Hollyday, E.F., and others, 1996, Hydrogeologic terranes and potential yield of water to wells in the Valley and Ridge Physiographic Province in Maryland, New Jersey, and Pennsylvania

## ABSTRACT

The hydrogeologic framework of the Valley and Ridge Physiographic Province in Maryland, New Jersey, and Pennsylvania was analyzed by the U.S. Geological Survey as part of the Appalachian Valleys–Piedmont Regional Aquifer-System Analysis project. Local differences in lithology, structure, and weathering result in large variation in the water-yielding properties of the rock that underlies the area. Selected rock types, however, can account for a substantial part of this variation because of the unique way in which these rock types deform and weather to produce secondary openings. On the basis of the relations among rock type and water-yielding openings and properties, the regolith and consolidated rock were classified and mapped as five hydrogeologic terranes—alluvium, dolomite, limestone, argillaceous carbonate rock, and siliciclastic rock.

Specific-capacity data for homogeneous data sets, which consist of all wells that have the same characteristics in regard to casing diameter, primary use of the water, and topographic setting, revealed significant differences in water-yielding properties among the five hydrogeologic terranes. According to results of Tukey tests at a probability (alpha level) of 0.10, eight out of ten pairs of hydrogeologic terranes had significantly different median specific-capacity values. Estimates of potential yields to public- and industrial-supply wells were calculated from specific-capacity data for most-productive wells—wells with casing diameter of 7 inches or more, used primarily for public or industrial supply, and in a valley—using median drawdowns for each hydrogeologic terrane. Estimated interquartile ranges in potential yields to most-productive wells in the hydrogeologic terranes, in gallons per minute, were 170 to 600 in alluvium; 280 to 1,700 in dolomite; 80 to 520 in limestone; 60 to 550 in argillaceous carbonate rock; and 60 to 240 in siliciclastic rock.

## INTRODUCTION

The U.S. Geological Survey (USGS) started the Regional Aquifer-System Analysis (RASA) Program in 1978 in response to Congressional concern about the adequacy of water supplies during drought. The purposes of the RASA Program were to define the regional hydrology and geology of the Nation's important aquifer systems and to establish a framework of background information on geology, hydrology, and water chemistry for each aquifer system. This critical information is needed to develop an understanding of regional ground-water flow systems and to support more efficient ground-water resources management (Sun, 1986, p. 1–8).

As part of the RASA Program, the USGS began a 5-year study in 1988 of the ground-water resources in parts of 11 States in the Eastern and Southeastern United States. The study was called the Appalachian Valleys–Piedmont Regional Aquifer-System Analysis (APRASA). The APRASA team investigated ground-water resources primarily in the unglaciated part of the Valley and Ridge, the Blue Ridge, the New England, and the Piedmont Physiographic Provinces (fig. 1). The Valley and Ridge subproject team of the APRASA study focused on a regional analysis of the hydrogeology of the carbonate and the siliciclastic rock in the Valley and Ridge Physiographic Province.

## PROBLEM

A major problem in the effective development and management of the ground-water resources of the Valley and Ridge Physiographic Province is insufficient information on the regional hydrogeologic framework. Definition of the framework is made difficult by the complexity of the geology, which causes large variation in the water-yielding properties of the rock. The range in yields of water to wells completed in any particular geologic unit (formation, group, member) or combination of units can span several orders of magnitude and overlap the ranges of many other units. Any analysis of this variation requires a large amount of well data to describe differences in the hydraulic characteristics within each unit and to test for significant differences in hydraulic characteristics among units.

## PURPOSE AND SCOPE

The purposes of this report are to provide background information on the hydrogeologic setting of the Valley and Ridge Physiographic Province in Maryland, New Jersey, and Pennsylvania; to describe and map hydrogeologic terranes within this setting; to test these hydrogeologic terranes for significant differences in water-yielding properties; and to estimate the quantity of water potentially available to wells in these hydrogeologic terranes. Hydrogeologic terranes are defined in this report as regionally mappable areas characterized by similar rock type and water-yielding properties. The hydrogeologic terranes represent areas of distinct hydrologic character.

## PREVIOUS INVESTIGATIONS

Previous investigations provided maps and descriptions of the geologic units, described the local quantity and quality of ground water within these units, and established the statistical methods for comparing the water-yielding properties of these units. State geologic maps show the distribution of geologic units at a scale of 1:250,000 for Maryland (Cleaves and others, 1968), New Jersey (Lewis and Kummel, 1912), and Pennsylvania (Berg and others, 1980). Descriptions of the geology of some individual topographic quadrangles, some counties, parts of counties, or several counties have been published. Twenty-one reports that describe the ground-water resources of a county or multicounty area are listed in the "Selected References" section of this report.

The statistical methods used in this report are largely based on those used by Knopman (1990, p. 7–9) in her analysis of well records in the USGS Ground-Water Site Inventory (GWSI) data base to rank factors that influence the water-yielding potential of the rock in the Piedmont and the Valley and Ridge Physiographic Provinces in Pennsylvania. In her analysis, she used values of the dependent variable that were transformed by their natural logarithm in order to work with a more symmetric distribution than for untransformed data. Nonparametric statistical methods were used because of the persistence of outliers and the occasional violation of the normality assumption when working with small subsets of the data. Statistical analysis included monotonic correlation, one-way and factorial analysis of variance, and multiple linear regression. Readers are referred to Knopman (1990) for the details regarding her statistical methods.

## HYDROGEOLOGIC SETTING

The ground-water hydrology of the Valley and Ridge Physiographic Province is strongly influenced by the geology. The complexity of the geology results in a large variation in the water-yielding properties of the carbonate and siliciclastic rock that underlies the study area. Even within a single geologic unit, the effects of local differences in lithology, structure, and weathering can result in a range in yields of water to wells that spans several orders of magnitude (Swain and others, 1991, p. 30).

### GENERAL FEATURES

The Valley and Ridge Physiographic Province is characterized by deformed sedimentary rock of Paleozoic age that overlies metamorphic and igneous rock of Precambrian age. The Paleozoic rock is, in order of abundance, shale, sandstone, dolomite, and limestone (Colton, 1970, p. 10). Folding and faulting of this rock, which was initially deposited in an almost horizontal position, have resulted in large structural features (anticlines, synclines, thrust faults). Regolith (soil, sediment, weathered rock) covers the consolidated rock throughout most of the study area.

Ground water in the consolidated rock of the study area resides in and flows through secondary openings (joints, fractures, bedding-plane partings, dissolution openings). The secondary openings were formed by mechanical breakage and enlarged by chemical weathering of the consolidated rock. These openings, which were produced after the rock was lithified, contrast with the primary openings that existed between grains in the original sediment.

Ground-water flow systems in consolidated rock tend to be restricted in depth and areal extent because of the restricted vertical extent of major weathering and the change in geologic structure over short distances. Weathering decreases with depth, thereby restricting the depth of development of the more permeable zones. Faults commonly restrict the areal extent of flow systems by cutting across geologic units and juxtaposing permeable rock with impermeable rock. Folds restrict the areal extent of flow systems by distorting the horizontal layering and exposure at the land surface of permeable and impermeable rock units. For these reasons, flow systems in the more permeable rock typically occupy a space of a few hundreds of feet in depth by a few tens of square miles in area. This is in contrast to most areas of unconsolidated deposits studied in the RASA Program, which have a space of many hundreds of feet in depth by several thousands of square miles.

The quality and quantity of ground water are influenced by the depth of the water and the lithology of the rock through which it flows. Freshwater in usable quantities is almost everywhere in this rock to depths of several hundred feet but tends to be deeper in carbonate rock than in argillaceous (clay-rich) siliciclastic rock. Freshwater, which is in supplies too small for economic use, and brine are in this same rock to depths of a few thousand feet. Compared with siliciclastic rock, carbonate rock tends to have more variable water-yielding properties, larger maximum potential yields of water to wells, and water with less dissolved iron but greater hardness.

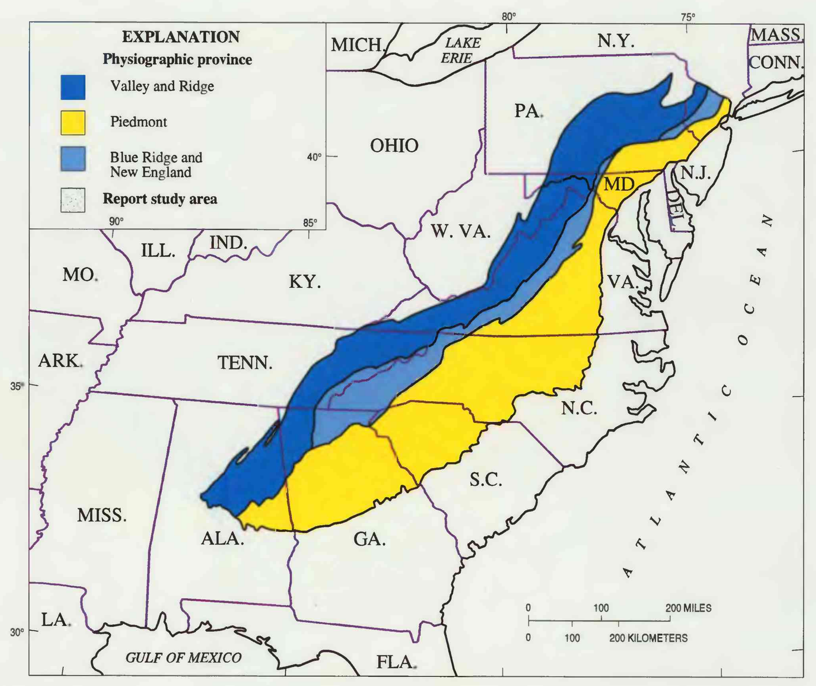

**Figure 1.** Map showing the Appalachian Valleys–Piedmont Regional Aquifer–System Analysis study area, physiographic provinces, and report study area.

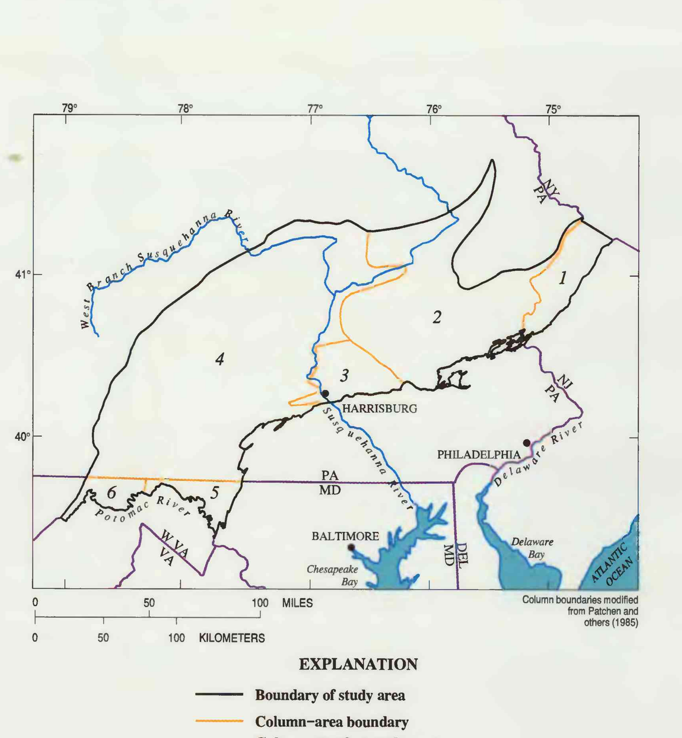

**Figure 3.** Map showing the location of areas described in stratigraphic columns in figure 2.

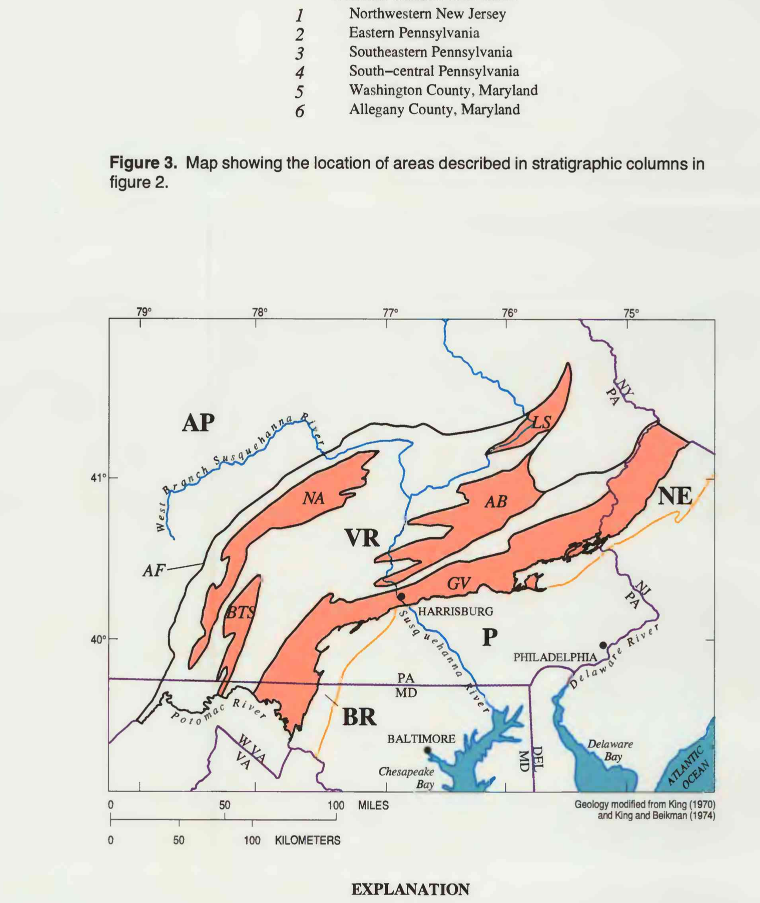

**Figure 4.** Map showing the location of major structural features in the Valley and Ridge Physiographic Province in Maryland, New Jersey, and Pennsylvania.

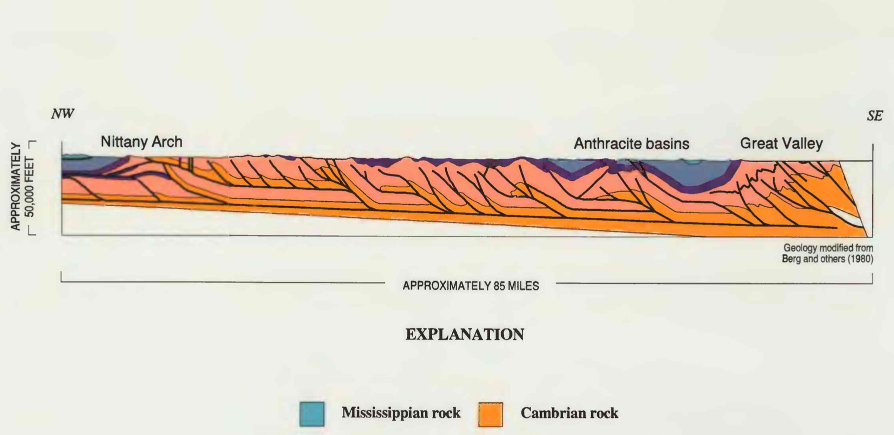

**Figure 5.** Diagrammatic geologic section of the Paleozoic rock in south–central Pennsylvania.

## LITHOLOGY

Differences in the lithology of selected rock types can account for a substantial part of the variation in the water-yielding properties of the rock. Different types of consolidated rock deform and develop secondary permeability in substantially different ways. Dolomite or limestone that is mostly free of clay or shale interbeds tends to deform plasticly or develop few fractures at depth within the Earth's crust. During weathering, the dissolution of soluble minerals along joints, fractures, and bedding-plane partings causes widening of these openings and results in a honeycomb rock that has variable, but commonly high, permeability. The pure or nearly pure carbonate rock typically is covered by only a few feet of residuum. Argillaceous carbonate rock also tends to deform plasticly and develop few fractures. During weathering, clays are likely to swell or otherwise fill the few fractures and dissolution openings, which results in a rock that has low permeability. This rock usually is covered by a few tens of feet of residuum. Argillaceous siliciclastic rock generally deforms and weathers in a manner similar to argillaceous carbonate rock but lacks any substantial development of dissolution openings and has low permeability. Sandstone that is mostly free of clay or shale interbeds develops fractures at depth, but during weathering, these fractures are not widened by dissolution. Permeability is higher than that of argillaceous siliciclastic rock but lower than that of clay-free carbonate rock. Nonargillaceous sandstone typically is covered by a few feet of sandy and stony residuum. Thus, because these selected rock types deform and weather differently, each type tends to have unique water-yielding properties.

Differences in the thickness and texture of regolith (unconsolidated materials) can account for a substantial part of the variation in the water-yielding properties of geologic materials in an area. Thick coarse-grained regolith has a high permeability and, where saturated, can form a productive aquifer above the consolidated rock. Thick fine-grained regolith has a low permeability; however where it is saturated, it can provide abundant recharge to the underlying aquifers in consolidated rock. The water-yielding properties of geologic materials in areas with thin regolith, which stores little water, are predominantly influenced by the properties of the underlying consolidated rock.

### Consolidated Rock

The consolidated rock units in the study area represent a wide variety of rock types—dolomite; magnesian limestone; limestone; argillaceous carbonate rock; shale, mudstone, and siltstone; sandstone; conglomerate; interbedded sandstone, siltstone, and shale; chert; and metamorphic rock (Patchen and others, 1985). The authors assumed, however, that most of these rock types could be grouped logically to establish a classification wherein each class is hydrologically unique. They propose that the rock types of hydrologic significance in the study area are dolomite, limestone, argillaceous carbonate rock, and siliciclastic rock (fig. 2). For the hydrologic purpose of this report, the dolomite includes units that are predominantly dolomite (such as the Ontelaunee Formation), a combination of dolomite and sandstone or chert (Gatesburg Formation), or dolomite and limestone with as much as 70 percent limestone (Epler Formation). The limestone includes units that are limestone (Annville Limestone) or limestone with less than 30 percent dolomite (Stonehenge Limestone). The argillaceous carbonate rock includes units that are predominantly clay-rich limestone (Chambersburg Limestone) or dolomite, as well as shale units that contain abundant calcite or magnesium calcite (Wills Creek Formation). The siliciclastic rock includes units that are predominantly shale with little or no carbonate content (such as the Marcellus Formation), claystone (Irish Valley Member of the Catskill Formation), siltstone (Mauch Chunk Shale), sandstone (Keefer Sandstone), or conglomerate (Shawangunk Formation), that consist of clay minerals, quartz grains, or siliceous rock fragments. The siliciclastic rock in the study area also includes several units that are predominantly slate (Ramseyburg Member of the Martinsburg Shale).

Lithology of the consolidated rock changes with geologic age and location in the study area (fig. 2). Substantial amounts of dolomite are only in the carbonate rock that is mostly of Middle Cambrian through Middle Ordovician age. The argillaceous carbonate rock typically is in a stratigraphic position between siliciclastic rock and either dolomite or limestone. A thick sequence of siliciclastic rock that is mostly of Middle Devonian through Pennsylvanian age occupies the top of the section. Changes in lithology across the study area are illustrated among and within the six stratigraphic columns (fig. 2). The columns depict lithology and geologic unit names representative of six parts of the study area (fig. 3). For the most part, the geologic names correspond to the usage of the Maryland, the New Jersey, and the Pennsylvania Geological Surveys. The columns contain the map symbols that are used in the State geologic map for that area and that can be used to identify the rock type and hydrologic significance of the map units.

### Regolith

The regolith in the study area varies greatly in thickness and texture. It was either formed in place by the weathering of the underlying bedrock (residuum) or deposited after being transported from the place of weathering (till, colluvium, alluvium). Only a small part of the regolith is shown on a map in this report because of the thinness and variable texture of most of these materials.

Much of the consolidated rock in the study area is covered by residuum or glacial till. A fine-grained residuum commonly covers the valleys and upland flats in the southern and western two-thirds of the study area (Sevon, 1989). Residuum is thin (commonly less than 3 ft) on shale, sandstone, and most carbonate rock. Residuum can be thick (more than 50 ft) on carbonate rock that contains substantial amounts of resistant chert or sandstone because these resistant materials protect the surface of the residuum from erosion (Hack, 1965, p. 56, fig. 35). Glacial till with a sandy to clayey matrix covers much of the northern and eastern one-third of the study area and is commonly less than 3 ft thick.

Alluvium underlies most river flood plains and is in terraces at the sides of the valleys. In major valleys in the northern and eastern one-third of the area, alluvium commonly exceeds 30 ft in thickness and is coarse grained, well sorted, and derived directly or indirectly from glacial deposits. Alluvium in this part of the study area produces some of the largest yields of water to wells of any of the geologic units in the entire study area (sheet 2, fig. 7).

Thin stony colluvium covers the slopes of mountains and many hills in the study area. The colluvium overlies residuum or bedrock on slopes that are crested by resistant siliciclastic rock; it generally is thickest beneath the lower part of the slopes. Adjacent to the Blue Ridge Physiographic Province along the south-central edge of the study area, sandy colluvium and alluvium interfinger to form a regolith apron that covers thick residuum and carbonate bedrock. This colluvial/alluvial apron has been associated with major springs and the potential development of large ground-water supplies (Becher and Root, 1981, p. 2) but is too small in area to show at a regional scale.

## STRUCTURE

Differences in structure can account for some of the variation in the water-yielding properties of the rock. Large-scale structures (anticlines, synclines, thrust faults) juxtapose rock types that have different water-yielding properties and bring rock from depth into the shallow zone of weathering where secondary porosity and permeability can be enhanced by chemical weathering. Small-scale structures (joints, fractures, bedding-plane partings) provide openings that allow water to enter and move through an otherwise dense rock mass.

Large-scale structures control the distribution and extent of the geologic units. The Nittany Arch (or anticlinorium) is a complex anticline near the northwestern edge of the study area (fig. 4). Complex synclines include the various coal basins (the Broad Top Syncline, the Anthracite basins, the Lackawanna Syncline) (King, 1970, p. 437–439) in the western and eastern parts of the study area. The Great Valley, which is a complexly faulted and folded area, borders the southeastern edge of the study area. Thrust faults, which vary in attitude from nearly horizontal to steeply dipping (fig. 5), cut across and displace the rock. Older rock from the southeast has been thrust over younger rock to the northwest, thus repeating the Cambrian and the Ordovician rock section in many places. Folds commonly are at the land surface where the thrust faults ramp upward from depth. The Great Valley is characterized by closely spaced faults, overturned and recumbent folds, and outcrops of Cambrian and Ordovician rock. In the Anthracite basins adjacent to the Great Valley, Cambrian rock is at depths of greater than 20,000 ft below land surface but crops out to the west along the axis of the Nittany Arch where it has been brought to the surface by thrust faults.

In the study area, the rock has been broken by small-scale structures. The densities of the joints, fractures, and bedding-plane partings vary with the lithology, bed thickness, and structural setting. Locally, all or some of these features can be sealed by deposition of naturally cementing materials subsequent to deformation or can be filled with fine-grained sediment transported by infiltrating surface water.

## HYDROGEOLOGIC TERRANES

Hydrogeologic terranes are regionally mappable areas characterized by similar rock type and water-yielding properties. A classification of hydrogeologic terranes was developed and a map of hydrogeologic terranes was compiled so that the study area could be subdivided on the basis of the unique water-yielding properties of each hydrogeologic terrane. The hydrogeologic terranes are intended to help water users in locating and developing adequate water supplies and to assist hydrologists in understanding the regional hydrogeology.

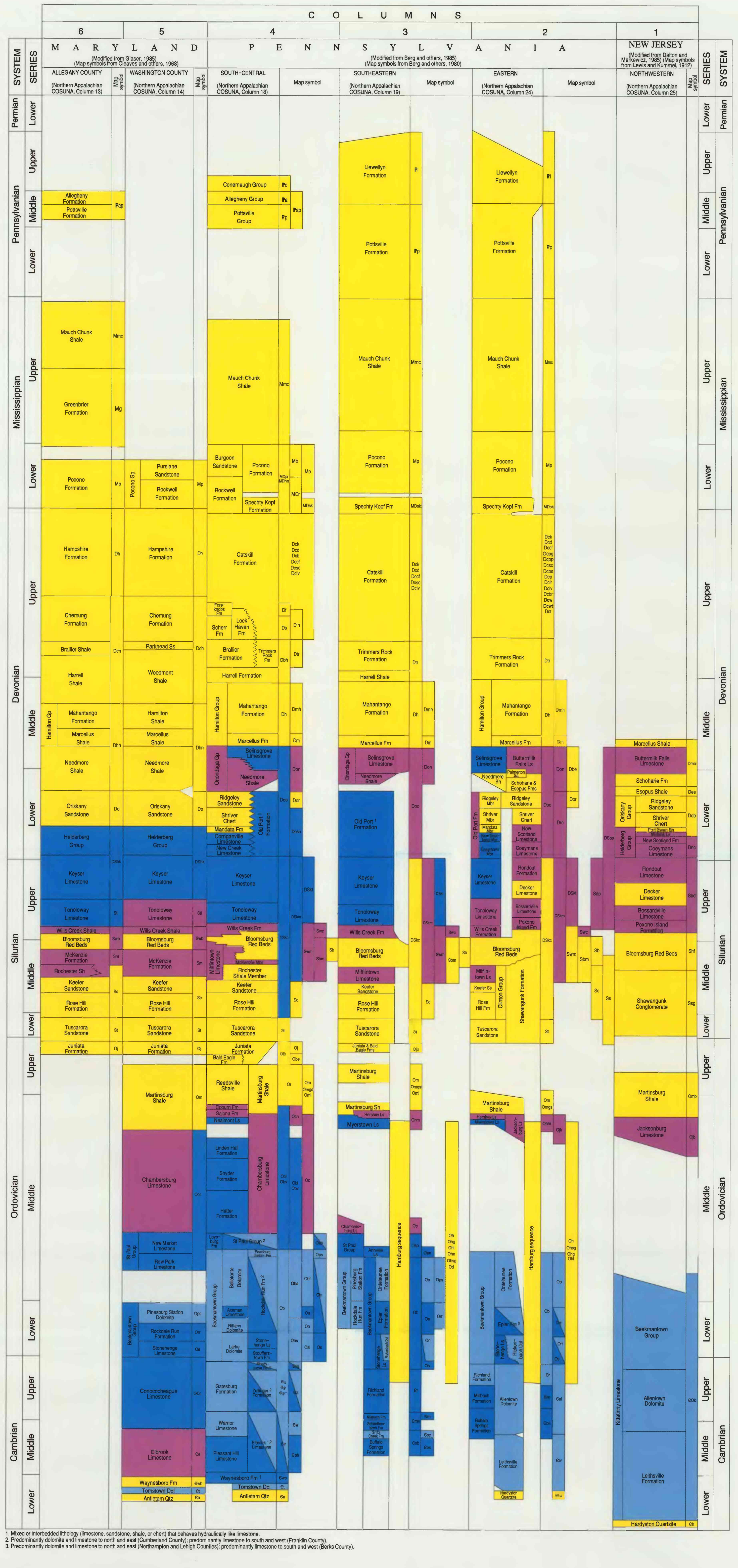

**Figure 2.** Chart with columns showing the stratigraphic position and lithology of the geologic units in the study area. Abbreviations:
COSUNA, Correlation of stratigraphic units of North America; Ls., Limestone; Dol., Dolomite; Ss., Sandstone; Sh., Shale; Fm(s)., Formation(s); Gp., Group; Mbr., Member.

## EXPLANATION

(See fig. 3 for the location of the areas described in the stratigraphic columns)

**Explanation of rock types**—Geologic units are classified into one of the following four rock types based on lithology

- **Dolomite**—Includes units that are predominantly dolomite, a combination of dolomite and sandstone or chert, and dolomite and limestone with as much as 70 percent limestone
- **Limestone**—Includes units that are predominantly limestone and limestone with less than 30 percent dolomite
- **Argillaceous carbonate rock**—Includes units that are predominantly clay–rich dolomite or limestone, as well as shale units that contain abundant calcite or magnesium calcite. Also includes units with a mixture of rock types
- **Siliciclastic rock**—Includes units that are predominantly shale with little or no carbonate content, claystone, siltstone, sandstone, and conglomerate that consist of clay minerals, quartz grains, or siliceous rock fragments. Includes one units that contains a substantial amount of slate

**Explanation of geologic contacts**—Contacts may be either conformable or unconformable and of established or uncertain age

- Contact between two units of equivalent age and stratigraphic position
- Contact between successive synchronous units
- Contact between successive time–transgressive units

**Explanation of geologic map symbol**—Symbols were taken from the State geologic map referenced above the stratigraphic columns and refer to the geologic unit(s) named in the column to the left of the symbol; for example:

## HYDROGEOLOGIC TERRANE CLASSIFICATION

Hydrogeologic terrane classes were defined on the basis of a rationale that relates rock type to the nature of water-yielding openings in the rock and the water-yielding properties of the rock. Thirteen lithologic descriptors from the GWSI data base were used to identify the rock type for classifying hydrogeologic terranes for the study area. For wells with lithologic descriptors, specific-capacity values, which are the discharge of a well divided by the drawdown, were used as measures of water-yielding properties. The following five hydrogeologic terrane classes, one consisting of regolith and four consisting of consolidated rock, are defined below: alluvium, dolomite, limestone, argillaceous carbonate rock, and siliciclastic rock. The relations among the 5 hydrogeologic terranes, the 13 lithologic descriptor groups, and the specific capacity of wells are shown in figure 6. There were sufficient specific-capacity data to treat each of the lithologic descriptor groups as a separate hydrogeologic terrane; however, as shown in figure 6, it is unlikely that all lithologic descriptor groups would have unique water-yielding properties according to specific capacity. The authors elected to reduce the number of hydrogeologic terranes in order to increase the likelihood of obtaining hydrogeologic terranes that would be unique in their water-yielding properties.

The distinction between regolith and consolidated rock was made on the basis of differences in the nature of the water-yielding openings and water-yielding properties of the two types of material. In the study area, well-sorted coarse-grained alluvium of glacial origin is the only regolith that covers a substantial area and yields large quantities of water to wells from pore spaces between sediment grains. Water in other materials principally occupies joints, fractures, bedding-plane partings, or dissolution openings within consolidated rock. In addition, median specific-capacity values of wells completed in the alluvium hydrogeologic terrane—sand (SAND), and sand and gravel (SDGL)—were greater than those for wells completed in consolidated rock hydrogeologic terranes (fig. 6).

Dolomite and limestone were defined as distinct hydrogeologic terrane classes on the basis of their composition, the nature of water-yielding openings, and water-yielding properties. They are carbonate rock that can be dissolved, thus leaving large secondary openings for water to occupy. In the study area, these large dissolution openings are unique features of carbonate rock, are in addition to the joints, fractures, and bedding-plane partings characteristic of siliciclastic rock, and contrast with the intergranular openings of unconsolidated material. Specific-capacity values further differentiate dolomite and limestone from other rock types. Wells completed in the dolomite hydrogeologic terrane—dolomite (DLMT) and limestone and dolomite (LMDM)—had the greatest median specific-capacity values of wells completed in consolidated rock hydrogeologic terranes in the study area (fig. 6). Wells completed in the limestone hydrogeologic terrane—limestone (LMSN)—had the second greatest median specific-capacity value.

Argillaceous carbonate rock also was defined as a hydrogeologic terrane class on the basis of composition and the nature of water-yielding openings and properties. Like dolomite and limestone, argillaceous carbonate rock mostly consists of magnesium calcite or calcite and can develop dissolution-enlarged secondary openings. However, the clay-mineral component of this rock mostly is insoluble, and its residue tends to clog some of the secondary openings and thereby reduce its water-yielding capacity. Median specific-capacity values for wells completed in the argillaceous carbonate rock hydrogeologic terrane—limestone and shale (LMSH) and dolomite and shale (DMSH)—were less than median values for wells completed in the dolomite or limestone hydrogeologic terranes (fig. 6).

Consolidated, noncarbonate, clastic rock was combined into a separate hydrogeologic terrane class on the basis of composition and the nature of water-yielding openings and properties. This rock, which mostly consists of insoluble silicate mineral grains or rock fragments, is termed "siliciclastic rock." It does not have primary, intergranular, water-yielding openings and generally does not develop secondary dissolution openings. The water-yielding openings in the siliciclastic rock are almost exclusively joints, fractures, and bedding-plane partings. Median specific-capacity values for wells completed in the siliciclastic rock hydrogeologic terrane—conglomerate (CGLM), sandstone and shale (SDSL), shale (SHLE), sandstone (SNDS), and siltstone (SLSN)—were similar to each other, but as a group, they generally were less than the values for lithologic descriptor groups in other hydrogeologic terranes (fig. 6).

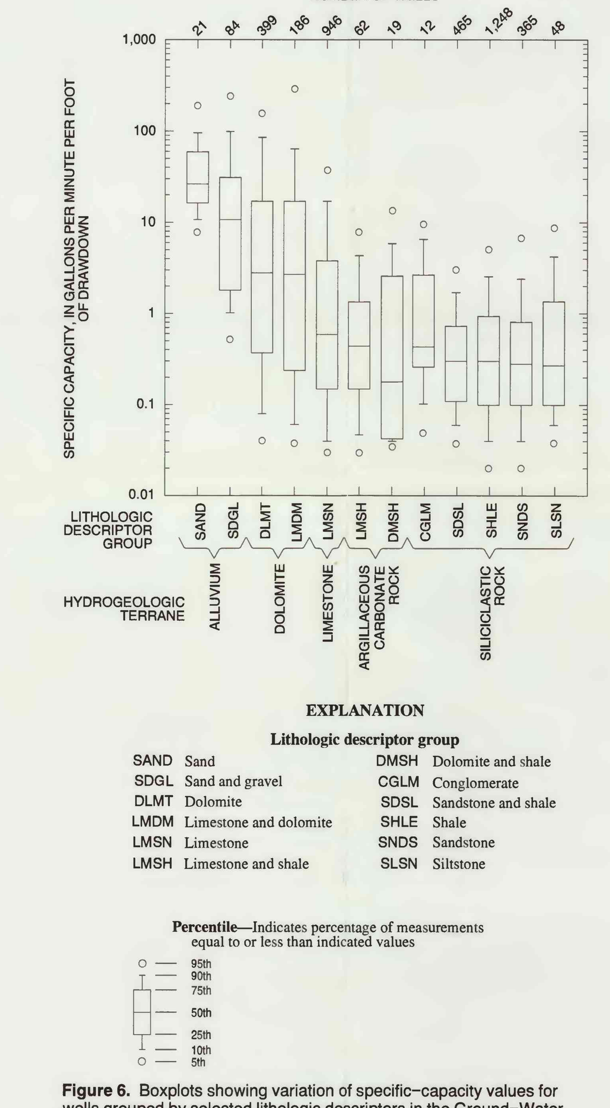

**Figure 6.** Boxplots showing variation of specific–capacity values for wells grouped by selected lithologic descriptors in the Ground–Water Site Inventory data base of the U.S. Geological Survey and the relation of lithologic descriptor groups to hydrogeologic terranes.

## HYDROGEOLOGIC TERRANE MAP

The hydrogeologic terrane map (fig. 7) was compiled from the hydrogeologic terrane classification, the predominant lithology of each geologic unit, and the State geologic maps. The predominant lithology (fig. 2) was determined primarily from the lithologic descriptors assigned to wells in each unit in the GWSI data base. For units that have few descriptors, the predominant lithology was determined from the lithologic descriptions in the explanations on the State geologic maps, data tables available for the Correlation of Stratigraphic Units of North America charts (Patchen and others, 1985), and county reports on the geology and ground-water resources. The rock types shown in color in figure 2 correspond to the hydrogeologic terrane classes in figure 7.

The alluvium hydrogeologic terrane generally coincides with the major valleys in the northern and eastern one-third of the study area (fig. 7), and the remaining hydrogeologic terranes coincide with the outcrop of the geologic units that have the corresponding predominant lithology. More than one-half of the study area is covered by the siliciclastic rock hydrogeologic terrane; the alluvium hydrogeologic terrane covers the least area. The dolomite and limestone hydrogeologic terranes are concentrated in the areas of the Great Valley and the Nittany Arch. In general, the argillaceous carbonate rock hydrogeologic terrane is between the siliciclastic rock hydrogeologic terrane and other carbonate hydrogeologic terranes.

A significant difference in water-yielding properties among the hydrogeologic terranes may exist as implied in figure 8, where the specific-capacity values were grouped by the five hydrogeologic terranes and the groups were arranged in order of decreasing median specific capacity. The alluvium hydrogeologic terrane has the largest median value of specific capacity, and the siliciclastic rock hydrogeologic terrane has the smallest. The dolomite and the limestone hydrogeologic terranes have the greatest variation as indicated by the interquartile range (25th–75th percentiles). Substantial overlap exists in data sets for the hydrogeologic terranes because of the large variation in specific-capacity values within data sets. Although the median specific-capacity values appeared to be different, as discussed below, statistical tests were performed on the data to determine if the apparent differences were significant.

## SELECTION AND ANALYSIS OF WELL RECORDS AND VARIABLES

### SELECTION OF RECORDS AND VARIABLES

A statistical analysis of well records was performed to determine if significant differences in water-yielding properties among the hydrogeologic terranes could be detected. To perform valid tests of significance, the authors first analyzed selected well records to investigate the influence of independent variables—casing diameter, primary use of the water, and topographic setting—upon the dependent variable—specific capacity.

All wells with values for specific capacity and well location were selected for inclusion in the data base for the study. Most of these were domestic wells, which generally have low yield and small specific capacity. Domestic wells commonly are not located in the most favorable setting, drilled to the optimum depth, developed for sufficient time, and equipped to produce large quantities of water. Consequently, domestic wells are not the most reliable source of information for classifying hydrogeologic terranes, investigating the influence of independent variables on specific capacity, testing for significance, or estimating the potential yield of water to wells. However, domestic wells together with nondomestic wells were used in classifying hydrogeologic terranes and investigating the influence of independent variables because the smaller size of the sample of nondomestic wells reduced the ability to detect potential differences. Only nondomestic wells were used in testing for significant differences among hydrogeologic terranes and estimating potential yield of water to wells.

Records for wells with 6,118 reported specific-capacity values were retrieved from the GWSI data base for Maryland, New Jersey, and Pennsylvania. Most of these records also included other data of interest—well yield, well depth, and well casing diameter. Of the records retrieved, 73 percent were from Pennsylvania; 26 percent, from Maryland; and 1 percent, from New Jersey. The largest number of records were for wells in the eastern one-half of the Valley and Ridge Physiographic Province in Maryland (fig. 9). The remainder of the records were for wells that were nearly evenly distributed throughout Pennsylvania.

Specific capacity, well yield, well depth, casing depth, and casing diameter were examined to describe the variation of numeric data contained in the well records (fig. 10). Of the specific-capacity values, 90 percent were between 0.02 and 5.5 (gal/min)/ft, a range that spans more than two orders of magnitude. The reported yields to one-half of the wells were 14 gal/min or less. The median depth of the wells was 150 ft; 95 percent of the wells were less than 440 ft deep, and only 5 percent of the wells were less than 55 ft deep. One-half of the wells were cased to a depth of 40 ft or less. Of the casing diameters, 75 percent were 6 in. or less.

Primary use of the water and topographic setting were examined to describe the distribution of categorical data contained in the well records. With regard to primary use of the water, 65 percent of the wells were domestic; 15 percent were either public supply or industrial; 7 percent were commercial, institutional, or stock; and 13 percent were used for other purposes or unused. With regard to topographic setting, 60 percent of the wells were on hilltops or hillsides; 31 percent, in valley flats or flats; and 9 percent, in other topographic settings. The data set predominantly consists of domestic wells on hilltops or hillsides.

Dependent and independent variables for analysis were selected on the basis of earlier work by Knopman (1990, p. 3–6), who analyzed Pennsylvania records in the GWSI data base for factors that influence the water-yielding potential of the rock. In her study, Knopman used specific capacity as the dependent variable, and casing diameter, primary use of the water, lithologic descriptor, topographic setting, depth of casing, depth of well, saturated interval (as calculated from depth of well, static water level, depth of casing), and primary aquifer (or geologic unit identifier) as independent variables. She determined that casing diameter, primary use of the water, lithologic descriptor, and topographic setting (in decreasing order) accounted for the most variation in specific-capacity values (Knopman, 1990, p. 27, fig. 9).

The dependent variable for this study was specific capacity. Both specific capacity and reported well discharge are measures of the yield of water to a well, and either one or both have been used by previous investigators. Specific capacity was selected for this study because it was considered to be a more accurate measure of yield for the following reason. According to the theory of ground-water flow in porous media, specific capacity, unlike well discharge, is related more closely to the transmitting property of the rock because it takes into account drawdown in addition to discharge. As an example, a group of wells that produce an average 10 gal/min with 10 ft of drawdown are completed in rock that has better water-yielding properties than a group of wells that produce an average 10 gal/min with 100 ft of drawdown. Specific capacity is only an approximate indicator of the water-yielding property of the rock, however, because the consolidated rock in the study area commonly is not homogeneous with respect to ground-water flow, and specific capacity varies with well discharge. Of the variables available for analysis, specific capacity nevertheless was considered to be the most accurate and abundant indicator.

The independent variables for this investigation—casing diameter, primary use of the water, hydrogeologic terrane, and topographic setting—were selected on the basis of the results of work by three investigators in addition to Knopman (1990). Casing diameter was assumed to correlate strongly with well diameter, which, in turn, was reported to correlate strongly with well yield; for example, average well yield was determined to be directly proportional to the diameter of wells in the Piedmont and the Blue Ridge Physiographic Provinces of North Carolina (Daniel, 1989, p. A16–A20). In the present study, casing diameter was not postulated to influence specific capacity directly. A large part of the correlation between well diameter and yield (or specific capacity) is probably due to economic bias in the siting and construction of the wells. This bias is related to the intended use of the water and not to the greater discharge capacity of the larger casing size; for example, wells with a diameter greater than 7 in. are likely to have been constructed at sites where a well owner who desired a large amount of water knew in advance that large quantities of water were available and warranted the expense of the larger casing size.

Concerning primary use of the water, Wood and MacLachlan (1978, p. 29–30, tables 5, 6) provided data to show that the median specific-capacity values of nondomestic wells in carbonate geologic units is 20 times the median values of domestic wells in the same units. A large part of the correlation between primary use of the water and specific capacity of wells is probably due to economic bias in the siting and construction of the wells; for example, well owners who intend to withdraw water for public supply or industrial purposes usually are willing to invest more time and money on their water supplies than are well owners who intend to withdraw water for domestic purposes.

# HYDROGEOLOGIC TERRANES AND POTENTIAL YIELD OF WATER TO WELLS IN THE VALLEY AND RIDGE PHYSIOGRAPHIC PROVINCE IN MARYLAND, NEW JERSEY, AND PENNSYLVANIA

By
E.F. Hollyday, G.E. Hileman, Mark A. Smith, and D.J. Pavlicek
1996

Sheet prepared and formatted by J.C. Smith and David C. Greene
INTERIOR—GEOLOGICAL SURVEY, RESTON, VIRGINIA—1996