- and coarsely crystalline dolomite. A prominent chert horizon occurs near the top of this formation. The dolomite is so pure that it has been quarried for magnesium products in Lancaster County (Stose and Jonas, 1939, p. 58). In the Chester Valley, the dolomite is interbedded with laminated limestone.

The Ledger Formation is moderately resistant to weathering. Weathering has produced a highly irregular pinnacled contact between the regolith and bedrock, providing solution openings along joint and bedding planes. Joints are fairly common, open, and widely spaced, which results in the formation of a blocky outcrop pattern. The Ledger Formation generally underlies valleys that display little local relief (Geyer and Wilshusen, 1982, p. 159-160).

Thickness of the Ledger Formation varies in York County from 100 ft (north of Wrightsville, near the Susquehanna River) to about 1,000 ft (Stose and Jonas, 1939, p. 59). The Ledger may thin eastward as Poth (1968, p. 64), in central Chester County, estimated a thickness of about 600 ft. Geyer and Wilshusen (1982, p. 159) estimated a maximum thickness of 2,000 ft.

The discovery of a thick (up to 210 ft) dominantly limestone unit within the Ledger Formation in York County have enabled Ganis and Hopkins (1990, p. 131) to identify three members within the Ledger Formation—the Lower and Upper Dolomite members, which are similar to the description of Stose and Jonas (1939), and the Willis Run Member. Taylor and Durika (1990, p. 148) have identified Early Cambrian-age fossils in the Willis Run Member and one that is characteristic of the upper part of the Lower Cambrian.

Taylor and Durika (1990, p. 143) believe the Ledger Formation represents a shallower depositional environment than the Kinzers and Vintage Formations, probably a platform facies. MacLachlan (1994a, p. 20-21) described the depositional environment to be bank edge rimmed by a slightly higher, marginal limestone shoal. The Willis Run Member represents a deeper subtidal or deeper shelf environment than the lower and upper members. The Ledger Formation is in conformable contact with the underlying Kinzers or Vintage Formations. Stose and Jonas (1939, p. 59) believe the Ledger Formation is equivalent to the upper part of the Tomstown Formation of the Great Valley. The Ledger interfingers with and is overlain by the Zooks Corner Formation in Lancaster County (Meisler and Becher, 1971, p. 17), and is in gradational contact with the Elbrook Formation except where unconformably overlain by the Conestoga Formation (Lyttle and Epstein, 1987).

Well depths and casing lengths.—Depths of wells completed in the Ledger Formation are presented in the table below. Six of the nine wells completed at depths of 500 ft or greater are high-demand wells. Casing lengths of five wells exceed 200 ft.

Reported well depth, Ledger Formation

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	195	65	95	170	267	400	16	624
Drilled, domestic	70	60	75	100	200	290	35	600
Drilled, high-demand	84	85	124	208	318	430	58	624

Depths of drilled wells can also vary significantly by county. Wells in Montgomery County (19 wells) are completed at significantly greater depths than wells in Chester (94 wells) or Lancaster (68 wells) Counties; the median well depths are 250, 154, and 143 ft, respectively.

Casing lengths for wells completed in the Ledger Formation are presented in the table below.

Reported casing length, Ledger Formation

[Casing length in feet; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	120	20	40	60	92	141	1	521
Drilled, domestic	31	18	40	70	85	142	1	521
Drilled, high-demand	63	26	42	60	105	146	10	388

Hydrologic properties.—Water levels for wells completed in the Ledger Formation are presented in the table below. Depths to water in 206 wells range from flowing at land surface to 105 ft below land surface; the median is 25 ft below land surface. Lloyd and Growitz (1977, p. 14) reported pumping from quarries can affect static water levels locally.

Water levels, Ledger Formation

[Water levels in feet below land surface; F, flowing well; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	8	—	29	37	48	—	17	65
Slope	79	14	22	31	51	78	11	105
Valley	101	7	11	18	26	38	F	87

Reported yields for wells completed in the Ledger Formation are presented in the table below. Yields of 5.0 gal / min or less are reported from 11 wells. Yields of 100 gal / min or greater are reported from 62 wells; 34 wells are deeper than 200 ft.

Reported well yield, Ledger Formation

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	146	6.9	15	60	203	500	0.0	1,810
Domestic	35	5.6	10	20	50	76	2.0	120
High-demand	83	8.9	45	190	400	675	2.0	1,810

Specific capacities for wells completed in the Ledger Formation are presented in the table below. Specific capacities of 1.0 (gal / min) / ft are reported from 44 wells; 14 wells are deeper than 200 ft. The specific capacities of wells with a pumping duration of 8 hours or longer (26 wells) range from 0.28 to 80 (gal / min) / ft; the median is 9.2 (gal / min) / ft. High-demand wells have significantly greater specific capacities than domestic wells.

Reported specific capacity, Ledger Formation

[Specific capacity in gallons per minute per foot of drawdown; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	73	0.15	0.39	2.6	13	34	0.05	155
Domestic	21	.09	.16	.38	1.9	14	.07	135
High-demand	38	.59	2.8	9.2	18	58	.05	155

Values of hydraulic conductivity and transmissivity for the Ledger Formation are presented in the table below; a specific yield of 0.04 was used in estimating these hydrologic properties. The median hydraulic conductivity of wells on hilltops (1 well), slopes (24 wells), and valleys (41 wells) are 0.71, 7.1, and 12 ft / d, respectively. The median transmissivity of wells on hilltops is 71 ft^2 / d; on slopes, 1,300 ft^2 / d; and in valleys, 710 ft^2 / d.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Ledger Formation

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	72	0.12	0.79	5.8	39	310	0.03	850
Transmissivity (ft^2 / d)	72	15	49	410	2,700	7,000	4.4	36,000

In other work, Meisler and Becher (1971, p. 56) estimated an average specific yield of 0.04 for the upper part of the Little Conestoga Creek Basin in Lancaster County. In their digital model of parts of Lancaster and Berks Counties, Pa., Gerhart and Lazorchick (1984b, tables 6 and 14) used a specific yield of 0.08 and a hydraulic conductivity of 7.0 ft / d for the Ledger Formation. For the Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, tables 8 and 16) estimated a specific yield of 0.035 for the upper 200 ft and hydraulic conductivities of 1.34, 2.01, and 11.36 ft / d for different carbonate blocks that included the Ledger Formation. For his digital model of the Valley Creek Basin in eastern Chester County, Sloto (1990) used a specific yield of 0.08 and a hydraulic conductivity of 45 ft / d. Transmissivities from six aquifer tests in the modeled area in Chester and Montgomery Counties ranged from 600 to 15,430 ft^2 / d; the median was 1,680 ft^2 / d. In extensive work at the Malvern TCE Site, Chester County, Pa., Sloto (1997, tables 3 and 4) estimated transmissivity from aquifer tests using nine wells. The estimates of transmissivity during pumping ranged from 52 to 860 ft^2/d; the median was 327 ft^2/d. Estimates of transmissivity during recovery ranged from 226 to 1,560 ft^2/d; the median was 835 ft^2/d. At the AIW Frank / Mid County Mustang Superfund Site, Chester County, Pa., Conger (U.S. Geological Survey, 1997, written commun.) estimated horizontal hydraulic conductivity and transmissivity from rising and falling slug tests using eight wells open to overburden or bedrock. The hydraulic conductivities of wells open to the overburden ranged from 0.031 to 8.1 ft / d, and transmissivities ranged from 2 to 360 ft^2/d; the medians were 4.3 ft / d and 146 ft^2/d, respectively. The hydraulic conductivities of wells open to bedrock ranged from 1.28 to 12 ft / d, and transmissivities ranged from 45 to 675 ft^2/d; the medians were 5.86 ft / d and 369 ft^2/d.

The depths of water-bearing zones in 51 wells drilled as deep as 605 ft range from 26 ft below land surface to 582 ft below land surface. Fifty percent of the 107 water-bearing zones reported are penetrated by a depth of 102 ft and 90 percent by a depth of 250 ft. The greatest density of water-bearing zones (0.70 per 50 ft of well depth) is from 151 to 200 ft below land surface (fig. 39). The density of water-bearing zones at depths of 201 ft or greater is based on the presence of four or fewer water-bearing zones per 50-ft interval. The overall density of water-bearing zones in the Ledger Formation is 0.42 per 50 ft of well depth.

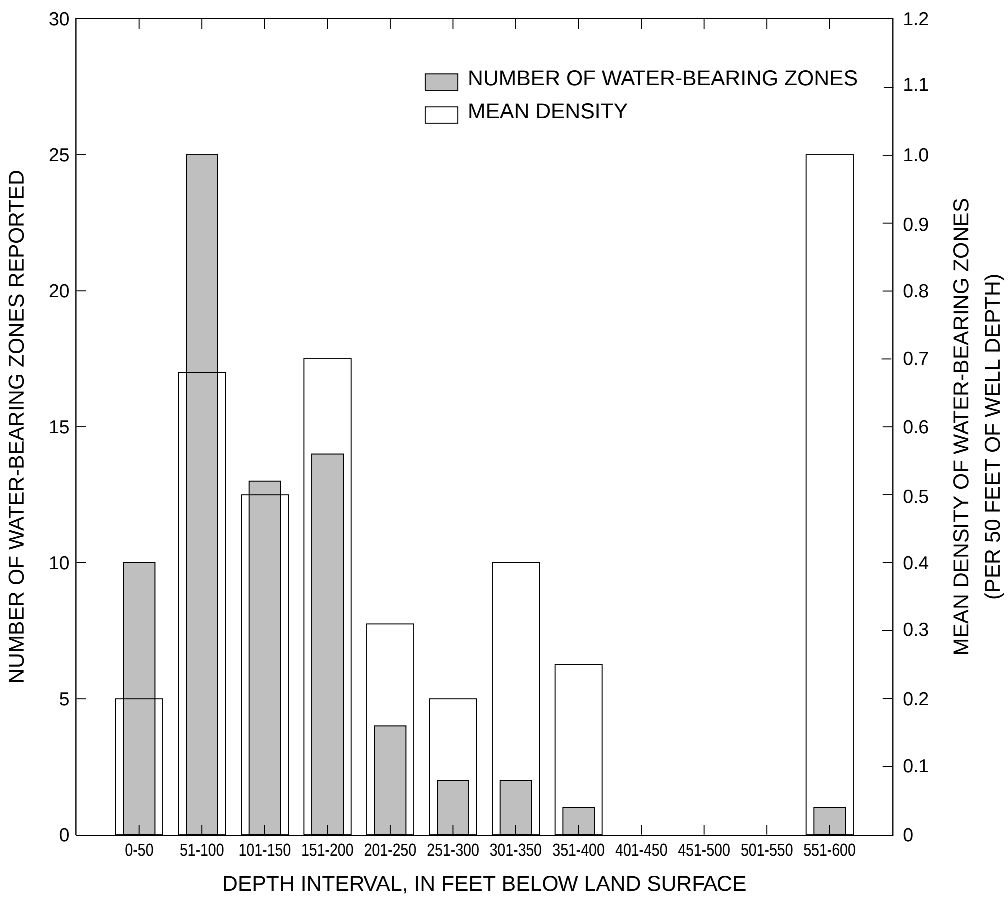


Figure 39. Number and density of water-bearing zones per 50 feet of well depth in the Ledger Formation of the Piedmont Physiographic Province, Piedmont Lowland Section.

Water quality.—As seen in the following table, wells completed in the Ledger Formation generally yield water that has moderate to high concentrations of dissolved solids, is hard to very hard, and is alkaline. Calcium is the dominant cation, and bicarbonate is the dominant anion. Lloyd and Growitz (1977, p. 15) considered the water in the Ledger to be a calcium bicarbonate type. Aside from hard water, elevated concentrations of manganese, nitrite, radon, and total dissolved solids are the most common water-quality problems. Elevated concentrations of calcium, magnesium, chloride, iron, lead, mercury, and sodium also have been reported. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Ledger Formation

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; pCi/L, picoCurie per liter; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	92	—	—	—	455	600	700	155	1,500
Field hardness	99	—	—	—	190	270	310	68	480
Field pH (standard units)	45	—	<6.5 >8.5	1	7.2	7.4	7.8	5.7	8.0
Bicarbonate	54	—	—	—	170	220	260	58	400
Calcium	39	—	—	—	50	62	72	10	120
Chloride	54	—	250	1	9.3	17	27	.00	290
Iron	50	—	.3	3	.010	.020	.060	.000	.860
Lead	28	0.015	—	1	.001	.002	.002	.000	.020
Magnesium	40	—	—	—	24	35	39	5.8	54
Manganese	47	—	.05	6	.001	.008	.012	.000	1.9
Mercury	21	.002	—	1	<.001	.001	.001	<.001	.003
Nitrate (as N)	37	10	—	11	2.6	6.5	12	.20	39
Potassium	38	—	—	—	1.4	2.2	3.6	.20	9.3
Radium 226 (pCi/L)	5	20	—	1	.15	.35	49	.10	98
Radium 228 (pCi/L)	5	20	—	0	.75	1.1	11	.50	20
Radon 222 (pCi/L)	13	[3] 300	—	9	220	620	1,500	120	5,800
Silica	28	—	—	—	7.6	8.2	9.5	6.6	18
Sodium	39	—	—	—	4.0	5.6	12	1.9	130
Sulfate	50	—	250	0	16	33	48	4.0	240
Total dissolved solids	54	—	500	8	269	356	414	73	730

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.
[3] U.S. Environmental Protection Agency, 1994, proposed maximum contaminant level.

The well with the lowest pH also has the softest water and lowest specific conductance. This well is in Chester Valley, about 300 to 400 ft down slope of a quartzite ridge. On the basis of field analyses, it is probable that this well is actually intercepting ground water which has originated or at least passed through the adjacent quartzite unit.

The water from four wells near the Pennsylvania Turnpike and State Route 29 have been analyzed for chloride (Sloto, 1987, table 23). Chloride concentrations in the water from one of the four wells is 290 mg/L, slightly greater than the USEPA SMCL of 250 mg/L. Sloto (1987, p. 68) attributed the elevated chloride concentrations to "* * * the use of deicing salt on the Pennsylvania Turnpike."

More recent work in the Ledger Formation (Durlin and Schaffstall, 1993, 1994) indicates elevated concentrations of radon are fairly widespread. Concentrations of radon-222 in the water from 11 of 25 wells sampled exceed the proposed USEPA MCL of 300 pCi/L; 5 wells contain water with radon-222 concentrations at or within 40 pCi/L of the proposed MCL. Activities up to 860 pCi/L radon-222 are reported by Durlin and Schaffstall (1993; 1994); the median is 300 pCi/L. Hess and others (1985, table 7) have shown that higher concentrations of radon are common in wells with low yields.

Zooks Corner Formation (Czc)

The Zooks Corner Formation underlies about 42 mi^2 of the Piedmont Lowland. It crops out in four, east-west trending belts that extend from the communities of Lancaster to New Holland, with one belt extending further eastward to near Morgantown (Berg and others, 1980). The Zooks Corner Formation was named by Meisler and Becher (1967) for exposures along Conestoga Creek, near the Village of Zooks Corner, Lancaster County.

Geologic description.—The Zooks Corner Formation is very fine-grained, white to medium-dark-gray, thin- to thick-bedded, silty to sandy dolomite with shaley beds common. White to medium-gray beds of limestone and medium bedded, crossbedded dolomitic sandstones also are present; at some stratigraphic horizons the limestones are dominant over the dolomite. Other sedimentary structures include small scale cross-laminae, ripple marks, mud cracks, graded bedding, and possible soft-sediment deformation (Meisler and Becher, 1971, p. 17-18). Thickness of the Zooks Corner Formation in the type section is about 1,600 ft (Meisler and Becher, 1971, p. 17) but may be considerably thinner elsewhere.

The Zooks Corner Formation commonly underlies valleys, with low rolling topography and gentle slopes. Joints are moderately to well developed, regularly spaced, and open; many are filled with calcite (Geyer and Wilshusen, 1982, p. 290). Solution cavities are common in the bedrock.

MacLachlan (1994a, p. 23) noted that the Lower (?) to Middle Cambrian Zooks Corner Formation is associated with the inner margin of the Ledger bank margin facies and may represent the transition from bank margin to shelf. To the west of Chester County, the Zooks Corner separates the Ledger from the Elbrook; it is less than 100 ft thick and consists of dolomitic, silty, and sandy rock. MacLachlan (1994b, p. 152-153) indicated the Zooks Corner Formation is present in the Downingtown area; however, this unit has not been mapped in Chester County.

The Zooks Corner Formation interfingers with the underlying Ledger Formation and grades into the overlying Buffalo Springs Formation. Because of its conformable relation with the underlying Ledger Formation, the Zooks Corner has been assigned a tentative Middle Cambrian age by Meisler and Becher (1967).

Well depths and casing lengths.—Depths of wells and casing lengths for wells completed in the Zooks Corner Formation are presented in the tables below.

Reported well depth, Zooks Corner Formation

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	94	81	109	151	231	399	68	700
Drilled, domestic	49	84	108	150	207	289	68	400
Drilled, high-demand	17	90	230	306	430	500	69	500

Reported casing length, Zooks Corner Formation

[Casing length in feet; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	44	12	20	51	78	100	5	208
Drilled, domestic	15	9	15	20	61	88	5	90
Drilled, high-demand	10	40	23	40	79	197	7	105

Hydrologic properties.—Water levels for wells completed in the Zooks Corner Formation are presented in the table below. Depths to water in 134 wells range from 5 to 190 ft below land surface; the median is 25 ft below land surface.

Water levels, Zooks Corner Formation

[Water levels in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	22	20	32	43	54	102	13	190
Slope	43	14	22	30	57	75	11	102
Valley	60	8	14	21	25	36	5	122

Reported yields for wells completed in the Zooks Corner Formation are presented in the table below. Yields of 5.0 gal / min or less are reported from five wells. Four of seven wells with reported yields of 100 gal / min or greater are deeper than 200 ft.

Reported well yield, Zooks Corner Formation

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	35	3.0	10	40	75	244	1.0	300
Domestic	15	1.6	3.0	10	30	54	1.0	75
High-demand	16	29	40	60	138	250	25	250

Specific capacities for wells completed in the Zooks Corner Formation are presented in the table below. One well has a specific capacity of 0.04 (gal / min) / ft or less and is incapable of meeting most domestic or other water-use demands. Wells with specific capacities of 1.0 (gal / min) / ft or greater are reported from 13 wells; only 2 wells are deeper than 200 ft. A 24-hour single-well aquifer test at an average discharge of 240 gal / min in a well completed at a depth of 232 ft resulted in a specific capacity of 48 (gal / min) / ft.

Reported specific capacity, Zooks Corner Formation

[Specific capacity in gallons per minute per foot of drawdown; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	20	0.29	0.75	1.8	28	120	0.04	160
Domestic	9	—	.80	1.1	3.8	—	.52	46
High-demand	2	—	—	24	—	—	.26	48

Values of hydraulic conductivity and transmissivity for the Zooks Corner Formation are presented below; a specific yield of 0.02 was used in estimating these hydrologic properties. The median hydraulic conductivities of wells on hilltops (2 wells), slopes (10 wells), and in valleys (4 wells) are 1.5, 46, and 0.65 ft / d, respectively. The median transmissivities of wells on hilltops is 110 ft^2 / d; on slopes, 2,300 ft^2 / d; and in valleys, 72 ft^2 / d.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Zooks Corner Formation

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	16	0.36	0.97	3.6	120	1,500	0.09	2,400
Transmissivity (ft^2 / d)	16	58	100	210	4,200	31,000	34	36,000

In their digital model of parts of Lancaster and Berks Counties, Pa., Gerhart and Lazorchick (1984b, tables 6 and 14) used a specific yield of 0.07 and a hydraulic conductivity of 1.5 ft / d for the Zooks Corner Formation. For the Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, tables 8 and 16) used a specific yield of 0.035 for the upper 200 ft and hydraulic conductivities of 2.01 and 11.36 ft / d for different carbonate blocks that included the Zooks Corner Formation.

The depths of water-bearing zones in 25 wells drilled as deep as 700 ft range from 42 to 562 ft below land surface. Fifty percent of the 58 water-bearing zones reported are penetrated by a depth of 110 ft and 90 percent by a depth of 267 ft. The greatest density of water-bearing zones (0.88 per 50 ft of well depth) is from 151 to 200 ft below land surface (fig. 40); the density of water-bearing zones at depths of 251 ft or greater are based on the presence of four or less water-bearing zones per 50-ft interval. The overall density of water-bearing zones in the Zooks Corner Formation is 0.48 per 50 ft of well depth.

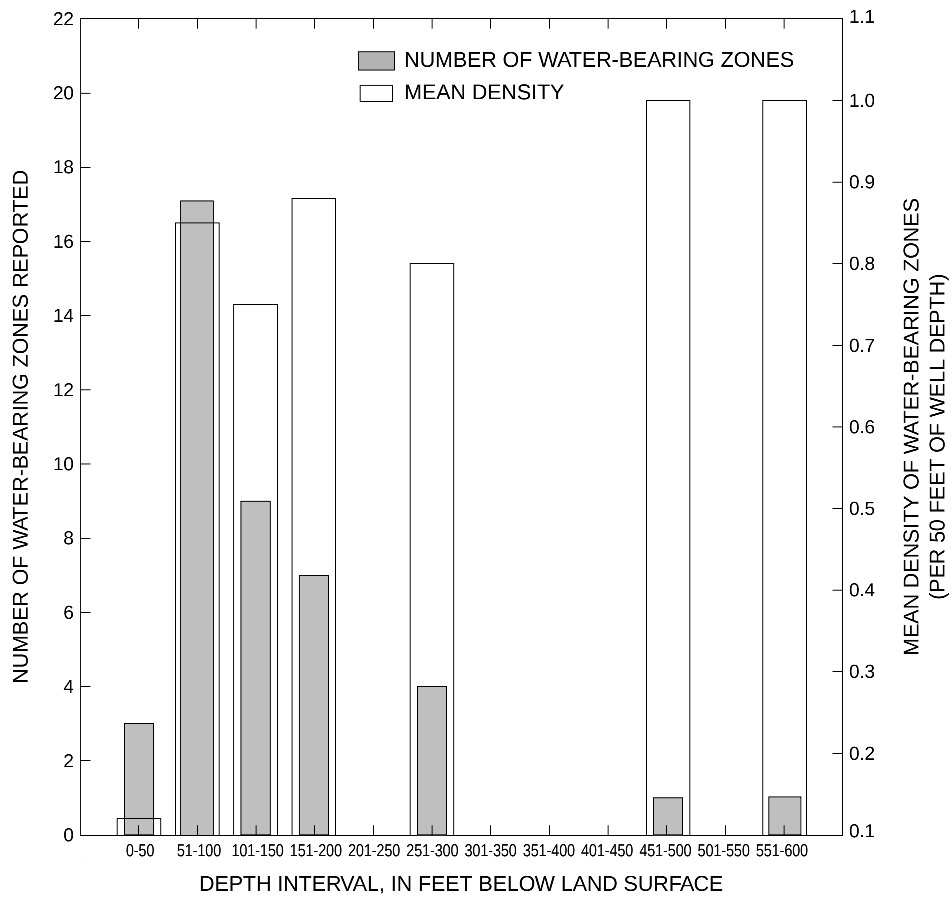


Figure 40. Number and density of water-bearing zones per 50 feet of well depth in the Zooks Corner Formation of the Piedmont Physiographic Province, Piedmont Lowland Section.

Water quality.—As seen in the following table, wells completed in the Zooks Corner Formation yield water that contains moderate to high concentrations of dissolved solids, is very hard, and is generally alkaline. Magnesium and calcium are the dominant cations, and bicarbonate is the dominant anion. Elevated concentrations of manganese, nitrate, and dissolved solids and very hard water are the most common water-quality problems. Elevated concentrations of aluminum, calcium, magnesium, chloride, iron, nickel, sodium, and potassium also have been reported.

The large number of wells containing water above the USEPA MCL for nitrate may, at least in part, be the result of incorporating samples collected during a study in Lancaster and Berks Counties (Fishel and Lietman, 1986). The purpose of the study was to evaluate the regional extent of nitrate and herbicide contamination in the Conestoga River headwaters and to evaluate the effects of agricultural best-management practices on water quality. Fishel and Lietman (1986) believed that elevated nitrate concentrations in the ground water were strongly correlated to agricultural land use. Of the 19 wells completed in the Zooks Corner Formation and included in the Lancaster and Berks Counties study, 12 contain water with nitrate (as N) above the MCL. However, M. Brown of the Pennsylvania Department of Environmental Resources (oral commun., 1991), noted that elevated nitrate concentrations may be more closely correlated to carbonate terrain and the associated soils than agricultural practices.

Summary of selected chemical constituents and properties analyzed for the Zooks Corner Formation

[Concentrations in milligram per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	108	—	—	—	556	650	809	375	1,510
Field hardness	111	—	—	—	240	290	340	120	580
Field pH (standard units)	11	—	<6.5 >8.5	0	7.1	7.2	7.4	6.8	7.5
Bicarbonate	34	—	—	—	210	240	270	2.0	490
Calcium	33	—	—	—	51	60	77	.60	130
Chloride	34	—	250	2	12	20	30	3.3	550
Iron	16	—	.3	2	.040	.10	.15	.010	1.2
Magnesium	33	—	—	—	34	39	44	.10	77
Manganese	12	—	.05	4	.000	.020	.060	.000	.21
Nickel	7	.1	—	1	.010	.015	.11	.010	.14
Nitrate (as N)	34	10	—	17	9.2	11	14	.01	48
Potassium	32	—	—	—	2.0	2.3	3.7	.10	100
Silica	9	—	—	—	7.9	8.8	11	6.3	14
Sodium	32	—	—	—	3.6	4.9	18	2.0	240
Sulfate	33	—	250	0	30	40	65	15	180
Total dissolved solids	34	—	500	13	327	392	488	0.0	1,500

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.

Additional work in the Zooks Corner Formation (Durlin and Schaffstall, 1993; 1994) indicates elevated concentrations of radon also are a common water-quality problem. Concentrations of radon-222 in the water from six wells met or exceeded the proposed USEPA MCL of 300 pCi/L. Activities in the Zooks Corner Formation ranged from 300 to 2,600 pCi/L; the median was 690 pCi/L. Senior and Vogel (1995) found that the concentrations of dissolved radium (radon-222 is the daughter product of radium-226) is inversely related to pH and directly to total dissolved solids, dissolved organic carbon, barium, and sulfate concentrations. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Buffalo Springs Formation (Cbs)

The Buffalo Springs Formation underlies about 22 mi^2 of the Piedmont Lowland. It crops out in several east-west trending belts in northern and central Lancaster County and extreme southern Berks County (Berg and others, 1980). The Buffalo Springs Formation was named for the Village of Buffalo Springs in the Great Valley Section of the Valley and Ridge Physiographic Province, which is north of the study area, by Gray and others (1958). Meisler and Becher (1967) extended the name Buffalo Springs Formation to the Lancaster area based upon stratigraphic position and lithologic similarities. MacLachlan (1994a, p. 22), however, has indicated that the Buffalo Springs Formation is actually the Elbrook Formation and that the name Buffalo Springs Formation should be abandoned.

Geologic description.—The Buffalo Springs Formation is composed of white, pinkish-gray, to medium-dark-gray limestones interbedded with light pinkish-gray and yellowish-gray to medium-dark-gray dolomites. There is extensive lateral variation in the composition, color, and texture of the formation.

Limestone beds contain stromatolites, oolites, and stringers composed of chert. Dolomite beds are commonly argillaceous, silty, or sandy and contain chert stringers, cross laminae and ripple marks. Thickness of the Buffalo Springs Formation varies from 1,500 to 3,800 ft (Meisler and Becher, 1968, p. 3).

The Buffalo Springs Formation commonly underlies valleys with rolling topography, low relief, and gentle slopes. Joints are moderately developed and moderately abundant but irregularly spaced. Most joints are open but some are filled with quartz and calcite (Geyer and Wilshusen, 1982, p. 51-53). The Buffalo Springs Formation is moderately resistant to weathering. The regolith contains small to large fragments of bedrock. Bedrock pinnacles beneath the regolith are common.

The Buffalo Springs Formation is of Middle Cambrian age and is the lower most formation in the Conococheague Group (Meisler and Becher, 1967). The formation is gradationally interbedded at the contacts with both the underlying Zooks Corner Formation and the overlying Snitz Creek Formation (table 8). MacLachlan (1994a, p. 22) believed that the Buffalo Springs Formation represents a predominantly subtidal, shelf deposit that received considerable amounts of terrigenous clastics.

Well depths and casing lengths.—Depths of wells and casing lengths for wells completed in the Buffalo Springs Formation are presented in the tables below.

Reported well depth, Buffalo Springs Formation

[Depth in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	51	80	105	192	243	482	63	595
Drilled, domestic	31	81	105	175	205	377	65	545
Drilled, high-demand	5	—	154	215	495	—	133	500

Reported casing length, Buffalo Springs Formation

[Casing length in feet; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	18	12	28	57	81	202	10	400
Drilled, domestic	11	12	20	50	80	337	12	400
Drilled, high-demand	3	—	—	118	—	—	53	180

Hydrologic properties .—Water levels for wells completed in the Buffalo Springs Formation are presented in the table below. Depths to water in 98 wells range from 5 to 178 ft below land surface; the median is 29 ft below land surface.

Water levels, Buffalo Springs Formation

[Water levels in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	11	15	28	65	78	166	13	178
Slope	28	13	29	38	58	75	11	147
Valley	55	8	14	23	32	42	5	74

Reported yields for wells completed in the Buffalo Springs Formation are presented in the table below. Yields of 5.0 gal / min or less are reported from four wells. Only two wells have reported yields greater than 80 gal / min; one is in a flood plain and within 900 ft of the Susquehanna River and the other is within 500 ft of the Chickies Creek.

Reported well yield, Buffalo Springs Formation

[Yield in gallons per minute; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	15	1.8	3.0	15	45	350	1.5	350
Domestic	9	—	2.7	15	23	—	1.5	45
High-demand	3	—	—	350	—	—	6.7	350

Specific capacities for wells completed in the Buffalo Springs Formation are presented in the table below and are from USGS single-well aquifer tests. Rates of discharge range from 3.5 to 14 gal / min. If wells pumped less than 1 hour (28 wells) are included, the range of specific capacities is from 0.01 to 200 (gal / min) / ft; the median is 1.6 (gal / min) / ft.

Reported specific capacity, Buffalo Springs Formation

[Specific capacity in gallons per minute per foot of drawdown; —, insufficient data available; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Well type	Number of wells	P25	Median	P75
All	6	1.5	56	0.17
Domestic	2	.93	—	.17
High-demand	1	—	—	.17

Values of hydraulic conductivity and transmissivity for the Buffalo Springs Formation are presented in the table below; a specific yield of 0.03 was used in estimating these hydrologic properties. The median hydraulic conductivities of wells on slopes (2 wells) and valleys (3 wells) are 0.99 and 68 ft / d, respectively. The median transmissivities of wells on slopes is 130 ft^2 / d; and in valleys, 1,400 ft^2 / d.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Buffalo Springs Formation

[ft/d, feet per day; ft^2/d, feet squared per day; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Hydrologic property	Number of wells	P25	Median	P75	Minimum	Maximum
Hydraulic conductivity (ft / d)	5	0.99	6.2	900	0.26	1,700
Transmissivity (ft^2 / d)	5	91	250	23,000	17	46,000

In their work in the Little Conestoga Creek Basin in Lancaster County, Meisler and Becher (1971) estimated a specific yield of 0.04 for different units that included the Buffalo Springs Formation. For their digital model of parts of Lancaster and Berks Counties, Pa., Gerhart and Lazorchick (1984b, tables 6 and 14) used a specific yield of 0.07 and a hydraulic conductivity of 1.1 ft / d for the Buffalo Springs Formation. For the Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, tables 8 and 16) estimated a specific yield of 0.035 for the upper 200 ft and hydraulic conductivities of 2.01 and 11.36 ft / d for different carbonate blocks that included the Buffalo Springs Formation.

The depths of water-bearing zones in nine wells drilled as deep as 595 ft range from 40 to 525 ft below land surface. Fifty percent of the 20 water-bearing zones reported are penetrated by a depth of 180 ft and 90 percent by a depth of 489 ft. The densities of water-bearing zones shown in figure 41 are based upon four or fewer water-bearing zones per 50-ft interval and may change considerably with additional information. The overall density of water-bearing zones in the Buffalo Springs Formation is 0.34 per 50 ft of well depth.

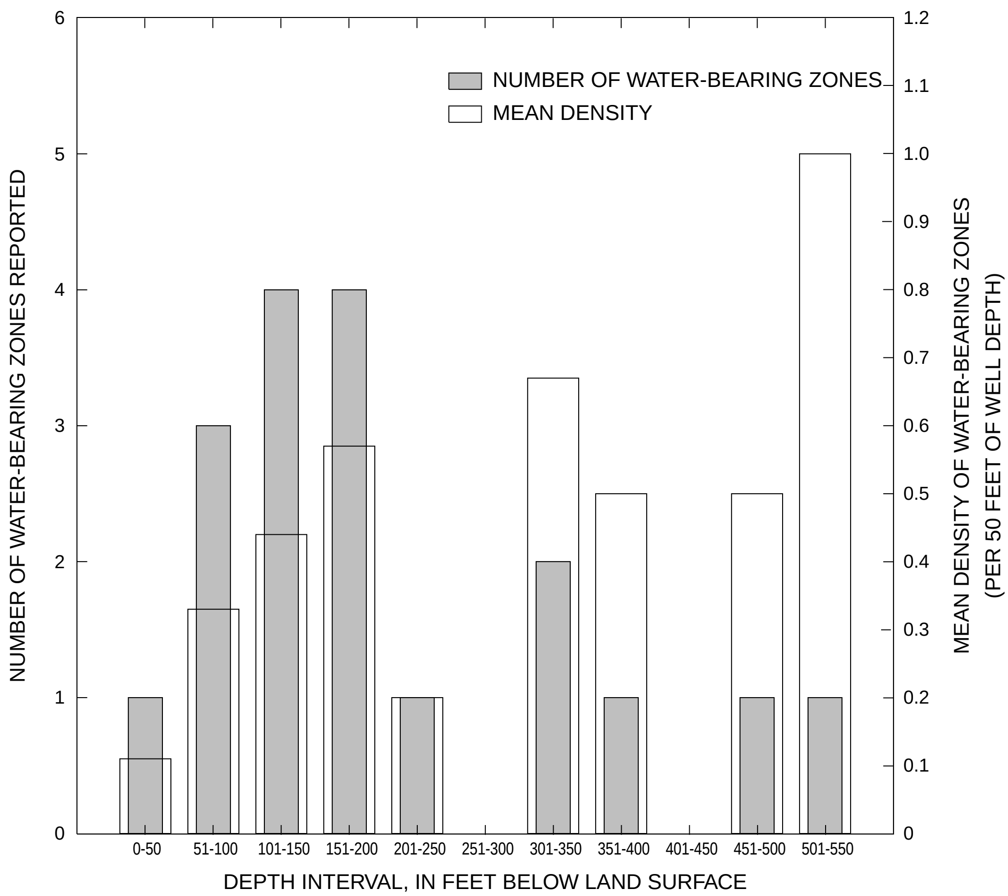


Figure 41. Number and density of water-bearing zones per 50 feet of well depth in the Buffalo Springs Formation of the Piedmont Physiographic Province, Piedmont Lowland Section.

Water quality.—As seen in the following table, wells completed in the Buffalo Springs Formation generally yield water that contains moderate to high concentrations of dissolved solids, is very hard, and alkaline. Calcium is the dominant cation, and bicarbonate is the dominant anion. Aside from hard water, elevated concentrations of nitrate and dissolved solids are the most common water quality problems. The well with the softest water also has the lowest specific conductance. This well is in a small draw that drains quartzite ridges about 500 ft away. Based on the soft water, low dissolved solids, and proximity to the Harpers and Chickies Formations, it is fairly certain that this well is intercepting noncarbonate water. The noncarbonate water probably is moving along solution openings or channels that the more aggressive water from the quartzite ridge has dissolved into the more soluble Buffalo Springs Formation.

Summary of selected chemical constituents and properties analyzed for the Buffalo Springs Formation

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	72	—	—	—	563	670	840	140	3,000
Field hardness	71	—	—	—	260	290	340	34	620
Field pH (standard units)	10	—	<6.5 >8.5	0	7.2	7.4	7.7	6.6	8.0
Bicarbonate	14	—	—	—	220	240	260	130	320
Calcium	14	—	—	—	60	66	90	29	120
Chloride	14	—	250	1	12	18	47	6.4	360
Iron	4	—	.3	0	.010	.050	.095	.000	.13
Magnesium	14	—	—	—	36	38	41	13	48
Manganese	4	—	.05	0	.000	.010	.025	.000	.030
Nitrate (as N)	16	10	—	4	.96	2.1	6.9	.23	30
Potassium	14	—	—	—	2.3	2.9	4.5	1.2	19
Silica	3	—	—	—	8.3	10	11	7.9	11
Sodium	14	—	—	—	2.9	9.8	18	2.3	32
Sulfate	14	—	250	1	36	68	79	20	410
Total dissolved solids	14	—	500	5	394	432	508	280	734

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.

Elbrook Formation (Ce)

The Elbrook Formation crops out over a 12-mi^2 area in the Chester Valley of Chester and Montgomery Counties (Berg and others, 1980). The Elbrook Formation was named for exposures near Elbrook, Franklin County, by Stose (1908). Jonas and Stose (1930) extended the name Elbrook to the Lancaster area on the basis of stratigraphic location and lithologic character. Meisler and Becher (1967), however, renamed this section the Buffalo Springs Formation, a name since rejected by MacLachlan (1994a, p. 22).

Geologic description.—The Elbrook Formation is light gray to white, finely laminated, fine-grained, interbedded limestone, dolomite, and marble. Muscovite and sericite are present along cleavage and bedding planes and are the result of pressure solution. Locally, a resistant sandy limestone and chert-rich sandstone occurs at the base. In Lancaster County a similar sandstone appears, which led Jonas and Stose (1930) to believe it represented the Waynesboro Formation of the Great Valley Section of the Ridge and Valley Physiographic Province. Lyttle and Epstein (1987) suggested that the Elbrook in the Chester Valley is at a slightly higher metamorphic grade than the rocks farther north. Faill (in Sloto, 1994, p. 13) noted that the Elbrook in the Chester Valley is possibly different than the Elbrook west of Chester County. Bascom and Stose (1932) estimated a total thickness of 300 ft for this unit and Lyttle and Epstein (1987) about 800 ft.

The Elbrook Formation commonly forms low hills, with gentle and stable slopes. Joints are moderately developed and moderately abundant but irregularly spaced. Most joints are open, but some are filled with quartz and calcite (Geyer and Wilshusen, 1982, p. 108-110). The Elbrook Formation is moderately resistant to weathering with a bedrock-mantle interface characterized by pinnacles.

The Middle to Upper Cambrian Elbrook Formation is a normal marine, subtidal to possibly supratidal limestone deposited on a shelf that was receiving a considerable amount of argillaceous terrigenous clastics (MacLachlan, 1994a, p. 22). The Elbrook Formation is in gradational contact with the underlying Ledger Dolomite and the upper contact with the Conestoga Formation is a possible unconformity or the locus of thrusting.

Well depths and casing lengths.—Depths of wells and casing lengths for wells completed in the Elbrook Formation are presented in the tables below.

Reported well depth, Elbrook Formation

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	88	95	143	228	329	500	60	600
Drilled, domestic	44	87	121	198	268	340	60	560
Drilled, high-demand	10	160	207	311	501	595	93	595

Reported casing length, Elbrook Formation

[Casing length in feet; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	61	20	25	49	107	156	11	230
Drilled, domestic	24	20	21	40	79	153	18	230
Drilled, high-demand	10	26	39	99	155	199	26	204

Hydrologic properties.—Water levels for wells completed in the Elbrook Formation are presented in the table below. Depths to water in 104 wells range from flowing at land surface to 172 ft below land surface; the median is 38 ft below land surface.

Water levels, Elbrook Formation

[Water levels in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	2	—	—	72	—	—	37	108
Slope	62	20	26	41	67	82	2	132
Valley	23	3	11	17	58	141	F	172

In his study of eastern Chester County, Sloto (1987, p. 34-35) monitored water-level fluctuations in five wells completed in the Elbrook Formation; one was near an active quarry. In the wells not near the active quarry, water levels were less than 40 ft below land surface and fluctuated from 6 to 15 ft. In the well near the active quarry, the water level was as deep as 156.8 ft below land surface and fluctuated more than 34 ft.

Reported yields for wells completed in the Elbrook Formation are presented in the table below. Yields of 5.0 gal / min or less are reported from 15 wells; 8 are domestic wells. Nine of 11 wells with reported yields of 100 gal / min or greater are deeper than 200 ft. Seven wells have reported yields of 450 gal / min or greater; 5 are within 300 ft of a small creek or a formational contact with the Ledger or Conestoga Formations.

Reported well yield, Elbrook Formation

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	67	2.0	9.0	20	75	460	0.0	1,400
Domestic	28	2.0	5.0	15	28	53	.4	85
High-demand	14	7.8	44	130	971	1,300	5.5	1,400

Specific capacities for wells completed in the Elbrook Formation are presented in the table below. Six wells (drilled to depths of 156 to 360 ft below land surface) have specific capacities of 0.04 (gal / min) / ft or less and are incapable of meeting most domestic or other water-use demands. Half of the eight wells with specific capacities of 1.0 (gal / min) / ft or greater are deeper than 200 ft. Wells with a pumping duration of 8 hours or longer (5 wells) have specific capacities that range from 0.01 to 167 (gal / min) / ft; the median is 1.9 (gal / min) / ft. The three wells with specific capacities of 10 (gal / min) / ft or greater are in valleys. Two of the three wells are within 400 ft of a creek; the other is within 400 ft of the Ledger Formation. High-demand wells generally have greater specific capacities than domestic wells.

Reported specific capacity, Elbrook Formation

[Specific capacity in gallons per minute per foot of drawdown; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	28	0.02	0.06	0.26	1.1	11	0.01	167
Domestic	14	.01	.04	.26	.83	6.3	.01	10
High-demand	7	—	.20	1.2	24	—	.02	167

Values of hydraulic conductivity and transmissivity for the Elbrook Formation are presented in the table below; a specific yield of 0.03 was used in estimating these hydrologic properties. Hydraulic conductivity and transmissivity are generally greater in valleys, than on slopes. The median hydraulic conductivities of wells on slopes (14 wells) and valleys (9 wells) are 0.80 and 0.58 ft / d, respectively. The median transmissivities of wells on slopes is 38 ft^2 / d, and in valleys, 98 ft^2 / d.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Elbrook Formation

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	25	0.00	0.04	0.58	1.8	23	0.00	120
Transmissivity (ft^2 / d)	25	.60	8.9	31	150	2,700	.40	49,000

For the Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, tables 8 and 16) used a specific yield of 0.035 for the upper 200 ft and estimated hydraulic conductivities of 1.34 and 2.01 ft / d for different carbonate blocks that included the Elbrook Formation. For his digital model in the Valley Creek Basin of eastern Chester County, Sloto (1990) used a specific yield of 0.08 and estimated a hydraulic conductivity of 7.0 ft / d. Analysis of five aquifer tests in the modeled area indicated transmissivities ranged from 13 to 2,740 ft^2 / d; the median was 211 ft^2 / d.

The depths of water-bearing zones in 33 wells drilled as deep as 512 ft range from 28 to 490 ft below land surface. Fifty percent of the 69 water-bearing zones reported are penetrated by a depth of 147 ft and 90 percent by a depth of 420 ft. The greatest density of water-bearing zones (0.83 per 50 ft of well depth) is from 451 to 500 ft below land surface (fig. 42). The overall density of water-bearing zones in the Elbrook Formation is 0.37 per 50 ft of well depth.

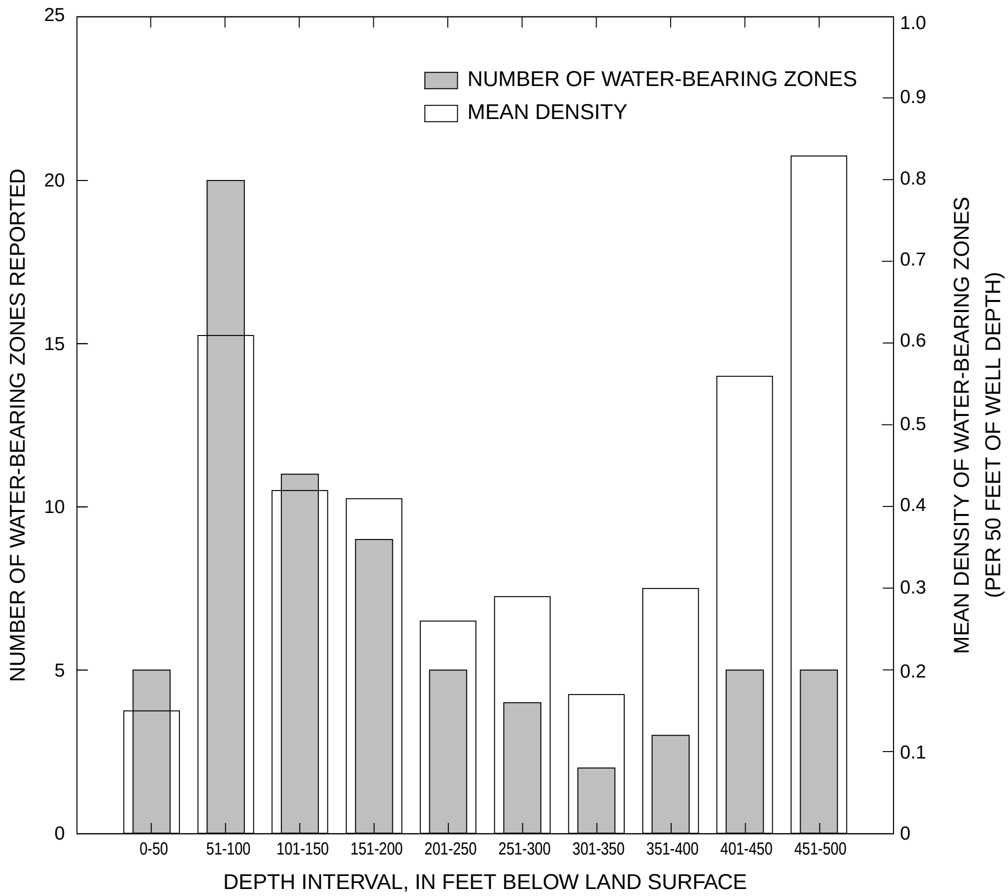


Figure 42. Number and density of water-bearing zones per 50 feet of well depth in the Elbrook Formation of the Piedmont Physiographic Province, Piedmont Lowland Section.

Water quality.—As seen in the following table, wells completed in the Elbrook Formation generally yield water that contains moderate to high amounts of dissolved solids, is very hard, and is alkaline. Calcium and magnesium are the dominant cations, and bicarbonate is the dominant anion. Hard water is the most common water-quality problem. However, elevated concentrations of iron, radon, and dissolved solids also have been reported. The elevated chloride concentration is from a well near the Pennsylvania Turnpike and State Route 29. Sloto (1987, p. 68) attributed the elevated chloride concentration to "* * * the use of deicing salt on the Pennsylvania Turnpike." Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Elbrook Formation

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; pCi/L, picoCurie per liter; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	12	—	—	—	543	603	650	360	960
Field hardness	11	—	—	—	180	270	290	140	310
Field pH (standard units)	13	—	<6.5 >8.5	0	7.2	7.4	7.7	7.1	8.2
Bicarbonate	27	—	—	—	190	220	260	4.0	400
Calcium	12	—	—	—	48	58	62	40	77
Chloride	25	—	250	1	9.2	10	20	.00	350
Iron	14	—	.3	1	.003	.009	.020	.000	.40
Magnesium	12	—	—	—	28	33	39	16	48
Manganese	13	—	.05	0	.001	.002	.010	.000	.010
Nitrate (as N)	8	10	—	0	.17	2.6	3.1	.10	4.7
Potassium	11	—	—	—	1.4	1.6	2.0	.60	6.9
Radon 222 (pCi/L)	4	[3] 300	—	1	—	220	—	142	306
Silica	10	—	—	—	7.7	8.2	9.8	6.5	11
Sodium	12	—	—	—	3.8	4.5	9.4	1.5	31
Sulfate	24	—	250	0	26	37	64	3.6	180
Total dissolved solids	23	—	500	2	304	329	380	236	696

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.
[3] U.S. Environmental Protection Agency, 1994, proposed maximum contaminant level.

Snitz Creek Formation (Csc)

The Snitz Creek Formation crops out over a 5-mi^2 area where it is mapped separately from the Buffalo Springs Formation in northern Lancaster County (Berg and others, 1980). The Snitz Creek Formation was named for exposures along the Cornwall-Lebanon Railroad tracks, about 0.5 mi south of Midway, Lebanon County, by Gray and others (1958). Meisler and Becher (1971) extended the name Snitz Creek to Lancaster County for exposures in a road cut about 1 mi south of Mount Joy.

Geologic description.—The Snitz Creek Formation is light- to dark-gray, fine-grained dolomite that contains scattered beds of dolomitic quartz sandstone and limestone. The dolomite is commonly argillaceous, silty, or sandy; weathered outcrops have a shaley appearance. The Snitz Creek Formation is part of the Conococheague Group and considered by Meisler and Becher (1967) to be Upper Cambrian in age. It is in gradational contact with the underlying Buffalo Springs Formation and the overlying Millbach Formation. Thickness of the formation is estimated at between 300 and 400 ft (Meisler and Becher, 1971, p. 21).

The Snitz Creek Formation is moderately resistant to weathering, generally forming low, broad hills. Joints are moderately well developed, common, and open. Bedrock pinnacles commonly occur in the regolith, solution cavities also are present (Geyer and Wilshusen, 1982, p. 262-263).

Well depths and casing lengths.—Depths of wells and casing lengths for wells completed in the Snitz Creek Formation are presented in the tables below.

Reported well depth, Snitz Creek Formation

[Depth in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	17	38	55	150	325	621	28	705
Drilled, domestic	7	—	175	300	350	—	150	500
Drilled, high-demand	1	—	—	—	—	—	600	—

Reported casing length, Snitz Creek Formation

[Casing length in feet; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	13	9	12	19	30	83	9	111
Drilled, domestic	5	—	20	30	76	—	19	111

Hydrologic properties.—Water levels for wells completed in the Snitz Creek Formation are presented in the table below. Depths to water in 18 wells range from 10 to 121 ft below land surface; the median is 29 ft below land surface.

Water levels, Snitz Creek Formation

[Water levels in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	2	—	—	84	—	—	47	121
Slope	16	12	16	24	32	45	10	57

Reported yields for wells completed in the Snitz Creek Formation are presented in the table below. Yields of 5.0 gal/min or less are reported from four wells. The presence of abundant argillaceous material in this formation may reduce well yields relative to most other formations composed of carbonate rocks.

Reported well yield, Snitz Creek Formation

[Yield in gallons per minute; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Well type	Number of wells	P25	Median	P75
All	8	0.5	8.0	17
Domestic	5	1.0	5.0	29

Values of hydraulic conductivity and transmissivity from specific-capacity tests are not available. In their work in the Little Conestoga Creek Basin in Lancaster County, Meisler and Becher (1971) estimated a specific yield of 0.04 for different units that included the Snitz Creek Formation. Gerhart and Lazorchick (1984b, tables 6 and 14), in their work in parts of Bucks and Lancaster Counties, used a specific yield of 0.07 and a hydraulic conductivity of 1.1 ft/d for a carbonate block that consisted of the Buffalo Springs and Snitz Creek Formations. For the Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, tables 8 and 16) determined a specific yield of 0.035 for the upper 200 ft and a hydraulic conductivity of 11.36 ft/d for a carbonate block that included the Snitz Creek Formation.

The depths of water-bearing zones in five wells drilled as deep as 350 ft range from 25 to 200 ft below land surface. Fifty percent of the 13 water-bearing zones reported are penetrated by a depth of 125 ft and 90 percent by a depth of 186 ft. The greatest density of water-bearing zones (1.50 per 50 ft of well depth) is from 101 to 150 ft below land surface (fig. 43). The overall density of water-bearing zones in the Snitz Creek Formation is 0.56 per 50 ft of well depth.

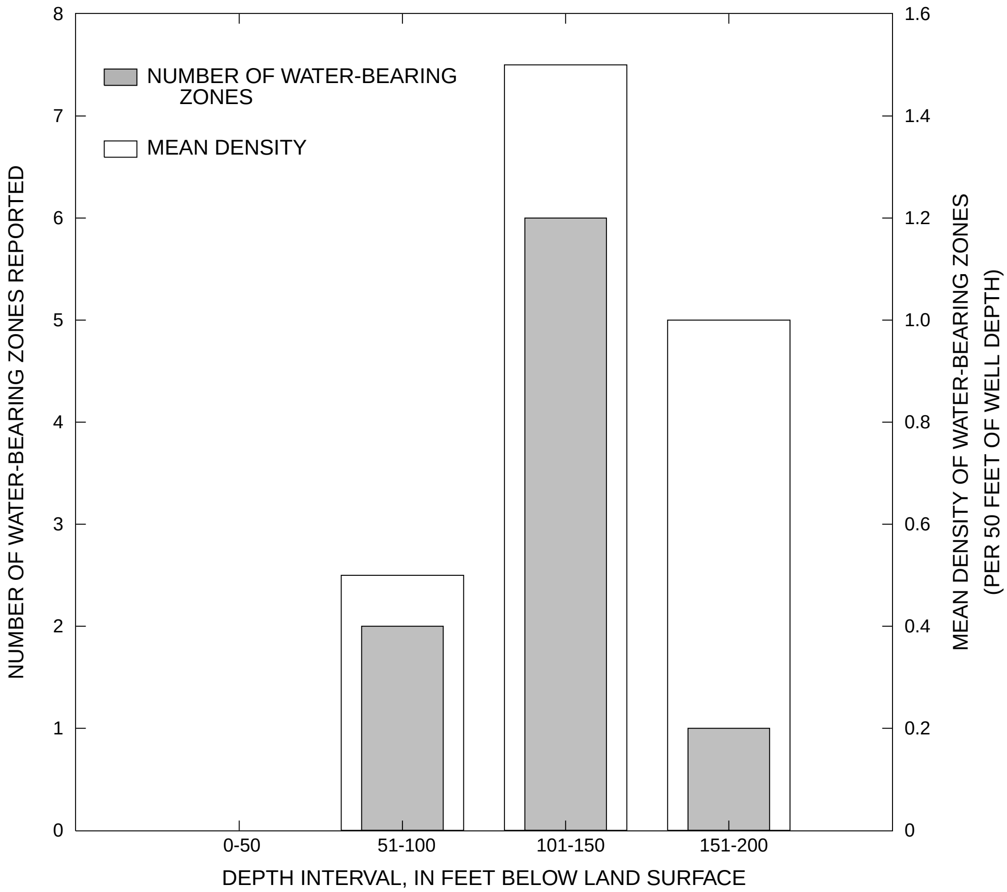


Figure 43. Number and density of water-bearing zones per 50 feet of well depth in the Snitz Creek Formation of the Piedmont Physiographic Province, Piedmont Lowland Section.

Water quality.—As seen in the following table, wells completed in the Snitz Creek Formation generally yield water that contains moderate amounts of dissolved solids, is very hard, and alkaline. Calcium is the dominate cation, and bicarbonate is the dominant anion. Aside from very hard water, elevated concentrations of dissolved solids and nitrate are the most common water-quality problems. However, 10 of the wells sampled were for studies of nonpoint-source pollution and agricultural best-management practices in Lancaster County (Fishel and Lietman, 1986; Chichester, 1988). Of these 10 wells, 7 are from a 47.5-acre site, and all 7 wells contain water with concentrations of nitrate in excess of the USEPA MCL.

Work in the Snitz Creek Formation (Durlin and Schaffstall, 1994) indicates elevated concentrations of radon in the ground water are possible. Concentrations of radon-222 in the water from one well exceeded the proposed USEPA MCL of 300 pCi/L; the measured activity was 850 pCi/L. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Snitz Creek Formation

[Concentrations in milligram per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	3	—	—	—	—	645	—	630	650
Field hardness	3	—	—	—	—	320	—	310	340
Field pH (standard units)	3	—	<6.5 >8.5	0	—	7.9	—	7.4	8.2
Bicarbonate	13	—	—	—	220	240	260	180	300
Calcium	13	—	—	—	68	94	110	47	190
Chloride	13	—	250	0	15	17	25	11	36
Iron	3	—	.3	0	—	.070	—	<.010	.080
Magnesium	13	—	—	—	21	31	42	13	63
Manganese	3	—	.05	0	—	.010	—	.010	.020
Nitrate (as N)	13	10	—	9	11	29	52	2.2	130
Potassium	13	—	—	—	1.6	2.5	10	.9	12
Silica	0	—	—	—	—	—	—	—	—
Sodium	13	—	—	—	5.1	5.9	9.5	1.3	38
Sulfate	6	—	250	0	25	33	37	20	40
Total dissolved solids	13	—	500	4	374	400	498	304	1,100

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.

Millbach Formation (Cm)

The Millbach Formation underlies about 15 mi^2 of the Piedmont Lowland Section in northern Lancaster County (Berg and others, 1980). The Millbach Formation was named for exposures in a quarry about 0.5 mi southwest of Sheridan, Lebanon County, by Gray and others (1958). Meisler and Becher (1967) extended the name Millbach Formation to the Lancaster area.

Geologic description.—The Millbach Formation generally consists of white to light-pinkish-gray finely crystalline limestone containing some gray laminae or thin gray beds of dolomite and limestone (Meisler and Becher, 1971, p. 21). A few silty and sandy beds similar to that found in the Buffalo Springs and Snitz Creek Formations are present. Thin chert beds, lenses, and stringers are scattered throughout the formation. A few beds of carbonate cemented quartz sandstone also are present.

The Millbach Formation generally forms valleys with rounded hills of low topographic relief. Joints are well developed, moderately abundant, regularly spaced, and open (Geyer and Wilshusen, 1982, p. 188-189). The Millbach Formation is moderately resistant to weathering with a bedrock-mantle interface characterized by pinnacles.

The formation is Upper Cambrian in age and is part of the Conococheague Group (Meisler and Becher, 1967). It is in gradational contact with the underlying Snitz Creek Formation and overlying the Richland Formation. Thickness of the formation is estimated to be between 1,200 and 2,000 ft (Meisler and Becher, 1971 p. 22).

Well depths and casing lengths.—Depths of wells and casing lengths for wells completed in the Millbach Formation are presented in the tables below.

Reported well depth, Millbach Formation

[Depth in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	44	67	125	185	248	350	55	500
Drilled, domestic	36	100	125	185	248	382	55	500
Drilled, high-demand	2	—	—	263	—	—	225	300

Reported casing length, Millbach Formation

[Casing length in feet; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	38	16	24	51	65	86	4	103
Drilled, domestic	30	20	41	60	65	84	4	103
Drilled, high-demand	2	—	—	63	—	—	41	85

Hydrologic properties.—Water levels for wells completed in the Millbach Formation are presented in the table below. Depths to water in 31 wells range from 8 to 63 ft below land surface; the median is 33 ft below land surface.

Water levels, Millbach Formation

[Water levels in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	3	—	—	42	—	—	19	48
Slope	11	12	22	28	34	59	9	62
Valley	17	10	16	34	45	62	8	63

Reported yields for wells completed in the Millbach Formation are presented in the table below. Yields of 5.0 gal / min or less are reported from 11 wells. Two of four wells with reported yields of 100 gal / min or greater are deeper than 200 ft. The well with the highest reported yield is about 400 ft from a creek and 500 ft from the Stonehenge Formation. Another well, with a reported yield of 100 gal / min, is on a fault and within 100 ft of a small stream.

Reported well yield, Millbach Formation

[Yield in gallons per minute; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	32	0.6	3.6	18	25	100	0.2	300
Domestic	28	.5	3.6	18	25	60	.2	300
High-demand	2	—	—	52	—	—	4.0	100

Specific capacities from three wells pumped 1 hour or longer are 0.21, 0.54, and 4.7 (gal / min) / ft. The well with the highest specific capacity was pumped at 100 gal / min and is near a major fault and a small creek. If wells pumped less than 1 hour (8 wells) are included, then the range of specific capacities are from 0.02 to 4.7 (gal / min) / ft; the median is 0.52 (gal / min) / ft.

Hydraulic conductivity and transmissivity for a domestic well on a hilltop is 0.14 ft / d and 21 ft^2 / d, respectively. For a high-demand well in a valley, the hydraulic conductivity is 4.8 ft / d and the transmissivity is 1,000 ft^2 / d. A specific yield of 0.04 was used to estimate these hydrologic properties.

In their work in the Little Conestoga Creek Basin in Lancaster County, Meisler and Becher (1971) estimated a specific yield of 0.04 for different units that included the Millbach Formation. In their digital model of parts of Lancaster and Berks Counties, Pa., Gerhart and Lazorchick (1984b, tables 6 and 14) used a specific yield of 0.07 and a hydraulic conductivity of 3.0 ft / d for the Millbach Formation. For the Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, tables 8 and 16) estimated a specific yield of 0.035 for the upper 200 ft and hydraulic conductivity of 11.36 ft / d for a carbonate block that included the Millbach Formation.

The depths of water-bearing zones in 31 wells drilled as deep as 500 ft range from 36 to 330 ft below land surface. Fifty percent of the 58 water-bearing zones reported are penetrated by a depth of 200 ft and 90 percent by a depth of 385 ft. The greatest density of water-bearing zones (0.69 per 50 ft of well depth) is from 51 to 100 ft below land surface (fig. 44). The overall density of water-bearing zones in the Millbach Formation is 0.36 per 50 ft of well depth.

Water quality.—As seen in the following table, wells completed in the Millbach Formation generally yield water that contains moderate to high amounts of dissolved solids, is very hard, and is alkaline. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Millbach Formation

[Concentrations in milligram per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS / cm)	23	—	—	—	550	640	740	425	900
Field hardness	24	—	—	—	225	260	310	140	380
Field pH (standard units)	1	—	<6.5 >8.5	0	—	6.9	—	6.9	—
Bicarbonate	2	—	—	—	—	280	—	240	300
Calcium	2	—	—	—	—	96	—	87	97
Chloride	2	—	250	0	—	15	—	14	20
Iron	2	—	.3	0	—	.11	—	.030	.17
Magnesium	2	—	—	—	—	33	—	16	33
Manganese	2	—	.05	0	—	.000	—	.000	.020
Nitrate (as N)	3	10	—	1	—	4.4	—	2.5	11
Potassium	2	—	—	—	—	14	—	1.1	15
Silica	1	—	—	—	—	8.5	—	7.7	9.2
Sodium	2	—	—	—	—	5.6	—	5.3	7.2
Sulfate	2	—	250	0	—	61	—	35	67
Total dissolved solids	2	—	500	0	—	420	—	406	424

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.

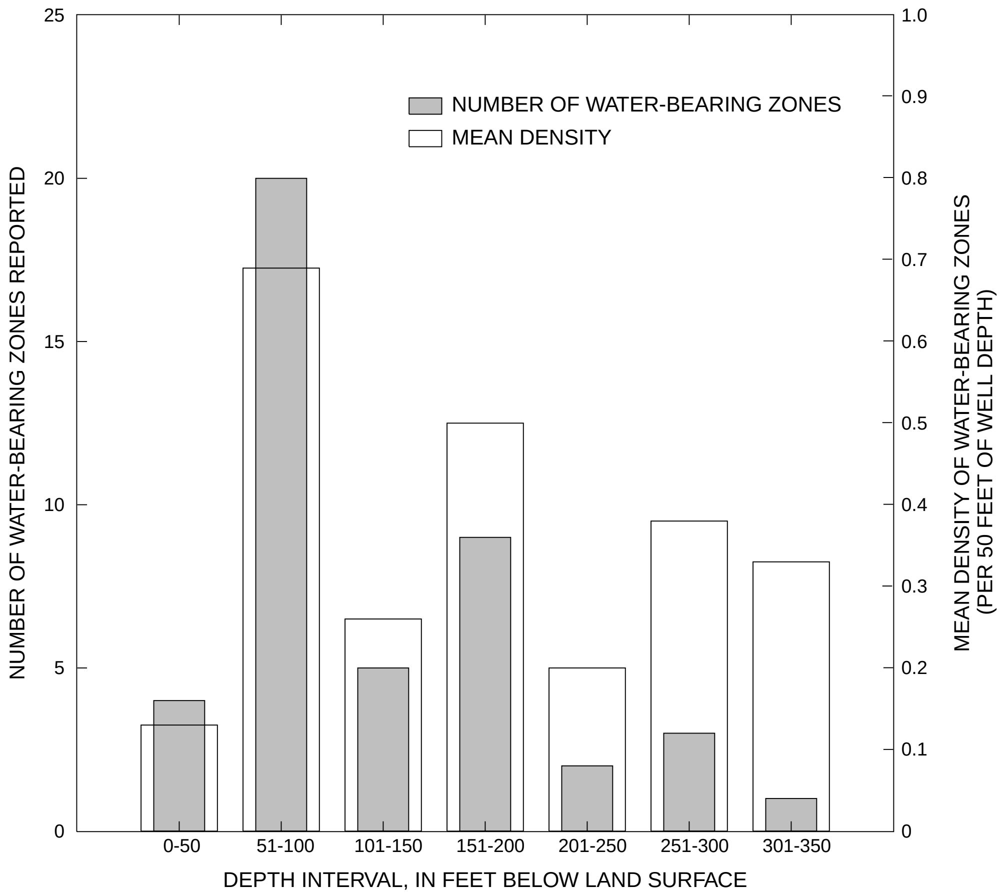


Figure 44. Number and density of water-bearing zones per 50 feet of well depth in the Millbach Formation of the Piedmont Physiographic Province, Piedmont Lowland Section.

Work in the Millbach Formation (Durlin and Schaffstall, 1994) indicates elevated concentrations of radon in the ground water are possible. Concentrations of radon-222 in the water from two wells exceeded the proposed USEPA MCL of 300 pCi/L; the measured activities were 770 and 820 pCi/L.

Richland Formation (Cr)

The Richland Formation underlies about 2.5 mi^2 in Lancaster County (Berg and others, 1980). The Richland Formation was named for exposures in a Reading Railroad cut 0.25 mi east of Richland, Lebanon County, by Gray and others (1958). Meisler and Becher (1967) extended the name Richland Formation to the Lancaster area on the basis of stratigraphic position and similar sedimentary characteristics.

Geologic description.—The Richland Formation is medium gray to medium-dark gray, finely crystalline, interbedded limestone and dolomite. About 70 percent of this unit consists of limestone and 30 percent dolomite. The limestones commonly contain small amounts of dolomite grains, patches, and laminae and some beds of conglomerate and calcarenite. Thin beds or stringers of chert also may be present (Meisler and Becher, 1971, p. 22).

The Richland Formation is part of a broad, undulating valley of low relief. Joints are well developed, abundant, regularly spaced, and open (Geyer and Wilshusen, 1982, p. 239-240). The Richland Formation is moderately resistant to weathering with a bedrock-mantle interface characterized by pinnacles.

The Richland Formation is Upper Cambrian in age and is the uppermost formation in the Conococheague Group (Meisler and Becher, 1967). The base of the Richland is gradational with the underlying Millbach Formation, contact with the overlying Stonehenge Formation is structually complex and abrupt. Meisler and Becher (1971, p. 22) estimated a maximum thickness of the Richland Formation at about 550 ft.

Well depths and casing lengths.—Only four domestic wells and one public well are completed in the Richland Formation of the Piedmont Lowland Section. Two domestic wells have well depths of 101 and 265 ft below land surface, the latter also has a casing depth of 35 ft. The public well has a depth of 135 ft.

Hydrologic properties.—Water levels in five wells range from 9 to 48 ft below land surface; the median is 28 ft. The two wells on slopes have depths to water of 9 and 48 ft, and the three wells in a valley have depths to water of 9, 28, and 39 ft.

Reported yields for wells completed in the Richland Formation are presented in the table below. All reported yields and specific capacities are from USGS single-well aquifer tests.

Reported well yield, Richland Formation

[Yield in gallons per minute; —, insufficient data available; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Well type	Number of wells	P25	Median	P75	Minimum	Maximum
All	5	2.4	3.9	6.1	1.7	7.6
Domestic	4	—	3.9	—	1.7	7.6
High-demand	1	—	3.9	—	3.9	—

Specific capacities of two wells with a pumping duration of 1 hour are 0.35 and 6.3 (gal / min) / ft. The specific capacities of three wells with a pumping duration of less than 1 hour are 0.03, 0.05, and 0.14 (gal / min) / ft.

Values of hydraulic conductivity and transmissivity for the Richland Formation are from one well. The hydraulic conductivity is 0.49 ft / d and the transmissivity is 39 ft^2 / d; these hydrologic properties were estimated by using a specific yield of 0.04.

In their digital model of parts of Lancaster and Berks Counties, Pa., Gerhart and Lazorchick (1984b, tables 6 and 14) used a specific yield of 0.07 and a hydraulic conductivity of 2.5 ft / d for the Richland Formation.

There is no information on water-bearing zones.

Water quality.—Field measurements of specific conductance are 630, 530, 450, and 650 µS / cm; the four hardness values are 260, 200, 170, and 290 mg / L (as $CaCO_3$).

Stonehenge Formation (Os)

The Stonehenge Formation underlies about 26 mi^2 of the Piedmont Lowland Section in northern Lancaster County. It crops out in a series of narrow, elongate, fault truncated, east-west trending belts (Berg and others, 1980). Meisler and Becher (1967) divided the Beekmantown Limestone of Jonas and Stose (1930) into three geologic units (Stonehenge, Epler, Ontelaunee), and, on the basis of lithology and stratigraphic position, correlated them to units of the Beekmantown Group in Berks (Hobson, 1957) and Lebanon (Gray and others, 1958) Counties, Pa.

Geologic description.—The Stonehenge Formation consists of medium gray to medium-dark gray, finely crystalline limestone and dark shale laminae. Beds of calcarenite are common locally and contain fragments of pelmatozoan stem plates and other fossil detritus. Thickness of the Stonehenge Formation varies from 500 to 1,000 ft (Meisler and Becher, 1967).

The Stonehenge Formation is moderately resistant to weathering, forming low-relief valleys with gentle and stable slopes. Joints are poorly to well developed, moderately abundant, and open. Bedrock pinnacles beneath the regolith are common and the regolith can be greater than 80 ft thick (Geyer and Wilshusen, 1982, p. 269-270).

The Stonehenge Formation is of Ordovician age and the lowermost unit of the Beekmantown Group (Hobson, 1957). Where the Richland Formation is absent, the Stonehenge Formation is in probable fault contact with the Buffalo Springs or Millbach Formations. However, near Mount Joy, the Stonehenge Formation may overlie the Millbach Formation in a normal stratigraphic sequence (Meisler and Becher, 1971). The Stonehenge Formation is conformably overlain by the Epler Formation.

Well depths and casing lengths.—Depths of wells and casing lengths for wells completed in the Stonehenge Formation are presented in the tables below. Little difference in well depth exists between high-demand and domestic wells. Only five wells have used more than 35 ft of casing.

Reported well depth, Stonehenge Formation

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	44	70	90	138	248	303	51	500
Drilled, domestic	25	60	78	120	237	320	51	500
Drilled, high-demand	15	81	110	150	300	305	67	312

Reported casing length, Stonehenge Formation

[Casing length in feet; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	21	6	14	21	37	59	5	64
Drilled, domestic	11	9	20	30	57	63	6	64
Drilled, high-demand	9	—	8	16	20	—	5	32

Hydrologic properties.—Water levels for wells completed in the Stonehenge Formation are presented in the table below. Depths to water in 59 wells range from 6 to 63 ft below land surface; the median is 30 ft below land surface.

Water levels, Stonehenge Formation

[Water levels in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	1	—	—	—	—	—	33	—
Slope	4	—	—	36	—	—	22	48
Valley	50	12	17	29	38	57	6	63

Reported yields for wells completed in the Stonehenge Formation are presented in the table below. Yields of 5.0 gal/min or less are reported from six wells. Four of 17 wells with reported yields of 200 gal/min or greater are deeper than 200 ft. All but 1 of the 17 wells with reported yields of 200 gal/min or greater are within 500 ft of streams or springs.

Reported well yield, Stonehenge Formation

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	32	2.8	11	200	350	450	1.0	600
Domestic	11	2.1	3.5	30	40	88	2.0	100
High-demand	19	12	250	325	400	500	10	600

Eleven wells have specific capacities of 1.0 (gal/min)/ft or greater; 1 is deeper than 200 ft. Of the eight wells with specific capacities greater than 2.0 (gal/min)/ft, six are within 500 ft of a stream; four of the six have specific capacities of 38 (gal/min)/ft or greater. The specific capacities of four wells with pumping durations of 8 hours or longer are 19, 27, 38, and 46 (gal/min)/ft. Meisler and Becher (1971, p. 47) reported that specific capacities are generally higher in the Lititz belt than in the Mount Joy belt. High-demand wells generally have greater specific capacities than domestic wells.

Reported specific capacity, Stonehenge Formation

[Specific capacity in gallons per minute per foot of drawdown; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	11	1.7	4.8	27	46	480	1.7	500
Domestic	4	—	—	3.5	—	—	1.7	30
High-demand	7	—	19	38	400	—	7.3	500

Values of hydraulic conductivity and transmissivity for the Stonehenge Formation are presented below; a specific yield of 0.04 was used in estimating these hydrologic properties. The median hydraulic conductivities of wells on slopes (2 wells) and in valleys (8 wells) are 52 and 67 ft / d, respectively. The median transmissivities of wells on slopes and in valleys are 6,100 and 5,900 ft^2 / d, respectively.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Stonehenge Formation

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	10	5.3	21	52	340	1,600	4.4	1,600
Transmissivity (ft^2 / d)	10	320	1,000	5,900	30,000	110,000	270	110,000

In their work in the Little Conestoga Creek Basin in Lancaster County, Meisler and Becher (1971) estimated a specific yield of 0.04 for different units that included the Stonehenge Formation. For their digital model of parts of Lancaster and Berks Counties, Pa., Gerhart and Lazorchick (1984b, tables 6 and 14) used a specific yield of 0.09 and a hydraulic conductivity of 85.2 ft / d for the Stonehenge Formation. For the Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, tables 8 and 16) determined a specific yield of 0.035 for the upper 200 ft and hydraulic conductivity of 11.36 ft / d for different carbonate blocks that included the Stonehenge Formation.

The depths of water-bearing zones in seven wells drilled as deep as 300 ft range from 37 to 220 ft below land surface. Fifty percent of the 13 water-bearing zones reported are penetrated by a depth of 152 ft and 90 percent by a depth of 215 ft (fig. 45). The overall density of water-bearing zones in the Stonehenge Formation is 0.38 per 50 ft of well depth.

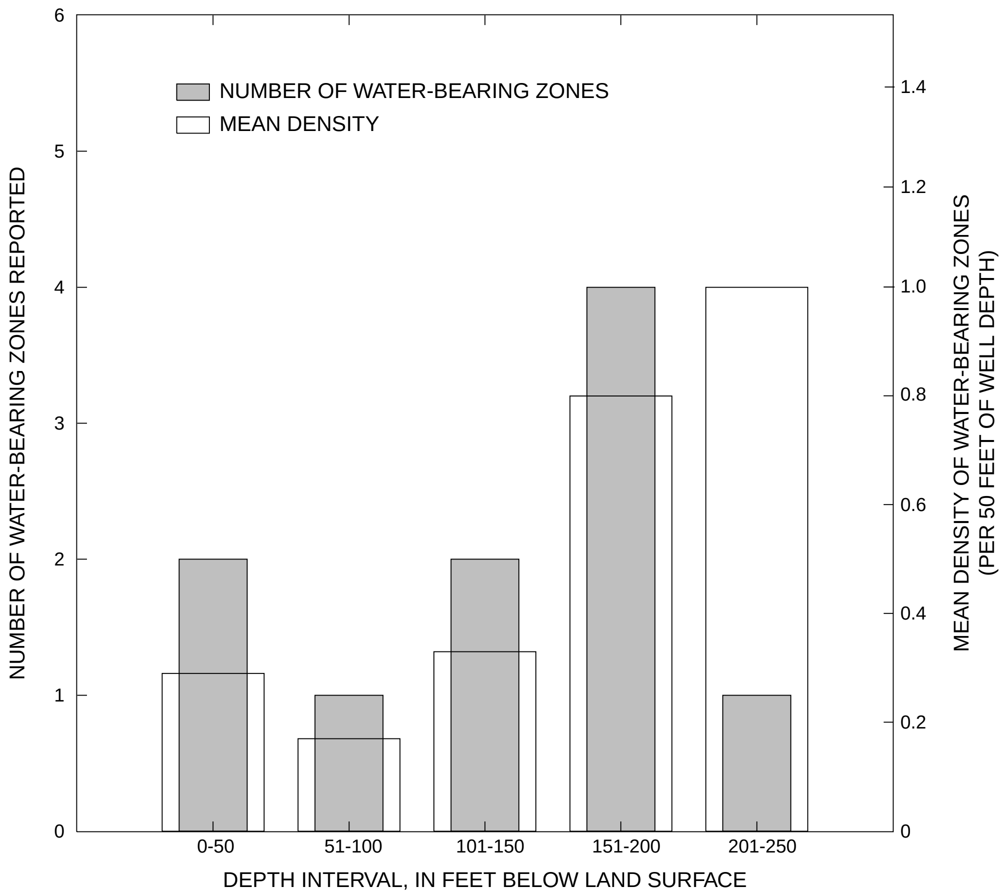


Figure 45. Number and density of water-bearing zones per 50 feet of well depth in the Stonehenge Formation of the Piedmont Physiographic Province, Piedmont Lowland Section.

Water quality.—As seen in the following table, wells completed in the Stonehenge Formation generally yield water that contains moderate to high amounts of dissolved solids, is very hard, and is alkaline. Calcium is the dominant cation, and bicarbonate is the dominant anion. Aside from very hard water, elevated concentrations of nitrate appear to be the most common water-quality problem. Of the 11 wells that contain water that exceeds the USEPA MCL for nitrate, 7 are part of a regional network of wells established for the USGS in the Conestoga River headwaters. In this study, a total of 42 wells completed in carbonate and noncarbonate units have been sampled to evaluate the regional extent of nitrate and herbicide contamination and to evaluate the effects of agricultural best-management practices on water quality (Fishel and Lietman, 1986).

Work in the Stonehenge Formation (Durlin and Schaffstall, 1994) indicates elevated concentrations of radon in the ground water are possible. Concentrations of radon-222 in the water from two wells exceeded the proposed USEPA MCL of 300 pCi/L. The measured activities were 660 and 750 pCi/L. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Stonehenge Formation

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	46	—	—	—	550	610	711	325	1,100
Field hardness	46	—	—	—	220	260	310	140	480
Field pH (standard units)	8	—	<6.5 >8.5	0	7.1	7.5	8.2	6.8	8.4
Bicarbonate	16	—	—	—	210	230	260	29	310
Calcium	16	—	—	—	79	96	100	50	140
Chloride	16	—	250	0	14	18	30	7.3	130
Iron	8	—	.3	1	.020	.030	.11	.000	.48
Magnesium	16	—	—	—	12	16	25	6.9	38
Manganese	8	—	.05	1	.000	.000	.020	.000	.43
Nitrate (as N)	16	10	—	11	7.8	11	13	4.6	33
Potassium	16	—	—	—	1.4	1.9	3.1	.80	14
Silica	7	—	—	—	8.1	8.7	9.9	5.8	11
Sodium	16	—	—	—	5.1	8.0	12	2.6	68
Sulfate	16	—	250	0	25	30	38	14	220
Total dissolved solids	16	—	500	2	334	390	481	280	638

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.

Epler Formation (Oe)

The Epler Formation underlies about 56 mi^2 of the Piedmont Lowland Section in northern Lancaster County where it is exposed in five, structually complex, narrow, east-west trending belts (Berg and others, 1980). Meisler and Becher (1967) divided the Beekmantown Limestone of Jonas and Stose (1930) into three geologic units (Stonehenge, Epler, Ontelaunee), and, on the basis of lithology and stratigraphic position, correlated them to units of the Beekmantown Group in Berks (Hobson, 1957) and Lebanon (Gray and others, 1958) Counties, Pa.

Geologic description.—The Epler Formation consists of interbedded sequences of medium to medium-dark gray, finely crystalline limestone and dolomite; with the limestone generally more abundant. The lowermost beds generally are light-colored, white to light-pinkish-gray. Fossil detritus containing pelmatozoan stem plates and coiled gastropods are more common in calcarenite beds than elsewhere. Color bands and shale laminations are common throughout the formation. Lenses and stringers of chert are scattered throughout this unit. Thickness of the Epler Formation is estimated to be about 2,000 to 2,500 ft (Meisler and Becher, 1971).

The Epler Formation is moderately resistant to weathering, forming rolling valleys with gentle and stable slopes. Joints are poorly to well developed, moderately abundant, and open. Bedrock pinnacles beneath the regolith are common and the regolith can be greater than 80 ft thick; sinkholes and caves are characteristic (Geyer and Wilshusen, 1982, p. 110-113).

The Epler Formation is of Ordovician age and is the middle unit of the Beekmantown Group (Meisler and Becher, 1967). It is in conformable contact with the underlying Stonehenge Formation and the overlying Ontelaunee Formation where present. In the Mount Joy belt and part of the Lititz belt, the Cocalico Formation unconformably overlies the Epler Formation.

Well depths and casing lengths.—Depths of wells and casing lengths for wells completed in the Epler Formation are presented in the tables below. Well depths of 500 ft or greater are reported from 14 wells, 6 of which are domestic wells. High-demand wells are not significantly deeper or use more casing than domestic wells. Casing depths of 100 ft or more are reported from seven wells; five are domestic wells.

Reported well depth, Epler Formation

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	193	75	124	190	300	400	25	657
Drilled, domestic	137	75	121	200	300	388	40	625
Drilled, high-demand	21	104	143	175	300	520	75	550

Reported casing length, Epler Formation

[Casing length in feet; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	140	20	30	41	59	78	3	200
Drilled, domestic	103	20	33	41	60	77	12	200
Drilled, high-demand	16	15	27	55	71	92	3	102

Hydrologic properties.—Water levels for wells completed in the Epler Formation are presented in the table below. Depths to water in 151 wells range from 3 to 220 ft below land surface; the median is 32 ft below land surface.

Water levels, Epler Formation

[Water levels in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	7	—	35	54	60	—	27	83
Slope	25	18	25	32	46	64	14	80
Valley	97	15	24	32	44	57	3	105

Reported yields for wells completed in the Epler Formation are presented in the table below. Yields of 5.0 gal / min are reported from 41 wells; 33 are domestic wells. Six of 10 wells with reported yields of 100 gal / min or greater are deeper than 200 ft. All but 1 of the 18 wells with reported yields of 200 gal / min or greater are within 500 ft of a creek.

Reported well yield, Epler Formation

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	124	1.0	3.1	12	34	73	0.2	800
Domestic	92	1.0	2.7	10	29	50	.5	154
High-demand	20	3.2	8.0	50	94	600	1.5	800

Specific capacities for wells completed in the Epler Formation are presented in the table below. Two wells (well depths of 340 and 450 ft below land surface) have specific capacities of 0.04 (gal / min) / ft or less and are incapable of meeting most domestic or other water-use demands. Of the eight wells with specific capacities greater than 1.0 (gal / min) / ft, only one is deeper than 200 ft. Specific capacities of wells with pumping durations of 8 hours or longer are 0.04, 1.3, and 4.6 (gal / min) / ft.

Reported specific capacity, Epler Formation

[Specific capacity in gallons per minute per foot of drawdown; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	16	0.03	0.32	1.4	2.4	13	0.02	14
Domestic	10	.02	.14	.99	4.6	14	.02	14
High-demand	5	—	.64	1.3	3.2	—	.64	4.6

Values of hydraulic conductivity and transmissivity for the Epler Formation are presented in the table below; a specific yield of 0.04 was used in estimating these hydrologic properties. The median hydraulic conductivities of wells on hilltops (1 well), slopes (1 well), and valleys (8 wells) are 0.99, 11, and 3.5 ft / d, respectively. The median transmissivity of wells on hilltops is 230 ft^2 / d; on slopes, 1,000 ft^2 / d; and in valleys, 230 ft^2 / d.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Epler Formation

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	15	0.01	0.30	0.99	6.1	18	0.00	20
Transmissivity (ft^2 / d)	15	2.8	32	220	250	1,500	.25	2,300

In their work in the Little Conestoga Creek Basin in Lancaster County, Meisler and Becher (1971) estimated a specific yield of 0.04 for different units that included the Epler Formation. For their digital model of parts of Lancaster and Berks Counties, Pa., Gerhart and Lazorchick (1984b, tables 6 and 14) used a specific yield of 0.06 and a hydraulic conductivity of 5.0 ft / d for several carbonate units that included the Epler Formation. For the Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, tables 8 and 16) determined a specific yield of 0.035 for the upper 200 ft and hydraulic conductivities of 2.67 and 11.36 ft / d for different carbonate blocks that included the Epler Formation.

The depths of water-bearing zones in 120 wells drilled as deep as 657 ft range from 10 to 630 ft below land surface. Fifty percent of the 237 water-bearing zones reported are penetrated by a depth of 143 ft and 90 percent by a depth of 313 ft. The greatest density of water-bearing zones (0.46 per 50 ft of well depth) is from 151 to 200 ft below land surface (fig. 46). The density of water-bearing zones at depths of 351 ft or greater are based on the presence of four or less water-bearing zones per 50-ft interval. The overall density of water-bearing zones in the Epler Formation is 0.33 per 50 ft of well depth.

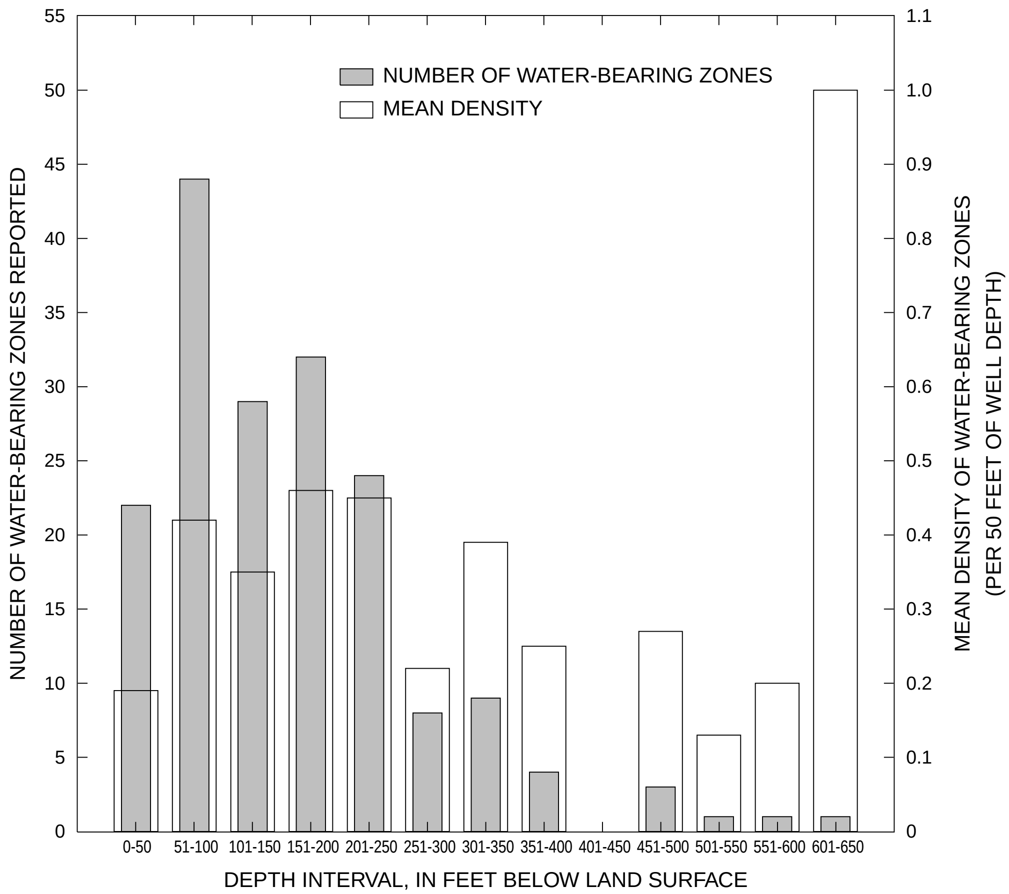


Figure 46. Number and density of water-bearing zones per 50 feet of well depth in the Epler Formation of the Piedmont Physiographic Province, Piedmont Lowland Section.

Water quality.—As seen in the following table, wells completed in the Epler Formation generally yield water that contains moderate to high amounts of dissolved solids, is hard to very hard, and is alkaline. Calcium is the dominant cation, and bicarbonate is the dominant anion. Aside from very hard water, elevated concentrations of iron, manganese, nitrate, and dissolved solids are the most common water-quality problems in the Epler Formation. Four of the 11 wells containing elevated nitrate concentrations are part of a regional well network of the USGS in the Conestoga River Headwaters area. In this study, 42 wells were sampled to evaluate the regional (188 mi^2) extent of nitrate and herbicide contamination and to evaluate the effects of agricultural best-management practices on water quality (Fishel and Lietman, 1986).

In general, wells on hilltops (6 wells) or slopes (16 wells) have considerably harder water than wells in valleys (72 wells); the medians are 350, 270, and 240 mg/L, respectively.

Work in the Epler Formation (Durlin and Schaffstall, 1994) indicates elevated concentrations of radon in the ground water are possible. Concentrations of radon-222 in the water from four wells exceeded the proposed USEPA MCL of 300 pCi/L; the measured activities were 390, 690, 1,100, and 1,200 pCi/L.

Summary of selected chemical constituents and properties analyzed for the Epler Formation

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	97	—	—	—	525	600	698	230	1,140
Field hardness	95	—	—	—	220	260	310	100	440
Field pH (standard units)	7	—	<6.5 >8.5	0	7.1	7.4	7.6	6.8	7.8
Bicarbonate	25	—	—	—	200	220	250	100	400
Calcium	25	—	—	—	80	88	100	36	140
Chloride	25	—	250	0	13	21	33	7.0	110
Iron	19	—	.3	4	.023	.080	.21	.000	1.8
Magnesium	25	—	—	—	17	21	29	8.5	38
Manganese	19	—	.05	3	.000	.010	.030	.000	.21
Nitrate (as N)	25	10	—	11	5.9	8.8	17	.02	40
Potassium	25	—	—	—	1.5	2.0	3.2	.52	7.9
Silica	14	—	—	—	7.9	8.5	10	7.0	19
Sodium	25	—	—	—	5.3	8.1	13	2.9	64
Sulfate	25	—	250	0	19	30	45	7.4	110
Total dissolved solids	24	—	500	4	341	416	474	106	864

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.

Ontelaunee Formation (Oo)

The Ontelaunee Formation underlies about 6 mi^2 of the Piedmont Lowland Section in northeast Lancaster County (Berg and others, 1980). Meisler and Becher (1967) divided the Beekmantown Limestone of Jonas and Stose (1930) into three geologic units (including the Ontelaunee Formation) and, on the basis of lithology and stratigraphic position, correlated them to units of the Beekmantown Group in Berks (Hobson, 1957) and Lebanon (Gray and others, 1958) Counties, Pa. According to Meisler and Becher (1971), the entire section and lower contact is exposed in a quarry adjacent to the sewage disposal plant on the south side of Manheim Borough.

Geologic description.—The Ontelaunee Formation consists generally of medium-light gray to medium-dark gray, cryptocrystalline to finely-crystalline dolomite that commonly contains fine laminae. A few, minor beds of dark gray limestone are scattered throughout the sequence. Thickness of the Ontelaunee Formation ranges from 0 to 600 ft (Meisler and Becher, 1971).

The Ontelaunee Formation is moderately resistant to weathering, forming flat to rolling valleys with gentle and stable slopes adjacent to dissected uplands of the Cocalico Formation. Joints are moderately to well developed, moderately abundant, and commonly open. Bedrock pinnacles beneath the regolith are characteristic (Geyer and Wilshusen, 1982, p. 213-215).

The Ontelaunee is of Middle Ordovician age and is the uppermost formation in the Beekmantown Group (Meisler and Becher, 1967). The Ontelaunee Formation is absent in the Mount Joy belt and occurs discontinuously between the Epler and Cocalico Formations in the Lititz belt. The southward thinning of the Ontelaunee Formation is believed by Meisler and Becher (1971) to be caused by an erosional truncation. Where present, the Ontelaunee Formation conformably overlies the limestones of the Epler Formation and either is overlain conformably by limestones of the Annville Formation or is unconformably overlain by the Cocalico Formation.

Well depths and casing lengths.—Depths of wells and casing lengths for wells completed in the Ontelaunee Formation are presented in the tables below.

Reported well depth, Ontelaunee Formation

[Depth in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	13	87	150	220	309	482	62	550
Drilled, domestic	10	127	188	223	304	374	125	380
Drilled, high-demand	2	—	—	106	—	—	62	150

Reported casing length, Ontelaunee Formation

[Casing length in feet; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	11	21	31	50	75	90	20	92
Drilled, domestic	8	—	31	51	79	—	20	92
Drilled, high-demand	2	—	—	49	—	—	23	75

Hydrologic properties.—Water levels for wells completed in the Ontelaunee Formation are presented in the following table. Depths to water in three wells in valleys are 9, 10, and 63 ft below land surface. The water level in one well on a slope is 82 ft below land surface.

Reported yields for wells completed in the Ontelaunee Formation are presented in the table below. Yields of 5.0 gal / min or less are reported from five wells. Yields of 10 gal / min or greater are reported from three wells; all are 200 ft or less in depth.

Reported well yield, Ontelaunee Formation

[Yield in gallons per minute; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	13	1.3	4.0	6.8	10	23	1.0	60
Domestic	10	2.4	4.0	6.4	9.4	24	1.0	60
High-demand	2	—	—	16	—	—	8.0	24

The two specific capacities available from wells completed in the Ontelaunee Formation are from USGS single-well aquifer tests. The first well, pumped at a discharge rate of 6.8 gal / min for 12 minutes, has a specific capacity of 0.1 (gal / min) / ft. The second well, pumped at a discharge rate of 24 gal / min for 1 hour, has a specific capacity of 2.2 (gal / min) / ft.

Values of hydraulic conductivity and transmissivity for the Ontelaunee Formation are limited. A specific yield of 0.04 was used in estimating the hydraulic conductivity of 8.1 ft / d and a transmissivity of 320 ft^2 / d for one well in a valley.

For their digital model of parts of Lancaster and Berks Counties, Pa., Gerhart and Lazorchick (1984b, tables 6 and 14) used a specific yield of 0.07 and a hydraulic conductivity of 2.5 ft / d for the Ontelaunee Formation. For the Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, tables 8 and 16) estimated a specific yield of 0.035 for the upper 200 ft and hydraulic conductivities of 2.67 and 11.36 ft / d for different carbonate blocks that included the Ontelaunee Formation.

The depths of water-bearing zones in 10 wells drilled as deep as 550 ft range from 62 to 270 ft below land surface. Fifty percent of the 19 water-bearing zones reported are penetrated by a depth of 140 ft and 90 percent by a depth of 250 ft. The greatest density of water-bearing zones (0.70 per 50 ft of well depth) is from 101 to 150 ft below land surface (fig. 47). The overall density of water-bearing zones in the Ontelaunee Formation is 0.32 per 50 ft of well depth.

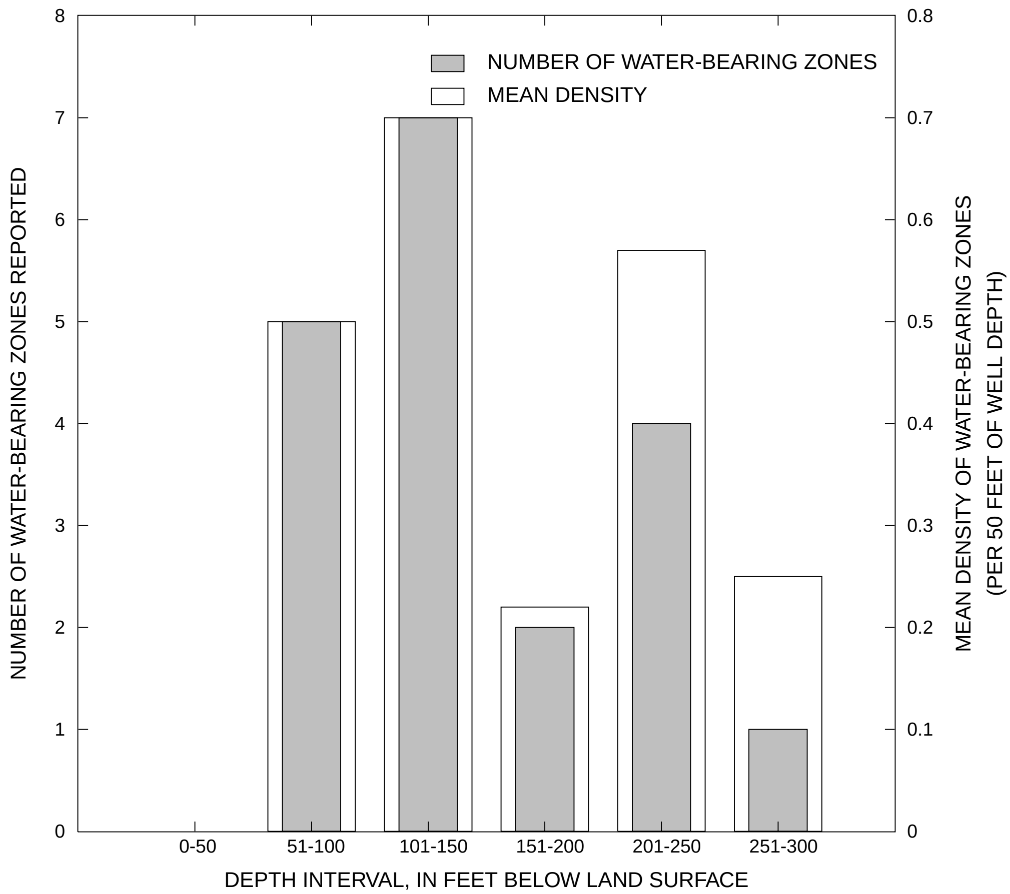


Figure 47. Number and density of water-bearing zones per 50 feet of well depth in the Ontelaunee Formation of the Piedmont Physiographic Province, Piedmont Lowland Section.

Water quality.—As seen in the following table, wells completed in the Ontelaunee Formation generally yield water that contains moderate amounts of dissolved solids, is hard to very hard, and is alkaline. Calcium is the dominant cation, and bicarbonate is the dominant anion.

Summary of selected chemical constituents and properties analyzed for the Ontelaunee Formation

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; less than; >, greater than; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	2	—	—	—	—	739	—	520	957
Field hardness	2	—	—	—	—	425	—	220	630
Field pH (standard units)	1	—	<6.5 >8.5	0	—	6.8	—	6.8	—
Bicarbonate	2	—	—	—	—	200	—	190	310
Calcium	2	—	—	—	—	86	—	65	120
Chloride	2	—	250	0	—	24	—	20	48
Iron	1	—	.3	0	—	.050	—	.050	—
Magnesium	2	—	—	—	-	16	—	13	37
Manganese	1	—	.05	0	—	.000	—	.000	—
Nitrate (as N)	2		—	2	—	17	—	13	24
Potassium	2	—	—	—	—	1.8	—	1.0	12
Silica	0	—	—	—	—	—	—	—	—
Sodium	2	—	—	—	—	5.6	—	4.3	14
Sulfate	2	—	250	0	—	17	—	15	55
Total dissolved solids	2	—	500	1	—	416	—	356	792

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.

Annville Formation, and Hershey and Myerstown Formations, Undivided (Oha)

The Annville Formation has been mapped separately and jointly with the Hershey and Myerstown Formations (Berg and others, 1980). Combined, these units underlie about 2.5 mi^2 of the Piedmont Lowland Section in Lancaster County. On the basis of lithology and stratigraphic position, Meisler and Becher (1967) correlated the Annville Formation and Myerstown Formation in the Piedmont Lowland Section to the Annville and Myerstown Formations of Prouty (1959) in the Great Valley Section of Dauphin County, Pa. They did not find any evidence to indicate the presence of the Hershey Formation.

Geologic description.—The Annville Formation is light gray to medium-dark gray, finely crystalline, partly laminated limestone. Thickness of the Annville in the Piedmont Lowland is about 200 ft (Meisler and Becher, 1971).

The Myerstown is dark gray, coarsely crystalline, thinly bedded limestone and dark gray shaley limestone. Fossil detritus, including pelmatozoan stem plates, are abundant. Thickness of the Myerstown Formation in the Piedmont Lowland is about 200 ft (Meisler and Becher, 1971).

The Annville Formation, and Hershey and Myerstown Formations, undivided form part of a rolling valley between the communities of Elizabethtown and Lancaster. For the Annville Formation, joints form a blocky pattern and are generally abundant and open; some, however, can be filled with calcite (Geyer and Wilshusen, 1982, p. 26-28). Joints in the Myerstown Formation have a platy pattern, are well developed, fractured, and open (Geyer and Wilshusen, 1982, p. 193-194). Sinkholes and bedrock pinnacles are common in the Annville Formation.

The Annville and Myerstown Formations are Middle Ordovician age (Prouty, 1959) and occur only in the Lititz belt. Where visible in Dauphin County, the contact between the Annville and Myerstown Formations is abrupt. If the Myerstown Formation is absent, the Annville Formation is either in fault contact with or is overlain unconformably by the Cocalico Formation. The contact between the Myerstown and the Cocalico Formations is the site of a major unconformity. According to MacLachlan (Pennsylvania Topographic and Geologic Survey, oral commun., 1996) the Annville Formation may represent a lagoonal environment and the Myerstown Formation could represent a rapid marine incursion over the Annville Formation.

Well depths and casing lengths.—Only two wells are known to be completed in the Annville and Myerstown Formations. The single domestic well in the Annville Formation is 142 ft deep with a casing length of 21 ft. For the Myerstown Formation, the well is 95 ft deep; data on casing length is not available.

Hydrologic properties.—Depth to water in the single Annville Formation well is 20 ft below land surface, and in the Myerstown Formation well, the depth to water is 12 ft below land surface. The specific capacity from a 1-hour USGS single-well aquifer test in the Annville Formation, with a discharge rate of 7.8 gal/min, is 0.16 (gal/min)/ft. The specific capacity of another 1-hour USGS single-well aquifer test in the Myerstown Formation, with a discharge rate of 7.3 gal/min, is 0.20 (gal/min)/ft.

Values of hydraulic conductivity and transmissivity for the Annville Formation are limited. A specific yield of 0.04 was used in estimating the hydraulic conductivity of 0.12 ft/d and a transmissivity of 15 ft^2/d for one well in a valley.

For their digital model of parts of Lancaster and Berks Counties, Pa., Gerhart and Lazorchick (1984b, tables 6 and 14) used a specific yield of 0.06 and a hydraulic conductivity of 5.0 ft/d for a unit of carbonate rocks that included the Annville and Myerstown Formations. For the Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, tables 8 and 16) estimated a specific yield of 0.035 for the upper 200 ft and hydraulic conductivities of 2.67 and 11.36 ft/d for different carbonate blocks that included the Annville and Myerstown Formations.

There are no data on reported water-bearing zones.

Water quality.—Field measurements of specific conductance and hardness in the water of the Annville Formation well are 560 µS/cm and 220 mg/L, respectively. For the well completed in the Myerstown Formation, the field measurements of specific conductance and hardness are 660 µS/cm and 260 mg/L, respectively. No laboratory analyses are available from either well.

Conestoga Formation (OCc)

The Conestoga Formation underlies about 200 mi^2 of the Piedmont Lowland in Adams, Chester, Lancaster, Philadelphia, and York Counties (Berg and others, 1980); the largest exposures are in northern Lancaster County. The reference section is along Conestoga Creek south of Lancaster, Lancaster County, Pa. (Stose and Jonas, 1922).

Geologic description.—The Conestoga Formation has long been divided by many workers into an upper and lower part; however, Gohn (1976) proposed a three-member (West York, Kreutz Creek, and Wrightsville) stratigraphy on the basis of lithology. The upper part of the Conestoga Formation (Wrightsville Member) consists of medium- to bluish-gray, fine- to coarse-grained, graphitic or micaceous limestone with argillaceous, shaley partings. The lower part (Kreutz Creek Member) consists of gray to blue, coarse-grained, thin- to thick-bedded limestone, argillaceous limestone and dolomite. Limestone conglomerate beds (West York Member), with clasts that range in size from pebbles to boulders 30 ft across, usually mark what has historically been considered the bottom of the formation. Coarsely crystalline, silty, and sandy limestones (West York Member) also occur and in some places are interbedded with conglomerates. Lyttle and Epstein (1987) noted that in the Chester Valley, the contact between the upper and lower parts is the locus of considerable faulting, which may contain some thin slivers of Albite-Chlorite Schist (Octoraro Phyllite).

The Conestoga Formation is moderately resistant to weathering, forming rolling hills and valleys. Joints are poorly formed, moderately abundant, and generally open. Thickness of the regolith is highly variable, bedrock pinnacles are common (Geyer and Wilshusen, 1982, p. 99-101).

Although the top of the Conestoga Formation is a tectonic contact, the base of the Conestoga Formation has long been considered, at least in part, an unconformity (Jonas and Stose, 1930; Stose and Jonas, 1922; 1939). MacLachlan (1994a), however, suggested that part of the Conestoga Formation is equivalent to the Kinzers. MacLachlan cited the black shale of the Conestoga Formation (Stose and Bascom, 1929) having been reassigned to the Kinzers Formation (Stose and Stose, 1944) owing to the discovery of Lower Cambrian fossils. MacLachlan (1994a) further proposed that the rocks formally assigned to the Conestoga Formation in the Downingtown area of Montgomery County, Pa., where fossils have been dated as Lower Ordovician (Bascom and others, 1909), should be renamed the Henderson Marble.

The Conestoga Formation is considered by MacLachlan (Pennsylvania Topographic and Geologic Survey, oral commun., 1996) to represent slope deposits that contain proximal megabreccia to thin distal turbidites with dark phyllitic partings. The West York Member is considered by Taylor and Durika (1990) to represent proximal toe-of-slope debris flow deposits from the adjacent shelf margin. An exact thickness of this unit is not known because the formation is repeatedly folded and faulted. Meisler and Becher (1971), in Lancaster County, estimated a thickness of at least 1,000 ft; Lloyd and Growitz (1977), in York County, estimated a thickness of 300 to 1,000 ft; and Poth (1968) and Sloto (1990), in Chester County, estimated a thickness of 500 to 800 ft. Wise (1953) estimated a structurally corrected thickness of 2,000 to 4,000 ft in Lancaster County.

Well depths and casing lengths.—Depths of wells completed in the Conestoga Formation are presented in the table below. Casing lengths of 100 ft or greater are reported from 21 wells, 15 of which are high-demand wells located in Montgomery County. Additional information is presented in the following table.

Reported well depth, Conestoga Formation

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	281	65	95	160	300	414	25	820
Drilled, domestic	112	61	80	100	158	285	36	489
Drilled, high-demand	111	81	155	285	400	500	30	820

Well depths in the Conestoga Formation can vary spatially. The depths of drilled wells in Adams (20 wells), Montgomery (48 wells), and York (49 wells) Counties are significantly greater than in Chester (96 wells) and Lancaster (68 wells) Counties. The depths of drilled wells in Montgomery County are also significantly greater than in York County. The median depth of drilled wells in Adams County is 329 ft; in Chester County, 120 ft; in Lancaster County, 125 ft; in Montgomery County, 271 ft; and in York County, 208 ft.

Casing lengths for wells completed in the Conestoga Formation are presented in the table below.

Reported casing length, Conestoga Formation

[Casing length in feet; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	153	18	22	40	70	125	6	562
Drilled, domestic	56	16	20	34	59	82	6	216
Drilled, high-demand	60	19	23	48	98	183	13	405

Casing length in the Conestoga Formation also can vary spatially. Casing lengths are significantly greater in Montgomery County (31 wells) than in Adams (12 wells), Chester (72 wells), Lancaster (14 wells), and York (24 wells) Counties. The median casing length of drilled wells in Adams County is 31 ft; in Chester County, 40 ft; in Lancaster County, 36 ft; in Montgomery County, 80 ft; and in York County, 24 ft. For high-demand wells, casing lengths in Montgomery County (25 wells) are significantly greater than in Adams (11 wells) and York (11 wells) Counties; the medians are 80, 32, and 36 ft, respectively.

Hydrologic properties.—Water levels for wells completed in the Conestoga Formation are presented in the table below. Depths to water in 265 wells range from flowing at land surface to 217 ft below land surface; the median is 24 ft below land surface. Water levels not only vary by topographic setting, but also vary by county. Water levels in Lancaster (78 wells) and Montgomery (29 wells) Counties are generally deeper than in Adams (18 wells), Chester (94 wells), or York Counties (46 wells). The median depth to water in Adams County is 20 ft; in Chester County, 19 ft; in Lancaster County, 33 ft; in Montgomery County, 64 ft; and for York County, 18 ft.

Reported yields for wells completed in the Conestoga Formation are presented in the table below. Yields of 5.0 gal / min or less are reported in 39 wells. Yields of 100 gal / min or greater are reported from 44 wells; 22 wells are deeper than 200 ft.

Water levels, Conestoga Formation

[Water levels in feet below land surface; F, flowing well; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	31	20	24	40	52	81	12	146
Slope	126	10	13	27	42	65	3	217
Valley	76	5	8	16	28	40	F	80

Reported well yield, Conestoga Formation

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	199	2.0	8.0	25	79	250	0.0	1,000
Domestic	68	2.0	5.0	15	30	50	.7	175
High-demand	98	11	25	62	156	448	0.0	1,000

Reported yields can vary by county. High-demand wells completed in the Conestoga Formation in Montgomery County (32 wells) have significantly greater reported yields than in Adams (16 wells), Lancaster (14 wells), and York (24 wells) Counties. The median reported yield of high-demand wells in Montgomery County is 135 gal / min; in Adams County, 35 gal / min; in Lancaster County, 29 gal / min; and in York County, 41 gal / min.

Specific capacities for wells completed in the Conestoga Formation are presented in the table below. Eight wells (drilled from 125 to 489 ft below land surface) have specific capacities of 0.04 (gal / min) / ft or less and are incapable of meeting most domestic or other water-use demands. Twelve of 46 wells with specific capacities of 1.0 (gal / min) / ft or greater are deeper than 200 ft. Five of 10 wells with specific capacities greater than 20 (gal / min) / ft are within 400 ft of a stream; 2 others are within 400 ft of a major fault or 200 ft of the Ledger Formation. The specific capacities of 23 wells with a pumping duration of 8 hours or longer range from 0.01 to 13 (gal / min) / ft; the median is 0.53 (gal / min) / ft.

Reported specific capacity, Conestoga Formation

[Specific capacity in gallons per minute per foot of drawdown; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	95	0.06	0.28	1.8	4.7	21	0.00	110
Domestic	37	.06	.43	2.1	6.7	36	.00	110
High-demand	42	.16	.33	2.1	4.1	20	.05	35

Lloyd and Growitz (1977) pumped two wells in the Conestoga Formation of York County at different rates and measured the change in specific capacity. They found that doubling the discharge rate more than doubled the drawdown and decreased specific capacity by 36 to 46 percent.

Values of hydraulic conductivity and transmissivity for the Conestoga Formation are presented below; a specific yield of 0.03 was used in estimating these hydrologic properties. Hydraulic conductivity and transmissivity are generally lower on hilltops or slopes than in valleys. The median hydraulic conductivities of wells on hilltops (9 wells), slopes (44 wells), and valleys (20 wells) are 0.55, 2.6, and 8.2 ft / d, respectively. The median transmissivities of wells on hilltops is 240 ft^2 / d; on slopes, 300 ft^2 / d; and in valleys, 550 ft^2 / d.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Conestoga Formation

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	77	0.02	0.15	1.9	20	49	0.00	5,400
Transmissivity (ft^2 / d)	77	5.9	40	310	790	5,500	.40	23,000

In their work in the Little Conestoga Creek Basin in Lancaster County, Meisler and Becher (1971) estimated a specific yield of 0.04 for different units that included the Conestoga Formation. In their digital model of parts of Lancaster and Berks Counties, Pa., Gerhart and Lazorchick (1984b, tables 6 and 14) used a specific yield of 0.08 and a hydraulic conductivity of 5.0 ft / d for the Conestoga Formation. For the Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, tables 8 and 16) determined a specific yield of 0.035 for the upper 200 ft and hydraulic conductivities of 1.34 and 2.01 ft / d for different carbonate blocks that included the Conestoga Formation. In a block consisting of just the Conestoga Formation, Gerhart and Lazorchick estimated a hydraulic conductivity of 6.69 ft / d. For his digital model in the Valley Creek Basin of eastern Chester County, Sloto (1990) used a specific yield of 0.08 and estimated a hydraulic conductivity of 10 ft / d. Transmissivities, based on the analysis of four aquifer tests in the modeled area, ranged from 1,250 to 1,680 ft^2 / d; the median was 1,540 ft^2 / d.

At the AIW Frank / Mid County Mustang Superfund Site, Chester County, Pa., Conger (U.S. Geological Survey, written commun., 1997) estimated horizontal hydraulic conductivities and transmissivities from rising and falling slug tests using three wells open to overburden or bedrock. The hydraulic conductivity and transmissivity of a single well open to the overburden was 95.58 ft / d and 908 ft^2 / d, respectively. The hydraulic conductivities and transmissivities of two wells open to bedrock were 0.11, 0.13, 0.013, and 0.019 ft / d and 7, 8, less than 2, and 3 ft^2 / d.

Near Littlestown, Pa., R.E. Wright Associates, Inc. (1989) conducted several step-drawdown and long-term (72-hour) multiple-well aquifer tests. The aquifer tests indicated the Conestoga Formation was anisotropic (drawdown elongate roughly parallel to strike); transmissivities were 121 and 92.9 ft^2 / d.

The depths of water-bearing zones in 59 wells drilled as deep as 508 ft range from 12 to 382 ft below land surface. Fifty percent of the 107 water-bearing zones reported are penetrated by a depth of 90 ft and 90 percent by a depth of 246 ft. The greatest density of water-bearing zones (0.46 per 50 ft of well depth) is from 151 to 200 ft below land surface (fig. 48). The overall density of water-bearing zones in the Conestoga Formation is 0.40 per 50 ft of well depth.

Heatpulse flowmetering was conducted by the USGS in two wells near Littlestown, Pa. (Low and Dugas, 1999). Under ambient conditions, the heatpulse flowmeter in well AD-208 (well depth 450 ft) measured upward flow at 70, 150, 200, 250, 290, 350, and 390 ft below land surface and no flow at 420 ft. Most water exits the borehole through a minor fracture at 66 ft below land surface. The driller reported water entering the borehole at 310 and 405 ft below land surface. The second well, AD-762 (well depth 745 ft, but mud filled to 680 ft) was drilled through the New Oxford Formation and penetrated the Conestoga Formation at a depth of 585 ft. Under ambient conditions, the heatpulse flowmeter measured downward flow at 72 ft below land surface, upward flow at 110, 150, 250, 300, 350, 450, 550, 600, and 640 ft below land surface, and no flow at 660 ft below land surface. Most water flowing upward exited the borehole through the fracture zone from 128 to 137 ft below land surface. A fracture zone from 647 to 654 ft below land surface produced most of the water entering the borehole from the Conestoga Formation.

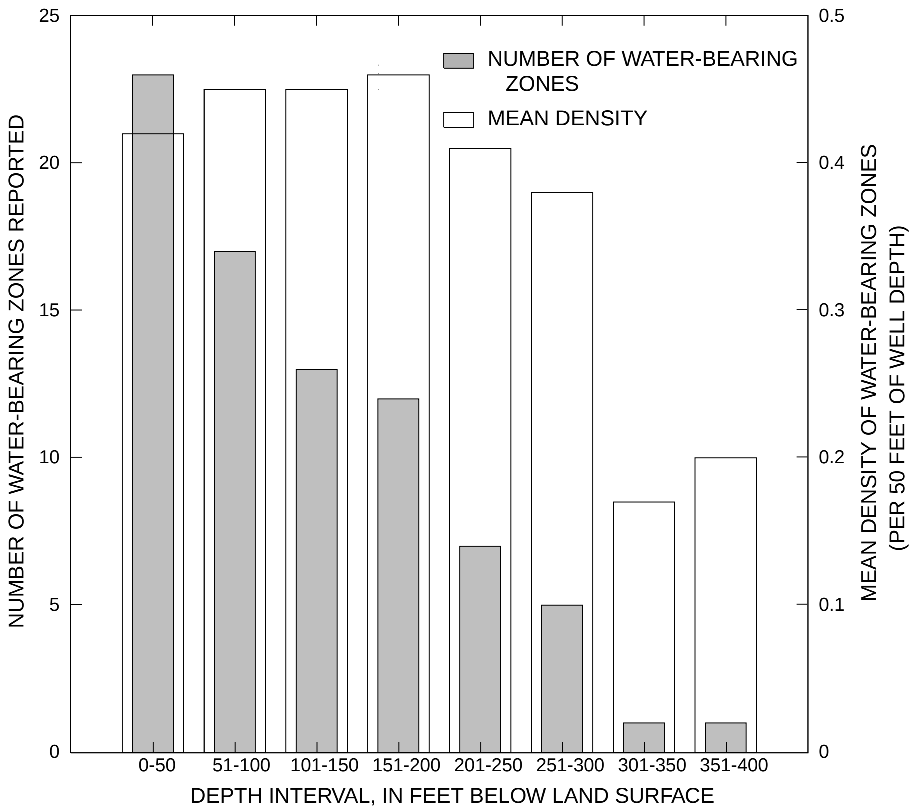


Figure 48. Number and density of water-bearing zones per 50 feet of well depth in the Conestoga Formation of the Piedmont Physiographic Province, Piedmont Lowland Section.

Water quality.—As seen in the following table, wells completed in the Conestoga Formation generally yield water that contains moderate amounts of dissolved solids, is very hard, and is alkaline. Calcium is the dominant cation, and bicarbonate is the dominant anion. Aside from very hard water, elevated concentrations of dissolved solids, iron, nitrate, and radon are the most common water-quality problems in the Conestoga Formation. Lloyd and Growitz (1977) considered the water in the Conestoga Formation to be a calcium bicarbonate type. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

The three wells containing water with a field pH below 6.5 are at or near (within 1,200 ft) the contact with the Albite-Chlorite Schist in the Chester Valley. The low pH, specific conductance, and hardness associated with these three wells suggests mixing of different water types.

Summary of selected chemical constituents and properties analyzed for the Conestoga Formation

[Concentrations in milligram per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; pCi/L, picoCurie per liter; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	137	—	—	—	440	570	723	65	1,390
Field hardness	148	—	—	—	210	260	310	51	530
Field pH (standard units)	66	—	<6.5 >8.5	4	7.0	7.2	7.5	5.4	8.9
Bicarbonate	57	—	—	—	160	190	230	8.0	330
Calcium	50	—	—	—	69	88	110	4.0	160
Chloride	55	—	250	0	14	21	36	2.0	110
Iron	57	—	.3	7	.010	.060	.130	.000	1.9
Lead	30	0.015	—	3	.000	.002	.005	.000	.087
Magnesium	50	—	—	—	10	16	23	.50	54
Manganese	51	—	.05	1	.000	.004	.010	.000	.49
Nitrate (as N)	45	10	—	16	2.8	6.0	13	.02	48
Potassium	45	—	—	—	1.7	2.3	3.8	.60	34
Radon (pCi/L)	6	[3] 300	—	5	520	640	800	65	2,100
Silica	29	—	—	—	9.7	10	12	6.5	22
Sodium	47	—	—	—	4.3	7.3	17	1.1	89
Sulfate	55	—	250	0	32	40	58	1.0	170
Total dissolved solids	52	—	500	11	305	351	486	34	919

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.
[3] U.S. Environmental Protection Agency, 1994, proposed maximum contaminant level.

Topographic setting can affect water quality. As seen in the two tables below, water from wells on hilltops and slopes have significantly higher specific conductance and hardness than wells in valleys. For pH, there is very little difference between topographic settings. The median pH of wells on hilltops (5 wells), slopes (39 wells), and in valleys are 7.1, 7.1, and 7.3, respectively.

Field specific conductance, by topographic setting, Conestoga Formation

[Specific conductance in microsiemens per centimeter at 25 degrees Celsius; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Topographic setting	Number of wells	P25	Median	P75	Minimum	Maximum
Hilltop	14	414	700	830	350	1,300
Slope	87	495	620	750	148	1,390
Valley	31	380	480	590	65	1,090

Field hardness, by topographic setting, Conestoga Formation

[Hardness in milligrams per liter; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Topographic setting	Number of wells	P25	Median	P75	Minimum	Maximum
Hilltop	15	170	310	340	140	410
Slope	94	220	270	310	85	530
Valley	32	170	220	268	51	410

There are also significant spatial differences in water quality. The field specific conductance of water from wells in Lancaster County (68 wells) is significantly greater than in Adams County (17 wells); the medians are 650 and 430 µS/cm, respectively. Whether this difference is natural or man-made is uncertain. According to Meisler and Becher (1971, p. 60-61), “Ground water in the Conestoga Formation is generally higher in silica, calcium, sodium, sulfate, chloride, nitrate, and dissolved solids than is the water in other carbonate rocks * * *.” They noted that much of the contamination is in the area near Lancaster and Millersville where sewage discharge, sanitary landfills, fertilizers, and insecticide are prevalent. The higher concentration of silica in the Conestoga Formation may be the result of leaching of siliceous metamorphic minerals. Higher concentrations of sulfate can, at least in part, be due to the abundance of disseminated pyrite crystals in the Conestoga Formation.

Work in the Conestoga Formation (Durlin and Schaffstall, 1993; 1994) indicates elevated concentrations of radon also are a common water-quality problem. Concentrations of radon-222 in the water from 19 of 20 wells exceed the proposed USEPA MCL of 300 pCi/L. Activities ranging from 230 to 7,700 pCi/L radon-222 are reported; the median is 1,200 pCi/L. Because of its short half-life (3.8 days) and no chemical affinities, radon-222 is not transported any considerable distance in ground water and its concentration in a water sample is directly controlled by the surrounding lithology (Michel, 1990, p. 90). Radon’s parent (radium-226) is derived from uranium-234, which, however, has a very long half-life and is easily dissolved and transported in ground water (Zapecza and Szabo, 1988, p. 50). Radium-226 is most mobile in chloride-rich reducing ground water with high dissolved-solids content (Tanner, 1964, p. 261). Radium’s parent (uranium-234) is more soluble in association with carbonate, phosphate, and fluoride ions, or with organic compounds (Langmuir, 1978, p. 556; Turner-Peterson, 1980, p. 163). Senior and Vogel (1995) found that the concentrations of dissolved radium is inversely related to pH and directly to total dissolved solids, dissolved organic carbon, barium, and sulfate concentrations.

Cocalico Formation (Oco)

The Cocalico Formation underlies about 60 mi^2 of the Piedmont Lowland in northern Lancaster County (Berg and others, 1980). The reference section is along Cocalico Creek in Lancaster County (Stose and Jonas, 1922).

Geologic description.—The Cocalico Formation consists predominantly of dark gray to bluish-black phyllitic shale that contains thin beds of fine, yellowish-green arkosic sandstone. Near the base are beds of bluish-purple to green shale interbeds and fine-grained, greenish-white, hard, vitreous quartz sandstone or quartzite.

The Cocalico Formation is slightly to highly resistant to weathering, with the shale forming rolling valleys and the sandstone forming more resistant hills and ridges. Joints in the shale and sandstone are well developed, abundant, and open. The shale can be highly weathered to a deep depth, whereas the sandstone is only slightly weathered to a shallow depth (Geyer and Wilshusen, 1982, p. 91-94).

The Cocalico Formation is possibly Cambrian to Ordovician in age and unconformably overlies rocks ranging from the Buffalo Springs Formation to the Epler Formation (Meisler and Becher, 1971). At some localities, rocks of the Cocalico Formation probably are allochthonous, comprising large faulted blocks that were thrusted substantial distances from where they were deposited. On the basis of lithologic similarities and fossil data, Jonas and Stose (1930) believed that the Cocalico Formation is the same age as the Martinsburg Formation in the Great Valley Section. Meisler and Becher (1971) and Poth (1977) considered the Cocalico Formation to be correlative with the Martinsburg Formation. Thickness estimates for the Cocalico Formation range from 1,000 (Geyer and Wilshusen, 1982, p. 92) to 2,000 ft (Jonas and Stose, 1930, p. 40).

Well depths and casing lengths.—Depths of wells and casing lengths for wells completed in the Cocalico Formation are presented in the tables below. Although water use or topographic setting does not significantly affect well depth, an analysis of well depths indicates that wells are commonly completed at

25 ft intervals, beginning at a depth of 100 ft. Almost one-third of all the drilled wells are completed at depths of 250 ft (41 wells) or 300 ft (54 wells). This is probably done by design, as the Cocalico Formation is the least productive unit in the Piedmont Lowland and well drillers are using the borehole to store all available ground water. High-demand wells are not significantly deeper nor use significantly more casing than domestic wells.

Reported well depth, Cocalico Formation

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	313	125	175	250	307	369	25	500
Drilled, domestic	299	125	175	250	302	360	25	500
Drilled, high-demand	11	115	200	300	350	400	94	400

Reported casing length, Cocalico Formation

[Casing length in feet; —, P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	304	20	29	40	48	61	11	187
Drilled, domestic	291	20	29	40	50	61	11	187
Drilled, high-demand	11	20	21	34	41	49	20	50

Hydrologic properties.—Water levels for wells completed in the Cocalico Formation are presented in the table below. Depths to water in 58 wells range from 4 to 69 ft below land surface; the median is 30 ft below land surface.

Water levels, Cocalico Formation

[Water levels in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	18	17	20	30	36	40	10	45
Slope	29	10	21	30	37	53	4	69
Valley	2	—	—	22	—	—	5	40

Reported yields for wells completed in the Cocalico Formation are presented in the table below. Yields of 5.0 gal/min or less are reported from 181 wells. None of the 15 wells with reported yields of 25 gal/min or greater are deeper than 200 ft. There is little difference between the yields of high-demand and domestic wells.

Reported well yield, Cocalico Formation

[Yield in gallons per minute; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	273	0.5	1.0	2.5	7.0	19	0.2	75
Domestic	261	.5	1.0	2.5	7.0	19	.2	75
High-demand	9	—	3.0	6.0	9.0	—	.5	20

Specific capacities for wells completed in the Cocalico Formation are presented in the table below. Eleven wells (well depths of 202 to 440 ft below land surface) have specific capacities of 0.04 (gal / min) / ft or less and are incapable of meeting most domestic or other water-use demands. Only two wells have specific capacities of 1.0 (gal / min) / ft or greater, both are less than 200 ft deep. The specific capacities of two wells with a pumping duration of 8 hours or longer are 0.01 and 1.0 (gal / min) / ft.

Reported specific capacity, Cocalico Formation

[Specific capacity in gallons per minute per foot of drawdown; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	18	0.00	0.01	0.01	0.50	1.0	0.00	1.2
Domestic	17	.00	.00	.01	.33	1.0	.00	1.2
High-demand	1	—	—	1.0	—	—	1.0	—

Values of hydraulic conductivity and transmissivity for the Cocalico Formation are presented in the table below; a specific yield of 0.02 was used in estimating these hydrologic properties. The median hydraulic conductivities of wells on hilltops (6 wells), slopes (2 wells), and valleys (1 well) are 0.00, 2.4, and 0.69 ft / d, respectively. The median transmissivities of wells on hilltops is 0.97 ft^2 / d; on slopes, 170 ft^2 / d; and in valleys, 150 ft^2 / d.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Cocalico Formation

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	11	0.00	0.00	0.19	1.0	2.9	0.00	3.3
Transmissivity (ft^2 / d)	11	.15	.51	11	150	170	.09	170

The hydraulic conductivity of a solid rock sample of the sandstone member of the Cocalico Formation ranged from 0.0 to 1.5 ft / d (Geyer and Wilshusen, 1982, p. 92). In their digital model of parts of Lancaster and Berks Counties, Pa., Gerhart and Lazorchick (1984b, tables 6 and 14) used a specific yield of 0.015 and a hydraulic conductivity of 2.0 ft / d for the Cocalico Formation. For the Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, tables 8 and 16) determined a specific yield of 0.020 for the upper 200 ft and hydraulic conductivity of 2.01 ft / d for the Cocalico Formation.

The depths of water-bearing zones in 611 wells drilled as deep as 725 ft range from 2 ft below land surface to 400 ft below land surface. Fifty percent of the 969 water-bearing zones reported are penetrated by a depth of 105 ft and 90 percent by a depth of 205 ft. The greatest density of water-bearing zones (0.57 per 50 ft of well depth) is from 51 to 100 ft below land surface (fig. 49). The overall density of water-bearing zones in the Cocalico Formation is 0.31 per 50 ft of well depth.

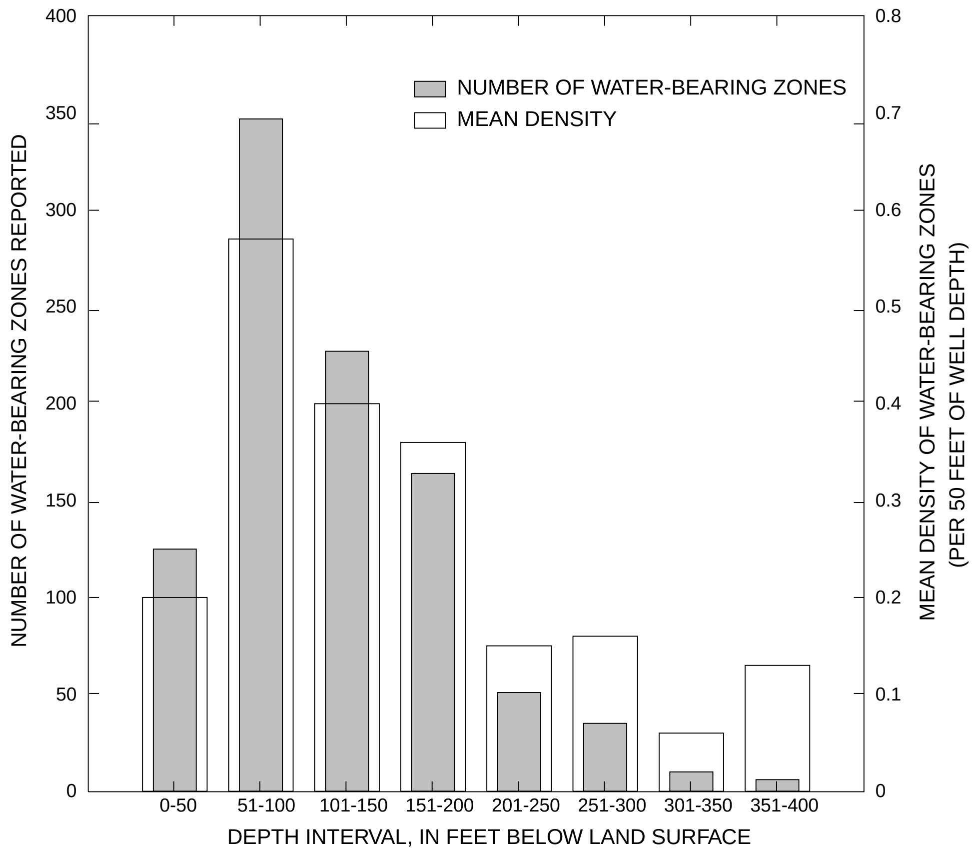


Figure 49. Number and density of water-bearing zones per 50 feet of well depth in the Cocalico Formation of the Piedmont Physiographic Province, Piedmont Lowland Section.

Water quality.—As seen in the following table, wells completed in the Cocalico Formation generally yield water that contains low to moderate amounts of dissolved solids, is soft to moderately hard, and is slightly alkaline. Calcium is the dominant cation, and bicarbonate is the dominant anion. Elevated concentrations of iron, manganese, and nitrate have been reported. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Cocalico Formation

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	11	—	—	—	250	280	417	195	582
Field hardness	11	—	—	—	100	120	190	85	270
Field pH (standard units)	3	—	<6.5 >8.5	0	—	7.0	—	6.8	7.1
Bicarbonate	10	—	—	—	43	64	110	36	160
Calcium	10	—	—	—	22	34	50	13	82
Chloride	10	—	250	0	6.8	9.5	16	4.0	50
Iron	8	—	.3	1	.030	.065	.12	.020	.75
Magnesium	10	—	—	—	4.8	6.2	7.7	3.5	10
Manganese	8	—	.05	2	.010	.020	.14	.010	.54
Nitrate (as N)	8	10	—	1	1.6	4.5	6.7	.02	11
Potassium	10	—	—	—	.59	.75	1.0	.20	2.0
Silica	0	—	—	—	—	—	—	—	—
Sodium	10	—	—	—	2.5	4.6	5.0	1.1	7.1
Sulfate	10	—	250	0	18	35	36	5.0	45
Total dissolved solids	10	—	500	0	176	200	230	152	476

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.

Summary of Characteristics of Bedrock Aquifers in the Piedmont Physiographic Province, Piedmont Lowland Section

Data evaluated for most units in the Piedmont Lowland Section are summarized in figures 50 to 55 and in tables 9-13. Well depths range from 16 to 830 ft below land surface and casing lengths from 1 to 560 ft. In general, high-demand wells are completed at significantly greater depths and use significantly more casing than domestic wells.

Reported yields range from 0 to 1,800 gal/min and specific capacities from 0.01 to 200 (gal/min)/ft. Reported yields and specific capacities can vary significantly by geohydrologic unit, water use, and topographic setting. High-demand wells generally have significantly greater reported yields than domestic wells.

The field specific conductance and hardness of water in the Cocalico and Vintage Formations are considerably lower than for the other geohydrologic units in the Piedmont Lowland. The highest specific conductance and hardness values are commonly found in the Buffalo Springs and Zooks Corner Formations. The pH of waters within the geohydrologic units of the Piedmont Lowland are not significantly different.

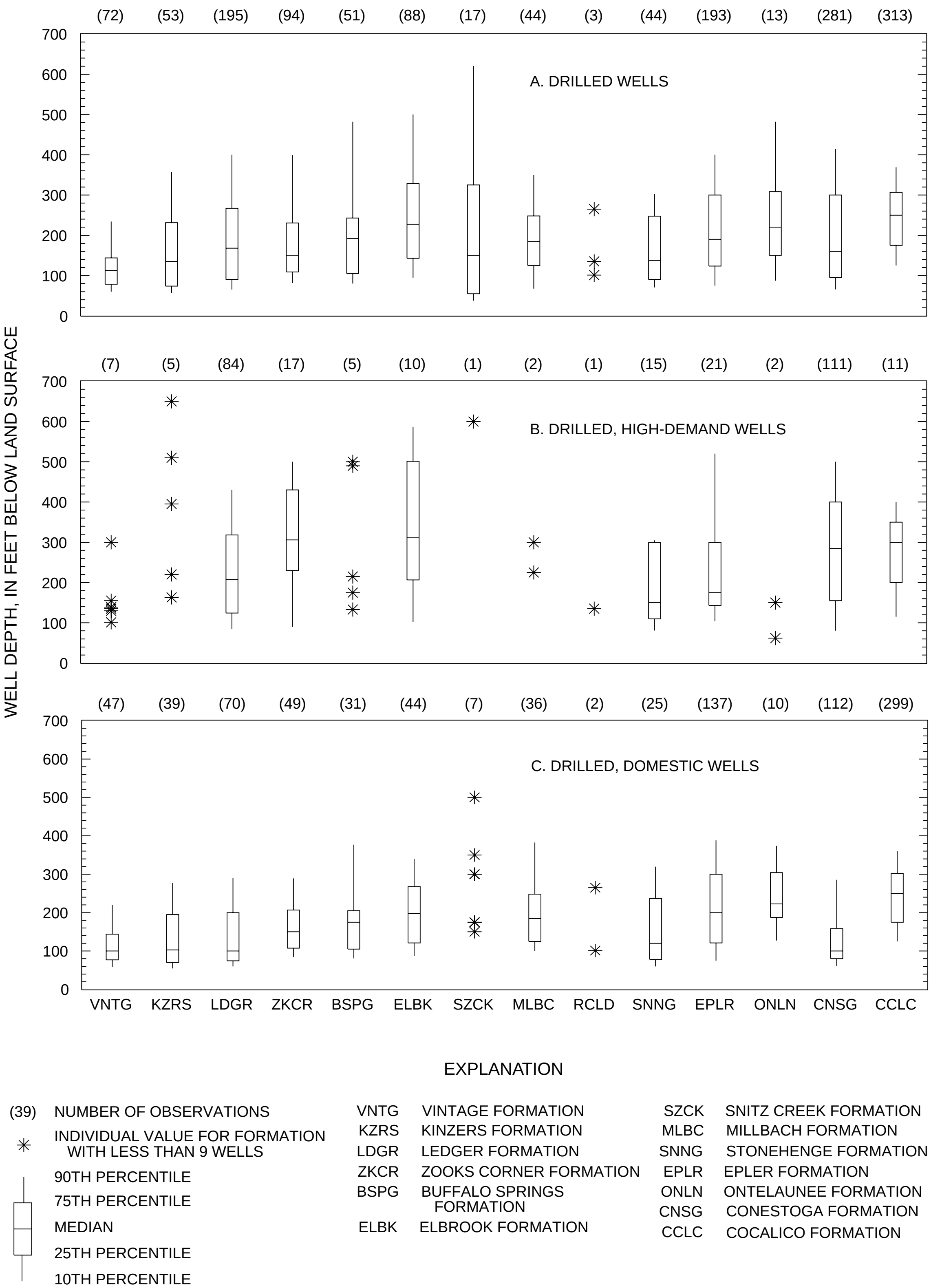


Figure 50. Depths of drilled wells in the Piedmont Physiographic Province, Piedmont Lowland Section.

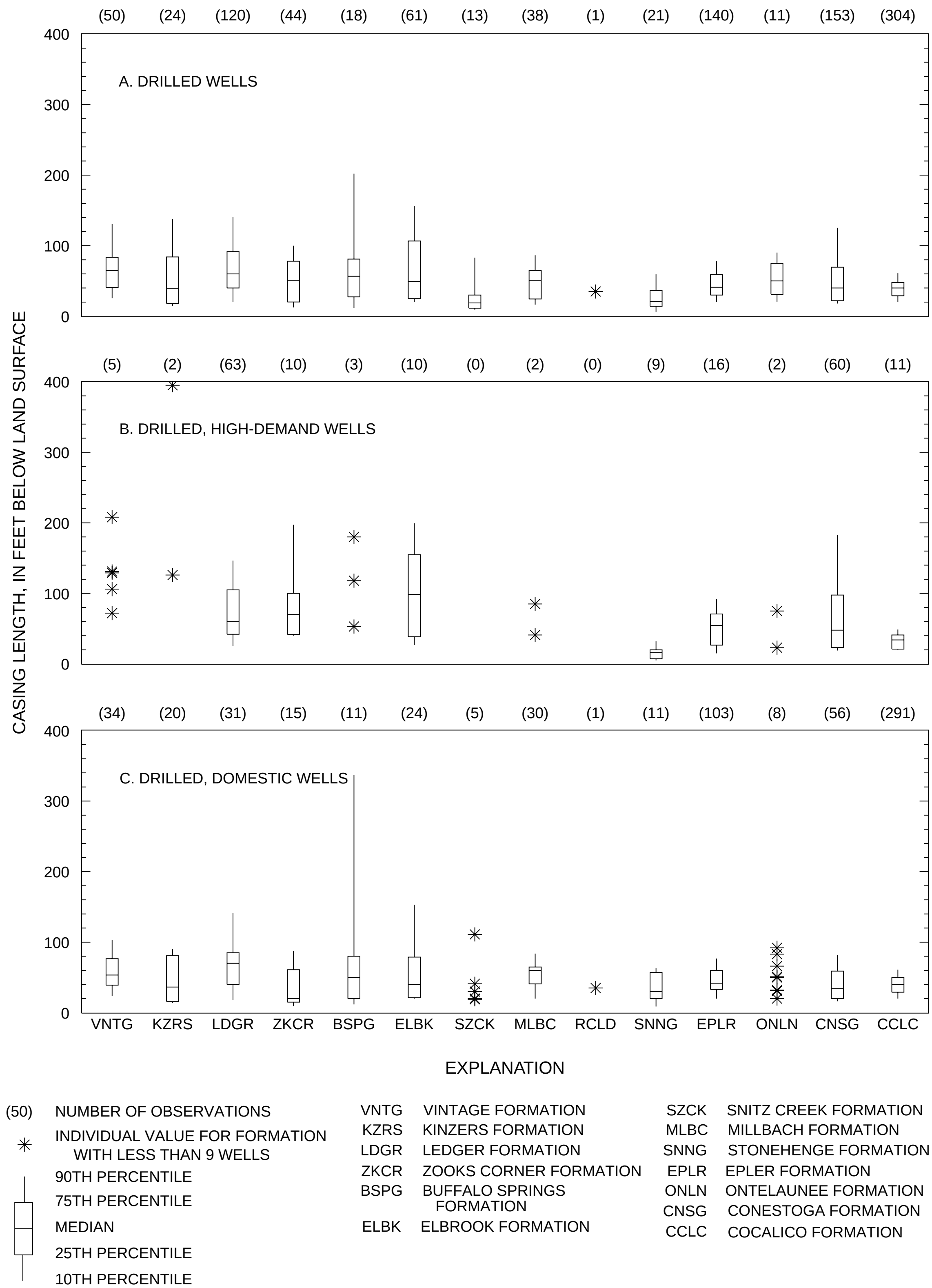
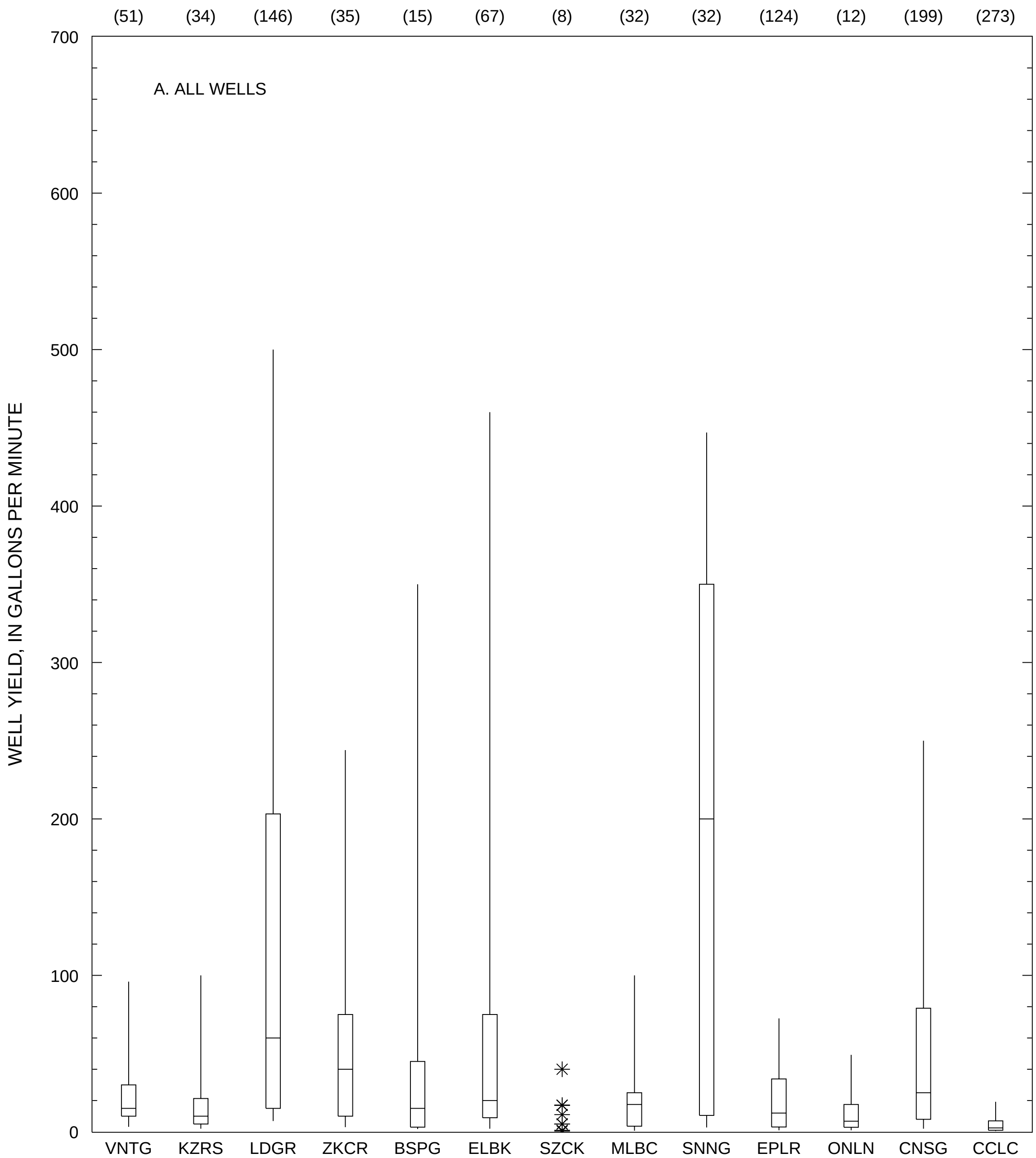


Figure 51. Casing lengths of drilled wells in the Piedmont Physiographic Province, Piedmont Lowland Section.



EXPLANATION

(51) NUMBER OF OBSERVATIONS

✳ INDIVIDUAL VALUE FOR FORMATION WITH LESS THAN 9 WELLS

90TH PERCENTILE
75TH PERCENTILE
MEDIAN
25TH PERCENTILE
10TH PERCENTILE

VNTG	VINTAGE FORMATION
KZRS	KINZERS FORMATION
LDGR	LEDGER FORMATION
ZKCR	ZOOKS CORNER FORMATION
BSPG	BUFFALO SPRINGS FORMATION
ELBK	ELBROOK FORMATION
SZCK	SNITZ CREEK FORMATION
MLBC	MILLBACH FORMATION
SNNG	STONEHENGE FORMATION
EPLR	EPLER FORMATION
ONLN	ONTELAUNEE FORMATION
CNSG	CONESTOGA FORMATION
CCLC	COCALICO FORMATION

Figure 52. Reported yields of wells in the Piedmont Physiographic Province, Piedmont Lowland Section.

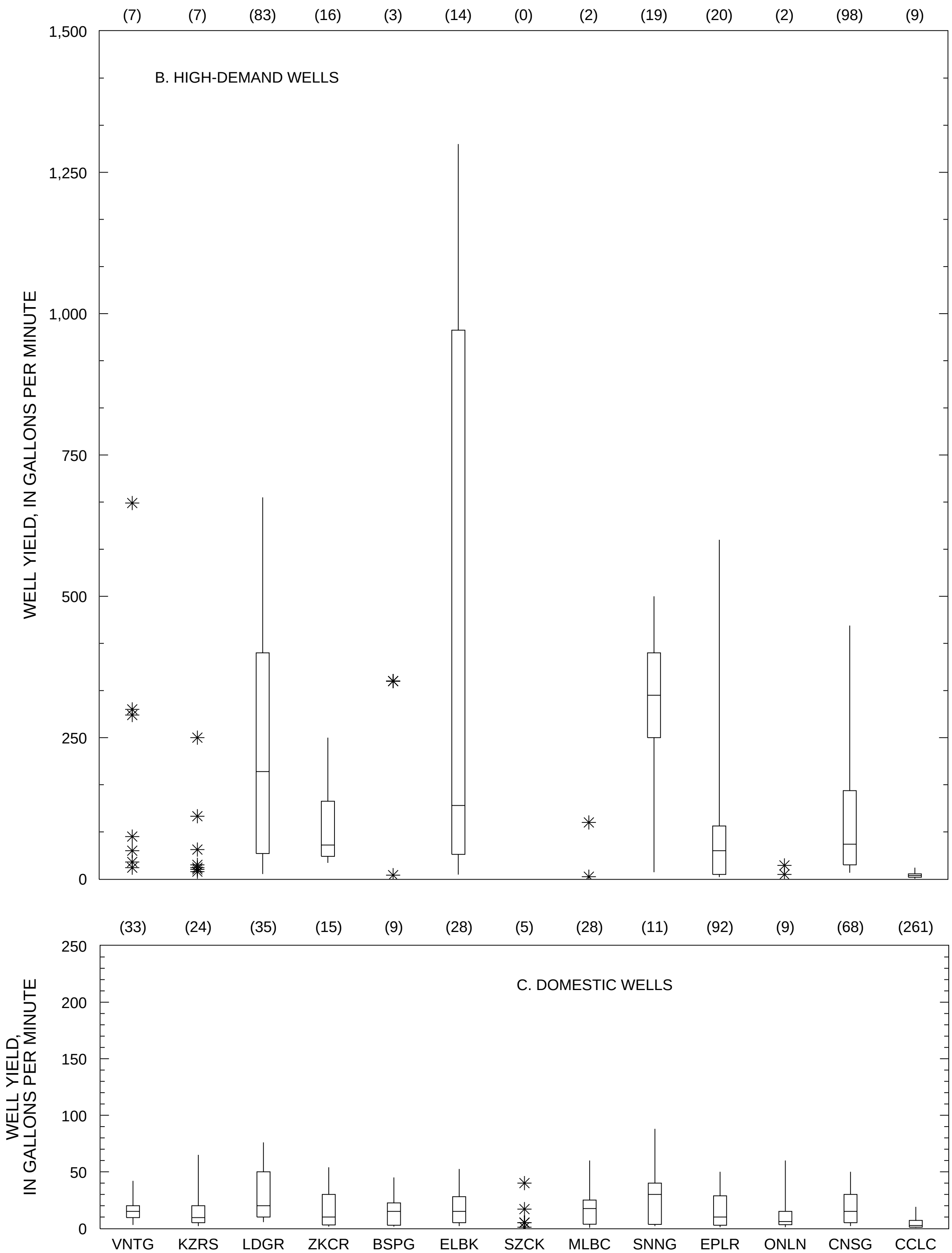
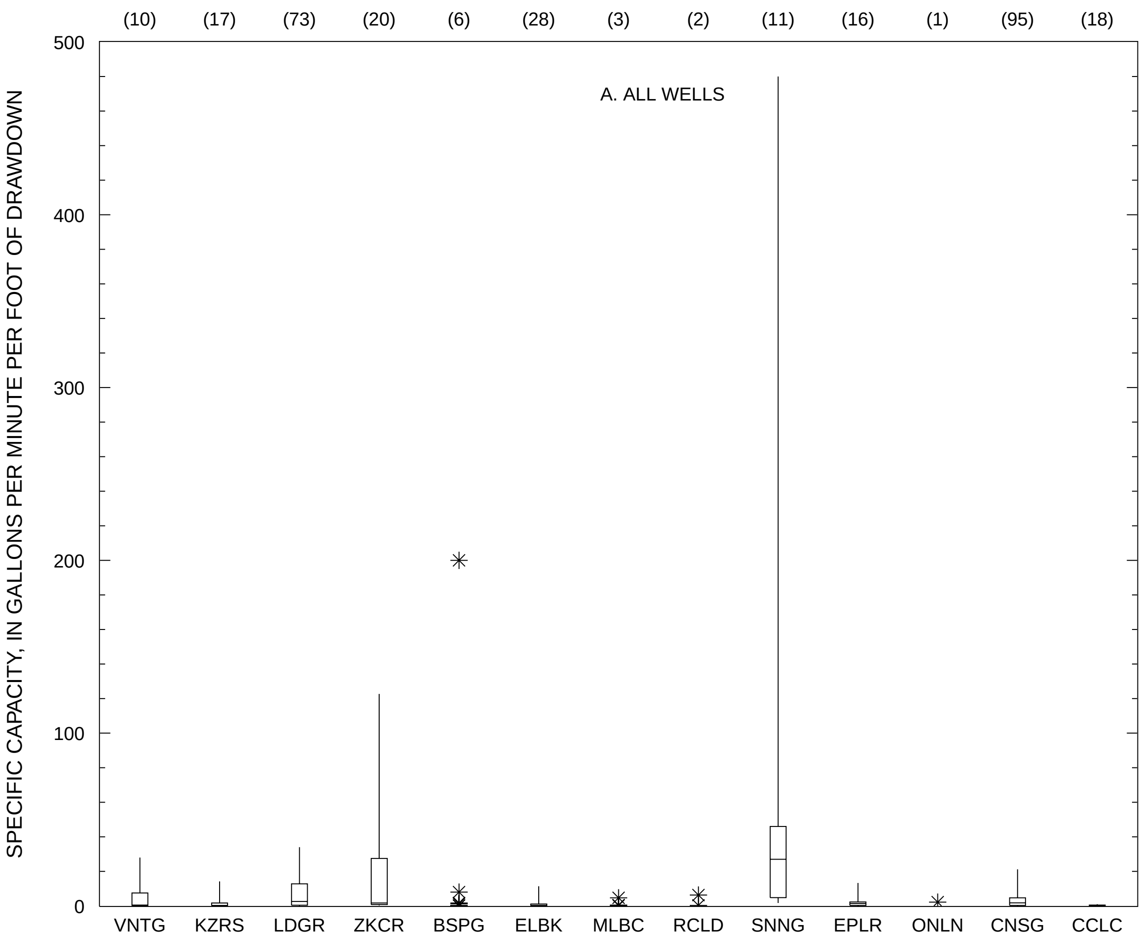


Figure 52. Reported yields of wells in the Piedmont Physiographic Province, Piedmont Lowland Section —Continued.



EXPLANATION

(10) NUMBER OF OBSERVATIONS

✳ INDIVIDUAL VALUE FOR FORMATION WITH LESS THAN 9 WELLS

90TH PERCENTILE

75TH PERCENTILE

MEDIAN

25TH PERCENTILE

10TH PERCENTILE

VNTG	VINTAGE FORMATION
KZRS	KINZERS FORMATION
LDGR	LEDGER FORMATION
ZKCR	ZOOKS CORNER FORMATION
BSPG	BUFFALO SPRINGS FORMATION
ELBK	ELBROOK FORMATION
SZCK	SNITZ CREEK FORMATION
MLBC	MILLBACH FORMATION
SNNG	STONEHENGE FORMATION
EPLR	EPLER FORMATION
ONLN	ONTELAUNEE FORMATION
CNSG	CONESTOGA FORMATION
CCLC	COCALICO FORMATION

Figure 53. Specific capacities of wells in the Piedmont Physiographic Province, Piedmont Lowland Section.

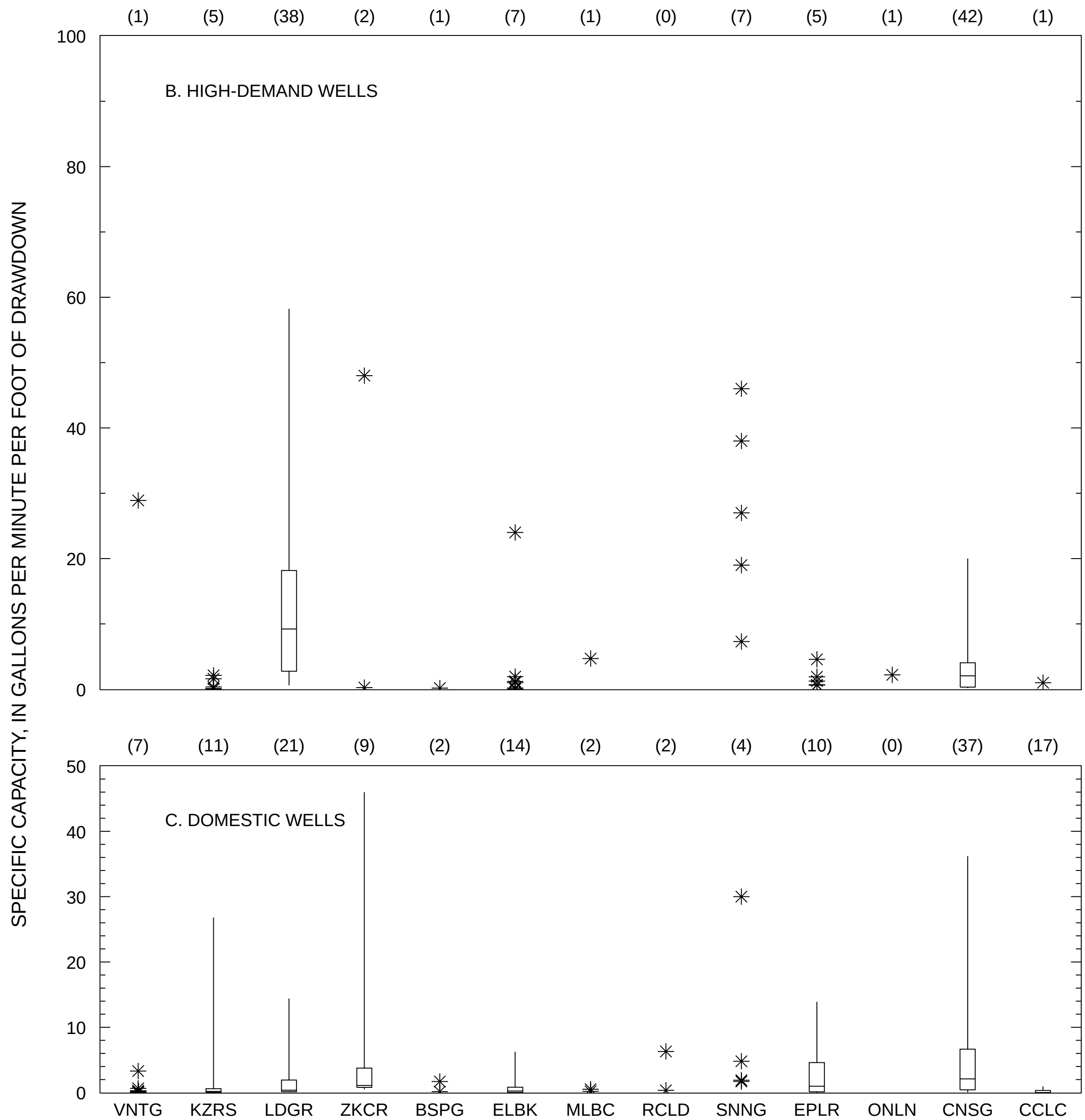
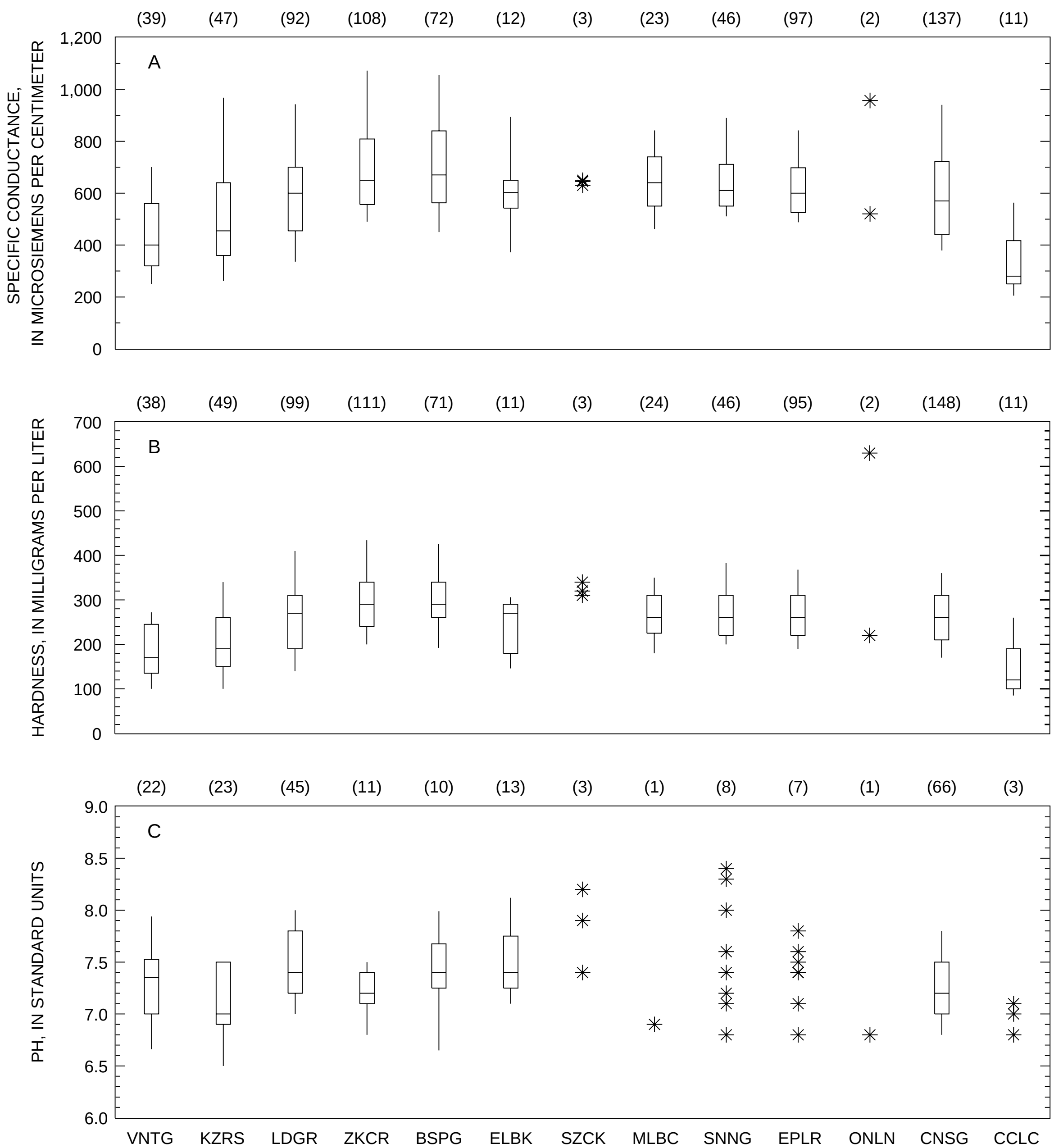


Figure 53. Specific capacities of wells in the Piedmont Physiographic Province, Piedmont Lowland Section—Continued.



EXPLANATION

(39) NUMBER OF OBSERVATIONS

✳ INDIVIDUAL VALUE FOR FORMATION WITH LESS THAN 9 WELLS

90TH PERCENTILE
75TH PERCENTILE
MEDIAN
25TH PERCENTILE
10TH PERCENTILE

VNTG VINTAGE FORMATION
KZRS KINZERS FORMATION
LDGR LEDGER FORMATION
ZKCR ZOOKS CORNER FORMATION
BSPG BUFFALO SPRINGS FORMATION
ELBK ELBROOK FORMATION
SZCK SNITZ CREEK FORMATION
MLBC MILLBACH FORMATION
SNNG STONEHENGE FORMATION
EPLR EPLER FORMATION
ONLN ONTELAUNEE FORMATION
CNSG CONESTOGA FORMATION
CCLC COCALICO FORMATION

Figure 54. Field water-quality characteristics of wells in the Piedmont Physiographic Province, Piedmont Lowland Section: A, specific conductance; B, hardness; C, pH.

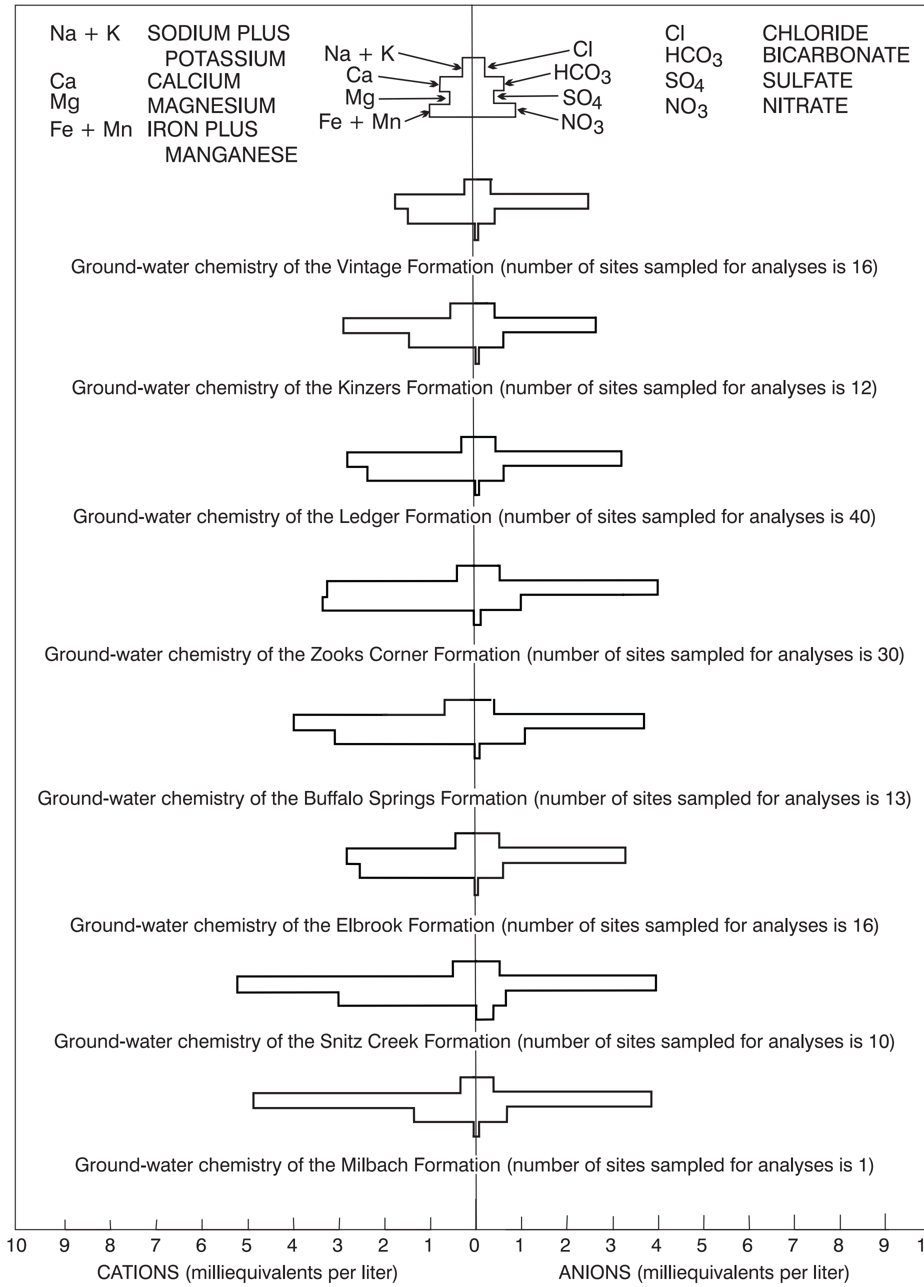


Figure 55. Median chemical analyses of selected chemical constituents from the ground water of the geohydrologic units in the Piedmont Physiographic Province, Piedmont Lowland Section.

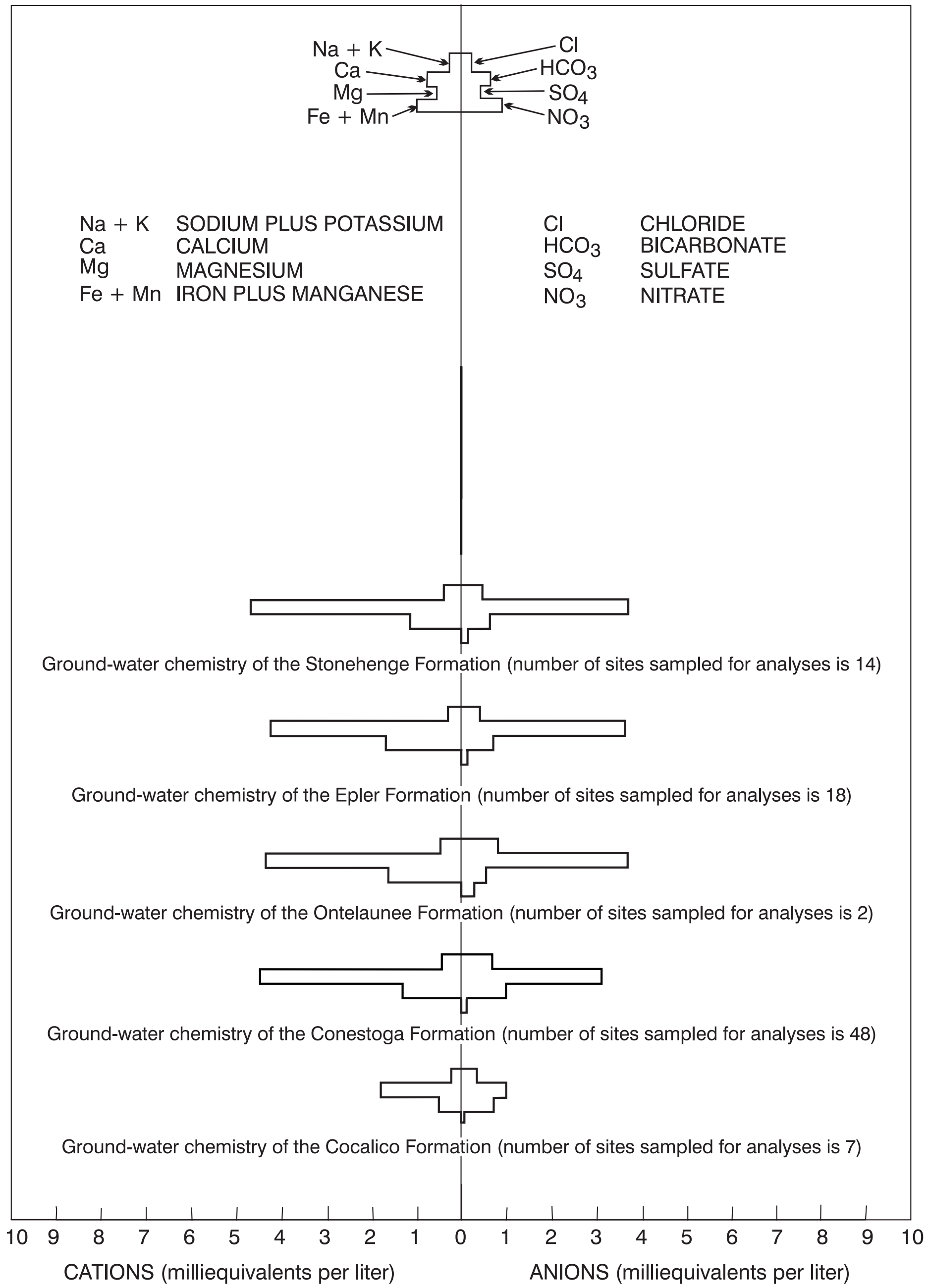


Figure 55. Median chemical analyses of selected chemical constituents from the ground water of the geohydrologic units in the Piedmont Physiographic Province, Piedmont Lowland Section—Continued.

Table 9. *Significant relations for depth of drilled wells among 13 geohydrologic units in the Piedmont Lowland Section of the Piedmont Physiographic Province, Pennsylvania*

[Table is read from top down. Example, depths of wells drilled in the Conestoga Formation are significantly greater than the depths of wells drilled in the Vintage Formation, but are significantly shallower (less) than in the Elbrook Formation. G, greater; L, less; -, insufficient data; blank indicates no significant differences between units]

VNTG, Vintage Formation; KZRS, Kinzers Formation; LDGR, Ledger Formation; ZKCR, Zooks Corner Formation; BSPG, Buffalo Springs Formation; ELBK, Elbrook Formation; SZCK, Snitz Creek Formation; MLBC, Millbach Formation; SNNG, Stonehenge Formation; EPLR, Epler Formation; ONLN, Ontelaunee Formation; CNSG, Conestoga Formation; CCLC, Cocalico Formation

	VNTG	KZRS	LDGR	ZKCR	BSPG	ELBK	SZCK	MLBC	SNNG	EPLR	ONLN	CNSG	CCLC
DRILLED WELLS													
VNTG													
KZRS													
LDGR	L												
ZKCR	L												
BSPG	L												
ELBK	L	L	L	L									
SZCK													
MLBC	L												
SNNG						G							
EPLR	L												
ONLN	L												
CNSG	L					G							
CCLC	L	L	L	L					L	L		L	
DRILLED, HIGH-DEMAND WELLS													
VNTG	-												
KZRS	-												
LDGR	-	-											
ZKCR	-	-	-										
BSPG	-	-	-	-									
ELBK	-	-	L	-	-								
SZCK	-	-	-	-	-	-							
MLBC	-	-	-	-	-	-	-						
SNNG	-	-		-	-		-	-					
EPLR	-	-		-	-		-	-					
ONLN	-	-	-	-	-	-	-	-	-	-			
CNSG	-	-		-	-	G	-	-		L	-		
CCLC	-	-	L	-	-		-	-	L	L	-	L	
DRILLED, DOMESTIC WELLS													
VNTG													
KZRS													
LDGR													
ZKCR													
BSPG													
ELBK	L	L	L										
SZCK	-	-	-	-	-	-							
MLBC	L	L	L				-						
SNNG							-						
EPLR	L	L	L				-						
ONLN	L	L	L				-						
CNSG						G	-	G		G	G		
CCLC	L	L	L	L	L		-		L	L		L	

Table 10. *Significant relations for casing length of wells among 13 geohydrologic units in the Piedmont Lowland Section of the Piedmont Physiographic Province, Pennsylvania*

[Table is read from top down. Example, casing lengths of wells drilled in the Conestoga Formation are significantly greater than the casing lengths of wells drilled in the Stonehenge Formation, but are significantly less than in the Vintage Formation. G, greater; L, less; -, insufficient data; blank indicates no significant differences between units]

VNTG, Vintage Formation; KZRS, Kinzers Formation; LDGR, Ledger Formation; ZKCR, Zooks Corner Formation; BSPG, Buffalo Springs Formation; ELBK, Elbrook Formation; SZCK, Snitz Creek Formation; MLBC, Millbach Formation; SNNG, Stonehenge Formation; EPLR, Epler Formation; ONLN, Ontelaunee Formation; CNSG, Conestoga Formation; CCLC, Cocalico Formation

	VNTG	KZRS	LDGR	ZKCR	BSPG	ELBK	SZCK	MLBC	SNNG	EPLR	ONLN	CNSG	CCLC
DRILLED WELLS													
VNTG													
KZRS													
LDGR													
ZKCR													
BSPG													
ELBK													
SZCK	G		G	G	G	G							
MLBC							L						
SNNG	G		G	G	G	G		G					
EPLR	G		G						L				
ONLN													
CNSG	G		G				L		L				
CCLC	G		G										
DRILLED, HIGH-DEMAND WELLS													
VNTG	-												
KZRS	-												
LDGR	-	-											
ZKCR	-	-											
BSPG	-	-	-	-									
ELBK	-	-			-								
SZCK	-	-	-	-	-	-							
MLBC	-	-	-	-	-	-	-						
SNNG	-	-	-	-	-	-	-	-					
EPLR	-	-			-		-	-	-				
ONLN	-	-	-	-	-	-	-	-	-	-			
CNSG	-	-			-		-	-	-		-		
CCLC	-	-	G		-		-	-	-		-		
DRILLED, DOMESTIC WELLS													
VNTG													
KZRS													
LDGR													
ZKCR			G										
BSPG													
ELBK													
SZCK	-	-	-	-	-	-							
MLBC							-						
SNNG							-						
EPLR							-						
ONLN	-	-	-	-	-	-	-	-	-	-			
CNSG	G		G				-				-		
CCLC	G		G				-				-		

Table 11. *Significant relations for reported yield from wells among 13 geohydrologic units in the Piedmont Lowland Section of the Piedmont Physiographic Province, Pennsylvania*

[Table is read from top down. Example, reported yields from wells in the Vintage Formation are significantly greater than the reported yields from wells in the Cocalico Formation, but are significantly less than in the Ledger Formation. G, greater; L, less; -, insufficient data; blank indicates no significant differences between units]

VNTG, Vintage Formation; KZRS, Kinzers Formation; LDGR, Ledger Formation; ZKCR, Zooks Corner Formation; BSPG, Buffalo Springs Formation; ELBK, Elbrook Formation; SZCK, Snitz Creek Formation; MLBC, Millbach Formation; SNNG, Stonehenge Formation; EPLR, Epler Formation; ONLN, Ontelaunee Formation; CNSG, Conestoga Formation; CCLC, Cocalico Formation

	VNTG	KZRS	LDGR	ZKCR	BSPG	ELBK	SZCK	MLBC	SNNG	EPLR	ONLN	CNSG	CCLC
ALL WELLS													
VNTG													
KZRS													
LDGR	L	L											
ZKCR													
BSPG													
ELBK			G										
SZCK	-	-	-	-	-	-							
MLBC			G				-						
SNNG	L	L					-	L					
EPLR			G	G			-		G				
ONLN			G				-		G				
CNSG			G				-			L			
CCLC	G	G	G	G	G	G	-		G	G		G	
HIGH-DEMAND WELLS													
VNTG	-												
KZRS	-												
LDGR	-	-											
ZKCR	-	-											
BSPG	-	-	-	-									
ELBK	-	-			-								
SZCK	-	-	-	-	-	-							
MLBC	-	-	-	-	-	-	-						
SNNG	-	-			-		-	-					
EPLR	-	-			-		-	-	G				
ONLN	-	-	-	-	-	-	-	-	-	-			
CNSG	-	-			-		-	-	G		-		
CCLC	-	-	-	-	-	-	-	-	-	-	-	-	
DOMESTIC WELLS													
VNTG													
KZRS													
LDGR													
ZKCR													
BSPG	-	-	-	-									
ELBK					-								
SZCK	-	-	-	-	-	-							
MLBC					-		-						
SNNG					-		-						
EPLR			G		-		-						
ONLN	-	-	-	-	-	-	-	-	-	-			
CNSG					-		-				-		
CCLC	G	G	G	G	-	G	-	G	G	G	-	G	

Table 12. *Significant relations for specific capacity from wells among 13 geohydrologic units in the Piedmont Lowland Section of the Piedmont Physiographic Province, Pennsylvania*

[Table is read from top down. Example, specific capacities from wells in the Stonehenge Formation are significantly greater than the specific capacities from wells in the Elbrook Formation and the Conestoga Formation. G, greater; L, less; -, insufficient data; blank indicates no significant differences between units]

VNTG, Vintage Formation; KZRS, Kinzers Formation; LDGR, Ledger Formation; ZKCR, Zooks Corner Formation; BSPG, Buffalo Springs Formation; ELBK, Elbrook Formation; SZCK, Snitz Creek Formation; MLBC, Millbach Formation; SNNG, Stonehenge Formation; EPLR, Epler Formation; ONLN, Ontelaunee Formation; CNSG, Conestoga Formation; CCLC, Cocalico Formation

	VNTG	KZRS	LDGR	ZKCR	BSPG	ELBK	SZCK	MLBC	SNNG	EPLR	ONLN	CNSG	CCLC
ALL WELLS													
VNTG													
KZRS													
LDGR													
ZKCR													
BSPG	-	-	-	-									
ELBK			G	G	-								
SZCK	-	-	-	-	-	-							
MLBC	-	-	-	-	-	-	-						
SNNG	L	L			-	L	-	-					
EPLR					-		-	-	G				
ONLN	-	-	-	-	-	-	-	-	-	-			
CNSG					-		-	-	G		-		
CCLC			G	G	-		-	-	G	G	-	G	
HIGH-DEMAND WELLS													
VNTG	-												
KZRS	-												
LDGR	-	-											
ZKCR	-	-	-										
BSPG	-	-	-	-									
ELBK	-	-	-	-	-								
SZCK	-	-	-	-	-	-							
MLBC	-	-	-	-	-	-	-						
SNNG	-	-	-	-	-	-	-	-					
EPLR	-	-	-	-	-	-	-	-	-				
ONLN	-	-	-	-	-	-	-	-	-	-			
CNSG	-	-	G	-	-	-	-	-	-	-	-		
CCLC	-	-	-	-	-	-	-	-	-	-	-	-	
DOMESTIC WELLS													
VNTG	-												
KZRS	-												
LDGR	-												
ZKCR	-	-	-										
BSPG	-	-	-	-									
ELBK	-			-	-								
SZCK	-	-	-	-	-	-							
MLBC	-	-	-	-	-	-	-						
SNNG	-	-	-	-	-	-	-	-					
EPLR	-			-	-	-		-	-				
ONLN	-	-	-	-	-	-	-	-	-	-			
CNSG	-			-	-	-		-	-		-		
CCLC	-		G	-	-	-		-	-		-	G	

Table 13. *Significant relations for field constituents from wells among 13 hydrogeologic units in the Piedmont Lowland Section of the Piedmont Physiographic Province, Pennsylvania*

[Table is read from top down. Example, field specific conductances are significantly greater in the Ledger Formation than the Cocalico Formation, but are significantly less than in the Zooks Corner Formation. G, greater; L, less; -, insufficient data; blank indicates no significant differences between units]

VNTG, Vintage Formation; KZRS, Kinzers Formation; LDGR, Ledger Formation; ZKCR, Zooks Corner Formation; BSPG, Buffalo Springs Formation; ELBK, Elbrook Formation; SZCK, Snitz Creek Formation; MLBC, Millbach Formation; SNNG, Stonehenge Formation; EPLR, Epler Formation; ONLN, Ontelaunee Formation; CNSG, Conestoga Formation; CCLC, Cocalico Formation

	VNTG	KZRS	LDGR	ZKCR	BSPG	ELBK	SZCK	MLBC	SNNG	EPLR	ONLN	CNSG	CCLC
SPECIFIC CAPACITY													
VNTG													
KZRS													
LDGR	L												
ZKCR	L	L	L										
BSPG	L	L	L										
ELBK													
SZCK	-	-	-	-	-	-							
MLBC	L						-						
SNNG	L	L					-						
EPLR	L	L					-						
ONLN	-	-	-	-	-	-	-	-	-	-			
CNSG	L			G	G		-				-		
CCLC			G	G	G	G	-	G	G	G	-	G	
HARDNESS													
VNTG													
KZRS													
LDGR	L	L											
ZKCR	L	L	L										
BSPG	L	L	L										
ELBK													
SZCK	-	-	-	-	-	-							
MLBC	L						-						
SNNG	L	L					-						
EPLR	L	L			G		-						
ONLN	-	-	-	-	-	-	-	-	-	-			
CNSG	L	L		G	G		-				-		
CCLC			G	G	G		-	G	G	G	-	G	
pH													
VNTG													
KZRS													
LDGR													
ZKCR													
BSPG													
ELBK													
SZCK	-	-	-	-	-	-							
MLBC	-	-	-	-	-	-	-						
SNNG	-	-	-	-	-	-	-	-					
EPLR	-	-	-	-	-	-	-	-	-				
ONLN	-	-	-	-	-	-	-	-	-	-			
CNSG							-	-	-	-	-		
CCLC	-	-	-	-	-	-	-	-	-	-	-	-	

GEOHYDROLOGY OF THE PIEDMONT PHYSIOGRAPHIC PROVINCE, GETTYSBURG-NEWARK LOWLAND SECTION

Location and Geographic Setting

The Gettysburg-Newark Lowland Section is part of the Piedmont Physiographic Province as originally described by Fenneman (1938). Berg and others (1989) have redefined the Gettysburg-Newark Lowland Section in Pennsylvania and their delineation is used throughout this report (fig. 1). In Pennsylvania, the Gettysburg-Newark Lowland Section occupies about 2,050 mi^2 of south-central and southeastern Pennsylvania (figs. 1 and 56). It consists of parts of two basins—the Gettysburg Basin in the west and the Newark Basin in the east that are joined by a narrow neck of Triassic sediments (Berg and others, 1980). The Gettysburg-Newark Lowland includes parts of Adams, York, Cumberland, Dauphin, Lancaster, Lebanon, Berks, Chester, Montgomery, Lehigh, and Bucks Counties. To the south, the Gettysburg-Newark Lowland extends into Maryland, and to the east it extends into New Jersey. The igneous and metamorphic rocks of the Piedmont Upland border the area to the southeast, and to the northwest the area is bounded by South Mountain of the Blue Ridge Physiographic Province, the Great Valley Section of the Ridge and Valley Physiographic Province, and the Reading Prong Section of the New England Physiographic Province (fig. 1).

The Gettysburg-Newark Lowland is characterized by a gently rolling topography of low to moderate relief with broad, shallow valleys and low ridges. The minimum altitude is about 40 ft above sea level, and the maximum altitude is about 1,355 ft above sea level (Berg and others, 1989). Many of the higher ridges are underlain by more resistant bedrock such as diabase dikes.

The eastern third of the Gettysburg-Newark Lowland is generally more developed than the central and western parts, including the communities of Pottstown, Norristown, Southampton, and Quakertown. Some of the principal population centers in the central and western part of the basin include Elizabethtown, Middletown, and Gettysburg. The western and central parts of the Gettysburg-Newark Lowland are predominantly rural; land is used mostly for forest and agricultural purposes (fig. 56).

The climate in the Gettysburg-Newark Lowland is humid continental; precipitation averages about 41 to 45 inches per year. Summer and winter mean temperatures are 24 and 0°C, respectively. Prevailing winds are from the west to northwest (Pennsylvania Department of Environmental Resources, 1979, 1980, 1983a, 1983b).

Water-Well Density

The location of 4,152 wells used in the analysis of the Gettysburg-Newark Lowland are shown in figure 57. The distribution of wells is related to the location of historical studies, population density, the availability of public supples, and USEPA site investigations. The highest density of inventoried wells are from Chester (4.7 well per square mile) and Lancaster (3.5 wells per square mile) Counties. Adams (1.4 wells per square mile) and Berks (1.1 wells per square mile) have the lowest well densities.

Previous Work

Some of the earliest geological work was done by Kummel (1897), Bascom (1904), and Bascom and others (1909). Stose and Bascom (1929), Stose (1932), Stose and Jonas (1933; 1939), and Stose and Stose (1944) extended the earlier geologic work. More recent geologic investigations include the work of Willard and others (1959), Faill (1973), Turner-Peterson and Smoot (1985), and Root (1989). Weems and Olsen (1997) have proposed to redefine the Newark Supergroup to emphasize stratigraphic and tectonic elements common to all 29 early Mesozoic rift basins exposed in eastern North America.

Hall (1934) briefly discussed the water-bearing characteristics of the major geological formations of southeastern Pennsylvania. Greenman (1955), Rima and others (1962), Wood and Johnston (1964), Longwill and Wood (1965), Johnston (1966), McGreevy and Sloto (1977), Wood (1980), Taylor and Royer

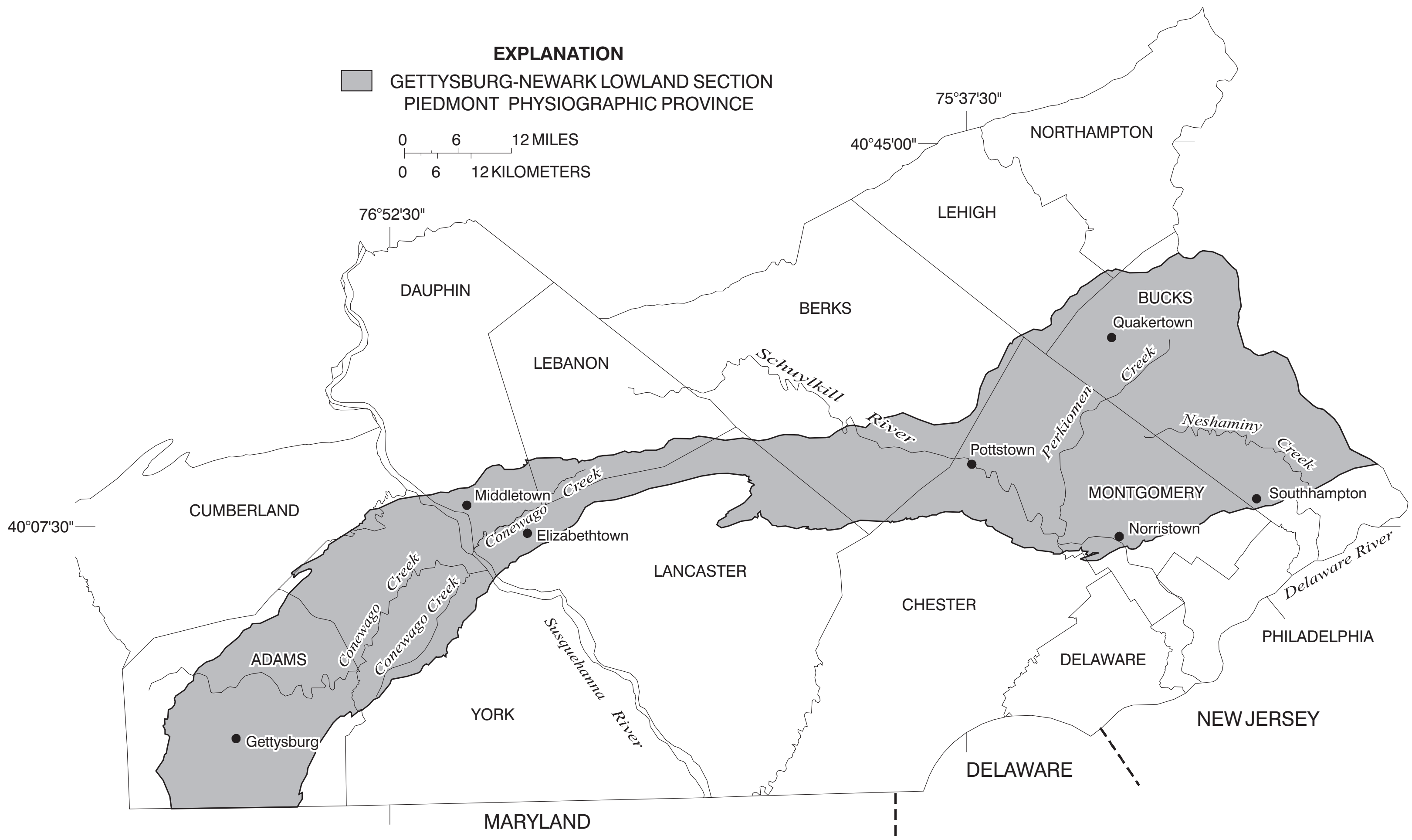


Figure 56. Piedmont Physiographic Province, Gettysburg-Newark Lowland Section, major streams, counties, and major population centers.

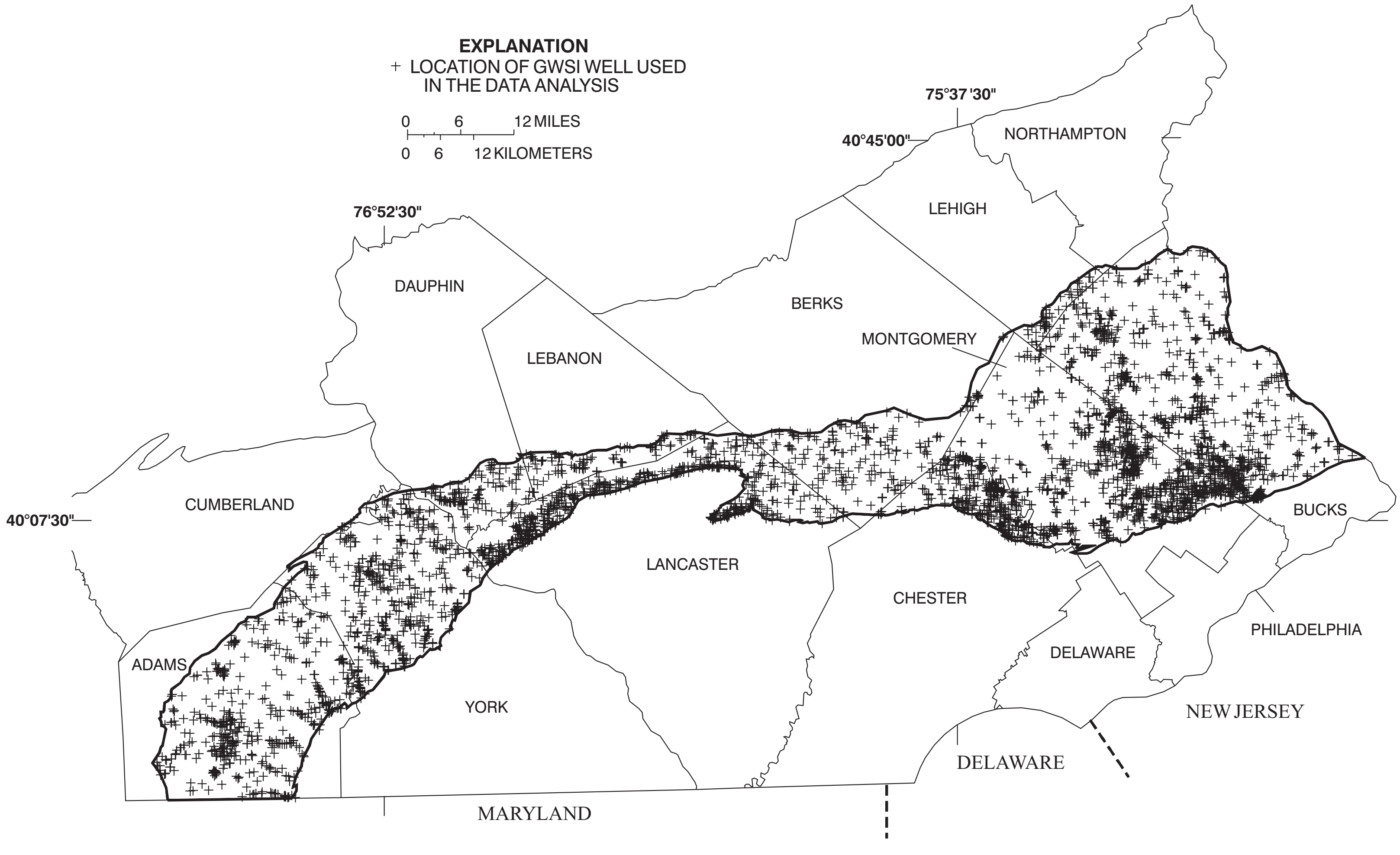


Figure 57. Locations of wells in the Piedmont Physiographic Province, Gettysburg-Newark Lowland Section.

(1981), Sloto and Davis (1983) added to our understanding of the area's hydrogeology. A more regional discussion of the geology and hydrogeology is available in Parker and others (1964) and Taylor and Werkheiser (1984).

Gerhart and Lazorchick (1984b) evaluated the ground water in a small part of the Newark Basin in Lancaster and Berks Counties using a digital flow model. Gerhart and Lazorchick (1988) later expanded their model to include the Lower Susquehanna River Basin.

Geologic Setting

The Gettysburg-Newark Lowland is composed of Upper Triassic and Lower Jurassic sedimentary rocks and Lower Jurassic age diabase (Lyttle and Epstein, 1987). The sedimentary rocks lie unconformably on strongly folded and deeply eroded Paleozoic and Precambrian Rocks (Rima and others, 1962, p. 6). The sediments were deposited principally by streams and rivers that originated in nearby uplands and discharged into lakes or swamps in a down-warping basin formed as eastern North America rifted from western Africa (Johnston, 1966, p. 8; Swanson, 1986). Smoot (1991) has divided the sedimentary rocks into four principal lithofacies: (1) alluvial-fan, (2) fluvial, (3) lacustrine, and (4) lake margin clastic. Detrital cycles have been mapped and identified in the Lockatong and Brunswick Formations; chemical cycles are common in the Lockatong Formation (Lyttle and Epstein, 1987). The intrusion of diabase dikes and sills occurred during the late stages of sedimentary deposition and at the completion of deposition. Following deposition, the basins were simultaneously faulted and folded to form a northwestward dipping homocline (Faill, 1973, p. 725). Ratcliff and others (1986), confirmed that the Newark Basin border faults dip 25 to 35° to the southeast and that it appeared that reactivation of Paleozoic thrusts controlled the formation of the border faults in eastern Pennsylvania.

In some formations, conglomerates are mapped as individual members; near basin borders the conglomerates commonly include clasts from older Paleozoic rocks. The New Oxford and Gettysburg Formations are present in the Gettysburg Basin; the Stockton, Lockatong, and Brunswick Formations occupy the Newark Basin (table 14). In the narrow neck between basins, the Hammer Creek and New Oxford Formation are present (Berg and others, 1980). The lateral extent of these formations is arbitrary in some cases, as many of the contacts are gradational in nature. The southern border of the Gettysburg-Newark Lowland is marked by an unconformable boundary with the igneous and metamorphic rocks of the Piedmont Upland and carbonate rocks of the Piedmont Lowland. The northern boundary of the Gettysburg-Newark Lowland is marked by normal faults in some places; in other areas an unconformable

Table 14. *Generalized stratigraphic section of the Piedmont Physiographic Province, Gettysburg-Newark Lowland Section in Pennsylvania*

[Modified from Berg and others, 1983; Lyttle and Epstein, 1987.]

<table>
<tr><th rowspan="2">Age</th><th colspan="3">Geohydrologic unit</th></tr>
<tr><th>Newark Basin</th><th></th><th>Gettysburg Basin</th></tr>
<tr><td>Lower Jurassic</td><td>Diabase (TRd)</td><td></td><td>Diabase (TRd)</td></tr>
<tr><td>Lower Jurassic and Upper Triassic</td><td>Brunswick Formation (TRb)</td><td rowspan="3">Hammer Creek Formation (TRh)</td><td>Gettysburg Formation (TRg)</td></tr>
<tr><td rowspan="2">Upper Triassic</td><td>Lockatong Formation (TRl)</td><td rowspan="2">New Oxford Formation (TRn)</td></tr>
<tr><td>Stockton Formation (TRs)</td></tr>
<tr><td>Paleozoic and older rocks</td><td colspan="3">Unconformity</td></tr>
</table>

boundary is present. The rocks of the Gettysburg-Newark Lowland have been tilted to form a northwestward dipping homocline with an average dip of about 25° for rocks west of the Susquehanna River (Wood and Johnston, 1964, p. 8) becoming less steeply dipping east of the Susquehanna River.

Hydrologic Setting

The Potomac, Susquehanna, and Delaware Rivers are the major rivers flowing through the Gettysburg-Newark Lowland. The Schuylkill River, a tributary of the Delaware River, also flows through the Gettysburg-Newark Lowland. It drains about a quarter of the area. Other streams draining the area include Conewago, Perkiomen, and Neshaminy Creeks (fig. 56).

The Gettysburg-Newark Lowland is generally well drained by a dendritic drainage pattern. However, as a result of relatively low storage and recharge rates streams tend to be flashy, that is, to have higher flood flows and lower low flows compared to streams in other areas (Pennsylvania Department of Environmental Resources, 1983b, p. 17). Parker and others (1964) noted that the permeability of the Stockton Formation and its thicker soil limits the rapid runoff of surface water. Whereas the low infiltration capacity, thin, poorly permeable clayey soils, and low ground-water storage of the Lockatong and Brunswick Formations favor rapid surface-water runoff.

The Gettysburg-Newark Lowland receives nearly equal amounts of precipitation throughout the year. The precipitation that does not evaporate or flow as overland runoff, infiltrates into the regolith and the underlying bedrock. After reaching the saturated zone, ground water moves from areas of high hydraulic head to areas of lower hydraulic head and eventually returns to land surface through wells, springs, or streams. Ground water discharged to streams as base flow is important to maintain adequate usable streamflow and for dilution of effluents discharged during periods of little precipitation. Wood (1980, p. 10-12) noted that base flow is higher for streams draining the Hammer Creek Formation than the Gettysburg Formation; for the West Conewago Creek Basin, base flow averages about 6 in / year. Gerhart and Lazorchick (1988, p. 27-28), using annual precipitation, base flow, and lithologies, estimated that average annual base flow as a percentage of precipitation in the Gettysburg-Newark Lowland ranged from about 15 to 25 percent.

The most productive bedrock aquifers in the Gettysburg-Newark Lowland are the Stockton and Brunswick Formations. The least productive bedrock aquifer is the Diabase. Rock units dominated by poorly cemented and well sorted sandstone and conglomerate are more productive than rock units that consist mainly of shale or siltstone.

Geohydrologic System

Ground-water flow in the Gettysburg-Newark Lowland is dominated by local flow largely controlled by topography (fig. 58). The shallow system discharges locally to nearby streams and springs. Deeper, regional ground-water flow is directed to the major streams such as the Susquehanna, Delaware, and Schuylkill Rivers. Ground-water divides may not coincide with surface-water divides and may be different for each major water-bearing zone (aquifer) of ground-water flow (Sloto, 1994, p. 31).

Precipitation is the principal source of water that enters the ground-water flow systems. Much of the recharge to ground water is from late fall to early spring, resulting in a rising water table. During the remainder of the year, rapid plant growth contributes to high evapotranspiration rates, creating soil-moisture deficits that greatly reduce the recharge reaching the ground-water systems, resulting in a lower water table.

The water-table surface is a subdued replica of the land surface. Water levels generally are closest (shallowest) to land surface in valleys (discharge areas) and deepest on hilltops (recharge areas). Commonly, the water table more closely replicates topography in aquifers with low permeability and storage than in aquifers with high permeability and storage.

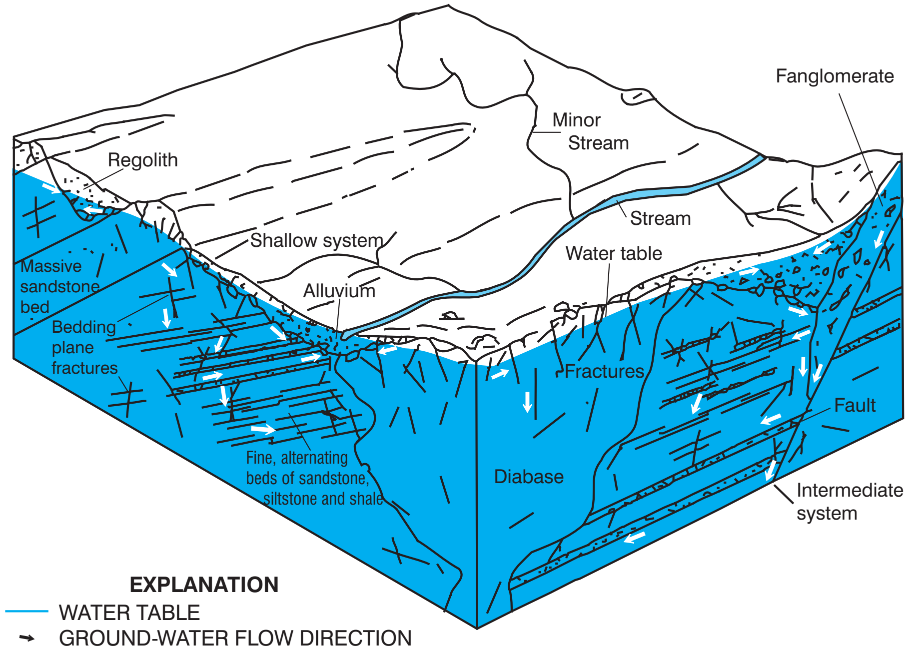


Figure 58. Topographic, geologic, and hydrologic features of the Piedmont Physiographic Province, Gettysburg-Newark Lowland Section.

Regolith

In the Gettysburg-Newark Lowland, regolith underlies the land surface almost everywhere. It is composed of granular to clayey soil and saprolite, and disaggregated bedrock. The regolith may also include deposits of colluvium on slopes and alluvium in valley bottoms. Regolith permits infiltration of precipitation and can store large quantities of water in intergranular pores, although considerably less than for areas with different parent material (Gerhart and Lazorchick, 1988, table 12; Sloto and Davis, 1983, p. 32; Wood, 1980, p. 16). These pores then slowly release water to the underlying, fractured bedrock. The amount of porosity in regolith typically far exceeds that of the underlying fractured bedrock, but the saturated regolith by itself commonly is not thick or permeable enough to provide sustained yields of ground water to wells.

In the regolith, ground water generally flows down slope and its movement is probably less complex than in the fractured bedrock. However, the direction and rate of ground-water flow can be affected by the amount of weathering, composition of the parent rock, the presence of shear zones, bedding planes, joints, cementing material, and intergranular openings. In some highly weathered arkosic or subarkosic sandstones and conglomerates, clays produced by the alteration of feldspars can reduce the permeability of the rock or prevent any significant increase in permeability (Johnston, 1966, p. 16-19).

Thickness of regolith and saturated (casing depth-static water level) regolith varies according to the underlying geohydrologic unit and topographic setting. The median thickness of regolith, estimated from the depth of casing in 1,038 domestic wells completed in the sedimentary rocks, is 35 ft; it is 27 ft for 155 domestic wells completed in the Diabase of the Gettysburg-Newark Lowland. Regolith thickness is least in the New Oxford Formation and greatest in the Hammer Creek Formation. Valleys have a greater thickness of saturated regolith than slopes or hilltops. Johnston (1966, p. 16-17) found that the saturated thickness of the regolith is greatest in the winter and spring and least in the summer and fall.

Fractured bedrock

Ground water in fractured bedrock of the Gettysburg-Newark Lowland generally moves through and is stored in networks of narrow secondary openings, such as bedding planes and joints; faults appear to be mostly barriers to flow (C.R. Wood, U.S. Geological Survey, written commun., 1997). Intergranular spacing in sandstones and conglomerates, and dissolution of cements can provide additional, but minor flow paths.

Ground-water flow in the fractured bedrock is very complex, anisotropic, and heterogeneous. Horizontal permeability is much greater than vertical permeability. Wood (1980, p. 17) described an aquifer test which indicated that the ratio of horizontal to vertical permeability was in excess of 100:1. In addition, permeability is generally greatest parallel to the strike of the bedding and lowest perpendicular to the plane of the bedding. Gerhart and Lazorchick (1984b, p. 27) estimated that the ratio between the hydraulic conductivity in the direction parallel to strike and perpendicular to strike is 5:1.

Continuity of individual beds is highly variable and limited by faults, diabase intrusions, thinning, and lateral gradations. Thick, massive beds, are less fractured and contain fewer joints than thinner beds. Siltstones and shales, which are generally less affected by weathering and deformation, commonly have fewer and poorly developed fractures than thin, hard sandstone and conglomerate beds (Wood, 1980, p. 16). Many of the beds are more or less continuous along strike and extend downdip for hundreds to thousands of feet below land surface (Wood, 1980, p. 16). Beds in the Brunswick and Lockatong Formations, however, are more continuous than in the Stockton Formation (Sloto, 1994, p. 31).

Several similar physical models of ground-water flow have been proposed for different units in the Gettysburg-Newark Lowland. Parker and others (1964, p. 84) considered most of the water in the Stockton Formation to be semiconfined or confined with shale and poorly permeable sandstones and conglomerates acting as confining layers. Wood (1980, p. 16-17) described the Gettysburg and Hammer Creek Formations as consisting of many overlapping, lens-shaped beds that form local, discontinuous, tabular aquifers which are in poor hydraulic connection. According to Parker and others (1964, p. 87) most of the water in the Lockatong Formation occurs near land surface in the weathered zone under unconfined or semiconfined conditions. Rima (1955), who studied the Brunswick Formation near Lansdale, Pa., described a weathered, unconfined upper aquifer with a maximum thickness of 250 ft and a lower zone that extended to a maximum depth of about 600 ft. Within this lower zone, numerous confined or semiconfined aquifers exist, each of which generally is less than 20 ft thick. Michalski (1990) argued for a leaky, multizone aquifer system for the Brunswick Formation. In this model, the thin aquifers are separated by much thicker, strata-bound, aquitards without any upper and lower zones. The Diabase can act as a barrier to flow (Becher and Root, 1981, p. 19; Wood, 1980, p. 29).

Although it is not possible to establish an exact thickness or maximum depth of the ground-water system, several methods can provide useful information. These methods include borehole temperature logs, borehole velocity measurements, heatpulse flowmetering, and depth distributions of water-bearing zones reported by well drillers.

Utilizing temperature logs, 13 wells in the Gettysburg-Newark Lowland have been identified as reaching geothermal gradient. Of the 13, only 1 reached gradient at a depth of 250 ft or less, indicating deeper ground-water flow is common. In the Brunswick Formation, the USGS logged a well completed at a depth of 587 ft. Analysis of the borehole temperature log indicated water was entering the borehole at a depth of about 584 ft and moving upward (R.W. Conger, U.S. Geological Survey, written commun., 1996).

Evidence for a deep, fresh-water flow system is found in the presence of water-bearing zones yielding fresh water at depths as great as 445 ft in the Hammer Creek Formation to 900 ft in the Gettysburg Formation. Fresh water has been reported to be present as deep as 2,300 ft (Wood, 1980, p. 36). Wood (1980, p. 18) reported that tests to measure vertical flow direction in wells showed that of seven wells tested which had downward flow, four were in valleys. This indicates that not all water discharges to local stream valleys and suggests that there is considerable lateral flow beneath some streams. Bain (1972, p. 100) concluded that the depth of potable water is somewhere between 1,000 and 2,000 ft.

Stockton Formation (TRs)

The Stockton Formation underlies about 240 mi^2 of the Gettysburg-Newark Lowland Section in Berks, Bucks, Chester, and Montgomery Counties (Berg and others, 1980). The reference section is north of Valley Forge along the Schuylkill River and along a railroad cut west of the Schuylkill River in Montgomery County; the type locality is near Stockton, N.J. (Kummel, 1897, p. 35-36).

Geologic description.—The Stockton Formation is light- to medium-gray, orange, brown, red, thin- to thick-bedded, fine- to very-coarse grained arkosic sandstone, arkosic conglomerate, shale, and siltstone. Individual beds in this formation typically grade from coarse- to fine-grained over rather short lateral distances; however, lithologic units may be as thick as 120 ft. These rocks contain channels, ripple marks, mudcracks, crossbeds, pinch-and-swell structures, and minor burrows. Pinch outs, interbedding, crossbedding, and lensing are also common (Willard and others, 1959, p. 65). Rima and others (1962) have, on the basis of lithology and grain size, identified three members: (1) the lower arkose member, (2) the middle arkose member, and (3) the upper shale member; Lyttle and Epstein (1987) provided thickness estimates for each of the three members. The formation thins westward from a thickness of more than 6,000 ft (the center of the basin) near the Montgomery-Bucks County line to 2,300 ft at Phoenixville.

The sandstone, shale, and siltstone of the Stockton Formation is only slightly resistant to weathering, forming undulating valleys of low relief. Joints are poorly formed with a seamy to platy pattern, highly fractured, and generally open. The conglomerate is moderately resistant to weathering and forms undulating hills of low relief. Joints are moderately well developed and open (Geyer and Wilshusen, 1982, p. 267-269). Thickness of the regolith is generally thin; ridges and valleys commonly parallel the strike of the beds.

The Stockton Formation is of Upper Triassic age and is the lowermost formation of the Newark Supergroup in the Newark Basin (Lyttle and Epstein, 1987). The formation unconformably overlies Precambrian and Paleozoic rocks. Lyttle and Epstein (1987) stated that the Hammer Creek Formation is a partial lateral correlative and unconformably overlies the Stockton Formation. The Stockton Formation interfingers with and grades into the overlying Lockatong Formation. Rima and others (1962, p. 18) considered the upper shale member of the Stockton Formation to be a transition zone between typical Stockton sediments and typical Lockatong sediments. They have drawn the contact where the upper shale member does not appear to contain arkosic beds and the base of the lowermost black argillite bed. The Stockton Formation is the lateral equivalent to the New Oxford Formation in the Gettysburg Basin. Depositional environments of the Stockton Formation include alluvial fans, fluvial, marginal lacustrine, and nearshore lacustrine (Turner-Peterson, 1980; Turner-Peterson and Smoot, 1985).

Well depths and casing lengths.—Depths of wells completed in the Stockton Formation are presented in the table below.

Reported well depth, Stockton Formation

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	798	80	104	185	350	484	27	1,500
Drilled, domestic	336	70	87	110	150	207	27	660
Drilled, high-demand	314	120	204	306	450	529	52	902

Topographic setting can affect well depth. Domestic wells drilled on slopes (213 wells) are completed to significantly greater depths than in valleys (41 wells). The median depth of domestic wells on slopes is 120 ft, and, in valleys, the median is 90 ft.

Casing lengths for wells completed in the Stockton Formation are presented in the table below.

Reported casing length, Stockton Formation

[Casing length in feet; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	449	22	30	41	60	76	6	330
Drilled, domestic	169	23	30	39	51	66	6	150
Drilled, high-demand	209	23	38	50	62	82	10	330

Hydrologic properties .—Water levels for wells completed in the Stockton Formation are presented in the table below. Depths to water in 580 wells range from 12 ft above land surface to 203 ft below land surface; the median is 24 ft below land surface. Of the 14 flowing wells, 6 are on slopes and 5 are in valleys.

Water levels, Stockton Formation

[Water levels in feet below land surface; -, flowing well with feet above land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	73	18	25	40	55	102	6	170
Slope	275	9	15	24	40	62	-4	203
Valley	127	3	8	15	27	54	-12	100

Reported yields for wells completed in the Stockton Formation are presented in the table below. Yields of 5.0 gal / min or less are reported from 31 wells; 23 are domestic wells. Most (230 wells) of the 250 wells with reported yields of 100 gal / min or greater are deeper than 200 ft.

Reported well yield, Stockton Formation

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	605	10	18	60	170	340	1.5	1,370
Domestic	203	5.0	10	15	25	50	2.0	350
High-demand	317	25	60	148	261	414	2.0	1,370

According to Rima and others (1962, p. 45), the middle arkose member has the highest yields in the Stockton Formation and the upper shale member the lowest yields. However, an analysis of yield by lithology seems to contradict this observation. High-demand wells drilled in shale (10 wells) have considerably greater reported yields than high-demand wells drilled in sandstone (14 wells); the median yields are 170 and 58 gal / min, respectively. Yields of domestic wells drilled in shale (25 wells) are approximately equal to the yields of domestic wells drilled in sandstone (27 wells); the medians are 15 gal / min.

Topographic setting can affect yield. Drilled domestic wells on hilltops have significantly lower reported yields than in valleys. The median reported yields of domestic wells on hilltops (23 wells), slopes (129 wells), and valleys (25 wells) are 12, 15, and 18 gal / min, respectively. Rima and others (1962, fig. 2) provide additional information on the relation between topography, lithology, and well yield.

Well yields can vary significantly spatially. Wells in Bucks (248 wells) and Montgomery (257 wells) Counties have significantly greater reported yields than wells in Chester County (87 wells). The median reported yields for wells in Bucks County is 90 gal / min; in Chester County, 20 gal / min; and in Montgomery County, 60 gal / min.

Specific capacities of wells completed in the Stockton Formation are presented in the table below. Specific capacities of 1.0 (gal / min) / ft or greater are reported from 111 wells; 106 are deeper than 200 ft. Specific capacities of wells with pumping durations of 8 hours or longer (143 wells) range from 0.10 to 75 (gal / min) / ft; the median is 1.5 (gal / min) / ft.

Reported specific capacity, Stockton Formation

[Specific capacity in gallons per minute per foot of drawdown; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	180	0.35	0.73	1.3	3.7	7.4	0.07	75
Domestic	31	.11	.17	.40	.80	2.3	.09	7.4
High-demand	143	.61	.91	1.7	4.2	8.6	.07	75

Rima and others (1962, p. 24-25) reported that the middle member, which is characterized by well sorted and weakly cemented sandstones interbedded with shale, has the highest average specific capacity [5.0 (gal / min) / ft]. The lower arkose member, which consists mainly of poorly sorted and weakly cemented conglomerate and sandstones, has the second highest average specific capacity [3.0 (gal / min) / ft]. The upper shale member has the lowest specific capacity [0.5 (gal / min) / ft].

At the Fischer and Porter Superfund Site in Warminster, Bucks County, Pa., Sloto and others (1995) conducted aquifer-isolation (packer) tests on six boreholes to obtain depth-discrete specific-capacity data. Specific capacities from 29 isolated zones with packer settings from 72 to 305 feet below land surface ranged from 0.01 to 8.7 (gal / min) / ft; the median was 0.055 (gal / min) / ft. On the basis of these tests, Sloto and others (1995, p. 52) concluded that specific capacity is not related to depth.

Aquifer-isolation (packer) tests also were conducted on five zones in the former John Wagner and Sons, Inc. production well, Ivyland, Pa. (Sloto, 1997b). The lowermost three zones (below 248, 223-248, and 198-223 ft below floor level) were hydraulically isolated from zones above and below; average specific capacities were 0.12, 0.034, and 0.15 (gal / min) / ft, respectively. The remaining two zones (81-106 and 57-81 ft below floor surface) are in the unconfined part of the Stockton Formation; the average specific capacities were 0.82 and 0.61 (gal / min) / ft, respectively.

Values of hydraulic conductivity and transmissivity for the Stockton Formation are presented below; a specific yield of 0.007 was used in estimating these hydrologic properties. Hydraulic conductivity and transmissivity are generally lower on hilltops and slopes than in valleys. The median hydraulic conductivity of wells on hilltops (22 wells), slopes (58 wells), and valleys (67 wells) in the Stockton Formation are 1.5, 1.1, and 1.6 ft / d, respectively. The median transmissivity of wells on hilltops is 320 ft^2 / d; on slopes, 160 ft^2 / d; and in valleys, 420 ft^2 / d.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Stockton Formation

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	174	0.25	0.50	1.2	3.0	8.0	0.04	93
Transmissivity (ft^2 / d)	174	66	140	290	850	1,700	5.8	21,000

Rima and others (1962, table 4) conducted laboratory tests for porosity, specific yield, and hydraulic conductivity (permeability) on 12 rock samples from the Stockton Formation. The specific yield on the 12 weathered or exposed rock samples ranged from 0.00 to 0.193; the median was 0.079. Hydraulic conductivity in the horizontal direction on 11 samples ranged from 0.00013 to 0.053 ft / d; the median was 0.0013 ft / d. Hydraulic conductivity in the vertical direction on 11 samples ranged from 0.00004 to 0.027 ft / d; the median was 0.00094 ft / d. Rima and others (1962, table 5) also conducted several single- and multiple-well aquifer tests. The specific storage ranged from 0.00002 to 0.0014; the median was 0.0002. Transmissivity ranged from 134 to 3,210 ft^2 / d; the median was 2,210 ft^2 / d.

Gerhart and Lazorchick (1984b, tables 6 and 14) developed a digital model for parts of Lancaster and Berks Counties, Pa. In their model, Gerhart and Lazorchick used a specific yield of 0.012 and a hydraulic conductivity of 1.2 ft / d for a block that consisted of the Stockton and New Oxford Formations. In an east-west and north-south direction, the hydraulic conductivities were 2.00 and 0.40 ft / d, respectively. For the Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, p. 38) estimated a specific yield of 0.007 for the upper 300 ft and a storage coefficient of 0.00007 for the lower 300 ft. They also used hydraulic conductivities of 0.40 and 3.34 ft / d for different hydrogeologic units that included the Stockton Formation (Gerhart and Lazorchick, 1988, p. 22).

Urban and Gburek (1988) estimated hydraulic conductivities, transmissivities, and specific yields of a sandstone bed near Willow Grove, Pa. Vertical hydraulic conductivities from 13 cores collected at depths of 2.2 to 19 ft ranged from 0.0696 to 0.135 ft / d; the median was 0.860 ft / d. Horizontal hydraulic conductivities from 12 cores collected at depths of 2.2 to 19 ft ranged from 0.788 to 0.141; the median was 0.0929 ft / d. Hydraulic conductivities, transmissivities, and specific yields from multiple-well aquifer tests, slug tests, and recharge methods varied by approximately an order of magnitude from that derived from the cores. Hydraulic conductivities ranged from 0.16 to 8.45 ft / d; the median was 1.60 ft / d. Transmissivities ranged from 2.59 to 155 ft^2 / d; the median was 47.1 ft^2 / d. Specific yields ranged from 0.00024 to 0.034; the median was 0.0035.

In his work on the Valley Creek Basin in eastern Chester County, Sloto (1989, table 10) estimated a hydraulic conductivity of 8.0 ft / d for the Stockton Formation. A specific yield of 0.08, estimated from change in ground-water storage in the water budgets, was used in the digital model.

Hydrologic properties of the rock matrix were determined by Sloto and others (1996, table 1) from two cores collected at the Raymark Superfund Site, Hatborough, Montgomery County, Pa. Average porosity was 3 percent for siltstone; 22.5 percent for silty, fine-grained sandstone; 9.6 percent for fine-grained sandstone; 8.6 percent for medium-grained sandstone; and 5.6 percent for coarse-grained sandstone (Sloto and others, 1996, fig. 15). Porosity was considerably greater in the horizontal direction than in the vertical direction. Hydraulic conductivity determined in the laboratory from four rock cores were 0.000118 ft / d for a gray, fine-grained sandstone; 0.00000292 ft / d for a red, silty, fine-grained sandstone; 0.000000514 ft / d for a red siltstone; and 0.19 ft / d for a medium- to coarse-grained sandstone, with some cement removed.

Sloto and Schreffler (1994, table 5) analyzed recovery data from seven long-term (48- or 72-hour) aquifer tests that were done by environmental consulting firms. The transmissivities calculated by use of the Theis (1935) recovery method ranged from 260 to 1,800 ft^2 / d; the median was 410 ft^2 / d.

The depths of water-bearing zones in 130 wells drilled as deep as 550 ft range from 8 to 454 ft below land surface. Fifty percent of the 388 water-bearing zones reported are penetrated by a depth of 97 ft and 90 percent by a depth of 265 ft. The greatest density of water-bearing zones (1.14 per 50 ft of well depth) is from 51 to 100 ft below land surface (fig. 59). The density of water-bearing zones at depths of 351 ft or greater are based on the presence of four or fewer water-bearing zones per 50-ft interval. The overall density of water-bearing zones in the Stockton is 0.66 per 50 ft of well depth.

Sloto and others (1998) investigated the geohydrology and distribution of volatile organic compounds in ground water in the vicinity of Casey Village, Bucks County, Pa. They determined that, in general, the sandstone beds were the major water-bearing units. Siltstone beds were only a minor source of water as these beds weathered easily and were finer grained, which favored clogging of minor

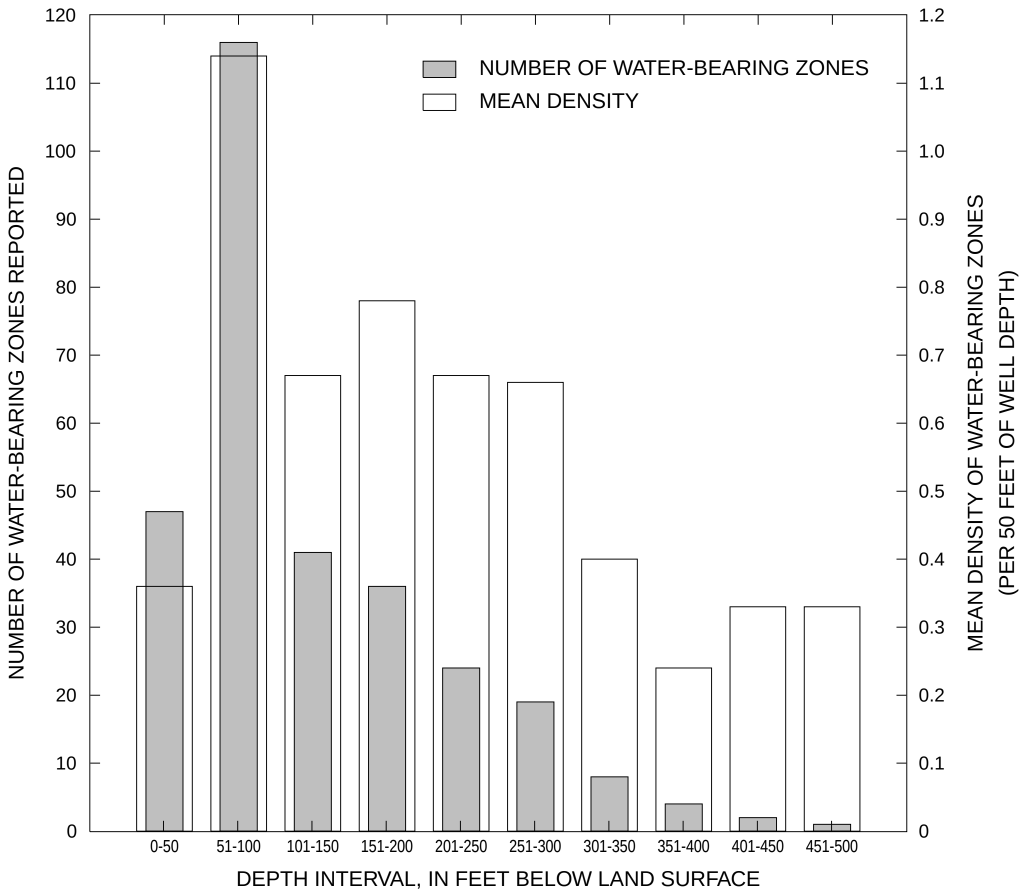


Figure 59. Number and density of water-bearing zones per 50 feet of well depth in the Stockton Formation of the Piedmont Physiographic Province, Gettysburg-Newark Lowland Section.

openings. Siltstone beds, unlike sandstone beds, deformed without breaking, which reduced the formation of secondary openings. Near horizontal fractures were observed within beds and at the contact between beds of differing lithology. Steeply dipping or nearly vertical fractures within sandstone beds were commonly water-bearing zones. Multiple-well aquifer tests in three lithologic units produced elliptical drawdown patterns that indicated anisotropy, however, the anisotropy was not aligned with strike or dip. Sloto and others (1998, p. 59) concluded that the response to pumping was "* * * controlled as much or more by depth of water-bearing zones below land surface than by geologic unit."

In the Hatborough and Warminster Township areas, ground-water flow is very complex (Sloto and others, 1996). Borehole flow, from wells drilled 31 to 591 ft deep, was measurable in 65 of 93 boreholes; no flow was measured in 19 boreholes and could not be determined for 9 other boreholes. Downward flow was measured in 36 boreholes and upward vertical flow was measured in 23 boreholes; 6 wells had upward and downward vertical flow.

Borehole geophysical logs were run in 12 wells at the Fischer and Porter Company Superfund Site in Warminster, Bucks County, Pa., by the USGS (Sloto and others, 1995). Brine testing of six wells indicated that most wells showed downward vertical flow, primarily caused by a downward head gradient formed in response to the pumping of public supply wells in the area. One well, BK-372 showed upward vertical flow at depths of 250, 355, and 400 ft below land surface under pumping conditions, but no vertical flow under nonpumping conditions.

Geophysical logging, borehole television surveys, and heatpulse flowmetering were used to identify water-bearing zones at the Willow Grove Naval Air Station, Montgomery County, Pa. and the former U.S. Naval Air Warfare Center in Warminster, Bucks County, Pa. (Conger, 1997a; 1998). The 21 wells investigated at the Willow Grove Naval Air Station range in depth from 73 to 148 ft below land surface. In general, under ambient conditions ground-water flow is downward, however, in three wells in topographic lows, ground-water flow was upwards. Three other wells exhibited upward and downward flow components. Water may enter the boreholes at depths as shallow as 19 ft or as deep as 156 ft. Water-receiving zones were as shallow as 14 ft below land surface and as deep as 149 ft below land surface. The 10 wells investigated at the former U.S. Naval Air Warfare Center range in depth from 69 to 300 ft below land surface and exhibit a complex pattern of vertical flow as well as numerous producing and receiving zones under nonpumping conditions. Water enters the boreholes from depths as shallow as 22 ft and as great as 292 ft.

Water quality.—As seen in the following table, wells completed in the Stockton Formation generally yield water that contains low to moderate amounts of dissolved solids, is moderately hard to hard, and is slightly acidic. Calcium is the dominant cation, and bicarbonate is the dominant anion. Elevated concentrations of iron, lead, manganese, and radon and low pH are common water-quality problems in the Stockton Formation. Rima and others (1962, p. 41) reported no significant difference in the chemical makeup of water from the different members of the Stockton Formation. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Stockton Formation

[Concentrations in milligram per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; pCi/L, picoCuries per liter; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	179	—	—	—	250	320	400	120	1,100
Field hardness	191	—	—	—	86	140	170	7.0	1,300
Field pH (standard units)	182	—	<6.5 >8.5	64	6.2	6.9	7.5	4.1	9.1
Bicarbonate	165	—	—	—	64	98	130	6.0	220
Calcium	126	—	—	—	23	40	52	2.0	230
Chloride	171	—	250	0	7.2	13	23	1.2	120
Iron	155	—	.3	24	.010	.050	.14	<.003	4.0
Lead	72	0.015	—	12	.001	.002	.006	<.001	.055
Magnesium	126	—	—	—	8.0	12	17	.70	49
Manganese	119	—	.05	25	.003	.010	.060	<.001	.87
Nickel	24	.1	—	2	.001	.002	.006	<.001	.12
Nitrate (as N)	165	10	—	3	.96	2.1	3.8	.00	17
Potassium	97	—	—	—	.90	1.1	1.6	.30	4.0
Radon (pCi/L)	30	[3] 300	—	30	1,100	1,400	1,700	610	4,100
Silica	123	—	—	—	20	23	26	1.3	52
Sodium	97	—	—	—	9.6	14	20	.70	87
Sulfate	164	—	250	5	19	29	54	2.4	600
Total dissolved solids	157	—	500	11	180	230	310	51	1,040

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.
[3] U.S. Environmental Protection Agency, 1994, proposed maximum contaminant level.

Well location can affect water quality. Rima and others (1962) classified 70 wells in their study as urban, suburban, and rural. They found that rural wells contained water with the lowest median dissolved solids and urban wells had the highest median dissolved solids. Sloto and Davis (1983) evaluated the effects of urbanization on the water resources of Warminster Township in Bucks County. They noted (Sloto and Davis, 1983, p. 41) that for seven wells sampled in 1953 and 1956 by Rima and others (1962), and again in 1979; the median concentration of most dissolved constituents in ground water increased.

Well depth can also affect water quality. Regarding high concentrations of sulfate and dissolved solids, Sloto and Davis (1983, p. 45) suggested that the dissolution of gypsum and anhydrite in the formation may be the source of the sulfate, and that poor or restricted ground-water circulation caused high sulfate and dissolved solids concentrations. Water from wells drilled to depths greater than 400 ft generally contain higher amounts of calcium, chloride, dissolved solids, iron, manganese, sodium, and sulfate and lesser amounts of magnesium, nitrate, potassium, and silica. Pumping of a well over a long period of time may flush the aquifer and lower the sulfate content.

Hammer Creek Formation (TRh)

The Hammer Creek Formation underlies about 130 mi^2 of the Gettysburg-Newark Lowland in Berks, Chester, Lancaster, and Lebanon Counties (Berg and others, 1980). The western most extent of the formation has been arbitrarily drawn at the Dauphin-Lebanon County line and the eastern most extent near the Schuylkill River (Wood, 1980, p. 14). The type section is along Hammer Creek, Lebanon County.

Geologic description.—The Hammer Creek Formation consists of red, brown, and less abundant light gray to gray, very fine to coarse-grained and conglomeratic, thin- to thick-bedded sandstone and thin- to medium-bedded red shale and siltstone. The sandstone exhibits some crossbedding, lensing, channeling, and ripple marks; the shale and siltstone show ripple marks and mudcracks. The Hammer Creek sandstones grade into siltstones having a high percentage of matrix and into conglomerates. The conglomerate member is thick bedded with clasts or interbeds of quartz, quartzite, sandstone, limestone, and shale (Glaeser, 1963). The easily eroded red shale is the dominant rock type in the extreme eastern and western parts of the outcrop belt. Maximum thickness estimates of the Hammer Creek Formation range from about 9,200 to 12,200 ft (Wood, 1980, p. 14).

The Hammer Creek Formation is moderately resistant to weathering, generally forming a rough terrain of high relief. Joints have a blocky pattern, are moderately developed, moderately abundant, and open. Thickness of the regolith is variable and commonly thinner over the conglomerate member (Geyer and Wilshusen, 1982, p. 137-141).

The Hammer Creek Formation is of Upper Triassic age and is the coarser-grained, partial lateral equivalent of the Gettysburg Formation to the west and the Brunswick Formation to the east. Lyttle and Epstein (1987) stated that the formation unconformably overlies Precambrian and Paleozoic rocks and is a partial lateral correlative and unconformably overlies the Stockton Formation and New Oxford Formation.

Well depths and casing lengths.—Depths of wells and casing lengths of wells completed in the Hammer Creek Formation are presented in the table below.

Reported well depths, Hammer Creek Formation

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	291	77	97	133	210	344	38	806
Drilled, domestic	192	68	86	114	158	219	38	505
Drilled, high-demand	50	111	163	252	389	453	91	800

Topographic setting can significantly affect well depth. Drilled domestic wells on hilltops (29 wells) are completed to significantly greater depths than on slopes (122 wells) or in valleys (32 wells). The median depths of domestic wells drilled on hilltops, slopes, and valleys are 160, 118, and 87 ft below land surface, respectively. Casing lengths for wells completed in the Hammer Creek Formation are presented in the table below.

Reported casing lengths, Hammer Creek Formation

[Casing length in feet; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	251	23	34	44	61	91	10	266
Drilled, domestic	170	22	36	43	60	82	10	164
Drilled, high-demand	35	30	34	58	88	138	18	266

Casing length also varies spatially. Wells drilled in Lancaster County (74 wells) use significantly more casing than in Berks (95 wells) and Lebanon (67 wells) Counties; the medians are 50, 40, and 42 ft, respectively. Domestic wells drilled in Lancaster County (57 wells) use significantly more casing than in Berks County (56 wells); the medians are 50 and 36 ft, respectively. According to Wood (1980), caving of the borehole is a problem along some sandstone ridges of the Hammer Creek Formation near the Berks-Lancaster county line.

Hydrologic properties.—Water levels of wells completed in the Hammer Creek Formation are presented in the table below. Depths to water in 239 wells range from 1 to 164 ft below land surface; the median is 30 ft below land surface.

Water levels, Hammer Creek Formation

[Water levels in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	36	21	41	52	86	140	12	164
Slope	147	10	19	34	50	71	1	132
Valley	52	7	11	16	20	33	1	52

Reported yields of wells completed in the Hammer Creek Formation are presented in the table below. Yields of 5.0 gal / min or less are reported from 11 wells; 9 are domestic wells. Twenty-seven of 37 wells with reported yields of 100 gal / min or greater are deeper than 200 ft. Wood (1980, p. 1) reported that “significant yields” are available to a depth of at least 1,000 ft.

Reported well yield, Hammer Creek Formation

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	273	8.0	12	21	50	134	1.0	800
Domestic	184	7.2	10	18	30	45	1.0	150
High-demand	59	25	50	100	230	300	4.0	800

Topographic setting can affect yields. Wells drilled on hilltops (40 wells) or slopes (163 wells) have significantly lower reported yields than wells in valleys (56 wells). The median reported yield of wells on hilltops is 17 gal / min; on slopes, 25 gal / min; and in valleys, 38 gal / min.

Specific capacities of wells completed in the Hammer Creek Formation are presented in the table below. Three wells (drilled to depths of 280, 320, 505 ft) have specific capacities of 0.04 (gal / min) / ft or less and are incapable of meeting most domestic or other water-use demands. Fifteen of 47 wells with specific capacities of 1.0 (gal / min) / ft or greater are deeper than 200 ft. Specific capacities of wells with pumping durations of 8 hours or longer (30 wells) range from 0.30 to 42 (gal / min) / ft; the median is 1.1 (gal / min) / ft.

Reported specific capacity, Hammer Creek Formation

[Specific capacity in gallons per minute per foot of drawdown; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	148	0.14	0.27	0.56	1.3	4.7	0.02	42
Domestic	97	.11	.19	.45	.99	4.1	.02	40
High-demand	37	.32	.69	1.3	3.4	14	.27	42

Values of hydraulic conductivity and transmissivity for the Hammer Creek Formation are presented in the table below; a specific yield of 0.007 was used in estimating these hydrologic properties. Hydraulic conductivity and transmissivity are generally lower on hilltops or slopes than in valleys. The median hydraulic conductivities of wells on hilltops (24 wells), slopes (89 wells), and valleys (31 wells) are 0.41, 1.3, and 1.5 ft / d, respectively. The median transmissivities of wells on hilltops is 46 ft^2 / d; on slopes, 94 ft^2 / d; and in valleys, 160 ft^2 / d.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Hammer Creek Formation

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	145	0.17	0.46	1.2	3.5	17	0.00	640
Transmissivity (ft^2 / d)	145	16	42	94	250	1,000	.64	12,000

In their digital model of parts of Lancaster and Berks Counties, Pa., Gerhart and Lazorchick (1984b, p. 15, tables 6 and 14), estimated an aquifer thickness of 250 ft, a specific yield of 0.012, and a hydraulic conductivity of 1.2 ft / d for a hydrogeologic unit that included the Hammer Creek Formation. Gerhart and Lazorchick also noted that hydraulic conductivity was anisotropic utilizing 2.0 and 0.40 ft / d in an east-west and north-south direction, respectively. For the conglomerate, they estimated a hydraulic conductivity of 2.0 ft / d, with east-west and north-south values of 3.33 and 0.67 ft / d, respectively. In their Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, p. 38) determined a specific yield of 0.007 for the upper 300 ft and a storage coefficient of 0.00007 for the lower 300 ft. They also used hydraulic conductivities of 0.13, 0.40, 2.67, and 3.34 ft / d for different hydrogeologic units that included the Hammer Creek Formation (Gerhart and Lazorchick, 1988, p. 22).

The depths of water-bearing zones in 207 wells drilled as deep as 505 ft range from 5 to 445 ft below land surface. Fifty percent of the 544 water-bearing zones reported are penetrated by a depth of 90 ft and 90 percent by a depth of 197 ft. The greatest density of water-bearing zones (1.00 per 50 ft of well depth) is from 51 to 100 ft below land surface (fig. 60). The density of water-bearing zones at depths of 301 ft or greater are based on the presence of six or fewer water-bearing zones per 50-ft interval. The overall density of water-bearing zones in the Hammer Creek Formation is 0.67 per 50 ft of well depth.

Geophysical logging, borehole video surveys, and heatpulse flowmetering were used to identify water-bearing zones at the Berkley Products Superfund Site, West Cocalico Township, Lancaster County, Pa. (Low and Conger, 1998). The wells investigated ranged in depth from 320 to 508 ft below land surface. Under ambient conditions, ground-water flow is downward in two wells and upward in two wells; the remaining wells exhibit upward and downward flow components. The two wells exhibiting upward flow

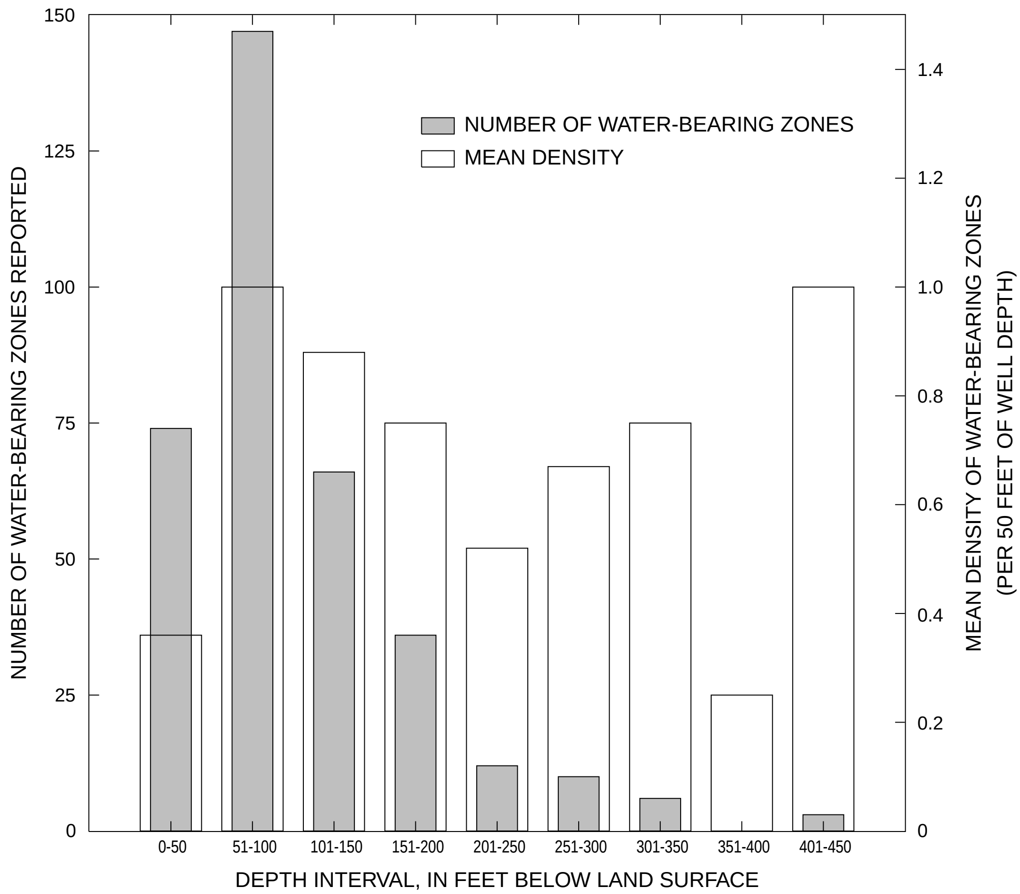


Figure 60. Number and density of water-bearing zones per 50 feet of well depth in the Hammer Creek Formation of the Piedmont Physiographic Province, Gettysburg-Newark Lowland Section.

are in a topographic low within 100 ft or so of Cocalico Creek. The remaining seven wells are on a slope with a maximum distance from Cocalico Creek of about 2,000 ft. Water-producing and water-receiving zones were penetrated as shallow as 34 ft below land surface and as deep as 475 ft below land surface.

Water quality.—As seen in the following table, wells completed in the Hammer Creek Formation generally yield water that is low in dissolved solids, is soft to moderately hard, and is slightly acidic. Calcium is the dominant cation, and bicarbonate is the dominant anion. The well with the most alkaline pH water is about 500 ft from a major fault contact with the Buffalo Springs Formation, and therefore, may be receiving some water that has originated in a carbonate terrain. Elevated concentrations of iron, radon, and dissolved solids; low pH; and possibly nitrate are the most common water-quality problems. Although only 2 of 47 wells contain water that exceeds the USEPA MCL for nitrate, the water in two other wells is at the MCL with two more within 1.0 mg/L of the MCL. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Hammer Creek Formation

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; pCi/L, picoCurie per liter; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	171	—	—	—	100	170	300	35	1,600
Field hardness	169	—	—	—	34	68	120	17	310
Field pH (standard units)	50	—	<6.5 >8.5	22	6.0	6.7	7.5	5.1	8.4
Bicarbonate	50	—	—	—	11	40	82	2.0	240
Calcium	43	—	—	—	4.7	13	31	.70	110
Chloride	49	—	250	0	3.0	5.0	10	.90	66
Iron	36	—	.3	4	.013	.060	.12	<.003	1.4
Magnesium	43	—	—	—	1.7	4.1	6.9	.60	40
Manganese	30	—	.05	1	.008	.010	.020	.000	.090
Nitrate (as N)	47	10	—	2	1.0	2.2	6.4	.05	20
Potassium	42	—	—	—	.65	.89	1.1	.30	3.1
Radon (pCi/L)	5	[3]300	—	5	800	990	1,600	690	1,900
Silica	19	—	—	—	11	16	23	7.3	40
Sodium	43	—	—	—	2.4	6.1	8.6	.80	28
Sulfate	46	—	250	2	5.0	10	20	.00	360
Total dissolved solids	49	—	500	4	67	120	170	10	878

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.
[3] U.S. Environmental Protection Agency, 1994, proposed maximum contaminant level.

Lithology has a definite affect on the quality of water in the Hammer Creek Formation. As seen in the tables below, wells completed in the conglomerate and sandstone generally produce water that contains lower amounts of dissolved solids, is softer, and more acidic than wells completed in the shale.

Field specific conductance, by lithology, Hammer Creek Formation

[Specific conductance in µS/cm, microsiemens per centimeter at 25 degrees Celsius; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Lithology	Number of wells	P25	Median	P75	Minimum	Maximum
Conglomerate	31	85	120	160	35	400
Sandstone	69	93	160	264	40	920
Shale	48	161	263	495	35	1,600

Field hardness, by lithology, Hammer Creek Formation

[Hardness in mg/L, milligrams per liter; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Lithology	Number of wells	P25	Median	P75	Minimum	Maximum
Conglomerate	31	34	51	68	17	210
Sandstone	72	34	68	115	17	270
Shale	47	68	100	210	17	310

Field pH, by lithology, Hammer Creek Formation

[pH in standard units; —, insufficient data available; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Lithology	Number of wells	P25	Median	P75	Minimum	Maximum
Conglomerate	3	—	6.0	—	5.9	7.7
Sandstone	20	6.2	6.7	7.3	5.1	8.1
Shale	12	6.2	7.4	7.6	5.6	8.4

New Oxford Formation (TRn)

The New Oxford Formation underlies about 200 mi^2 of the Gettysburg-Newark Lowland in a 0.5- to 5-mi wide belt in Adams, Lancaster, Lebanon, and York Counties (Berg and others, 1980). The reference section is in quarries southeast of the borough of New Oxford, Adams County (Stose and Bascom, p. 9, 1929).

Geologic description.—The New Oxford Formation consists of a complex, interbedded sequence of sandstones, siltstones, shales, and conglomerates. Bedding is lenticular, and individual beds grade rapidly into rocks of different textures. The generally gray to green (weathering yellowish to deep-buff), very-fine to coarse-grained, angular to subangular subarkosic sandstones are characteristic and consist of quartz, white kaolinized feldspar, and mica. The matrix is composed of very-fine grained quartz, feldspar, silt, and clay. The siltstones and shales, which are present throughout the formation, are generally red, but gray, greenish gray, and tan are not uncommon; many of the shales are micaceous and calcareous (Johnston, 1966, p. 10). The conglomerates are most common in the lower two-thirds of the formation and generally consist of subangular to subrounded quartzose cobbles and boulders in a poorly sorted red sand matrix with ferruginous and siliceous cements. Stose and Jonas (1939, p. 109) and Wood and Johnston (1964, p. 10) noted the presence of a basal limestone conglomerate near the contact with rocks of Paleozoic age. The New Oxford Formation generally thickens east to west from about 500 ft to about 6,900 ft (Wood, 1980, table 4).

The New Oxford Formation forms a gently rolling plain that is characterized by broad, shallow valleys and low, flat-topped ridges. The ridges consist of moderately resistant, coarse conglomerate that in most places approximately parallels the strike of the beds. The slightly resistant shale and sandstone members form the intervening shallow valleys. Joints in the conglomerate are vertical, open, and widely spaced whereas the joints in the shale and sandstone are closely spaced (Geyer and Wilshusen, 1982, p. 196-200). In Lancaster County, the thickness of the regolith ranges from less than 1 ft to about 50 ft and averages about 23 ft (Johnston, 1966, p. 13).

The Upper Triassic New Oxford Formation is a basal member of the Newark Supergroup. It unconformably overlies older Cambrian and Ordovician rocks and is stratigraphically lower than the Gettysburg Formation. However, the upper contact is gradational with the overlying Gettysburg Formation and therefore, partly contemporaneous (Johnston, 1966, p. 10). A change in lithology from arkosic sandstone in the New Oxford Formation to red shales and soft red sandstones in the Gettysburg Formation mark this contact. The Stockton Formation is the equivalent unit in the Newark Basin.

Well depths and casing lengths.—Depths of wells and casing lengths of wells completed in the New Oxford Formation are presented in the table below.

Reported well depth, New Oxford Formation

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	621	66	86	109	153	274	40	1,010
Drilled, domestic	414	65	82	100	123	171	40	601
Drilled, high-demand	78	110	153	252	391	600	65	800

Topographic setting can affect well depth. Domestic wells drilled on hilltops are completed to significantly greater depths than on slopes. The median depths of domestic wells drilled on hilltops (72 wells), slopes (268 wells), and valleys (47 wells) are 110, 95, and 98 ft below land surface, respectively.

Reported casing length, New Oxford Formation

[Casing length in feet; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	373	16	21	25	42	63	3	180
Drilled, domestic	252	16	20	25	40	63	4	180
Drilled, high-demand	58	20	23	35	53	80	13	152

Casing length also varies by county. Domestic wells drilled in Adams (15 wells) and Lancaster (159 wells) Counties have significantly more casing than wells drilled in York County (78 wells). The median casing lengths of domestic wells drilled in Adams, Lancaster, and York Counties are 42, 29, and 22 ft, respectively.

Hydrologic properties.—Water levels of wells completed in the New Oxford Formation are presented in the table below. Depths to water in 539 wells range from 1 ft above land surface to 93 ft below land surface; the median is 19 ft below land surface. There are three flowing wells: one is on a slope and two are in valleys.

Water levels, New Oxford Formation

[Water levels in feet below land surface; F, flowing well; -, flowing well in feet above land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	85	10	20	27	45	55	4	71
Slope	322	6	10	18	30	42	-1	93
Valley	93	5	9	14	23	30	F	60

Water levels also can vary considerably by county. The median depths to water in wells in Adams County (106 wells) is 11 ft; in Lancaster County (290 wells), 21 ft; and in York County (143 wells), 20 ft.

Reported yields of wells completed in the New Oxford Formation are presented in the table below. Yields of 5.0 gal / min or less are reported from 91 wells; 73 are domestic wells. Twenty-two of the 30 wells with reported yields of 100 gal / min or greater are deeper than 200 ft.

Reported well yield, New Oxford Formation

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	465	4.0	6.0	12	25	60	0.1	450
Domestic	307	4.0	6.0	10	16	25	.1	75
High-demand	87	10	20	45	100	200	2.8	450

Well yield also varies spatially. Domestic wells in Lancaster County (203 wells) have significantly greater reported yields than in York County (88 wells). The median reported yields of domestic wells in Lancaster and York Counties are 10 and 7 gal / min, respectively. High-demand wells in Adams (13 wells) and York (32 wells) Counties have significantly lower yields than in Lancaster County (42 wells); the medians are 20, 45, and 63 gal / min, respectively.

Specific capacities of wells completed in the New Oxford Formation are presented in the table below. Two wells (drilled to depths of 64 and 138 ft) have specific capacities of 0.04 (gal / min) / ft or less and are incapable of meeting most domestic or other water-use demands. Twelve of 28 wells with specific capacities of 1.0 (gal / min) / ft or greater are deeper than 200 ft. Specific capacities of wells with pumping durations of 8 hours or longer (39 wells) range from 0.07 to 21 (gal / min) / ft; the median is 0.55 (gal / min) / ft.

Reported specific capacity, New Oxford Formation

[Specific capacity in gallons per minute per foot of drawdown; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	92	0.09	0.22	0.50	1.2	4.7	0.02	21
Domestic	31	.07	.10	.24	.70	3.3	.06	7.1
High-demand	45	.14	.25	.58	1.6	5.8	.04	21

Values of hydraulic conductivity and transmissivity for the New Oxford Formation are presented in the table below; a specific yield of 0.007 was used in estimating these hydrologic properties. Hydraulic conductivity and transmissivity are generally lower on hilltops and slopes than in valleys. The median hydraulic conductivities of wells on hilltops (12 wells), slopes (42 wells), and valleys (27 wells) are 0.75, 0.59, and 0.89 ft / d, respectively. The median transmissivities of wells on hilltops is 89 ft^2 / d; on slopes, 69 ft^2 / d; and in valleys, 120 ft^2 / d.

Hydraulic conductivity and transmissivity from single-well aquifer tests, New Oxford Formation

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	89	0.09	0.17	0.68	1.7	5.3	0.02	76
Transmissivity (ft^2 / d)	89	11	35	97	250	760	1.0	5,800

In Carol and Frederick Counties, Md., Meyer and Beall (1958) estimated a specific yield of 0.001 and a transmissivity of 668 ft^2 / d for six wells completed in the New Oxford Formation. Wood and Johnston (1964, table 6) used the Cooper and Jacob method (1946) to estimate transmissivities of nine single-well aquifer tests with pumping durations of 1 hour. The transmissivities ranged from 0.936 to 695 ft^2 / d; the median was 46.8 ft^2 / d.

In their digital model of parts of Lancaster and Berks Counties, Pa., Gerhart and Lazorchick (1984b, p. 15, tables 6 and 14) estimated an aquifer thickness of 250 ft, a specific yield of 0.012, and a hydraulic conductivity of 1.2 ft / d for a hydrogeologic unit that included the New Oxford Formation. Gerhart and Lazorchick noted also that hydraulic conductivity was anisotropic utilizing 2.0 and 0.40 ft / d in an east-west and north-south direction, respectively. For the Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, p. 38) determined a specific yield of 0.007 for the upper 300 ft and a storage coefficient of 0.00007 for the lower 300 ft. They also used hydraulic conductivities of 0.40, 2.67, and 3.34 ft / d for different hydrogeologic units that included the New Oxford Formation (Gerhart and Lazorchick, 1988, p.22).

In response to a gasoline spill near Abbottstown, Pa., R.E. Wright Associates, Inc. (1994) conducted a long-term (72-hour), constant rate (225 gal / min), multiple-well aquifer test. The drawdown data indicated that the New Oxford Formation was not anisotropic. Transmissivities and storativities were determined from the long-term test at seven wells and ranged from 331 to 4,760 ft^2 / d and from 0.000003 to 0.001; the medians were 917 ft^2 / d and 0.003, respectively.

R.E. Wright Associates, Inc. (1993b) conducted a long-term (74-hour) multiple-well aquifer test on a proposed public supply well drilled in the New Oxford Formation just west of Littlestown, Pa. Transmissivity estimated during the pumping phase of the aquifer test was 206 ft^2 / d and 142 ft^2 / d during the recovery phase; storativity was estimated at 0.0001. The drawdown data indicated the New Oxford Formation was only slightly anisotropic, elongate and parallel to formational contacts (R.E. Wright Associates, Inc., 1993b, fig. 1).

The depths of water-bearing zones in 165 wells drilled as deep as 730 ft range from 8 to 629 ft below land surface. Fifty percent of 336 water-bearing zones reported are penetrated by a depth of 89 ft and 90 percent by a depth of 174 ft. The greatest density of water-bearing zones (0.95 per 50 ft of well depth) is from 51 to 100 ft below land surface (fig. 61). The density of water-bearing zones at depths of 301 ft or greater are based on the presence of one or two water-bearing zones per 50-ft interval. The overall density of water-bearing zones in the New Oxford Formation is 0.55 per 50 ft of well depth.

Geophysical logging and heatpulse flowmetering were used to identify water-bearing zones and direction of borehole flow in an unused, 504 ft deep well near Abbottstown, Pa. (Low and Dugas, 1999). Under ambient conditions, downward vertical flow was measured from 115 to 320 ft with no flow measured at depths of 80, 364, and 380 ft. Most water enters the borehole at minor fractures around 90 ft and major fractures at 137 and 140-154 ft below land surface. The water then exits the borehole through a major fracture at 358 ft below land surface. R.E. Wright Associates, Inc. (1993a), noted the reported water-bearing zones in this well were at lithologic and color changes.

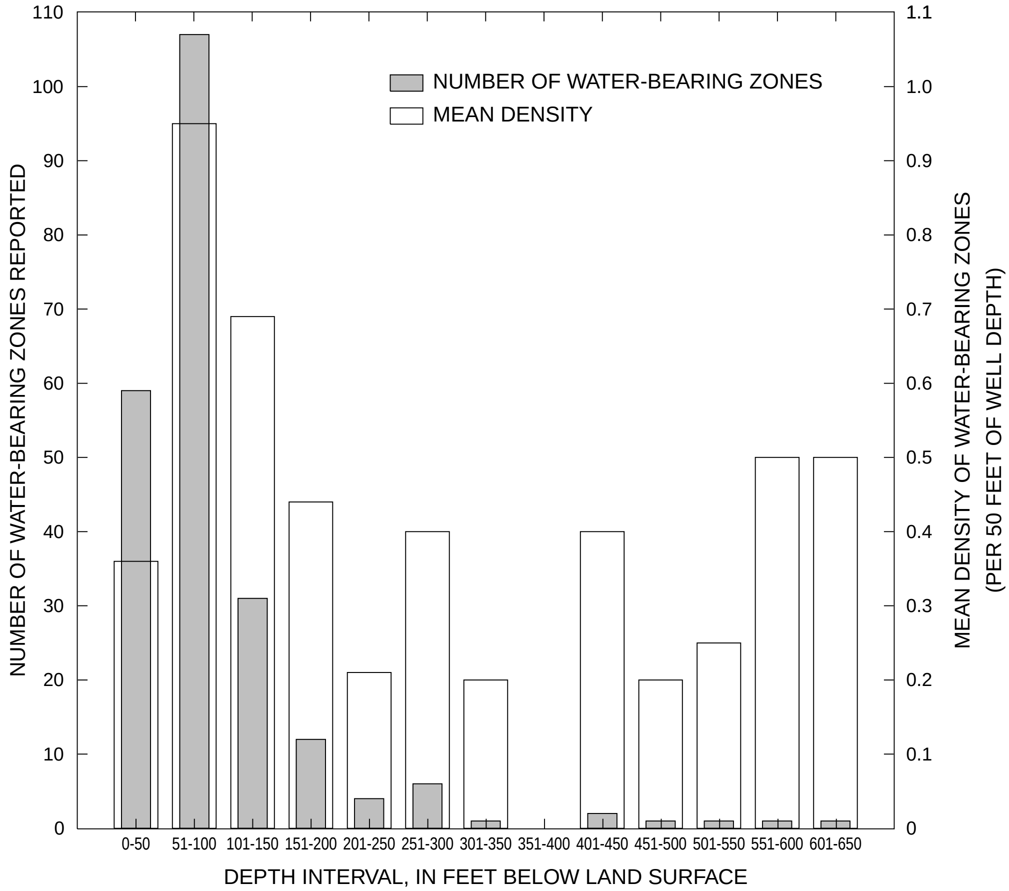


Figure 61. Number and density of water-bearing zones per 50 feet of well depth in the New Oxford Formation of the Piedmont Physiographic Province, Gettysburg-Newark Lowland Section.

Water quality.—As seen in the following table, wells completed in the New Oxford Formation generally yield water that contains moderate amounts of dissolved solids, is moderately hard, and is slightly acidic. Calcium is the dominant cation, and bicarbonate is the dominant anion. Elevated concentrations of iron, manganese, and nitrate and low pH are common water-quality problems in the New Oxford Formation.

Several of the wells with relatively high field specific conductances are less than 100 ft deep and may be contaminated by agricultural runoff or sewage. None of the wells containing water with nitrate concentrations above the USEPA MCL are deeper than 325 ft. Elevated concentrations of aluminum are common in the New Oxford Formation with 7 of 22 wells containing water with aluminum greater than 0.10 mg/L; the aluminum concentration in the water of one well was 1.0 mg/L.

Field parameters also can vary significantly spatially. Wells in Lancaster County (333 wells) contain water that has significantly lower field specific conductance than wells in Adams (60 wells) County; the medians are 295 and 380 µS/cm, respectively. The water from wells in Adams County is significantly harder (55 wells) than in Lancaster County (329 wells) and York County (93 wells). The median hardness of water in Adams County wells is 150 mg/L; in Lancaster County, 100 mg/L; and in York County, 120 mg/L. The pH of water from wells in Lancaster County (161 wells) is significantly lower than in

Adams (19 wells) and York (57 wells) Counties; the medians are 6.7, 7.4, and 7.2, respectively. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the New Oxford Formation

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	488	—	—	—	240	325	415	51	2,100
Field hardness	477	—	—	—	85	120	150	6.0	510
Field pH (standard units)	236	—	<6.5 >8.5	69	6.4	6.8	7.3	5.2	8.1
Bicarbonate	79	—	—	—	84	110	130	11	250
Calcium	76	—	—	—	30	48	58	6.0	100
Chloride	79	—	250	0	7.1	11	22	2.0	170
Iron	78	—	.3	9	.050	.090	.17	.000	22
Lead	22	0.015	—	1	.002	.015	<.050	.000	<.050
Magnesium	76	—	—	—	6.6	8.8	12	2.5	79
Manganese	73	—	.05	14	.010	.020	.050	.000	.58
Nitrate (as N)	78	10	—	10	3.3	5.7	8.5	.36	28
Potassium	65	—	—	—	.60	1.0	1.6	.00	5.6
Silica	67	—	—	—	8.4	16	20	1.3	39
Sodium	65	—	—	—	6.3	9.5	15	.50	56
Sulfate	80	—	250	0	15	26	43	2.5	120
Total dissolved solids	64	—	500	4	177	220	270	63	773

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.

Lockatong Formation (TRl)

The Lockatong Formation underlies about 160 mi^2 of the Gettysburg-Newark Lowland in Berks, Bucks, Chester and Montgomery Counties (Berg and others, 1980). The reference section is along the Delaware River between Point Pleasant and Lumberville, Bucks County.

Geologic description.—The Lockatong Formation is predominantly laminated to very thick-bedded, gray and black siltstone and shale or argillite that contain fine sand. Thin beds of calcareous shale or impure limestone are present locally (Greenman, 1955, p. 30). The rocks are typically even bedded and very fine grained. Lower beds in the Lockatong Formation may contain coarser-grained beds. Alternating detrital and chemical-lacustrine cycles have been identified by Van Houten (1964). Beds in the Lockatong Formation do not display the interbedding and intergrading that is typical of other sedimentary rocks in the Gettysburg-Newark Lowland. Individual beds in the Lockatong Formation can commonly be traced for considerable distances along strike. The Lockatong Formation has an estimated maximum thickness of about 3,800 ft near the Delaware River (Greenman, 1955, p. 31) but is only about 1,500 ft thick at the Schuylkill River and thins westward (Bascom and Stose, 1938, p. 72).

The Lockatong Formation is moderately resistant to weathering, forming rolling hills of medium relief. Where the Lockatong Formation comes in contact with the Stockton Formation, a distinct change in topography occurs, with as much as 200 ft of elevation difference between areas underlain by the two formations (Greenman, 1955, p. 30). Joints have a blocky pattern, are closely spaced, and are open (Geyer and Wilshusen, 1982, p. 165-166).

The Lockatong Formation is of Upper Triassic age and is the middle unit in the Newark Supergroup in the Newark Basin (Lyttle and Epstein, 1987). The formation interfingers laterally with and gradationally into the underlying Stockton Formation as well as the lower part of the Brunswick Formation. Turner-Peterson (1980) suggested the Lockatong was deposited in an offshore lacustrine environment. Greenman (1955, p. 31) believed the red beds of the upper part of the Lockatong were deposited in a different environment from that which produced the dark-colored argillite, possibly fluvial.

Well depths and casing lengths.—Depths of wells and casing lengths of wells completed in the Lockatong Formation are presented in the table below.

Reported well depth, Lockatong Formation

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	172	77	100	187	311	497	12	820
Drilled, domestic	88	75	93	135	245	378	36	635
Drilled, high-demand	54	80	148	217	400	668	31	820

Well depth varies spatially. The depths of domestic wells drilled in Chester County (12 wells) are significantly greater than in Bucks County (55 wells). The median depths of drilled domestic wells in Bucks and Chester Counties are 113 and 277 ft, respectively.

Casing lengths for wells completed in the Lockatong Formation are presented in the table below. High-demand wells do not use significantly more casing than domestic wells.

Reported casing length, Lockatong Formation

[Casing length in feet; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	62	20	21	30	40	56	10	82
Drilled, domestic	35	19	20	27	35	41	12	43
Drilled, high-demand	19	13	22	40	52	71	10	82

Hydrologic properties.—Water levels of wells completed in the Lockatong Formation are presented in the table below. Depths to water in 89 wells range from flowing at land surface to 165 ft below land surface; the median is 22 ft below land surface.

Water levels, Lockatong Formation

[Water levels in feet below land surface; F, flowing well; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	15	3	18	38	64	123	2	139
Slope	48	4	10	21	61	95	F	165
Valley	17	7	8	12	24	36	6	60

Water levels vary considerably by county. Depths to water in Bucks County (58 wells) are considerably less than in Chester (13 wells) or Montgomery (18 wells) Counties. The median depth to water in Bucks County is 12 ft; in Chester County, 80 ft; and in Montgomery County, 26 ft.

Reported yields for wells completed in the Lockatong Formation are presented in the table below. Yields of 5.0 gal / min or less are reported from 36 wells; 21 are domestic wells. Six of seven wells with yields of 100 gal / min or greater are deeper than 200 ft. Six of the seven wells are near (within 1,000 ft) a formational contact or the Neshaminy Creek.

Reported well yield, Lockatong Formation

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	131	3.0	5.0	10	25	57	1.0	1,000
Domestic	68	2.4	5.0	9.0	15	32	1.0	130
High-demand	43	2.4	5.7	20	30	117	2.0	1,000

Specific capacities for wells completed in the Lockatong Fomation are presented in the table below. Seven of nine wells deeper than 200 ft have specific capacities of 1.0 (gal / min) / ft or greater. Specific capacities of 11 wells pumped 8 hours or longer range from 0.05 to 10 (gal / min) / ft; the median is 0.45 (gal / min) / ft.

Reported specific capacity, Lockatong Formation

[Specific capacity in gallons per minute per foot of drawdown; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	25	0.07	0.18	0.40	5.1	12	0.05	40
Domestic	14	.06	.15	.33	.95	28	.06	40
High-demand	11	.06	.23	1.6	7.6	10	.05	10

Values of hydraulic conductivity and transmissivity for the Lockatong Formation are presented in the table below; a specific yield of 0.007 was used in estimating these hydrologic properties. Hydraulic conductivity and transmissivity are generally lower on hilltops and slopes than in valleys. The median hydraulic conductivities of wells on hilltops (4 wells), slopes (16 wells), and valleys (4 wells) are 1.3, 0.78, and 2.0 ft / d, respectively. The median transmissivity of wells on hilltops is 610 ft^2 / d; on slopes, 55 ft^2 / d; and in valleys, 1,000 ft^2 / d.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Lockatong Formation

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	24	0.04	0.20	0.78	3.2	48	0.01	130
Transmissivity (ft^2 / d)	24	9.8	28	81	1,100	2,900	2.1	8,900

Information on aquifer properties from other sources is relatively rare. Longwill and Wood (1965, table 2) conducted six single-well aquifer tests in Bucks and Montgomery Counties. They determined from these tests that transmissivities of the Lockatong Formation ranged from 8.0 to 267 ft^2 / d; the median was 20.1 ft^2 / d.

Sloto and Schreffler (1994, table 5) analyzed recovery data from three long-term (48- or 72-hour) aquifer tests that were done by environmental consulting firms. The transmissivities calculated by use of the Theis (1935) recovery method are 820 and 1,500 ft^2 / d. The transmissivity calculated by use of the Cooper and Jacob (1946) method is 250 ft^2 / d.

The depths of water-bearing zones in 14 wells drilled as deep as 693 ft range from 35 to 598 ft below land surface. Fifty percent of the 38 water-bearing zones reported are penetrated by a depth of 173 ft and 90 percent by a depth of 521 ft. The greatest density of water-bearing zones (1.33 per 50 ft of well depth) is from 501 to 550 ft below land surface (fig. 62). The overall density of water-bearing zones in the Lockatong Formation is 0.38 per 50 ft of well depth.

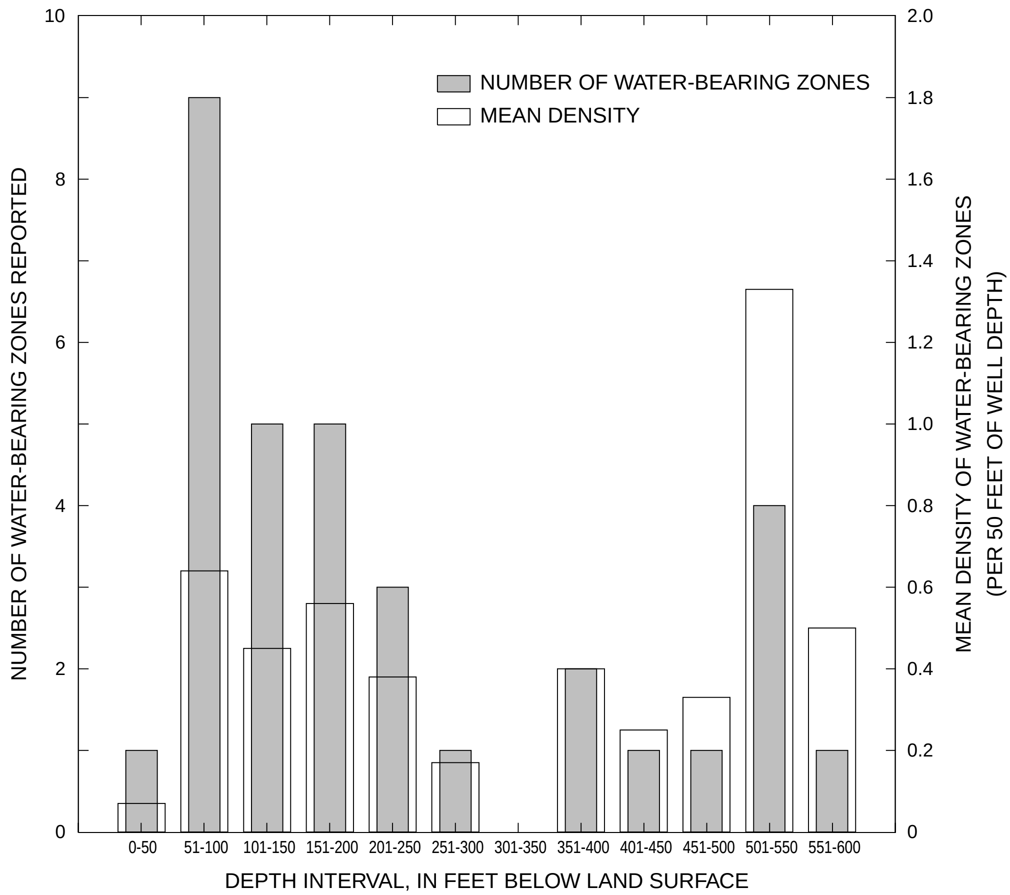


Figure 62. Number and density of water-bearing zones per 50 feet of well depth in the Lockatong Formation of the Piedmont Physiographic Province, Gettysburg-Newark Lowland Section.

Water quality.—As seen in the following table, wells completed in the Lockatong Formation generally yield water that contains moderate amounts of dissolved solids, is moderately hard to very hard, and is alkaline. Calcium is the dominant cation, and bicarbonate is the dominant anion. Elevated concentrations of iron, manganese, nitrate, radon, sulfate, and dissolved solids have been reported as exceeding the existing or proposed USEPA MCLs or SMCLs. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Lockatong Formation

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; pCi/L, picoCurie per liter; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	33	—	—	—	410	470	528	230	950
Field hardness	35	—	—	—	170	200	240	85	480
Field pH (standard units)	7	—	<6.5 >8.5	0	7.2	7.3	7.8	7.2	8.0
Bicarbonate	19	—	—	—	130	160	170	39	230
Calcium	20	—	—	—	37	47	60	12	170
Chloride	19	—	250	0	6.3	7.4	21	4.2	68
Iron	20	—	.3	4	.003	.010	.09	.000	17
Magnesium	20	—	—	—	15	17	23	12	40
Manganese	12	—	.05	1	.000	.002	.008	.000	.051
Nitrate (as N)	18	10	—	1	.47	1.9	3.1	.02	11
Potassium	20	—	—	—	.80	1.0	1.6	.50	12
Radon (pCi/L)	5	[3] 300	—	4	330	420	950	270	960
Silica	20	—	—	—	13	15	16	11	36
Sodium	20	—	—	—	10	15	22	7.0	160
Sulfate	20	—	250	1	27	36	42	3.8	390
Total dissolved solids	19	—	500	1	222	246	280	109	739

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.
[3] U.S. Environmental Protection Agency, 1994, proposed maximum contaminant level.

Brunswick Formation (TRb)

The Brunswick Formation underlies about 500 mi^2 of the Gettysburg-Newark Lowland in Berks, Bucks, Chester, Lehigh, and Montgomery Counties (Berg and others, 1980). The reference section is along the Delaware River between Kintnersville and Erwinna, Bucks County. Lyttle and Epstein (1987) proposed raising the Brunswick Formation in rank to the Brunswick Group.

Geologic description.—The Brunswick Formation is typically soft, grayish-red to reddish-brown, evenly to irregularly bedded, thin- to thick-bedded shale, mudstone, or siltstone locally interbedded with fine- to coarse-grained red sandstone. Mud cracks, ripple marks, crossbeds, burrows, and raindrop impressions are common. The Brunswick Formation contains detrital cycles of shale and siltstone as thick as 250 ft (Lyttle and Epstein, 1987).The lower beds of the Brunswick Formation include a considerable thickness of hard, red, thick-bedded argillite and occasional beds of tough gray shale or argillite. Near intrusive bodies, the shale has been altered to a hard, dark-colored hornfels. Near the north border the typical shales, mudstones and siltstones are interbedded with and grade laterally into sandstone and fanglomerate. MacLachlan (1983) divided the Brunswick Formation into three members: (1) a lower member that is predominantly a reddish-brown shale and mudstone, (2) the Jacksonwald Basalt Member, and (3) an upper member that consists principally of reddish-brown mudstone and siltstone. Thickness of the Brunswick Formation is variable. Bascom and Stose (1938, p. 76) estimated a thickness of 16,000 ft near Pottstown, Willard and others (1959, p. 99) estimated 9,000 ft, Greenman (1955, p. 34) estimated about 6,000 ft in Bucks County, and MacLachlan (1983) estimated at least 11,200 ft in Berks County.

The Brunswick Formation is moderately resistant to weathering, forming broad shallow valleys with hills of low relief that trend parallel to the strike of the beds. Joints have a blocky pattern, are moderately abundant, and are commonly open; infillings include calcite and quartz; occasional barite and pyrite are present. The regolith is moderately thick (Geyer and Wilshusen, 1982, p. 48-50).

The Brunswick Formation is the upper most unit of the Newark Supergroup in the Newark Basin and is the equivalent to the Gettysburg Formation in the Gettysburg Basin. The Jurassic-Triassic boundary lies beneath the Jacksonwald Basalt Member and within the uppermost 130 ft of the lower member of the Brunswick Formation (MacLachlan, 1983). The Brunswick Formation interfingers laterally with the Lockatong and Hammer Creek Formations. The lower contact with the Lockatong Formation is gradational through about 1,600 ft and is conformable and gradational to older rocks of the Newark Supergroup but unconformable on basement rocks (Lyttle and Epstein, 1987). The upper contact is unconformable with the rocks of the Reading Prong section; this contact is commonly delineated by the faults that border the Newark Basin. The lower and upper members represent a lacustrine-nearshore environment (Sloto, 1994, p. 14). According to MacLachlan (1983), the Jacksonwald Basalt Member is chemically identical to York Haven-type intrusives.

Well depths and casing lengths.—Depths of wells completed in the Brunswick Formation are presented the table below.

Reported well depth, Brunswick Formation

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	877	87	120	225	385	500	10	2,080
Drilled, domestic	247	72	90	110	150	210	38	642
Drilled, high-demand	454	126	203	302	426	534	10	1,000

Well depths can vary spatially. Domestic wells drilled in Montgomery County (48 wells) are completed to significantly greater depths than in Lehigh (27 wells) and Bucks (82 wells) Counties. The median depths of domestic wells in Bucks County is 104 ft; in Lehigh County, 92 ft; and in Montgomery County, 124 ft. High-demand wells drilled in Montgomery County (288 wells) are significantly deeper than in Bucks County (120 wells); the median well depths are 320 and 275 ft, respectively.

Casing lengths of wells completed in the Brunswick Formation are presented in the table below. Topographic setting can affect casing length. Domestic wells on hilltops use significantly less casing than on slopes. The median casing lengths of domestic wells on hilltops (22 wells), slopes (80 wells), and valleys (23 wells) are 27, 41, and 28 ft, respectively.

Reported casing length, Brunswick Formation

[Casing length in feet; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	537	20	28	40	51	78	1	1,780
Drilled, domestic	142	18	24	35	50	81	1	150
Drilled, high-demand	301	20	30	41	58	77	6	850

Casing length also varies spatially. Domestic wells in Chester County (60 wells) have significantly more casing than in Bucks (34 wells) and Montgomery (27 wells) Counties. The median casing lengths of domestic wells in Chester County is 48 ft; in Bucks and Montgomery Counties, the median is 25 ft.

Hydrologic properties.—Water levels for wells completed in the Brunswick Formation are presented in the table below. Depths to water in 604 wells range from flowing 6 ft above land surface to 260 ft below land surface; the median is 30 ft below land surface. There are six flowing wells: two are on slopes and four are in valleys.

Water levels, Brunswick Formation

[Water levels in feet below land surface; -, flowing well with feet above land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	60	11	25	44	75	167	1	245
Slope	241	8	16	38	64	92	-1	260
Valley	188	6	12	20	41	63	-6	122

Reported yields for wells completed in the Brunswick Formation are presented in the table below. Yields of 5.0 gal/min or less are reported from 21 wells; 16 are domestic wells. Almost all (247 wells) of the wells with yields of 100 gal/min or greater are deeper than 200 ft. Longwill and Wood (1965, p. 36) reported that wells should be drilled at least 200 ft deep for yields of 200 gal/min or more.

Reported well yield, Brunswick Formation

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	684	10	20	60	146	250	0.3	1,500
Domestic	157	5.8	10	15	25	60	.5	180
High-demand	413	25	50	100	200	300	.3	1,500

Topographic setting can affect well yields. High-demand wells on hilltops have significantly lower reported yields than in valleys. The median reported yields of high-demand wells on hilltops (38 wells), slopes (137 wells), and valleys (147 wells) are 55, 80, and 150 gal/min, respectively.

Reported yields also vary spatially. Wells in Berks (52 wells) and Montgomery (356 wells) Counties have significantly greater reported yields than in Chester County (90 wells); the medians are 40, 90, and 20 gal/min, respectively. Domestic wells in Montgomery County (28 wells) have significantly greater reported yields than in Bucks County (42 wells). The median reported yield of domestic wells in Montgomery County is 19 gal/min; in Bucks County, the median is 15 gal/min.

Specific capacities of wells completed in the Brunswick Formation are presented in the table below. Specific capacities of 1.0 (gal / min) / ft or greater are reported from 108 wells; 76 are deeper than 200 ft. Specific capacities of wells with pumping durations of 8 hours or longer (98 wells) range from 0.13 to 140 (gal / min) / ft; the median is 2.0 (gal / min) / ft.

Reported specific capacity, Brunswick Formation

[Specific capacity in gallons per minute per foot of drawdown; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	157	0.27	0.58	1.5	3.5	11	0.07	140
Domestic	35	.13	.27	.46	1.2	13	.07	32
High-demand	111	.40	.97	2.0	4.2	11	.13	140

Values of hydraulic conductivity and transmissivity for the Brunswick Formation are presented in the table below; a specific yield of 0.007 was used in estimating these hydrologic properties. Hydraulic conductivity and transmissivity are generally lower on hilltops and slopes than in valleys. The median hydraulic conductivities of wells on hilltops (18 wells), slopes (62 wells), and valleys (56 wells) are 0.59, 1.0, and 2.0 ft / d, respectively. The median transmissivity of wells on hilltops is 140 ft^2 / d; on slopes, 210 ft^2 / d; and in valleys, 520 ft^2 / d.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Brunswick Formation

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	150	0.22	0.49	1.3	3.7	16	0.05	450
Transmissivity (ft^2 / d)	150	42	110	350	860	2,700	6.4	39,000

Longwill and Wood (1965) conducted numerous multiple-well and single-well aquifer tests of the Brunswick Formation in Berks, Chester, and Montgomery Counties, Pa. The storativities and transmissivities determined from the multiple-well aquifer tests ranged from 0.000033 to 0.00029 and 13.4 to 24,100 ft^2 / d; the medians were 0.00009 and 1,200 ft^2 / d, respectively. For the single-well aquifer tests, transmissivities ranged from 18.7 to 535 ft^2 / d; the median was 80.2 ft^2 / d.

Sloto and Schreffler (1994, table 5) analyzed recovery data from five long-term (48- or 72-hour) aquifer tests that were done by environmental consulting firms. The transmissivities calculated by use of the Theis (1935) recovery method ranged from 94 to 2,220 ft^2 / d.

The depths of water-bearing zones in 122 wells drilled as deep as 750 ft range from 25 to 625 ft below land surface. Fifty percent of the 392 water-bearing zones reported are penetrated by a depth of 135 ft and 90 percent by a depth of 339 ft. The greatest density of water-bearing zones (0.86 per 50 ft of well depth) is from 151 to 200 ft below land surface (fig. 63). The density of water-bearing zones at depths of 401 ft or greater are based on the presence of five or fewer water-bearing zones per 50-ft interval. The overall density of water-bearing zones in the Brunswick Formation is 0.50 per 50 ft of well depth.

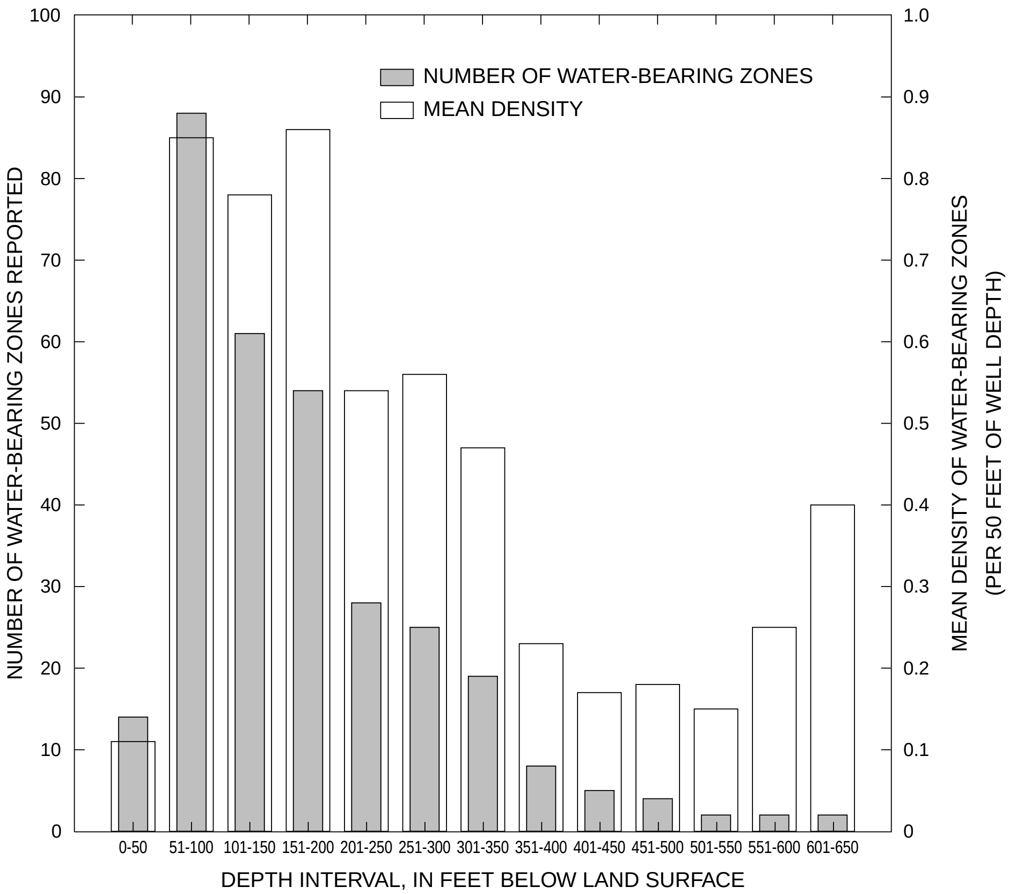


Figure 63. Number and density of water-bearing zones per 50 feet of well depth in the Brunswick Formation of the Piedmont Physiographic Province, Gettysburg-Newark Lowland Section.

Water quality.—As seen in the following table, wells completed in the Brunswick Formation generally yield water that contains low to moderate amounts of dissolved solids, is soft to very hard, and is slightly acidic. Calcium is the dominant cation, and bicarbonate is the dominant anion. Elevated concentrations of dissolved solids, iron, manganese, radon, and sulfate and low pH are the most common water-quality problems in the Brunswick Formation.

Field parameters can vary significantly spatially. Wells in Bucks and Montgomery Counties contain water with significantly greater field specific conductance and hardness than wells in Chester County. The median specific conductance of water from wells in Bucks (31 wells) and Montgomery (50 wells) Counties is 450 µS/cm; in Chester County (26 wells), the median is 395 µS/cm. The median hardness of water from wells in Bucks (34 wells), Chester (25 wells), and Montgomery (60 wells) Counties is 190, 120, and 170 mg/L, respectively. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Brunswick Formation

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; pCi/L, picoCurie per liter; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	107	—	—	—	330	410	500	70	1,280
Field hardness	119	—	—	—	130	170	200	17	810
Field pH (standard units)	36	—	<6.5 >8.5	14	6.0	6.9	7.4	5.3	8.2
Bicarbonate	93	—	—	—	100	130	160	30	290
Calcium	74	—	—	—	37	49	63	7.7	250
Chloride	94	—	250	0	6.0	10	17	1.0	68
Iron	95	—	.3	25	.016	.10	.30	.000	5.3
Lead	10	0.015	—	1	.000	.001	.002	.000	.35
Magnesium	74	—	—	—	8.8	16	24	.60	64
Manganese	72	—	.05	14	.001	.016	.040	.000	.38
Nitrate (as N)	90	10	—	0	.52	1.6	3.9	.02	9.5
Potassium	70	—	—	—	.80	1.0	1.6	.20	11
Radon (pCi/L)	7	[3] 300	—	7	760	1,300	1,600	520	2,200
Silica	72	—	—	—	17	22	26	5.0	33
Sodium	70	—	—	—	9.9	13	16	1.0	140
Sulfate	91	—	250	8	17	30	80	1.1	790
Total dissolved solids	87	—	500	11	217	272	360	62	1,340

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.
[3] U.S. Environmental Protection Agency, 1994, proposed maximum contaminant level.

Gettysburg Formation (TRg)

The Gettysburg Formation underlies about 420 mi^2 of the Gettysburg-Newark Lowland in Adams, Cumberland, Dauphin, Lancaster, and York Counties (Berg and others, 1980). Type section of the Gettysburg Formation is near Gettysburg, Adams County (Stose and Bascom, 1929, p. 10). Type section of the conglomerate or Conewago Member (Stose and Jonas, 1939, p. 115) is at Conewago, York County. For the Heidlersburg Member, the reference section is in the vicinity of the village of Heidlersburg, Adams County.

Geologic description.—The Gettysburg Formation, in general, is soft, reddish-brown shale and red-brown, fine- to medium-grained sandstone with minor amounts of yellowish-brown shale and sandstone. This formation consists of about equal amounts of red shale and pebbly sandstone in northeastern York County, gradually changing northeastward along strike to mostly shale in Adams County. From the Susquehanna River to the Dauphin-Lebanon County line shale appears to be somewhat more abundant than sandstone and conglomerate; thickness of the formation is estimated to be about 15,500 ft (Wood, 1980, p. 14).

In their work on the Gettysburg Formation in Adams and York Counties, Stose and Bascom (1929, p. 10) and Stose and Jonas (1939, p.115-120) identified several members or lithologic units distinctly different from the dominant red-brown shale and sandstones. The upper most lithologic unit is a limestone conglomerate and, near South Mountain, a quartzose fanglomerate. A middle member, named the Heidlersburg, consists of a gray to white sandstone and conglomerate with interbeds of red shale and sandstone, and some green, gray, and black shale. A basal member called the Conewago Conglomerate

Member consists of numerous beds of hard, pebbly siliceous sandstone and poorly sorted pebble to cobble size red and white sandstone and quartz conglomerate in a red sand matrix. Glaeser (1966, p. 10), however, could not separate the Conewago Conglomerate Member and did not recognize it in his study.

The Gettysburg Formation is moderately resistant to weathering, forming undulating hills of low relief to small hills and ridges that are higher than the surrounding countryside. Joints have a blocky pattern, are moderately to well developed, fairly common and open (Geyer and Wilshusen, 1982, p. 121-125). The regolith is thinner in the Conewago and Heidlersburg Members than for the rest of the formation. Wood (1980, p. 26) reported that regolith thickness rarely exceeds 100 ft; the median overburden thickness was 11 ft for shale and sandstone and 23 ft for limestone conglomerate.

The Triassic-Jurassic age Gettysburg Formation is the upper unit of the Newark Supergroup in Adams, Cumberland, and Dauphin Counties. The southern contact of the Gettysburg Formation is gradational with the underlying New Oxford Formation. Its northern boundary, in many areas, is in fault contact with older rocks. In other areas, an unconformable contact exists between the Gettysburg Formation and older rocks.

Well depths and casing lengths.—Depths of wells completed in the Gettysburg Formation are presented in the table below.

Reported well depth, Gettysburg Formation

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	531	81	120	175	300	500	35	900
Drilled, domestic	308	80	106	147	200	298	35	900
Drilled, high-demand	112	86	195	307	510	686	57	900

Topographic setting can affect well depth. High-demand wells drilled on slopes are significantly shallower than in valleys. The median depths of high-demand wells drilled on hilltops (12 wells) is 200 ft; on slopes (27 wells), 230 ft; and in valleys (64 wells), 351 ft. The depths of domestic wells drilled on hilltops (62 wells) and slopes (170 wells) are significantly greater than in valleys (52 wells). The median depths of domestic wells drilled on hilltops, slopes, and in valleys are 166, 145, and 125 ft, respectively.

Well depth also varies spatially. Domestic wells drilled in York County (139 wells) are completed to significantly greater depths than in Adams County (121 wells); the median well depths are 160 and 125 ft, respectively. High-demand wells drilled in Dauphin County (34 wells) are completed to significantly greater depths than in Adams (64 wells) and York (13 wells) Counties. The median well depths of high-demand wells in Adams, Dauphin, and York Counties are 250, 455, and 196 ft, respectively.

Casing lengths of wells completed in the Gettysburg Formation are presented in the table below. Topographic setting can affect casing length. Domestic wells drilled on hilltops have significantly less casing than on slopes. The median casing lengths of domestic wells drilled on hilltops (58 wells), slopes (143 wells), and valleys (48 wells) are 30, 40, and 30 ft, respectively.

Reported casing length, Gettysburg Formation

[Casing length in feet; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	427	20	23	39	50	78	2	600
Drilled, domestic	270	20	22	36	42	71	6	471
Drilled, high-demand	84	14	29	43	72	100	2	600

Casing length also varies spatially. High-demand wells in Dauphin County (25 wells) have significantly more casing than in Adams County (47 wells); the median casing lengths are 64 and 32 ft, respectively. Domestic wells drilled in Dauphin County (40 wells) have significantly more casing than in Adams (102 wells) or York (124 wells) Counties. The median casing lengths of domestic wells in Adams County is 36 ft; for Dauphin and York Counties, the median casing lengths are 41 and 30 ft, respectively.

Hydrologic properties.—Water levels for wells completed in the Gettysburg Formation are presented in the table below. Depths to water in 416 wells range from flowing at land surface to 363 ft below land surface; the median is 30 ft below land surface.

Water levels, Gettysburg Formation

[Water levels in feet below land surface; F, flowing well; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	71	10	22	35	71	99	1	363
Slope	200	10	18	34	55	80	F	300
Valley	123	4	10	20	32	55	1	111

Reported yield for wells completed in the Gettysburg Formation are presented in the table below. Yields of 5.0 gal / min or less are reported from 76 wells; 67 are domestic wells. Almost all (61 wells) of the 68 wells with yields of 100 gal / min or greater are deeper than 200 ft.

Reported well yield, Gettysburg Formation

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	480	4.0	8.0	15	40	150	0.2	1,000
Domestic	281	3.0	6.0	10	20	30	.2	75
High-demand	124	20	30	85	182	293	4.0	1,000

Reported well yields vary by county. Wells in Dauphin County have significantly greater reported yields than wells in Adams or York Counties. The median reported yields of high-demand wells in Dauphin County (44 wells) is 128 gal / min; in Adams County (63 wells), 80 gal / min; and in York County (15 wells), 25 gal / min. For domestic wells in Dauphin (40 wells), Adams (110 wells), and York (127 wells) Counties; the medians are 20, 11, and 8 gal / min, respectively.

Specific capacities of wells completed in the Gettysburg Formation are presented in the table below. Specific capacities in 15 wells (drilled from 110 to 464 ft below land surface) are 0.04 (gal / min) / ft or less and are incapable of meeting most domestic or other water-use demands. Forty-three of the 57 wells with specific capacities of 1.0 (gal / min) / ft or greater are deeper than 200 ft. Specific capacities of wells with pumping durations of 8 hours or longer (74 wells) range from 0.12 to 18 (gal / min) / ft; the median is 1.0 (gal / min) / ft. Three wells, with constant discharge rates, had declines in specific capacities of 20-75 percent as pumping duration increased from 1 hour to 8 hours or more.

Reported specific capacity, Gettysburg Formation

[Specific capacity in gallons per minute per foot of drawdown; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	207	0.05	0.13	0.34	1.1	2.4	0.01	20
Domestic	98	.03	.08	.18	.29	.74	.01	2.0
High-demand	82	.25	.56	1.1	2.3	6.6	.12	18

Specific capacity can vary by county. Wells in Dauphin County (78 wells) have significantly greater specific capacities than wells in York County (53 wells). The median specific capacities for wells in Dauphin and York Counties are 0.43 and 0.15 (gal / min) / ft, respectively.

Values of hydraulic conductivity and transmissivity for the Gettysburg Formation are presented in the following table; a specific yield of 0.007 was used in estimating these hydrologic properties. Hydraulic conductivity and transmissivity are generally lower on hilltops and slopes than in valleys. The median hydraulic conductivities of wells on hilltops (39 wells), slopes (79 wells), and valleys (73 wells) are 0.38, 0.42, and 0.86 ft / d, respectively. The median transmissivity of wells on hilltops is 35 ft^2 / d; on slopes, 30 ft^2 / d; and in valleys, 170 ft^2 / d.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Gettysburg Formation

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	193	0.05	0.16	0.55	1.5	4.6	0.00	120
Transmissivity (ft^2 / d)	193	6.8	22	57	230	550	.64	4,400

For the Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, p. 38) used a specific yield of 0.007 for the upper 300 ft and a storage coefficient of 0.00007 for the lower 300 ft. They also used hydraulic conductivities of 0.13, 0.40, 2.67, and 3.34 ft / d for different hydrogeologic units that included the Gettysburg Formation (Gerhart and Lazorchick, 1988, p. 22).

Low and Dugas (1999) analyzed drawdown data from single- and multiple-well aquifer tests that were done by the Gettysburg Municipal Authority and from an environmental consulting firm. The transmissivities for five wells ranged from 670 to 6,800 ft^2 / d; the median was 750 ft^2 / d. Storativity for three wells were 0.000031, 0.000073, and 0.00009.

At the Westinghouse Elevator Plant Superfund Site, just north of Gettysburg, Pa., Rizzo Associates, Inc. (1991) utilized a double-packer system to isolate individual horizons in seven monitor wells that ranged in depth from 60 to 245 ft. In general, the greatest hydraulic conductivities (0.28 to 1.4 ft / d) were obtained in the upper 35 ft of the borehole. Deeper sections of the borehole were characterized by much lower hydraulic conductivities (average 0.00028 ft / d) except where the rock was weathered, broken, or contained water-bearing zones. At these permeable horizons, the hydraulic conductivity of the rock was again greater (up to 2.8 ft / d).

Rising and falling slug tests were used to estimate hydraulic conductivities in 13 wells ranging in depth from 16 to 247 ft below land surface at the Berkley Products Superfund Site, Denver, Pa. (R.W. Conger, U.S. Geological Survey, written commun., 1992). The hydraulic conductivities ranged from 0.01 to 3.4 ft / d; the median was 0.17 ft / d.

The depths of water-bearing zones in 322 wells drilled as deep as 900 ft range from 5 to 900 ft below land surface. Fifty percent of the 669 water-bearing zones reported are penetrated by a depth of 115 ft and 90 percent by a depth of 288 ft. The greatest density of water-bearing zones (0.65 per 50 ft of well depth) is from 51 to 100 ft below land surface (fig. 64). The density of water-bearing zones at depths of 401 ft or greater are based on the presence of five or fewer water-bearing zones per 50-ft interval. The overall density of water-bearing zones in the Gettysburg Formation is 0.41 per 50 ft of well depth. The deepest, fresh water-bearing zone known was penetrated by an oil and gas well at a depth of about 2,300 ft.

Borehole geophysical logs were run in five wells in the Gettysburg area by the USGS (Low and Dugas, 1999). Brine testing of the five wells indicated that most wells showed downward vertical flow, primarily caused by a downward head gradient formed in response to the pumping of surrounding wells in the area. One well showed no flow at 360 and 600 ft below land surface, but downward flow at 800 ft below land surface. A second well showed downward flow from 302 to 600 ft below land surface. Another well, however, showed no flow from 70 to 240 ft below land surface.

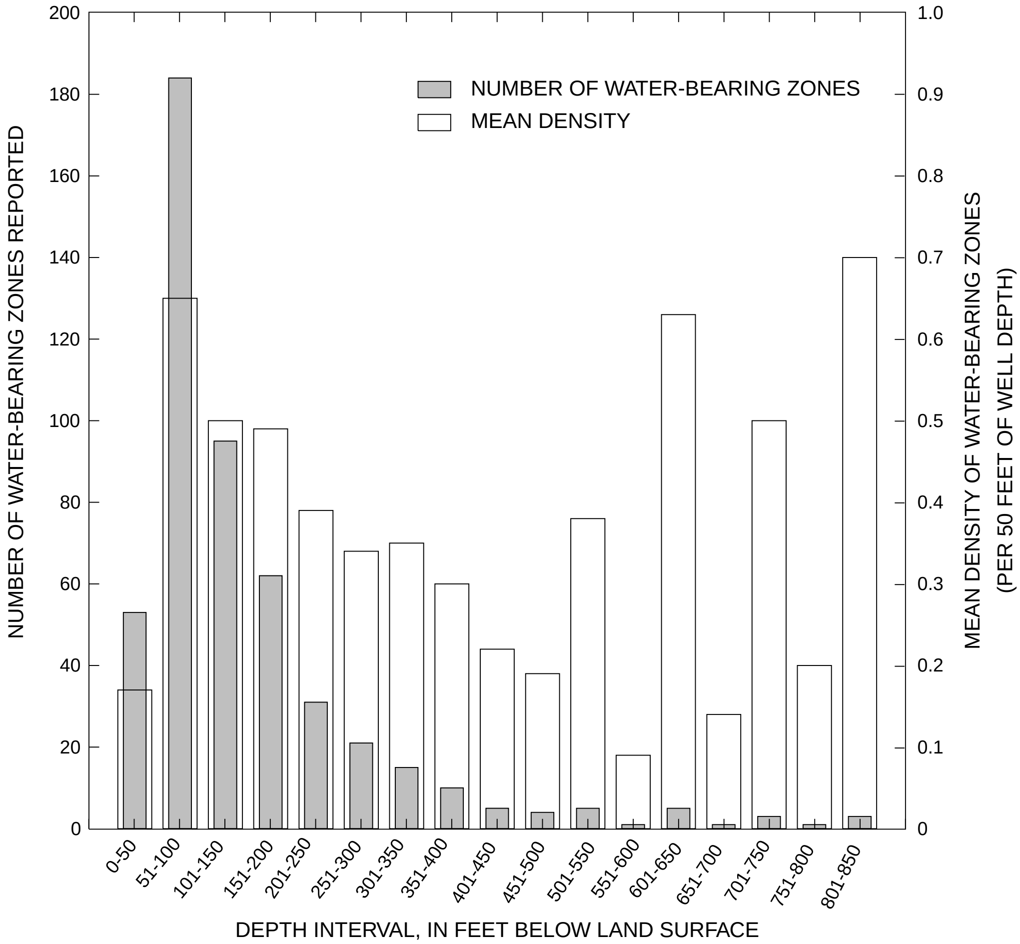


Figure 64. Number and density of water-bearing zones per 50 feet of well depth in the Gettysburg Formation of the Piedmont Physiographic Province, Gettysburg-Newark Lowland Section.

Water quality.—As seen in the following table, wells completed in the Gettysburg Formation generally yield water that contains low to moderate amounts of dissolved solids and is soft to very hard. Calcium is the dominant cation, and bicarbonate is the dominant anion. Elevated concentrations of iron, manganese, sulfate, and dissolved solids and low pH are the most common water-quality problems in the Gettysburg Formation. Aggressive water (pH below 7.0 or poorly buffered) can dissolve considerable amounts of lead from plumbing and may be the reason for the four elevated lead concentrations. Additional information on the source and significance of these and selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Gettysburg Formation

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	305	—	—	—	228	360	485	30	1,300
Field hardness	301	—	—	—	93	150	210	17	990
Field pH (standard units)	98	—	<6.5 >8.5	14	6.8	7.3	7.6	5.8	8.2
Bicarbonate	75	—	—	—	110	140	160	1.0	260
Calcium	74	—	—	—	50	75	100	1.5	320
Chloride	76	—	250	0	6.4	10	14	.90	86
Iron	85	—	.3	15	.040	.070	.13	.000	5.9
Lead	42	0.015	—	4	.003	.005	.010	.000	.071
Magnesium	74	—	—	—	11	15	22	.70	68
Manganese	81	—	.05	18	.000	.010	.021	.000	1.2
Nitrate (as N)	91	10	—	0	1.5	2.9	4.2	.07	10
Potassium	70	—	—	—	.80	1.2	2.0	.20	26
Silica	59	—	—	—	18	22	26	1.1	45
Sodium	70	—	—	—	7.8	11	16	2.6	50
Sulfate	76	—	250	8	27	79	170	.00	890
Total dissolved solids	62	—	500	10	258	371	515	37	1,460

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.

Lithology has a definite effect on the quality of water in the Gettysburg Formation. As seen in the tables below, wells completed in the conglomerate and sandstone generally produce water that contains lower amounts of dissolved solids, is softer, and more acidic than wells completed in the shale.

Field specific conductance, by lithology, Gettysburg Formation

[Specific conductance in µS/cm, microsiemens per centimeter at 25 degrees Celsius; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Well type	Number of wells	P25	Median	P75	Minimum	Maximum
Conglomerate	17	133	220	333	50	820
Sandstone	112	151	260	360	30	620
Shale	144	330	418	529	100	1,300

Field hardness, by lithology, Gettysburg Formation

[Hardness in mg/L, milligrams per liter; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Well type	Number of wells	P25	Median	P75	Minimum	Maximum
Conglomerate	20	55	89	120	17	190
Sandstone	117	68	120	150	17	340
Shale	126	120	170	240	17	840

Field pH, by lithology, Gettysburg Formation

[pH in standard units; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Well type	Number of wells	P25	Median	P75	Minimum	Maximum
Conglomerate	8	6.6	6.8	7.4	6.5	7.7
Sandstone	34	6.5	7.0	7.6	5.8	7.9
Shale	47	7.0	7.4	7.6	5.9	8.2

Field parameters also can vary spatially. Wells in Adams County (125 wells) contain water with significantly greater specific conductance than wells in Dauphin (57 wells) or York (119 wells) Counties; the medians are 450, 317, and 270 µS/cm, respectively. The water from wells in Adams County is significantly harder (118 wells) and more alkaline than in York County (114 wells). The median hardness of water in Adams County is 190 mg/L; in York County, the median is 120 mg/L. For pH, the median in Adams County (62 wells) is 7.4; in York County (19 wells), the median is 6.8. The spatial differences, however, may be related to lithology. As noted under the section describing the geology, the Gettysburg Formation contains more shale in Adams County than in York County.

Increasing well depth can significantly increase the concentration of sulfate and dissolved solids. Wells drilled to a depth of 400 ft or less (43 wells) have a median sulfate concentration of 22 mg/L, deeper wells (23 wells) have a median sulfate concentration of 100 mg/L. For dissolved solids, the median concentration in water from wells drilled to a depth of 400 ft or less (35 wells) is 200 mg/L and in deeper wells (20 wells) the median concentration is 400 mg/L. In their work, Meisler and Longwill (1961), Bain (1972), and Wood (1980) noted that elevated concentrations of sulfate appear to be related to residence time; the older, deeper water generally contains more sulfate and higher amounts of dissolved solids and is harder than water that is shallow with a brief residence time. Bain (1972, p. 100) concluded, “The depth of potable water (less than 1,000 mg/L total dissolved solids) appears to lie between 1,000 and 2,000 feet.” It should be noted also, that continued, high-demand withdrawals from wells considerably shallower than 1,000 ft have been associated with increases in the concentrations of sulfate and total dissolved solids.

Diabase (TRd)

The Diabase occurs as dikes and sills throughout the Gettysburg-Newark Lowland, underlying about 260 mi^2 (Berg and others, 1980). Dikes are generally between 5 and 100 ft thick, and major sills are commonly 800 to 2,500 ft thick. The reference section is at Devils Den in Gettysburg National Park, Adams County.

Geologic description.—The Diabase is dark gray to black, medium- to coarse-grained in the center of large intrusions and fine grained at contacts and in narrow dikes. The lithology of the Diabase is remarkably uniform, with an ophitic or subophitic texture. The major minerals labradorite and augite are present in about equal proportions; ilmenite, quartz, and apatite are accessory minerals (Wood and Johnston, 1964, p. 12). The composition of a Diabase dike just west of Gettysburg, Pa., is similar to a basalt. This type of basalt is quartz normative (high silica content, greater than 50 percent), and indicates it was intruded in the late stages of rifting. It is similar in composition and age to diabase in New England (Tom Armstrong, U.S. Geological Survey, oral commun., 1999).

The Diabase is highly resistant to weathering and commonly weathers to large spheroidal boulders (Poth, 1977, p. 14). Dikes typically form narrow ridges, and larger intrusions form hills of moderate relief. Joints are well developed, abundant, and open (Geyer and Wilshusen, 1982, p. 106-108). A thin mantle composed of stiff clay that is relatively impervious to moisture generally overlies the Diabase. Low-lying areas underlain by Diabase are poorly drained (MacLachlan and others, 1975, p. 168).

In some areas, the Diabase has intruded into bedding planes as sills and also may have followed fractures created by faults (Wood, 1980, p. 15). The shales and sandstones in the immediate vicinity of the Diabase have been thermally altered to porcelanite and their color changed from red or brown to blue-black by reduction of the iron oxide (Stose and Jonas, 1933, p. 44). Porphyroblasts of andalusite and corderite indicate a temperature range of about 500 to 600°C and pressure of a few kilobars, which is equivalent to burial of less than 10 kilometers (Tom Armstrong, U.S. Geological Survey, oral commun., 1999). Most of the Diabase is thought to have been intruded during Early to Middle Jurassic time but is difficult to date radiometrically (Sutter and Smith, 1979, p. 808).

Well depths and casing lengths.—Depths of wells and casing lengths for wells completed in the Diabase are presented in the tables below. High-demand wells are not significantly deeper than domestic wells.

Reported well depth, Diabase

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	255	52	80	122	220	311	27	1,250
Drilled, domestic	184	50	80	119	200	300	27	600
Drilled, high-demand	22	51	72	228	404	760	29	1,250

Reported casing lengths, Diabase

[Casing length in feet; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	190	15	20	27	40	60	4	240
Drilled, domestic	155	15	20	27	41	60	4	110
Drilled, high-demand	8	—	11	17	31	—	7	50

Hydrologic properties.—Water levels for wells completed in the Diabase are presented in the table below. Water levels in 191 wells range from flowing at land surface to 155 ft below land surface; the median is 14 ft below land surface. Wood and Johnson (1964, p. 12) reported that "springs are common in ravines, draws, and other depressions crossed by the dikes."

Water levels, Diabase

[Water levels in feet below land surface; F, flowing well; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	27	6	11	15	45	81	3	90
Slope	107	5	9	15	30	50	F	155
Valley	41	3	6	10	18	30	F	95

Reported yields for wells completed in the Diabase are presented in the table below. Yields of 5.0 gal / min or less are reported from 89 wells; 66 are domestic wells. Only one of the four wells with reported yields of 100 gal / min or greater is deeper than 200 ft. Yields of high-demand wells are not significantly greater than domestic wells.

Reported well yield, Diabase

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	209	1.0	2.0	7.5	15	25	0.0	100
Domestic	154	1.0	2.0	6.0	15	25	.0	100
High-demand	15	1.6	3.0	16	35	70	1.0	100

Twenty-four wells and borings were drilled to depths of 11 to 200 ft below land surface into the Coffman Hill diabase sheet to characterize the overburden soil and the weathered bedrock zone in the vicinity of the Boarhead Farms Superfund Site, Bridgeton Township, Bucks County, Pa. (Schreffler, 1996, table 1). Driller reported yields from 17 of the 24 wells ranged from dry to 7 gal / min; the median was 1 gal / min.

Specific capacities of wells completed in the Diabase are presented in the table below. Nineteen wells (drilled from 98 to 405 ft below land surface) have specific capacities of 0.04 (gal / min) / ft or less and are incapable of meeting most domestic or other water-use demands. Specific capacities of 1.0 (gal / min) / ft are reported from three wells; only one is deeper than 200 ft. The specific capacity of one well pumped 8 hours or longer is 0.14 (gal / min) / ft.

Reported specific capacity, Diabase

[Specific capacity in gallons per minute per foot of drawdown; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	59	0.01	0.04	0.12	0.29	0.54	0.01	5.0
Domestic	45	.01	.03	.12	.28	.46	.01	2.1
High-demand	1	—	—	.12	—	—	.12	—

Values of hydraulic conductivity and transmissivity for the Diabase are presented in the following table; a specific yield of 0.007 was used in estimating these hydrologic properties. Hydraulic conductivity and transmissivity are generally greater on hilltops (7 wells) than on slopes (25 wells) or in valleys (11 wells). The median hydraulic conductivities of wells on hilltops, slopes, and in valleys are 2.4, 0.22, and 0.09 ft / d, respectively. The median transmissivity of wells on hilltops is 49 ft^2 / d; on slopes, 14 ft^2 / d; and in valleys, 15 ft^2 / d.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Diabase

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	44	0.01	0.05	0.23	1.3	2.7	0.00	170
Transmissivity (ft^2 / d)	44	1.5	4.9	18	40	69	.24	930

Gerhart and Lazorchick (1984b, tables 6 and 14) developed a digital model for parts of Lancaster and Berks Counties, Pa. In their model, Gerhart and Lazorchick used a specific yield of 0.012 and a hydraulic conductivity of 0.1 ft / d for a block that consisted of the Diabase. For the Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, p. 38) determined a specific yield of 0.007 for the upper 300 ft and a storage coefficient of 0.00007 for the lower 300 ft. They also used a hydraulic conductivity of 0.40 ft / d for different hydrogeologic units that included the Diabase (Gerhart and Lazorchick, 1988, p. 22).

At the Boarhead Farms Superfund Site, Bridgeton Township, Bucks County, Pa., Schreffler (1996) used slug tests to determine transmissivities in seven boreholes. The transmissivities ranged from 2.8 to 440 ft^2 / d; the median was 180 ft^2 / d. Open-hole constant-discharge tests in boreholes with reported yields greater than 1.0 gal / min were conducted at five wells. The transmissivities ranged from 3.1 to 100 ft^2 / d; the median was 50 ft^2 / d.

The depths of water-bearing zones in 145 wells drilled as deep as 600 ft range from 4 to 583 ft below land surface. Fifty percent of the 249 water-bearing zones reported are penetrated by a depth of 75 ft and 90 percent by a depth of 226 ft. The greatest density of water-bearing zones (0.57 per 50 ft of well depth) is from 301 to 350 ft below land surface (fig. 65). The density of water-bearing zones at depths of 301 ft or greater are based on the presence of four or fewer water-bearing zones per 50-ft interval. The overall density of water-bearing zones in the Diabase is 0.41 per 50 ft of well depth.

Borehole geophysical logging at the Boarhead Farms Superfund Site, Bridgeton Township, Bucks County, Pa., was conducted on 18 wells that ranged in depth from 49 to 199 ft below land surface to determine depths of fractures that were possible water-bearing zones (Schreffler, 1996, table 2). A total of 23 fractures in 10 wells were identified. These fractures ranged in depth from 12 to 63 ft below land surface; the median was 21 ft below land surface.

Six wells, ranging in depth from 161 to 760 ft were drilled through the Coffman Hill diabase sheet, Bridgeton and Nockamixon Townships, Bucks County, Pa. (Schreffler, 1996). Borehole geophysical logging in the six wells indicated most of the ground water entered the boreholes through the underlying shale and not from fractures in the diabase. Only one of the six wells penetrated a water-bearing zone in the diabase.

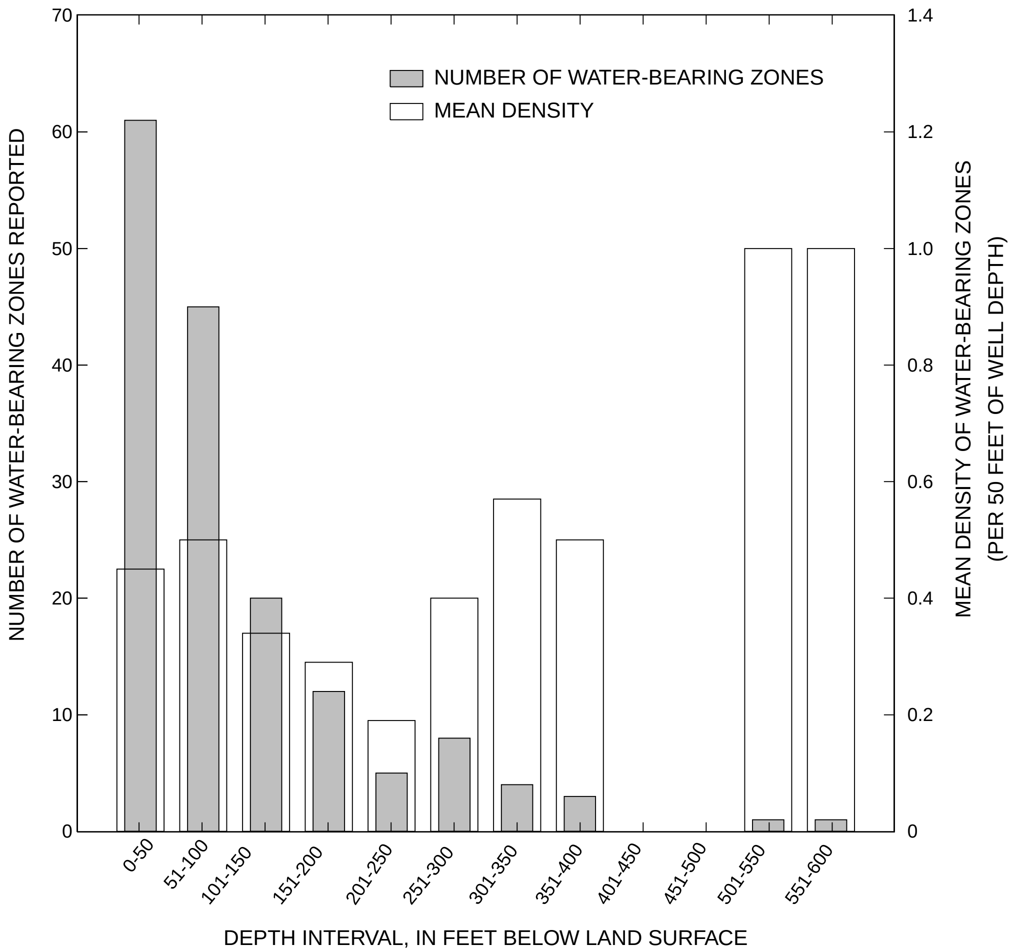


Figure 65. Number and density of water-bearing zones per 50 feet of well depth in the Diabase of the Piedmont Physiographic Province, Gettysburg-Newark Lowland Section.

Water quality.—As seen in the following table, wells completed in the Diabase generally yield water that contains low to moderate amounts of dissolved solids, is soft to moderately hard, and is slightly acidic. Calcium is the dominant cation, and bicarbonate is the dominant anion. Elevated concentrations of iron and manganese and low pH are the most common water-quality problems in the Diabase. Chloride concentrations greater than 250 mg/L and two of the three total dissolved solids concentrations greater than 500 mg/L are from two wells near salt piles. Water with a pH below 7.0 or water that is poorly buffered can dissolve considerable amounts of different metals including lead and zinc from plumbing and may be the reason for the elevated lead and zinc concentrations. Langland and Dugas (1996) determined that most of the water (62 percent of wells sampled) in the Diabase is moderately to highly corrosive. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Diabase

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; pH in standard units; —, insufficient data available; <, less than; >, greater than; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	165	—	—	—	220	320	420	69	3,600
Field hardness	132	—	—	—	86	140	190	17	800
Field pH (standard units)	36	—	<6.5 >8.5	11	6.6	6.9	7.3	6.0	8.0
Bicarbonate	44	—	—	—	59	90	130	10	370
Calcium	44	—	—	—	24	37	51	5.5	370
Chloride	45	—	250	2	4.7	9.9	23	2.2	1,300
Iron	39	—	.3	10	.020	.11	.25	.000	4.4
Lead	16	0.015	—	2	.000	.004	.011	.000	<.10
Magnesium	44	—	—	—	8.8	15	21	1.7	210
Manganese	33	—	.05	5	.000	.010	.013	.000	.15
Nitrate (as N)	46	10	—	5	1.1	2.1	4.7	.02	33
Potassium	42	—	—	—	.50	.85	2.3	.10	18
Silica	39	—	—	—	22	35	42	7.9	56
Sodium	42	—	—	—	4.9	6.5	8.7	2.8	50
Sulfate	44	—	250	0	24	35	57	5.8	170
Total dissolved solids	38	—	500	3	165	231	326	66	2,130
Zinc	21	—	5	1	.043	.11	.63	.000	8.5

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.

Summary of Characteristics of Bedrock Aquifers in the Piedmont Physiographic Province, Gettysburg-Newark Lowland Section

Data evaluated for most units in the Gettysburg-Newark Lowland Section are summarized in figures 66 to 71 and tables 15 to 19. Well depths range from 10 to 2,080 ft below land surface and casing lengths from 1 to 1,800 ft. Well depths and casing lengths can vary significantly by hydrogeologic unit (tables 15 and 16), water use, topographic setting, and county. In general, high-demand wells (figs. 54b and 55b) are completed at significantly greater depths and use significantly more casing than domestic wells (figs. 54c and 55c).

Reported yields range from 0.0 to 1,500 gal/min and specific capacities from 0.00 to 140 (gal/min)/ft. Reported yields and specific capacities can vary significantly by geohydrologic unit (figs. 57 and 58, tables 17 and 18), water use, topographic setting, and spatially. High-demand wells generally (figs. 56b and 57b) have significantly greater reported yields and specific capacities than domestic wells (figs. 56c and 57c).

Field-water-quality parameters (specific conductance, hardness, pH) most commonly vary by geohydrologic unit (fig. 71 and table 19). Water from wells completed in the Lockatong and Brunswick Formations have significantly higher specific conductance and hardness than every other geohydrologic unit in the Gettysburg-Newark Lowland.

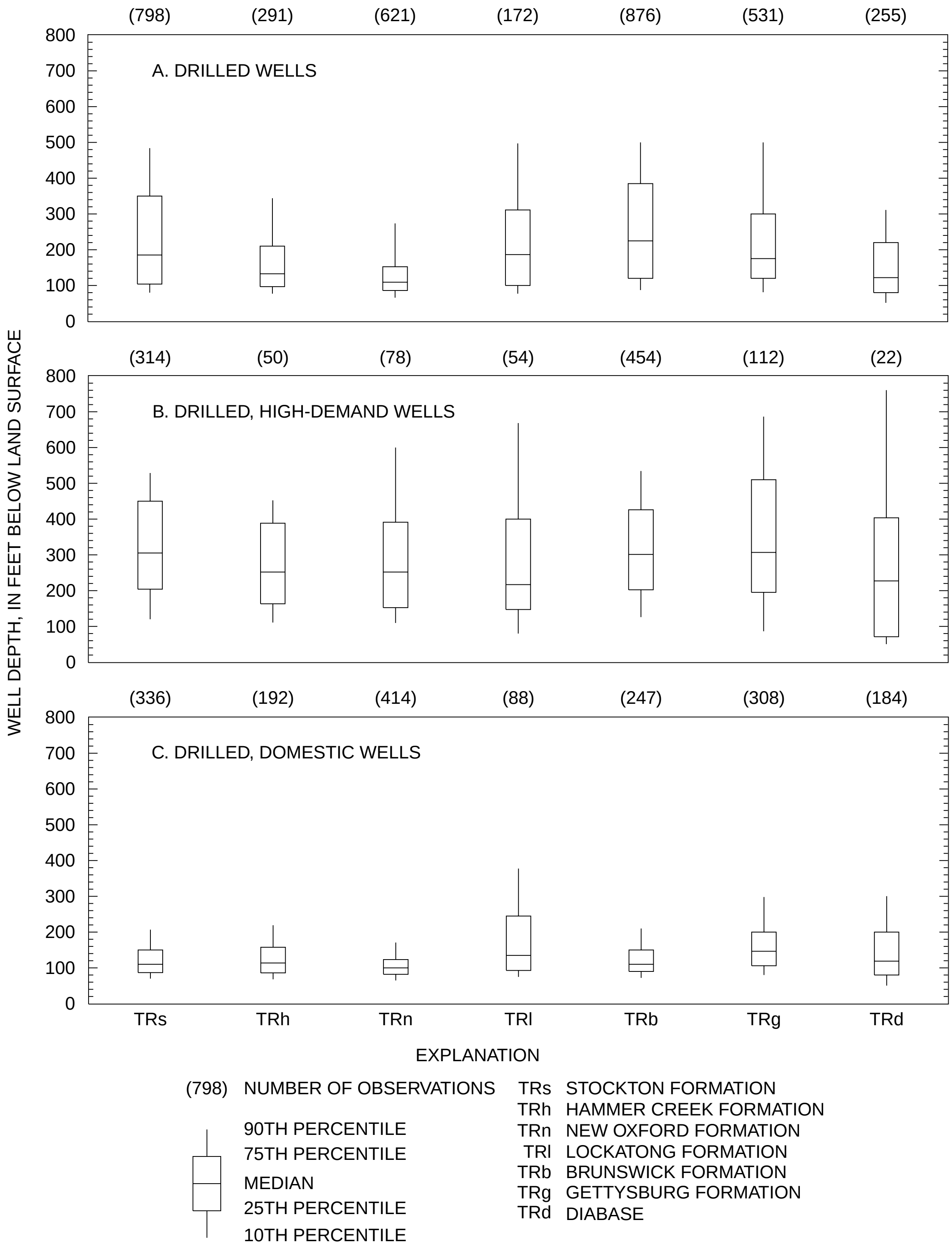


Figure 66. Depths of drilled wells in Piedmont Physiographic Province, Gettysburg-Newark Lowland Section.

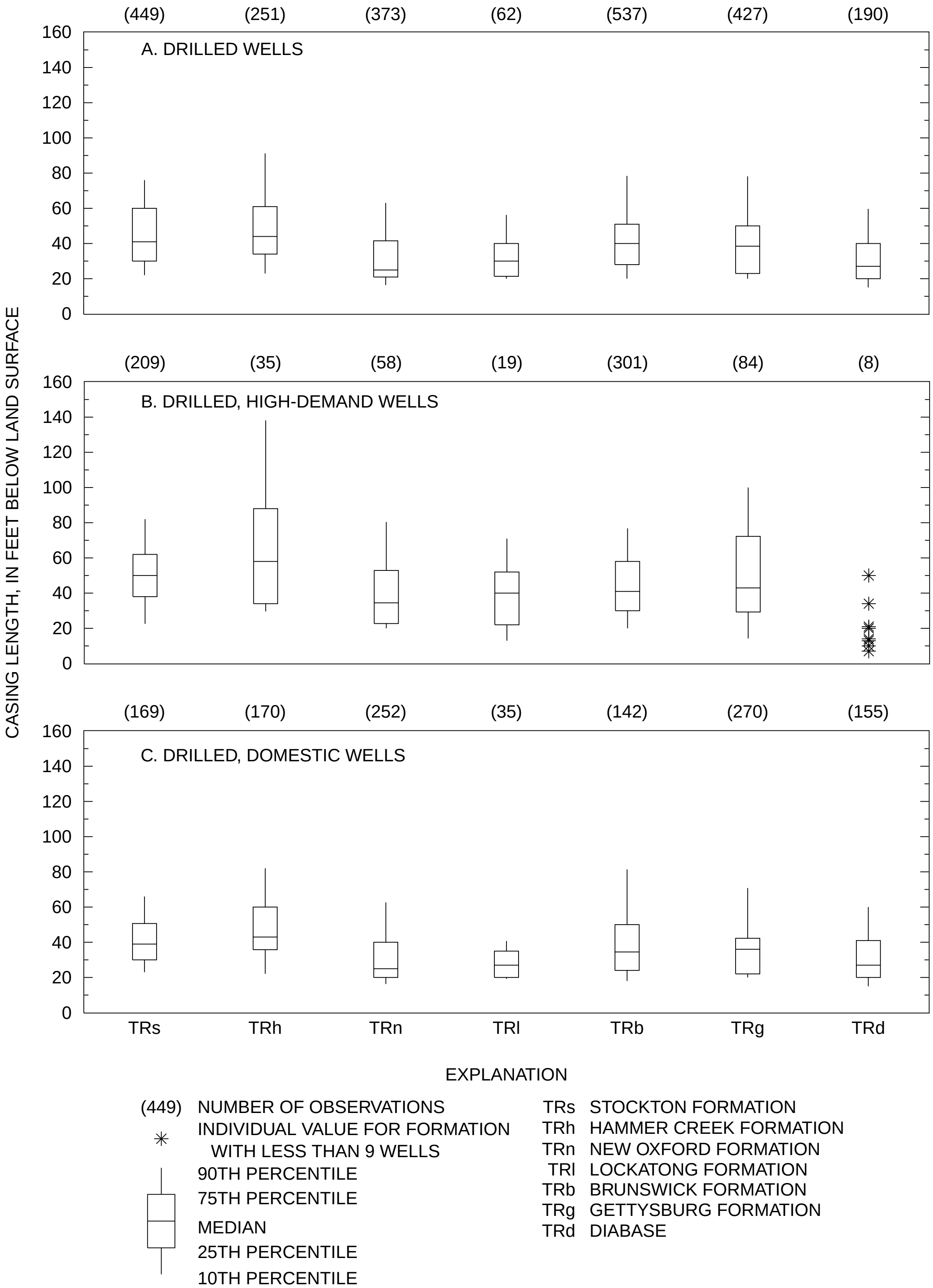


Figure 67. Casing lengths of drilled wells in Piedmont Physiographic Province, Gettysburg-Newark Lowland Section.

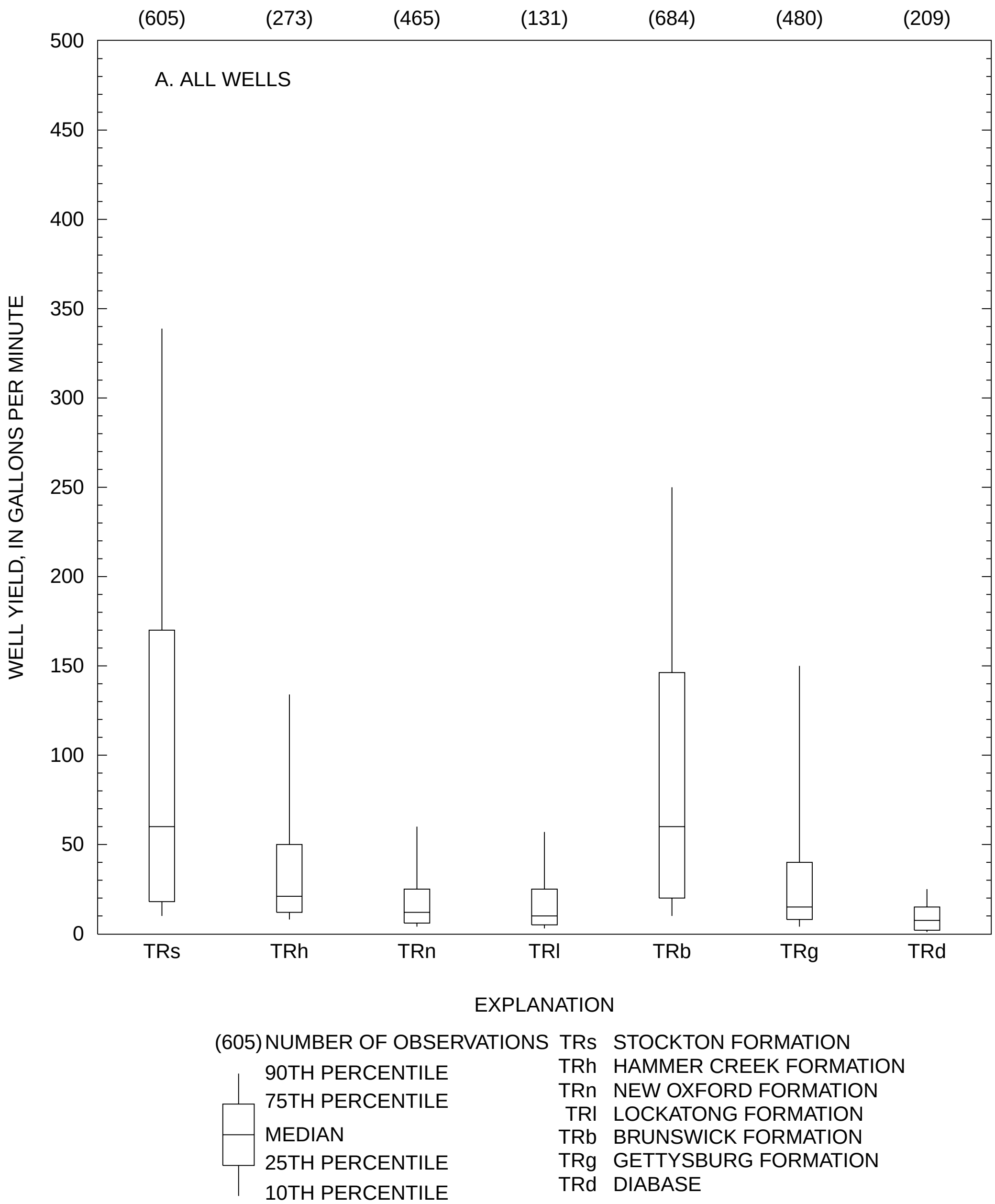


Figure 68. Reported yields of wells in Piedmont Physiographic Province, Gettysburg-Newark Lowland Section.

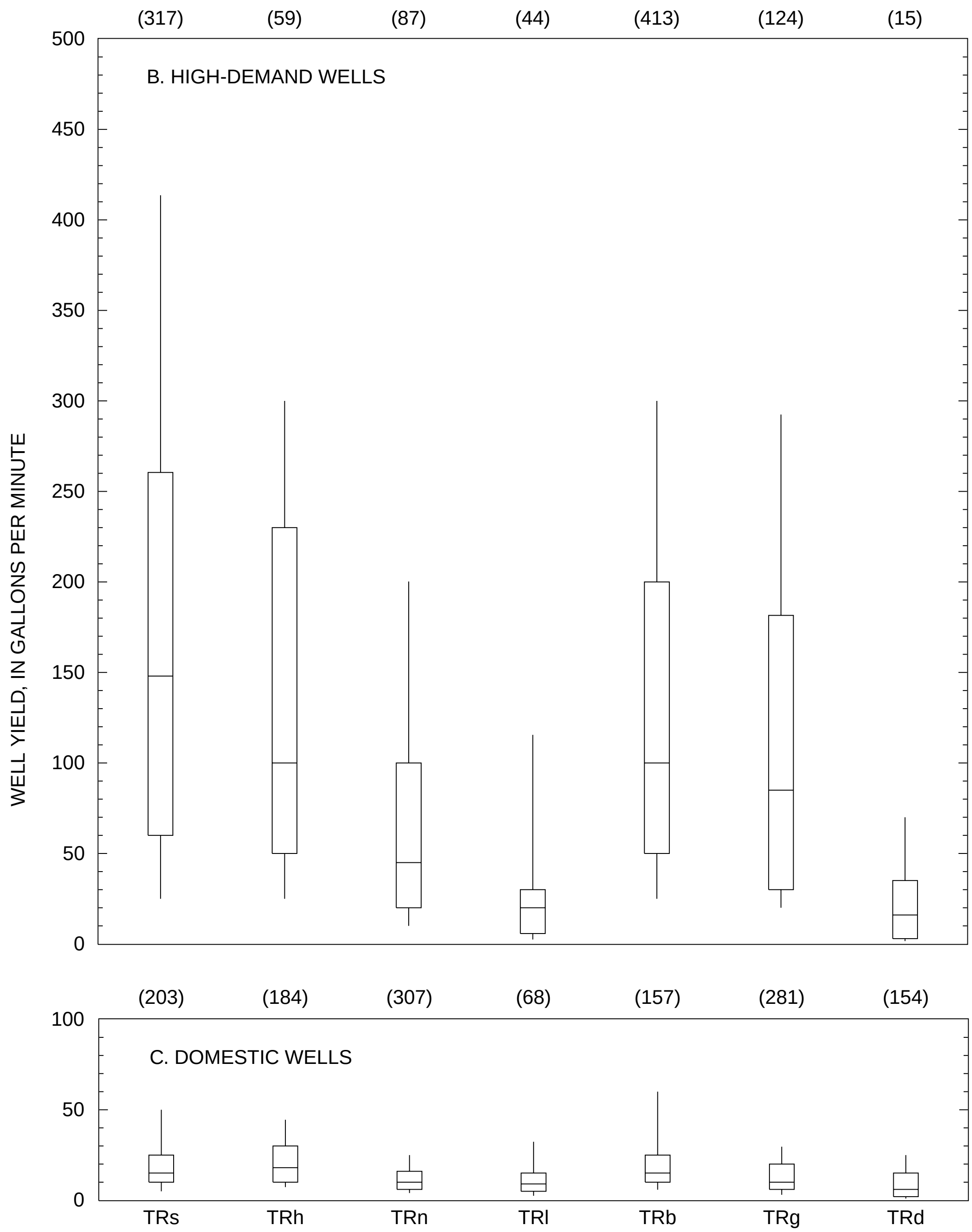


Figure 68. Reported yields of wells in Piedmont Physiographic Province, Gettysburg-Newark Lowland Section—Continued.

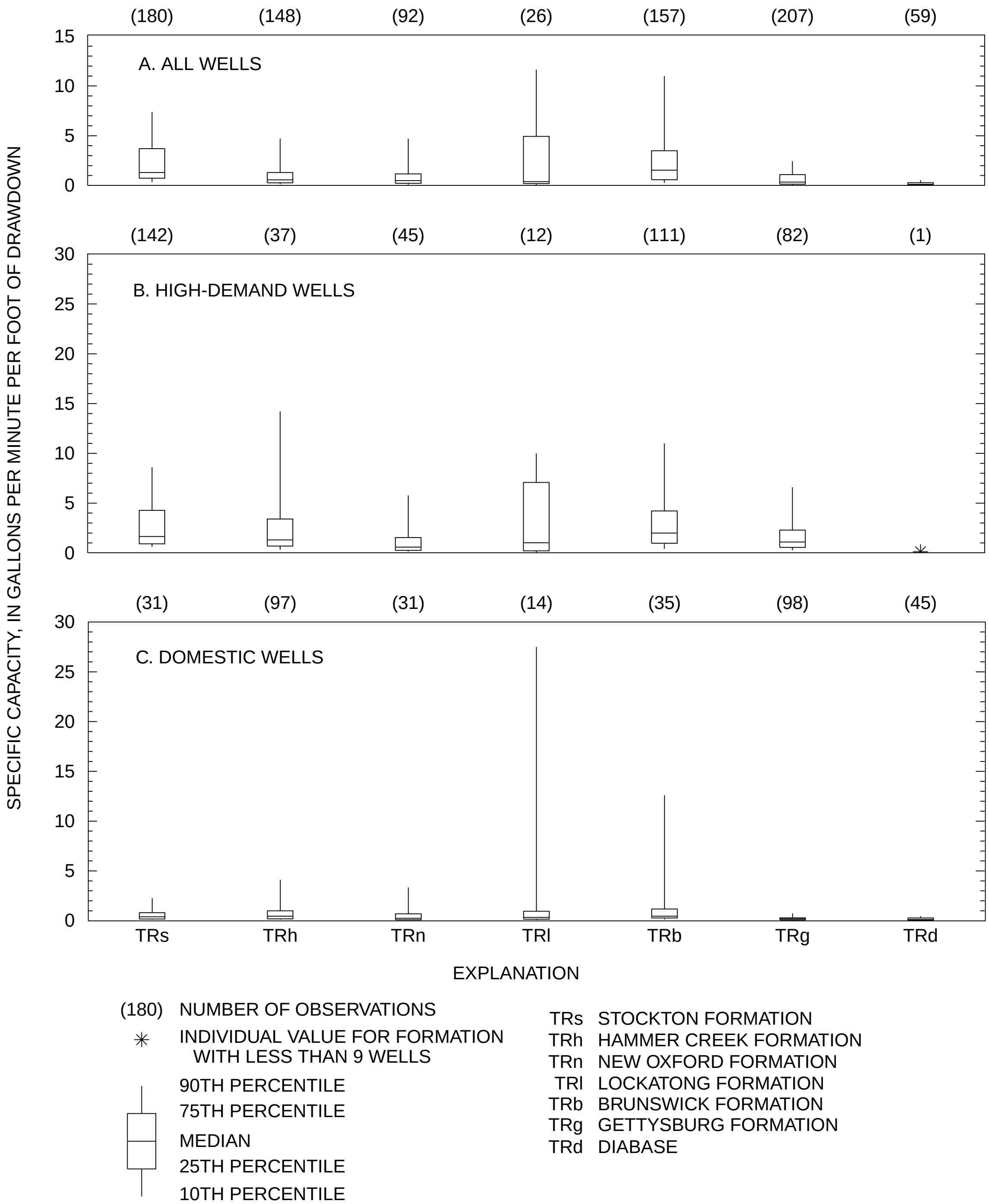


Figure 69. Specific capacities of wells in Piedmont Physiographic Province, Gettysburg-Newark Lowland Section.

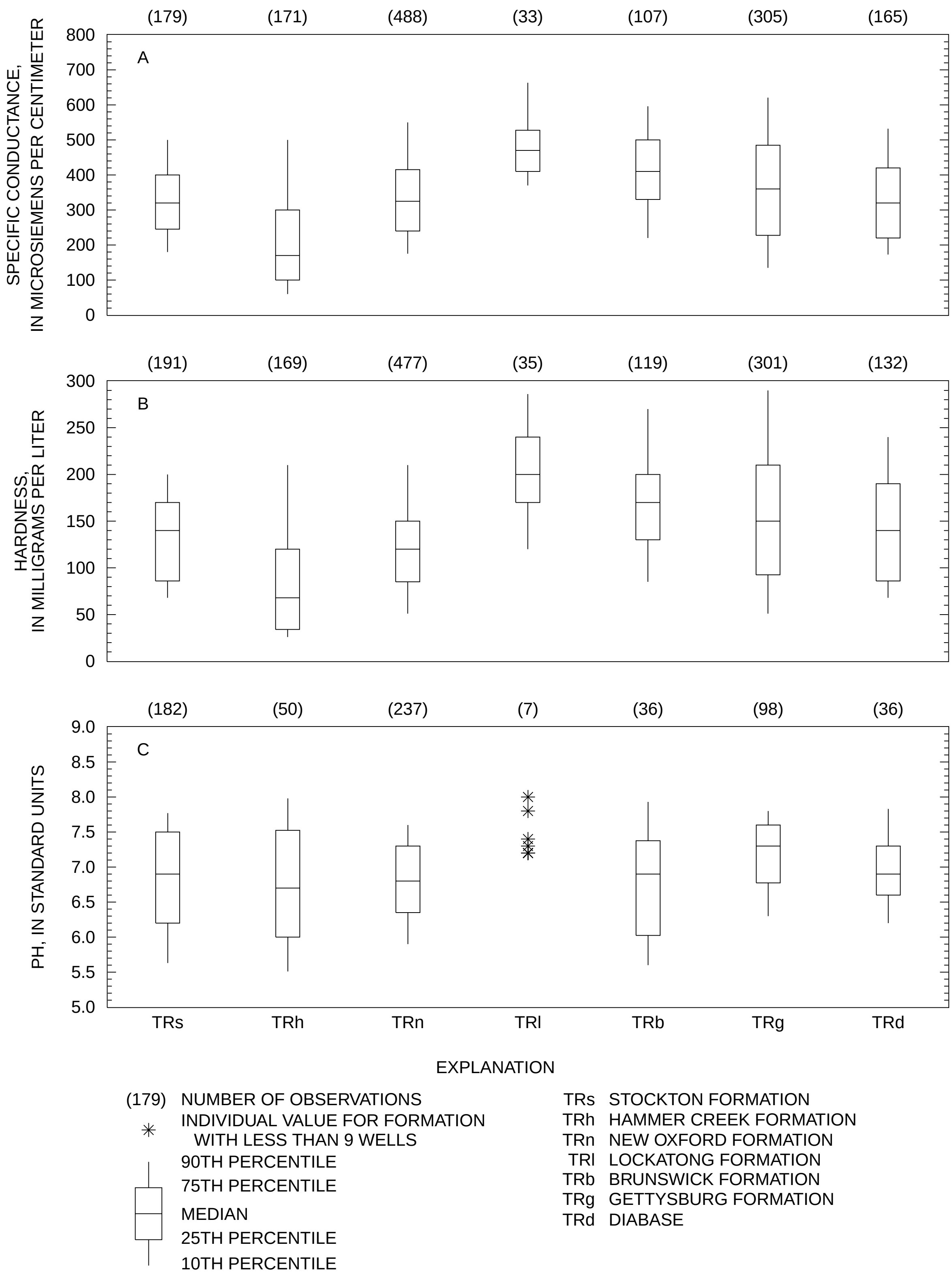


Figure 70. Field water-quality characteristics of wells in the Piedmont Physiographic Province, Gettysburg-Newark Lowland Section: A, specific conductance; B, hardness; C, pH.

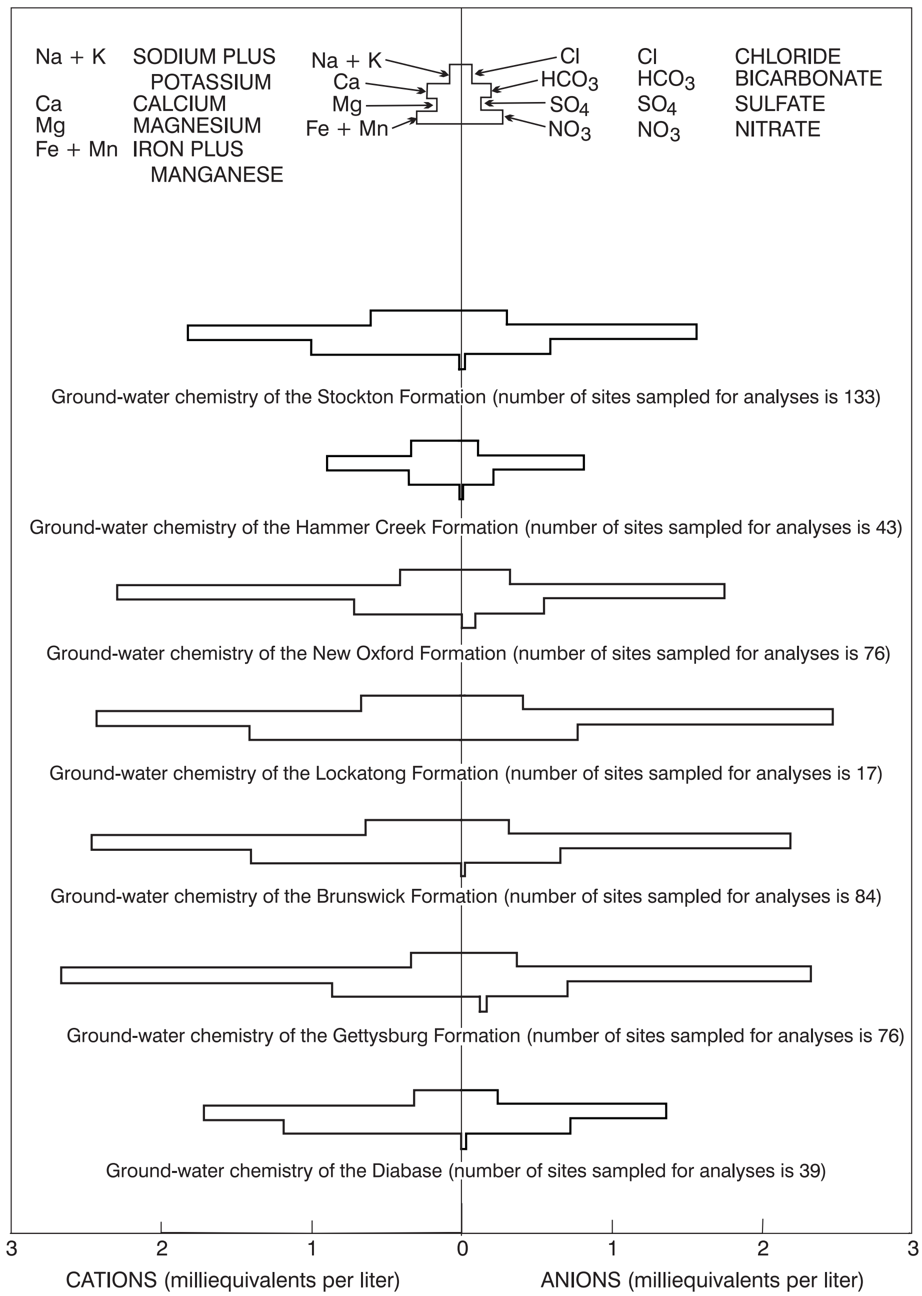


Figure 71. Median chemical analyses of selected chemical constituents from the ground water of the geohydrologic units in the Piedmont Physiographic Province, Gettysburg-Newark Lowland Section.

Table 15. *Significant relations for depth of drilled wells among seven geohydrologic units in the Gettysburg-Newark Lowland Section of the Piedmont Physiographic Province, Pennsylvania*

[Table is read from top down. Example, depths of wells in the Stockton Formation are significantly greater than the depths of wells in the Hammer Creek Formation, but are significantly shallower (less) than in the Brunswick Formation. G, greater; L, less; -, insufficient data; blank indicates no significant differences between units]

SCKN, Stockton Formation; HMCK, Hammer Creek Formation; NOXF, New Oxford Formation; LCKG, Lockatong Formation; BRCK, Brunswick Formation; GBRG, Gettysburg Formation; DIBS, Diabase

	SCKN	HMCK	NOXF	LCKG	BRCK	GBRG	DIBS
DRILLED WELLS							
SCKN							
HMCK	G						
NOXF	G	G					
LCKG		L	L				
BRCK	L	L	L				
GBRG		L	L		G		
DIBS	G			G	G	G	
DRILLED, HIGH-DEMAND WELLS							
SCKN							
HMCK							
NOXF							
LCKG							
BRCK							
GBRG							
DIBS							
DRILLED, DOMESTIC WELLS							
SCKN							
HMCK							
NOXF	G	G					
LCKG	L		L				
BRCK			L	G			
GBRG	L	L	L		L		
DIBS			L			G	

Table 16. *Significant relations for casing length of drilled wells among seven geohydrologic units in the Gettysburg-Newark Lowland Section of the Piedmont Physiographic Province, Pennsylvania*

[Table is read from top down. Example, casing lengths of wells in the Gettysburg Formation are significantly greater than the casing lengths of wells in the Diabase, but are significantly less than in the Stockton Formation. G, greater; L, less; -, insufficient data; blank indicates no significant differences between units]

SCKN, Stockton Formation; HMCK, Hammer Creek Formation; NOXF, New Oxford Formation; LCKG, Lockatong Formation; BRCK, Brunswick Formation; GBRG, Gettysburg Formation; DIBS, Diabase

	SCKN	HMCK	NOXF	LCKG	BRCK	GBRG	DIBS
DRILLED WELLS							
SCKN							
HMCK							
NOXF	G	G					
LCKG	G	G					
BRCK	G	G	L	L			
GBRG	G	G	L				
DIBS	G	G			G	G	
DRILLED, HIGH-DEMAND WELLS							
SCKN							
HMCK							
NOXF	G	G					
LCKG		G					
BRCK	G	G					
GBRG							
DIBS	-	-	-	-	-	-	
DRILLED, DOMESTIC WELLS							
SCKN							
HMCK							
NOXF	G	G					
LCKG	G	G					
BRCK		G	L	L			
GBRG		G	L				
DIBS	G	G			G	G	

Table 17. *Significant relations for reported yield from wells among seven geohydrologic units in the Gettysburg-Newark Lowland Section of the Piedmont Physiographic Province, Pennsylvania*

[Table is read from top down. Example, reported yields from wells in the Hammer Creek Formation are significantly greater than the reported yields from wells in the New Oxford Formation, but are significantly less than in the Brunswick Formation. G, greater; L, less; blank indicates no significant differences between units]

SCKN, Stockton Formation; HMCK, Hammer Creek Formation; NOXF, New Oxford Formation; LCKG, Lockatong Formation; BRCK, Brunswick Formation; GBRG, Gettysburg Formation; DIBS, Diabase

	SCKN	HMCK	NOXF	LCKG	BRCK	GBRG	DIBS
ALL WELLS							
SCKN							
HMCK	G						
NOXF	G	G					
LCKG	G	G					
BRCK		L	L	L			
GBRG	G	G	L	L	G		
DIBS	G	G	G	G	G	G	
HIGH-DEMAND WELLS							
SCKN							
HMCK							
NOXF	G	G					
LCKG	G	G	G				
BRCK	G		L	L			
GBRG	G		L	L	G		
DIBS	G	G			G	G	
DOMESTIC WELLS							
SCKN							
HMCK							
NOXF	G	G					
LCKG	G	G					
BRCK			L	L			
GBRG	G	G			G		
DIBS	G	G	G		G	G	

Table 18. *Significant relations for specific capacity from wells among seven geohydrologic units in the Gettysburg-Newark Lowland Section of the Piedmont Physiographic Province, Pennsylvania*

[Table is read from top down. Example, specific capacities from wells in the Hammer Creek Formation are significantly greater than the specific capacities from wells in the Diabase, but are significantly less than in the Brunswick Formation. G, greater; L, less; -, insufficient data; blank indicates no significant differences between units]

SCKN, Stockton Formation; HMCK, Hammer Creek Formation; NOXF, New Oxford Formation; LCKG, Lockatong Formation; BRCK, Brunswick Formation; GBRG, Gettysburg Formation; DIBS, Diabase

	SCKN	HMCK	NOXF	LCKG	BRCK	GBRG	DIBS
ALL WELLS							
SCKN							
HMCK	G						
NOXF	G						
LCKG	G						
BRCK		L	L	L			
GBRG	G	G			G		
DIBS	G	G	G	G	G	G	
HIGH-DEMAND WELLS							
SCKN							
HMCK							
NOXF	G	G					
LCKG							
BRCK			L				
GBRG	G				G		
DIBS	-	-	-	-	-	-	
DOMESTIC WELLS							
SCKN							
HMCK							
NOXF							
LCKG							
BRCK							
GBRG	G	G			G		
DIBS	G	G	G	G	G		

Table 19. *Significant relations for field constituents among seven geohydrologic units in the Gettysburg-Newark Lowland Section of the Piedmont Physiographic Province, Pennsylvania*

[Table is read from top down. Example, field specific conductances are significantly greater in the Stockton Formation than field specific conductances in the Hammer Creek Formation, but are significantly less than in the Lockatong Formation. G, greater; L, less; -, insufficient data; blank indicates no significant differences between units]

SCKN, Stockton Formation; HMCK, Hammer Creek Formation; NOXF, New Oxford Formation; LCKG, Lockatong Formation; BRCK, Brunswick Formation; GBRG, Gettysburg Formation; DIBS, Diabase

	SCKN	HMCK	NOXF	LCKG	BRCK	GBRG	DIBS
SPECIFIC CONDUCTANCE							
SCKN							
HMCK	G						
NOXF		L					
LCKG	L	L	L				
BRCK	L	L	L				
GBRG		L		G	G		
DIBS		L		G	G		
HARDNESS							
SCKN							
HMCK	G						
NOXF		L					
LCKG	L	L	L				
BRCK	L	L	L				
GBRG		L	L	G	G		
DIBS		L		G	G		
pH							
SCKN							
HMCK							
NOXF							
LCKG	-	-	-				
BRCK				-			
GBRG	L	L	L	-			
DIBS				-			

GEOHYDROLOGY OF THE BLUE RIDGE PHYSIOGRAPHIC PROVINCE, SOUTH MOUNTAIN SECTION

Location and Geographic Setting

South Mountain, the northern most extension of the Blue Ridge Physiographic Province as described by Fenneman (1938), is in south-central Pennsylvania where it occupies about 290 mi^2 of Adams, Cumberland, Franklin, and York Counties (fig. 1). South Mountain is bounded on the west and north by the Cumberland Valley, part of the Great Valley Section of the Ridge and Valley Physiographic Province, and on the east by the Gettysburg-Newark Lowland Section of the Piedmont Physiographic Province. South Mountain extends south into Maryland where the Blue Ridge divides into two ridges, Catoctin Mountain on the east and South Mountain on the west. For the purpose of this study, the southern boundary of South Mountain is the Pennsylvania state line with Maryland (fig. 72).

South Mountain is composed of linear, sub-parallel, ridges and valleys that generally trend northeast-southwest. South Mountain forms a moderate to rugged topography that rises from 450 ft above sea level to a maximum altitude of 2,080 ft (Berg and others, 1989). The sandstone and quartzite rocks and extrusives form steep but stable slopes and ridges that are cut by deep, lateral valleys. Valleys are generally underlain by metamorphic rocks. The maximum vertical relief between valley floor and hilltop is about 500 ft. Local relief, however, generally averages 250 to 350 ft.

Population centers within the South Mountain Section are in numerous small communities and residential developments. Major centers of population such as Carlisle, Chambersburg, Gettysburg, and York lie outside the province (fig. 72). Forest is the dominant land cover in the study area. Agricultural and residential land use is minor.

The climate of South Mountain is humid continental; precipitation averages 41 in. per year. Summer and winter mean temperatures are 25 and -1°C, respectively. Winds are predominantly from the west (Pennsylvania Department of Environmental Protection, 1979). Weather systems that affect the area generally originate in either Canada or central United States and move eastward. Most of the precipitation is derived from another flow pattern that originates in the Gulf of Mexico.

Water-Well Density

The locations of GWSI wells used in the analysis of the South Mountain Section are shown in figure 73. In addition, 563 wells from the WWI database also were used to aid in this study. Well densities by county range from 0.7 wells per square mile in Franklin County to 3.9 wells per square mile in York County. The overall well density is about 1.5 wells per square mile.

Previous Work

Stose (1906; 1907; 1909; 1932), Hall (1934), and Jonas and Stose (1939) are some of the earliest authors to work at or near South Mountain. These early workers emphasized the geology, structure, and mineral resources on a county-wide scale. More recent authors such as Fauth (1968; 1978), Freedman (1967), and Root (1968; 1978) have studied South Mountain on a quadrangle-size scale. Work by Rankin and others (1969), Rankin (1976), Simpson and Sundberg (1987), Key (1991) and Root and Smith (1991) have re-examined the tectonic history of South Mountain.

Meyer and Beall (1958) and Slaughter and Darling (1962) conducted studies on aquifer properties of metarhyolites and metabasalts at South Mountain in Maryland. The transmissivities and storage coefficients derived for the metarhyolite and the metabasalt were determined from single and multiple-well aquifer tests. Trainer and Watkins (1975) working in the Upper Potomac River Basin used streamflow discharges and aquifer tests to determine the transmissivities and storage coefficients of fractured rock with thin or thick regolith. The work by Taylor and Royer (1981), which summarizes the ground water of Adams County by formation and includes information on well yields and water quality, is the most extensive study of the ground water at South Mountain currently available for Pennsylvania.

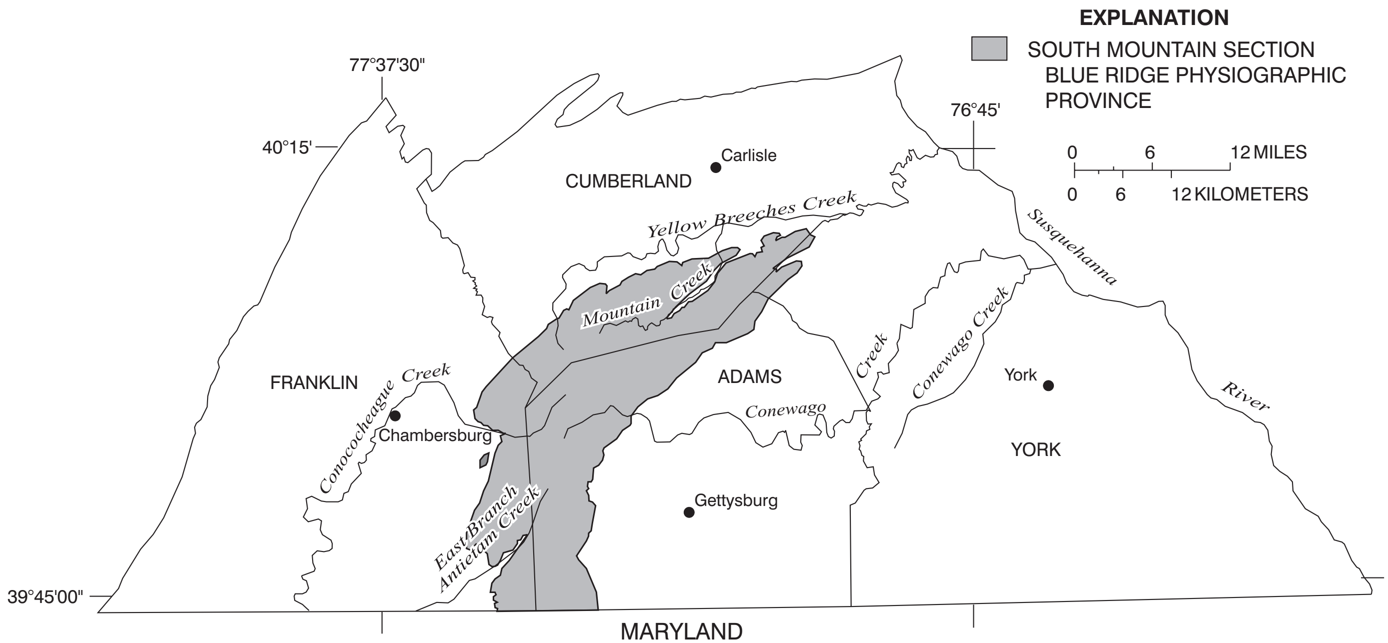


Figure 72. Blue Ridge Physiographic Province, South Mountain Section, major streams, counties, and major population centers.

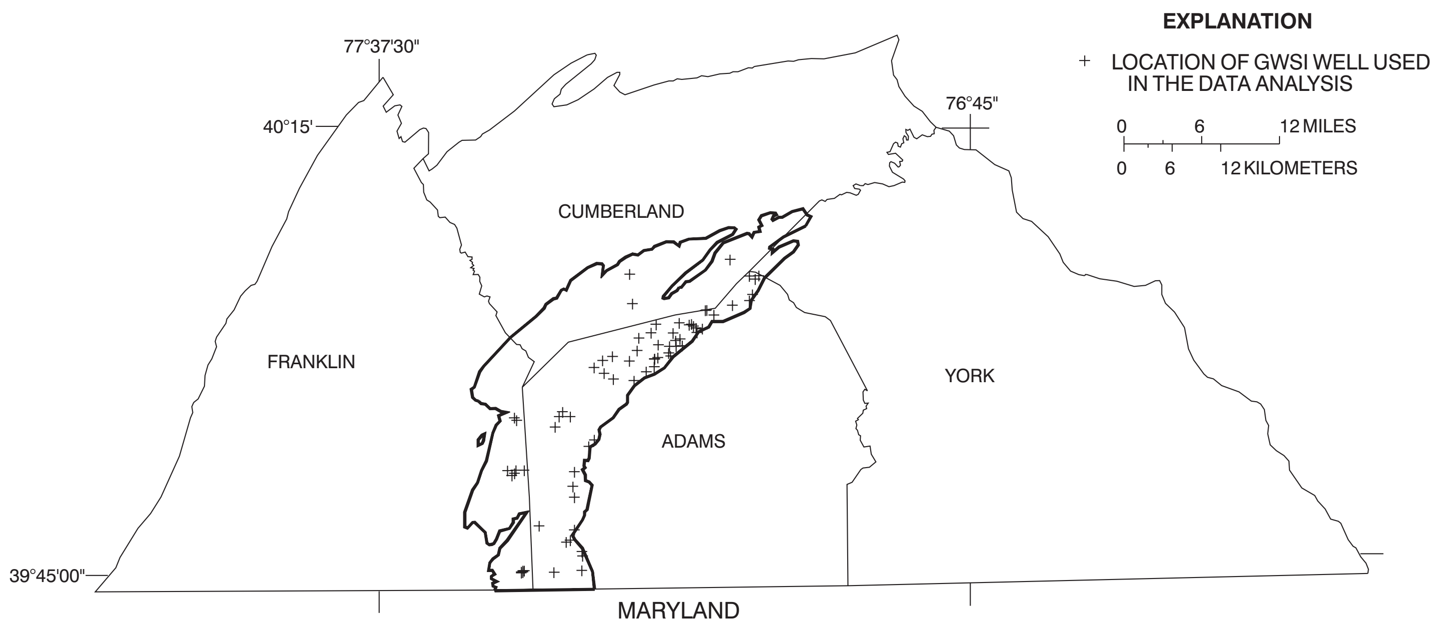


Figure 73. Locations of wells in the Blue Ridge Physiographic Province, South Mountain Section counties.

Geologic Setting

The South Mountain anticlinorium consists of asymmetrical folds that plunge east-northeast at 20 degrees or less. The asymmetrical folds are often terminated by faults, and have steeply dipping or overturned limbs; folding is generally less intense to the south (Fauth, 1968). Longitudinal faults are dominant, trending north-northeast to northeast, parallel to the regional structural trend. The longitudinal faults are truncated by transverse faults that trend east-west (Berg and others, 1980). The anticlinorium extends north to the vicinity of Carlisle where Precambrian and Cambrian rocks of the Blue Ridge plunge northeast beneath Cambrian and Ordovician carbonates of the Great Valley. To the west, Cambrian quartzites grade into Cambrian carbonates which form the eastern part of the Cumberland Valley. On the eastern side of South Mountain, Precambrian and Cambrian rocks are truncated by Triassic-Jurassic faults which define the western border of the Gettysburg-Newark Lowland Section.

The buried core of South Mountain is a Precambrian granodiorite biotite-granite complex (Jonas and Stose, 1939, p. 575-580) that is unconformably overlain by the Swift Run Formation (Jonas and Stose, 1939, p. 585). The Precambrian volcanics of the Catoctin Formation conformably overlie the Swift Run Formation (Fauth, 1968, p. 12) and account for almost one-half of the rocks exposed at South Mountain. The Cambrian age Chilhowee Group may conformably overlie the Catoctin Formation and, except for several small Triassic or Jurassic age diabase dikes, represent the remainder of the rocks at South Mountain (table 20).

Table 20. *Generalized stratigraphic section of the Blue Ridge Physiographic Province, South Mountain Section in Pennsylvania*

[Modified from Berg and others, 1983]

<table>
<tr><th rowspan="2">Age</th><th colspan="2">Geohydrologic unit</th></tr>
<tr><th colspan="2">This report</th></tr>
<tr><td rowspan="4">Lower Cambrian</td><td rowspan="4">Chilhowee Group</td><td>Antietam Formation (Ca)</td></tr>
<tr><td>Montalto Quartzite Member (Chm)</td></tr>
<tr><td>Harpers Formation (Ch)</td></tr>
<tr><td>Weverton and Loudon Formations, undivided (Cwl)</td></tr>
<tr><td rowspan="3">Upper Precambrian</td><td rowspan="3">Catoctin Formation</td><td>Greenstone Schist (vs)</td></tr>
<tr><td>Metarhyolite (mr)</td></tr>
<tr><td>Metabasalt (mb)</td></tr>
</table>

Hydrologic Setting

No through-going stream bisects South Mountain. Small streams whose headwaters occur on South Mountain flow into the Potomac and Susquehanna River Basins (fig. 72). Drainage from South Mountain into the Potomac River Basin is principally through Conococheague, East Branch of Antietam Creeks and other minor tributaries to the Potomac River; all have fairly steep channel slopes within South Mountain. Some of the major streams which head in South Mountain and drain into the Susquehanna River Basin are Yellow Breeches, Mountain, and Conewago Creeks. Typically, the main channels of these creeks within South Mountain consist of narrow valleys and steep slopes.

Within South Mountain drainage patterns tend to be trellis-shaped on clastic rock units and dendritic on the Catoctin Formation. These streams have steep gradients which decline by about half upon reaching the diamicton or colluvial aprons (Clark, 1991). Many of the streams originating in South Mountain parallel local faults until they reach the colluvial aprons which flank much of South Mountain.

South Mountain receives slightly more precipitation in the summer months than in the winter months. Local precipitation is the source of all of the ground water in South Mountain. Much of the precipitation returns to the atmosphere through evapotranspiration or reaches streams as overland runoff. Overland runoff is greatest in late winter or early spring, and lowest in late summer and early fall. The remaining precipitation infiltrates into the regolith and the underlying bedrock, flowing from areas of high relief (high hydraulic head) to areas of low relief (low hydraulic head), through joints, bedding planes, faults, fractures, and other secondary openings. This movement of ground water generally results in a water table that is a subdued replica of the land surface. Water levels are strongly influenced by the amount and duration of precipitation and topographic setting. Where the water table is above the land surface, springs can occur. In South Mountain, springs are reported to be common in the Antietam Formation near the contact with the colluvium, and are present in the Metarhyolite, and the Weverton-Loudon Formations.

Water moving from South Mountain toward the Cumberland Valley flows through or across a thick wedge of colluvium. The colluvium that mantles the ridge slopes and overlies the Cambrian carbonates consists of a mixture of clay, silt, sand, pebbles, cobbles, and boulders derived from weathering and mass wasting of limestone, dolomite, and quartzite. The water that filters through the colluvium is high in carbon dioxide and low in dissolved solids enabling it to rapidly dissolve carbonate rocks, producing large solution channels and a deeply-weathered residuum. In their work on the ground water of the Cumberland Valley, Becher and Root (1981, p. 16-18) noted at Boiling Springs, just north of South Mountain, that (1) the water temperature lags air-temperature changes by 4 to 6 months, (2) specific conductance of the water is only 50 percent of the usual value of ground water in carbonate rock, (3) strong boils in the spring are evident and indicate significantly greater heads than the static elevation head, and (4) the configuration of water-level contours is not altered by the discharge of the springs. The existence of a natural conduit system associated with a large northeast-southeast fault, directly south of Boiling Springs (Berg and others, 1980), is a possible path way for the ground water supplying the springs. The shearing associated with the fault is a zone of weakness that allows the development of the conduit system. Diabase dikes, however, can act as subsurface dams stopping and redirecting ground-water flow (Becher and Root, 1981, p. 19).

The Metarhyolite is the most important aquifer at South Mountain. It comprises about one-third of all the rocks presently exposed and is capable of meeting the needs of most domestic and some high-demand wells. The Antietam Formation is probably the best yielding unit and the Greenstone Schist is one of the least productive units.

Geohydrologic System

South Mountain is comprised of numerous local and intermediate ground-water flow systems (fig. 74). Precipitation is the only source of water that enters the ground-water flow systems. Ground-water flow paths in the local system are shallow and residence times are brief. The duration and intensity of precipitation has an almost immediate effect on the local system by raising static water levels and increasing ground-water discharge to springs and other surface-water bodies. The local system supplies ground water to the numerous small springs, streams, and creeks on South Mountain and to the underlying regolith and fractured bedrock.

The intermediate system is characterized by flow paths that are deeper and longer, having residence times measured in months rather than days. Because of the time required for moisture to reach the intermediate flow system, fluctuations in water levels and discharges caused by abundant precipitation (or lack thereof) are greatly reduced. The intermediate ground-water flow system supplies water to the

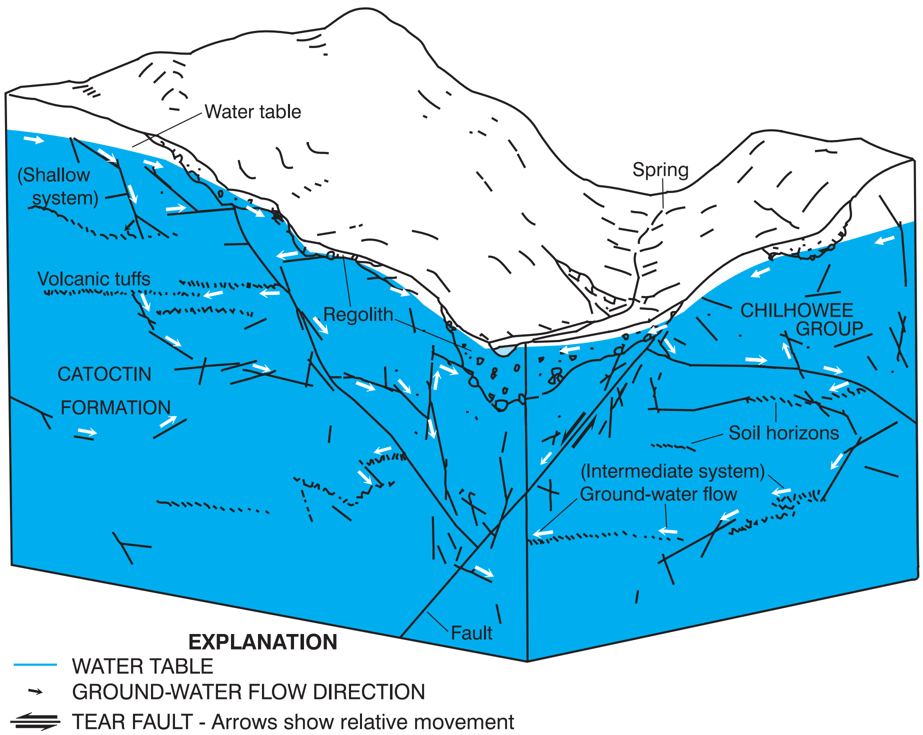


Figure 74. Topographic, geologic, and hydrologic features of the Blue Ridge Physiographic Province, South Mountain Section.

Antietam, Conodoguinet, and Conococheague Creek Basins, and the many springs in the carbonate valley including Boiling Springs, Big Spring, and Baker Spring (Becher and Root, 1981, p. 17-18; Becher and Taylor, 1982, p. 7).

Regolith

At South Mountain, the regolith is composed of granular to clayey soil, saprolite, disaggregated bedrock, and colluvium. According to Becher and Root (1981, p. 32), colluvium is thickest on the mountain slope near the contact between the Antietam or Harpers Formation and the Tomstown Formation. The thick regolith facilitates infiltration of precipitation, storing and slowly releasing water to wells, underlying fractured bedrock, and base flow to streams. Infiltration rates are highest in areas where the regolith is thick.

The median thickness of the regolith, estimated from the length of casing in 464 domestic wells completed in the Catoctin Formation is 42 ft. Based upon the casing lengths of 91 domestic wells completed in the Chilhowee Group the median regolith is 70 ft.

Fractured bedrock

Ground water is stored in and moves through a network of secondary openings such as cooling joints, flow breccias, weathered horizons, faults, cleavage planes, and fractures; intergranular porosity is negligible. Although fractured bedrock may have a low porosity, the permeability of secondary openings can be quite high and these openings may be the pathway for water supplying Boiling Springs (Becher and Root, 1981, p. 17).

Although it is not possible to establish an exact thickness or maximum depth of the intermediate ground-water system, the frequency and density of water-bearing zones can be helpful. Of the 721 water-bearing zones reported in wells penetrating the Catoctin Formation, 90 percent were penetrated by a depth of 270 ft. The greatest water-bearing zone densities are from a depth of 51-100 ft (0.62 per 50 ft of well depth). In the Chilhowee Group, 90 percent of the 167 water-bearing zones were penetrated by a depth of 396 ft. However, the greatest water-bearing zone densities in the Chilhowee Group occur at a depth interval of 351-400 ft (0.54 per 50 ft of well depth).

Catoctin Formation

The Catoctin Formation consists principally of late Precambrian (Badger and Sinha, 1991), rift-related volcanic rocks (dominantly basalts and rhyolites) which formed during the opening of the Proto-Atlantic (Iapetus) Ocean (Rankin, 1976). The metabasalt, metarhyolite, and greenstone schist are the only rocks exposed in South Mountain that have been identified as Precambrian (Rankin and others, 1969, p. 330). The metarhyolite is the most extensive unit of the Catoctin Formation, representing about one-third of all the rocks presently exposed at South Mountain in Pennsylvania. The metabasalt and greenstone schist are present mainly as thin linear belts within the metarhyolite except near the Maryland-Pennsylvania border where the metabasalt is more extensive. The volcanics of the Catoctin Formation, which are as much as 3,000 ft thick, are subaerial lava flows which extruded upon a gneissic and granitic core complex (Fauth, 1968, 1978; Freedman, 1967). Despite intensive study (Fauth, 1968, 1978; Freedman, 1967; Root, 1977; Stose, 1932; Stose and Jonas, 1939) no recognizable stratigraphic correlation has been established between the various units in the Catoctin Formation. However, work by Smith and others (1991) indicate that (1) younger magma pulses trend toward higher concentrations of TiO_2, (2) overturning of the metabasalts is very common, and (3) that locally, the metarhyolites represent the last phase of volcanism.

Although at least nine lithologic units in the Catoctin Formation at South Mountain have been recognized (Fauth, 1978), no formal stratigraphic units have been proposed or designated. However, for clarity and compliance with the Geologic Map of Pennsylvania (Berg and others, 1980), three informal geohydrologic units are assigned to the Catoctin Formation, these units are (1) Metabasalt, (2) Metarhyolite, and (3) Greenstone Schist.

Metabasalt

The Metabasalt crops out as thin, linear belts that trend northeast to southwest (Berg and others, 1980) over a 29 mi^2 area within the Metarhyolite. These linear belts become more extensive near the Maryland-Pennsylvania border. Smith and Barnes (1994) identified metabasalts in the Accomac area (just west of Chickies Rock, in York County) and metadiabase dikes in Grenville terrains (Reading Prong, Womelsdorf outlier, Honey Brook Upland, and Trenton Prong) that are chemically similar to the Metabasalt at South Mountain. The reference section is in a small quarry near Mt. Hope, Adams County.

Geologic description.—The Metabasalt is typically green to greenish-gray or gray, and fine- to medium-grained, but is, in places, coarse-grained, porphyritic or amygdaloidal; veins of quartz are common (Fauth, 1968, p. 17-18). Smith and others (1991) identified and described pyroclastic-bearing flows, bombs, pahoehoe flows (and possible feeder tubes), pipe vesicles, and thin basalt flows. Thickness estimates of the Metabasalt, which ranges from 550 to 3,000 ft, are complicated by the existence of complex folding which repeats the section (Freedman, 1967, p. 12).

The Metabasalt is highly resistant to weathering, forming high ridges with fairly steep and stable slopes. Joints have a blocky pattern, are moderately developed, and generally open, the regolith is relatively thin (Geyer and Wilshusen, 1982, p. 181-183).

Badger and Sinha (1988) obtained a Strontium (Sr) isochron age of 570 +/- 36 million years (Latest Precambrian) for Catoctin Metabasalt near Waynesboro, Va. Smith and Barnes (1994, p. 62) reported that a probable tuff bed within the Metabasalt was roughly correlated chemically with the Metarhyolite. Smith and Barnes (1994, p. 45) believed that the Metabasalt is a within-plate initial-rifting continental tholeiite.

Well depths and casing lengths.—Depths of wells and casing lengths for wells completed in the Metabasalt are presented in the tables below. High-demand wells are generally completed at shallower depths than domestic wells. Five wells in the Metabasalt are drilled to depths greater than 500 ft.

Reported well depth, Metabasalt

[Depth in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	75	88	115	170	300	400	60	700
Drilled, domestic	69	90	122	175	300	400	60	700
Drilled, high-demand	6	—	100	129	176	—	85	200

Casing lengths for wells completed in the Metabasalt are presented in the table below. Only three domestic wells have used more than 100 ft of casing.

Reported casing length, Metabasalt

[Casing length in feet; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	65	19	23	40	48	82	4	188
Drilled, domestic	64	19	22	40	48	82	4	188
Drilled, high-demand	1	—	—	40	—	—	40	—

Hydrologic properties .—Water levels for wells completed in the Metabasalt are presented in the table below. Depths to water in 66 wells range from 3 to 100 ft below land surface; the median is 35 ft below land surface. Water levels show strong seasonal influence.

Water levels, Metabasalt

[Water levels in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	2	—	—	43	—	—	26	59
Slope	27	9	24	42	54	77	4	100

Reported yields for wells completed in the Metabasalt are presented in the table below. Yields of 5.0 gal / min or less are reported from 37 wells. Yields of 20 gal / min or greater are reported from 11 wells; 1 is deeper than 200 ft. Both wells with reported yields greater than 100 gal / min are drilled through the Weverton Formation and into the Metabasalt. High-demand wells generally have greater yields than domestic wells.

Reported well yield, Metabasalt

[Yield in gallons per minute; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	72	1.0	3.0	5.0	15	32	0.2	165
Domestic	66	1.0	3.0	5.0	11	20	.2	50
High-demand	6	—	24	32	144	—	5.0	165

Specific capacities for wells completed in the Metabasalt are presented in the table below. Specific capacities in seven wells (drilled from 130 to 400 ft below land surface) are 0.04 (gal / min) / ft or less and are incapable of meeting most domestic or other water-use demands. Wells with specific capacities of 0.2 (gal / min) / ft or greater are reported from six wells, all are less than 175 ft deep. Only one well has a pumping duration of 8 hours or longer, its specific capacity is 0.38 (gal / min) / ft. The three wells with the highest specific capacities are at or within 400 ft of the contact with the Weverton and Loudon Formations.

Reported specific capacity, Metabasalt

[Specific capacity in gallons per minute per foot of drawdown; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	19	0.0	0.03	0.09	0.27	0.50	0.00	1.0
Domestic	15	.0	.03	.07	.15	.28	.00	.29
High-demand	4	—	—	.44	—	—	.04	1.0

Values of hydraulic conductivity and transmissivity for the Metabasalt are presented in the following table; a specific yield of 0.02 was used in estimating these hydrologic properties. Median hydraulic conductivities and transmissivities for wells on slopes (8 wells) are 0.69 ft / d and 36 ft^2 / d, respectively.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Metabasalt

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	15	0.01	0.02	0.22	0.79	2.5	0.00	4.4
Transmissivity (ft^2 / d)	15	1.1	2.0	15	38	110	.46	150

Meyer and Beall (1958) and Slaughter and Darling (1962) conducted multiple-well aquifer tests on the Metabasalt in Maryland. The specific yield of these tests ranged from 0.002 to 0.021 and transmissivities from 454 to 909 ft^2 / d. Slaughter and Darling (1962) also ran a 48-hour single-well aquifer test on the Metabasalt in Maryland; the transmissivity from this test was 430 ft^2 / d. Wood and Fernandez (1988) summarized the hydraulic conductivities of different volcanic tuffs and lava flows. They found that hydraulic conductivities for tuffs ranged over eight orders of magnitude and for basalts over 13 orders of magnitude. Garabedian (1989a; 1989b) in his digital model of the Snake River Plain in Idaho, which is underlain by basalt, used a specific yield of 0.05.

The depths of water-bearing zones in 56 wells drilled as deep as 700 ft range from 8 to 350 ft below land surface. Fifty percent of the 90 water-bearing zones reported are penetrated by a depth of 103 ft and 90 percent by a depth of 236 ft. The greatest density of water-bearing zones (0.52 per 50 ft of well depth) is from 51 to 100 ft below land surface (fig. 75). The density of water-bearing zones at depths of 251 ft or greater are based on the presence of three or fewer water-bearing zones per 50-ft interval. The overall density of water-bearing zones in the Metabasalt is 0.33 per 50 ft of well depth.

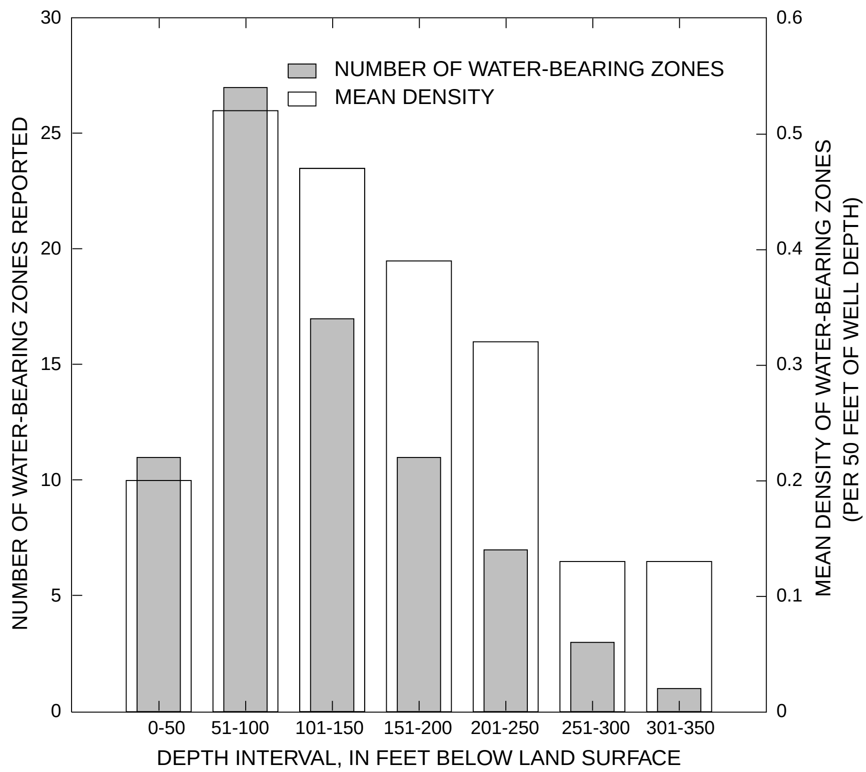


Figure 75. Number and density of water-bearing zones per 50 feet of well depth in the Metabasalt of the Blue Ridge Physiographic Province, South Mountain Section.

Water quality.—As seen in the following table, wells completed in the Metabasalt generally yield water that is low in dissolved solids and is moderately hard. Scatter plots (not shown) of specific conductance and hardness suggest that these two parameters tend to increase with increasing well depth. Fauth (1978, pl. 1) reported that there was a considerable range in mineral content of the ground water and that objectionable quantities of iron were locally present. Additional information on the source and significance of these and selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Metabasalt

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; P25 twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	6	—	—	—	151	197	247	80	312
Field hardness	6	—	—	—	73	86	110	34	140
Laboratory pH (standard units)	1	—	<6.5 >8.5	0	—	6.5	—	6.5	—
Bicarbonate	1	—	—	—	—	70	—	70	—
Calcium	1	—	—	—	—	18	—	18	—
Chloride	1	—	250	0	—	6.0	—	6.0	—
Iron	1	—	.3	0	—	.060	—	.060	—
Magnesium	1	—	—	—	—	6.0	—	6.0	—
Manganese	1	—	.05	0	—	.020	—	.020	—
Nitrate (as N)	1	10	—	0	—	2.6	—	2.6	—
Potassium	1	—	—	—	—	.30	—	.30	—
Sodium	1	—	—	—	—	3.6	—	3.6	—
Sulfate	1	—	250	0	—	5.0	—	5.0	—
Total dissolved solids	1	—	500	0	—	110	—	110	—

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.

Metarhyolite

The Metarhyolite is exposed over a 98 mi^2 area, primarily along the eastern flank of South Mountain as a broad, linear belt that trends northeast to southwest (Berg and others, 1980). Smaller exposures are present near the center of South Mountain and within the Metabasalt near the Maryland-Pennsylvania border. The reference section is along Rocky Mountain Creek about 1 mi south of Caledonia Park, Franklin County.

Geologic description.—At least six lithologic units of Metarhyolite were recognized by Fauth (1978, table 2), but no stratigraphic correlation was established between these various units. The Metarhyolite exhibits a range of colors from blues to purples, and textures from fine-grained to porphyritic; phenocrysts of feldspar and quartz are moderately abundant. Flow breccias, tuff breccias, and tuffs also are present. Stose (1932, p. 29) estimated a total thickness of about 1,000 ft for the Metarhyolite at South Mountain.

The Metarhyolite is highly resistant to weathering, forming high ridges with fairly steep and stable slopes. Joints have a platy to irregular pattern, are moderately developed, highly abundant, and generally open. The overlying mantle is thin (Geyer and Wilshusen, 1982, p. 185-186).

Rankin and others (1969, p. 330) dated the Catoctin Metarhyolite as Precambrian (820 million years). However, more recent age dating in Virginia suggests a younger age for the Catoctin volcanics. Aleinikoff and others (1991), used optically sorted zircons from three Pennsylvania Catoctin Metarhyolite samples and reported an age of 597 +/- 18 million years. The Metarhyolite was interpreted to be subaerially extruded during rifting of the continental plate prior to formation of the Iapetus Ocean (Root and Smith, 1991, p. 45).

Well depths and casing lengths.—Depths of wells completed in the Metarhylite are presented in the table below. Twelve wells were drilled to a depth of 500 ft or greater; 11 are domestic wells.

Reported well depth, Metarhyolite

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	422	86	119	195	300	400	37	700
Drilled, domestic	384	85	115	197	300	400	38	700
Drilled, high-demand	18	107	160	198	305	431	77	445

Depths of wells also vary significantly by county. Domestic wells in Adams County (197 wells) are completed to significantly shallower depths than in Cumberland (76 wells), Franklin (75 wells), and York Counties (36 wells). The median depth of wells in Adams County is 165 ft; in Cumberland County, 250 ft; in Franklin County, 205 ft; and in York County, 220 ft.

Casing lengths of wells completed in the Metarhyolite are presented in the table below. Casing lengths of 100 ft or more are used in 23 wells; all are domestic wells.

Reported casing length, Metarhyolite

[Casing length in feet; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	409	21	39	42	60	80	4	189
Drilled, domestic	374	21	39	42	60	81	4	189
Drilled, high-demand	17	15	36	40	60	66	14	67

Casing lengths vary significantly by county. Wells in Franklin County (77 wells) use significantly less casing than in Cumberland (76 wells) or York Counties (36 wells); the median casing lengths are 40, 43, and 55 ft, respectively. The casing lengths of wells in Adams County (220 wells) are significantly less than in York County. The median casing length of wells in Adams County is 42 ft.

Hydrologic properties.—Water levels of wells completed in the Metarhyolite are presented in the table below. Depths to water in 279 wells range from 1 to 270 ft below land surface; the median is 34 ft below land surface. Water levels show strong seasonal influence and vary considerably between counties. Median water levels in Adams (168 wells), Cumberland (52 wells), Franklin (35 wells), and York (24 wells) Counties are 27, 40, 35, and 47 ft below land surface, respectively.

Water levels, Metarhyolite

[Water levels in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	15	13	20	45	52	76	11	84
Slope	223	9	20	34	48	71	1	270
Valley	19	3	6	15	32	48	1	64

Reported yields of wells completed in the Metarhyolite are presented in the table below. Yields of 5.0 gal / min or less are reported from 170 wells. Only 4 of the 16 wells with reported yields of 50 gal / min or greater are deeper than 200 ft.

Reported well yield, Metarhyolite

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	414	2.0	4.0	7.5	15	25	0.2	500
Domestic	379	2.0	4.0	7.0	15	25	.2	150
High-demand	16	1.3	5.1	20	42	205	1.0	500

Specific capacities of wells completed in the Metarhyolite are presented in the table below. Specific capacities in 20 wells (drilled from 106 to 478 ft below land surface) are 0.04 (gal / min) / ft or less and are incapable of meeting most domestic or other water-use demands. Only one of the seven wells with specific capacities of 0.5 (gal / min) / ft or greater is deeper than 200 ft. The specific capacities of two wells with pumping durations of 8 hours or longer are 0.16 and 0.33 (gal / min) / ft.

Reported specific capacity, Metarhyolite

[Specific capacity in gallons per minute per foot of drawdown; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	49	0.00	0.02	0.07	0.35	0.57	0.00	7.5
Domestic	43	.00	.02	.07	.38	.63	.00	7.5
High-demand	2	—	—	.24	—	—	.16	.33

Values of hydraulic conductivity and transmissivity for the Metarhyolite are presented in the following table; a specific yield of 0.02 was used in estimating these hydrologic properties. Median hydraulic conductivities for wells on hilltops (2 wells) is 0.13 ft / d; on slopes (31 wells), 0.28 ft / d; and in valleys (1 well), 0.19 ft / d. For transmissivity, the median values on hilltops, slopes, and valleys are 16, 31, and 55 ft^2 / d, respectively.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Metarhyolite

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	37	0.01	0.03	0.19	1.2	3.7	0.00	28
Transmissivity (ft^2 / d)	37	2.7	4.6	29	61	93	.46	1,400

In other work, Meyer and Beall (1958) conducted a single-well aquifer test on the Metarhyolite in Maryland. They estimated the transmissivity of the Metarhyolite from this test as 290 ft^2 / d.

Hydraulic conductivity, transmissivity, and storativity in the vicinity of the Fairfield, Pa., well field for the Metarhyolite was estimated by Meiser and Earl, Inc. (1991); this data are presented in the table below.

Summary of hydrologic properties from the long-term (48-hour) multiple-well aquifer tests of Fairfield, Pa., wells AD-751 and AD-754 (data from Meiser and Earl, Inc., 1991)

[ft/d, feet per day; ft^2/d, feet squared per day; —, not applicable]

Source of estimate	Hydraulic conductivity (ft/d)	Transmissivity (ft^2/d)	Storativity
AD-751 (pumping)	0.36	150	—
AD-754	.82	270	—
AD-755	1.5	130	0.00008
AD-754 (pumping)	.28	94	—
AD-751	.24	94	.00048
AD-755	.76	67	.00012

Peffer (1996) used several different methods in estimating hydrologic properties of the Metarhyolite in the vicinity of the Fairfield well field during a long term (49-hour) multiple-well aquifer test of well AD-750. Estimates of hydraulic conductivity were 0.21 and 1.5 ft / d, transmissivity ranged from 66 to 500 ft^2 / d, and storativity was 0.00037.

The depths of water-bearing zones in 334 wells drilled as deep as 700 ft range from 3 to 660 ft below land surface. Fifty percent of the 598 water-bearing zones reported are penetrated by a depth of 108 ft and 90 percent by a depth of 280 ft. The greatest density of water-bearing zones (0.63 per 50 ft of well depth) is from 51 to 100 ft below land surface (fig. 76). The density of water-bearing zones at depths of 451 ft or greater are based on the presence of two or fewer water-bearing zones per 50-ft interval. The overall density of water-bearing zones in the Metarhyolite is 0.35 per 50 ft of well depth.

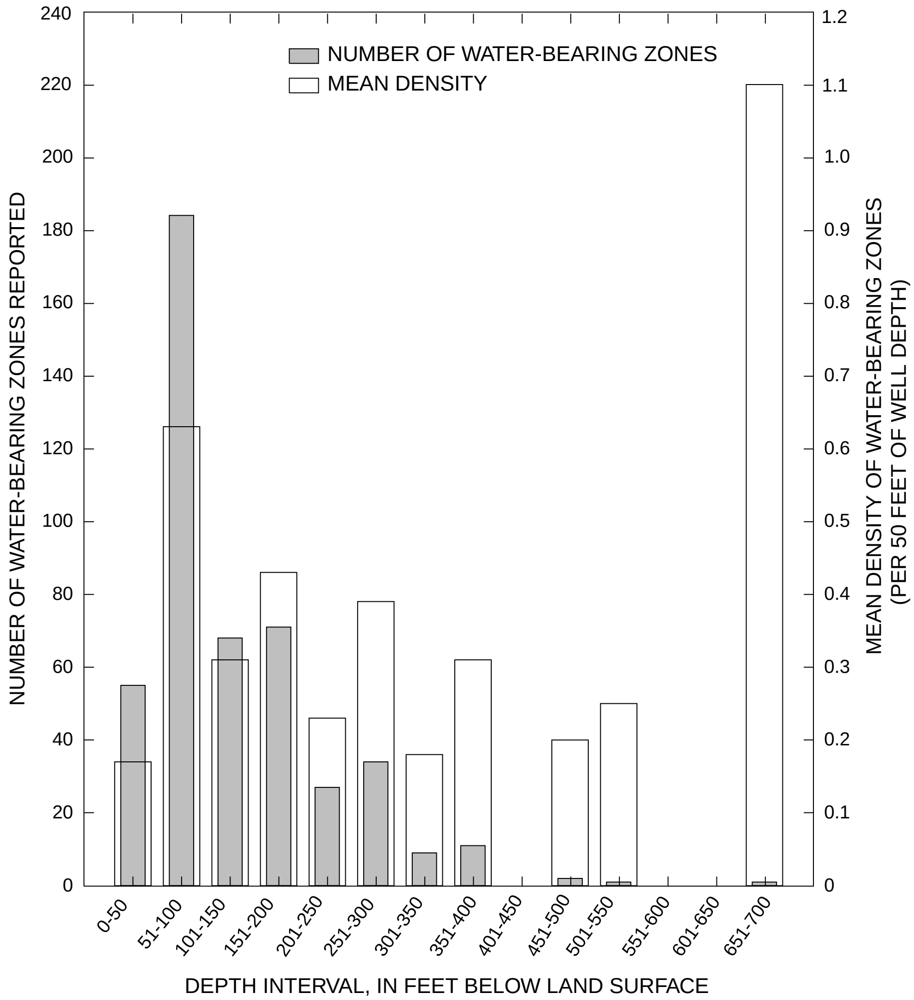


Figure 76. Number and density of water-bearing zones per 50 feet of well depth in the Metarhyolite of the Blue Ridge Physiographic Province, South Mountain Section.

Water quality.—As seen in the following table, wells completed in the Metarhyolite generally yield water that is low in dissolved solids, is soft to moderately hard, and is slightly acidic. Information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Metarhyolite

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	17	—	—	—	124	162	189	33	376
Field hardness	21	—	—	—	34	51	68	17	120
Field pH (standard units)	3	—	<6.5 >8.5	0	—	6.8	—	6.8	7.2
Bicarbonate	2	—	—	—	—	14	—	5.0	23
Calcium	2	—	—	—	—	2.5	—	1.1	3.9
Chloride	2	—	250	0	—	1.3	—	1.0	1.6
Iron	2	—	.3	1	—	1.4	—	.17	2.7
Magnesium	2	—	—	—	—	1.1	—	.5	1.8
Manganese	1	—	.05	0	—	.050	—	.050	—
Nitrate (as N)	1	10	—	0	—	.72	—	.72	—
Potassium	2	—	—	—	—	1.5	—	.8	2.3
Sodium	2	—	—	—	—	3.9	—	2.5	5.3
Sulfate	2	—	250	0	—	3.9	—	3.6	4.2
Total dissolved solids	2	—	500	0	—	43	—	34	52

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.

Greenstone Schist (vs)

The Greenstone Schist is exposed over a 7-mi^2 area primarily along the eastern flank of South Mountain and within the Metarhyolite, as narrow, linear belts which trend northeast to southwest (Berg and others, 1980). Smaller exposures are present within the Metabasalt near the Maryland-Pennsylvania border. The reference section is in a small quarry about 0.5 mi east of Mt. Hope Church, Adams County.

Geologic description.—At least two lithologic units of Greenstone Schist are recognized at South Mountain (Fauth, 1978, table 2). The first is lustrous, light- to medium-gray, banded phyllite with gray to dusky-blue blebs and clasts that are strongly flattened, and aligned in plane of regional cleavage. The second unit is lustrous, greenish-gray to greenish-black and grayish-yellow green to light-greenish-gray, finely banded phyllite that locally may contain elongated and flattened blebs and clasts. One cleavage plane is strongly developed in all of the Greenstone Schist, and locally, two cleavage directions occur. Veins and ellipsoidal masses of milky quartz are present, usually along older foliation planes. Fauth (1978, p. 12) estimated a total thickness of 150 to 250 ft for the Greenstone Schist at South Mountain.

The Greenstone Schist is moderately resistant to weathering, forming local intermountain valleys having gentle slopes. Cleavage is well developed, abundant, and closely spaced. Joints are well developed, steeply dipping, and closed. The overlying regolith is thin (Geyer and Wilshusen, 1982, p. 134-135).

The age of the Greenstone Schist is estimated as Latest Precambrian as based upon radiometric ages of the Metabasalt (Badger and Sinha, 1988) and Metarhyolite (Aleinikoff and others, 1991). The Greenstone Schist was thought to be formed in response to rifting of the continental plate prior to formation of the Iapetus Ocean (Root and Smith, 1991, p. 45).

Well depths and casing lengths.—Depths of wells and casing lengths of wells completed in the Greenstone Schist are presented in the table below.

Reported well depth, Greenstone Schist

[Depth in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	27	78	105	145	300	376	55	410
Drilled, domestic	26	77	105	140	300	380	55	410
Drilled, high-demand	1	—	—	180	—	—	180	—

Reported casing length, Greenstone Schist

[Casing length in feet; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	27	27	38	45	60	64	20	101
Drilled, domestic	26	26	37	48	60	64	20	101
Drilled, high-demand	1	—	—	45	—	—	45	—

Hydrologic properties.—Water levels of wells completed in the Greenstone Schist are presented in the table below. Depths to water in 20 wells range from 7 to 90 ft below land surface; the median is 36 ft below land surface. Most of the wells are on slopes (15 wells) where depths to water range from 7 to 90 ft below land surface; the median is 34 ft below land surface.

Water levels, Greenstone Schist

[Water levels in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	P10	P25	Median	P75	P90	Minimum	Maximum
Slope	15	22	34	39	55	7	90

Reported yields of wells completed in the Greenstone Schist are presented in the table below. Yields of 5.0 gal / min or less are reported from eight wells. Yields of 10 gal / min or greater are reported from 10 wells; none of the wells are deeper than 160 ft.

Reported well yield, Greenstone Schist

[Yield in gallons per minute; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	25	1.8	3.0	7.5	14	20	1.5	30
Domestic	24	1.7	3.0	7.2	14	20	1.5	30
High-demand	1	—	—	8.0	—	—	8.0	—

Specific capacities of two wells in the Greenstone Schist are 0.08 and 0.8 (gal / min) / ft. One well was pumped for 15 minutes, the pumping duration for the other well is unknown.

The depths of water-bearing zones in 21 wells that are as deep as 410 ft range from 20 to 293 ft below land surface. Fifty percent of the 33 water-bearing zones reported are penetrated by a depth of 84 ft and 90 percent by a depth of 194 ft. The greatest density of water-bearing zones (0.82 per 50 ft of well depth) is from 51 to 100 ft below land surface (fig. 77). The density of water-bearing zones at depths of 101 ft or greater are based on the presence of two or fewer water-bearing zones per 50-ft interval. The overall density of water-bearing zones in the Greenstone Schist is 0.33 per 50 ft of well depth.

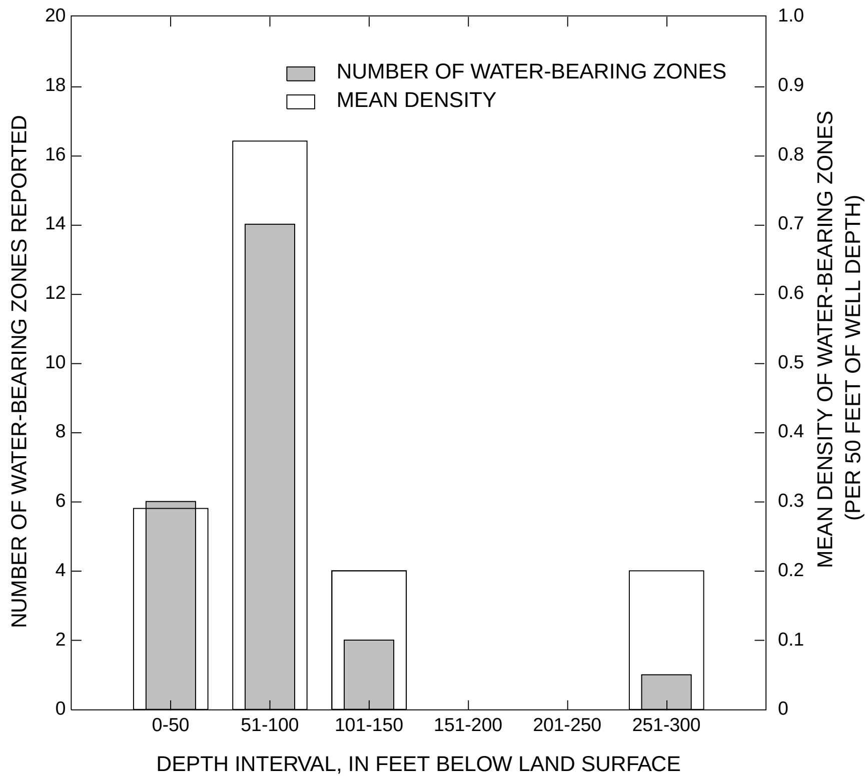


Figure 77. Number and density of water-bearing zones per 50 feet of well depth in the Greenstone Schist of the Blue Ridge Physiographic Province, South Mountain Section.

Water quality.—The Greenstone Schist has only one field water-quality analysis, and no laboratory water-quality analyses. This ground-water sample has a hardness of 34 mg / L and a specific conductance of 130 µS / cm.

Weverton and Loudon Formations, Undivided (Cwl)

The Weverton and Loudon Formations are exposed over a 55 mi^2 area within the center of South Mountain as broad, repeating, northeast-southwest trending beds, which have been extensively faulted (Berg and others, 1980). The type section for the Weverton Formation is at Weverton, Washington County, Md., in the Potomac River Gorge (Keith, 1893, p. 329). For the Loudon Formation, the type section is Loudon County, Va., along Catoctin Mountain (Keith, 1893, p. 324).

Geologic description.—The Loudon Formation is the basal member of the Chilhowee Group and consists of two lithologic units. The lower lithologic unit is gray to blue or red-purple phyllite which grades into a conglomeratic unit common to both the Loudon and the Weverton Formations (Fauth, 1968, p. 28). This conglomeratic unit becomes upwardly (stratigraphically higher) richer in quartz until it forms a gray, medium- to coarse-grained quartzite at the top of the Weverton Formation (Fauth, 1978, p. 29-33). Thickness of the Loudon Formation is estimated at 100 to 450 ft (Fauth, 1968, p. 28; 1978, p. 42) and thickness of the Weverton Formation is reported to range from 500 (Stose and Jonas, 1939, p. 68) to 1,400 ft (Fauth, 1968, p. 32).

The Weverton Formation is moderately resistant to weathering, forming ridges or mountains of medium relief; the regolith is thin. The Loudon Formation is less resistant to weathering, forming mantle covered slopes with a thin to moderately thick regolith; outcrops are sparse. Joints are abundant and open, cleavage is well developed in the phyllite of the Loudon Formation (Geyer and Wilshusen, 1982, p. 168-169; p. 285-286).

The Loudon Formation thins eastward and is represented by the Hellam Conglomerate Member of the Chickies Formation in western York County (Fauth, 1968, p. 81). The Weverton Formation has been correlated eastward with part of the Chickies Formation (Stose and Jonas, 1939, p. 68; Stose, 1932). Simpson and Sundberg (1987) working in southwestern Virginia on a stratigraphic equivalent to the Weverton Formation, found evidence of earliest Early Cambrian fossils (Fedonkin, 1981).

The Weverton and Loudon Formations were deposited in rift-induced sedimentary basins, dominantly shallow marine as Iapetus Ocean onlapped the subaerially exposed Catoctin Formation (Nickelsen, 1956). Both units contain rhyolite fragments and plutonic quartz derived from the Precambrian volcanic-granitic terrane (Fauth, 1968, p. 85). Contact with the Precambrian Catoctin Formation may be unconformable (Stose and Jonas, 1939, p. 67) or conformable (Cloos, 1951). If the contact is unconformable, the radiometric ages on the Metabasalt and Metarhyolite, and the biostratigraphic ages of the Chilhowee Group suggest only a brief hiatus (Key, 1991).

Well depths and casing lengths.—Depths of wells and casing lengths of wells completed in the Weverton and Loudon Formations are presented in the tables below.

Reported well depth, Weverton and Loudon Formations, undivided

[Depth in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	28	145	239	374	454	595	125	650
Drilled, domestic	25	145	204	350	438	537	125	650
Drilled, high-demand	2	—	—	375	—	—	250	500

Reported casing length, Weverton and Loudon Formations, undivided

[Casing length in feet; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	26	37	47	67	104	177	25	267
Drilled, domestic	23	34	42	63	84	132	25	263
Drilled, high-demand	2	—	—	170	—	—	74	267

Hydrologic properties.—Water levels of wells completed in the Weverton and Loudon Formations are presented in the table below. Depths to water in 13 wells range from 2 to 100 ft below land surface; the median is 50 ft below land surface. Water levels show strong seasonal influence.

Water levels, Weverton and Loudon Formations, undivided

[Water levels in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Slope	10	3	22	55	80	98	2	100
Valley	1	—	—	15	—	—	15	—

Reported yields of wells completed in the Weverton and Loudon Formations are presented in the table below. Yields of 5.0 gal / min or less are reported from 12 wells. Nine of the 12 wells with yields of 10 gal / min or greater are deeper than 200 ft.

Reported well yield, Weverton and Loudon Formations, undivided

[Yield in gallons per minute; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	27	0.9	3.0	8.0	15	26	0.5	40
Domestic	24	.9	2.2	5.5	14	19	.5	25
High-demand	2	—	—	25	—	—	10	40

The specific capacities of four domestic wells with a pumping duration of 1 hour or longer are 0.00, 0.04, 0.04, and 0.20 (gal / min) / ft. The specific capacities of three wells with pumping durations less than 1 hour are 0.05, 0.13, and 0.17 (gal / min) / ft. Well depths for these seven wells range from 144 to 598 ft below land surface.

No published information is available on hydraulic conductivity or transmissivity on the Weverton and Loudon Formations. The hydraulic conductivity and transmissivity from three single-well aquifer tests of 1 hour or longer are 0.01, 0.01, 0.21 ft / d and 2.8, 3.2, and 22 ft^2 / d, respectively.

The depths of water-bearing zones from 27 wells as deep as 650 ft range from 29 to 592 ft below land surface. Fifty percent of the 49 water-bearing zones reported are penetrated by a depth of 266 ft and 90 percent by a depth of 450 ft. The greatest density of water-bearing zones (0.55 per 50 ft of well depth) is from 351 to 400 ft below land surface (fig. 78). The density of water-bearing zones at depths greater than 400 ft are based on the presence of two or fewer zones per 50-ft interval. The overall density of water-bearing zones in the Weverton and Loudon Formations is 0.23 per 50 ft of well depth.

Water quality.—No water-quality data are available from the Weverton or Loudon Formations. However, Fauth (1978), and Geyer and Wilshusen (1982) indicated that the water is soft and of low mineral content except for iron.

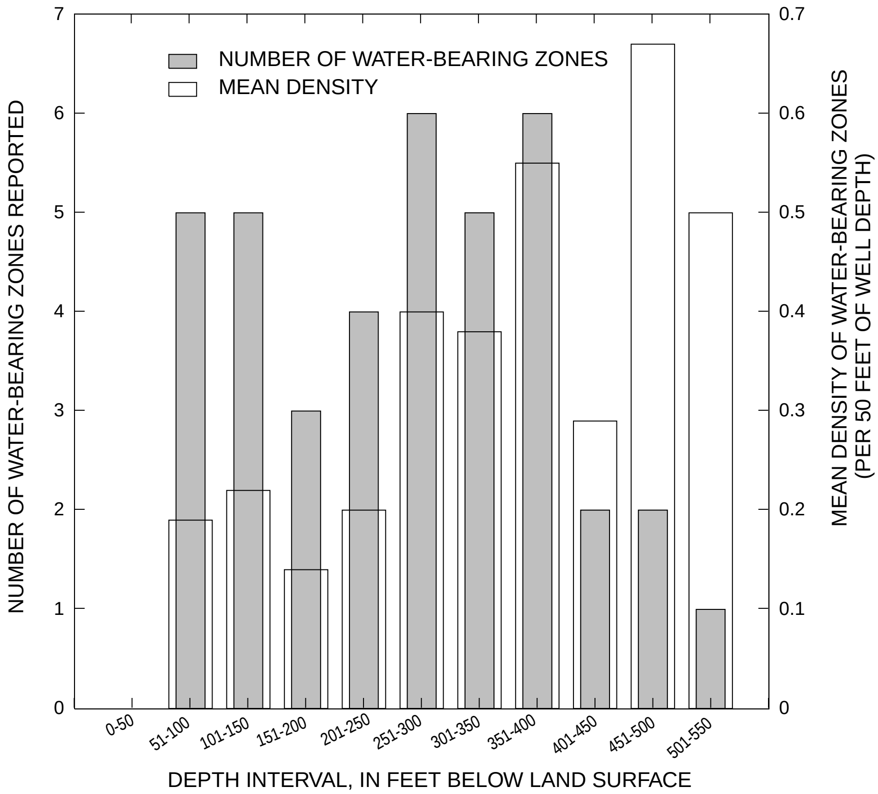


Figure 78. Number and density of water-bearing zones per 50 feet of well depth in the Weverton and Loudon Formations, undivided, of the Blue Ridge Physiographic Province, South Mountain Section.

Harpers Formation (Ch)

The Harpers Formation crops out over a 10-mi^2 area primarily in a narrow, faulted, discontinuous band along the southern and western flanks of South Mountain (Berg and others, 1980). It is gradually replaced to the north and northwest by the Montalto Quartzite Member. It was named for exposures along the Potomac River at Harpers Ferry, W.Va. (Keith, 1892, p. 363; Keith, 1893, p. 332). The reference section is east of New Providence, Lancaster County.

Geologic description.—The Harpers Formation is generally green to greenish-gray or olive-gray graywacke and graywacke siltstone having interbedded phyllite, shale, and sandstone, and a prominent quartzite member (Montalto Quartzite). Contact with the underlying Weverton Formation is gradational. Estimated thickness of the Harpers Formation, excluding its quartzite member, is extremely variable. The Harpers Formation is absent in the northern part of the South Mountain Section, being replaced by the Montalto Member (Berg and others, 1980). Fauth (1968, p. 35) and Stose (1932, p. 46) estimated a thickness of 300 to 1,000 ft for the Harpers Formation. Cloos (1951, p.34-36), however, measured 3,100 ft east of Waynesboro, Pa., but noted that the section may be folded.

The Harpers Formation is moderately resistant to weathering, forming narrow valleys and depressions. Joints and cleavage planes are moderately well developed, abundant, and open. Regolith is generally thin; the overlying mantle is relatively thick at the foot of slopes (Fauth, 1978, pl. 1).

The Harpers Formation is generally assigned a lower Cambrian age because of its conformable stratigraphic relation to the overlying Antietam Formation which contains lower Cambrian fossils. The Harpers Formation was deposited in a dominantly shallow marine, continental shelf environment (Nickelsen, 1956). Deposition of the upper part of the Harpers Formation was interrupted by renewed tectonic or volcanic activity (Fauth, 1968, p. 85).

Well depths and casing lengths.—Depths of wells and casing lengths of wells completed in the Harpers Formation are presented in the tables below.

Reported well depth, Harpers Formation

[Depth in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	35	108	187	247	350	455	80	675
Drilled, domestic	31	106	187	247	345	422	80	675
Drilled, high-demand	3	—	—	370	—	—	111	500

Reported casing length, Harpers Formation

[Casing length in feet; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	33	23	42	70	132	265	18	365
Drilled, domestic	29	27	42	66	119	240	20	298
Drilled, high-demand	3	—	—	267	—	—	114	365

Hydrologic properties.—Water levels of wells completed in the Harpers Formation are presented in the table below. Depths to water in 20 wells range from 6 to 300 ft below land surface; the median is 44 ft below land surface.

Water levels, Harpers Formation

[Water levels in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Slope	12	17	32	53	83	298	12	300
Valley	4	—	—	9	—	—	6	16

Reported yields for wells completed in the Harpers Formation are presented in the table below. Yields of 5.0 gal / min or less are reported from eight wells. Six of the nine wells with reported yields of 20 gal / min or greater are deeper than 200 ft.

Reported well yield, Harpers Formation

[Yield in gallons per minute; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	32	1.6	5.2	10	23	36	0.3	80
Domestic	29	1.5	5.0	9.0	18	35	.3	80
High-demand	3	—	—	30	—	—	12	36

Specific capacities for wells completed in the Harpers Formation are presented in the table below. Specific capacities in one well (drilled to a depth of 350 ft) is less than 0.04 (gal / min) / ft and is incapable of meeting most domestic or other water-use demands. Specific capacities greater than 0.20 (gal / min) / ft are reported from two wells that are completed at depths of 160 ft and 275 ft. Two other wells with pumping durations of 30 min or less have specific capacities of 0.00 (gal / min) / ft with well depths of 500 and 675 ft.

Reported specific capacity, Harpers Formation

[Specific capacity in gallons per minute per foot of drawdown; —, insufficient data available; P25, twenty-fifth percentile; P75, seventy-fifth percentile

Well type	Number of wells	P25	Median	P75	Minimum	Maximum
All	5	0.08	0.16	0.45	0.01	0.48
Domestic	4	—	.16	—	.01	.42
High-demand	1	—	.48	-	.48	—

Several wells owned by the Fairfield, Pa., Municipal Authority (written commun., 1997) are completed in the Harpers Formation. The specific capacities of these three wells, determined from several aquifer tests with varying discharge rates, range from 0.00 to 0.38 (gal / min) / ft; the median is 0.19 (gal / min) / ft.

Values of hydraulic conductivity and transmissivity for the Harpers Formation are presented in the table below; a specific yield of 0.02 was used in estimating these hydrologic properties. The median hydraulic conductivity and transmissivity of wells on slopes (4 wells) are 0.13 ft / d and 20 ft^2 / d, respectively. The hydraulic conductivity of a single well in a valley is 0.75 ft / d and the transmissivity is 88 ft^2 / d.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Harpers Formation

[ft/d, feet per day; ft^2/d, feet squared per day; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Hydrologic property	Number of wells	P25	Median	P75	Minimum	Maximum
Hydraulic conductivity (ft / d)	5	0.05	0.16	0.53	0.00	0.75
Transmissivity (ft^2 / d)	5	9.9	21	75	.18	88

For the Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, p. 38) estimated a specific yield of 0.02 for the upper 200 ft and a storage coefficient of 0.0002 for the lower 300 ft of a Paleozoic sedimentary rock unit that included the Harpers Formation. They also used hydraulic conductivities of 1.34 and 0.67 ft / d for different hydrogeologic units that included the Harpers Formation (Gerhart and Lazorchick, 1988, p. 22).

Peffer (1996) used several different methods in determining hydrologic properties of the Harpers Formation during the multiple-well aquifer test of well AD-736. The results from Peffer are presented in the table below.

Summary of hydrologic properties from the long-term (48.5-hour) multiple-well aquifer test of wells in the Harpers Formation (data from Peffer, 1996)

[ft/d, feet per day; ft^2/d, feet squared per day; —, not applicable]

Source of estimate	Hydraulic conductivity (ft/d)	Transmissivity (ft^2/d)	Storativity
AD-736 (pumping)	0.028	1.0 - 14	—
AD-749	.001	.5	0.000066

The depths of water-bearing zones in 28 wells as deep as 675 ft range from 44 to 490 ft below land surface. Fifty percent of the 48 water-bearing zones reported are penetrated by a depth of 180 ft and 90 percent by a depth of 367 ft. The greatest density of water-bearing zones (1.0 per 50 ft of well depth) is at 351-400 ft below land surface (fig. 79). The overall density of water-bearing zones in the Harpers Formation is 0.26 per 50 ft of well depth.

Water quality.—No water-quality data are available on the Harpers Formation in the South Mountain Section. However, Fauth (1978) reported the water was soft and had a moderate mineral content and could be slightly corrosive with a pH of about 6.0.

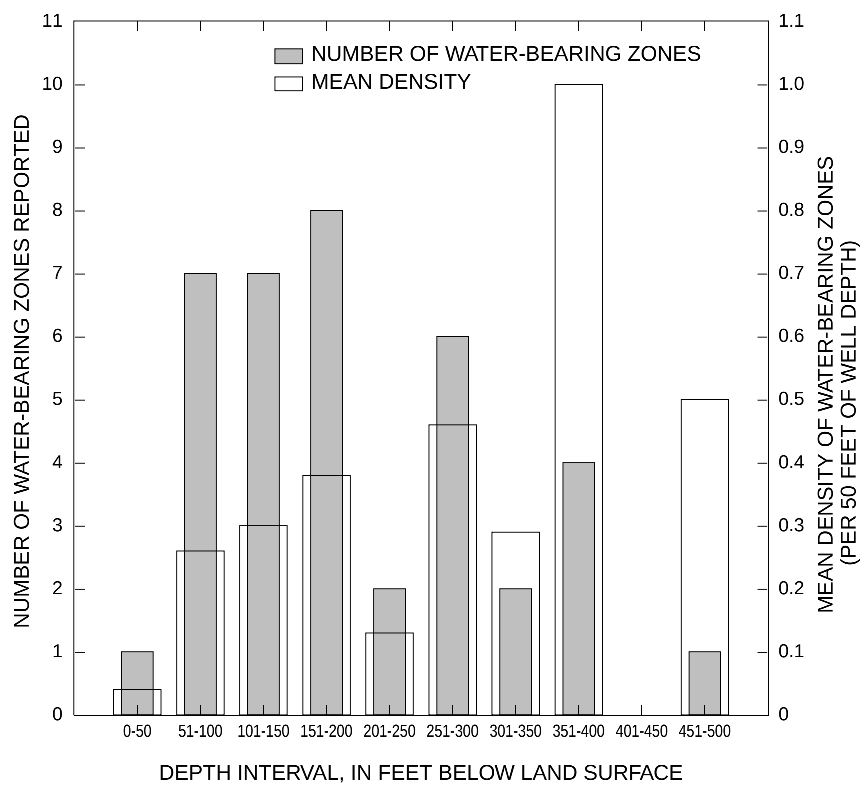


Figure 79. Number and density of water-bearing zones per 50 feet of well depth in the Harpers Formation of the Blue Ridge Physiographic Province, South Mountain Section.

Montalto Quartzite Member (Chm)

The Montalto Quartzite is exposed over a 78-mi^2 area at South Mountain. Near the center of South Mountain, the Montalto Quartzite is present in small, linear beds that trend northwest-southeast along a major high-angle fault (Berg and others, 1980). Stose (1906, p. 206) recognized a thick section of quartzite in the Harpers Formation at Mont Alto, Franklin County, Pa. The reference section is along the Western Maryland railroad tracks west of the village of Iron Springs, Adams County.

Geologic description.—The Montalto Quartzite is hard, medium- to thick-bedded, generally white to gray, medium- to coarse-grained quartzite (Fauth, 1968, p. 34). Minor, thin interbeds of dark gray to black, silty to sandy phyllite and medium-gray to bluish-gray, fine-grained sandstone are present also. Stose and Jonas (1939, p. 69) reported the presence of dark quartz grains, scattered feldspar grains, and beds containing Scolithus tubes. In York County, the Montalto Quartzite directly overlies the Weverton Formation; in Adams and Franklin County it lies in the middle of the Harpers Formation. Thickness of the Montalto Quartzite ranges from 20 ft near the Maryland-Pennsylvania border to 1,900 ft on the northern flank of South Mountain.

The Montalto Quartzite is moderately to highly resistant to weathering, it underlies high, steep ridges with stable slopes. Joints are very abundant and open, the regolith is relatively thin (Geyer and Wilshusen, 1982, p. 143-144).

The Montalto Quartzite was deposited in a dominantly shallow marine, continental shelf environment, as evidenced by the presence of Scolithus worm tubes (Key, 1991, p. 27). Because of its stratigraphic position between the Weverton Formation and the overlying Antietam Formation, Stose and Jonas (1939, p. 69) assigned the Montalto Quartzite a lower Cambrian age.

Well depths and casing lengths.—Depths of wells and casing lengths of wells completed in the Montalto Quartzite Member are presented in the tables below.

Reported well depth, Montalto Quartzite Member

[Depth in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	20	84	156	261	374	491	52	700
Drilled, domestic	16	98	162	261	374	560	95	700
Drilled, high-demand	2	—	—	381	—	—	350	411

Reported casing length, Montalto Quartzite Member

[Casing length in feet; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	18	36	42	130	268	369	18	410
Drilled, domestic	16	32	42	120	258	317	18	365
Drilled, high-demand	2	—	—	275	—	—	140	410

Water-bearing properties .—Water levels of wells completed in the Montalto Quartzite Member are presented in the table below. Depths to water in 10 wells range from 10 to 280 ft below land surface; the median is 78 ft below land surface. Numerous springs are reported (Fauth, 1968) in the Montalto Quartzite, however, no flowing wells are known to occur.

Water levels, Montalto Quartzite Member

[Water levels in feet below land surface; —, insufficient data available; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Topographic setting	Number of wells	P25	Median	P75	Minimum	Maximum
Hilltop	1	—	96	—	96	—
Slope	7	50	115	130	19	280
Valley	2	—	11	—	10	12

Reported yields of wells completed in the Montalto Quartzite Member are presented in the table below. Yields of 5.0 gal / min or less are reported from three wells. Four of the six wells with yields of 20 gal / min or greater are deeper than 200 ft.

Reported well yield, Montalto Quartzite Member

[Yield in gallons per minute; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	18	0.9	8.0	14	28	160	0.0	250
Domestic	15	1.6	8.0	12	36	190	1.0	250
High-demand	2	—	—	18	—	—	15	20

The specific capacity of a single well with a pumping duration of 1 hour or greater is 0.48 (gal / min) / ft. The specific capacities of two wells with pumping durations of 30 minutes are 0.11 and 0.01 (gal / min) / ft.

The hydraulic conductivity of the 1-hour single-well aquifer test is 0.41 ft / d. The transmissivity of this single-well aquifer test is 62 ft^2 / d.

The depths of water-bearing zones in 16 wells as deep as 700 ft range from 65 to 410 ft below land surface. Fifty percent of the 27 water-bearing zones reported are penetrated by a depth of 250 ft and 90 percent by a depth of 386 ft. The greatest density of water-bearing zones (0.38 per 50 ft of well depth) is from 251 to 300 ft below land surface (fig. 80). The overall density of water-bearing zones in the Montalto Quartzite is 0.20 per 50 ft of well depth.

Water quality.—No water-quality data are available for the Montalto Quartzite Member at South Mountain. However, Fauth (1978) reported the water should be soft and of excellent quality.

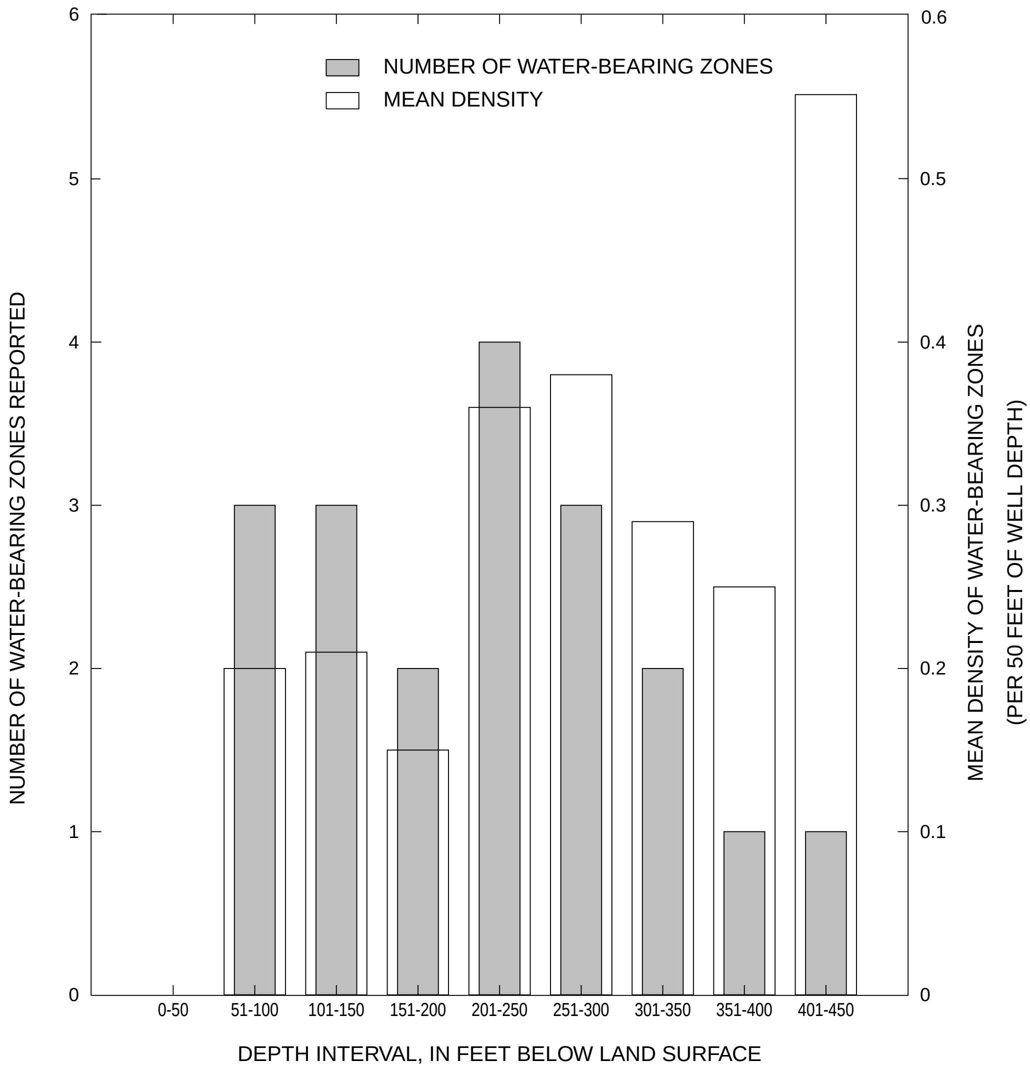


Figure 80. Number and density of water-bearing zones per 50 feet of well depth in the Montalto Quartzite Member of the Blue Ridge Physiographic Province, South Mountain Section.

Antietam Formation

The Antietam Formation crops out over a 12-mi^2 area primarily along the western and northern flanks of South Mountain, as a thin, semi-continuous bed, which has been truncated repeatedly by numerous faults (Berg and others, 1980). The Antietam Formation derived its name for exposures along Antietam Creek, Washington County, Md. (Keith, 1892, p. 365; Cloos, 1951, p. 39).

Geologic description.—The Antietam Formation is generally white, light gray, and yellowish-gray, medium- to coarse-grained, light gray protoquartzite and quartzite; locally, a fine conglomerate of round to oval quartz pebbles is present. The lower member is a dense quartzite, the upper member is a granular sandstone that contains occasional thin clay beds and numerous Scolithus linearis worm tubes (Fauth, 1968, p. 37-38; Stose, 1932, p. 47). Residual iron ore is also associated with the upper member (Stose and Jonas, 1939, p. 70). Thickness of the Antietam Formation at South Mountain ranges from 500 (Stose and Jonas, 1939, p, 70) to 900 ft (Fauth, 1968, p. 38).

The Antietam Formation is highly resistant to weathering. The lower quartzite member is generally a ridge former with steep and stable slopes, the upper sandstone member forms gentler slopes. Joints and cleavage planes are moderately abundant and open. The regolith is relatively thin (Geyer and Wilshusen, 1982, p. 30-31).

The Antietam Formation is the upper unit of the Chilhowee Group, it conformably overlies the Harpers Formation (Fauth, 1978, p. 44). This unit is in gradational contact with the overlying and younger Tomstown Formation (Fauth, 1968, p. 45), and forms part of the outer boundary of South Mountain (Berg and others, 1980). The Antietam Formation was deposited in a high energy, shallow marine environment such as an offshore bar (Sevon and van Sycoc, 1991). On the basis of the presence of fossils, Walcott (1896, p. 25), and Resser and Howell (1938, p. 205) date the Antietam Formation as Lower Cambrian in age.

Well depths and casing lengths.—Depths of wells and casing lengths of wells completed in the Antietam Formation are presented in the tables below. There is very little difference between the depths of high-demand and domestic wells but a considerable difference in casing length.

Reported well depth, Antietam Formation

[Depth in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	32	110	184	300	402	516	67	623
Drilled, domestic	23	87	172	300	400	514	67	623
Drilled, high-demand	6	—	167	296	415	—	132	490

Reported casing length, Antietam Formation

[Casing length in feet; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	32	22	44	118	197	287	20	382
Drilled, domestic	23	30	45	133	200	297	20	382
Drilled, high-demand	6	—	28	95	150	—	20	174

Hydrologic properties.—Water levels of wells completed in the Antietam Formation are presented in the table below. Depths to water in 20 wells range from flowing at land surface to 400 ft below land surface; the median is 46 ft below land surface. Fauth (1978) reported that soft-water springs appear locally near the contact with the overlying Tomstown Formation.

Water levels, Antietam Formation

[Water levels in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Slope	10	4	32	41	130	194	1	200
Valley	1	—	—	33	—		33	—

Reported yields for wells completed in the Antietam Formation are presented in the table below. Yields of 5.0 gal / min or less are reported from six wells. Seven of the eight wells with yields of 50 gal / min or greater are deeper than 200 ft.

Reported well yield, Antietam Formation

[Yield in gallons per minute; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	32	2.6	8.0	23	49	150	1.0	200
Domestic	23	2.0	5.0	15	30	50	1.0	200
High-demand	6	—	39	85	170	—	35	200

Specific capacities for wells completed in the Antietam Formation are presented in the table below. Specific capacities in two wells (drilled to depths of 229 and 623 ft below land surface) are 0.04 (gal / min) / ft or less and are incapable of meeting most domestic or other water-use demands. Three of the five wells with specific capacities of 0.20 (gal / min) / ft are deeper than 200 ft. Specific capacities of three wells pumped 8 hours or longer are 0.32, 1.2, and 3.1 (gal / min) / ft.

Reported specific capacity, Antietam Formation

[Specific capacity in gallons per minute per foot of drawdown; —, insufficient data available; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Well type	Number of wells	P25	Median	P75	Minimum	Maximum
All	8	0.06	0.33	1.0	0.02	3.1
Domestic	5	.02	.17	.80	.02	1.2
High-demand	3	—	.35	—	.32	3.1

Values of hydraulic conductivity and transmissivity for the Antietam Formation are presented in the table below; a specific yield of 0.02 was used in estimating these hydrologic properties. The median hydraulic conductivity and transmissivity of wells on slopes (5 wells) are 0.69 ft / d and 57 ft^2 / d, respectively.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Antietam Formation

[ft/d, feet per day; ft^2/d, feet squared per day; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Hydrologic property	Number of wells	P25	Median	P75	Minimum	Maximum
Hydraulic conductivity (ft / d)	7	0.16	0.47	2.6	0.01	330
Transmissivity (ft^2 / d)	7	18	57	250	2.6	660

In other work, Gerhart and Lazorchick (1984b) created a digital model of parts of Lancaster and Berks Counties, Pa. They estimated (Gerhart and Lazorchick, 1984b, tables 8 and 14) a specific yield of 0.20 and a hydraulic conductivity of 0.5 ft / d for a metamorphic rock unit that included the Antietam Formation. For the Lower Susquehanna River Basin digital model, Gerhart and Lazorchick (1988, tables 8 and 16) determined a specific yield of 0.020 for the upper 200 ft and hydraulic conductivities of 0.67, 1.34 and 2.01 ft / d for different hydrogeologic units that included the Antietam Formation.

The depths of water-bearing zones in 22 wells as deep as 623 ft range from 60 to 592 ft below land surface. Fifty percent of the 43 water-bearing zones are penetrated by a depth of 230 ft and 90 percent by a depth of 387 ft. The greatest density of water-bearing zones (0.43 per 50 ft of well depth) is from 351-350 ft below land surface (fig. 81). The density of water-bearing zones at depths of 401 ft or greater are based on the presence of only one water-bearing zone per 50-ft interval. The overall density of water-bearing zones in the Antietam Formation is 0.25 ft per 50 ft of well depth.

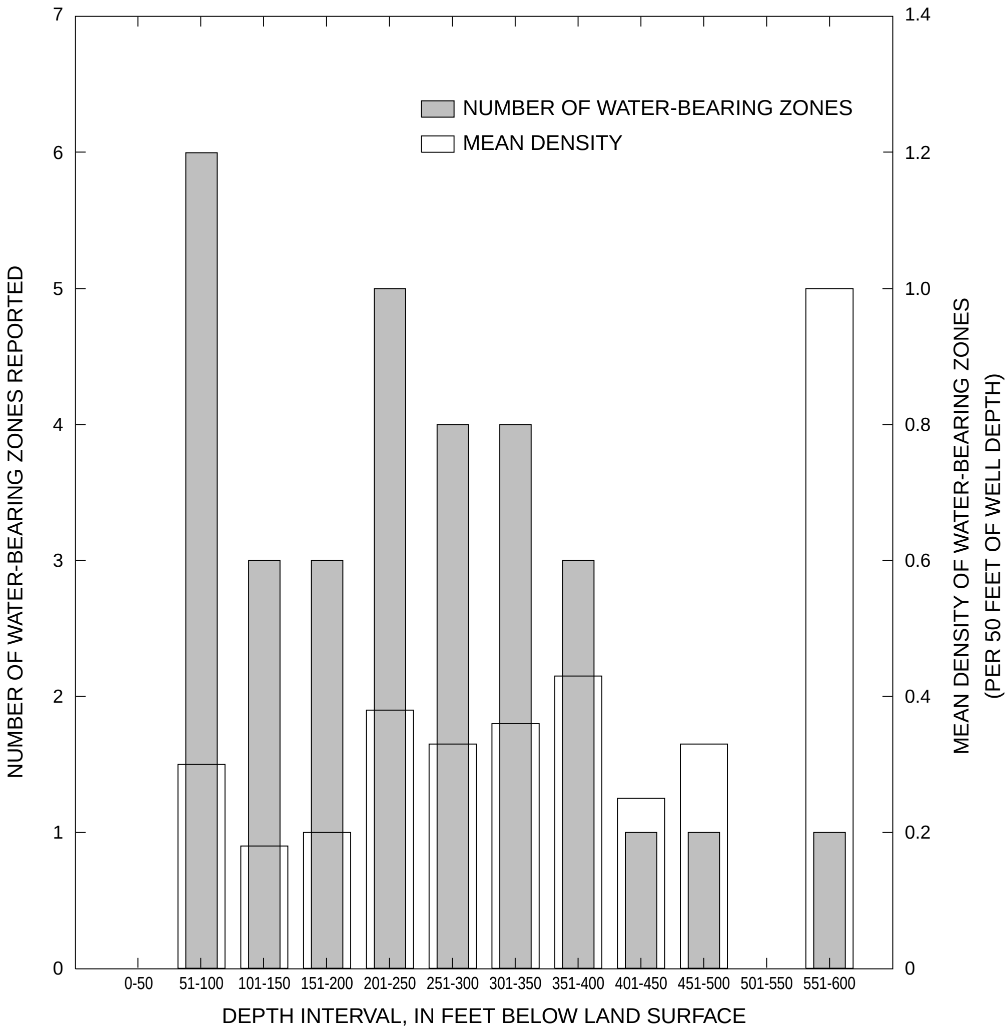


Figure 81. Number and density of water-bearing zones per 50 feet of well depth in the Antietam Formation of the Blue Ridge Physiographic Province, South Mountain Section.

Water quality.—As seen in the following table, wells completed in the Antietam Formation generally yield water that is low in dissolved solids, soft, and acidic. Elevated concentrations of iron and low pH are probably the most common water-quality problems in the Antietam Formation. Although not analyzed for in the three wells sampled, radon concentrations in water from four wells completed in the Antietam Formation of the Piedmont Upland exceeded the proposed USEPA MCL of 300 pCi/L. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Antietam Formation

[Concentrations in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; pH in standard units; —, insufficient data available; <, less than; >, greater than; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	4	—	—	—	—	30	—	30	70
Field hardness	5	—	—	—	10	17	60	10	85
Field pH (units)	3	—	<6.5 >8.5	2	—	5.7	—	5.6	7.0
Bicarbonate	3	—	—	—	—	8.0	—	8.0	12
Calcium	3	—	—	—	—	2.8	—	2.4	6.4
Chloride	3	—	250	0	—	1.5	—	1.0	2.0
Iron	3	—	.3	2	—	.67	—	.13	1.8
Magnesium	3	—	—	—	—	2.2	—	.7	2.5
Manganese	3	—	.05	0	—	.030	—	.020	.080
Nitrate (as N)	3	10	—	0	—	.12	—	.10	.26
Potassium	2	—	—	—	—	1.7	—	1.4	2.0
Silica	3	—	—	—	—	8.5	—	7.2	8.5
Sodium	2	—	—	—	—	.80	—	.60	1.0
Sulfate	3	—	250	0	—	11	—	10	15
Total dissolved solids	3	—	500	0	—	36	—	33	47

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.

Summary of Characteristics of Bedrock Aquifers in the Blue Ridge Physiographic Province, South Mountain Section

Data evaluated for most units in the South Mountain Section are summarized in figures 82 to 86 and tables 21 to 23. Well depths range from 37 to 700 ft below land surface and casing lengths from 4 to 189 ft. Well depths and casing lengths can vary by water use (figs. 71b, 71c, 72b and 72c), topographic setting, and hydrogeologic unit (tables 21 and 22).

Reported yields range from 0.2 to 170 gal/min and specific capacities from 0.00 to 7.5 (gal/min)/ft. Reported yields and specific capacities can vary by water use, topographic setting, and hydrogeologic unit (table 23).

Field water-quality data for the South Mountain Section is sparse. But the available data suggest ground water contains low amounts of dissolved solids, is soft, and slightly acidic. Work by Langland and Dugas (1996) indicate that most water obtained from the geohydrologic units in South Mountain will be moderately to extremely corrosive.

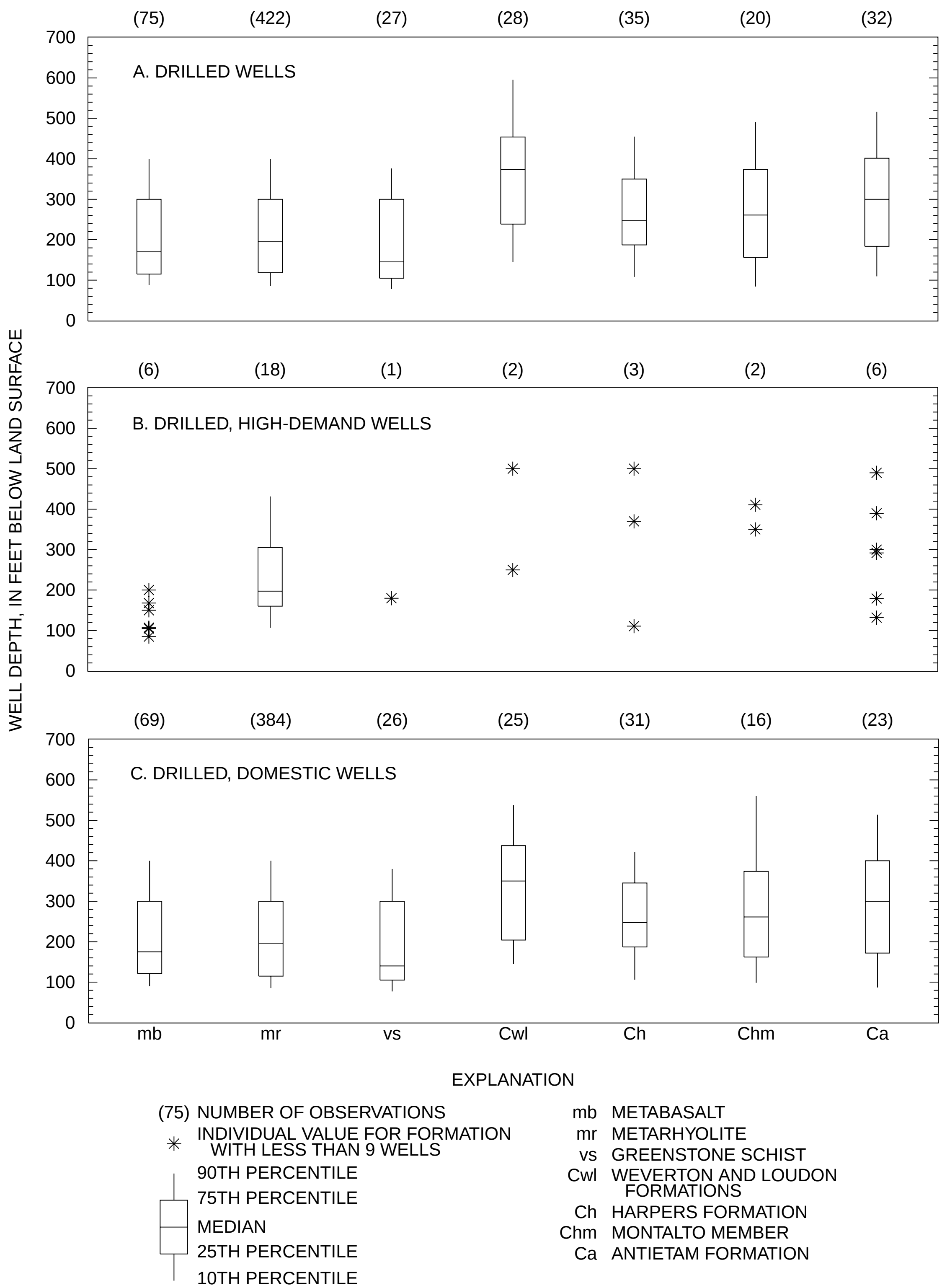


Figure 82. Depths of drilled wells in the Blue Ridge Physiographic Province, South Mountain Section.

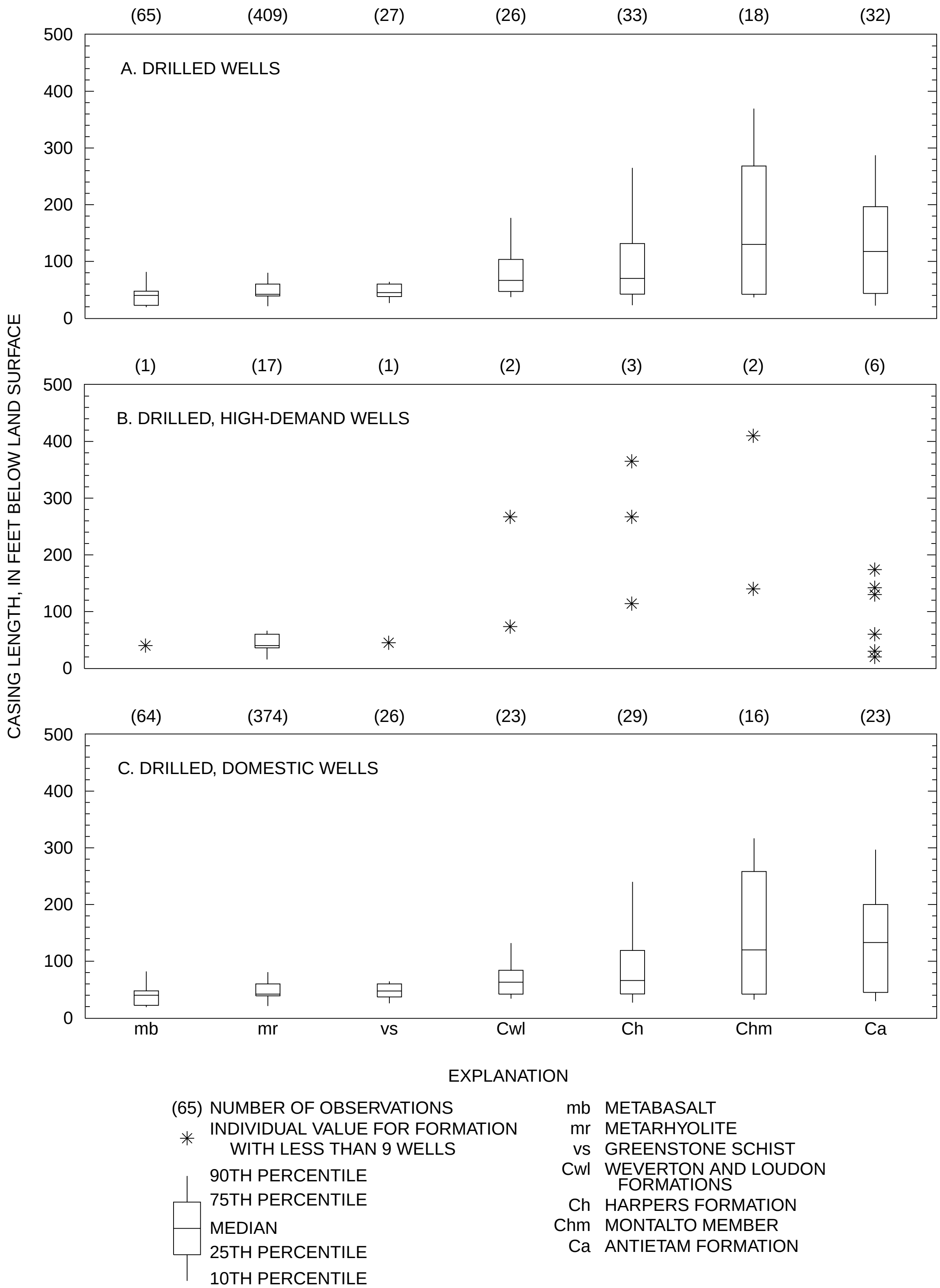


Figure 83. Casing lengths of drilled wells in the Blue Ridge Physiographic Province, South Mountain Section.

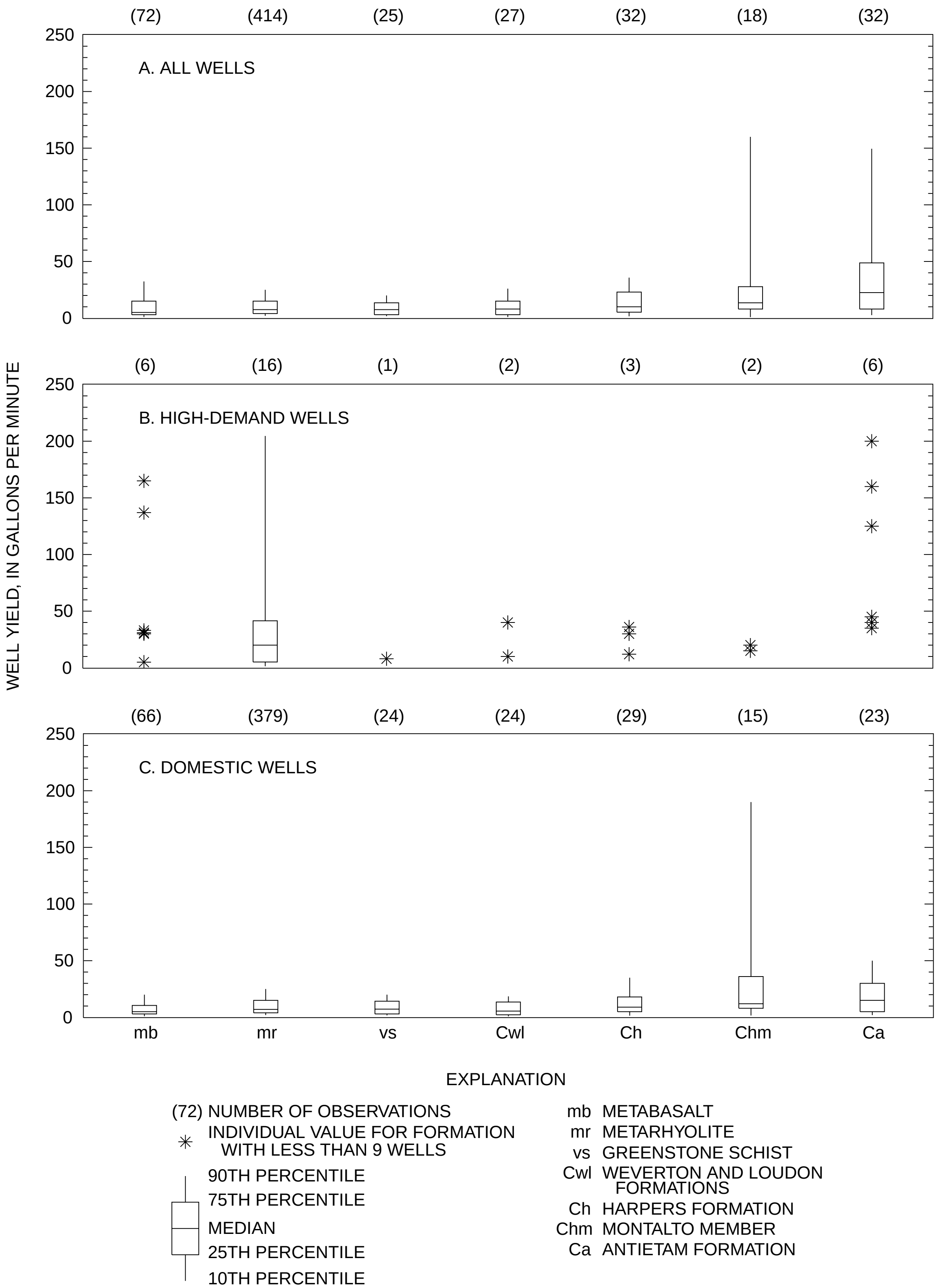


Figure 84. Reported yields of wells in the Blue Ridge Physiographic Province, South Mountain Section.

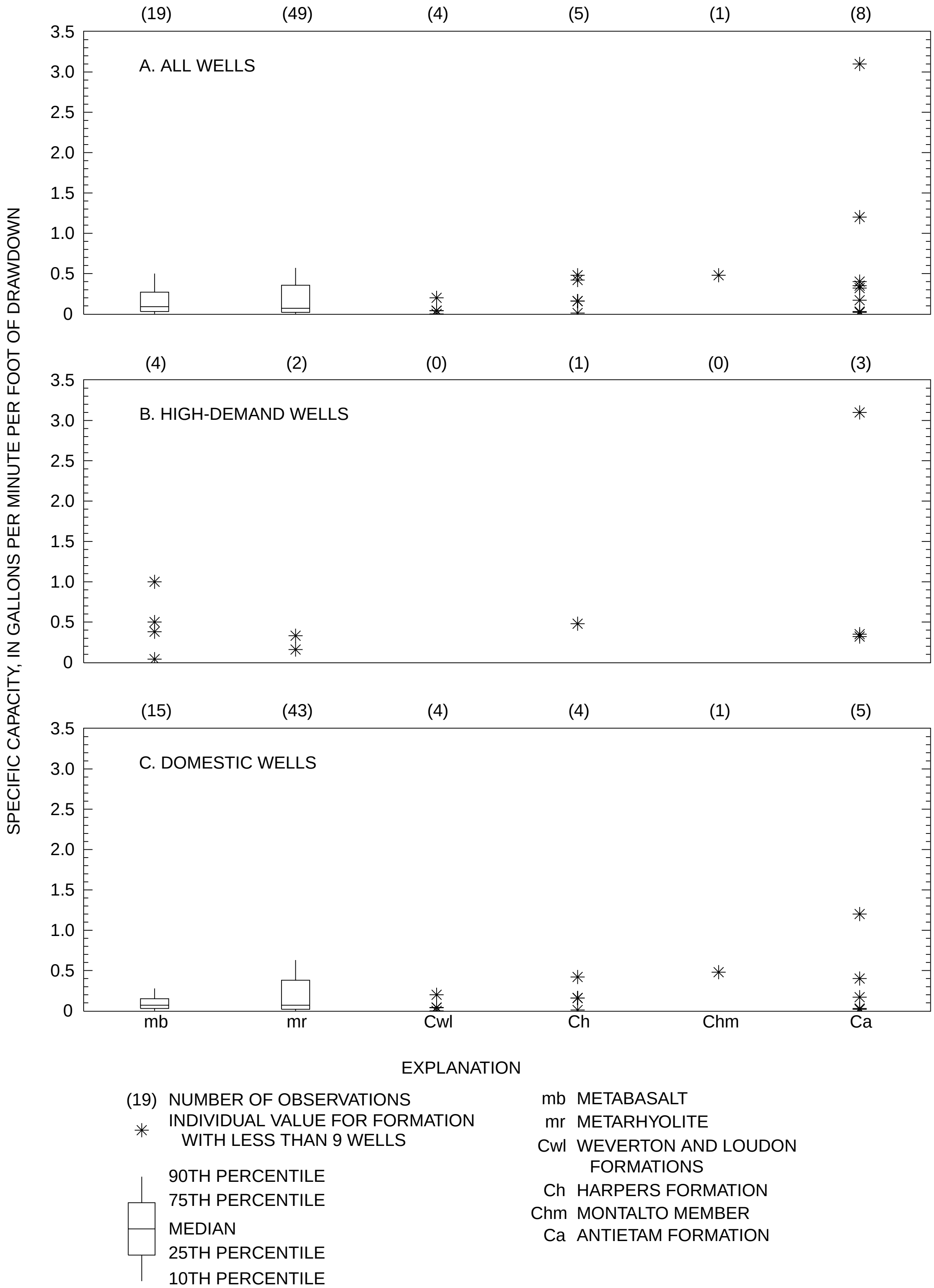


Figure 85. Specific capacities of wells in the Blue Ridge Physiographic Province, South Mountain Section.

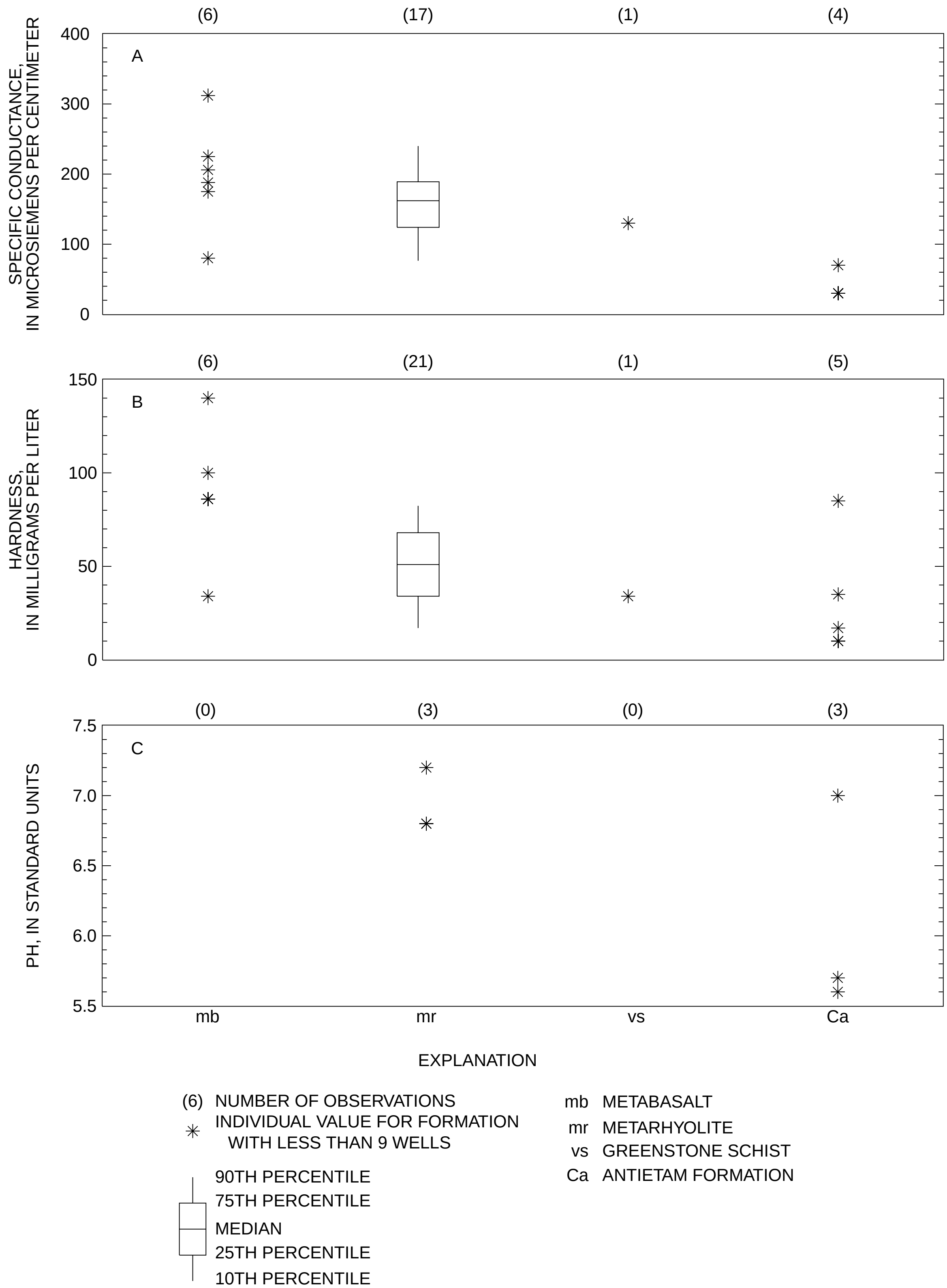


Figure 86. Field water-quality characteristics of wells in the Blue Ridge Physiographic Province, South Mountain Section: A, specific conductance, B, hardness, C, pH.

Table 21. *Significant relations for depth of drilled wells among seven geohydrologic units in the South Mountain Section of the Blue Ridge Physiographic Province, Pennsylvania*

[Table is read from top down. Example, depths of wells in the Metabasalt are significantly shallower than the depths of wells in the Antietam Formation. L, less; blank indicates no significant differences between units]

MSBL, Metabasalt; MTRL, Metarhyolite; GRNS, Greenstone Schist; WVLU; Weverton and Loudon Formations; HRPR, Harpers Formation; MNTL, Montalto Member; ANTM, Antietam Formation

	MBSL	MTRL	GRNS	WVLU	HRPR	MNTL	ANTM
DRILLED WELLS							
MBSL							
MTRL							
GRNS							
WVLU	L	L	L				
HRPR							
MNTL							
ANTM	L	L	L				
DRILLED, DOMESTIC WELLS							
MBSL							
MTRL							
GRNS							
WVLU	L	L	L				
HRPR							
MNTL							
ANTM			L				

Table 22. *Significant relations for casing length of drilled wells among seven geohydrologic units in the South Mountain Section of the Blue Ridge Physiographic Province, Pennsylvania*

[Table is read from top down. Example, casing lengths of wells in the Metabasalt are significantly less than in the Antietam Formation. L, less; blank indicates no significant differences between units]

MSBL, Metabasalt; MTRL, Metarhyolite; GRNS, Greenstone Schist; WVLU; Weverton and Loudon Formations; HRPR, Harpers Formation; MNTL, Montalto Member; ANTM, Antietam Formation

	MBSL	MTRL	GRNS	WVLU	HRPR	MNTL	ANTM
DRILLED WELLS							
MBSL							
MTRL							
GRNS							
WVLU	L	L	L				
HRPR							
MNTL	L	L	L				
ANTM	L	L	L				
DRILLED, DOMESTIC WELLS							
MBSL							
MTRL							
GRNS							
WVLU	L	L					
HRPR	L	L					
MNTL	L	L	L				
ANTM	L	L	L				

Table 23. *Significant relations for reported yield from wells among seven geohydrologic units in the South Mountain Section of the Blue Ridge Physiographic Province, Pennsylvania*

[Table is read from top down. Example, reported yields from wells in the Metabasalt are significantly less than the reported yields from wells in the Antietam Formation. L, less; blank indicates no significant differences between units]

MSBL, Metabasalt; MTRL, Metarhyolite; GRNS, Greenstone Schist; WVLU; Weverton and Loudon Formations; HRPR, Harpers Formation; MNTL, Montalto Member; ANTM, Antietam Formation

	MBSL	MTRL	GRNS	WVLU	HRPR	MNTL	ANTM
ALL WELLS							
MBSL							
MTRL							
GRNS							
WVLU							
HRPR							
MNTL							
ANTM	L	L	L	L			
DOMESTIC WELLS							
MBSL							
MTRL							
GRNS							
WVLU							
HRPR							
MNTL	L						
ANTM	L						

GEOHYDROLOGY OF THE NEW ENGLAND PHYSIOGRAPHIC PROVINCE, READING PRONG SECTION

Location and Geographic Setting

The Reading Prong Section, the southern most extension of the New England Physiographic Province as described by Fenneman (1938), is in eastern Pennsylvania in parts of Lebanon, Lancaster, Berks, Bucks, Lehigh, and Northampton Counties extending eastward into New Jersey (figs. 1 and 87). The Reading Prong covers about 225 mi^2 of southeastern Pennsylvania. It is bounded on the south by the Gettysburg-Newark Lowland Section of the Piedmont Physiographic Province, on the north by the Great Valley Section of the Ridge and Valley Physiographic Province and on the east by the New Jersey-Pennsylvania border.

The Reading Prong is underlain by a thin, linear, discontinuous band of granitic gneiss, granodiorite, quartzite, and sandstone that trends west-southwest, widening to 8 miles near Reading (Berg and others, 1980). It is an area of high flat-topped hills and steep-sided ridges that are separated by narrow valleys. Local relief can exceed 800 ft above the surrounding shale and carbonate valleys. Altitudes exceed 1,100 ft near Reading and are over 1,300 ft above sea level at the Reading Prong's western most extension.

Because of the rugged topography, the hills and ridges that form the Reading Prong are lightly populated. However, major population centers which directly border the Reading Prong include Allentown, Reading, Bethlehem, Fountain Hill, Emmaus, Easton, and Hellertown (fig. 87). Forest is the dominant land use cover in the study area. Large scale agriculture is limited to the carbonate and shale valleys; only minor agriculture and residential use appears on the hills and ridges.

The climate of the Reading Prong is humid continental, although on the higher hills the weather is more moderate. Precipitation averages 45 inches per year. Summer and winter mean temperatures are 24 and -1°C, respectively (Pennsylvania Department of Environmental Resources, 1983a, 1983b). Northern slopes undergo less freeze-thaw conditions than southern slopes. Prevailing winds are generally westerly during the winter and southerly to westerly during the summer.

Water-Well Density

The location of wells used in the analysis of the Reading Prong Section is shown in figure 88. The highest density of recorded wells are from Lehigh (2.0 wells per square mile) and Lebanon (2.6 wells per square mile) Counties. Areas with the least dense well data are Lancaster (0.0 wells per square mile), Northampton (0.49 wells per square mile), Berks (0.59 wells per square mile) and Bucks (0.71 wells per square mile) Counties.

Previous Work

Miller (1925; 1944), Hall (1934), Miller and others (1941), Stose and Jonas (1935), and Fraser (1938) are some of the first workers to study the geology of Reading Prong. Some of the more recent workers include Buckwalter (1959; 1962), MacLachlan and others (1975), and MacLachlan (1979).

Hall (1934) and Greenman (1955) present fairly detailed and abundant hydrologic information by county on the rock units which comprise the Reading Prong. Both authors provide information on well yields, drawdowns, well and casing depths, and some water-quality analyses. More recent studies by MacLachlan (1983), Royer (1983), Biesecker and others (1968), Wood and others (1972), and Wood and MacLachlan (1978) discuss the geology and hydrology of counties or quadrangles within and around the Reading Prong. Of these five reports, probably the most extensive is the one by Wood and others (1972) which discusses the water resources of Lehigh County. In their report, Wood and others (1972) provide yield, construction, and water quality data for almost 100 wells that are completed in the rock units of the Reading Prong. Cecil (1988) studied the geohydrology of the Furnace Creek Basin and vicinity in Berks, Lancaster, and Lebanon Counties. About three-quarters of this small (8.95 mi^2) basin is underlain by rocks that comprise the Reading Prong.

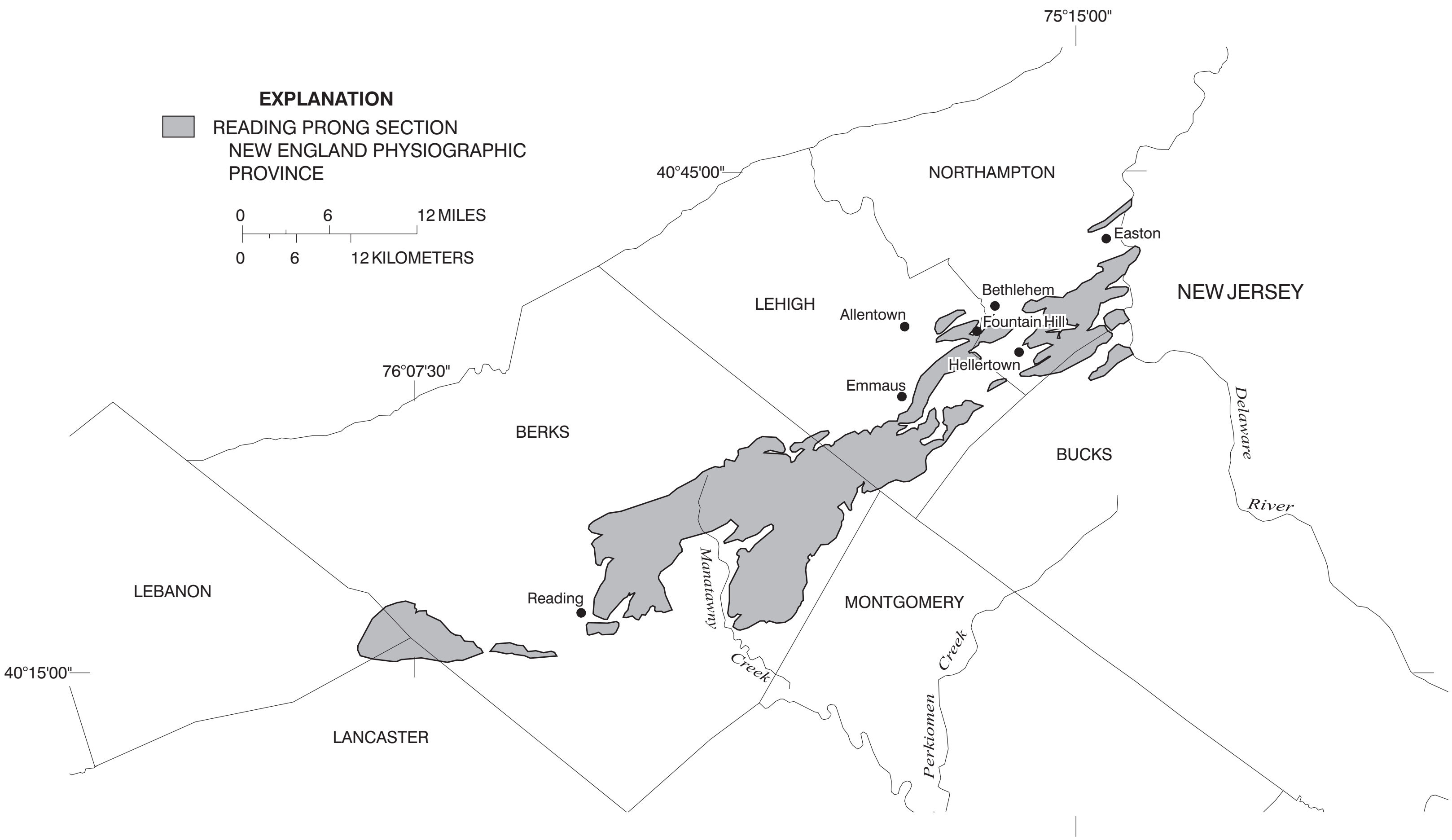


Figure 87. New England Physiographic Province, Reading Prong Section, major streams, counties and major population centers.

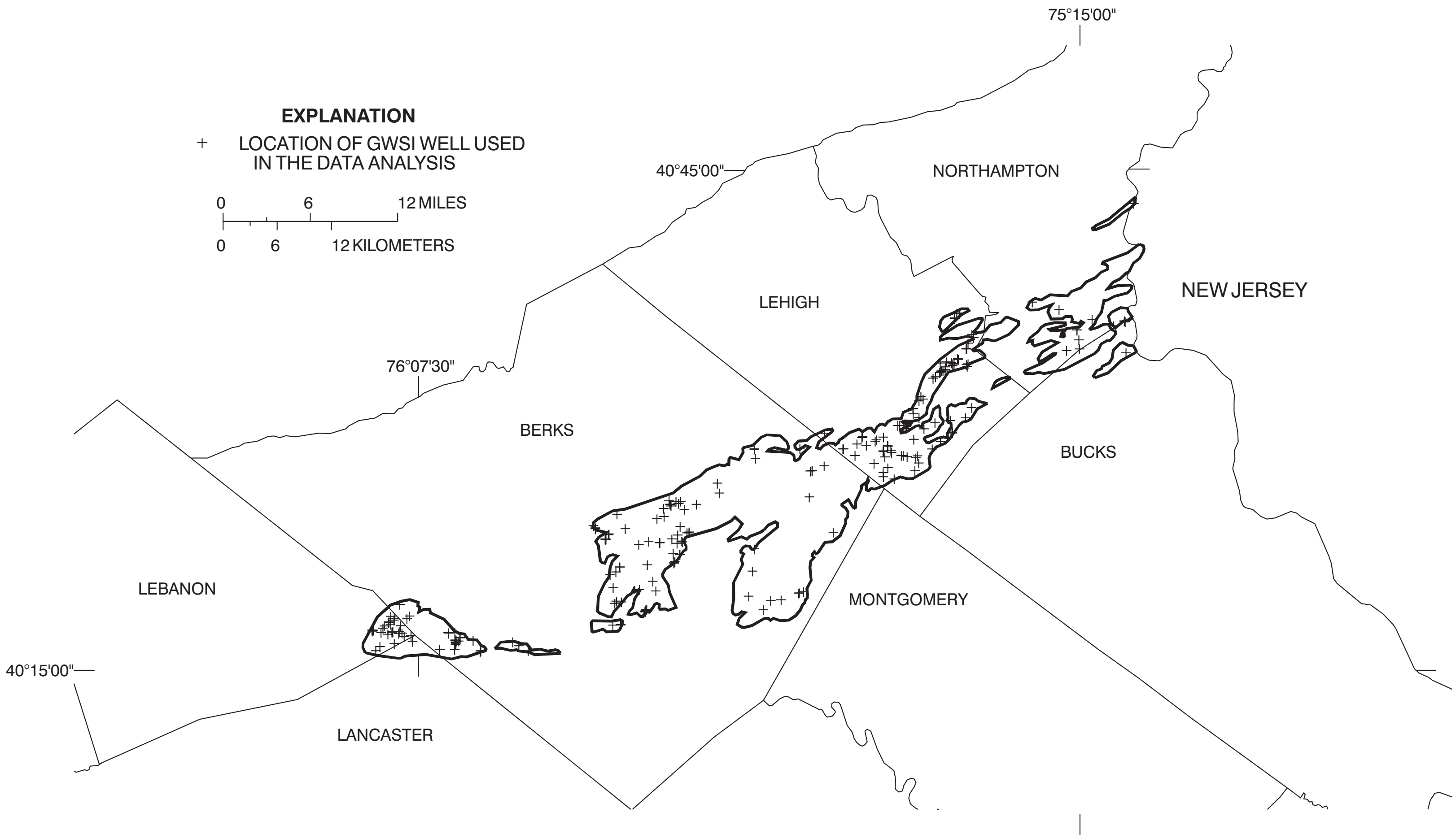


Figure 88. Location of wells in the New England Physiographic Province, Reading Prong Section.

Geologic Setting

In Pennsylvania, the Reading Prong consists of Precambrian gneisses, migmatites, granodiorites, and Cambrian sandstones and quartzites that were thrust eastward over shallow water carbonates and shales of the Great Valley (table 24). These highly deformed and imbricately-faulted rocks form Precambrian-cored nappes (MacLachlan, 1979; 1983) that overlie and are surrounded by rocks of the Great Valley. Aeromagnetic mapping by Bromery and Griscomb (1967) indicate many of the nappes are thin, and Precambrian rocks underlie the Great Valley and Gettysburg-Newark Lowland at various depths. Small but numerous metadiabase dikes intrude the central and western parts of the study area.

Table 24. *Generalized stratigraphic section of the New England Physiographic Province, Reading Prong Section in Pennsylvania*

[Modified from Berg and others, 1983.]

Age	Geohydrologic unit
Lower Cambrian	Hardyston Formation (Cha)
	Nonconformity
Precambrian	Granitic Rocks (gn, gg, hg, md, ggd)

All of the rocks of the Reading Prong Section are allochthonous and represent an imbricate stack of thrust sheets that have been thrust over the Paleozoic rocks of the Great Valley. Thrusting probably took place during Taconic and Alleghenian time, with most of the movement occurring late in the Paleozoic. The Proterozoic rocks have undergone at least one high-grade Proterozoic metamorphism and two low-grade Paleozoic metamorphisms (Lyttle and Epstein, 1987).

Hydrologic Setting

All of the Reading Prong lies within the Delaware River Basin. The Reading Prong is drained by the Delaware River and its tributaries. It also forms the headwaters for numerous streams within the Delaware River Basin including Manatawny and Perkiomen Creeks (Berg and others, 1980). The discharge per unit area of streams in the Reading Prong ranges from 0.05 to 0.30 ft^3/mi^2 for a flow exceeded 99 percent of the time (Biesecker and others, 1968, p. 137).

The Reading Prong receives slightly more precipitation in the summer months than any other season. Precipitation is the principal source of water that enters the ground-water flow systems. Much of the recharge to ground water is from late fall to early spring, resulting in a higher water table. During the remainder of the year rapid plant growth contributes to high evapotranspiration rates, creating soil-moisture deficits that greatly reduce the amount of precipitation that reaches ground-water flow systems, lowering the water table.

Ground-water recharge (precipitation) infiltrates into the regolith and the underlying bedrock, moving from areas of high hydraulic head to areas of lower hydraulic head and eventually returning to land surface through wells, springs, or streams. Ground-water discharged to streams as base flow is important to maintain adequate instream flows for use and for dilution of effluents discharged during periods of little precipitation. Wood and others (1972, p. 104) have determined that 85 percent of total runoff is derived from base flow (base runoff).

The Granitic Rocks, because of their areal extent, are the most important aquifer in the Reading Prong, representing about 80 percent of the study area. The Granitic Rocks are capable of meeting the needs of most domestic and some high-demand wells. The Hardyston Formation, however, is a better yielding unit than the Granitic Rocks. Appreciable amounts of water in both units is found near the contact with the underlying carbonate rocks or at the contact between the Hardyston Formation and the Granitic Rocks (Wood and others, 1972, p. 158-159; Miller, 1925, p. 182).

Geohydrologic System

The Reading Prong Section is comprised of numerous local and intermediate ground-water flow systems (fig. 89). The local systems are developed in the regolith, and where fractures, joints, bedding planes, and fault zones appear near land surface. The duration and intensity of precipitation has an almost immediate affect on the local system by raising water levels and increasing ground-water discharge to springs and other surface-water bodies.

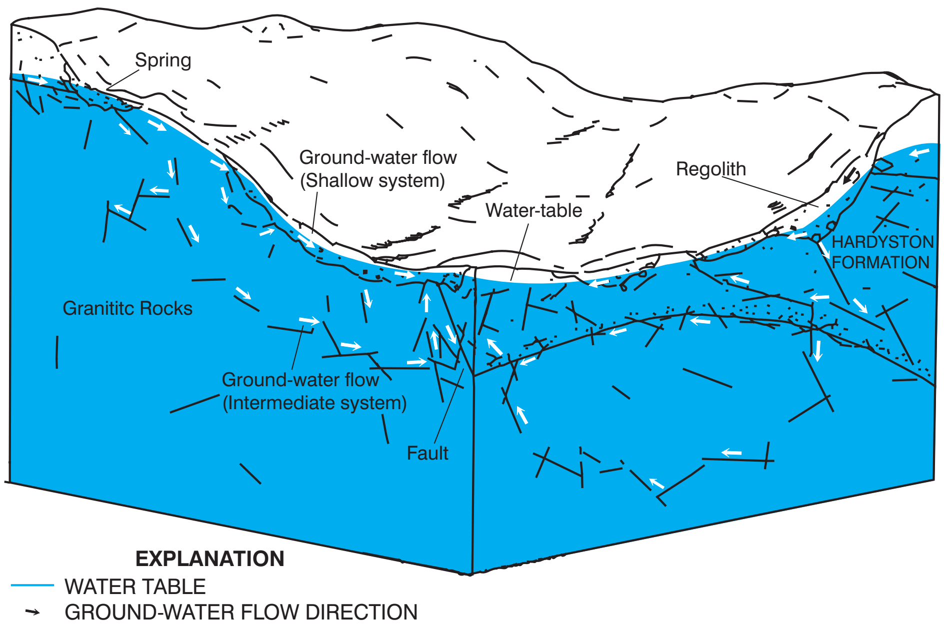


Figure 89. Topographic, geologic, and hydrologic features of the New England Physiographic Province, Reading Prong Section.

The intermediate ground-water flow system is characterized by flow paths that are deeper and longer. This system occurs probably in zones of weakness, such as faults or in shattered pegmatite dikes and quartz veins. The zones of weakness increase porosity and commonly permits fairly rapid ground-water movement, allowing the fractured rocks to yield more water than the surrounding less-fractured rocks (Parker and others, 1964, p. 74-75).

Regolith

In the Reading Prong, regolith is composed of impure kaolin, loamy clay, disaggregated bedrock, and colluvium that consists of gravelly silt which contains quartzite and subordinate gneiss ranging in size from pebbles to boulders (MacLachlan, 1979, p. 36). Regolith is generally thin on hilltops and relatively thicker on slopes. Regolith permits infiltration of precipitation, storing and slowly releasing water to wells, underlying fractured bedrock, and base flow to streams. In general, infiltration rates are good only where the regolith is extensive.

In the regolith, ground water generally flows down slope. However, the direction and rate of ground-water flow can be affected by the amount of bedrock weathering, mineral composition of the parent rock, orientation of mineral grains (especially micas), the presence of shear zones, quartz veins, and joints (Stewart, 1962, p. B-106).

The median thickness of the regolith, estimated from the length of casing in 55 domestic wells completed in the Granitic Rocks of the Reading Prong is 42 ft. For 11 domestic wells completed in the Hardyston Formation, the median thickness of regolith is 130 ft. In general, topographic setting does not significantly affect regolith thickness.

Fractured bedrock

Ground water is stored in and moves through consolidated bedrock in networks of fault zones, joints, bedding planes, and fractures. These secondary openings can form by unloading caused by erosion and uplift, cooling, or compressive stresses. Secondary openings, porosity, and permeability vary with depth and topographic setting, generally decreasing with increasing depth.

In the Reading Prong, springs and seeps are reported to be common in the Granitic Rocks, but not in the Hardyston Formation except where it is shattered (Miller, 1925, p. 182). Wells in both geohydrologic units consistently have shallower water levels in valleys than on slopes or hilltops. The Hardyston Formation, however, has the greatest range in water levels with water levels ranging from flowing to over 200 ft below land surface.

Depth distributions of water-bearing zones vary between the Granitic Rocks and the Hardyston Formation. Wells in the Granitic rocks penetrate 90 percent of the reported water-bearing zones by a depth of 266 ft. In the Hardyston Formation, 90 percent of the reported water-bearing zones are penetrated by a depth of 325 ft. The larger percentage of water-bearing zones penetrated at a greater depth in the Hardyston Formation may be affected, at least in part, by the limited thickness of this unit and the shattered fault contact of the Hardyston Formation with the underlying carbonate rocks. Wood and others (1972, p. 158) noted that large supplies of water could possibly be obtained at or near this contact, and Biesecker and others (1968, p. 139) mentioned that numerous high-demand wells received much of their water near the fault contact.

Granitic Rocks

The Geologic Map of Pennsylvania (Berg and others, 1980) lists five igneous or metamorphic bodies for the Reading Prong Section-granitic gneiss (gn), hornblende gneiss (hg), granodiorite and granodiorite gneiss (ggd), graphitic gneiss (gg), and metadiabase (md). However, because of the similarity of water-bearing properties and the need for clarity, these bodies will be treated as a single unit called “Granitic Rocks.”

The Granitic Rocks underlie about 181 mi^2 of the Reading Prong and consist principally of granitic gneiss and hornblende gneiss; granodiorite and granodiorite gneiss and graphitic gneiss generally are present only in small, widely-scattered bodies. Metadiabase dikes are fairly common but comprise a very minor percentage of the Reading Prong (Berg and others, 1980). Many of the older granitic gneisses in the Reading Prong area were formed by intruding into pre-existing rocks of sedimentary and metasedimentary origin (Royer, 1983; Buckwalter, 1959, 1962). Granites and related pegmatites assimilated or replaced the older gneisses to form migmatites (MacLachlan and others, 1975). These bear a considerable resemblance to the rocks of the highlands of northern New Jersey but are different to those in the Pennsylvania Piedmont just south of the Gettysburg-Newark Lowland (Long and Kulp, 1962; Buckwalter, 1962).

The granitic gneiss and granodiorite and granodiorite gneiss are highly resistant to weathering forming most of the high hills and ridges; regolith is generally thin. The hornblende gneiss and graphitic gneiss are moderately resistant to weathering with a thicker regolith and generally form low hills and slopes. Joints are common, well developed, and open (Geyer and Wilshusen, 1982).

Geologic description.—The granitic gneiss is generally light gray, tan or pink; the hornblende gneiss is usually dark gray to black or greenish-gray, the granodiorite and granodiorite gneiss is light pink to green; the graphitic gneiss is light to medium gray. Grain size ranges from one-sixteenth to one-half inch. The gneissic texture is generally poorly defined except in migmatites and some hornblende gneisses. Microcline, quartz, and plagioclase are the dominant minerals in the granitic gneiss and the granodiorite and granodiorite gneiss; hornblende and pyroxene in the hornblende gneiss. The most common minerals in the graphitic gneiss are orthoclase, hornblende, biotite, and graphite.

The hornblende gneiss, graphitic gneiss, and to some extent the granitic gneiss, were originally sedimentary rocks that were later metamorphosed and intruded by pegmatites and other igneous intrusives (Buckwalter, 1962). There is no known estimated thickness for the Granitic Rocks in the Reading Prong. Magnetic data from Bromery and Griscomb (1967) indicates that the thickness of the Granitic Rocks at South Mountain is less than that at Mount Penn and other hills to the east. These rocks have been dated as Precambrian (Lapham and Root, 1971). Buckwalter (1962, p. 23) stated that most of the metadiabase dikes are Precambrian, but noted that one has cut the Cambrian-age Hardyston Formation.

Well depths and casing lengths.—Depths of wells completed in the Granitic Rocks are presented in the table below. Wells in the Granitic Rocks are significantly shallower than wells in the Hardyston Formation. Domestic wells in the Granitic Rocks also are completed to significantly greater depths than in the Hardyston Formation. High-demand wells are completed at significantly greater depths than domestic wells. A total of 11 wells are completed at depths of 400 ft or greater; 4 are domestic wells and 7 are high-demand wells.

Reported well depth, Granitic Rocks

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	178	72	95	147	246	400	40	1,070
Drilled, domestic	92	65	80	119	162	262	40	1,070
Drilled, high-demand	36	86	127	239	360	500	62	700

Topographic setting also affects well depth. High-demand wells on slopes (22 wells) are completed at significantly greater depths than in valleys (13 wells). The median depth of high-demand wells on slopes is 338 ft; more than double the 152-ft median of high-demand wells in valleys.

Casing lengths of wells completed in the Granitic Rocks are presented in the following table. Casing lengths of wells in the Granitic Rocks are significantly less than the casing lengths of wells in the Hardyston Formation. High-demand and domestic wells in the Granitic Rocks also use significantly less casing than similar wells in the Hardyston Formation. High-demand wells generally use more casing than domestic wells. Eight wells use 100 ft or more of casing; seven are on slopes.

Reported casing length, Granitic Rocks

[Casing length in feet; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	108	21	31	44	63	86	6	183
Drilled, domestic	55	20	30	42	51	77	13	183
Drilled, high-demand	27	26	41	55	75	103	20	135

Hydrologic properties.—Water levels of wells completed in the Granitic Rocks are presented in the table below. Depths to water in 131 wells range from 1 to 160 ft below land surface; the median is 26 ft below land surface.

Water levels, Granitic Rocks

[Water levels in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	13	9	18	35	75	116	8	120
Slope	96	8	16	28	40	74	1	160
Valley	21	5	6	15	32	50	4	80

Yields of wells completed in the Granitic Rocks are significantly lower than in the Hardyston Formation. For high-demand and domestic wells, however, there are no significant differences in reported yields between the Granitic Rocks and the Hardyston Formation.

Well yields for wells completed in the Granitic Rocks are presented in the table below. Yields of 5.0 gal / min or less are reported from 24 wells. There are eight wells with reported yields of 100 gal / min or greater; seven of these wells are in Berks County and one is in Lehigh County. Five of the eight high-yielding wells are completed by a depth of 200 ft. high-demand wells have significantly greater reported yields than domestic wells.

Reported well yield, Granitic Rocks

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	138	4.0	8.0	15	40	61	0.3	275
Domestic	74	4.0	6.5	12	20	38	.3	50
High-demand	34	15	22	47	80	210	8.0	275

Topographic position of a well can affect reported yield. Wells on hilltops (14 wells) have significantly lower yields than wells on slopes (101 wells) or valleys (22 wells); the medians are 7.5, 15, and 42 gal / min, respectively. The yield of wells on slopes is also significantly lower than in valleys. High-demand wells on slopes (21 wells) have significantly lower yields than in valleys (12 wells). The median reported yield of high-demand wells on slopes is 38 gal / min; in valleys, it is 80 gal / min. Topographic position does not significantly affect the reported yields of domestic wells.

Specific capacities of wells completed in the Granitic Rocks are presented in the table below. The specific capacities of wells in the Granitic Rocks are not significantly different than the specific capacities of wells in the Hardyston Formation. Specific capacities in seven wells (drilled to depths of 180 to 514 ft below land surface) have specific capacities of 0.04 (gal / min) / ft or less and are incapable of meeting most domestic or other water-use demands. Eighteen of 20 wells with specific capacities of 1.0 (gal / min) / ft or greater are completed by a depth of 200 ft. Specific capacities for 15 wells with pumping durations of 8 hours or longer range from 0.08 to 30.0 (gal / min) / ft; the median is 0.95 (gal / min) / ft. There is very little difference in the specific capacities of high-demand and domestic wells.

Reported specific capacity, Granitic Rocks

[Specific capacity in gallons per minute per foot of drawdown; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	53	0.03	0.13	0.60	1.8	3.7	0.01	30
Domestic	29	.03	.13	.80	2.1	3.2	.01	5.0
High-demand	16	.09	.27	.76	2.7	16	.08	30

Values of hydraulic conductivity and transmissivity for the Granitic Rocks are presented in the table below; a specific yield of 0.02 was used in estimating these hydrologic properties. Hydraulic conductivity and transmissivity are generally greater on hilltops and in valleys than on slopes. The median hydraulic conductivities of wells on hilltops (7 wells), slopes (37 wells), and valleys (9 wells) are 3.2, 0.98, and 1.4 ft / d, respectively. The median transmissivities of wells on hilltops, slopes, and in valleys are 190, 87, and 130 ft^2 / d, respectively.

Hydraulic conductivity and transmissivity from single-well aquifer tests, Granitic Rocks

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	53	0.01	0.20	1.1	5.6	21	0.00	580
Transmissivity (ft^2 / d)	53	3.3	18	90	310	650	.00	7,500

In other work, Dingman and others (1956) determined transmissivities of 307 to 709 ft^2 / d using one well completed in the Baltimore Gneiss of the Maryland Piedmont. Gerhart and Lazorchick (1988, p. 22) estimated hydraulic conductivities of 0.67 to 1.34 ft / d for the upper 200 ft of their Lower Susquehanna River Basin digital model and hydraulic-conductivities of 0.67 to 0.134 ft / d for the lower 200 ft of their model.

Roy F. Weston / IT (1988) conducted a hydrogeologic investigation near the town of Hereford, Berks County, Pa. In this investigation they performed slug tests on two wells in the Granitic Rocks. The estimated hydraulic conductivities are 231 and 0.0027 ft / d. The exceptionally low hydraulic conductivity was from a well with 249 ft of open borehole, and therefore, probably is not an accurate representation.

Depths of water-bearing zones in 68 wells as deep as 640 ft range from 25 to 440 ft below land surface. Of 150 water-bearing zones reported 50 percent are penetrated by a depth of 99 ft and 90 percent by a depth of 266 ft. The greatest density of water-bearing zones (0.96 per 50 ft of well depth) is from 51-100 ft below land surface (fig. 90). The density of water-bearing zones located at depths of 201 ft or greater are based on the presence of four or fewer water-bearing zones per 50-ft interval. The overall density of water-bearing zones in the Granitic Rocks is 0.41 per 50 ft of well depth.

Borehole geophysical and video-borehole logs were run in 23 wells in the vicinity of the Crossley Farms Superfund Site near Bally, Berks County, Pa. Fluid velocity and direction were measured in two wells drilled to depths of 302 and 278 ft below land surface (Conger, 1998b). The heat-pulse flowmetering indicated that water entered the boreholes near the bottom and moved upward. In the deepest well, the water exited the borehole through minor fractures at 245 and 220 ft below land surface. In the second well, water exited the borehole through fractures at 84 and 57 ft below land surface.

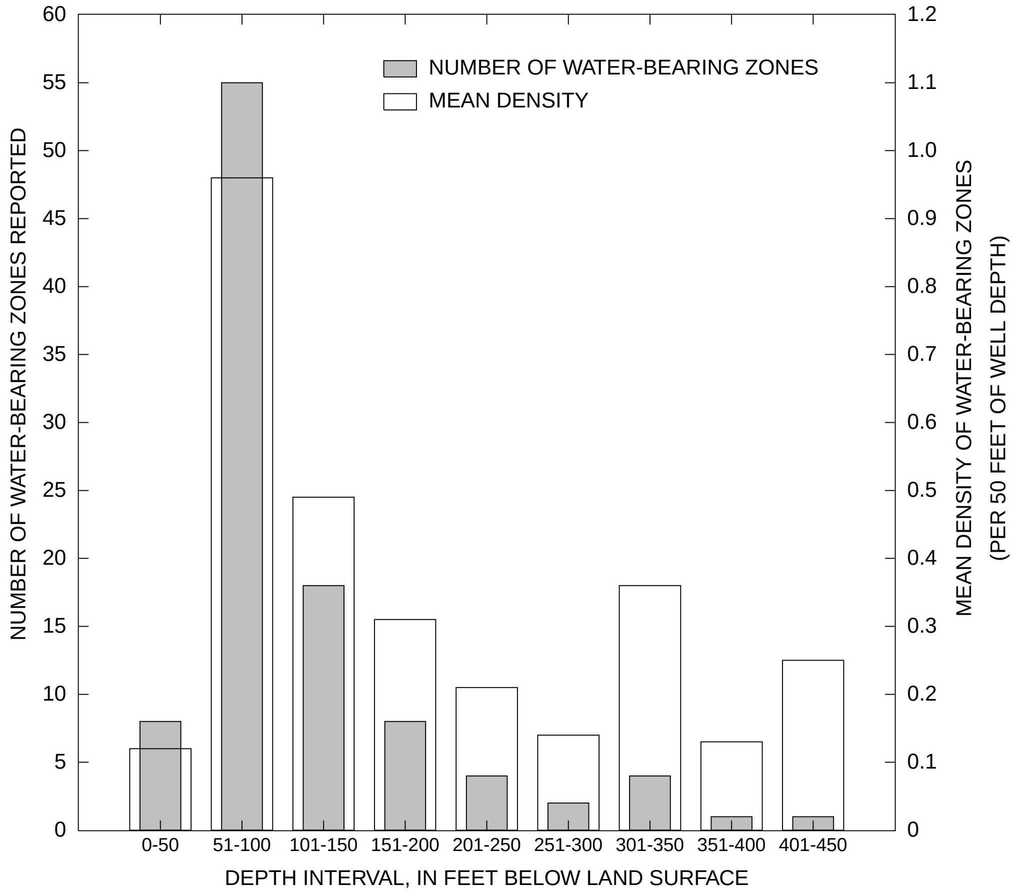


Figure 90. Number and density of water-bearing zones per 50 feet of well depth in the Granitic Rocks of the New England Physiographic Province, Reading Prong Section.

Water quality.—As seen in the following table, wells completed in the Granitic Rocks generally yield water that is low in dissolved solids, is soft to moderately hard, and is acidic. Calcium is the dominant cation, and bicarbonate is the dominant anion. In one well, however, sodium is the dominant cation. Elevated concentrations of iron and low pH are probably the most common water-quality problems in the Granitic Rocks. According to Miller (1925, p. 183) iron is a common problem where the mineral pyrite is present. The elevated concentrations of zinc are probably related to the low pH of the water, and subsequent leaching of the metal from plumbing fixtures. Langland and Dugas (1996) found that water from the Granitic Rocks is moderately to extremely corrosive. Although only analyzed for in two wells, radon concentrations in water from wells completed in the Granitic Rocks will probably exceed the proposed USEPA MCL of 300 pCi/L. Smith (1974) reported the occurrence of uranium in a pegmatitic gneiss in Berks County. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Granitic Rocks

[Concentrations in milligram per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; pCi/L, picocurie per liter; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	27	—	—	—	75	140	200	47	270
Field hardness	16	—	—	—	41	52	82	29	170
Field pH (standard units)	17	—	<6.5 >8.5	15	5.7	6.0	6.3	5.3	6.7
Bicarbonate	38	—	—	—	21	30	44	8.0	100
Calcium	24	—	—	—	7.1	12	20	5.6	56
Chloride	36	—	250	0	2.8	4.5	8.2	1.0	46
Iron	31	—	0.3	8	.010	.080	.33	.000	1.5
Magnesium	24	—	—	—	3.0	4.6	7.1	1.9	12
Manganese	26	—	.05	0	.000	.000	.010	.000	.030
Nitrate (as N)	31	10	—	0	.89	1.5	4.3	.09	8.3
Potassium	33	—	—	—	.80	1.0	1.5	.50	2.7
Radon (pCi/L)	2	[3] 300	—	2	—	35,000	—	20,000	50,000
Silica	34	—	—	—	21	25	32	13	38
Sodium	33	—	—	—	4.4	6.9	9.0	3.0	16
Sulfate	34	—	250	0	9.7	20	33	1.1	70
Total dissolved solids	26	—	500	0	76	110	150	41	317
Zinc	18	5	—	1	.010	.040	.43	.000	8.0

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.
[3] U.S. Environmental Protection Agency, 1994, proposed maximum contaminant level.

Hardyston Formation (Chm)

The Hardyston Formation underlies about 44 mi^2 of the Reading Prong in numerous, elongate, fault truncated beds (Berg and others, 1980). Its reference section is at Mt. Penn, Reading, Berks County.

Geologic description.—The lower part of the Hardyston Formation consists of light to dark gray, basal quartz-pebble conglomerate that grades upward through a conglomeratic, feldspathic quartzite to the Hardyston sandstone. The sandstone, typical of the Hardyston Formation, is generally light gray to light buff, fine- to medium-grained quartzite and arkose; jasper is common locally. Feldspathic beds are common, with feldspar comprising from 5 to 30 percent of these beds (Buckwalter, 1962, p. 26). Scolithus tubes are relatively common. The basal conglomerate was frequently a locus for thrusting (MacLachlan, 1979). Because of its structural displacement the true thickness of the Hardyston Formation is not known. However, Miller (1925, p. 26) reported a thickness of 20-300 ft near Allentown, whereas Buckwalter (1962, p. 27) reported a thickness of about 600 ft, and Lyttle and Epstein (1987) a maximum thickness of 900 ft.

The Hardyston Formation is generally highly resistant to weathering and helps form the topographic ridges and hills typical of the Reading Prong. In Lehigh County, however, this unit generally crops out on slopes, and in places underlies relatively flat, lower tracts (Miller, 1941, p. 165). Joints are wide spread, blocky, moderately well developed, abundant, and open. The regolith is usually thin (Geyer and Wilshusen, 1982, p. 141-142).

Contact with the older Granitic Rocks is generally unconformable and abrupt. Based upon fossil evidence in New Jersey, the Hardyston is considered Cambrian in age (Miller and others, 1941, p. 171-172).

Well depths and casing lengths.—Depths of wells completed in the Hardyston Formation are presented in the table below. Wells in the Hardyston Formation are completed to significantly greater depths than in the Granitic Rocks. Depths of domestic wells in the Hardyston Formation are also completed at significantly greater depths than in the Granitic Rocks. High-demand wells are completed at significantly greater depths than domestic wells.

Reported well depth, Hardyston Formation

[Depth in feet below land surface; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	79	90	135	225	312	487	10	702
Drilled, domestic	22	85	107	202	281	374	29	487
Drilled, high-demand	31	126	200	296	400	600	54	702

Casing lengths of wells completed in the Hardyston Formation are presented in the following table. Casing lengths of wells in the Hardyston Formation are significantly greater than the casing lengths of wells in the Granitic Rocks. High-demand and domestic wells in the Hardyston Formation also use significantly more casing than in the Granitic Rocks. High-demand wells generally use more casing than domestic wells. Of the 11 wells with casing lengths of 100 ft or greater, 9 are on slopes.

Reported casing length, Hardyston Formation

[Casing length in feet; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Drilled	54	34	44	119	164	243	20	367
Drilled, domestic	11	21	33	130	222	248	20	251
Drilled, high-demand	26	36	42	100	162	236	23	367

Hydrologic properties.—Water levels of wells completed in the Hardyston Formation are presented in the table below. Depths to water in 56 wells range from flowing at land surface to 202 ft below land surface; the median is 34 ft. Depths to water in wells located in Berks County (35 wells) are considerably deeper than in Lehigh County (15 wells). The median depth to water in Berks County is 47 ft and in Lehigh County; the median is 22 ft.

Water levels, Hardyston Formation

[Water levels in feet below land surface; F, flowing well; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	3	—	—	33	—	—	21	74
Slope	38	9	21	52	116	164	F	202
Valley	14	7	10	16	38	47	6	48

Reported yields of wells completed in the Hardyston Formation are presented in the table below. Yields of wells completed in the Hardyston Formation are significantly greater than in the Granitic Rocks.

Reported well yield, Hardyston Formation

[Yield in gallons per minute; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	66	5.7	10	31	64	133	1.0	530
Domestic	15	1.6	5.0	10	25	64	1.0	100
High-demand	30	21	38	60	120	284	6.0	530

Yields of 5.0 gal / min or less are reported from six wells. Eight of 11 wells with reported yields of 100 gal / min or greater are deeper than 200 ft. Nine of these 11 high-yielding wells are located in Berks County. High-demand wells have significantly greater reported yields than domestic wells.

Specific capacities of wells completed in the Hardyston Formation are presented in the following table. Specific capacities of wells in the Hardyston Formation are not significantly different than the specific capacities of wells in the Granitic Rocks. Only one well (drilled to a depth of 425 ft) has a specific capacity of 0.04 (gal / ft) / min or less and is incapable of meeting most domestic or other water-use demands. Seven of 13 wells with specific capacities of 1.0 (gal / min) / ft or greater are deeper than 200 ft. Specific capacities for 18 wells with pumping durations of 8 hours or longer range from 0.10 to 18 (gal / min) / ft; the median is 0.83 (gal / min) / ft.

Reported specific capacity, Hardyston Formation

[Specific capacity in gallons per minute per foot of drawdown; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Well type	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
All	34	0.15	0.32	0.57	1.8	7.2	0.04	18
Domestic	4	—	—	.45	—	—	.19	2.0
High-demand	22	.31	.42	.83	2.2	14	.10	18

Values of hydraulic conductivity and transmissivity for the Hardyston Formation are presented in the table below; a specific yield of 0.02 was used in estimating these hydrologic properties. Hydraulic conductivity and transmissivity are generally greater in valleys than on slopes. The median hydraulic conductivities of wells on hilltops (3 wells), slopes (21 wells), and valleys (8 wells) are 0.93, 0.76, and 11 ft / d, respectively. The median transmissivities of wells on hilltops, slopes, and valleys are 73, 74, and 560 ft^2 / d, respectively.

Hydraulic conductivity and transmissivity of single-well aquifer tests, Hardyston Formation

[ft/d, feet per day; ft^2/d, feet squared per day; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Hydrologic property	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hydraulic conductivity (ft / d)	33	0.12	0.24	1.1	7.5	21	0.01	140
Transmissivity (ft^2 / d)	33	21	50	110	340	1,800	3.2	4,800

Roy F. Weston / IT (1988) conducted a hydrogeologic investigation near the town of Hereford, Berks County, Pa. In this investigation they performed slug tests on three wells and a multiple-well aquifer test. The estimated hydraulic conductivities from the slug tests are 85.8, 58.7, and 0.19 ft / d. The exceptionally low hydraulic conductivity was from a well with 104 ft of open borehole, and therefore, probably is not an accurate representation. Transmissivities estimated from the aquifer test are 1,960, 2,080, 2,210, and 2,710 ft/d; storativity was estimated as 0.0011.

The depths of water-bearing zones in 29 wells as deep as 678 ft range from 18 to 592 ft below land surface. Fifty percent of the 66 water-bearing zones reported are penetrated by a depth of 159 ft and 90 percent by a depth of 325 ft. The greatest density of water-bearing zones (0.57 per 50 ft of well depth) is from 301 to 350 ft below land surface (fig. 91). The overall water-bearing zone density of the Hardyston Formation is 0.30 per 50 ft of well depth.

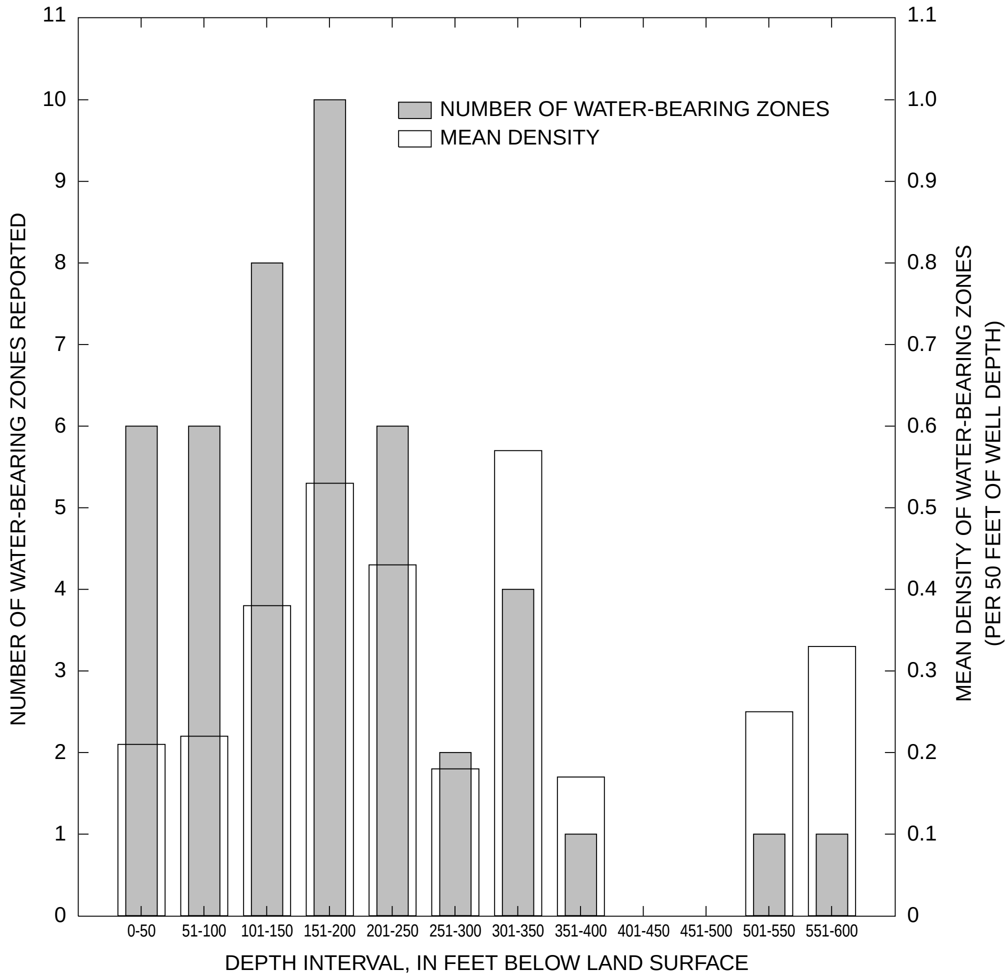


Figure 91. Number and density of water-bearing zones per 50 feet of well depth in the Hardyston Formation of the New England Physiographic Province, Reading Prong Section.

Fluid velocity and borehole flow were measured in two wells in the vicinity of the Crossley Farms Superfund Site near Bally, Berks County, Pa. that were drilled to depths of 232 and 299 ft below land surface (Conger, 1998b). The heat-pulse flowmetering indicated that water entered the boreholes at depths of 228-230 ft, and 222 and 238 ft below land surface, respectively. The water moved upward and exited the borehole in the deepest well at 196 ft below land surface.

Water quality.—As seen in the following table, wells completed in the Hardyston Formation generally yield water that is low in dissolved solids, is moderately hard, and is alkaline. Calcium is the dominant cation, and bicarbonate is the dominant anion. Elevated concentrations of iron and manganese are the most common water-quality problems. The reason for the elevated lead concentration is uncertain; the laboratory pH of water from this 700-ft-deep well is 7.8. Although only analyzed for in one well, radon concentrations in water from wells completed in the Hardyston Formation may commonly exceed the proposed USEPA MCL of 300 pCi/L. Smith (1974) reported the occurrence of uranium in Hardyston float in Lehigh County. Additional information on the source and significance of these and other selected dissolved constituents and properties of ground water are presented in the appendix.

Summary of selected chemical constituents and properties analyzed for the Hardyston Formation

[Concentrations in milligram per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, insufficient data available; <, less than; >, greater than; pCi/L, picocurie per liter; P25, twenty-fifth percentile; P75, seventy-fifth percentile]

Chemical constituent or property	Number of wells sampled	Maximum contaminant or action level[1]	Secondary maximum contaminant level[2]	Number of wells containing water that exceeds contaminant level	P25	Median	P75	Minimum reported	Maximum reported
Field specific conductance (µS/cm)	3	—	—	—	—	92	—	65	390
Field hardness	2	—	—	—	—	130	—	51	210
Field pH (standard units)	4	—	<6.5 >8.5	1	—	7.4	—	5.1	7.6
Bicarbonate	13	—	—	—	13	38	110	7.0	140
Calcium	10	—	—	—	2.4	8.6	24	1.6	27
Chloride	13	—	250	0	1.6	2.7	4.5	.50	10
Iron	12	—	.3	3	.015	.060	1.2	.000	22
Lead	2	0.015	—	1	—	.013	—	.005	.020
Magnesium	10	—	—	—	1.4	4.0	14	.60	14
Manganese	12	—	.05	2	.000	.010	.022	.000	.13
Nitrate (as N)	13	10	—	0	.37	.72	2.1	.00	3.0
Potassium	8	—	—	—	1.1	1.4	2.3	.50	5.3
Radon (pCi/L)	1	[3] 300	—	1	—	12,000	—	12,000	—
Silica	9	—	—	—	12	14	18	7.1	25
Sodium	8	—	—	—	2.4	2.9	5.0	2.2	5.4
Sulfate	12	—	250	0	2.9	6.3	30	.60	32
Total dissolved solids	13	—	500	0	37	114	143	20	206

[1] U.S. Environmental Protection Agency, 1994.
[2] U.S. Environmental Protection Agency, 1986b.
[3] U.S. Environmental Protection Agency, 1994, proposed maximum contaminant level.

Summary of Characteristics of Bedrock Aquifers in the New England Physiographic Province, Reading Prong Section

Data evaluated for the units in the Reading Prong Section are summarized in figures 92 to 97. Well depths range from 10 to 1,070 ft below land surface and casing lengths from 6 to 367 ft. Well depths and casing lengths can vary significantly by water use, topographic setting, and geohydrologic unit. In general, high-demand wells are completed at significantly greater depths than domestic wells.

Reported yields range from 0.3 to 530 gal/min and specific capacities from 0.01 to 30 (gal/min)/ft. Reported yields and specific capacities can vary significantly by water use, topographic setting, and geohydrologic unit. High-demand wells generally have significantly greater reported yields than domestic wells.

Field-water quality data for the Reading Prong Section are presented in figure 96, most of the analyses are from the Granitic Rocks. Ground water generally contains low amounts of dissolved solids, is soft, and acidic. The influence of the surrounding carbonate rocks is evident from the Hardyston Formation as seen in the sample containing very hard water and pH above 7.0.

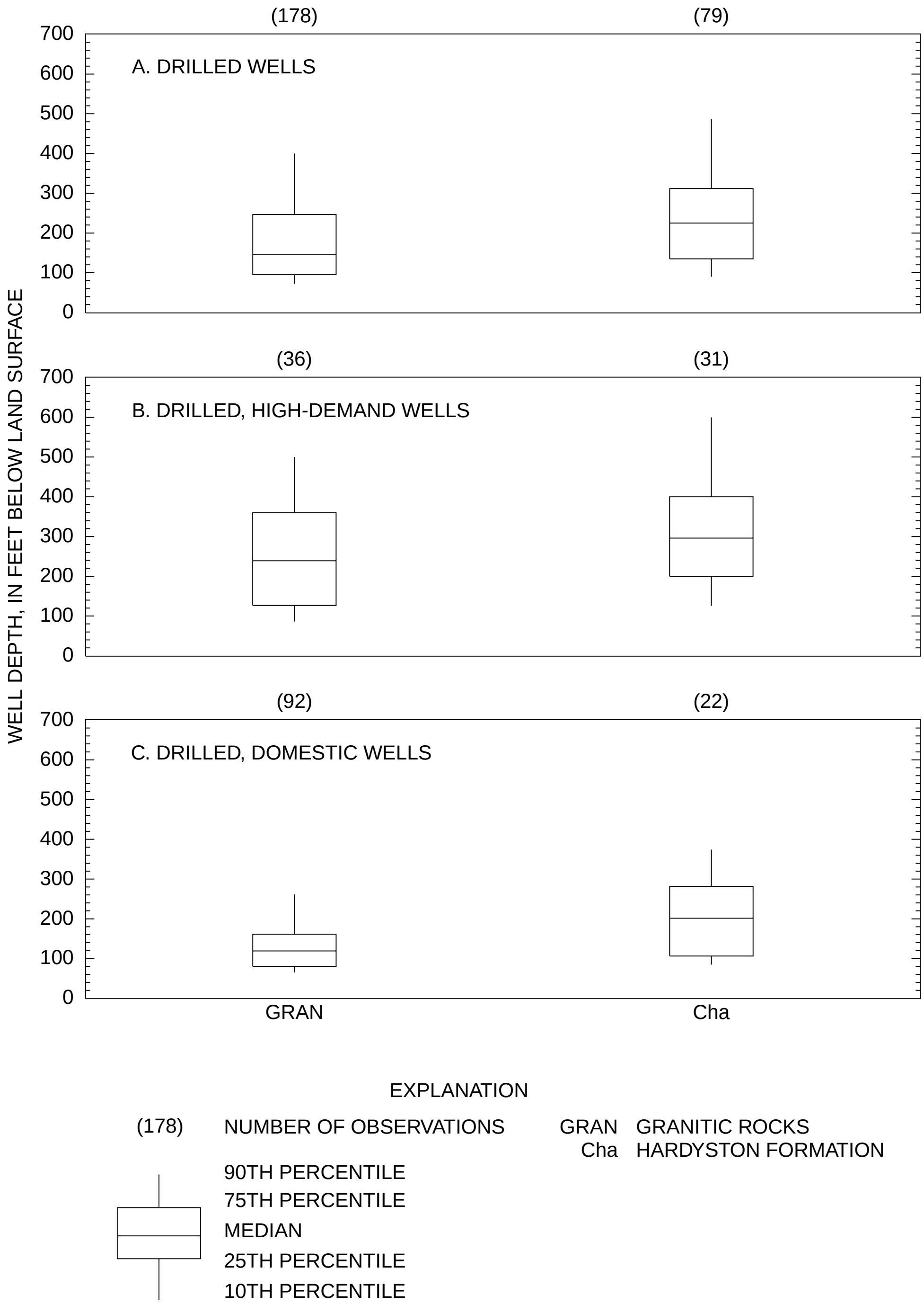


Figure 92. Depths of drilled wells in the New England Physiographic Province, Reading Prong Section.

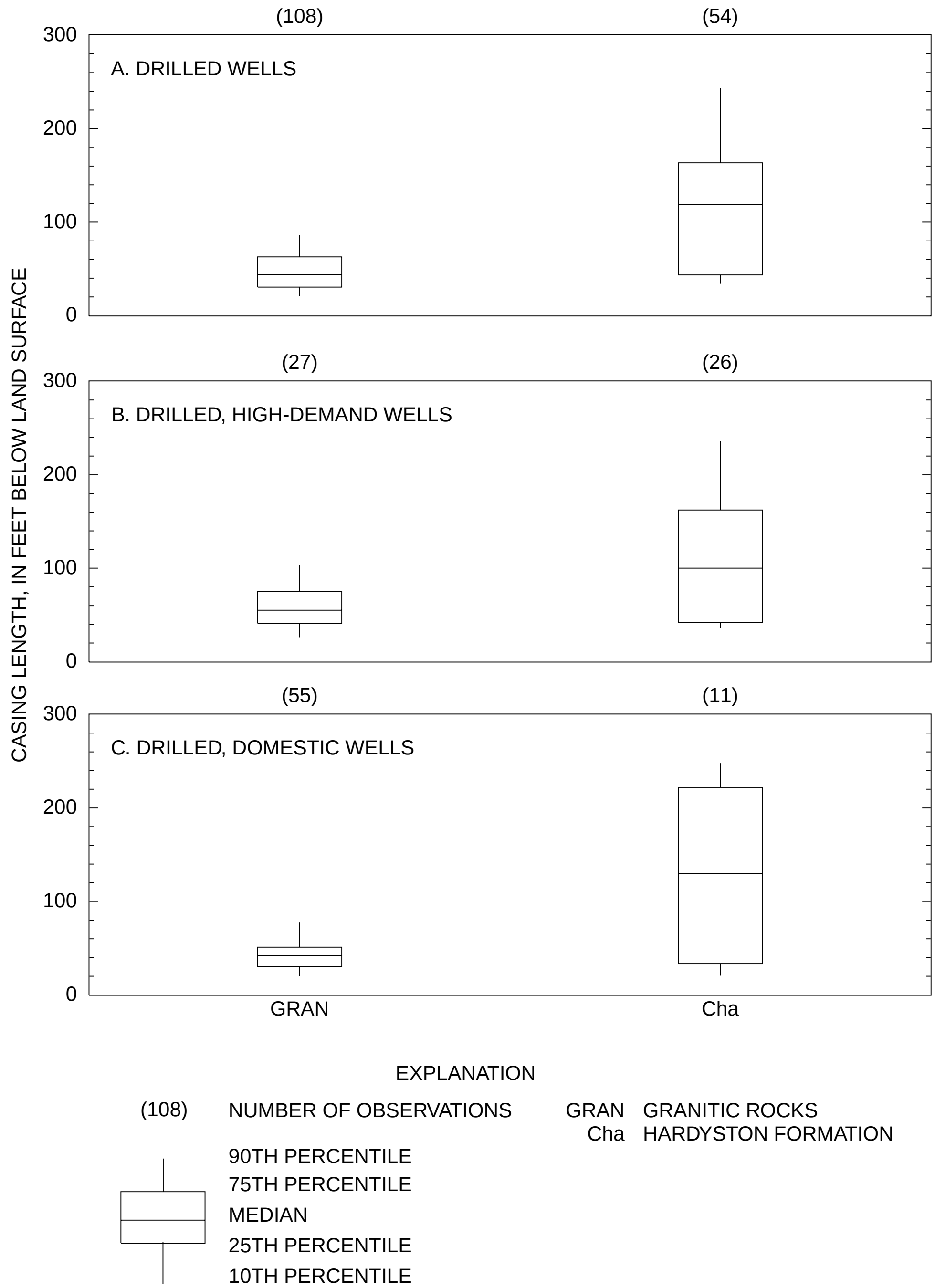


Figure 93. Casing lengths of drilled wells in the New England Physiographic Province, Reading Prong Section.

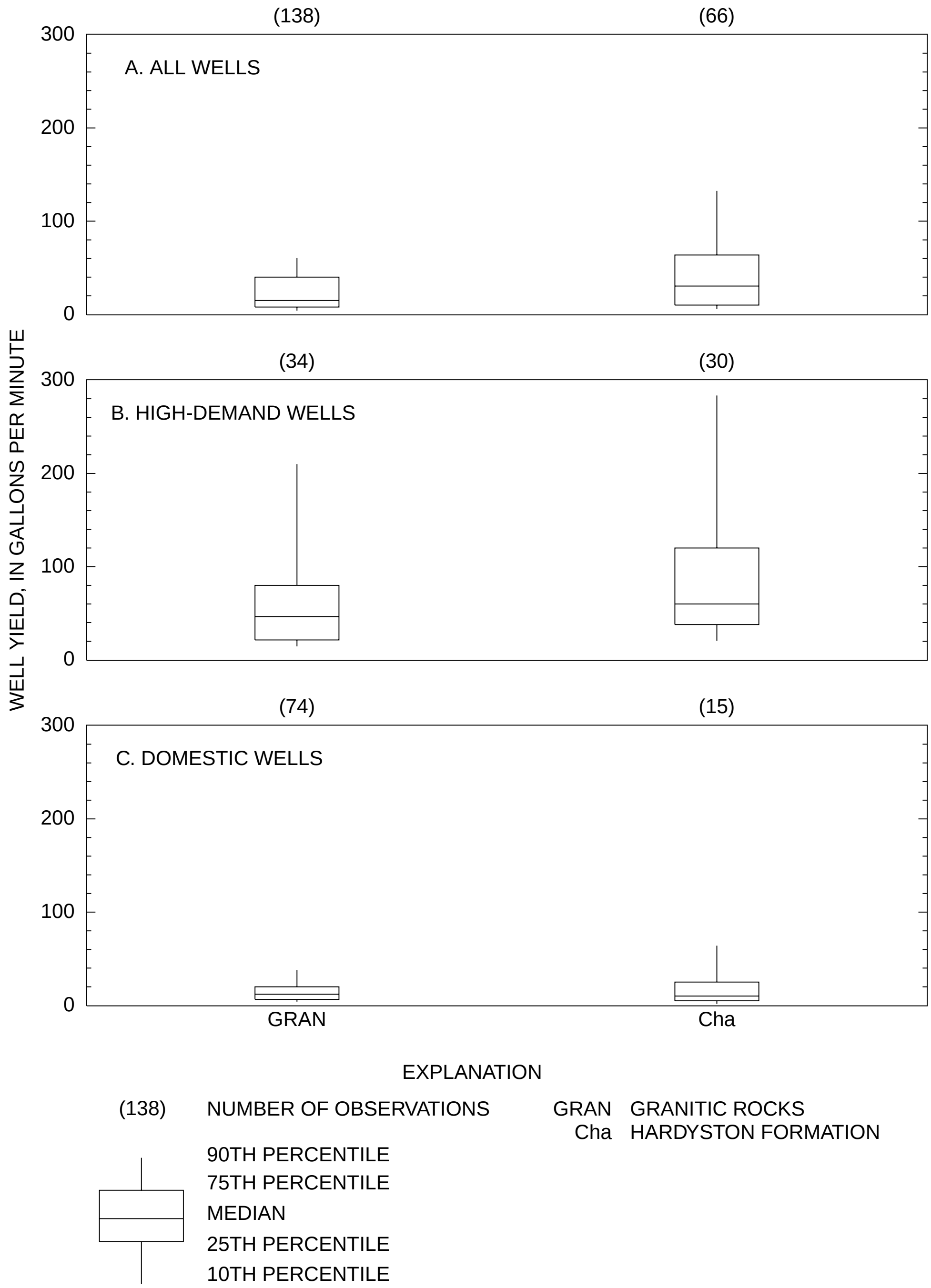


Figure 94. Reported yields of wells in the New England Physiographic Province, Reading Prong Section.

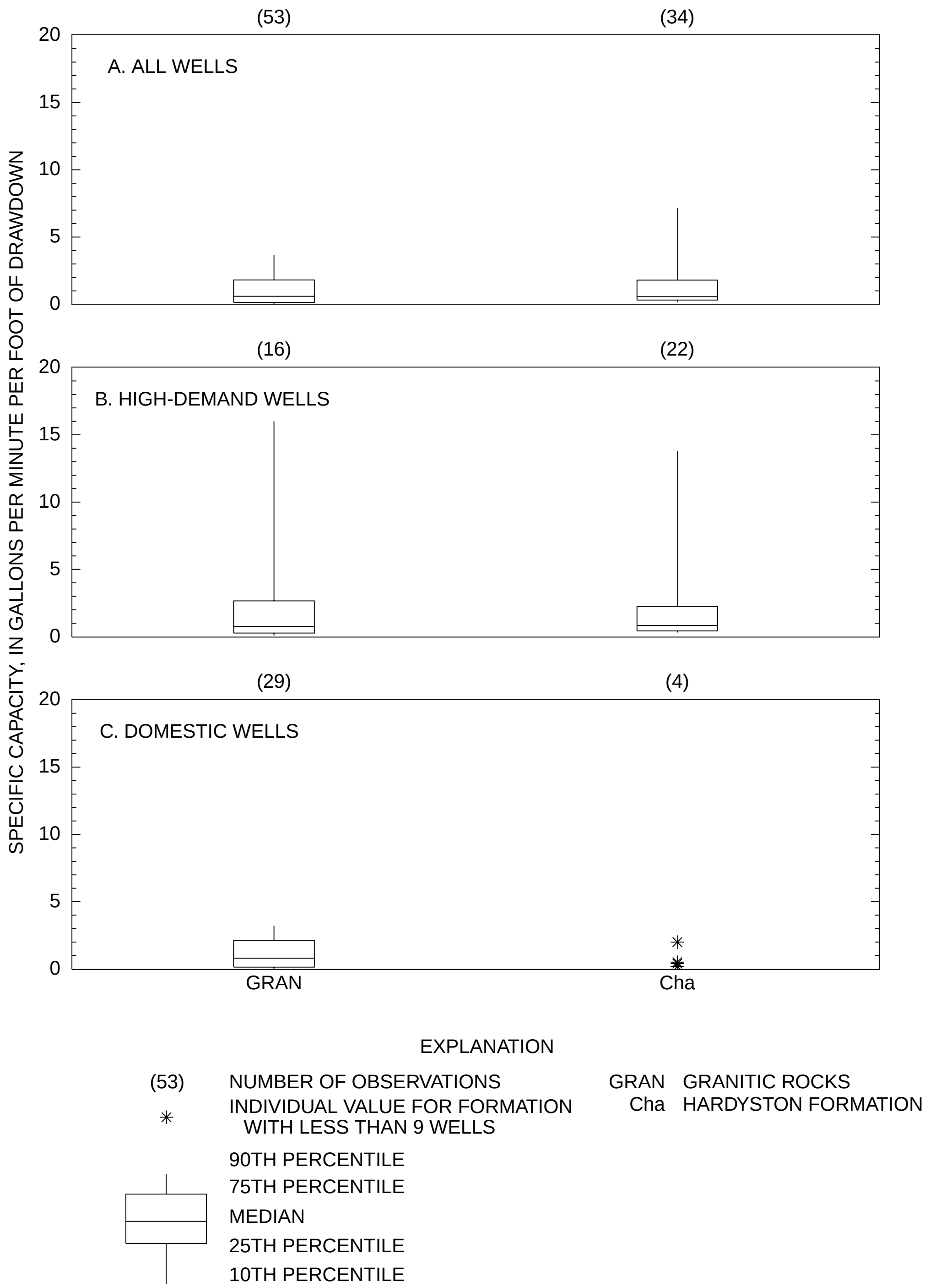


Figure 95. Specific capacities of wells in the New England Physiographic Province, Reading Prong Section.

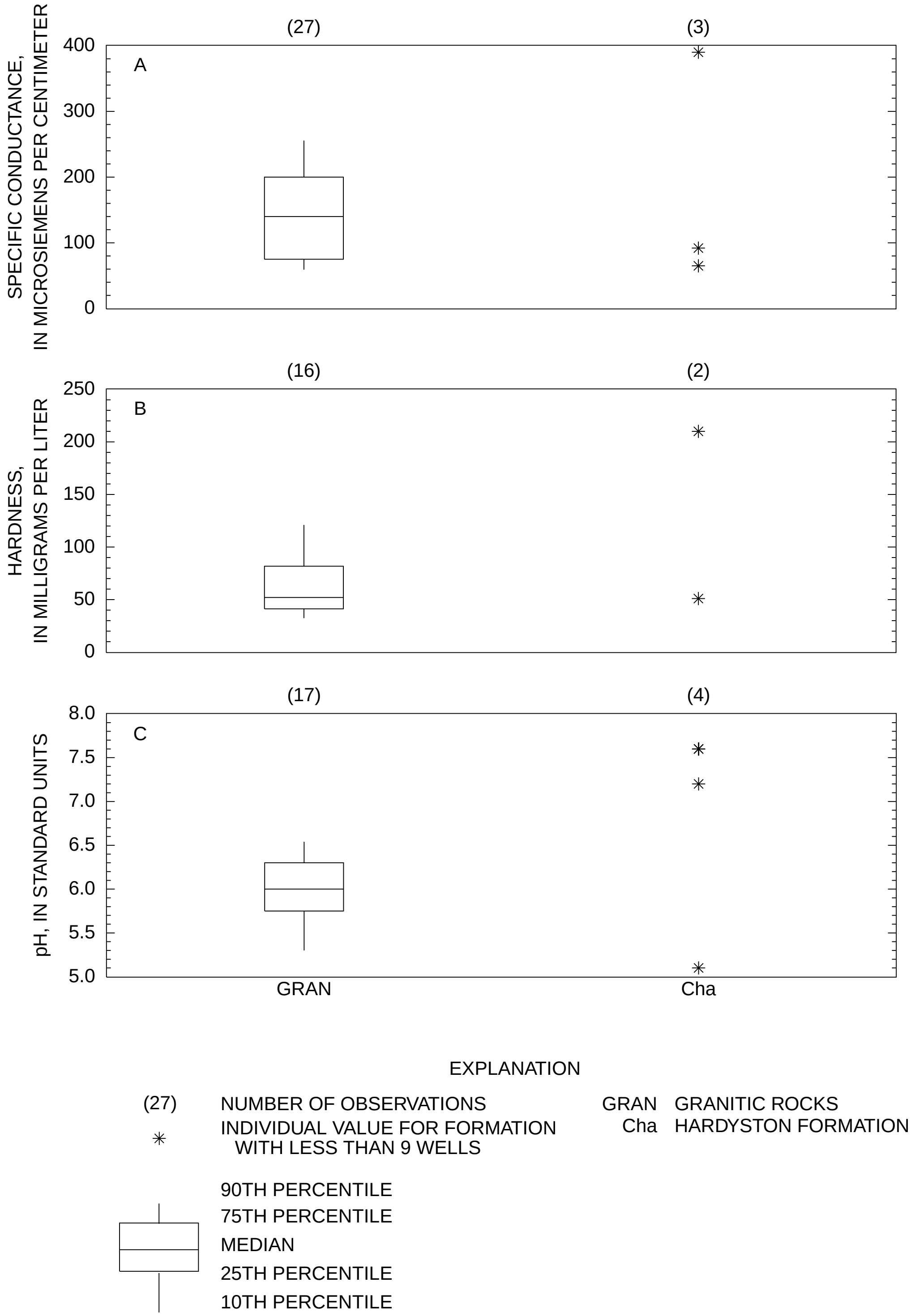


Figure 96. Field water-quality characteristics of wells in the New England Physiographic Province, Reading Prong Section: A, specific conductance: B, hardness; C, pH.

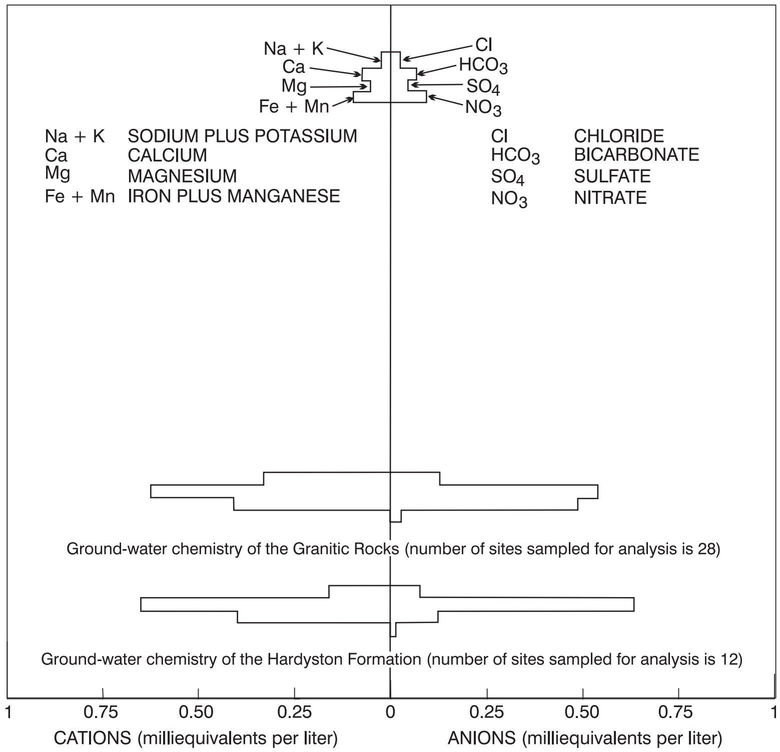


Figure 97. Median chemical analyses of selected chemical constituents from the ground water of the geohydrologic units in the New England Physiographic Province, Reading Prong Section.

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APPENDIX—SOURCE AND SIGNIFICANCE OF SELECTED DISSOLVED CONSTITUENTS AND PROPERTIES OF GROUND WATER

Alkalinity (as $CaCO_3$)

The major cause of alkalinity is the bicarbonate (HCO_3) and to some extent the carbonate (CO_3) ions. The bicarbonate ion may result from atmospheric carbon dioxide and the solution of carbon dioxide produced during the decomposition of organic matter in the soil. The major source, however, is from solution of carbonate rocks and cement by carbon dioxide in ground water. Bicarbonates of calcium and magnesium decompose in steam boilers and other hot-water facilities to form scale and release corrosive carbon dioxide gas (see “Hardness”). Concentrations of bicarbonate somewhat greater than 200 mg/L are not uncommon in ground water (Hem, 1985, p. 109).

Aluminum

Dissolved in small quantities from aluminum-bearing rocks rich in feldspars, feldspathoids, micas, amphiboles, and clays. The addition of aluminum sulfate (alum) in water-treatment processes may increase aluminum concentrations. Aluminum forms scale on boiler tubes. Typical concentrations of aluminum in ground water range from 1 to 60 µg/L (Cook and Miles, 1980, p. 5). USEPA SMCL is 200 µg/L.

Cadmium

Generally present in zinc ore minerals such as sphalerite and recovered from some copper ores during smelting and refining. Other sources of cadmium include combustion of fossil fuels and metallugical processes, and corrosion of galvanized pipes. Cadmium is used for electroplating, as a pigment in paints, printing inks, and plastics; it is a stabilizer for PVC plastics. Cadmium is also used in electrical batteries and fluorescent and video tubes. Excessive concentrations are generally the result of contamination by industrial wastes from metal-plating operations. Elevated concentrations of cadmium affects the kidneys and can be toxic. Median concentration of cadmium in U.S. surface waters is about 1 µg/L (Durum and others, 1971). USEPA MCL is 5 µg/L.

Calcium and Magnesium

Dissolved from practically all rocks and soils, especially from limestone, dolomite, and gypsum. Cause of most of the hardness and, in combination with bicarbonate, is the cause of scale formation in steam boilers, water heaters, and pipes (see “Hardness”). Water low in calcium and magnesium is desired in electroplating, tanning, dyeing, and textile manufacturing, Typical concentrations of calcium and magnesium in ground water range from 5 to 500 mg/L and 1 to 50 mg/L, respectively (Cook and Miles, 1980, p. 14 and 30).

Chloride

The most important natural sources of chloride are from sedimentary rocks, especially evaporites; fine-grained marine shales might retain chloride for considerable amounts of time. Relatively large amounts of chloride are derived from sewage, industrial wastes, and highway deicing practices. Water with less than 150 mg/L chloride is satisfactory for most purposes. A chloride content of more than 250 mg/L is generally objectionable for public supply, and water with a chloride content of more than 350 mg/L is objectionable for most irrigation and industrial uses. Water containing 500 mg/L or more of chloride generally has a disagreeable taste. In large quantities chloride increases the corrosiveness of water. Large amounts in combination with sodium give a salty taste. Typical concentrations of chloride in ground water range from 10-2,000 mg/L (Cook and Miles, 1980, p. 17). USEPA SMCL is 250 mg/L.

Chromium

Dissolved from chromium-bearing rocks, generally ultramafics, in minute quantities. Commonly found in paint pigments and electroplating. Excessive concentrations are generally the result of contamination by industrial wastes. Concentrations of chromium in natural waters not affected by waste disposal are commonly less than 10 µg/L (Hem, 1985, p. 139). Potential health effects from ingestion of water with elevated concentrations of chromium include liver, kidney, and circulatory disorders. USEPA MCL (total) is 100 µg/L.

Hardness (as $CaCO_3$)

In most waters nearly all of the hardness is due to calcium and magnesium. All of the metallic cations other than the alkali metals also cause hardness. There are two classes of hardness—carbonate (temporary) and noncarbonate (permanent). Carbonate hardness refers to the hardness resulting from cations in association with carbonate and bicarbonate; it is called temporary because it may be removed by boiling the water. Noncarbonate hardness refers to that resulting from cations in association with other anions. Hardness consumes soap before a lather will form and deposits soap curds on bathtubs. Carbonate hardness is the cause of scale formation in boilers, water heaters, radiators, and pipes, resulting in a decrease in heat transfer and restricted flow of water. Hardness in water used for ordinary domestic purposes does not become particularly objectionable until it reaches a level of about 100 mg/L.

Waters of hardness up to 60 mg/L are considered soft; 61 to 120 mg/L are moderately hard; 121 to 180 mg/L are hard; and more than 180 mg/L are very hard (Durfor and Becker, 1964, p. 27). Very soft water that has a low pH may be corrosive to plumbing. The number of milligrams per liter divided by 17.1 yields the concentration in grains per gallon.

Iron

Dissolved from practically all rocks and soils, iron is present in organic wastes, plant debris in soils, and coal mine drainage water. It may also be derived from iron pipes, pumps, and other equipment. On exposure to air, iron in ground-water oxidizes to a reddish-brown precipitate. More than about 300 µg/L stains laundry, porcelain, and utensils reddish brown. Elevated concentrations of iron are objectionable for food processing, textile processing, beverages, ice manufacturing, brewing, and other processes. Typical concentrations of iron in ground water range from 1 to 30 mg/L (Cook and Miles, 1980, p. 25). USEPA SMCL is 300 µg/L.

Lead

Some of the principle sources of lead in ground water are cars burning leaded gasoline, smelting of ores, and burning coal. Other sources of lead include brass alloy faucets, plumbing, and solder. Water with pH below 7.0 or is poorly buffered may dissolve considerable amounts of lead from lead water pipes and solders. Concentrations of lead in rain and snow vary widely from less than 1.0 µg/L to 200 µg/L (Hem, 1985, p. 144), in surface waters concentrations of lead can exceed 10 µg/L (Durum and others, 1971). Lead is accumulated by the body and affects the kidneys and causes nervous system damage; excessive concentrations may cause sickness or death. USEPA MCLG is zero; the action level is 15 µg/L.

Manganese

Manganese is dissolved from many rocks and soils and is commonly found associated with iron in natural waters, but is not as common as iron; like iron, it is a principle constituent of acid mine drainage. Manganese has the same undesirable characteristics as iron but is more difficult to remove from water. Concentrations greater than 200 µg/L precipitate upon oxidation. Typical concentrations of manganese in ground water range from 1 to 100 µg/L (Cook and Miles, 1980, p. 31); ground waters rarely contain more than 1.0 mg/L manganese (Hem, 1985, p. 89). USEPA SMCL is 50 µg/L.

Mercury

Found in industrial wastes, smelting, organomercuric compounds, natural deposits, batteries, and electrical switches; released during the electrolysis of molten sodium chloride to produce chlorine and sodium hydroxide. Mercury also is released in the incineration of municipal trash. Potential health effects from ingestion of water containing elevated concentrations of mercury include kidney and nervous system disorders. USEPA MCL is 2 µg/L.

Nickel

Dissolved from nickel-bearing rocks, commonly associated with iron and manganese. Nickel is released from the production of metal alloys, electroplating, batteries, and chemicals. Typical concentrations of nickel in ground water range from 1 to 50 µg/L (Cook and Miles, 1980, p. 33). Potential health effects from ingestion of water containing elevated concentrations of nickel include heart and liver damage. USEPA MCL is 100 µg/L.

Nitrate (as N)

Decaying organic matter, animal waste, sewage, septic tanks, and fertilizers are principle sources of nitrate. Small concentrations of nitrate have no effect on the usefulness of water. Most ground water contains less than 2 mg/L nitrate. Waters containing more than 10 mg/L nitrate may cause methoglobinemia (“blue-baby syndrome,” a disease often fatal in infants) and, therefore, should not be used in infant feeding. USEPA MCL is 10 mg/L.

pH

The negative logarithm of the hydrogen-ion concentration. A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote alkaline (basic) solutions; values lower than 7.0 indicate acidic solutions. Corrosiveness of water generally increases with decreasing pH. USEPA SMCL range is less than 6.5 to greater than 8.5.

Phosphate

Dissolved in very small quantities from most rocks, especially igneous and sedimentary rocks, and soils. The chief sources of phosphate in ground water are fertilizers and detergents, domestic and industrial sewage, and animal wastes; other more localized sources occur in areas where marine phosphorites are mined and processed. Typical concentrations in ground water range from 3 to 170 µg/L (Cook and Miles, 1980, p. 34).

Radium-226

This radium isotope can occur naturally in ground water or by the disposal of radioactive wastes. Radium-226 is most mobile in chloride-rich reducing ground water with high dissolved-solids content (Tanner, 1964, p. 261). Radium's parent (uranium-234) is easily dissolved and transported in ground water, but is more soluble in association with carbonate, phosphate, and fluoride ions, or with organic compounds (Langmuir, 1978, p. 556; Turner-Peterson, 1980, p. 163; Zapecza and Szabo, 1988, p. 50). The concentrations of radium-226 is inversely related to pH and directly to total dissolved solids, dissolved organic carbon, barium, and sulfate concentrations. The sources of radium may be uranium- and thorium-bearing heavy minerals, such as zircon and monazite. The concentration of radium-226 in most natural waters is generally below 1.0 pCi/L (Hem, 1985, p. 149). Radium-226 is a bone marrow seeker, forms bone sarcomas and head carcinomas. Proposed USEPA MCLG is zero; the proposed MCL is 20 pCi/L.

Radium-228

Another radium isotope, radium-228 occurs naturally in ground water or by the disposal of radioactive wastes. Radium-228 is in solution in granitic rocks which have not been metamorphosed, arkosic sand and sandstone, and quartzose sandstone which have high total dissolved solids. The concentration of radium in most natural waters is generally below 1.0 pCi/L (Hem, 1985, p. 149). Radium-228 is a bone marrow seeker, forms bone sarcomas. Proposed USEPA MCLG is zero, the proposed MCL is 20 pCi/L. The interim standard for combined radium-226/228 MCLG is zero, and the MCL is 5 pCi/L.

Radon-222

Radon-222 is produced from the radioactive decay of radium-226. Because of its short half-life (3.8 days) and no chemical affinities, radon-222 is not transported any considerable distance in ground water and its concentration in a well sample is directly controlled by the surrounding lithology (Michel, 1990, p. 90); but can also be transported in the gas phase. Radon-222 activities are greatest in acidic ground water, such as typically found in conglomerates and quartzites, and least in more neutral waters. Higher concentrations of radon commonly occur in wells with low yields (Hess and others, 1985, table 7). Radon-222 can cause lung cancer. The concentration of radium in most natural waters is generally below 1.0 pCi/L (Hem, 1985, p. 149). Proposed USEPA MCLG is zero; the proposed MCL is 300 pCi/L.

Selenium

Dissolved selenium is generally associated with rocks containing iron or uranium, or with selenium bearing minerals such as selenite and selenate. It is a product of mining, smelting, burning of coal and oil. The average concentration of selenium in surface waters is 0.2 µg/L (Goldberg and others, 1971). Potential health effects from ingestion of water containing elevated concentrations of selenium include liver damage. USEPA MCL is 50 µg/L.

Silica

Silica is dissolved from practically all rocks and soils, it is a major constituent in igneous rocks and as quartz grains in sandstones. Silica forms hard scale in pipes and boilers. Silicate scale cannot be dissolved by acids or other chemicals that are used for chemical treatment of wells. When carried over in steam of high-pressure boilers, it forms deposits on blades of turbines unless treated beforehand by absorption or ion-exchange techniques. Davis (1964) reported a median value of silica for ground water of 17 mg/L.

Sodium and Potassium

Sodium and potassium are dissolved from practically all rocks and soils. Sodium is slightly more abundant in igneous rocks, but much less abundant in sedimentary rocks than potassium. Sodium can be withdrawn from clays and shale layers after long term ground-water withdrawals and water level declines alter water-circulation patterns. Major sources of sodium in ground water include salt used for deicing highways and brines pumped or flowing from oil wells; sewage and industrial wastes also are major sources of sodium and potassium. Concentrations of less than 50 mg/L have little effect on the usefulness of water for most purposes. More than 50 mg/L may cause foaming in steam boilers and limit the use of water for irrigation. In large concentrations, sodium may adversely affect persons with cardiac difficulties, hypertension, and certain other medical conditions. In most aquifers, if sodium concentrations substantially exceeds 10 mg/L, the potassium concentration commonly is one-half or one-tenth that of sodium. Concentrations of potassium greater than a few tens of milligrams per liter are unusual except in water having high-dissolved solids concentrations or in water from hot springs (Hem, 1985, p. 105).

Specific Conductance

Specific conductance is a measure of the capacity of water to conduct an electrical current. It varies with concentration and degree of ionization of the constituents. Specific conductance may be used to obtain a rapid estimate of the total dissolved-solids content of water by multiplying the specific conductance by a factor of 0.55 to 0.75. The multiplication factor for saline waters is usually higher than 0.75, and for acidic water it is generally much lower. Water that has relatively high specific conductance can corrode iron and steel.

Sulfate

Major sources of sulfate are from rocks and soils that contain gypsum, anhydrite, iron sulfides (such as pyrite), and other sulfur compounds. Sulfate is commonly present in some industrial wastes and sewage, and is produced in the combustion of fuels and smelting of ore. Sulfates in water containing calcium may form hard calcium sulfate scale in steam boilers. Typical concentrations of sulfate in ground water range from 0.05 to 10 mg/L (Cook and Miles, 1980, p. 51). USEPA SMCL is 250 mg/L.

Total Dissolved Solids

This is a measure of all of the chemical constituents dissolved in a particular water. Fresh water has total dissolved solids (TDS) of 0 to 1,000 mg/L, slightly saline water is defined as TDS from 1,000 to 3,000 mg/L, moderately saline water is defined as TDS from 3,000 to 10,000 mg/L, very saline water has TDS from 10,000 to 35,000 mg/L, and briny water has TDS more than 35,000 mg/L (Robinove and others, 1958). USEPA SMCL is 500 mg/L.

Zinc

Dissolved from zinc-bearing rocks, brass, bronze, or galvanized pipe. Zinc is used as a white pigment in paint and rubber, and is present in many industrial wastes and acid mine drainage. Concentrations greater than 5 mg/L can be detected by taste; greater than 30 mg/L have been known to cause nausea and fainting. In surface waters, the average concentration of zinc has been estimated to be 10 µg/L (Bowen, 1966, p. 164). USEPA SMCL is 5 mg/L.

GLOSSARY

Anticline—A fold, generally convex upward, whose core contains the stratigraphically older rocks.

Anticlinorium—A composite anticlinal structure of regional extent composed of lesser folds.

Argillaceous—Clay-size particles or clay minerals that form an appreciable amount of the sediment or sedimentary rock.

Artesian aquifer—Synonymous with confined aquifer.

Aquifer—A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield economical quantities of water to wells and springs.

Aquifer test—A test involving the withdrawal of measured quantities of water from, or addition of water to, a well and the measurement of resulting changes in head in the aquifer both during and after the period of discharge or addition. Usually, one or more observation wells are utilized to measure various parameters before, during, and after the test.

Base flow—Fair-weather flow of a stream sustained by the discharge of ground water.

Borehole storage—Water that is contained within the casing of the well or the borehole of the well. In wells with low specific capacities, water enters the well at a very low rate and drawdown is rapid. A 6-in. diameter well pumped 1 hour, with a specific capacity of 0.05 (gal / min) / ft, would obtain half the calculated specific capacity value from water contained in the casing or borehole. If the well was 8 in. in diameter, almost 90 percent of the calculated specific capacity value would be from water stored in the casing or borehole.

Capillary fringe—The lower subdivision of the unsaturated zone immediately above the water table in which the interstices are filled with water under pressure less than that of the atmosphere, being continuous with the water below the water table but held above it by capillary forces.

Carbonate rock—A rock consisting chiefly of carbonate minerals, such as limestone and dolomite.

Casing—Usually a metal or plastic pipe, which is lowered into a borehole during or after drilling to prevent the sides of the borehole from caving in. Casing also prevents the loss of drilling fluids from the borehole and prevents unwanted fluids from entering the borehole. Casing depths are related to the susceptibility of the rock to weathering, thickness of the overlying regolith, state and local law, and drilling practices. Casing diameter is usually 6 in. or less for domestic wells and 8 in. or greater for high-demand wells.

Channery soil—A soil that is, by volume, more than 15 percent thin, flat fragments of sandstone, shale, slate, limestone, or schist as much as 6 in. along the longest axis. A single piece is called a fragment.

Cleavage—Secondary aligned fractures produced by deformation or metamorphism.

Colluvium—Any loose, heterogeneous mass of soil material or rock fragments deposited chiefly by weathering and gravity movement.

Cone of depression—A depression in the potentiometric surface of a body of ground water in the shape of an inverted cone that develops around a well from which water is being withdrawn.

Confined aquifer—An aquifer bounded above and below by impermeable beds, or by beds of distinctly lower permeability than that of the aquifer itself; an aquifer containing confined ground water.

Confined ground water—Ground water under pressure significantly greater than that of the atmosphere. Its upper surface is the bottom of an impermeable bed or a bed of distinctly lower permeability than the material in which the water occurs.

Conformable—A succession of strata characterized by an unbroken sequence of deposition.

Dip—The angle that a structural surface, such as a bedding or fault plane, makes with the horizontal, measured perpendicular to the strike of the structure and in the vertical plane.

Discharge—The rate of flow at a given moment, usually expressed in gal / min.

Dissolved solids—The quantity of residue material in a sample of water after evaporation, dried at 180°C.

Domestic well—A low-demand well (generally yielding less than 5 to 20 gal / min) that is not completed or finished for maximum potential yield. These wells are commonly drilled to meet single family requirements (about 5 gal / min), are not professionally sited, and contain casing that is 6 in. or less in diameter.

Drawdown—The lowering of the water level in a well as a result of withdrawal.

Driller reported yields—Estimated yields from wells which utilized blown air or bailer to discharge water from a well, usually measured in gal / min.

Evapotranspiration—Loss of water from a land area through transpiration of plants and evaporation from the soil and surface-water bodies.

Fault—A fracture or a zone of fractures along which there has been displacement of the two sides relative to each other. Displacement may range from a few inches to many miles.

Ferruginous—Pertaining to or containing iron; said of a rock having a red or rusty color due to the presence of ferric oxide.

Fecal coliform bacteria—A group of bacteria that live in the intestinal tracts of all warm-blooded animals and are measured as indicators of the pollution of water.

Fecal streptococci bacteria—A group of bacteria that live in the intestinal tracts of all warm-blooded animals, but are less numerous in the human intestine, and are measured as source indicators of the pollution of water.

Flat—May be part of a larger feature, such as an upland flat, mesa or plateau, coastal plain, lake plain, or pediment. Terraces and valley flats, which are special varieties of flat surfaces, are classified under valleys.

Formation—A body of rock identified by lithic characteristics and stratigraphic position; it must be mappable at the Earth's surface or traceable in the subsurface.

Fracture—A break in the rock.

Geohydrologic unit—An aquifer, a confining unit, or a combination of both. Generally equivalent to a geologic unit such as member or formation. However, a geohydrologic unit can consist of more than one geologic unit especially in areas of complex structure and (or) geology where it is difficult to identify individual aquifers.

Geothermal gradient—The rate of increase of temperature in the water of a well with increasing depth, generally 1°F per 100 ft of depth. This gradient can be affected by ground-water flow within the well.

Gneiss—A foliated rock formed by regional metamorphism, in which compositional banding occurs between granular minerals and minerals with flaky or elongate prismatic habits predominate; commonly rich in feldspar and quartz.

Ground-water divide—A ridge in the water table or other potentiometric surface from which the ground water represented by that surface moves away in both directions.

GWSI (Ground-Water Site-Inventory file)—GWSI is a national repository for data from sites where ground water has been, is, or can be withdrawn. The Water Resources Division of the U.S. Geological Survey maintains this data base for storing data collected by Federal, State, and local organizations active in the field of water resources. In Pennsylvania, the data contained within the GWSI database are field verified and currently contains site records of more than 49,000 springs, wells, and test holes. Each site record can have more than 300 components that describe the well and aquifer, physical and chemical properties, political descriptors, and data-collection methods. Physical properties include use of water, hydrologic and topographic settings, construction and discharge data, site location, geohydrologic unit, driller and geophysical logs, and water level. Chemical properties are chiefly field parameters which include pH, hardness, and specific conductance. Political descriptors include name of owner, township or borough, and county name. Data commonly include the date of visit, sampled constituents, measuring points, when and how the water level was measured, who pumped the well, when, how, and for how long the well was pumped, and at what discharge rate.

Hardness—A chemical property of water causing formation of an insoluble residue when the water is used with soap, and forming a scale in vessels in which water has been allowed to evaporate. It is caused primarily by the presence of ions of calcium and magnesium, but also to ions of other alkali metals, other metals, and even hydrogen. Water hardness is generally reported as soft (0 to 60 mg / L of $CaCO_3$), moderately hard (61 to 120 mg / L of $CaCO_3$), hard (121 to 180 mg / L of $CaCO_3$), or very hard (> 180 mg / L of $CaCO_3$).

Head—The height above a standard datum of the surface of a column of water that can be supported by the static pressure at a given point. The static head is the sum of the elevation head and the pressure head.

High-demand well—A well (generally yielding 21 to more than 1,000 gal / min) which is completed or finished for maximum potential yield. This would generally include municipal, industrial, bottling, air conditioning, and institutional wells. Such wells characteristically have casing diameters greater than 6 in., and may be professionally sited.

Hilltop—The upper part of a hill or ridge above a well-defined break in slope.

Homocline—A series of rock strata having the same dip.

Hydraulic conductivity—The volume of water that will move through a medium in a unit of time under a unit hydraulic gradient through a unit are measured perpendicular to the direction of flow. $K = Qdl / Adh$, where K is hydraulic conductivity, Q is the quantity of water per unit of time, dl is distance, A is cross-sectional area at right angle to the flow direction, dh is change in head.

Hydraulic gradient—The change in static head per unit of distance in a given direction. If not specified, the direction generally is understood to be that of the maximum rate of decrease in head. $D = (dh / dl)$, where D is hydraulic gradient, dh is change in static head and dl is change in unit distance.

Hydrostatic pressure—The pressure exerted by the weight of water at any given point in a body of water at rest.

Igneous rock—A rock that solidified from molten or partially molten material.

Impermeable—A characteristic of some geologic material that limits its ability to transmit significant quantities of water under the head differences ordinarily found in the subsurface.

Induced infiltration—Recharge to ground water by infiltration, either natural or manmade, from a body of surface water as a result of the lowering of the ground-water head below the surface-water level.

Interstice—An opening in a rock or soil that is not occupied by solid matter.

Joint—A surface or fracture or parting in a rock, without displacement; often occurring parallel to other joints as a set.

Karst—A type of topography that is formed generally on carbonate rocks by dissolution, and that is characterized by sinkholes, caves, and underground drainage.

Lithology—The description of rocks on the basis of color, mineralogic composition, and grain size. Lithology is the single most important geologic factor determining the potential yield of an aquifer. It strongly influences the development of primary and secondary porosity and permeability, the type, density, and number of water-bearing zones, topography, and structural setting.

Loam—Soil material that is 7 to 27 percent clay particles, 28 to 50 percent silt particles, and less than 52 percent sand particles.

Maximum Contaminant Level (MCL)—The maximum permissible level of a contaminant in water which is delivered to the user of a public water system, except in the case of turbidity where the maximum permissible level is measured at the point of entry to the distribution system.

Median—The central or middle point of the data. The equation to calculate the median is:

$$\text{median} = (n + 1)/2$$

where n is equal to the number of samples.

Metamorphic rock—Any rock derived from pre-existing rocks by mineralogical, chemical, or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical environment.

Nonconformable—see Nonconformity.

Nonconformity—Older, eroded plutonic or massive metamorphic rocks are overlain by younger sediments.

Open hole—That portion of the well extending below the depth at which casing has been set.

Permeability—The property or capacity of a material to transmit a fluid, commonly expressed as ft / d.

pH—The negative log10 of the hydrogen-ion activity in solution. A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote alkaline (basic) solutions; values lower than 7.0 indicate acidic solutions.

Physiographic Province—A region of which all parts are similar in geologic structure and climate.

Physiographic Section—Part of a physiographic province of which geologic and geomorphic history, structure, lithology or rock type, and topographic expression, are similar.

Pressure head—Hydrostatic pressure expressed as the height of a column of water that the pressure can support at the point of measurement.

Porosity—The percentage of the bulk volume of a rock or a soil that is occupied by interstices, whether isolated or connected.

Potentiometric surface—An imaginary surface representing the static head of ground water and defined by the level to which water will rise in a well.

Primary porosity—The porosity that developed during the final stages of sedimentation or that was present within sedimentary particles at the time of deposition.

Pumping test—A test that is conducted to determine well characteristics, usually utilizing blown air or a bailer to remove water from the well at an estimated rate of discharge (gal / min) with the amount of drawdown reported at one or more specified time periods.

Quartiles—The quartiles are defined so that one quarter (25 percentile) of the data lies below the lower quartile and one quarter (75 percentile) of the data lies above the upper quartile.

GLOSSARY—Continued

QW—Water Quality. A data base of Pennsylvania ground-water quality analyses collected by U.S. Geological Survey personnel, which also contains water-quality analyses submitted by other Federal, State, and local government agencies. Currently (1992), the QW database contains laboratory analyses of water from more than 17,000 wells, test holes, and springs throughout Pennsylvania. These analyses commonly include concentration of major and minor cations and anions, metals, nitrogen species, organic, and radiochemicals.

Recharge—The process by which water is added to the zone of saturation.

Reported yield—An estimated discharge measurement, usually by the driller bailing or blowing the well. Factors that effect reported yield and equivalency to other reported yields include (1) how fast a well can be bailed, (2) limits on the rate a compressor can blow air against head in a well, and (3) how much of the water is forced back into the well or formation.

Runoff—The part of precipitation that appears in streams. It is the same as streamflow unaffected by diversions, dams, or other works of man.

Saturated zone—The zone in which the interstices of a material are filled with water.

Schist—A strongly foliated crystalline rock, formed by metamorphism, with a well developed parallelism of more than 50 percent of the minerals present.

Secondary Maximum Contaminant Level (SMCL)—Federal guidelines regarding certain aesthetic (taste, color, odor) and other non-aesthetic effects of drinking water.

Secondary opening—Voids produced in rocks by solution, weathering, jointing, or breaks in the rock subsequent to the original formation of the rock.

Secondary porosity—The porosity developed in a rock after its deposition or emplacement, through such processes as solution or fracturing.

Single-well aquifer test—Synonymous with aquifer test, however, no observation wells are utilized. Instead all measured parameters are taken at the pumping well.

Slope—The sloping side of a hill; that is, the area between a hilltop and valley.

Specific capacity—The rate of discharge of a water well, in gallons per minute, divided by the drawdown of water level in the well, in feet; usually determined from pumping or aquifer tests.

Specific conductance—A measure of the capacity of water to conduct an electrical current. It varies with concentration and degree of ionization of the constituents.

Specific yield—The ratio of the volume of water which the porous medium after being saturated, will yield by gravity to the volume of the porous medium.

Static head—The height above a standard datum of the surface of a column of water that can be supported by the static pressure at a given point. The static head is the sum of the elevation head and the pressure head.

Static water level—That water level of a well that is not being affected by withdrawal of ground water.

Storativity—see storage coefficient.

Storage coefficient—The volume of water that an aquifer releases or takes into storage per unit surface area of the aquifer per unit change in head. The storage coefficient is a dimensionless number. In an unconfined aquifer, the storage coefficient is virtually equal to the specific yield.

Strike—The direction or trend taken by a structural surface such as a bedding or fault plane, as it intersects the horizontal; perpendicular to the direction of dip.

Surface water—Water on the surface of the earth.

Topography—The general expression of surface features, including its relief.

Syncline—A fold, concave upward, that contains the stratigraphically younger rocks in the core.

Transmissivity—The rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is equal to an integration of the hydraulic conductivities across the saturated part of the aquifer perpendicular to the flow paths. T = Kb, where T is transmissivity, K is hydraulic conductivity, b is aquifer thickness. Q = TW(dh / dl), where Q is quantity of water moving through a large width (W) of an aquifer under a unit hydraulic gradient (dh / dl) and T is transmissivity. If an aquifer has a transmissivity of less than 134 ft^2 / d, it can supply only enough water for domestic wells or other low-yield uses. If the transmissivity is 1,340 ft^2 / d or greater, well yields can be adequate for most high-demand uses (Driscoll, 1986, p. 210-211).

Transpiration—The process by which water absorbed by plants, is evaporated into the atmosphere from the plant surface (principally from its leaves).

Unconfined aquifer—An aquifer which has a water table.

Unconformity—A substantial break or gap in the geologic record where a rock unit is overlain by another that is not next in stratigraphic succession.

Unsaturated zone—The zone between the land surface and the deepest water table which includes the capillary fringe. Water in this zone is generally under less than atmospheric pressure, and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched water bodies the water pressure locally may be greater than atmospheric.

Upland draw—A small natural drainage way or depression, usually dry, on a hillside or upland.

USEPA—United States Environmental Protection Agency.

Vadose zone—See unsaturated zone.

Valley—A low flat area between valley walls; it includes flood plains, terraces, stream, and river channels.

Water-table aquifer—See unconfined aquifer.

Water-bearing zone—In bedrock, a secondary opening that is saturated with water. Typically, such zones are interconnected to more than one saturated fracture, void, joint, fault, cleavage plane, or other such secondary openings. The yield of a well depends largely on the size and number of water-bearing zones that it encounters.

Water use—The principal consumptive use of water discharged from a well. A well whose principal use of water is for air conditioning, bottling, industrial, institutional, or public supply would be classified as a high-demand well. A well whose principal use of water is to meet single family requirements (up to four families), turnpike gates, or other similar installations would be classified as a domestic well.

Well—A drilled, dug, driven, bored, or jetted hole, whose depth is greater than the width.

Well point—Generally a hollow vertical pipe that ends in a perforated pointed shoe and fitted with a fine-mesh wire screen.

WWI (Water Well Inventory system)—A state-run data base similar to the GWSI data base of the U.S. Geological Survey. The WWI data base consists of water-well driller completion reports that are on file at the Pennsylvania Topographic and Geologic Survey in Harrisburg, Pa. These completion reports commonly contain information about the well site, owner, yield, depth to water-bearing zones, and construction characteristics. The WWI data base contains unverified locations and information on more than 160,000 wells and test holes completed in the Commonwealth of Pennsylvania. The data for many of the wells and test holes in the GWSI data base originated from the WWI data base.