ESTIMATED HYDROLOGIC CHARACTERISTICS OF SHALLOW AQUIFER SYSTEMS IN THE VALLEY AND RIDGE, THE BLUE RIDGE, AND THE PIEDMONT PHYSIOGRAPHIC PROVINCES BASED ON ANALYSIS OF STREAMFLOW RECESSION AND BASE FLOW

REGIONAL AQUIFER-SYSTEM ANALYSIS

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Estimated Hydrologic Characteristics of Shallow Aquifer Systems in the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces Based on Analysis of Streamflow Recession and Base Flow

By A.T. RUTLEDGE *and* T.O. MESKO

REGIONAL AQUIFER-SYSTEM ANALYSIS—
APPALACHIAN VALLEY AND PIEDMONT

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FOREWORD

THE REGIONAL AQUIFER-SYSTEM ANALYSIS PROGRAM

The Regional Aquifer-System Analysis (RASA) Program represents a systematic effort to study a number of the Nation's most important aquifer systems, which, in aggregate, underlie much of the country and which represent an important component of the Nation's total water supply. In general, the boundaries of these studies are identified by the hydrologic extent of each system and, accordingly, transcend the political subdivisions to which investigations have often arbitrarily been limited in the past. The broad objective for each study is to assemble geologic, hydrologic, and geochemical information; to analyze and develop an understanding of the system; and to develop predictive capabilities that will contribute to the effective management of the system. The use of computer simulation is an important element of the RASA studies to develop an understanding of the natural, undisturbed hydrologic system and the changes brought about in it by human activities and to provide a means of predicting the regional effects of future pumping or other stresses.

The final interpretive results of the RASA Program are presented in a series of U.S. Geological Survey Professional Papers that describe the geology, hydrology, and geochemistry of each regional aquifer system. Each study within the RASA Program is assigned a single Professional Paper number beginning with Professional Paper 1400.

Gordon P. Eaton
Director

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ILLUSTRATIONS

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CONVERSION FACTORS

Multiply	By	To obtain
inch per year (in/yr)	25.4	millimeter per year
foot (ft)	0.3048	meter
square mile (mi^2)	2.590	square kilometer
gallon per day (gal/d)	0.003785	cubic meter per day

ESTIMATED HYDROLOGIC CHARACTERISTICS OF SHALLOW AQUIFER SYSTEMS IN THE VALLEY AND RIDGE, THE BLUE RIDGE, AND THE PIEDMONT PHYSIOGRAPHIC PROVINCES BASED ON ANALYSIS OF STREAMFLOW RECESSION AND BASE FLOW

BY A.T. RUTLEDGE AND T.O. MESKO

ABSTRACT

Hydrologic properties of aquifer systems are estimated from the interpretation of streamflow records in the Appalachian Valley and Ridge, the Piedmont, and the Blue Ridge Physiographic Provinces. The analysis is divided into two parts—streamflow recession and base flow.

The master recession curve (MRC) represents the recession of streamflow during times when all flow is from ground-water discharge, when no ground-water recharge is occurring, and when the configuration of the ground-water-head profile is nearly stable. The method used to describe the MRC shows flow on a logarithmic scale as a function of time on a linear scale and allows for the possibility that the MRC is nonlinear. The variation in the slope of one particular MRC and the variations among recession characteristics of different basins can be related to variation of transmissivity, specific yield, and the average distance from stream to hydrologic divide. The recession index is slightly lower in the Valley and Ridge Physiographic Province as compared with that in the other physiographic provinces possibly because of the high transmissivities of limestones and dolomites that underlie the Valley and Ridge Physiographic Province. The shape of the MRC can be related to variations in aquifer properties with changes in ground-water levels. Low parts of the MRC correspond to low ground-water levels in the basin. Upward concavity of the MRC may be caused by an increase in specific yield as the water table moves downward through zones of differing lithology. Convexity may result from the reduction of specific yield with depth in the crystalline rocks of the Piedmont Physiographic Province. The MRC can be concave upward for basins of large relief, such as those of the Valley and Ridge and the Blue Ridge Physiographic Provinces. As ground-water levels decline, some streams may go dry, which results in an increase in the average distance from the stream to the hydrologic divide. Upward concavity of the MRC can result when the stream is fed by more than one aquifer. The concavity that results from multiple aquifers may be particularly evident in the Valley and Ridge Physiographic Province because of differences between the lithologies of the low-lying valleys and the adjacent ridges.

Variations in recession characteristics related to variation in precipitation and basin relief are, for the most part, obscured by scatter, which is possibly caused by variations in other unmeasured physical properties. The relation between the water-yielding capacity of rocks and the basin recession index is noticeably positive. From the analysis of streamflow recession, most values of hydraulic diffusivity are from 8,000 to 60,000 feet squared per day, and most values of transmissivity are from 80 to 5,000 feet squared per day. The annual minimum average 7-consecutive-day low-flow discharge with a 2-year occurrence interval is a variable that is related to the recession index, but a considerable amount of the scatter in the relation may be caused by variations in mean recharge.

Among the 89 basins for which the streamflow record from 1961 to 1990 is continuous, the distribution of mean ground-water recharge, in inches per year, is minimum, 6; median, 13; and maximum, 50. The distribution of mean ground-water discharge, in inches per year, is minimum, 5; median, 12; and maximum, 46. Riparian-zone evapotranspiration, which is the loss of water to the atmosphere from ground water and from the stream channel, is generally 1 to 2 inches per year. The relation between precipitation and recharge for the study area shows a considerable amount of scatter; the best-fit linear equation has roughly unit gradient and an X-intercept that is about 24 inches per year. Plots of recharge as a function of basin relief show a slight negative relation for the Valley and Ridge Physiographic Province and a clear positive relation in the other physiographic provinces. In the Blue Ridge and the Piedmont Physiographic Provinces (combined), a good estimator of recharge can be derived from precipitation and basin relief. The relation between the capacity of rocks to yield water to wells and recharge in the Valley and Ridge Physiographic Province is generally not clear, but a positive relation is noted between the water-yielding capacity of rocks and the rate of recharge in the Piedmont Physiographic Province.

The base-flow index, which is the ratio of mean ground-water discharge to mean streamflow, ranges from 32 to 94 percent; the median is 67 percent. The base-flow index is largest in the southern part of the Blue Ridge Physiographic Province. The best surrogate for mean ground-water discharge from the flow-duration curve is flow that is equalled or exceeded 42 percent of the time for the Valley and Ridge Physiographic Province and 46 percent for the Blue Ridge and Piedmont Physiographic Provinces.

On the basis of 72 basins, the median values for components of the hydrologic budgets in the study area (excluding the southern part of the Blue Ridge Physiographic Province) are, in inches per year, precipitation, 43; evapotranspiration, 26; streamflow, 16; ground-water recharge, 12; ground-water discharge, 11; and storm runoff, 6. On the basis of 17 basins, the median values for the components of the hydrologic budgets in the southern part of the Blue Ridge Physiographic Province are, in inches per year, precipitation, 58; streamflow, 38; ground-water recharge, 33; ground-water discharge, 29; evapotranspiration, 25; and storm runoff, 8.

INTRODUCTION

The rates of surface- and ground-water use are 37 trillion and 1.7 trillion gal/d, respectively, in the Appalachian Valley and Ridge, the Piedmont, and the Blue Ridge Physiographic Provinces (Swain and others, 1991). Although large amounts of water are currently (1995) being withdrawn, processes of recharge, discharge, ground-water flow, and stream-aquifer interactions are poorly understood. This lack of understanding is related primarily to the diverse and complex nature of the hydrologic system.

BACKGROUND

This study is one of several regional investigations to assess the Nation's principal aquifer systems (Sun, 1986). In 1978, the U.S. Geological Survey (USGS) began the Regional Aquifer-System Analysis (RASA) Program, as mandated by Congress, and was given the task of "initiating a program to identify the water resources of the major aquifer systems within the United States***and***establish the aquifer boundaries, the quantity and quality of the water within the aquifer, and the recharge characteristics of the aquifer" (Sun, 1986, p. 2). This report is part of a RASA study of the area that includes the Appalachian Valley and Ridge, Blue Ridge, and Piedmont Physiographic Provinces (APRASA) (Swain and others, 1991). The RASA study was designed to provide a basis for more efficient use and management of water resources within the study area than is now possible by supplying data bases, a regional hydrogeologic framework, and interpretive analyses of ground-water flow systems.

PURPOSE AND SCOPE

This report describes how streamflow records were used to enhance the understanding of shallow ground-water-flow systems in the APRASA area. Of particular interest was the definition of streamflow recession during periods of base flow and the quantification of mean ground-water recharge and discharge. The nature of shallow ground-water-flow systems in the APRASA area, which generally are distinct in each basin, leads to the potential for analyzing properties of shallow aquifers by means of streamflow records. Also, the presence of fractured-rock flow systems in the study area adds to the benefit of streamflow analysis for determining aquifer properties over traditional aquifer-test methods, which can be unreliable in these systems because well diameter and length can be small relative to the scale of fractures. Because the scale of streams is large relative to the scale of most fractures, ground-water flow can be conceptualized by means of continuum mathematics. Hydraulic properties obtained from stream-flow analysis are likely to be "average" values for the aquifer system. The principal problem with traditional aquifer-test methods in fractured rocks is the variance between the hydrogeologic conditions at the well site and the idealized conditions in the equations used for analyzing test results.

This report also (1) describes relations among properties of shallow ground-water flow systems, such as recession index and mean recharge rate, and the physical properties of the basins, such a relief, rock characteristics, and precipitation, (2) demonstrates relations among properties of shallow ground-water flow systems and streamflow statistics that have been widely used as indexes of stream-aquifer interactions, such as low-flow and flow-duration-curve variables, and (3) demonstrates the application of computerized methods that were developed as part of this study to interpret streamflow records [although these methods are described briefly in this report, the reader is referred to Rutledge (1993) for a thorough discussion]. Although the geology of the APRASA area is briefly described in this report, the reader is referred to Swain and others (1991) for a complete discussion.

STUDY METHODS

For the most part, this report describes the results of two types of analysis—streamflow recession and base flow. The rate of streamflow recession is related to hydraulic diffusivity, which is transmissivity (T) divided by specific yield (S_y), and the configuration of the master recession curve (MRC), which is a graph of flow on a logarithmic scale as a function of time on a linear scale, is related in a general way to the capacity of the aquifer to yield water for supply during a time of sparse precipitation. Base-flow analysis consists mainly of the estimation of the mean rates of ground-water recharge and discharge over a long period of time (usually years). Computer programs were developed for describing the recession of ground-water discharge during periods of no recharge and for estimating the mean rates of ground-water recharge and discharge from streamflow records (Rutledge, 1993).

A total of 157 streamflow-gaging stations were selected in the APRASA area for analysis (fig. 1). The criteria for selection of these stations included a complete record of daily streamflow from 1981 to 1990, negligible regulation or diversion of flow, a record that was

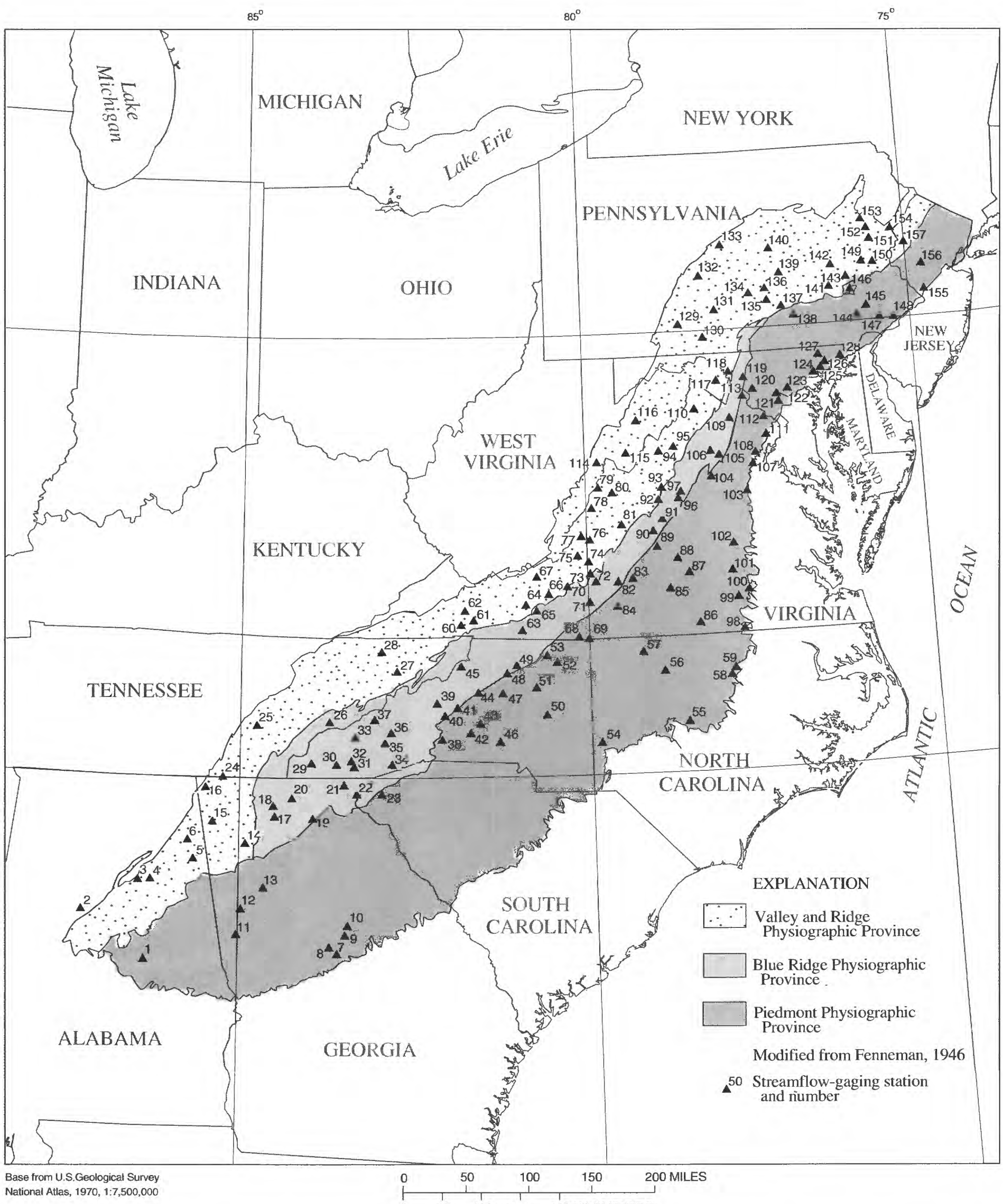


FIGURE 1.—Locations of the Regional Aquifer-System Analysis study area, which consists of the three physiographic provinces, and the streamflow-gaging stations. (Gaging-station numbers are in sequence generally from southwest to northeast for cross reference with tables 1 to 4, which follow "References.")

classified as "good" in USGS data books, and at least 75 percent of the drainage area being within the APRASA study area. The drainage areas of all stations were larger than 2 mi^2 and with the exception of three stations, all were less than 400 mi^2. In the selection of stations, larger basins were avoided for the purpose of minimizing errors owing to bank storage and nonuniformity of storm systems. Although some calculations were performed by using the period from 1981 to 1990, the analysis of streamflow recession used the entire period of available record, and basin hydrologic budgets were calculated by using the period from 1961 to 1990, for which 89 of the stations have complete records. Results of calculations of the components of hydrologic budgets of basins were based on the calendar year (January 1 through December 31).

A considerable part of the effort for this report consisted of compiling or determining the physical characteristics of the 157 basins. Discussion of the sources of basin characteristics is in the "Appendix" which includes precipitation, relief, and type of hydrogeologic terrane, and a listing of variables for all 157 basins is in table 1, which follows the "References." Basins are assigned numbers in figure 1 generally from southwest to northeast, from one State to another. These numbers are also listed in tables 2 through 4, which also follows the "References." Physical characteristics and analysis results listed in these tables (especially tables 3, 4) are only estimates. The accuracy of these results is considerably less than that implied by the number of decimal places.

APPLICABILITY OF METHODS

The methods developed and used in this study are intended for the analysis of the shallow ground-water-flow system of a basin with a streamflow-gaging station at the downstream end of the major draining stream. Regulation and diversion of flow should be negligible. The methods of base-flow analysis are appropriate only if the stream channel is the sink (discharge boundary) of the ground-water-flow system and if the flow system is driven by areally diffuse recharge events that can be considered to be roughly concurrent with peaks in streamflow. The methods are appropriate only if all or nearly all water is assumed to discharge to the stream, except for that water which is lost by riparian-zone evapotranspiration. The area of contribution in the ground-water system is assumed to be equal to the area of surface drainage area for the purpose of expressing flow in units of specific discharge, such as inches per year. Results are most accurate if the computerized methods are used with data that covers a period of at least 1 year, as they are for this study.

PREVIOUS INVESTIGATIONS

Regional descriptions of the hydrology of the APRASA study area include works by Cederstrom, Boswell, and Tarver (1979), Heath (1984), Miller (1990), Schneider (1965a), Sinnott and Cushing (1978), Swain and others (1991), Wyrick (1968), Wyrick and Lloyd (1968), and Zurawski (1978).

Previous studies that include the analysis of streamflow records for the purpose of understanding properties of shallow ground-water systems in the APRASA area include Barksdale and others (1943), Becher and Root (1981), Becher and Taylor (1982), Biesecker, Liscensky, and Wood (1968), Bingham (1982, 1986), Carswell and Lloyd (1979), Daniel and Sharpless (1983), Dingman and Meyer (1954), Dingman and Ferguson (1956), Dine (1990), Duigon and Dine (1987, 1991), Evaldi and Lewis (1983), Gerhart and Lazorchick (1988), Harkins (1982), Hely and Olmsted (1963), Hewlett and Hibbert (1967), Hobba, Friel, and Chisholm (1972), Hoos (1990), Laczniak and Zenone (1985), Lichtler and Wait (1974), Lloyd and Growitz (1977), McGreevy and Sloto (1977), Nutter (1973, 1974), Nutter and Otton (1969), Olmsted and Hely (1962), Richardson (1982), Schneider (1965b), Stewart and others (1964), Stuart, Schneider, and Crooks (1967), Taylor, and others (1982), Taylor, Werkheiser, and Kriz (1983), Trainer and Watkins (1974, 1975), Waller (1976), White (1977), Wood (1980), and Wood and others (1972). Some of these studies simply involve estimation of mean ground-water discharge, whereas others include additional subjects, such as characteristics of the recession of ground-water discharge or the effects of hydrogeologic variables on the rate of ground-water recharge.

GEOLOGIC FRAMEWORK

As described by Swain and others (1991), the APRASA study area is considered to be two distinct subareas on the basis of differences in geology and hydrologic characteristics. The first subarea consists of carbonate rock, sandstone, and shale of the Valley and Ridge Physiographic Province. The second subarea includes metamorphic and igneous crystalline rocks in the Piedmont and the Blue Ridge Physiographic Provinces. In addition, large rift basins, which extend from New Jersey to South Carolina within the Piedmont crystalline rocks, have been filled with sedimentary deposits of early Mesozoic age. Glaciation covered only a small part (about 3,000 mi^2) of the study area in eastern Pennsylvania and New Jersey. Locally, glacial deposits can provide significant quantities of water, but these deposits are not regionally significant.

Regolith, which consists of soil, alluvium, and weathered rock material, overlies most of the geologic units throughout both subareas. In some locations, it includes material that has been transported and deposited as glacial drift, colluvium, or alluvium, and in others, it consists only of weathered material called residuum, or saprolite, which remains atop the parent rock from which it has been derived. Thickness of the regolith throughout the study area is extremely variable and ranges from 0 to more than 150 ft. In some areas, the rate of weathering is about equal to the rate at which weathered material is removed by erosion; thus, thickness of regolith remains fairly constant in time.

The Valley and Ridge Physiographic Province is characterized by a sequence of parallel ridges and valleys that formed, in part, as a result of thrust faulting and folding. Ridge development is controlled by geologic structure and weathering characteristics of the different rock types. Generally, ridges are underlain by resistant conglomerate, sandstone, or cherty dolomite, whereas valleys are underlain by less-resistant siltstone, shale, limestone, or dolomite.

The Piedmont and the Blue Ridge Physiographic Provinces are underlain by Precambrian to Mesozoic igneous, metamorphic, and sedimentary rocks, which include massive granites and gneisses, foliated phyllites and schists, and consolidated sandstones. Sedimentary rocks of early Mesozoic age fill basins within the Piedmont Physiographic Province. Igneous and volcanic activity, which accompanied sedimentation, is manifested by basaltic and diabase dikes that were intruded into the Mesozoic sedimentary rocks. Rocks that crop out in the Piedmont underlie parts of the Atlantic Coastal Plain at depth.

ANALYSIS OF STREAMFLOW RECESSION

The mathematical description of the recession of ground-water discharge can be useful for estimating aquifer diffusivity and for discerning qualitative similarities or dissimilarities between ground-water-flow systems of various basins. Possible additional applications are the comparison of ground-water-supply potential of various basins and the assessment of loss of ground water to evapotranspiration or from the shallow local ground-water-flow system to deeper regional ground-water-flow systems.

MATHEMATICAL BASIS FOR AND METHOD OF DETERMINING THE MASTER RECESSION CURVE OF GROUND-WATER DISCHARGE

For the purpose of this report, the MRC represents the recession of streamflow during times when all flow is from ground-water discharge, no ground-water recharge is occurring, and the configuration of the ground-water-head profile is nearly stable. The MRC is usually assembled from numerous intervals of continuous recession; thus, it illustrates the recession that would occur for a period without recharge that is greater than any such time period that could be observed in nature. The matching strip method has been used for assembly of the MRC by Snyder (1939), Toebes and Strang (1964), and Nathan and McMahon (1990). The MRC is often constructed from nonsummer data so that the result will be minimally affected by evapotranspiration.

The log-linear model of base-flow recession may be sufficient in many applications (Barnes, 1939; Ineson and Downing, 1964; Rorabaugh, 1964; Bevans, 1986). When a period of time has elapsed since the last recharge event, the rate of base-flow recession for a basin is expressed as the recession index K (days per log cycle), which also is known as the storage delay factor (Singh and Stall, 1971). Rorabaugh's mathematical model is based on assumptions that the aquifer has uniform thickness, hydraulic conductivity, and storage coefficient, that it is fully penetrated by the stream, and that the distance from the stream to the hydrologic divide is equal at all places in the basin. It can be used to express recession by using the following equation (from Rorabaugh and Simmons, 1966, p. 12):

$$\frac{T}{S_y a^2} = \frac{0.933}{K} . \qquad (1)$$

Equation 1 can be rearranged to give the following base-flow recession index:

$$K = \frac{0.933 S_y a^2}{T} . \qquad (2)$$

The above linear model of recession of ground-water discharge applies only after an amount of time has transpired since the last recharge event that is equal to critical time $0.2a^2S_y/T$ (Rorabaugh, 1964, p. 434). Before critical time, the configuration of the ground-water-head profile is unstable, and recession is nonlinear. After critical time, the configuration of the ground-water-head profile is stable, and recession is linear.

Many factors can cause MRC nonlinearity in nature, even if the MRC represents times when the ground-water-head profile is stable, which is the case for this report. Most of these factors cause continuous variation in recession slope as streamflow recedes. Physical and mathematical models have shown that the presence of the declining free surface (water table) can cause non-linearity of base-flow recession for a stream that is fed by an unconfined aquifer (Ibrahim and Brutsaert, 1965; Hornberger, Ebert, and Remson, 1970), and this nonlinearity can be enhanced by variable head at the ground-water-outflow boundary (the stream) (Werner and Sundquist, 1951; Singh, 1969; Singh and Stall, 1971). Nonlinearity can result from evapotranspiration or the gain or loss from shallow flow systems owing to interactions with underlying aquifers (Singh, 1969; Daniel, 1976) or from geologic heterogeneities in the basin (Horton, 1933; Riggs, 1964; Ineson and Downing, 1964; Trainer and Watkins, 1974, 1975; Petras, 1986). Wood and others (1972) developed nonlinear MRC's for several streams in eastern Pennsylvania. Nutbrown and Downing (1976) indicated that nonlinearity can be common for even the simplest of ground-water systems in England.

For the purpose of constructing the MRC, its nonlinearity is assumed to be slight compared with that of streamflow recession during times when either storm runoff is significant or when the shape of the ground-water-head profile is not yet stable. Therefore, it is possible to extract segments of continuous recession from the record and to select "near-linear" parts of each segment that are indicative of the MRC. The recession segments are analogous to recession that occurs after Rorabaugh's critical time, except that the mathematical model used here allows for the possibility of nonlinearity.

The basic steps for determining the MRC of ground-water discharge, as executed by a computer program (Rutledge, 1993), are illustrated in figure 2. First, the program locates periods of streamflow recession and allows the user to select nearly linear segments (fig. 2*A*). These segments represent periods during which all flow is from ground-water discharge, when there is no ground-water recharge, and when the configuration of the ground-water-head profile is nearly stable. Then, the best linear equation for time as a function of the logarithm of flow (Log*Q*) for each segment is determined by the program, which extracts a coefficient that is *K* of the segment (data points, fig. 2*B*). By using the assumption that *K* varies linearly with Log*Q*, the program then determines the best linear equation for *K* as a function of Log*Q*, which is the line in figure 2*B*. Coefficients of this equation are used to obtain the MRC (fig. 2*C*), which is a second-order polynomial expression for time as a function of Log*Q* in the following form:

$$t = A\,(\mathrm{Log}Q)^2 + \mathrm{B}\,(\mathrm{Log}Q) + \mathrm{C}, \qquad (3)$$

where t is time, and A, B, and C are coefficients.

In the application of this recession model, considerable variation in the rate of recession can be assumed about the central tendency represented by the MRC. Nutbrown and Downing (1976) indicated that the precise shape of the recession curve may vary from time to time because of variations in the original distribution of hydraulic head. Another assumption is that the central

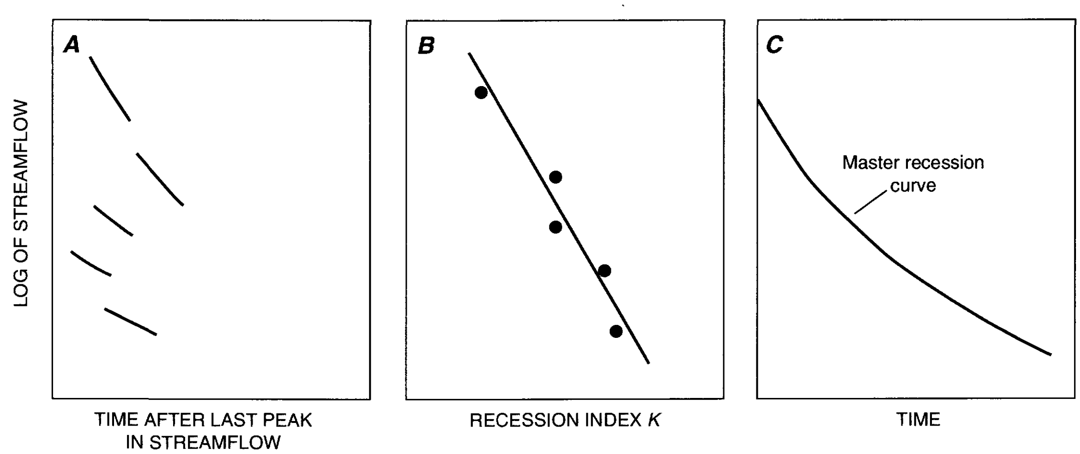


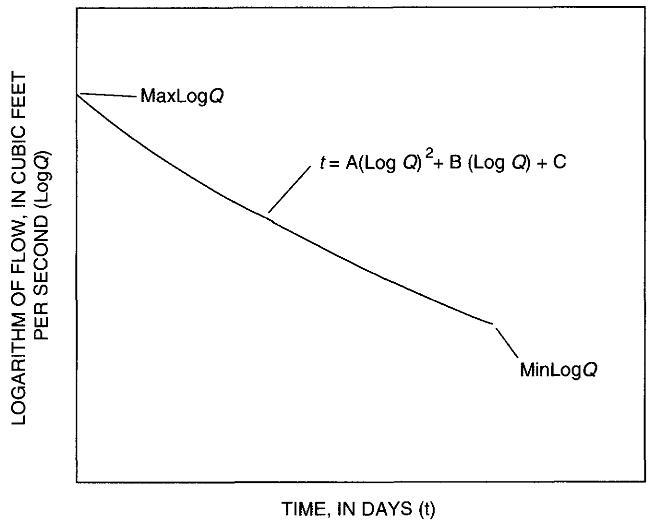
FIGURE 2.—Schematic representation of the method used to determine the master recession curve (MRC) of ground-water discharge. *A*, Selected recession segments, *B*, Recession index K (time per log cycle of streamflow recession) and best-fit line; *C*, The MRC, which is obtained from coefficients of function in *B*.

tendency shows a continuous relation between the recession rate and the flow; in other words, the MRC can be curved but does not show abrupt changes in slope. An abrupt change in slope may be attributed to processes at work during a specific recession segment; these processes are dependent on, for example, the areal distribution of recharge before that particular event. Anderson and Burt (1980) stated that such breaks in slope may prove to be apparent rather than real and may not indicate a change in flow process. Trainer and Watkins (1975, p. 37) identified compound MRC's with abrupt slope changes but stated that the discharge at which inflection occurs differs from year to year in a given basin. Detailed output files that are generated by the computer program yielded evidence that continuity is reasonable for basins in this study area.

DEFINITION OF THE MASTER RECESSION CURVE IN THE STUDY AREA

The computerized method of Rutledge (1993) was used to determine the MRC of ground-water discharge for all 157 streamflow-gaging stations. The entire period of record was used, but recession segments that began from June through August were eliminated from consideration to reduce the effects of evapotranspiration. Table 2 (follows "References") shows the years of record and the number of recession segments that were utilized for each station. The MRC is defined with the greatest accuracy for stations that have the longest period of record. The variables that describe the MRC, which are listed in table 2, are illustrated in figure 3. These include the coefficients A, B, and C, of equation 3, in addition to the variables MinLogQ and MaxLogQ, which are the smallest and the largest values of the LogQ respectively, among all the recession segments that are selected. MinLogQ and MaxLogQ define the lower and upper limits for the applicability of the equation.

When the values of the variables above have been computed for each basin (table 2), the MRC's can be plotted for the purpose of defining similarities or dissimilarities among the various parts of the study area. Figures 4 through 6 show MRC's that are typical for the three physiographic provinces. All graphs are shown at the same scale. From the perspective of ground-water hydrology, the important features of an MRC are its inclination and shape. Vertical differences in positions of MRC's are due mainly to differences in drainage area above the streamflow-gaging stations. Because of the notable variation between the northern and southern



EXPLANATION

A, B, C	Coefficients of the equation defining the Master Recession Curve (eq 3)
Max*LogQ*	The maximum value of the logrithm of flow among all recession segments selected
Min*LogQ*	The minimum value of the logarithm of flow among all recession segments selected

FIGURE 3.—Schematic representation of the master recession curve and the variables that define it.

parts of the Blue Ridge Physiographic Province, two graphs are shown (fig. 6). Figures 4 through 6 will be discussed further.

Although the variables described above precisely identify the MRC, two variables—inclination and shape—need to be added. These two variables represent the basic characteristics of the MRC for the purpose of testing relations between hydrogeologic variables and MRC characteristics. The inclination is represented by the median value of the recession index among all recession segments that are selected (table 2). For the 157 basins, this variable ranges from 22 to 168 days, and the 25th, 50th, and 75th percentiles of its distribution are 58, 72, and 100 days, respectively. The shape is represented by the second derivative of the MRC (eq 3), which is equal to 2 $\times$ A. This variable is positive if the MRC is concave (as viewed from above), negative if the MRC is convex, or 0 (or nearly 0) if the MRC is linear (or nearly linear). This variable ranges from -180 to 310, and the 25th, 50th, and 75th percentiles of its distribution are -2, 40, and 90, respectively.

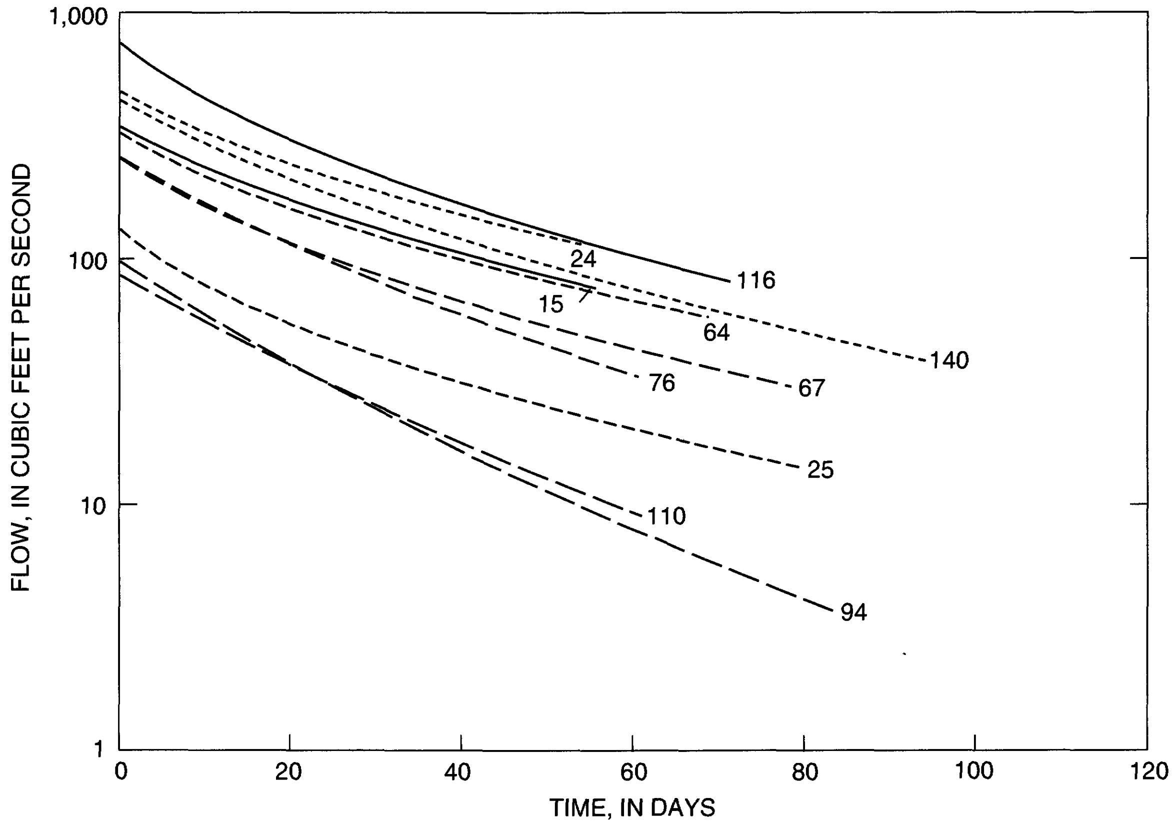


FIGURE 4.—Typical master recession curves of ground-water discharge for streams in the Valley and Ridge Physiographic Province. [Each curve is assigned a number that corresponds to map numbers in fig. 1 and table 2 (follows "References").]

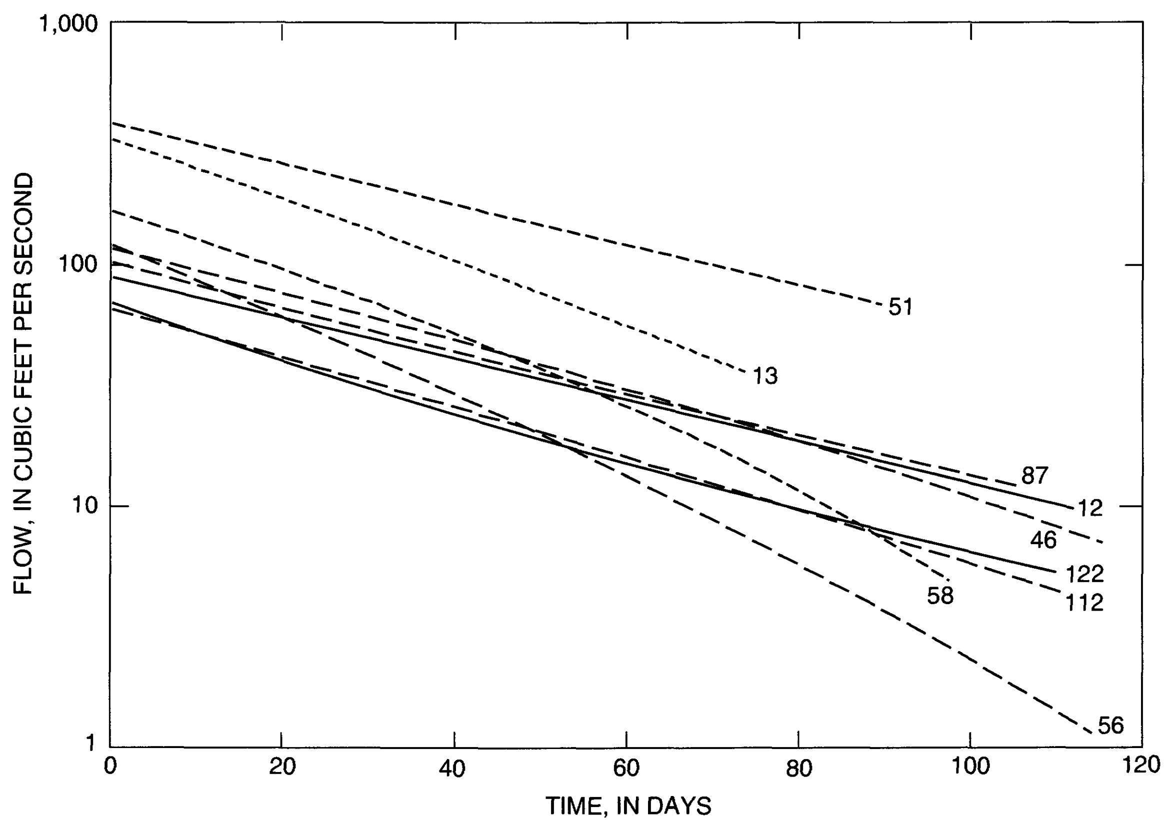


FIGURE 5.—Typical master recession curves of ground-water discharge for streams in the Piedmont Physiographic Province. [Each curve is assigned a number that corresponds to map numbers in fig. 1 and table 2 (follows "References").]

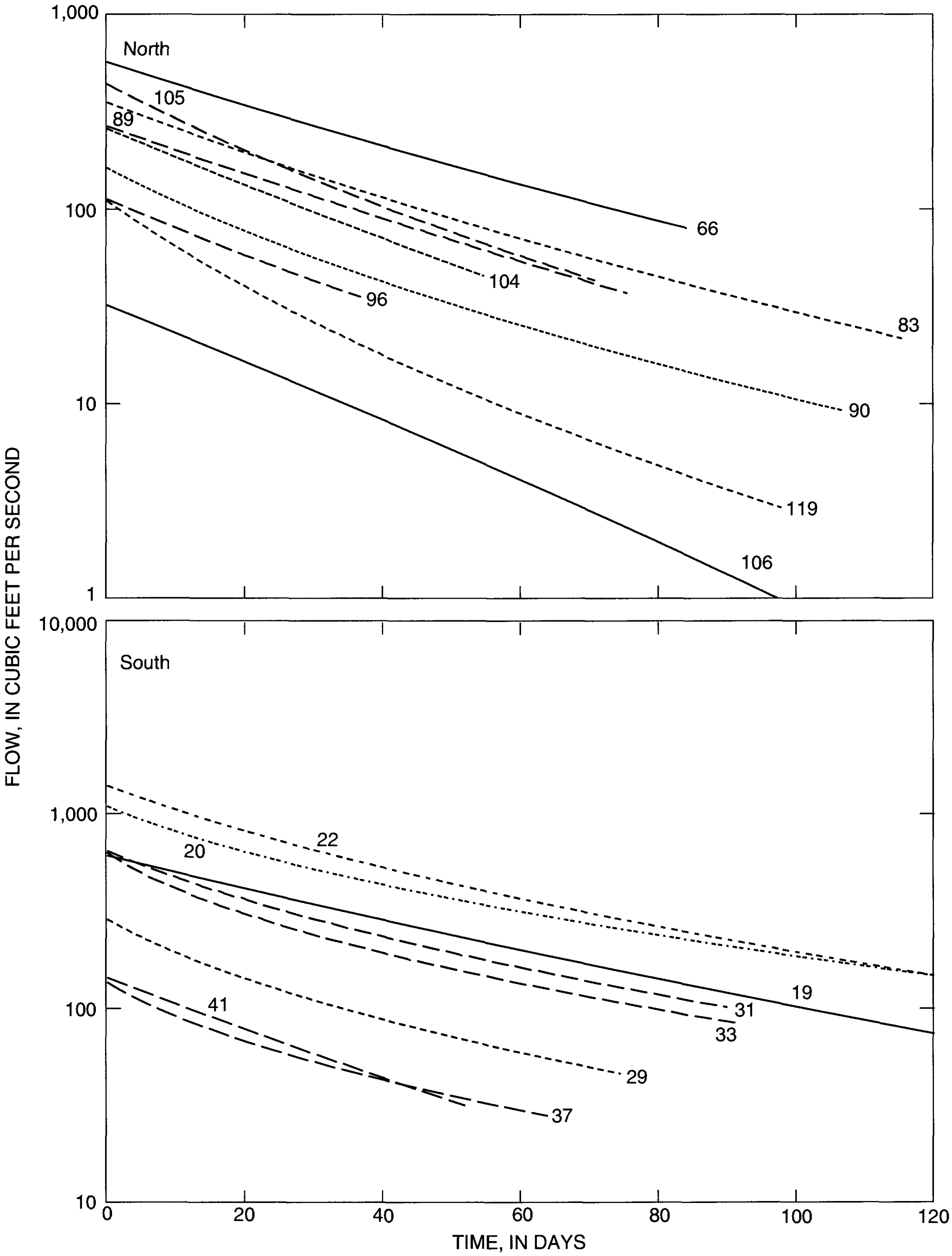


FIGURE 6.—Typical master recession curves of ground-water discharge for streams in the Blue Ridge Physiographic Province shown for stations north and south of latitude 37. [Each curve is assigned a number that corresponds to map numbers in fig. 1 and table 2 (follows "References").]

VARIATION IN RECESSION CHARACTERISTICS IN THE STUDY AREA

Although no strict generalizations can be made about the factors that determine base-flow-recession characteristics throughout the study area, some attempt is made here to show graphically the ways in which characteristics vary. The variation in the slope of one MRC and the variations in base-flow-recession characteristics among basins can be related to variation of transmissivity, specific yield, and the average distance from a stream to the hydrologic divide (eq 2).

As transmissivity becomes larger, the recession index becomes smaller (more rapid recession), but as the specific yield becomes larger, the recession index becomes larger (slower recession of flow). This direct opposition of the effects of transmissivity and specific yield can complicate the interpretation of ground-water recession as it relates to water-supply potential because it is usually considered to be favorable for water-supply purposes if T and S_y are large. A large recession index is often equated with the best conditions for water supply. This may often be reasonable because the aquifer may have a large specific yield, which may reflect reliability of water supply during periods of drought. However, a large recession index also may result from small transmissivity, which generally indicates small well yields.

The recession index is slightly smaller in the Valley and Ridge Physiographic Province, and its distribution shows less scatter than the other provinces (fig. 7). A possible explanation for small recession indexes in the Valley and Ridge Physiographic Province is that larger transmissivities are associated with limestone and dolomite aquifers in the area. The second derivative of the MRC is considerably smaller in the Piedmont as compared with the other provinces—negative values are observed for a large number of streams in the Piedmont, for only a small number of Blue Ridge streams, and for no Valley and Ridge streams (fig. 7). This tendency also is evident from figures 4 through 6, which show MRC's that are "typical" for each of the provinces—all MRC's for the Valley and Ridge Physiographic Province are concave (fig. 4), and most MRC's for the Blue Ridge Physiographic Province are concave (fig. 6), while several MRC's in the Piedmont Physiographic Province are convex (fig. 5). More than one-half of the streams in the Piedmont show convexity (fig. 7), and the tendency is spatially correlated (fig. 8).

The shape of an MRC can be related to variations in T/S_y with ground-water levels because lower parts of the MRC correspond to lower ground-water levels in the basin. Concavity of the MRC could theoretically be caused by the decrease in aquifer transmissivity that occurs as the zone of saturation becomes thinner, but the amount by which the thickness of the saturated zone actually decreases is probably not enough to explain observed concavity. The effect also could be caused by an increase in specific yield that may occur as the water table declines through zones of varying lithology. If the specific yield becomes smaller as the water table declines, then the MRC may be convex. This may be one reason for the convexity of MRC's in the Piedmont Physiographic Province—crystalline rocks may exhibit reduction of specific yield with depth. Olmsted and Hely (1962, p. 20) stated that the gravity yield in the basin of Brandywine Creek basin in the Piedmont of Pennsylvania decreases rapidly with depth. Barksdale and others (1943, p. 143) stated that the specific yield of rocks of the Triassic system in New Jersey decrease with depth. Stewart (1962) showed graphically that as depth increases, specific yield continuously decreases at a site north-northeast of Atlanta, Georgia, in the Blue Ridge Physiographic Province.

Concavity of the MRC can occur for basins with large relief for the following reasons. As ground-water levels decline, some stream segments may go dry. This, in turn, causes an increase in the distance from some points on the hydrologic divide to the nearest active stream segment, which results in an increase in the average distance from the stream to the hydrologic divide (a) (J.F. Daniel, U.S. Geological Survey, oral commun., 1993). The positive relation between a and the recession index is shown in equation 2. Concavity may be more prevalent in the Blue Ridge Physiographic Province than in the lithologically similar Piedmont because of the greater relief in the former (fig. 9). The tendency of concavity of the MRC in the Blue Ridge Physiographic Province caused by variation in the average distance from the stream to the divide may outweigh the tendency for convexity as a result of the reduction of specific yield as the water table recedes. Amounts of scatter in the relations between basin relief and median basin recession characteristics are considerable (fig. 10). The slight positive relation between relief and the second derivative of the MRC in the Blue Ridge Physiographic Province indicates that concavity tends to increase with relief.

Concavity of the MRC can result when the stream is fed by more than one aquifer. Riggs (1964, p. 353–354, fig. 1) explained and showed graphically that when a stream is fed by two aquifers, the various combinations of two straight-line recession curves (each of which represents one of the aquifers) result in a family of concave recessions that blend into a flatter curve at the lower end. The analyses of stream-flow records for this project do not indicate a flatter curve at the lower end but instead demonstrate a continuous nonlinear ten-

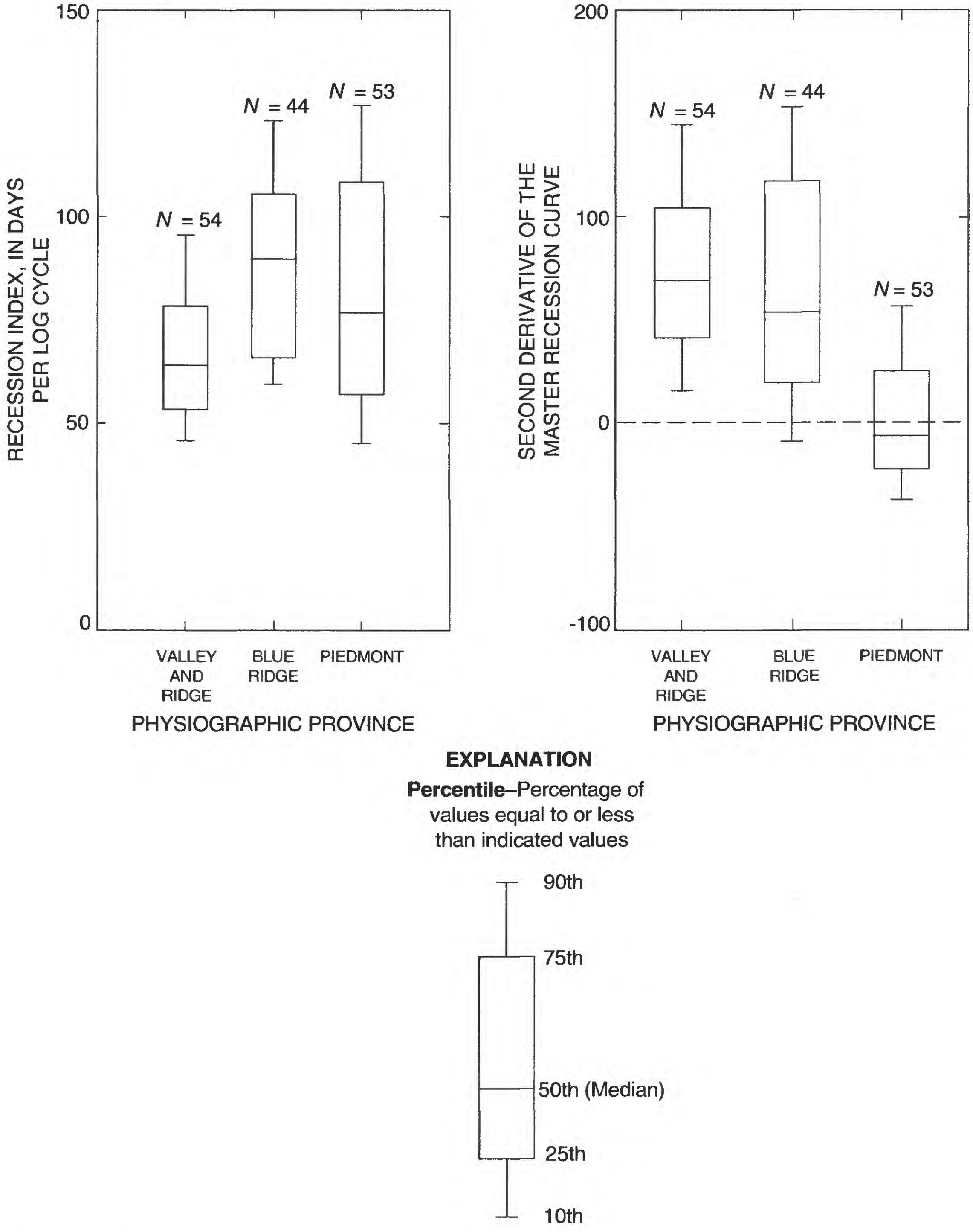


FIGURE 7.—Distribution of the median basin recession index and the second derivative of the master recession curve for basins in the three physiographic provinces. (*N* is the number of gaging stations in the sample.)

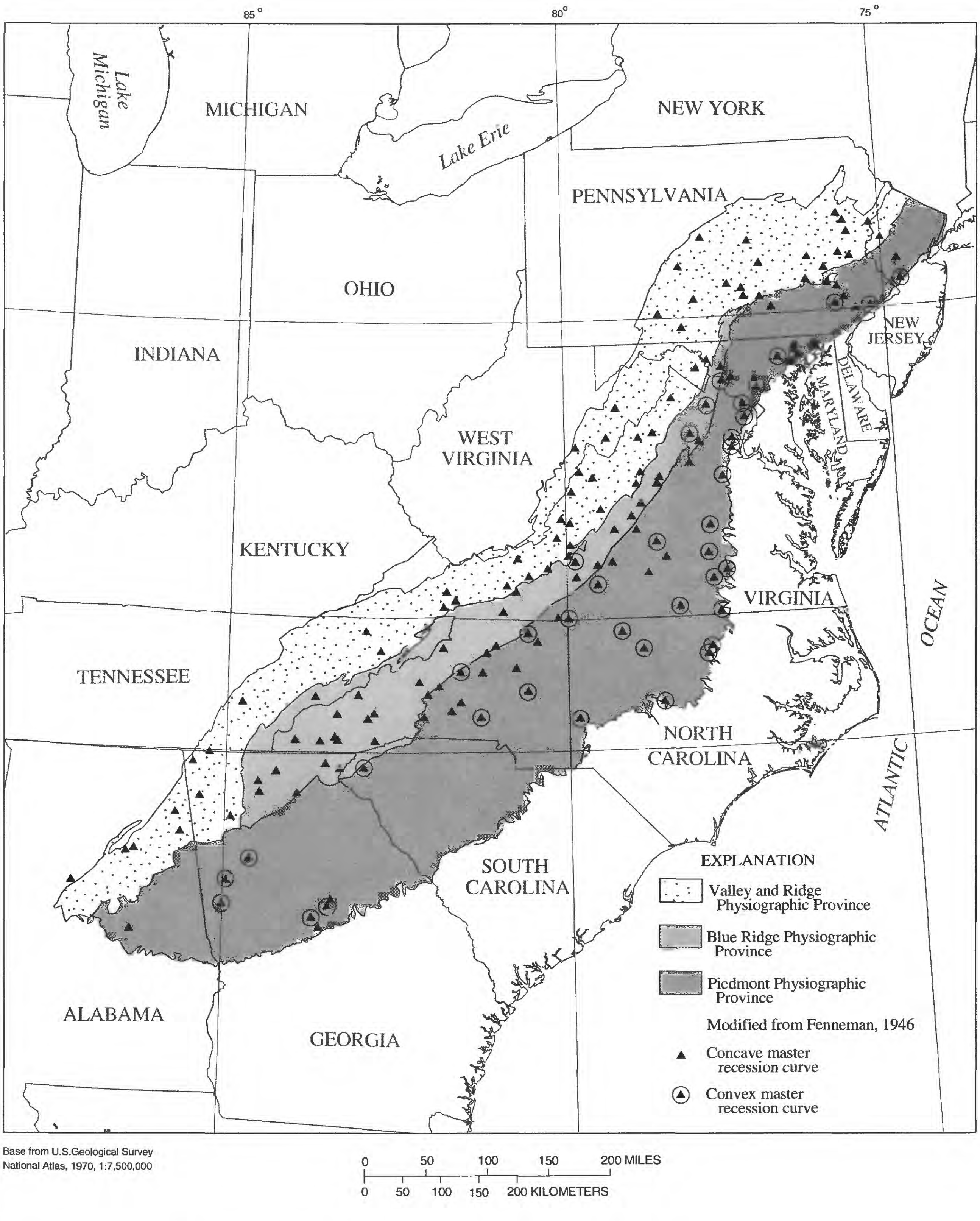


FIGURE 8.—Locations of gaging stations for which master recession curves are concave and convex.

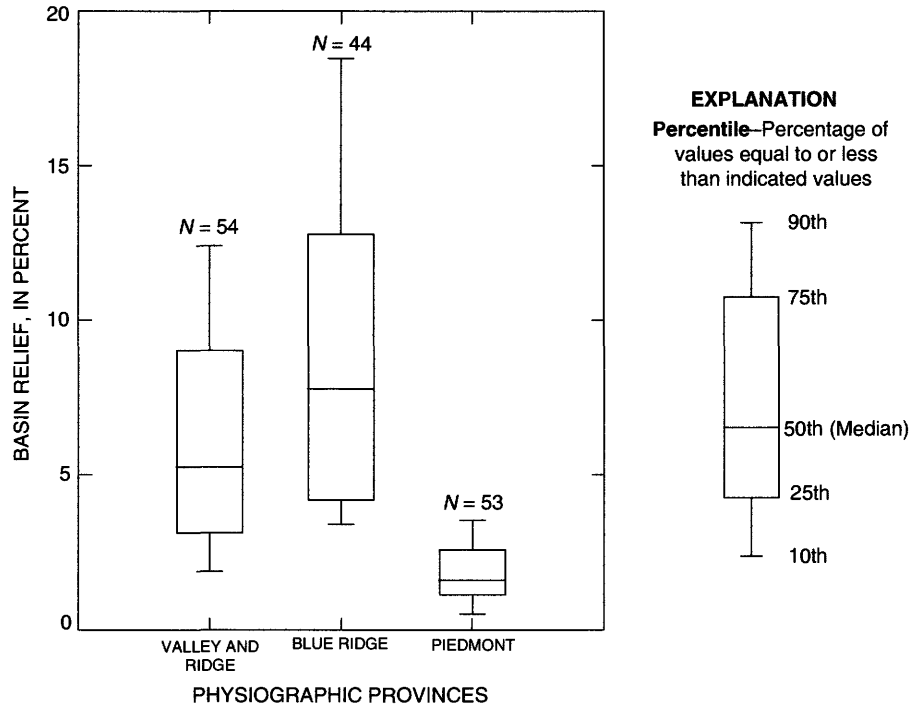


FIGURE 9.—Distribution of basin relief in the three physiographic provinces. (The quantity N is the number of basins in the sample.)

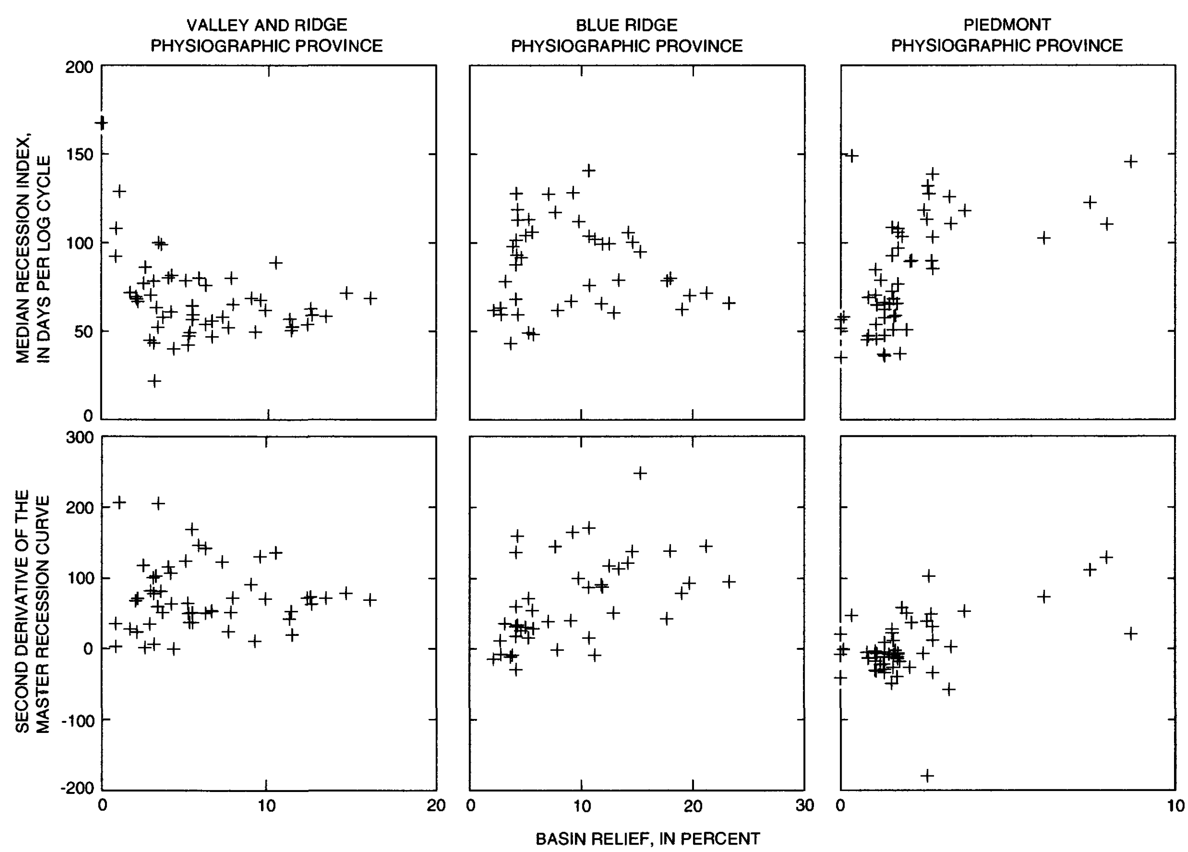


FIGURE 10.—Relations between basin relief and the median basin recession index and between basin relief and the second derivative of the master recession curve for the three physiographic provinces.

dency. This may indicate the effects of more than two aquifers. The concavity that results from this multiple-aquifer effect may be particularly evident in the Valley and Ridge Physiographic Province because of differences between the lithologies of the low-lying valleys and those of the surrounding ridges. This may explain why all streams in the Valley and Ridge Physiographic Province exhibit concavity.

The median basin recession index is notably small for basins that have extremely small relief (close to zero) in the Piedmont Physiographic Province (fig. 10). If the relief gradually increases above zero, then the increase in the recession index is marked. However, when relief exceeds some small value, the recession index exhibits no further increase. This effect may exist only for basins that have extremely small relief, such as those of the Piedmont Physiographic Province. The effect may not manifest itself in other areas of similar geology, such as the Blue Ridge Physiographic Province, because extremely small values of basin relief have not been sampled (fig. 9).

Convexity also may be caused by downward leakage to deeper ground-water-flow systems (Singh, 1969; Daniel, 1976). Chlorofluorocarbons were used to age date ground water in Prince William County, Virginia, by Nelms and Ahlin (1993), who found that young waters (post-1945) are present at depths of greater than 200 ft and that the median age of water from fractured-rock aquifers in the Piedmont is generally younger than that of water from the Coastal Plain aquifers. Swain (1993) identified zones of high well yield in the Piedmont between depths of 350 and 650 ft, which indicates the potential for deep ground-water flow.

The characteristics of the MRC vary with precipitation differently in the three physiographic provinces (fig. 11). Variations with precipitation are slight and only evident for the Blue Ridge Physiographic Province, where the tendency is slight for the recession index and the second derivative of the MRC to increase with precipitation. The increase in the recession index with precipitation may be evident from figure 6, which shows that MRC's have a larger recession index in the

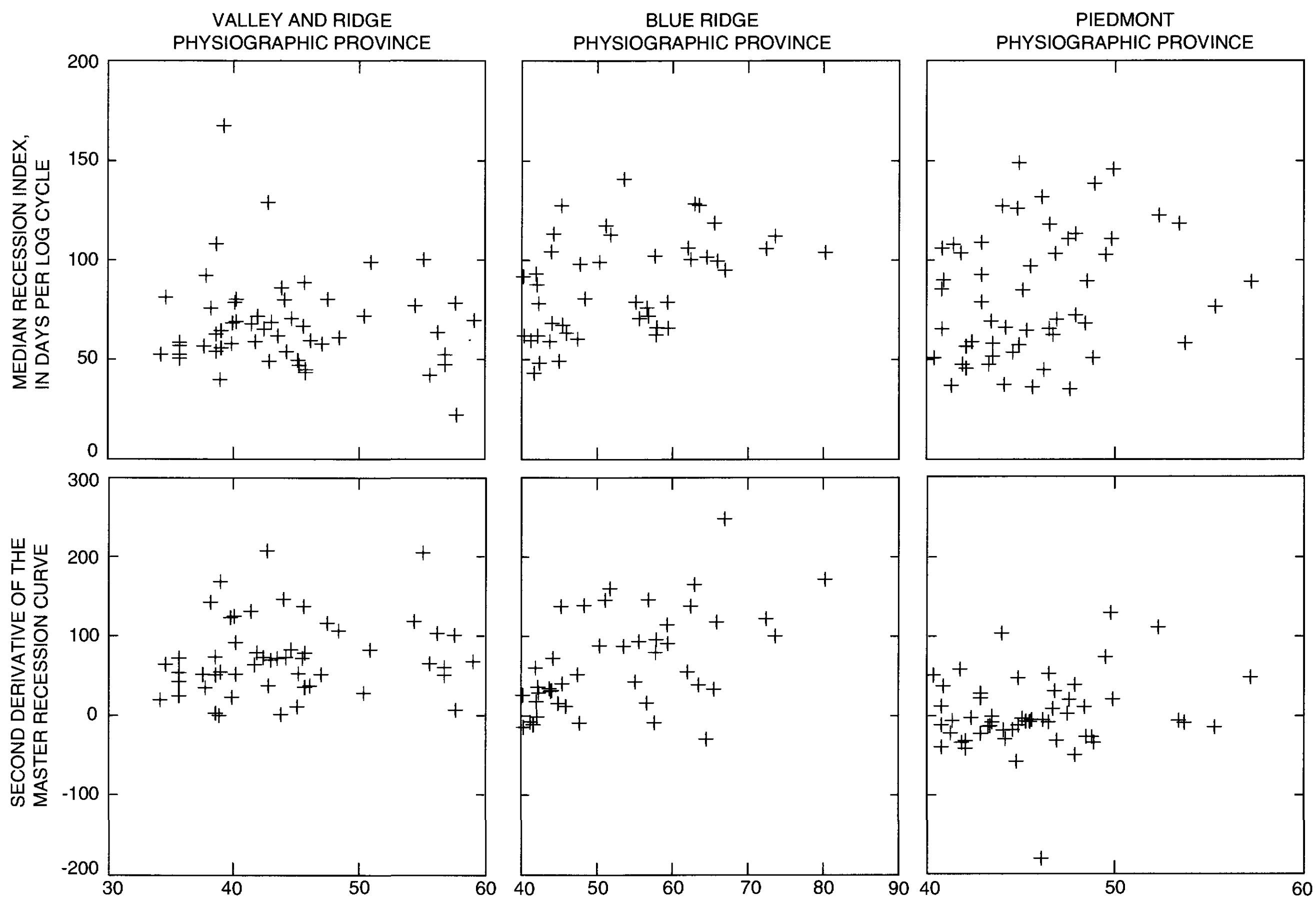


FIGURE 11.—Relations between precipitation and the median basin recession index and between precipitation and the second derivative of the master recession curve for the three physiographic provinces. (The rate of precipitation is the mean for the period from 1961 to 1990.)

southern part of the Blue Ridge Physiographic Province than in the northern part. The rate of precipitation is considerably higher in the southern part of that province than in the northern part (fig. 12).

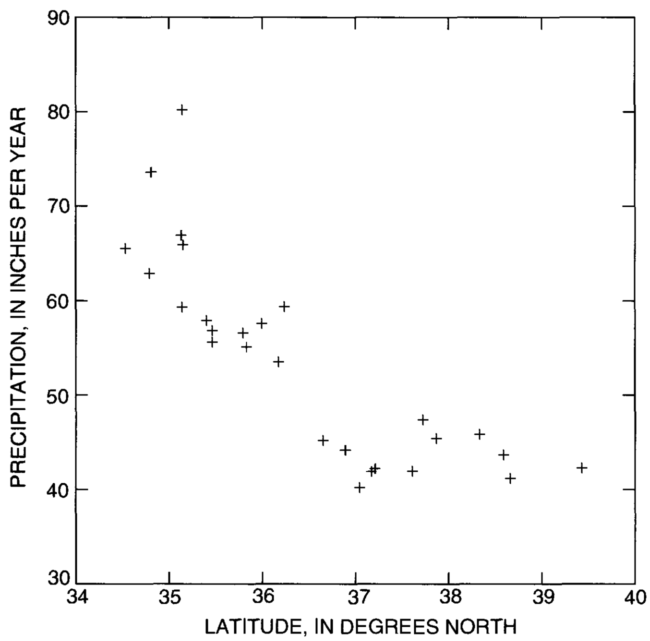


FIGURE 12.—Relation between latitude and precipitation for the Blue Ridge Physiographic Province. (The rate of precipitation is the mean for the period from 1961 to 1990.)

Relations between the capacity of rocks to yield water to wells and the recession characteristic of basins are slight and can be obscured somewhat by scatter, as shown in figures 13 and 14. Because there are no rocks with high well yields in the Blue Ridge Physiographic Province, these illustrations are presented for the Valley and Ridge and the Piedmont Physiographic Provinces only. In both physiographic provinces, the relation between the water-transmitting capacity of rocks—as measured by well yield and specific capacity—and the recession index is notably positive. Figures 13 and 14 may indicate that the capacity of aquifers to transmit water to wells is dependent on the specific yield of aquifers. If transmissivity were the only variable that determined well yield, then rocks with high well yields would coincide with small recession indexes (eq 2). However, because these rocks coincide with large recession indexes, the specific yield may be significantly larger for rocks with high well-yielding properties than for rocks with low well-yielding properties.

ESTIMATES OF DIFFUSIVITY, SPECIFIC YIELD, AND TRANSMISSIVITY

The hydraulic diffusivity of the aquifer can be determined by the following rearrangement of equation 1:

$$\frac{T}{S_y} = \frac{0.933a^2}{K} . \qquad (4)$$

Although estimates could be made for specific basins, the intent here is to give estimates of the range of most diffusivities in the APRASA area. For this estimate, it is reasonable to begin with lower and upper limits between which most values would fall. In figure 7, most values of K fall between 60 and 110 days; the median is about 70 days. Initial estimates for the range of a, which are obtained by scanning the literature (Hely and Olmsted, 1963; Horton, 1945; Langbein, 1947; Trainer, 1969; Trainer and Watkins, 1975), include lower and upper limits of 1,000 ft and 2,000 ft, respectively; an initial estimate of the median is about 1,300 ft. By solving equation 4 for various combinations, it is estimated that most diffusivities will range from 8,000 to 60,000 ft^2/d. The central tendency for the distribution of diffusivity, which is calculated from the median values of K and a, is about 20,000 ft^2/d.

Transmissivity can be estimated by rearranging equation 4 as follows:

$$T = \frac{0.933S_y a^2}{K} .$$

The solution of this equation requires an estimate of the apparent specific yield of the aquifer, which is considered to be the "gravity yield" of the zone of water-table fluctuation. Because the estimation of the apparent specific yield requires considerable ground-water-level monitoring in a basin in combination with an estimate of the volume of outflow from ground water, only a few estimates are available (table 5). To estimate the range within which most values of transmissivity in the APRASA area will occur, a method is used that is similar to that described above for estimating a range for diffusivities. A simplistic approach is used, wherein all the numbers for specific yield in table 5 are considered to be a sample, and the 25th, 50th, and 75th percentiles are determined. The resulting numbers, which are 0.01, 0.04, and 0.08 after conversion to decimals, are then combined with the corresponding ranges for K and a; it is estimated that most transmissivities will range from 80 to 5,000 ft^2/d and that the central tendency is about 900 ft^2/d in the APRASA area.

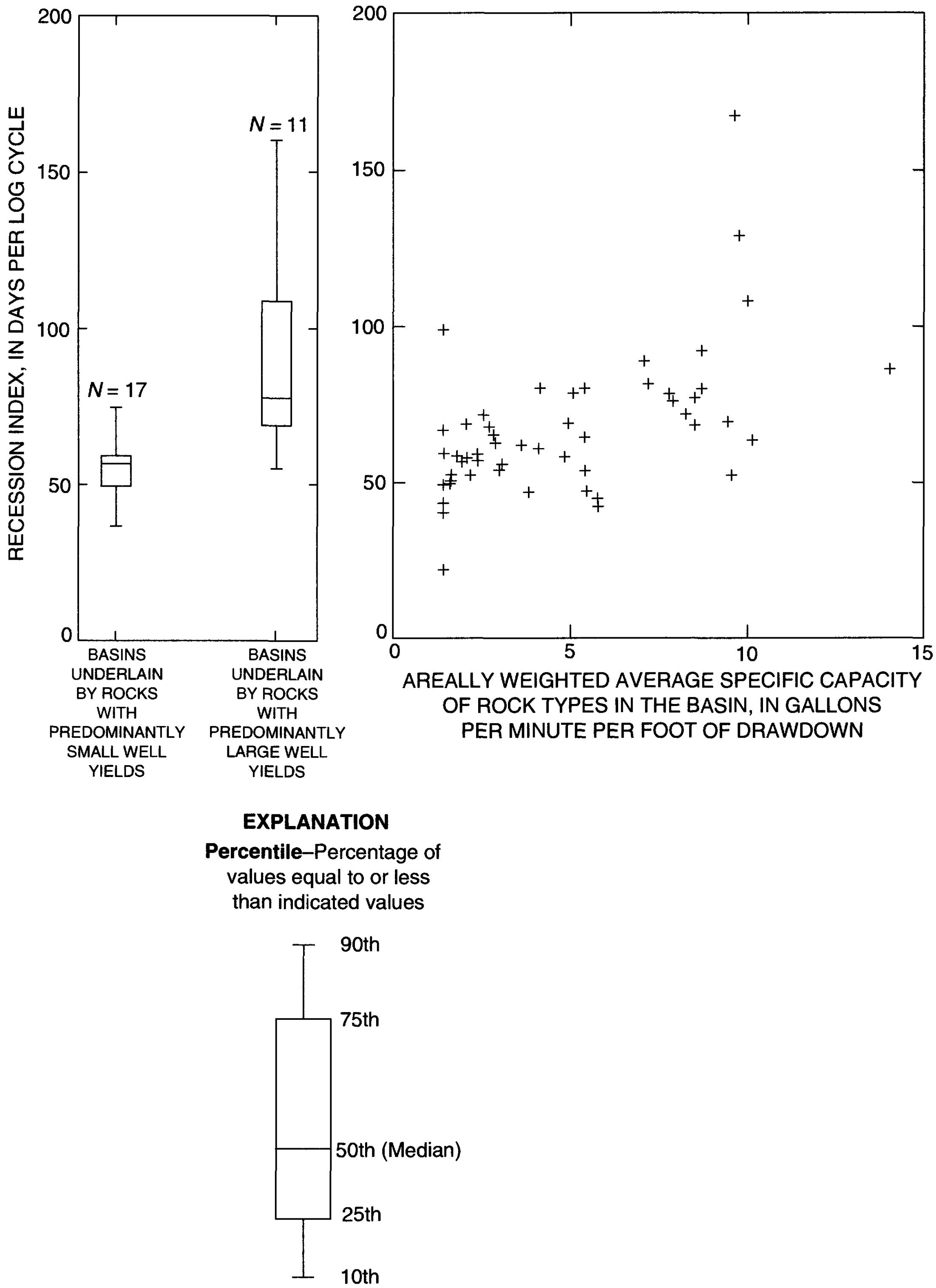


FIGURE 13.—Relation between hydrologic characteristics of rocks in basins and the median basin recession index for the Valley and Ridge Physiographic Province. (Hydrologic characteristics of rocks in basins are explained in the Appendix. N is the number of basins in the sample.)

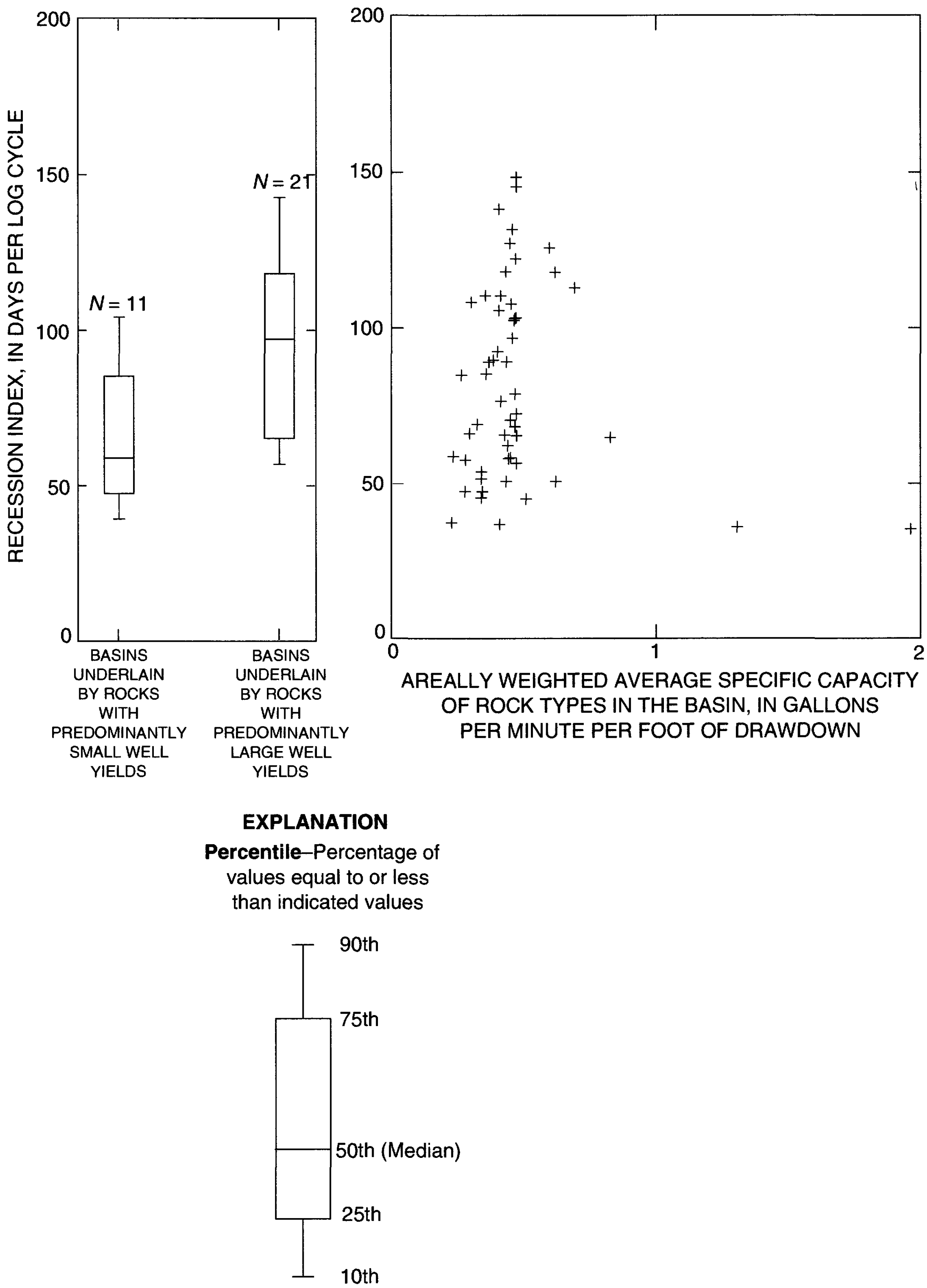


FIGURE 14.—Relation between hydrologic characteristics of rocks in basins and the median basin recession index for the Piedmont Physiographic Province. (Hydrologic characteristics of rocks in basins are explained in the Appendix. The variable *N* is the number of basins in the sample.)

TABLE 5.—*Estimates of the apparent specific yield in the study area*

Source citation	Location of basin	Specific yield, in percent
Becher and Root (1981, p. 12)	Conodoguinet River Basin in the Valley and Ridge Physiographic Province in Pennsylvania (Great Valley).	5.0
Becher and Taylor (1982, p. 32)	Shales of the Martinsburg Formation in the Valley and Ridge Physiographic Province in Pennsylvania.	.5
Duigon and Dine (1987, table 3).	Frederick County, Maryland:	
	Blue Ridge Physiographic Province:	
	Catoctin Creek Basin	8.0
	Hunting Creek Basin	1.2
	Fishing Creek Basin	21.0
	Piedmont Physiographic Province:	
	Monocacy River Basin	1.6
	Bennett Creek Basin	6.3
Hoos, (1990, table 4).	Tennessee:	
	Valley and Ridge Physiographic Province:	
	Lick Creek Basin	1.0
	South Chestuee Creek Basin	1.1
	Blue Ridge Physiographic Province:	
	Doe River Basin	1.0
	Little River Basin	14.0
Lloyd and Growitz (1977, p. 29)	Muddy Creek Basin in the crystalline rocks of the Piedmont Physiographic Province in Pennsylvania.	8.0
Meisler (1963, p. 32)	Lebanon Valley carbonates, in the Valley and Ridge Physiographic Province of Pennsylvania (Great Valley).	5.0
Nutter and Otton (1969, p. 28)	Quartz-mica schist of the Wissahickon Formation in the Piedmont of Maryland.	8.0
Olmsted and Hely (1962, p. 18)	Brandywine Creek Basin in the crystalline rocks of the Piedmont Physiographic Province in Pennsylvania.	7.5–10
Trainer and Watkins (1975, p. 40)	Potomac River Basin:	
	Fractured rock with thin regolith	.5
	Fractured rock with thick regolith	1.0
	Carbonate rocks	3–4
Wood and others (1972, p. 111)	Schantz Spring Basin in the Valley and Ridge Physiographic Province in Pennsylvania (Great Valley).	4.1

RELATIONS AMONG THE RECESSION INDEX AND LOW-FLOW VARIABLES

Because low-flow variables are measurements of flow after periods of sparse recharge, their magnitudes can be related to the rate of recession. Variables such as the annual minimum average 7-consecutive-day low-flow discharge with a 2-year recurrence interval (7*Q*2) and a 10-year recurrence interval (7*Q*10), have been related to the recession index (Harkins, 1982; Bingham, 1982, 1986; Vogel and Kroll, 1992). Johnston (1971) showed that in the Coastal Plain, another low-flow variable, the flow at 90-percent duration, is related to the hydraulic diffusivity of the aquifer, T/S_y, which is as shown related to the recession index, equation 4. How the recession index is related to low-flow variables needs to be demonstrated because of the abundance of past work that relates low-flow variables to the hydrogeologic framework (Hely and Olmsted, 1963; Schneider, 1965b; Trainer and Watkins, 1975; White, 1977; Armbruster, 1976; Hayes, 1991).

The 7*Q*2 is positively related to the median basin recession index (fig. 15*A*) and the mean ground-water recharge (fig. 15*B*). The former relation (fig. 15*A*) indicates that to some extent, the recession index can determine the 7*Q*2. For example, a large recession index will mean that the rate of recession of flow is small and that the residual flow after the period of recession is, there-

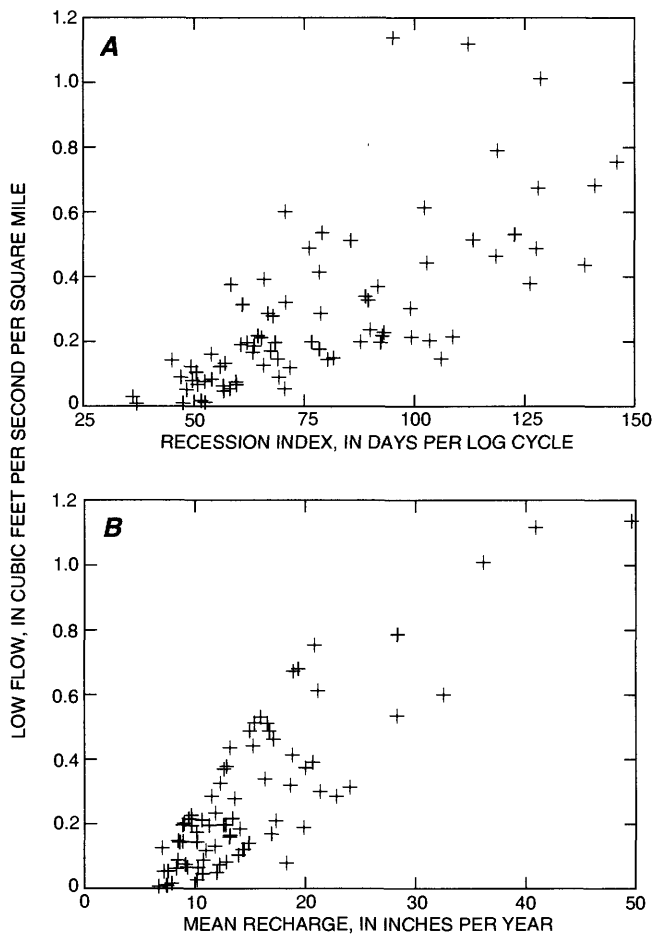


FIGURE 15.—The 7-day, 2-year low flow (7 $Q2$) shown as a function of (A) the median basin recession index and (B) the mean recharge for streamflow-gaging stations in the study area. (The period of calculation is from 1961 to 1990.)

fore, large. Conversely, a small recession index will result in rapid attrition of flow and, therefore, a smaller residual flow. The latter relation (fig. 15*B*) indicates that after some period of sparse recharge, the residual flow (7Q2) may be dependent on the long-term rate of recharge. This could be conceptualized as a relation that is separate from the one that involves the recession index. If two basins have the same recession index, yet one exhibits larger recharge over time, then the recession curves may have the same slope, but one will be displaced upward relative to the other, which will result in a larger residual flow after prolonged periods of sparse recharge. The 7Q2 is determined by using methods described by Hayes (1991), and recharge is determined by using the Rorabaugh Method, which is computerized (Rutledge, 1993).

If the two x-axis variables in figure 15 are considered to be the variables that determine the value of the 7Q2, then it may be proposed that the considerable scatter in each plot is due to variations in the determining variable in the other plot. A new determining variable, which accounts for the recession index and the recharge, is introduced. This new variable is considered to be an estimator of the 7Q2 and is the best-fit linear equation of 7Q2 as a function of the median basin recession index and the mean basin recharge:

$$E = (0.00445\,K_m) + (0.022258\,GWR) - 0.401682,$$

where

E is the estimator of the 7Q2, in cubic feet per second per square mile,

K_m is the median basin recession index, in days per log cycle, and

GWR is the mean rate of ground-water recharge for the basin, in inches per year.

A plot of the 7Q2 as a function of the estimator shows a clear positive relation with relatively small scatter (fig. 16). This and the previous figure demonstrate that the 7Q2 is related to the recession index, but the considerable scatter in the relation is due to variations in recharge. Conversely, the 7Q2 is related to the rate of recharge, and a considerable amount of the scatter in the relation is due to variations in the recession index.

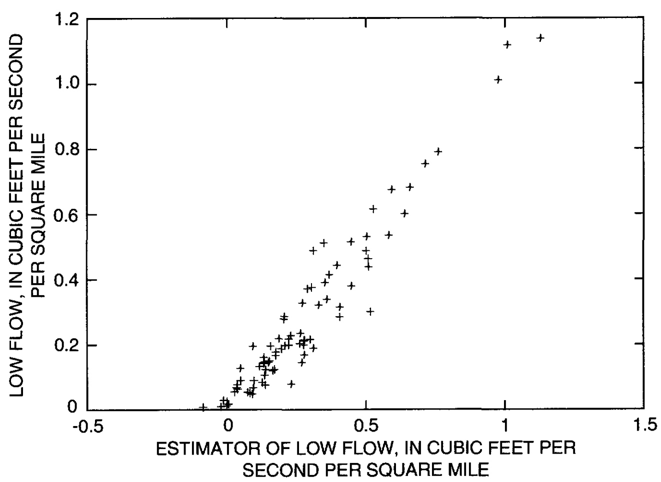


FIGURE 16.—The 7-day, 2-year low flow (7Q2) plotted against an estimator of the low flow that is a linear function of the median basin recession index and the mean recharge for streamflow-gaging stations in the study area.

ANALYSIS OF BASE FLOW AND HYDROLOGIC BUDGETS

The main purpose of base-flow analysis is to estimate the mean rates of ground-water recharge and discharge, which are important components of the hydrologic budgets of basins. The methods are applied over a long period of record (several years), so that the effects of changes in storage can be considered to be negligible. The mean ground-water discharge (base flow), therefore, may be considered to be equal to effective recharge. The mean ground-water recharge should exceed the mean effective recharge by an amount equal to riparian evapotranspiration, which is the loss of water to the atmosphere from ground water and from the stream channel.

Estimates of components of the hydrologic budgets of basins are presented for two periods—1981 to 1990 and 1961 to 1990. The 157 basins that are used in this report (fig. 1) have complete records for 1981 to 1990, and 89 of these have complete records for 1961 to 1990. This 30-year period is used for construction of the "best" estimates of hydrologic budgets because this period should be representative of long-term conditions and corresponds to that of "normal" precipitation data available from the National Climatic Data Center (Appendix).

HYDROLOGIC BUDGET EQUATIONS

The various components of the hydrologic budgets of basins in the APRASA are estimated by using three equations, which are presented here. These equations begin with the most basic and continue with those that include ground-water terms. Ground-water withdrawals and leakage to or from deeper ground-water-flow systems are assumed to be negligible. In the simplest form, the hydrologic budget of a basin in the APRASA can be expressed as follows:

$$PR = ET + SF, \tag{5}$$

where

PR is the mean precipitation, in inches per year,

ET is the mean evapotranspiration, in inches per year, and

SF is the mean streamflow, in inches per year.

The variable PR is obtained as described in the appendix, the variable SF is obtained from USGS streamflow records; and the variable ET, which represents total evapotranspiration, is estimated simply as the difference.

The streamflow can be expressed as the sum of a surface and a subsurface term:

$$SF = DR + GWD \tag{6}$$

where DR is the mean direct runoff in inches per year, and GWD is the mean ground-water discharge (base flow), in inches per year.

The following equation is used to account for ground-water recharge:

$$GWR = GWD + RET, \tag{7}$$

where RET is the mean riparian evapotranspiration, in inches per year.

ESTIMATES OF GROUND-WATER RECHARGE AND DISCHARGE AND RIPARIAN-ZONE EVAPOTRANSPIRATION

Two computerized methods are used in base-flow analysis—recession-curve displacement, which estimates ground-water recharge, and base-flow-record estimation, which estimates ground-water discharge. The documentation of the computerized methods used here (Rutledge, 1993) includes detailed discussion of the mathematical development of the methods, instructions for execution of the programs, and comparisons between results of the programs and those of the corresponding manual methods. Results of the computerized recession-curve-displacement method are tested by comparison with results of the corresponding manual method (Rutledge and Daniel, 1994).

The recession-curve-displacement method, or the Rorabaugh Method (Rorabaugh, 1964; Daniel, 1976), is based on the estimation of the total potential ground-water discharge of the aquifer at a critical time after the peak. Two estimates of the total potential ground-water discharge are obtained for each streamflow peak—one extrapolated from the period of recession that precedes the peak and the other from the period that follows the peak. The recharge is determined from the difference. The method, which can be applied to a long period of record to give an estimate of the GWR, was applied in earlier studies by using manual methods (Wilder and Simmons, 1978, 1982; Daniel and Sharpless, 1983; Bevans, 1986; Gerhart and Lazorchick, 1988; Faye and Mayer, 1990; Hoos, 1990).

The computerized method of base-flow-record estimation, which was adapted from earlier methods called streamflow partitioning (Knisel and Sheridan, 1983; Shirmohammadi, Knisel, and Sheridan, 1984; Shirmohammadi, Sheridan, and Knisel, 1987), consists of the estimation of a daily record of ground-water discharge as part of the total stream-discharge record. The algorithm scans the record for days that fit a requirement of antecedent recession, designates ground-water discharge to be equal to streamflow on these days, and then linearly interpolates the daily record of ground-water discharge for days that do not fit the requirement of antecedent recession. The practice of base-flow-record estimation, which is usually applied to a long period of record to give an estimate of the GWD, has been applied earlier by manual methods (Horton, 1933; Barnes, 1939; Snyder, 1939; Olmsted and Hely, 1962; Chow, 1964).

Correlation is good between ground-water recharge and discharge (fig. 17). The distributions of recharge and discharge are shown in table 6 for 1981 to 1990, during which complete records were available for 157 basins, and for 1961 to 1990, during which complete records were available for 89 basins.

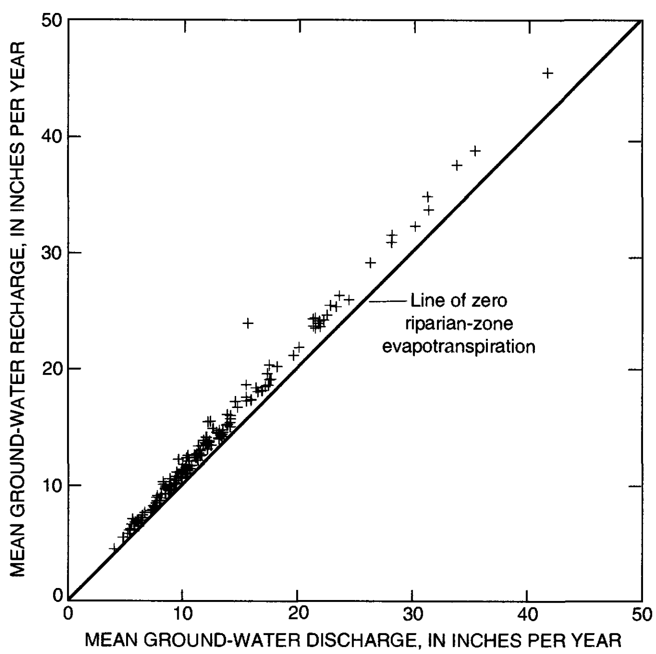


FIGURE 17.—Relation between mean ground-water recharge and discharge. (Data points represent the mean rates from 1981 to 1990 for 157 streamflow-gaging stations in the study area.)

TABLE 6. *Statistical distribution of recharge and discharge, in inches per year, for basins in the study area*

	1981 to 1990 (sample size, 157)		1961 to 1990 (sample size, 89)	
	Mean recharge	Mean discharge	Mean recharge	Mean discharge
Maximum	46	42	50	46
75th percentile	18	16	19	17
Median	13	12	13	12
25th percentile	10	9	10	9
Minimum	5	4	6	5

Theoretically, riparian evapotranspiration is the difference between mean ground-water recharge and discharge (eq 7). This difference, which shows a positive relation to ground-water recharge (fig. 18), has the potential for considerable error in its representation of riparian evapotranspiration because it is calculated as the difference between two other variables that are about an order of magnitude larger. However, the range of *RET* in the APRASA area can be assumed to be as depicted in figure 18*B*. After elimination of the apparent outlier at 8.4 in/yr, *RET* ranges from 0.4 to 3.8 in/yr, and the 25th, 50th, and 75th percentiles of the distribution are 1.0, 1.4, and 2.1 in/yr, respectively. Ground-water evapotranspiration was estimated to be about 3 in/yr for three Coastal Plain basins in the Delmarva Peninsula (Johnston, 1976) and 2.4 in/yr for a stream in Alabama (Daniel, 1976).

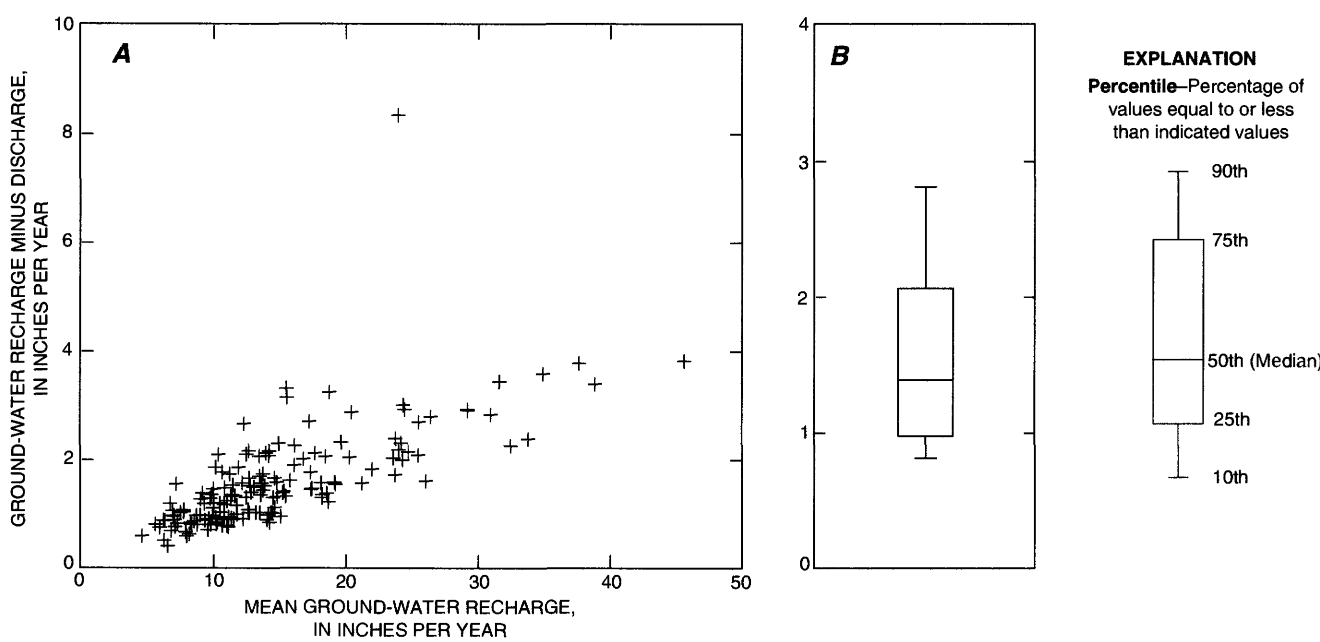


FIGURE 18.—Mean ground-water recharge minus mean ground-water discharge. *A*, As a function of the mean ground-water recharge; *B*, As a box plot. (The sample represents mean rates for 157 streamflow-gaging stations in the study area from 1981 to 1990.)

VARIATION IN RECHARGE IN THE STUDY AREA

A plot of recharge as a function of precipitation for the APRASA area shows a positive correlation with a considerable amount of scatter (fig. 19). The best-fit linear equation has roughly unit gradient (0.86) and an X-intercept that is close to 28 in/yr. The X-intercept may be dependent, for the most part, on evapotranspiration and may represent a threshold that must be exceeded by precipitation before recharge is significant. The median evapotranspiration for the study area, which was calculated from equation 5, is 26 in/yr. Similar plots generated for each physiographic province show that the widest range of precipitation (and thus recharge) occurs in the Blue Ridge Physiographic Province (fig. 20); the highest rates of precipitation tend to be in the southern parts of that province (fig. 12).

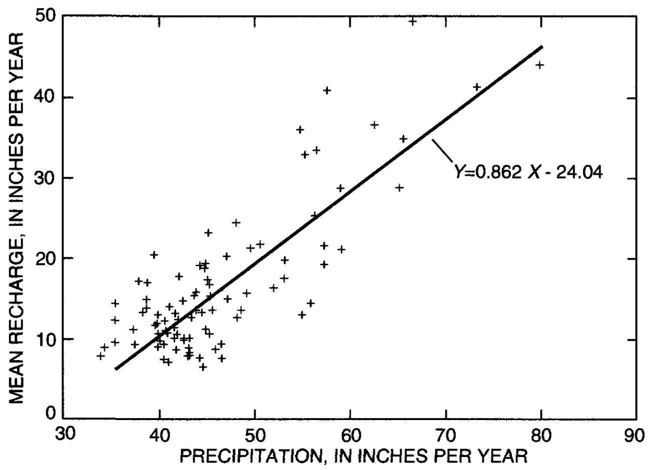


FIGURE 19.—Relation between precipitation and the rate of recharge for the study area. (Rates shown are the mean from 1961 to 1990.)

Plots of recharge as a function of basin relief differ among the three physiographic provinces. A slight negative relation between recharge and relief is suggested in the Valley and the Ridge Physiographic Province; however, the relation is clearly positive in the Blue Ridge and Piedmont Physiographic Provinces (fig. 21). The reason for the positive correlation is not known—a negative correlation is more easily reconciled because as relief increases, the direct runoff would seem to increase, thus reducing the amount of infiltration. The positive correlation may be related to a slight increase in precipitation as relief increases. This, in turn, is related to orographic effects because areas of high elevation tend to be areas of greater relief.

In the Blue Ridge and the Piedmont Physiographic Provinces (combined), a reasonably good estimator of recharge can be derived from precipitation and basin relief (fig. 22). The estimator is obtained from the best-fit linear equation of recharge, which is a function of precipitation and relief,

$$E_r = (0.70963\,PR) + (0.88927\,REL) - 22.996,$$

where E_r is the estimator of recharge, in inches per year, and REL is the median basin relief, in percent. Other such attempts were made to relate physical properties to recharge in other parts of the APRASA study area, with little success.

For the most part, the relations are not clear between the water-yielding capacity of rocks and recharge in the Valley and Ridge Physiographic Province (fig. 23), but the tendency is slightly positive in the Piedmont Physiographic Province (fig. 24).

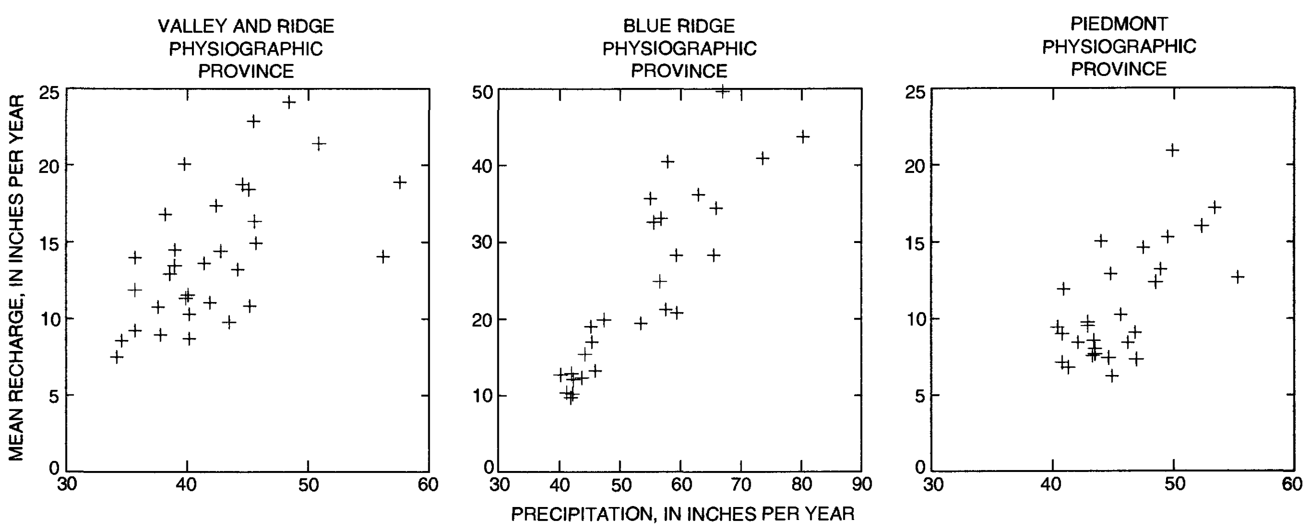


FIGURE 20.—Relation between precipitation and the rate of recharge for the three physiographic provinces. (Rates represent the mean 1961 to 1990.)

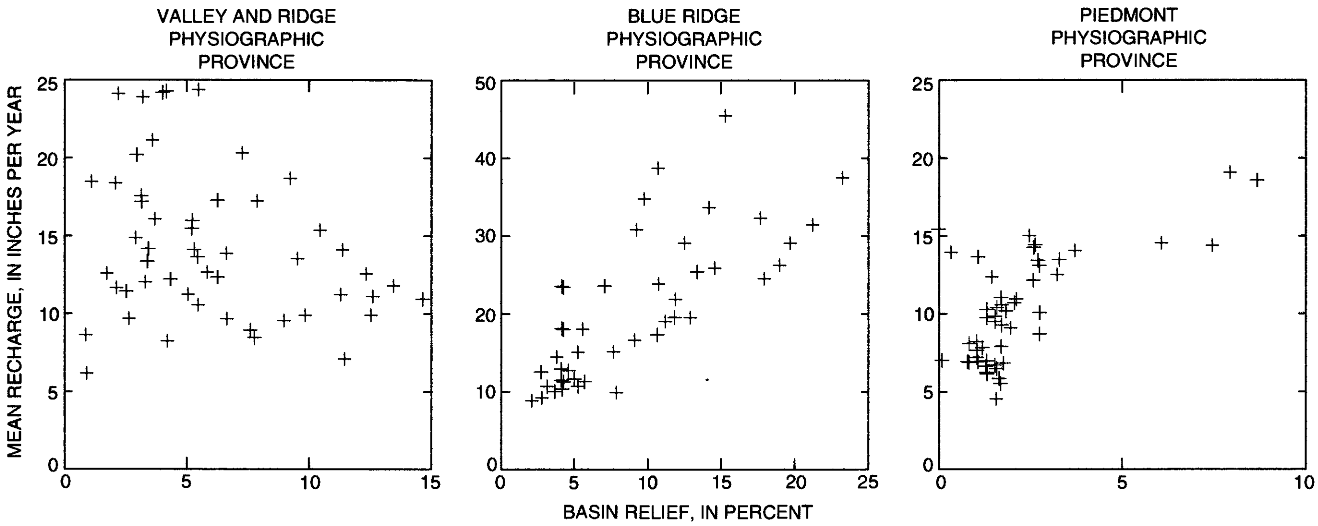


FIGURE 21.—Relation between basin relief and the rate of recharge for the three physiographic provinces. (Recharge shown is the mean for 1981 to 1990.)

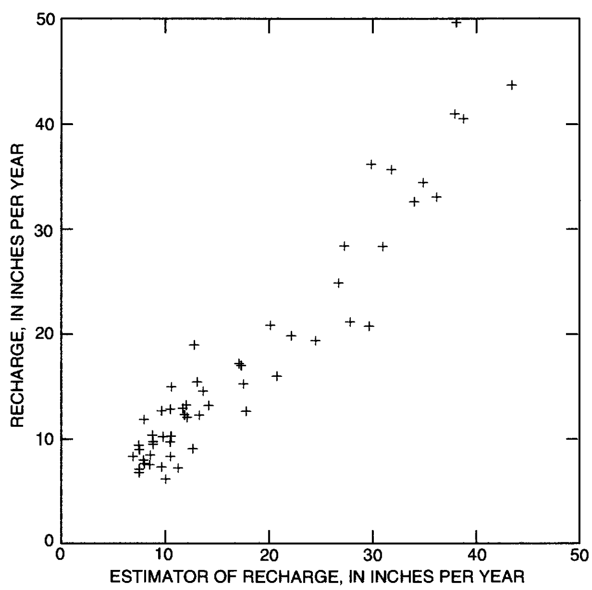


FIGURE 22.—Relation between mean recharge and an estimator of mean recharge that is a linear function of precipitation and relief for 55 streamflow-gaging stations in the Blue Ridge and the Piedmont Physiographic Provinces. (The period of calculation is from 1961 to 1990).

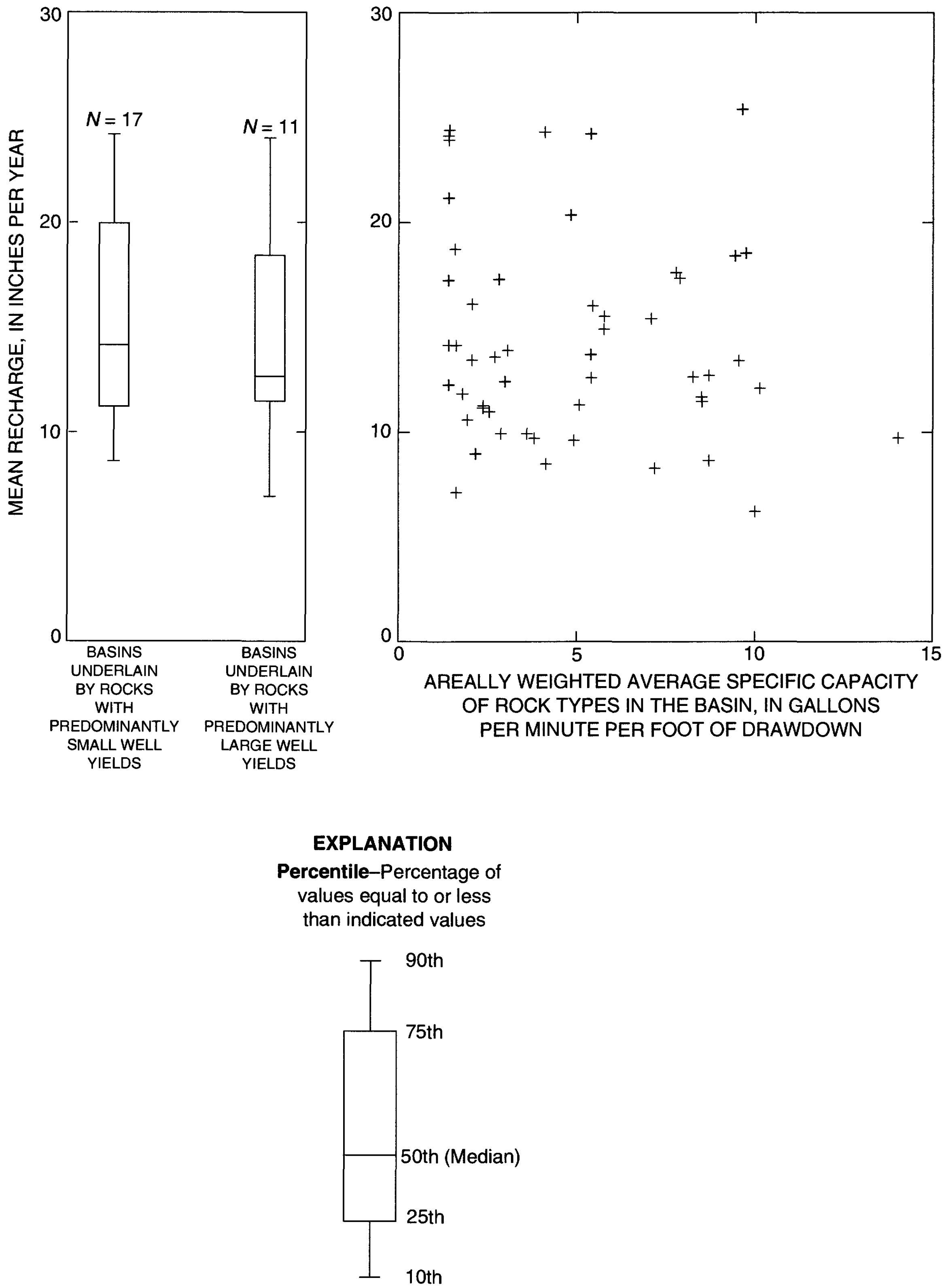


FIGURE 23.—Relation between hydrologic characteristics of the rocks in basins and the mean recharge for the Valley and Ridge Physiographic Province. (Hydrologic characteristics of rocks in basins are explained in the Appendix. Recharge is calculated for 1981 to 1990. *N* is the number of basins or sample size.)

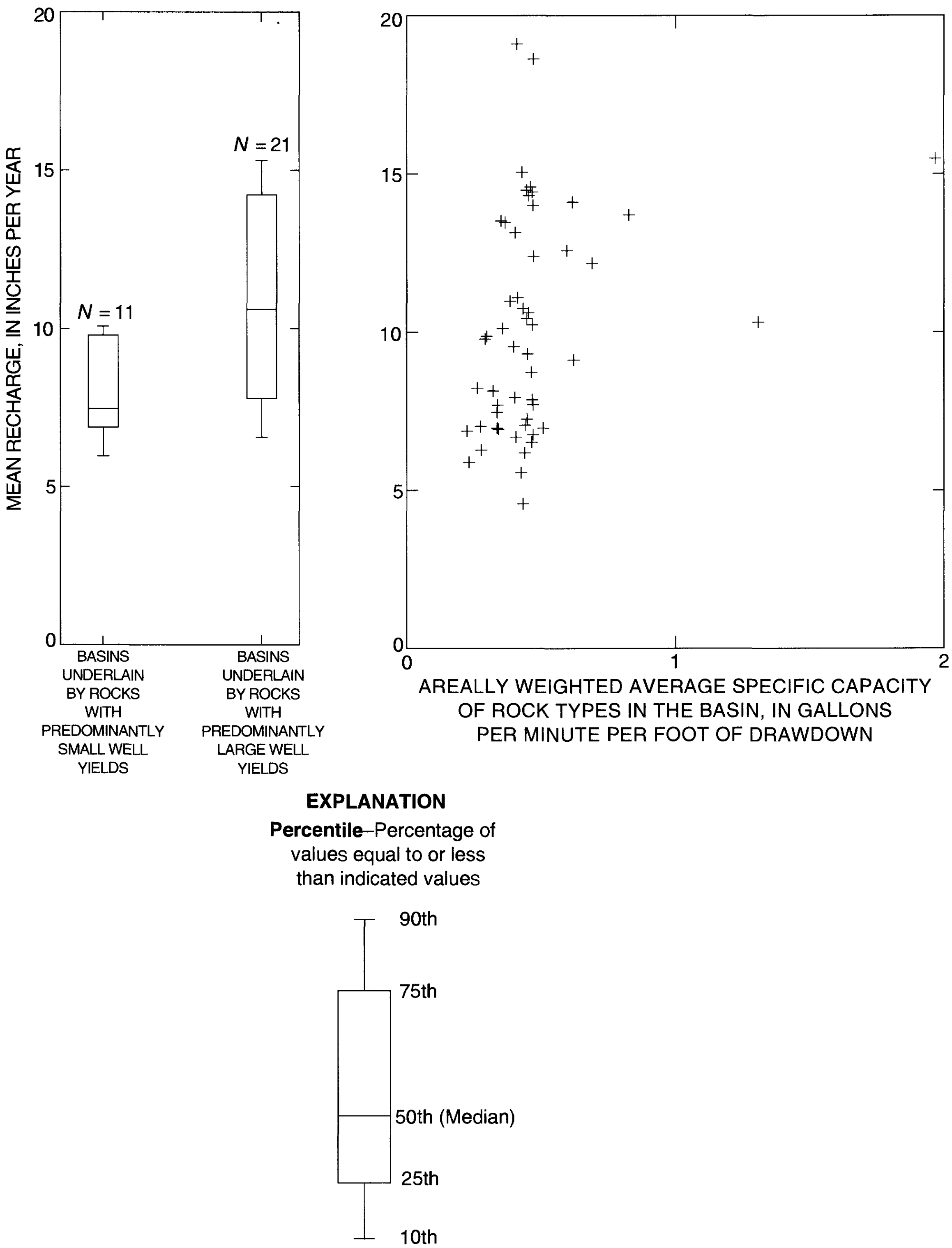


FIGURE 24.—Relation between hydrologic characteristics of rocks in basins and the mean recharge for the Piedmont Physiographic Province. (Hydrologic characteristics of rocks in basins are explained in the Appendix. Recharge is calculated for 1981 to 1990. *N* is the number of basins or sample size.)

BASE-FLOW INDEX

The base-flow index (BFI) (Nathan and McMahon, 1990), which is calculated as the ratio of mean ground-water discharge (base flow) to mean streamflow, provides a way of normalizing ground-water discharge to climatic conditions. The stability of the BFI relative to various components of the hydrologic budget can be demonstrated by calculating the ratio of BFI for one time period to that for another time period and comparing this ratio with the corresponding ratios for various components of the water balance. Stability of the BFI is demonstrated by the proximity of the ratio to unity (fig. 25). The stability of the BFI may make it ideal for basin comparisons when the various basins have differing periods of streamflow record or the available period of record is short.

The BFI ranges from 32 to 94 percent, and the 25th, 50th, and 75th percentiles are 59, 67, and 75 percent, respectively, for the APRASA area (sample size is 157). The BFI is largest in the southern part of the Blue Ridge Physiographic Province (fig. 26).

The BFI exhibits a clear increase with precipitation for the Blue Ridge Physiographic Province, but not for the other provinces (fig. 27). A slightly negative relation is evident for the Valley and Ridge Physiographic Province, although the relation shows considerable scatter.

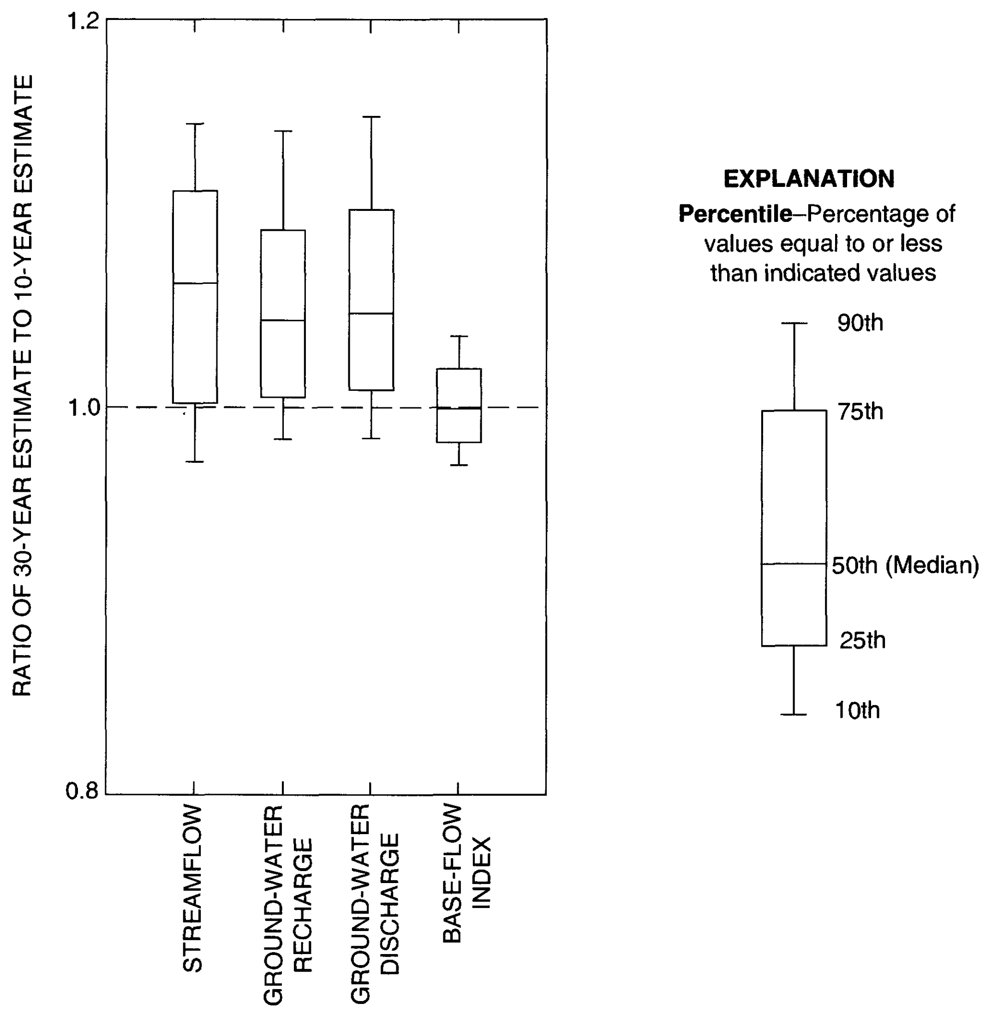


FIGURE 25.—Distributions of the ratio of the 30-year estimate to the 10-year estimate for the streamflow, ground-water recharge and discharge, and the base-flow index. (The 30-year period is from 1961 to 1990, and the 10-year period is from 1981 to 1990. Sample size is 89.)

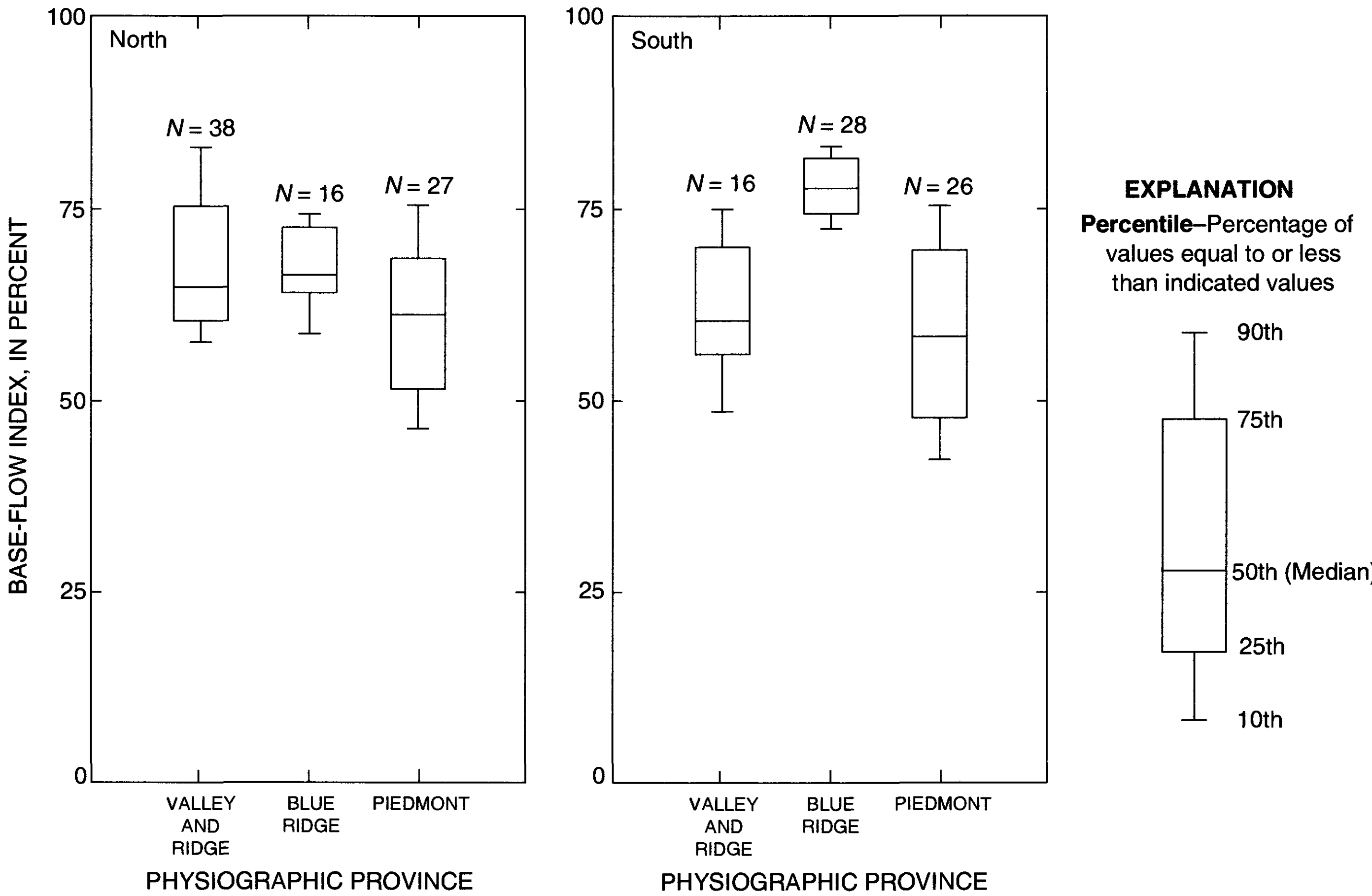


FIGURE 26.—Distributions of the base-flow index for basins in various parts of the study area. (The time period of calculation is from 1981 to 1990. For each physiographic province, the base-flow index is shown for streamflow-gaging stations north and south of latitude 37. *N* is the number of gaging stations in the sample.)

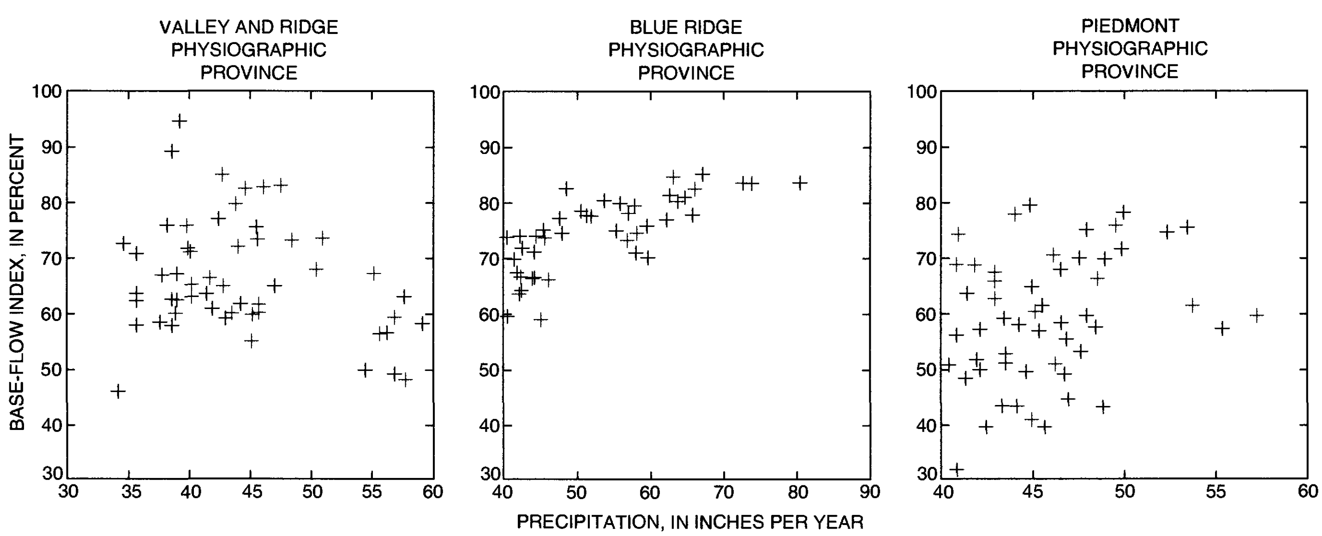


FIGURE 27.—Relation between precipitation and the base-flow index for the three physiographic provinces. (The period of calculation is from 1981 to 1990 for the base-flow index and from 1961 to 1990 for precipitation.)

DURATION-CURVE SURROGATES FOR MEAN GROUND-WATER DISCHARGE

Many studies have used a statistic from the flow-duration curve as a substitute for direct estimates of mean ground-water discharge (base flow). The flow-duration curve, which is simply a cumulative frequency curve (Searcy, 1959), shows the percentage of time that specified rates of flow are equaled or exceeded. Some workers select a variable, such as the *Q*90 (the flow that is equaled or exceeded by 90 percent of the flow on record), as a conservative estimator for ground-water discharge (Wyrick, 1968; Lichtler and Wait, 1974). Others have run tests to determine the best surrogate for mean ground-water discharge. Cushing, Kantrowitz, and Taylor (1973) found that the *Q*50 (median flow) was a reasonable estimate on the basis of comparisons of duration-curve statistics and results of hydrograph separation for Coastal Plain streams in the Delmarva Peninsula. Trainer and Watkins (1975, p. 42–43) stated that in the upper Potomac River Basin, "the estimated base-runoff discharges correspond to discharge values on the flow-duration curve that range from 39 to 61 percent and average 52 percent." The correct duration-curve statistic may depend on the hydrogeologic setting (Lichtler and Wait, 1974, p. 19; Wyrick and Lloyd, 1968, p. H–19).

The ratio of flow-frequency statistic to mean ground-water discharge is plotted for a range of flow-frequency statistics to determine the best surrogate for the APRASA area. As a result of experimentation, these statistics were found to be similar for the Blue Ridge and the Piedmont Physiographic Provinces and, therefore, are plotted together (fig. 28). The best surrogate will result in a ratio that is closest to 1.0. The surrogates are, therefore, determined to be *Q*42 for the Valley and Ridge Physiographic Province and *Q*46 for the other two provinces. They can be confirmed by plotting ground-water discharge as functions of *Q*42 for the Valley and Ridge Physiographic Province (fig. 29) and *Q*46 for the Blue Ridge and Piedmont Physiographic Provinces (fig. 30).

COMPONENTS OF HYDROLOGIC BUDGETS OF BASINS

The results of equations 5 through 7 and the computer programs for estimating ground-water recharge and discharge, which are listed for 89 basins in table 3, are illustrated for various subareas of the APRASA in figure 31. Notable differences between the southern part of the Blue Ridge Physiographic Province and the rest of the study area are shown in table 7. Numbers that represent the distribution of each hydrologic budget component were determined separately. Therefore, the numbers in any given row in table 7 may not represent the same basin.

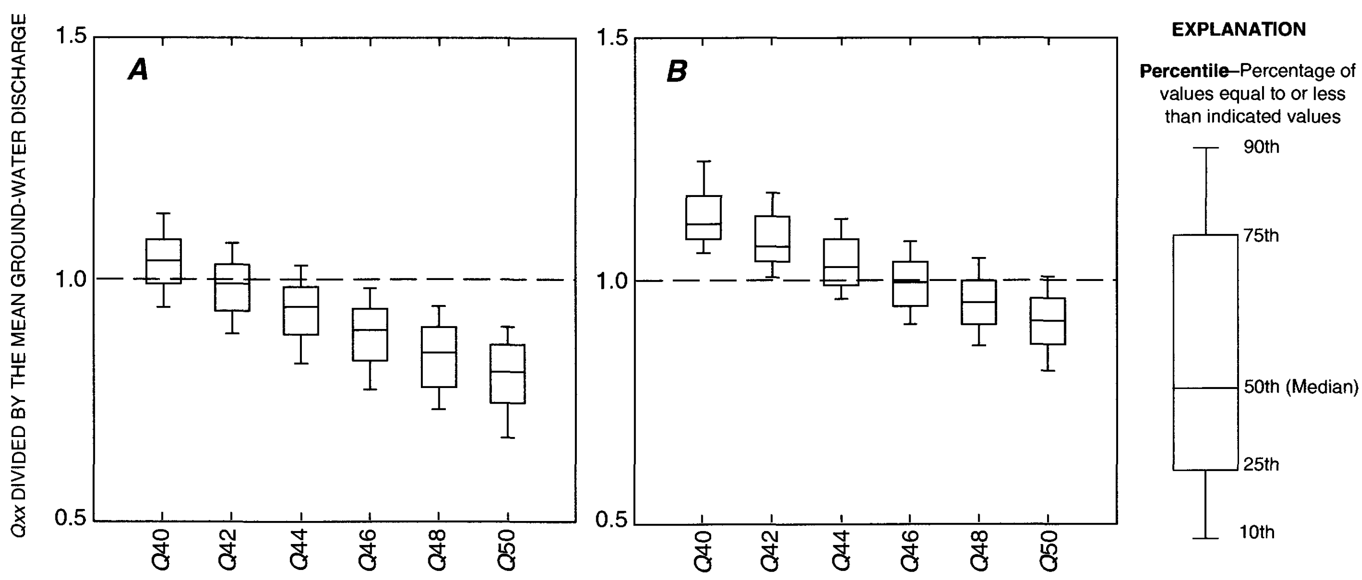


FIGURE 28.—Ratio of six flow frequency statistics to the mean ground-water discharge. *A*, Valley and Ridge Physiographic Province; *B*, Blue Ridge and the Piedmont Physiographic Provinces. (The *Q*xx is the streamflow that is equal to or exceeded by xx percent of streamflow on record. The time period is from 1981 to 1990. Sample sizes are 54 for *A* and 97 for *B*.)

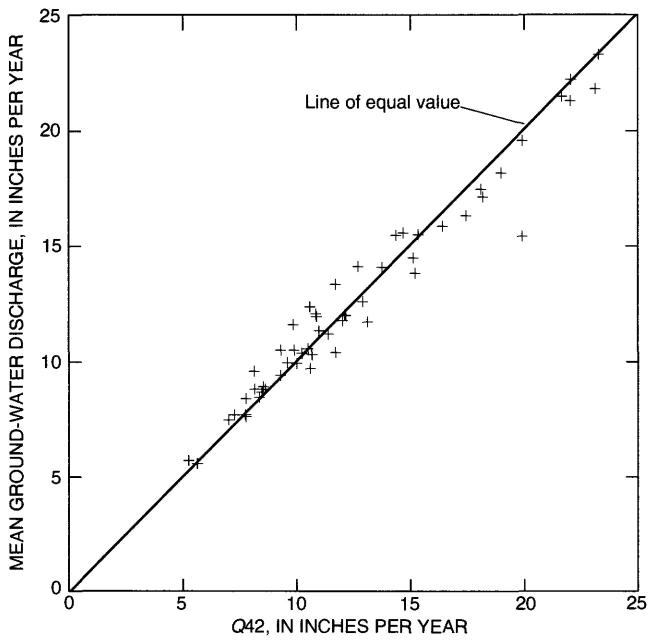


FIGURE 29.—Relation between the $Q42$ flow-frequency statistic and the mean ground-water discharge for the Valley and Ridge Physiographic Province. (The $Q42$ is the streamflow that is equal to or exceeded by 42 percent of the streamflow on record. The time period is from 1981 to 1990. The number of data points is 54.)

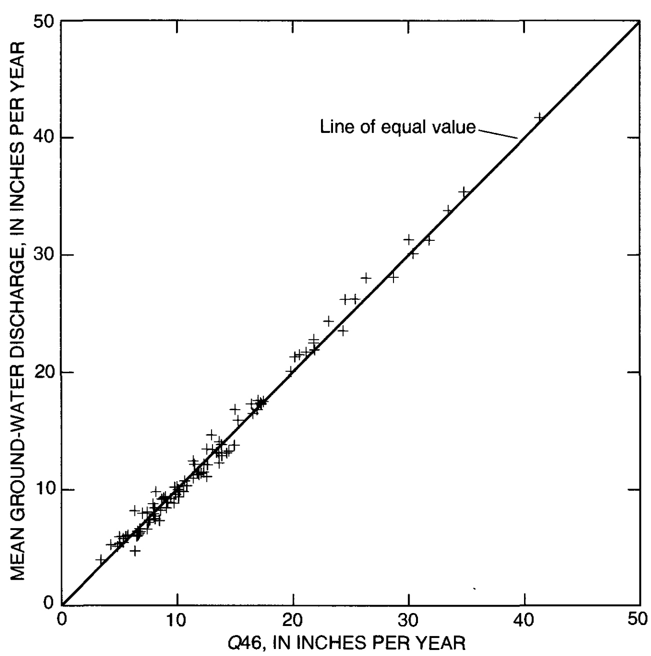


FIGURE 30.—Relation between the $Q46$ flow-frequency statistic and the mean ground-water discharge for the Blue Ridge and the Piedmont Physiographic Provinces. (The $Q46$ is the streamflow that is equal to or exceeded by 46 percent of the streamflow on record. The time period is from 1981 to 1990. The number of data points is 97.)

EFFECTS OF DRAINAGE AREA ON BASIN HYDROLOGIC CHARACTERISTICS

In general, basin hydrologic characteristics indicate diminishing variability from one basin to another as basin drainage area increases (fig. 32). Although part of this effect may be related to the reduction in sample number as the drainage area increases, part also may be attributed to an averaging of physical properties within the basins. This averaging effect can be demonstrated by using an idealized hypothetical model in which a number of physical variables precisely determine a hydrologic variable. For this simple example, the hydrologic variable is mean recharge, and the three physical variables each represent a particular geology—A, B, or C. Any particular map location in the hypothetical model is characterized as having one of these geologic types. The mean rate of ground-water recharge at that location is determined by the geologic type; that is, locations with geologic type A have a rate of 5 in/yr; geologic type B, 10 in/yr; and geologic type C, 15 in/yr. The hypothetical world is mapped by polygons of various sizes and shapes that represent geologic types. If basins also are conceptualized as polygons of various sizes, then the rate of mean recharge for the entire basin (averaged over time and over the basin area) can be determined by the following

$$R_{mean} = \frac{5G_a}{100} + \frac{10G_b}{100} + \frac{15G_c}{100} \quad , \qquad (8)$$

where G_a, G_b, and G_c are the percentages of the basin area that is covered by geology A, B, or C, respectively.

The small basins are considerably more likely than the large basins to be underlain by only one geologic type. This characteristic causes a larger spread among values of mean recharge for the small basins than for the larger basins. This apparent effect of drainage area manifests itself on a graph of mean basin recharge as a function of basin area, and similar effects should be evident for other basin hydrologic variables (fig. 32). The effect of drainage area is referred to as "apparent" because the model shows the effect without explicitly using the variable "drainage area."

Other models could be constructed for determining the other hydrologic characteristics. Some of these models might have a mathematical structure that is similar to equation 8 but with different variables. In the case of variables such as the recession index, the mathematical model would be considerably more complex—if it could be formulated at all—but the tendency for variables to exhibit greater variations among basins of small drainage area would probably be similar.

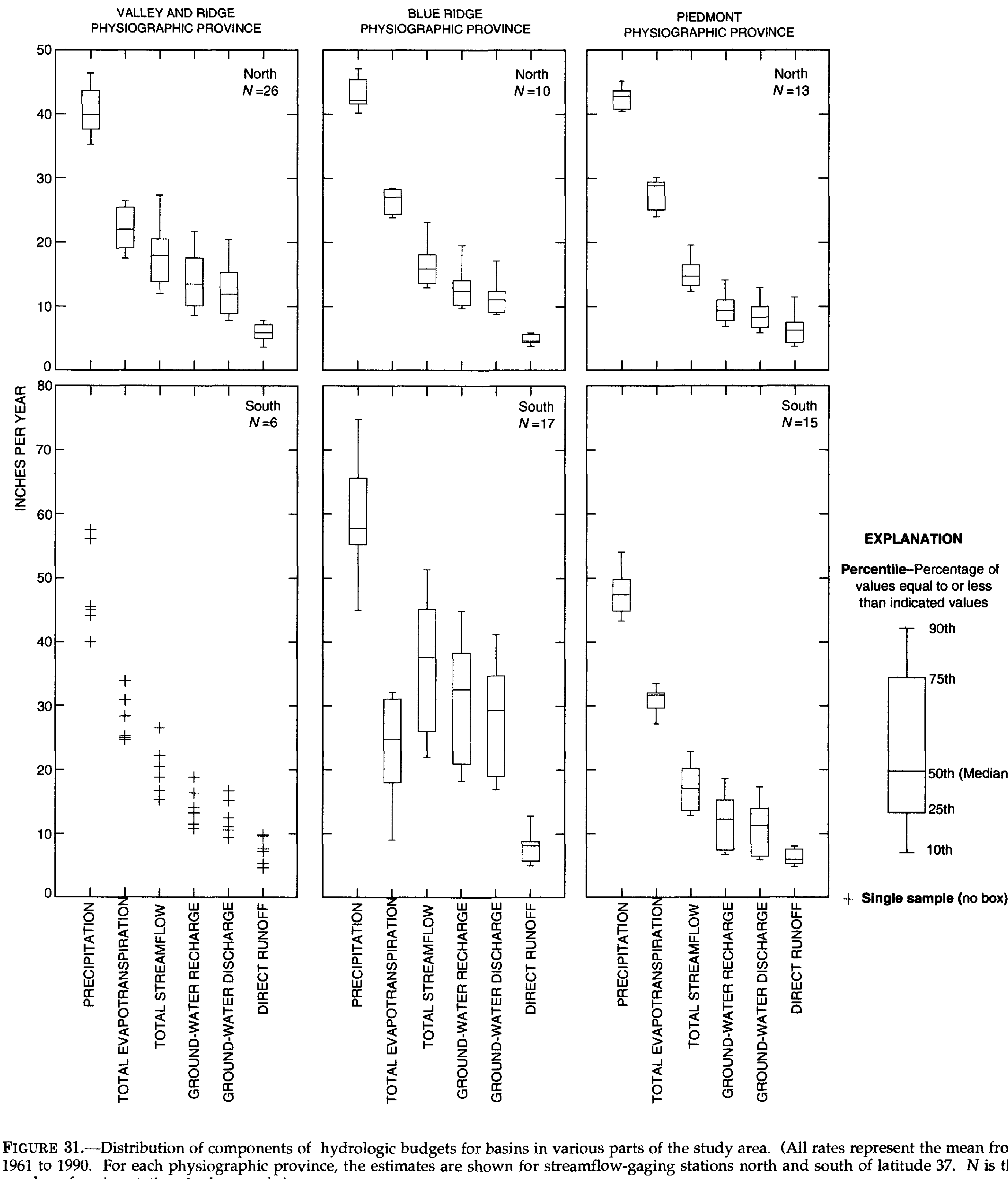


FIGURE 31.—Distribution of components of hydrologic budgets for basins in various parts of the study area. (All rates represent the mean from 1961 to 1990. For each physiographic province, the estimates are shown for streamflow-gaging stations north and south of latitude 37. N is the number of gaging stations in the sample.)

TABLE 7. *Statistical distribution of hydrologic budget components, in inches per year*

	Precipi-tation	Evapo-trans-piration	Stream-flow	Ground-water recharge	Ground-water discharge	Direct runoff
Study area, except the southern part of the Blue Ridge Physiographic Province[1]						
Maximum	58	35	29	24	21	12
75th percentile	46	30	20	15	14	7
Median	43	26	16	12	11	6
25th percentile	40	24	14	9	8	5
Minimum........	34	16	11	6	5	3
Southern part of the Blue Ridge Physiographic Province[2]						
Maximum	80	33	55	50	46	14
75th percentile	66	31	45	38	34	9
Median	58	25	38	33	29	8
25th percentile	55	18	26	21	19	6
Minimum........	44	7	19	16	14	5

[1]Sample size is 72. [2]Sample size is 17.

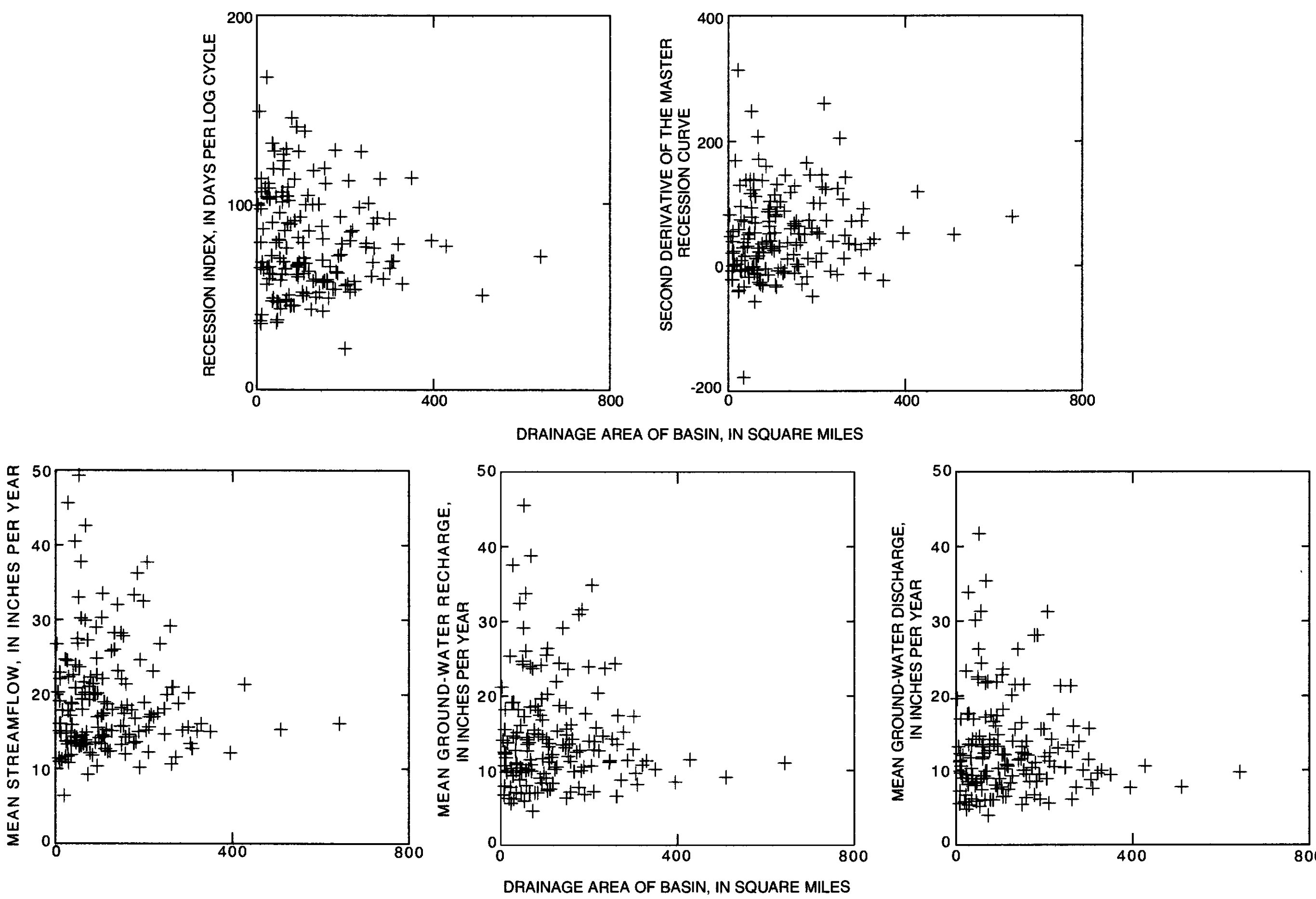


FIGURE 32.—Relation between the basin drainage area and various hydrologic variables for basins in the study area.

Although the simple conceptual model would show a greater spread of mean recharge rates among basins of small area, all basins would exhibit mean recharge that agrees with the result of equation 8, regardless of the drainage area of the basin. A verification that no other effects of drainage area are taking place could be obtained simply by comparing the result of equation 8 with the estimate of recharge obtained from analysis of the stream-flow record. In the real case of the APRASA project, no such simple model was obtained for the hydrologic variables of interest. However, some tests were performed to determine whether effects that cannot be explained simply by averaging the physical properties explained above were due to drainage area. Results of these tests indicate no readily apparent change in relation between large and small basins (fig. 33). A change in relation would manifest itself as a significant difference in graphical location between the small and large basins. If such a difference occurred, then it would be analogous in the hypothetical model to unreliability of equation 8. For example, it might be valid for small basins but invalid for large basins. Other tests not illustrated yielded results similar to those in figure 33.

The above discussion of variability with drainage area may highlight the importance of central tendencies of distributions of hydrologic variables relative to the extreme values. Drainage area may be only one of many physical variables that can cause extreme values of the hydrologic variables for various basins. For this reason, many of the descriptions in this report of variable distributions include statistics, such as the 25th, 50th, and 75th percentiles.

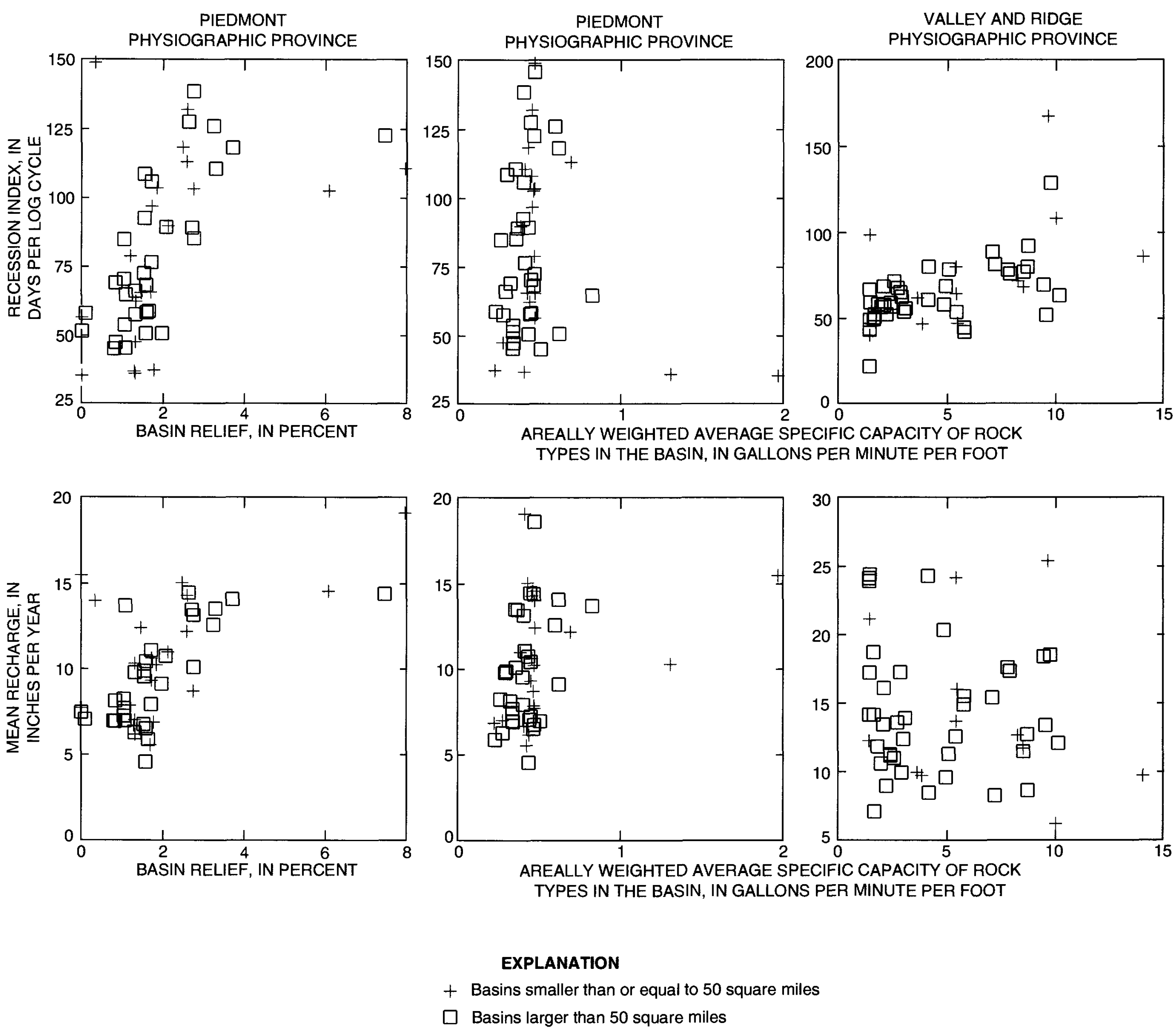


FIGURE 33.—Relation among physical and hydrologic variables for basins that are smaller than or equal to 50 square miles and larger than 50 square miles.

SUMMARY

Interpretations of streamflow records in the Appalachian Valley and Ridge, the Piedmont, and the Blue Ridge Physiographic Provinces have provided estimates of hydraulic properties of shallow aquifers and quantified the rates of ground-water recharge and discharge. The analysis is divided into two parts—streamflow recession and base flow. Streamflow recession can relate to the hydraulic diffusivity of the aquifers and their capacity to yield water during times of sparse recharge. Base-flow analysis consists mainly of the estimation of the mean rates of ground-water recharge and discharge over a long period of time (usually years).

The study area is considered to be two distinct subareas on the basis of differences in geologic and hydrologic characteristics. One subarea consists of carbonate rock, sandstone, and shale of the Valley and Ridge Physiographic Province. Generally, ridges are underlain by resistant conglomerate, sandstone, or cherty dolomite, whereas valleys are underlain by less-resistant siltstone, shale, limestone, or dolomite. The other subarea consists of metamorphic and igneous crystalline rocks in the Blue Ridge and the Piedmont Physiographic Provinces. Types of rocks include massive granites and gneisses, foliated phyllites and schists, and consolidated sandstones. Sedimentary rocks of early Mesozoic age fill basins within the Piedmont Physiographic Province. Regolith, which consists of soil, alluvium, and weathered rock material, overlies most of the bedrock units throughout both subareas.

For the purpose of this report, the base-flow MRC represents the recession of streamflow during times when all flow is from ground-water discharge, no ground-water recharge is occurring, and the shape of the ground-water-head profile is nearly stable. The MRC, which is a graph of flow on a logarithmic scale as a function of time on a linear scale, is assembled from numerous intervals of continuous recession. Two variables are introduced for defining recession characteristics of a basin. The first variable, which represents the inclination of the MRC, is the median basin recession index among all recession segments that are selected in the computerized method. The second variable, which represents the shape of the MRC, is the second derivative of the MRC, which is positive for concave (as viewed from above) curves and negative for convex curves.

As transmissivity increases, the median basin recession index decreases (more rapid recession of flow), but as the specific yield increases, the recession index increases (slower recession). The opposite effects of T and S_y can complicate the interpretation of ground-water recession as it relates to water-supply potential because T and S_y should be large for the most favorable water-supply potential. A large recession index is commonly related to good potential for water supply because the aquifer likely has a large specific yield, which may reflect reliability of water supply during periods of drought. However, a large recession index also may reflect a small transmissivity and, consequently, small well yields.

The median basin, recession index is slightly lower in the Valley and Ridge Physiographic Province compared with the other physiographic provinces possibly because of the comparatively high transmissivities of limestones and dolomites in this area. In the Piedmont Physiographic Province, the tendency is much greater for MRC convexity than in the other provinces; all MRC's for the Valley and Ridge Physiographic Province and most MRC's for the Blue Ridge Physiographic Province are concave.

The shape of the MRC can be related hypothetically to a variation in aquifer diffusivity with changes in ground-water levels. Low parts of the MRC correspond to low ground-water levels in the basin; thus, MRC concavity may be caused by an increase in specific yield that may occur as the water table declines through zones of variable lithology. If the specific yield becomes smaller as the water table declines, then the MRC may be convex. This may be one reason for convexity of MRC's in the Piedmont Physiographic Province—namely, specific yield of crystalline rocks may decrease with depth.

The MRC can be concave for basins with high relief because as ground-water levels decline, some streams may go dry, which can result in an increase in the average distance from the stream to the hydrologic divide. Concavity may be considerably more prevalent in the Blue Ridge Physiographic Province than in the lithologically similar Piedmont Physiographic Province because of the greater relief in the former.

Concavity of the MRC can result when the stream is fed by more than one aquifer. The concavity that results from this multiple-aquifer effect may be particularly evident in the Valley and Ridge Physiographic Province because of differences between lithologies of the low-lying valleys and adjacent ridges.

Variations in recession characteristics with variations in basin relief and precipitation are, for the most part, obscured by scatter. A noticeably positive relation between the water-yielding capacity of rocks and the median basin recession index may indicate that the capacity of aquifers in the APRASA area to supply water to wells depends on the specific yield of the aquifers.

Most values of diffusivity range from 8,000 to 60,000 ft^2/d; the central tendency is about 20,000 ft^2/d. Most values of transmissivity range from 80 to 5,000 ft^2/d; the central tendency is about 900 ft^2/d.

The 7Q2 is related to mean recharge, but a considerable amount of the scatter in the relation may reflect variations in the recession index. Conversely, the 7Q2 is related to the recession index, whereas a considerable amount of the scatter in the relation may be related to variations in recharge.

Two variables are obtained from the base-flow analysis—mean ground-water recharge, which is obtained from the recession-curve-displacement method, and mean ground-water discharge, which is obtained from base-flow-record estimation. Among the 89 basins for which the 1961 to 1990 record is continuous, recharge ranges from 6 to 50 in/yr, and the median is 13 in/yr. The discharge ranges from 5 to 46 in/yr, and the median is 12 in/yr. Riparian-zone evapotranspiration is generally from 1 to 2 in/yr.

The relation between precipitation and recharge for the study area shows a considerable amount of scatter. The best-fit linear equation has roughly unit gradient (0.86) and an *X*-intercept of about 28 in/yr. The intercept may, for the most part, depend on evapotranspiration and may represent a threshold that must be exceeded by precipitation before recharge is significant.

Plots of recharge as a function of basin relief show a slight negative relation for the Valley and Ridge Physiographic Province and a clear positive relation in the other physiographic provinces. In the Blue Ridge and the Piedmont Physiographic Provinces (combined), a reasonably good estimator of recharge can be derived from precipitation and basin relief.

No clear relation between recharge and the water-yielding potential of rocks in the Valley and Ridge Physiographic Province was found, but a slightly positive relation is noted between recharge and the water-yielding capacity of rocks in the Piedmont Physiographic Province.

The stability of the BFI makes it ideal for basin comparisons when the various basins have differing periods of streamflow record or the available period of record is short. Among the 157 basins, the BFI ranges from 32 to 94 percent; the median is 67 percent. The BFI is largest in the southern part of the Blue Ridge Physiographic Province.

A statistic from the flow-duration curve can be used as a surrogate for direct estimates of mean ground-water discharge (base flow). The best surrogates are the Q42 in the Valley and Ridge Physiographic Province and the Q46 in the Blue Ridge and Piedmont Physiographic Provinces.

Basic water-balance equations are combined with the results of base-flow analysis to obtain hydrologic budgets of basins in the study area. Except for the southern part of the Blue Ridge Physiographic Province, the median values for components of the budgets for the study area (sample size, 72) are, in inches per year, precipitation, 43; evapotranspiration, 26; streamflow, 16; ground-water recharge, 12; ground-water discharge, 11; and storm runoff, 6. For the southern part of the Blue Ridge Physiographic Province (sample size, 17), the median values are, in inches per year, precipitation, 58; evapotranspiration, 25; streamflow, 38; ground-water recharge, 33; ground-water discharge, 29; and storm runoff, 8.

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TABLES 1 THROUGH 4

TABLE 1. *Physical properties of drainage basins in the Valley and Ridge, Blue Ridge, and Piedmont Physiographic Provinces Regional Aquifer-System Analysis Program study area*

[mi^2, square miles; >, greater than. Basins correspond to streamflow-gaging stations in figure 1 and are listed generally from southwest to northeast. Province 1, Valley and Ridge; Province 2, Blue Ridge; Province 3, Piedmont; V1, siliciclastics; V2, argillaceous carbonates; V3, limestone; V4, dolomite, and mixtures of limestone and dolomite; V5, alluvium; B1 through B2 and P1 through P6, hydrogeologic terranes grouped by well yield, numbers in parentheses are in gallons per minute. Explanation of variables are located in the Appendix.]

Map number (fig. 1)	U.S. Geological Survey station number	Latitude	Longitude	Drainage area (mi^2)	Relief (percent)	Province	Percentage of basin covered by the geohydrologic terranes indicated												
							V1	V2	V3	V4	V5	B1 (0-25)	B2 (> 25)	P1 (0-10)	P2 (10-20)	P3 (20-30)	P4 (30-50)	P5 (50-100)	P6 (>100)
1	02408540	32.92	86.27	263.0	2.71	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	35.7	4.7	54.2	0.0	0.0	0.0
2	02462000	33.45	87.12	148.0	2.06	1	34.5	.0	31.1	34.4	.0	.0	.0	.0	.0	.0	.0	.0	.0
3	02401370	33.81	86.38	45.0	5.22	1	54.0	.0	45.0	1.1	.0	.0	.0	.0	.0	.0	.0	.0	.0
4	02401390	33.84	86.26	141.0	3.38	1	20.8	.0	57.8	20.4	.0	.0	.0	.0	.0	.0	.0	.0	.0
5	02400100	34.06	85.61	252.0	3.42	1	35.5	.0	13.0	27.1	.0	.0	.0	20.8	.0	.0	.0	.0	.0
6	02399200	34.29	85.68	199.0	3.19	1	99.9	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
7	02213050	32.97	83.62	29.0	1.32	3	.0	.0	.0	.0	.0	.0	.0	.0	6.1	90.1	.0	.0	.0
8	02212600	33.10	83.72	72.2	1.57	3	.0	.0	.0	.0	.0	.0	.0	9.8	.0	86.0	.0	.0	.0
9	02221525	33.25	83.48	190.0	1.53	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	99.9	.0	.0	.0
10	02220900	33.31	83.44	262.0	1.58	3	.0	.0	.0	.0	.0	.0	.0	.4	.0	98.6	.0	.0	.0
11	02338660	33.24	84.99	127.0	1.59	3	.0	.0	.0	.0	.0	.0	.0	.0	6.4	92.1	.0	.0	.0
12	02337500	33.53	84.93	37.0	2.48	3	.0	.0	.0	.0	.0	.0	.0	.0	17.2	82.8	.0	.0	.0
13	02337000	33.77	84.61	246.0	1.71	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	87.4	.0	.0	.0
14	02395120	34.24	84.89	33.1	1.72	1	17.8	.0	80.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
15	02398000	34.47	85.34	192.0	3.12	1	25.8	.0	74.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
16	03568933	34.90	85.46	149.0	5.19	1	54.1	.0	39.8	6.1	.0	.0	.0	.0	.0	.0	.0	.0	.0
17	02381600	34.57	84.47	10.0	5.59	2	.0	.0	.0	.0	.0	.0	100.0	.0	.0	.0	.0	.0	.0
18	02380500	34.67	84.51	236.0	7.06	2	.0	.0	.0	.0	.0	4.1	81.0	.0	.0	.0	.0	.0	.0
19	02333500	34.53	83.94	153.0	4.26	2	.0	.0	.0	.0	.0	77.2	8.8	.0	.0	.0	.0	.0	.0
20	03558000	34.79	84.24	177.0	9.25	2	.0	.0	.0	.0	.0	34.4	65.1	.0	.0	.0	.0	.0	.0
21	02178400	34.89	83.53	56.5	14.18	2	.0	.0	.0	.0	.0	66.8	18.3	.0	.0	.0	.0	.0	.0
22	02177000	34.81	83.31	207.0	9.76	2	.0	.0	.0	.0	.0	24.5	24.0	.0	.0	.0	.0	.0	.0
23	02185200	34.84	82.98	72.0	4.15	2	.0	.0	.0	.0	.0	65.5	16.6	.0	.0	.0	.0	.0	.0
24	03567500	35.01	85.21	428.0	2.52	1	19.9	.1	77.0	3.1	.0	.0	.0	.0	.0	.0	.0	.0	.0
25	03543500	35.58	84.75	117.0	3.28	1	30.7	1.5	26.9	40.9	.0	.0	.0	.0	.0	.0	.0	.0	.0
26	03497300	35.66	83.71	106.0	18.99	2	.0	.0	.0	.0	.0	.2	18.1	.0	.0	.0	.0	.0	.0
27	03466228	36.20	82.74	13.7	2.62	1	19.1	.0	.0	80.9	.0	.0	.0	.0	.0	.0	.0	.0	.0
28	03491000	36.43	82.95	47.3	6.62	1	75.5	.0	20.4	4.2	.0	.0	.0	.0	.0	.0	.0	.0	.0
29	03550000	35.14	83.98	104.0	13.35	2	.0	.0	.0	.0	.0	.0	70.8	.0	.0	.0	.0	.0	.0
30	03504000	35.13	83.62	51.9	15.28	2	.0	.0	.0	.0	.0	85.4	12.6	.0	.0	.0	.0	.0	.0
31	03500000	35.15	83.38	140.0	12.49	2	.0	.0	.0	.0	.0	78.6	2.8	.0	.0	.0	.0	.0	.0
32	03500240	35.16	83.39	57.1	14.57	2	.0	.0	.0	.0	.0	91.2	8.7	.0	.0	.0	.0	.0	.0
33	03512000	35.46	83.35	184.0	21.22	2	.0	.0	.0	.0	.0	19.9	5.5	.0	.0	.0	.0	.0	.0
34	03439000	35.14	82.82	67.9	10.69	2	.0	.0	.0	.0	.0	66.3	8.7	.0	.0	.0	.0	.0	.0
35	03455500	35.40	82.94	27.6	23.25	2	.0	.0	.0	.0	.0	100.0	.0	.0	.0	.0	.0	.0	.0
36	03456500	35.46	82.87	51.5	19.70	2	.0	.0	.0	.0	.0	100.0	.0	.0	.0	.0	.0	.0	.0
37	03460000	35.67	83.07	49.2	17.95	2	.0	.0	.0	.0	.0	.9	37.7	0	.0	.0	.0	.0	.0
38	02149000	35.42	82.11	79.0	8.68	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0	.0	.0	.0
39	03463300	35.83	82.18	43.3	17.67	2	.0	.0	.0	.0	.0	17.9	.0	.0	.0	.0	.0	.0	.0
40	02137727	35.69	82.06	126.0	11.89	2	.0	.0	.0	.0	.0	81.4	8.1	.0	.0	.0	.0	.0	.0

TABLE 1. *Physical properties of drainage basins in the Valley and Ridge, Blue Ridge, and Piedmont Physiographic Provinces Regional Aquifer-System Analysis Program study area—Continued*

							Percentage of basin covered by the geohydrologic terranes indicated												
Map number (fig. 1)	U.S. Geological Survey station number	Latitude	Longitude	Drainage area (mi²)	Relief (percent)	Province	V1	V2	V3	V4	V5	B1 (0-25)	B2 (> 25)	P1 (0-10)	P2 (10-20)	P3 (20-30)	P4 (30-50)	P5 (50-100)	P6 (>100)
41	02138500	35.79	81.89	66.7	10.73	2	0.0	0.0	0.0	0.0	0.0	30.5	3.2	0.0	0.0	0.0	0.0	0.0	0.0
42	02152100	35.49	81.68	60.5	7.46	3	.0	.0	.0	.0	.0	.0	.0	.0	1.5	98.5	.0	.0	.0
43	02143040	35.59	81.57	25.7	7.95	3	.0	.0	.0	.0	.0	.0	.0	.0	25.2	74.8	.0	.0	.0
44	02111000	35.99	81.56	28.8	11.21	2	.0	.0	.0	.0	.0	69.9	0.9	.0	.0	.0	.0	.0	.0
45	03479000	36.24	81.82	92.1	11.81	2	.0	.0	.0	.0	.0	53.0	6.6	.0	.0	.0	.0	.0	.0
46	02143500	35.42	81.26	69.2	2.07	3	.0	.0	.0	.0	.0	.0	.0	.0	15.1	84.8	.0	.0	.0
47	02142000	35.95	81.24	28.2	6.08	3	.0	.0	.0	.0	.0	.0	.0	.0	4.1	95.9	.0	.0	.0
48	02111500	36.17	81.17	89.2	10.65	2	.0	.0	.0	.0	.0	88.2	11.8	.0	.0	.0	.0	.0	.0
49	02112120	36.25	81.04	128.0	7.68	2	.0	.0	.0	.0	.0	58.4	17.9	.0	.0	.0	.0	.0	.0
50	02120780	35.72	80.60	118.0	1.04	3	.0	.0	.0	.0	.0	.0	.0	8.4	80.2	11.4	.0	.0	.0
51	02118500	36.00	80.75	155.0	3.29	3	.0	.0	.0	.0	.0	.0	.0	.0	47.3	51.4	.0	.0	.0
52	02114450	36.30	80.43	42.8	2.75	3	.0	.0	.0	.0	.0	.0	.0	.0	3.0	97.0	.0	.0	.0
53	02113850	36.40	80.56	231.0	3.83	2	.0	.0	.0	.0	.0	74.9	15.8	.0	.0	.0	.0	.0	.0
54	02128000	35.39	79.83	106.0	1.04	3	.0	.0	.0	.0	.0	.0	.0	.0	9.3	90.7	.0	.0	.0
55	02088000	35.57	78.59	83.5	.79	3	.0	.0	.0	.0	.0	.0	.0	.0	3.5	57.9	29.0	.0	.0
56	02085500	36.18	78.88	149.0	1.31	3	.0	.0	.0	.0	.0	.0	.0	.0	80.7	19.3	.0	.0	.0
57	02077200	36.40	79.20	45.9	1.77	3	.0	.0	.0	.0	.0	.0	.0	.0	97.2	.0	.0	.0	.0
58	02082770	36.11	77.92	166.0	1.31	3	.0	.0	.0	.0	.0	.0	.0	.0	72.0	26.8	.0	.0	.0
59	02082950	36.19	77.88	177.0	1.05	3	.0	.0	.0	.0	.0	.0	.0	.0	52.7	45.9	.0	.0	.0
60	03475000	36.71	81.82	211.0	5.82	1	47.6	6.4	.7	45.3	.0	.0	.0	.0	.0	.0	.0	.0	.0
61	03471500	36.76	81.63	76.1	10.44	1	63.6	.0	.0	36.4	.0	.0	.0	.0	.0	.0	.0	.0	.0
62	03488000	36.90	81.75	222.0	12.32	1	74.2	.0	.3	25.5	.0	.0	.0	.0	.0	.0	.0	.0	.0
63	03165000	36.65	80.92	39.4	4.14	2	.0	.0	.0	.0	.0	80.3	.0	.0	.0	.0	.0	.0	.0
64	03167000	36.94	80.89	247.0	5.04	1	57.7	22.8	.0	19.5	.0	.0	.0	.0	.0	.0	.0	.0	.0
65	03167500	36.89	80.73	278.0	5.27	2	.0	.0	.0	.0	.0	94.5	4.4	.0	.0	.0	.0	.0	.0
66	03170000	37.04	80.56	300.0	4.60	2	5.0	.0	.0	.0	.0	73.2	21.2	.0	.0	.0	.0	.0	.0
67	03173000	37.27	80.71	305.0	8.97	1	77.4	.0	.0	22.6	.0	.0	.0	.0	.0	.0	.0	.0	.0
68	02069700	36.57	80.13	84.6	4.28	2	.0	.0	.0	.0	.0	7.0	60.8	0.0	21.8	1.1	.0	.0	.0
69	02070000	36.57	79.99	108.0	2.75	3	.0	.0	.0	.0	.0	.6	.0	4.1	23.7	71.7	.0	.0	.0
70	02053800	37.14	80.27	110.0	8.34	0	34.5	2.1	.0	1.4	.0	44.2	15.4	.0	.0	.0	.0	.0	.0
71	02056900	37.04	79.84	115.0	5.00	2	.0	.0	.0	.0	.0	98.4	.0	.0	.0	.0	.0	.0	.0
72	02056650	37.23	79.87	56.8	7.87	2	17.0	.0	.0	7.2	.0	75.8	.0	.0	.0	.0	.0	.0	.0
73	02055000	37.26	79.94	395.0	7.76	1	56.4	30.5	.0	12.3	.0	.7	.0	.0	.0	.0	.0	.0	.0
74	02055100	37.42	79.94	11.7	2.12	1	.0	65.9	.0	34.1	.0	.0	.0	.0	.0	.0	.0	.0	.0
75	02017500	37.51	80.11	104.0	11.36	1	97.5	.0	2.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
76	02018000	37.67	79.91	329.0	11.27	1	91.5	.3	4.5	3.7	.0	.0	.0	.0	.0	.0	.0	.0	.0
77	02014000	37.73	80.04	153.0	13.43	1	95.6	.2	4.1	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0
78	02011400	38.04	79.88	158.0	12.59	1	90.6	.0	6.7	2.5	.0	.0	.0	.0	.0	.0	.0	.0	.0
79	02011460	38.25	79.77	60.1	16.07	1	94.4	.0	2.9	2.6	.0	.0	.0	.0	.0	.0	.0	.0	.0
80	02015700	38.20	79.57	110.0	9.52	1	84.8	.3	15.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
81	02022500	37.83	79.44	35.0	9.83	1	85.9	.0	.0	14.1	.0	.0	.0	.0	.0	.0	.0	.0	.0
82	02059500	37.17	79.52	188.0	4.18	2	15.1	.4	.0	.0	.0	82.4	2.0	.0	.0	.0	.0	.0	.0
83	02061500	37.21	79.30	320.0	3.15	2	.0	.0	.0	.0	.0	82.6	.0	14.9	.0	2.4	.0	.1	.0
84	02058400	36.95	79.53	350.0	3.28	0	.0	.0	.0	.0	.0	40.8	.0	.0	3.7	54.1	.0	.0	.0
85	02065500	37.08	78.76	98.0	1.54	3	.0	.0	.0	.0	.0	.0	.0	1.3	29.3	69.4	.0	.0	.0

TABLE 1. *Physical properties of drainage basins in the Valley and Ridge, Blue Ridge, and Piedmont Physiographic Provinces Regional Aquifer-System Analysis Program study area—Continued*

Map number (fig. 1)	U.S. Geological Survey station number	Latitude	Longitude	Drainage area (mi²)	Relief (percent)	Province	Percentage of basin covered by the geohydrologic terranes indicated												
							V1	V2	V3	V4	V5	B1 (0-25)	B2 (> 25)	P1 (0-10)	P2 (10-20)	P3 (20-30)	P4 (30-50)	P5 (50-100)	P6 (>100)
86	02079640	36.68	78.33	53.4	1.64	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0
87	02039000	37.26	78.49	69.7	1.54	3	.0	.0	.0	.0	.0	.0	.0	1.1	71.1	27.9	.0	.0	.0
88	02038850	37.42	78.64	8.5	1.19	3	.0	.0	.0	.0	.0	.0	.0	1.9	.0	98.1	.0	.0	.0
89	02027800	37.61	78.92	147.0	4.12	2	.0	.0	.0	.0	.0	78.5	0.2	19.3	.0	1.1	.0	.0	.0
90	02027000	37.72	78.98	92.8	12.90	2	.0	.0	.0	.0	.0	91.2	.0	.0	.0	.0	.0	.0	.0
91	02028500	37.87	78.82	94.6	9.10	2	.0	.0	.0	.0	.0	97.9	1.9	.0	.0	.0	.0	.0	.0
92	01626850	38.09	78.88	149.0	4.11	0	19.5	15.7	.0	22.8	.0	9.8	15.4	.0	.0	.0	.0	.0	.0
93	01627500	38.22	78.84	212.0	3.92	0	17.6	21.9	.0	20.0	.0	1.6	36.2	.0	.0	.0	.0	.0	.0
94	01632000	38.64	78.85	210.0	11.43	1	96.8	1.1	2.1	0.1	.0	.0	.0	.0	.0	.0	.0	.0	.0
95	01632900	38.69	78.64	93.2	4.20	1	62.4	.6	.0	37.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
96	02031000	38.10	78.59	95.4	4.13	2	.0	.0	.0	.0	.0	93.6	6.4	.0	.0	.0	.0	.0	.0
97	02032400	38.15	78.54	37.0	5.26	2	.0	.0	.0	.0	.0	80.0	20.0	.0	.0	.0	.0	.0	.0
98	02052500	36.62	77.70	65.2	.83	3	.0	.0	.0	.0	.0	.0	.0	.0	68.5	20.3	11.2	.0	.0
99	02044500	36.98	77.80	309.0	.83	3	.0	.0	.0	.0	.0	.0	.0	.3	61.7	38.0	.0	.0	.0
100	02046000	37.07	77.60	112.0	.00	3	.0	.0	.0	.0	.0	.0	.0	30.1	39.0	25.8	5.2	.0	.0
101	02041000	37.28	77.87	158.0	.09	3	.0	.0	.0	.0	.0	.0	.0	.0	12.1	87.8	.0	.0	.0
102	02036500	37.60	77.82	22.1	.00	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0	.0	.0	.0
103	01673800	38.17	77.60	77.4	1.07	3	.0	.0	.0	.0	.0	.0	.0	.0	55.9	44.1	.0	.0	.0
104	01666500	38.33	78.10	179.0	2.75	2	.0	.0	.0	.0	.0	93.1	2.0	.7	1.7	2.5	.0	.0	.0
105	01663500	38.59	77.97	287.0	4.28	2	.0	.0	.0	.0	.0	98.1	1.8	.0	.0	.0	.0	.0	.0
106	01662800	38.66	78.07	27.6	2.80	2	.0	.0	.0	.0	.0	100.0	.0	.0	.0	.0	.0	.0	.0
107	01660400	38.49	77.43	34.9	1.31	3	.0	.0	.0	.0	.0	.0	.0	41.7	48.6	9.7	.0	.0	.0
108	01658500	38.59	77.43	7.6	1.29	3	.0	.0	.0	.0	.0	.0	.0	.0	26.9	73.1	.0	.0	.0
109	01643700	38.99	77.80	123.0	3.67	2	.0	.0	.0	.0	.0	100.0	.0	.0	.0	.0	.0	.0	.0
110	01634500	39.08	78.33	103.0	7.59	1	90.4	.8	8.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
111	01654000	38.81	77.23	23.5	1.69	3	.0	.0	.0	.0	.0	.0	.0	.0	19.1	80.9	.0	.0	.0
112	01646000	38.98	77.25	57.9	1.71	3	.0	.0	.0	.0	.0	.0	.0	3.0	30.5	64.8	0.4	1.3	.0
113	01638480	39.26	77.58	89.6	2.13	2	.0	.0	.0	.0	.0	94.4	2.3	.0	.0	.0	.0	.0	.0
114	03180500	38.54	79.83	133.0	9.21	1	97.8	.0	2.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
115	01605500	38.64	79.34	182.0	12.52	1	78.0	10.0	9.3	2.6	.0	.0	.0	.0	.0	.0	.0	.0	.0
116	01606500	38.99	79.18	642.0	14.64	1	80.4	9.1	10.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
117	01616500	39.42	77.94	272.0	0.86	1	43.1	4.8	13.3	38.7	.0	.0	.0	.0	.0	.0	.0	.0	.0
118	01617800	39.51	77.78	18.9	0.89	1	.0	.0	100.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
119	01637500	39.43	77.56	66.9	5.71	2	.0	.0	.0	.0	.0	99.3	0.7	.0	.0	.0	.0	.0	.0
120	01643500	39.29	77.41	62.8	2.76	3	.0	.0	.0	.0	.0	.0	.0	84.5	.0	9.2	.0	6.3	.0
121	01591700	39.17	77.02	27.0	1.72	3	.0	.0	.0	.0	.0	.0	.0	.0	8.9	91.1	.0	.0	.0
122	01591000	39.24	77.06	34.8	2.12	3	.0	.0	.0	.0	.0	.0	.0	46.0	.0	54.0	.0	.0	.0
123	01591400	39.26	77.05	22.9	1.84	3	.0	.0	.0	.0	.0	.0	.0	1.1	.0	98.9	.0	.0	.0
124	01583500	39.51	76.68	59.8	3.24	3	.0	.0	.0	.0	.0	.0	.0	1.9	.0	80.5	.0	17.6	.0
125	01584050	39.45	76.48	9.4	2.58	3	.0	.0	.0	.0	.0	.0	.0	.0	6.7	61.1	.0	32.2	.0
126	01581700	39.52	76.37	34.8	2.60	3	.0	.0	.0	.0	.0	.0	.0	10.8	.0	88.6	.0	.6	.0
127	01580000	39.63	76.40	94.4	2.64	3	.0	.0	.0	.0	.0	.0	.0	1.1	.0	92.9	.0	.5	.0
128	01496200	39.63	76.04	9.0	1.72	3	.0	.0	.0	.0	.0	.0	.0	.0	6.8	93.2	.0	.0	.0
129	01560000	40.07	78.49	172.0	6.24	1	79.0	3.8	17.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
130	01613050	39.90	78.13	10.7	4.33	1	100.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

TABLE 1. *Physical properties of drainage basins in the Valley and Ridge, Blue Ridge, and Piedmont Physiographic Provinces Regional Aquifer-System Analysis Program study area—Continued*

Map number (fig. 1)	U.S. Geological Survey station number	Latitude	Longitude	Drainage area (mi^2)	Relief (percent)	Province	Percentage of basin covered by the geohydrologic terranes indicated												
							V1	V2	V3	V4	V5	B1 (0-25)	B2 (> 25)	P1 (0-10)	P2 (10-20)	P3 (20-30)	P4 (30-50)	P5 (50-100)	P6 (>100)
131	01564500	40.21	77.93	205.0	5.44	1	92.3	2.3	5.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
132	01558000	40.61	78.14	220.0	7.24	1	69.9	1.5	15.4	13.2	.0	.0	.0	.0	.0	.0	.0	.0	.0
133	01547200	40.94	77.79	265.0	6.24	1	53.3	1.5	16.5	23.7	5.0	.0	.0	.0	.0	.0	.0	.0	.0
134	01567500	40.37	77.40	15.0	5.43	1	49.1	6.5	44.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
135	01569800	40.23	77.14	21.6	0.00	1	3.3	4.2	90.2	2.3	.0	.0	.0	.0	.0	.0	.0	.0	.0
136	01568000	40.32	77.17	200.0	6.61	1	71.4	13.4	15.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
137	01571500	40.22	76.90	216.0	3.59	0	8.0	.3	18.5	16.0	.0	26.4	3.1	.0	5.4	12.3	10.0	.0	.0
138	01574000	40.08	76.72	510.0	1.97	3	.0	.0	.0	.0	.0	10.1	7.8	.0	11.0	12.7	52.3	.0	6.1
139	01555500	40.61	76.91	162.0	5.29	1	100.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
140	01555000	40.87	77.05	301.0	7.87	1	72.0	18.6	7.8	1.6	.0	.0	.0	.0	.0	.0	.0	.0	.0
141	01470779	40.41	76.17	66.5	1.09	1	15.1	21.1	18.4	40.2	.0	.0	.0	.0	.2	4.2	.0	.9	.0
142	01468500	40.63	76.13	133.0	5.47	1	99.2	.8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
143	01470756	40.51	75.88	159.0	3.68	1	92.8	2.7	1.5	3.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
144	01480675	40.10	75.74	8.6	1.45	3	.0	.0	.0	.0	.0	.0	.0	.4	.6	98.6	.0	.4	.0
145	01472157	40.15	75.60	59.1	3.71	3	.0	.0	.0	.0	.0	.0	.0	4.0	8.2	62.8	2.3	22.6	.1
146	01471980	40.27	75.68	85.5	4.36	0	13.4	1.1	.2	24.1	.0	.0	.0	.0	1.2	59.7	.2	.0	.0
147	01475300	40.02	75.42	5.2	0.33	3	.0	.0	.0	.0	.0	.0	.0	.4	.0	99.6	.0	.0	.0
148	01474000	40.01	75.21	64.0	1.08	3	.0	.0	.0	.0	.0	.0	.0	.2	.0	40.0	22.5	33.6	2.8
149	01451800	40.66	75.63	53.0	3.14	1	100.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
150	01452000	40.62	75.48	75.8	2.90	1	59.3	2.1	24.6	14.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
151	01449360	40.90	75.50	49.9	4.01	1	85.0	.0	.0	.0	15.0	.0	.0	.0	.0	.0	.0	.0	.0
152	01448500	41.04	75.54	2.4	3.58	1	100.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
153	01447500	41.13	75.63	91.7	2.19	1	100.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
154	01442500	41.00	75.14	259.0	4.16	1	88.7	1.3	.0	.0	10.0	.0	.0	.0	.0	.0	.0	.0	.0
155	01401000	40.33	74.68	44.5	1.31	3	.0	.0	.0	.0	.0	.0	.0	.0	15.1	.0	34.6	5.0	45.3
156	01398107	40.56	74.73	9.0	0.00	3	.0	.0	.0	.0	.0	.0	.0	.0	6.1	.0	.0	.0	93.9
157	01445500	40.83	74.98	106.0	2.95	1	7.4	.0	44.9	.0	5.0	.0	.0	.0	.0	.0	.0	.0	.0

TABLE 2. *Characteristics of recession analysis and master recession curves in the Appalachian Valley and Ridge, Blue Ridge, and Piedmont Physiographic Provinces Regional Aquifer-System Analysis study program*

[MRC, master recession curve]

Map number (fig. 1)	Period of analysis	Number of recession segments used	Median recession index (d/log cycle)	Range of MRC (fig. 3)		Coefficients of MRC (fig. 3)		
				MinLogQ	MaxLogQ	A	B	C
1	1980–91	10	89.3	1.892	2.445	24.817	–203.888	350.125
2	1953–91	6	69.6	1.776	2.416	34.135	–217.011	325.059
3	1978–91	26	47.3	.963	1.903	25.272	–123.898	144.247
4	1965–91	39	52.3	1.324	2.217	30.001	–165.256	218.904
5	1962–91	19	100.2	1.861	2.407	102.765	–560.863	754.595
6	1958–90	44	22.1	–.109	2.531	3.449	–38.952	76.489
7	1961–91	24	62.4	.062	1.353	4.422	–75.758	94.422
8	1964–91	31	50.8	–.625	1.626	–13.169	–24.195	74.149
9	1977–91	11	72.6	1.540	2.151	–24.451	13.484	84.093
10	1977–91	10	68.4	1.369	2.282	5.782	–92.423	180.783
11	1978–91	25	58.4	0.708	2.245	–4.252	–42.930	117.793
12	1954–91	35	118.5	0.995	1.952	–2.917	–108.322	222.619
13	1937–91	26	76.7	1.561	2.522	–6.948	–48.259	165.893
14	1980–91	12	71.9	1.202	1.639	14.615	–116.134	151.063
15	1937–91	47	78.4	1.885	2.543	50.538	–307.926	456.252
16	1979–91	22	42.3	1.237	2.294	32.495	–173.075	226.039
17	1974–91	19	106.1	.472	1.387	27.712	–166.135	177.160
18	1938–91	24	127.8	2.156	2.906	19.647	–231.227	505.997
19	1929–91	42	118.8	1.833	2.787	16.786	–209.503	453.457
20	1913–91	44	128.6	2.152	3.041	82.675	–568.914	965.512
21	1964–91	17	105.9	1.630	2.357	61.230	–365.005	520.185
22	1939–91	46	112.2	2.068	3.148	50.277	–390.431	730.810
23	1967–91	14	101.6	1.512	2.443	–14.506	–45.623	198.020
24	1928–91	46	77.2	2.063	2.686	59.504	–368.754	561.187
25	1934–91	43	63.6	1.156	2.124	51.717	–251.319	300.474
26	1963–91	19	62.5	1.418	2.396	39.867	–224.954	310.115
27	1977–91	46	86.3	.411	1.328	.954	–88.708	116.083
28	1941–91	42	47.0	.450	1.688	26.630	–121.617	129.414
29	1914–91	37	79.0	1.667	2.460	57.228	–330.128	465.799
30	1940–91	36	95.1	1.604	2.320	124.202	–628.039	788.550
31	1944–91	35	99.6	2.010	2.811	59.136	–397.346	649.688
32	1961–91	15	100.7	1.682	2.276	69.259	–383.806	514.777
33	1945–91	25	71.9	1.927	2.803	73.188	–450.495	687.701
34	1935–91	39	103.9	1.792	2.507	85.922	–497.270	706.609
35	1954–91	22	66.1	1.386	2.049	47.984	–239.244	288.763
36	1954–91	37	70.6	1.358	2.183	46.857	–256.209	336.001
37	1934–91	26	80.7	1.449	2.136	69.641	–342.661	414.203
38	1951–91	35	145.9	1.581	2.333	10.644	–200.738	410.456
39	1957–91	28	78.9	1.242	2.079	21.804	–157.682	233.558
40	1980–91	21	99.4	1.803	2.483	44.186	–298.212	468.034
41	1922–91	33	76.1	1.502	2.160	8.139	–108.764	196.978
42	1959–91	24	122.7	1.491	2.186	55.902	–327.645	449.069
43	1961–91	23	110.7	1.077	1.653	64.853	–304.887	326.774
44	1939–91	31	102.2	1.040	1.879	–4.219	–88.302	180.813
45	1940–91	30	65.9	1.448	2.217	45.771	–251.472	332.524

TABLE 2. *Characteristics of recession analysis and master recession curves in the Appalachian Valley and Ridge, Blue Ridge, and Piedmont Physiographic Provinces Regional Aquifer-System Analysis study program—Continued*

Map number (fig. 1)	Period of analysis	Number of recession segments used	Median recession index (d/log cycle)	Range of MRC (fig. 3)		Coefficients of MRC (fig. 3)		
				MinLogQ	MaxLogQ	A	B	C
46	1951–91	45	89.5	.854	2.071	–13.106	–56.436	173.040
47	1953–91	40	102.8	.975	1.815	37.201	–209.000	256.798
48	1939–91	35	140.9	1.623	2.434	43.803	–322.924	526.509
49	1964–91	12	117.6	1.720	2.323	73.033	–427.932	600.006
50	1979–91	15	85.1	1.409	1.990	–1.620	–83.158	171.933
51	1951–91	20	110.8	1.842	2.588	1.400	–126.346	317.560
52	1960–91	18	103.4	1.056	1.674	15.871	–150.037	206.713
53	1964–91	26	98.0	2.163	2.720	–4.316	–78.783	246.173
54	1954–91	46	70.5	.558	2.066	–15.324	–20.833	108.454
55	1939–91	29	45.2	–.366	1.960	–2.414	–39.454	86.589
56	1925–91	41	57.7	.063	2.086	–5.844	–43.838	116.873
57	1964–91	28	37.5	-1.511	1.598	–8.941	–22.503	58.773
58	1963–91	19	66.2	.696	2.227	–14.509	–21.272	119.293
59	1959–91	35	53.9	.121	2.228	–8.743	–33.553	118.123
60	1931–91	16	80.1	1.902	2.439	73.325	–408.782	560.843
61	1920–91	38	88.9	1.349	1.984	68.685	–329.373	383.107
62	1920–91	28	53.9	1.443	2.446	36.333	–206.629	288.041
63	1944–91	27	128.0	1.307	2.040	68.909	–363.999	455.759
64	1911–91	38	78.7	1.767	2.517	62.207	–357.891	506.694
65	1911–91	40	113.3	2.024	2.832	36.073	–300.123	560.629
66	1928–91	47	91.7	1.905	2.759	12.939	–158.854	339.795
67	1938–91	48	69.0	1.484	2.414	45.944	–263.120	367.426
68	1962–91	14	113.0	1.779	2.212	80.140	–454.012	612.155
69	1928–91	49	138.7	1.683	2.299	–16.756	–76.850	265.247
70	1960–91	17	99.3	1.382	2.226	47.573	–264.537	353.150
71	1976–91	17	104.3	1.329	2.200	15.489	-166.514	291.380
72	1974–91	21	61.9	.413	2.019	-.604	-66.104	135.901
73	1917–91	43	80.3	1.737	2.679	26.294	-196.146	336.736
74	1956–91	25	68.4	.356	1.223	11.736	-95.949	99.785
75	1926–91	49	50.5	.939	1.986	26.751	-143.387	179.259
76	1925–91	44	57.0	1.524	2.417	21.451	-152.110	242.350
77	1928–91	36	58.5	1.241	2.117	35.998	-191.788	244.663
78	1974–91	18	59.1	1.528	2.181	31.814	-180.850	243.114
79	1974–91	16	68.7	.466	1.595	34.823	-152.019	153.892
80	1960–91	28	67.9	1.519	2.060	65.641	-313.772	367.805
81	1927–91	48	62.0	.837	1.527	35.912	-157.351	156.545
82	1930–91	28	93.1	1.672	2.369	30.308	-221.848	355.481
83	1937–91	19	78.4	1.337	2.552	18.070	-165.208	303.950
84	1963–91	20	113.9	1.793	2.734	-12.004	-50.204	226.936
85	1946–91	34	92.7	1.257	2.145	14.101	-149.585	256.006
86	1961–91	25	58.9	-.352	1.557	-1.117	-62.328	99.754
87	1946–91	40	108.7	1.087	2.015	11.311	-148.904	254.099
88	1966–91	23	79.0	-.006	1.213	-11.241	-73.908	106.173
89	1960–91	36	87.7	1.570	2.429	8.957	-123.687	247.625
90	1938–91	46	60.6	.968	2.215	25.922	-168.102	245.162

TABLE 2. *Characteristics of recession analysis and master recession curves in the Appalachian Valley and Ridge, Blue Ridge, and Piedmont Physiographic Provinces Regional Aquifer-System Analysis study program—Continued*

Map number (fig. 1)	Period of analysis	Number of recession segments used	Median recession index (d/log cycle)	Range of MRC (fig. 3)		Coefficients of MRC (fig. 3)		
				MinLogQ	MaxLogQ	A	B	C
91	1943–91	46	67.4	.860	2.190	20.210	-148.855	229.042
92	1974–91	27	81.0	1.720	2.321	64.472	-358.496	484.726
93	1925–91	39	84.7	1.937	2.493	63.552	-368.531	523.789
94	1925–91	45	52.5	.565	1.992	10.311	-84.737	127.868
95	1960–91	36	81.6	1.059	2.015	32.055	-195.330	263.464
96	1942–91	18	68.3	1.550	2.054	15.970	-130.656	201.025
97	1979–91	15	49.3	1.093	1.576	7.826	-71.300	92.933
98	1953–91	27	47.5	-.306	1.846	-6.708	-34.115	85.859
99	1950–91	43	69.2	.487	2.578	-6.334	-45.535	159.518
100	1946–91	29	51.6	.274	2.099	-3.896	-42.419	106.229
101	1946–91	23	58.1	.402	2.197	-.395	-57.096	127.330
102	1944–91	15	56.6	.400	1.436	-20.515	-22.928	75.193
103	1962–91	14	45.5	.850	1.909	-15.658	.805	55.502
104	1943–91	34	63.3	1.659	2.416	6.074	-97.057	199.010
105	1942–91	28	59.5	1.636	2.646	17.102	-143.360	259.598
106	1958–91	31	59.6	.002	1.508	-3.838	-58.832	97.421
107	1971–91	36	47.6	.593	1.537	-16.774	-14.244	61.524
108	1951–91	47	37.0	-.385	.863	-10.748	-35.623	38.765
109	1965–91	15	43.2	.599	2.077	-5.604	-29.788	86.053
110	1937–91	48	52.4	.957	1.936	12.394	-97.890	143.086
111	1947–91	29	65.7	.291	1.372	-19.609	-33.797	83.290
112	1935–91	23	106.0	.645	1.820	-5.716	-80.236	164.937
113	1970–91	14	61.9	1.020	1.922	-7.230	-34.158	92.339
114	1943–91	25	49.6	.289	2.093	5.669	-66.057	113.431
115	1940–91	33	62.7	1.271	2.236	36.845	-204.048	272.030
116	1928–91	35	71.7	1.910	2.884	39.521	-262.420	428.090
117	1947–91	25	92.3	1.545	2.415	17.756	-171.330	310.187
118	1963–91	29	108.2	.281	1.405	1.508	-111.681	153.918
119	1947–91	47	48.3	.467	2.045	14.502	-98.414	140.631
120	1948–91	32	85.4	1.049	1.936	6.003	-109.788	190.034
121	1978–91	17	108.1	.357	1.480	-3.037	-102.069	157.669
122	1944–91	49	89.9	.731	1.847	18.953	-147.325	207.463
123	1978–91	18	103.6	.415	1.645	29.334	-176.008	210.143
124	1944–91	28	126.2	1.120	1.922	-28.740	-36.621	176.607
125	1975–91	27	113.3	.356	1.188	19.761	-149.486	149.715
126	1967–91	14	132.1	1.196	1.684	-89.675	123.786	45.889
127	1926–91	48	127.7	1.525	2.271	51.961	-336.176	495.470
128	1967–91	14	97.0	-.016	1.159	-3.720	-92.538	112.223
129	1939–91	31	54.0	1.055	2.163	25.500	-144.692	193.680
130	1965–91	36	40.3	-.089	1.186	.073	-41.737	49.399
131	1938–91	25	56.7	.952	2.168	25.750	-163.037	232.461
132	1938–91	26	58.3	1.911	2.593	61.676	-347.531	486.452
133	1955–91	10	76.1	2.317	2.575	71.288	-428.883	631.716
134	1954–91	29	64.5	.488	1.341	84.671	-256.946	192.290
135	1976–91	25	167.5	1.345	1.893	156.935	-677.004	719.184

TABLE 2. *Characteristics of recession analysis and master recession curves in the Appalachian Valley and Ridge, Blue Ridge, and Piedmont Physiographic Provinces Regional Aquifer-System Analysis study program—Continued*

Map number (fig. 1)	Period of analysis	Number of recession segments used	Median recession index (d/log cycle)	Range of MRC (fig. 3)		Coefficients of MRC (fig. 3)		
				MinLogQ	MaxLogQ	A	B	C
136	1929–91	34	55.9	1.522	2.438	27.254	-181.717	281.045
137	1911–91	18	85.5	2.049	2.513	130.353	-727.613	1005.326
138	1928–91	35	50.8	1.444	2.674	25.442	-174.266	284.089
139	1929–91	18	49.3	1.081	2.354	18.776	-125.837	192.175
140	1929–91	45	65.3	1.588	2.650	36.403	-242.557	387.153
141	1974–91	16	129.1	1.604	2.173	103.719	-524.080	649.038
142	1947–91	18	59.4	1.924	2.480	18.718	-150.158	257.270
143	1973–91	15	57.9	1.433	2.341	25.849	-178.765	276.845
144	1966–91	26	65.5	-.163	1.134	-3.825	-63.508	76.927
145	1968–91	16	118.3	1.070	1.920	26.804	-206.544	297.754
146	1974–91	14	90.8	1.539	2.110	19.310	-162.946	257.841
147	1972–91	14	149.0	.251	1.169	23.828	-176.854	174.206
148	1965–91	19	64.9	1.209	2.059	-3.390	-57.450	132.662
149	1966–91	22	43.4	1.106	1.851	39.218	-171.918	183.843
150	1944–91	27	44.9	.584	1.980	17.799	-106.291	140.675
151	1966–91	39	80.2	1.254	2.080	58.190	-293.749	359.244
152	1948–91	27	99.0	-.367	.618	41.042	-122.830	60.221
153	1943–91	31	66.8	.898	2.262	35.865	-220.176	314.557
154	1950–91	47	61.0	1.747	2.740	53.709	-335.582	516.273
155	1953–91	23	36.1	-.151	1.442	-2.328	-30.771	49.202
156	1978–91	22	35.4	.031	1.436	10.370	-53.556	55.527
157	1921–91	20	70.8	1.370	2.323	41.301	-239.790	334.165

TABLE 3. *Components of hydrologic budgets of basins in the Appalachian Valley and Ridge, Blue Ridge, and Piedmont Physiographic Provinces Regional Aquifer-System Analysis study area, 1961–90*

[in/yr, inches per year]

Map number (fig. 1)	Precip-itation (in/yr)	Evapo-trans-piration (in/yr)	Streamflow (in/yr)	Recharge (in/yr)	Base flow (in/yr)	Direct runoff (in/yr)	Base-flow index (percent)
12	53.40	31.77	21.63	17.20	16.03	5.60	74.1
13	55.30	34.95	20.35	12.67	11.87	8.48	58.3
15	57.60	30.98	26.62	18.93	16.76	9.86	63.0
19	65.50	31.78	33.72	28.44	26.01	7.70	77.2
20	62.90	23.90	39.00	36.24	33.00	6.00	84.6
22	73.60	28.64	44.96	40.97	36.98	7.98	82.3
25	56.20	33.96	22.24	14.12	12.51	9.73	56.3
28	45.20	28.42	16.78	10.85	9.46	7.32	56.4
29	59.30	25.21	34.09	28.40	25.74	8.35	75.5
[1]30	66.90	12.06	54.84	49.70	45.97	8.87	83.8
31	65.90	27.68	38.22	34.48	31.22	7.00	81.7
33	56.80	18.25	38.55	33.11	29.53	9.02	76.6
34	80.20	31.46	48.74	43.72	40.11	8.63	82.3
[1]35	57.90	7.33	50.57	40.54	36.57	14.00	72.3
36	55.60	17.91	37.69	32.63	29.41	8.29	78.0
38	49.90	25.04	24.86	20.94	19.49	5.37	78.4
[1]39	55.10	9.60	45.50	35.72	32.89	12.61	72.3
41	56.60	24.00	32.60	24.95	22.69	9.91	69.6
42	52.30	32.07	20.23	16.01	14.91	5.32	73.7
44	57.60	32.89	24.71	21.23	19.50	5.21	78.9
45	59.40	32.02	27.38	20.77	18.66	8.73	68.1
46	48.50	31.03	17.47	12.35	11.37	6.10	65.1
47	49.50	30.42	19.08	15.32	14.06	5.03	73.6
48	53.50	30.87	22.63	19.47	17.99	4.64	79.5
51	47.50	28.76	18.74	14.66	13.30	5.43	71.0
52	46.80	31.86	14.94	9.10	8.42	6.52	56.3
54	46.90	32.70	14.20	7.29	6.52	7.68	45.9
55	46.20	32.69	13.51	8.41	7.46	6.05	55.2
56	44.90	31.89	13.01	6.23	5.31	7.70	40.8
59	44.60	31.83	12.77	7.39	6.47	6.30	50.6
61	45.60	25.04	20.56	16.40	15.23	5.33	74.1
62	44.20	25.32	18.88	13.22	11.14	7.74	59.0
63	45.20	21.80	23.40	19.01	17.76	5.64	75.9
64	40.10	24.73	15.37	11.57	10.64	4.74	69.2
65	44.20	24.81	19.39	15.48	14.10	5.30	72.7
66	40.20	24.23	15.97	12.70	11.44	4.53	71.6
67	40.20	25.60	14.60	10.29	9.27	5.33	63.5
69	48.90	31.78	17.12	13.24	12.29	4.83	71.8
70	41.00	27.15	13.85	10.69	9.80	4.05	70.8
73	40.20	28.09	12.11	8.70	7.84	4.27	64.7
74	39.90	25.86	14.04	11.36	10.32	3.72	73.5
75	35.70	18.45	17.25	14.05	12.05	5.20	69.9
76	35.70	19.24	16.46	11.90	10.58	5.88	64.3
80	41.40	22.93	18.47	13.66	12.20	6.27	66.0
81	43.50	29.80	13.70	9.79	8.81	4.89	64.3

TABLE 3. *Components of hydrologic budgets of basins in the Appalachian Valley and Ridge, Blue Ridge, and Piedmont Physiographic Provinces Regional Aquifer-System Analysis study area, 1961–90* —*Continued*

Map number (fig. 1)	Precip-itation (in/yr)	Evapo-trans-piration (in/yr)	Streamflow (in/yr)	Recharge (in/yr)	Base flow (in/yr)	Direct runoff (in/yr)	Base-flow index (percent)
82	41.90	28.38	13.52	9.74	8.81	4.71	65.2
83	42.20	28.39	13.81	10.23	9.10	4.70	65.9
85	42.90	28.91	13.99	9.51	8.81	5.18	63.0
87	42.90	29.46	13.44	9.76	8.99	4.44	66.9
89	42.00	26.06	15.94	12.86	11.50	4.45	72.1
90	47.40	23.95	23.45	19.91	17.46	5.99	74.5
91	45.40	24.57	20.83	17.02	15.11	5.72	72.5
94	34.20	21.19	13.01	7.51	5.82	7.19	44.7
95	34.60	23.99	10.61	8.57	7.79	2.82	73.4
98	43.30	28.75	14.55	7.56	6.57	7.98	45.2
99	43.40	29.72	13.68	8.55	7.77	5.91	56.8
100	43.50	29.90	13.60	8.00	6.90	6.69	50.8
101	43.50	30.35	13.15	7.66	6.72	6.43	51.1
102	42.10	29.52	12.58	8.42	7.44	5.14	59.2
104	45.90	28.58	17.32	13.24	11.59	5.73	66.9
105	43.70	27.26	16.44	12.32	10.92	5.52	66.4
106	41.20	28.24	12.96	10.38	9.18	3.78	70.8
108	41.30	29.03	12.27	6.81	5.67	6.60	46.2
110	35.70	22.32	13.38	9.24	7.93	5.45	59.3
111	40.80	24.08	16.72	7.13	6.34	10.38	37.9
112	40.80	26.01	14.79	8.99	8.43	6.36	57.0
114	45.10	17.56	27.54	18.42	15.32	12.22	55.6
116	41.90	25.81	16.09	11.08	9.79	6.30	60.8
117	37.80	25.75	12.05	8.96	8.11	3.94	67.3
119	42.30	27.07	15.23	12.08	10.53	4.70	69.1
122	40.90	25.43	15.47	11.93	11.09	4.38	71.7
124	44.80	29.36	15.44	12.94	11.94	3.51	77.3
127	44.00	25.91	18.09	15.04	13.81	4.28	76.3
129	38.60	19.91	18.68	12.93	10.75	7.93	57.5
131	37.60	21.36	16.24	10.80	8.98	7.26	55.3
132	39.80	16.29	23.51	20.09	17.47	6.05	74.3
133	38.20	17.63	20.57	16.83	15.40	5.17	74.8
134	39.00	21.38	17.62	13.48	11.88	5.74	67.4
136	39.00	19.04	19.96	14.53	12.40	7.56	62.1
137	39.10	20.67	18.43	16.65	14.96	3.47	81.2
138	40.40	24.04	16.36	9.42	7.90	8.47	48.3
139	42.80	23.63	19.17	14.42	12.18	6.99	63.5
140	42.40	21.85	20.55	17.40	15.42	5.13	75.0
150	45.70	25.56	20.14	14.97	12.68	7.46	63.0
152	50.90	24.36	26.54	21.41	20.31	6.23	76.5
153	45.50	18.04	27.46	22.88	20.91	6.55	76.1
154	48.40	19.27	29.13	24.12	21.36	7.76	73.3
155	45.60	24.89	20.71	10.28	8.39	12.32	40.5
157	44.60	24.01	20.59	18.75	16.97	3.62	82.4

[1] Estimates of precipitation and evapotranspiration for this station may be in error because of difficulty in estimating precipitation.

TABLE 4. *Streamflow, recharge, and base flow in basins in the Appalachian Valley and Ridge, Blue Ridge, and Piedmont Physiographic Provinces Regional Aquifer-System Analysis study areas, 1981–90*

Map number (fig. 1)	Streamflow (in/yr	Recharge (in/yr)	Base flow (in/yr)	Base-flow index (percent)
1	20.94	13.47	12.44	59.4
2	28.22	18.41	16.35	57.9
3	23.92	16.03	14.12	59.0
4	23.17	13.40	11.34	48.9
5	19.96	14.21	13.36	66.9
6	32.53	23.94	15.59	47.9
7	10.80	6.18	5.29	48.9
8	9.23	4.57	3.97	43.0
9	10.19	6.76	6.06	59.5
10	10.64	6.52	6.10	57.4
11	15.07	10.44	9.23	61.2
12	18.71	15.06	14.09	75.3
13	18.07	11.09	10.32	57.1
14	17.15	12.65	11.62	67.7
15	24.65	17.61	15.48	62.8
16	22.05	15.52	12.36	56.1
17	22.07	18.17	16.86	76.4
18	26.76	23.71	21.32	79.7
19	27.84	23.54	21.50	77.2
20	33.39	30.95	28.11	84.2
21	37.78	33.75	31.35	83.0
22	37.73	34.88	31.28	82.9
23	27.26	23.65	21.92	80.4
24	21.32	11.47	10.56	49.5
25	18.71	12.10	10.52	56.2
26	33.53	26.39	23.59	70.3
27	11.23	9.74	8.93	79.5
28	14.14	9.71	8.42	59.5
29	30.28	25.51	22.80	75.3
30	49.33	45.53	41.70	84.5
31	32.04	29.19	26.27	82.0
32	30.22	26.02	24.41	80.8
33	36.29	31.58	28.13	77.5
34	42.62	38.81	35.40	83.1
35	45.69	37.60	33.82	74.0
36	33.06	29.18	26.24	79.4
37	27.47	24.67	22.51	81.9
38	22.30	18.64	17.41	78.1
39	40.52	32.41	30.15	74.4
40	25.80	21.93	20.10	77.9
41	29.90	23.93	21.74	72.7
42	17.99	14.42	13.40	74.5
43	24.53	19.11	17.52	71.4
44	22.33	19.17	17.61	78.9
45	24.88	19.63	17.30	69.5

TABLE 4. *Streamflow, recharge, and base flow in basins in the Appalachian Valley and Ridge, Blue Ridge, and Piedmont Physiographic Provinces Regional Aquifer-System Analysis study areas, 1981–90* —*Continued*

Map number (fig. 1)	Streamflow (in/yr	Recharge (in/yr)	Base flow (in/yr)	Base-flow index (percent)
46	14.87	10.75	9.85	66.2
47	17.77	14.58	13.46	75.7
48	19.95	17.40	15.92	79.8
49	17.96	15.27	13.84	77.1
50	12.30	8.24	7.39	60.1
51	17.43	13.52	12.16	69.8
52	14.33	8.73	7.91	55.2
53	17.46	14.57	12.90	73.9
54	14.48	7.25	6.42	44.3
55	11.79	6.97	5.99	50.8
56	13.23	6.28	5.39	40.8
57	13.47	6.88	5.81	43.1
58	14.56	9.79	8.42	57.8
59	13.45	7.69	6.65	49.4
60	15.60	12.72	11.19	71.8
61	19.28	15.41	14.08	73.1
62	16.98	12.60	10.43	61.4
63	22.60	18.19	16.83	74.5
64	14.65	11.30	10.37	70.8
65	18.82	15.19	13.80	73.3
66	15.57	12.80	11.39	73.1
67	13.39	9.61	8.69	64.9
68	21.42	18.08	16.50	77.0
69	17.42	13.15	12.12	69.6
70	14.25	11.09	10.13	71.1
71	15.22	11.74	10.73	70.5
72	13.30	9.99	8.78	66.0
73	12.15	8.49	7.62	62.7
74	14.73	11.69	10.52	71.5
75	17.12	14.15	12.07	70.5
76	16.03	11.27	9.94	62.0
77	15.73	11.84	9.96	63.3
78	14.23	11.16	9.42	66.2
79	19.95	13.44	11.74	58.8
80	19.00	13.58	12.01	63.2
81	14.76	9.94	8.82	59.8
82	14.95	10.45	9.41	62.9
83	15.07	10.76	9.58	63.6
84	14.97	10.16	9.34	62.4
85	14.13	9.55	8.83	62.5
86	13.02	5.89	5.13	39.4
87	13.23	9.88	8.90	67.2
88	10.96	7.86	7.19	65.6
89	15.68	13.00	11.50	73.4
90	22.60	19.65	17.32	76.6

TABLE 4. *Streamflow, recharge, and base flow in basins in the Appalachian Valley and Ridge, Blue Ridge, and Piedmont Physiographic Provinces Regional Aquifer-System Analysis study areas, 1981–90 —Continued*

Map number (fig. 1)	Streamflow (in/yr	Recharge (in/yr)	Base flow (in/yr)	Base-flow index (percent)
91	20.16	16.75	14.72	73.0
92	18.21	14.74	13.15	72.2
93	16.95	13.83	12.30	72.6
94	12.22	7.15	5.58	45.7
95	10.34	8.29	7.47	72.3
96	15.51	11.56	10.22	65.9
97	15.90	10.78	9.29	58.4
98	13.83	6.93	5.96	43.1
99	12.72	8.13	7.49	58.9
100	12.65	7.47	6.44	50.9
101	11.97	7.06	6.29	52.5
102	11.64	7.71	6.63	56.9
103	12.10	6.97	6.01	49.7
104	16.74	12.64	10.97	65.5
105	15.19	11.35	9.99	65.8
106	11.66	9.27	8.07	69.2
107	11.85	7.01	6.11	51.6
108	11.38	6.68	5.48	48.1
109	12.35	10.11	8.24	66.8
110	13.35	8.98	7.70	57.7
111	15.01	5.56	4.74	31.6
112	13.13	7.94	7.34	55.9
113	13.52	8.95	7.96	58.9
114	28.23	18.73	15.47	54.8
115	13.60	9.94	8.47	62.3
116	16.06	10.99	9.74	60.6
117	11.56	8.68	7.70	66.6
118	6.42	6.23	5.71	89.0
119	13.83	11.39	9.85	71.2
120	13.35	10.12	9.18	68.7
121	13.28	9.31	8.43	63.5
122	13.76	10.99	10.20	74.1
123	13.67	10.23	9.38	68.6
124	14.48	12.59	11.50	79.4
125	15.03	12.19	11.27	75.0
126	18.87	14.31	13.28	70.4
127	16.95	14.48	13.17	77.7
128	16.05	10.62	9.82	61.2
129	17.90	12.41	10.30	57.6
130	16.06	12.26	9.60	59.7
131	15.16	10.59	8.82	58.2
132	23.13	20.37	17.48	75.6
133	21.00	17.34	15.88	75.6
134	17.86	13.69	11.94	66.9
135	24.68	25.40	23.30	94.4

TABLE 4. *Streamflow, recharge, and base flow in basins in the Appalachian Valley and Ridge, Blue Ridge, and Piedmont Physiographic Provinces Regional Aquifer-System Analysis study areas, 1981–90* —*Continued*

Map number (fig. 1)	Streamflow (in/yr	Recharge (in/yr)	Base flow (in/yr)	Base-flow index (percent)
136	18.94	13.90	11.77	62.2
137	17.28	15.74	14.12	81.7
138	15.30	9.13	7.73	50.6
139	18.53	14.16	11.99	64.7
140	20.20	17.28	15.51	76.7
141	20.22	18.53	17.14	84.7
142	26.02	24.42	21.49	82.6
143	21.37	16.11	13.84	64.8
144	19.10	12.42	11.11	58.1
145	19.36	14.10	13.11	67.8
146	19.97	14.79	13.46	67.4
147	20.30	14.01	13.11	64.6
148	21.64	13.71	12.26	56.7
149	23.67	17.24	14.52	61.3
150	21.05	14.90	12.60	59.8
151	26.83	24.22	22.22	82.8
152	26.74	21.18	19.60	73.3
153	29.00	24.15	21.83	75.3
154	29.20	24.32	21.30	72.9
155	20.85	10.32	8.22	39.4
156	22.94	15.48	12.16	53.0
157	22.11	20.24	18.19	82.3

APPENDIX

SOURCES OF INFORMATION ON BASIN PROPERTIES

This appendix describes the sources of information on physical properities of basins that are used in this report. The listing of properties for all basins is in table 1 (follows "References) and mean precipitation from 1961 to 1990 is listed in table 3 (follows "References) for basins that have complete streamflow records for this period.

Variables From U.S. Geological Survey Data Books

Data obtained directly from USGS data books include latitude, longitude, and drainage area. The latitude and longitude reported in USGS data books (published separately for each State) represent the location of the streamflow-gaging station.

Precipitation

The source of basin precipitation is a data tape obtained from the National Climatic Data Center (NCDC) in Ashville, North Carolina. The data tape includes the "normal" precipitation from 1961 to 1990, which represents the mean annual precipitation for this period for specific locations in the United States. The data were transferred to a point coverage in a geographic informaiton system (GIS) by using the latitude and longitude that are obtained from the NCDC. The point values of mean precipitation were then plotted with polygon coverages that represent the drainage boundaries of the 157 basins. A value for mean precipitation was then assigned to each basin by visual interpolation.

Physiographic Province

The physiographic province of a basin was assigned by intersecting the polygon coverage of basin boundaries with that of physiographic province. If more than 75 percent of a basin is located in a particular province, then the basin is assigned a number in table 1 according to the following:

Physiographic province	Number issued
Valley and Ridge	1
Blue Ridge	2
Piedmont	3

If the largest fraction of a basin's area that is in one physiographic province is less than 75 percent, then the number assigned is 0.

Basin Relief

Elevation point data were digitized from 30-second point elevation data provided by the National Oceanic and Atmospheric Administration, National Geophysical Data Center, Boulder, Colorado (D.C. Schoolcraft, National Geophysical Data Center, written commun., 1989). For purposes of this study, data were reformatted with each point being assigned a latitude, longitude, and elevation value. GIS point data coverages were created from the reformatted elevation data. A Triangulated Irregular Network was constructed to interpolate surface-elevation contours and surface-relief model. The variable basin relief that is used in this report is the median of all values for relief in that basin. The variable is listed for each basin in table 1.

Hydrogeologic Terrane

The first step in development of variables for testing the relations between hydrologic characteristics and geologic characteristics of basins is the introduction of 13 variables; each represents the percent of the basin that is characterized by a hydrogeologic terrane. The hydrogeologic terranes represent different ranges of well yield or specific capacity. State geologic maps were digitized into a GIS coverage. This included assigning a rock type to each geologic formation and aggregating all polygons that contain the same rock type into groups. The rock type was based on the lithologic term in the geologic formation name and may not reflect the bulk lithology of the formation in the study area. In the Valley and Ridge Physiographic Province, all units are placed in one of five hydrogeologic terranes that are based on Hollyday and others (1992) and Knopman and Hollyday (1993). For this report, the following five variables represent the percentage of the basin that is characterized by a hydrogeologic terrane:

Variable name included	Rock types
V1	Siliciclastics.
V2	Argillaceous carbonates.
V3	Limestone.
V4	Dolomite and mixtures of limestone and dolomite.
V5	Alluvium.

Because the GIS data base does not include alluvium, values for the V5 were assigned manually for use in this report on the basis of map information from E.F. Hollyday and others (written commun., 1994). The only alluvium of any significance to regional hydrogeology in this study area is of glacial origin and is restricted to New Jersey and Pennsylvania (E.F. Hollyday, U.S. Geological Survey, written commun., 1994).

Two hydrogeologic terranes are designated for the Blue Ridge Physiographic Province, and six for the Piedmont Physiographic Province. The following eight variables represent the percentage of the basin that is covered by a hydrogeologic terrane. The prefix B stands for the Blue Ridge Physiographic Province and the prefix P stands for the Piedmont Physiographic Province. The numbers in parentheses represent the range of well yields in gallons per minute:

Variable name	
B1	Group BRM1 (0–25).
B2	Group BRM2 (greater than 25).
P1	Group PDM1 (0–10).
P2	Group PDM2 (10–20).
P3	Group PDM3 (20–30).
P4	Group PDM4 (30–50).
P5	Group PDM5 (50–100).
P6	Group PDM6 (greater than 100).

Because some rock types are not areally extensive, there were not enough well-yield data to allow for a statistically significant assignment to a terrane. Because of this, the sum of all variables that quantify the amount of a basin covered by each terrane may not be equal to 100 percent for some basins. The variables pertain only to the part of the basin that is within the APRASA area.

As described in the following text, data are reduced further, before testing relations between rock characteristics of basins and hydrologic variables. The tests, which are illustrated in figures 13, 14, 23, 24, and 33, are performed in such a way that basins in the Valley and Ridge Physiographic Province are tested separately from those in the Blue Ridge and the Piedmont Physiographic Provinces because of the difference between these two subareas of the study area (Swain and others, 1991). In the latter subarea, tests are performed for the Piedmont Physiographic Province only because of the absence of rocks with high well yields in the Blue Ridge Physiographic Province. The elimination of the Blue Ridge Physiographic Province from these tests also reduces the interference caused by other variables, such as relief and precipitation, that vary much more in that province than in the Piedmont Physiographic Province.

Basins With Predominantly Small or Predominantly Large Well-Yield Rocks

This report designates some basins as being predominantly underlain by rocks with small or large well yields. The designations include various sets of hydrogeologic terranes and various thresholds that must be exceeded, which are established in such a way as to distinguish between the basins with small well yields and those with large well yields, without allowing the sample size of either to become excessively small.

- In the Valley and Ridge Physiographic Province, basins are considered to have predominantly small well-yield rocks if V1 exceeds 90 percent.
- In the Valley and Ridge Physiographic Province, basins are considered to have predominantly large well-yield rocks if the sum of V2, V3, V4, and V5 exceeds 60 percent.
- In the Piedmont Physiographic Province, basins are considered to have predominantly small well-yield rocks if the sum of P1 and P2 exceeds 60 percent.
- In the Piedmont Physiographic Province, basins are considered to have predominantly large well-yield rocks if the sum of P3, P4, P5, and P6 exceeds 90 percent.

Areally Weighted Average Basin Specific Capacity

This report uses a variable that represents the areally weighted average specific capacity of the rocks in a basin, the derivation of which is described below. The average basin specific capacity is a representation of the general water-transmitting capacity of the rock types in the basin and is simply a method for quantifying hydrogeologic properties.

First, a value for the median specific capacity for each hydrogeologic terrane is selected. To minimize bias, specific capacities are used instead of well yield, and the values used represent only the "most-productive" wells in the Valley and Ridge Physiographic Province (E.F. Hollyday, U.S. Geological Survey, written commun., 1994) and the "nondomestic" wells in the Blue Ridge and the Piedmont Physiographic Provinces.

Variable representing the percentage of a basin underlain by rocks of a terrane	Specific capacity of rocks in this terrane [(gal/min)/ft]
V1	1.4
V2	4.1
V3	10.0
V4	17.0
V5	28.0
P1	0.285
P2	0.230
P3	0.470
P4	0.780
P5	1.200
P6	2.080

The areally weighted average specific capacity of rock types in a basin (*SCB*) is then determined by using one of the following equations:

Valley and Ridge Physiographic Province:

$$SCB = \frac{1.4 \times V1 + 4.1 \times V2 + 10 \times V3 + 17 \times V4 + 28 \times V5}{100}$$

Piedmont Physiographic Province:

$$SCB = \frac{0.285 \times P1 + 0.23 \times P2 + 0.47 \times P3 + 0.78 \times P4 + 1.2 \times P5 + 2.08 \times P6}{100}$$

The only values of *SCB* that are used are for basins that have sufficient areal definition of rock characteristics—the sum of V1 through V5 or the sum of P1 through P6 must be larger than 80 percent.

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Maps

Geologic Quadrangle Maps are multicolor geologic maps on topographic bases in 7.5- or 15-minute quadrangle formats (scales mainly 1:24,000 or 1:62,500) showing bedrock, surficial, or engineering geology. Maps generally include brief texts; some maps include structure and columnar sections only.

Geophysical Investigations Maps are on topographic or planimetric bases at various scales; they show results of surveys using geophysical techniques, such as gravity, magnetic, seismic, or radioactivity, which reflect subsurface structures that are of economic or geologic significance. Many maps include correlations with the geology.

Miscellaneous Investigations Series Maps are on planimetric or topographic bases of regular and irregular areas at various scales; they present a wide variety of format and subject matter. The series also includes 7.5-minute quadrangle photogeologic maps on planimetric bases that show geology as interpreted from aerial photographs. Series also includes maps of Mars and the Moon.

Coal Investigations Maps are geologic maps on topographic or planimetric bases at various scales showing bedrock or surficial geology, stratigraphy, and structural relations in certain coal-resource areas.

Oil and Gas Investigations Charts show stratigraphic information for certain oil and gas fields and other areas having petroleum potential.

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Hydrologic Investigations Atlases are multicolored or black-and-white maps on topographic or planimetric bases presenting a wide range of geohydrologic data of both regular and irregular areas; principal scale is 1:24,000, and regional studies are at 1:250,000 scale or smaller.

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