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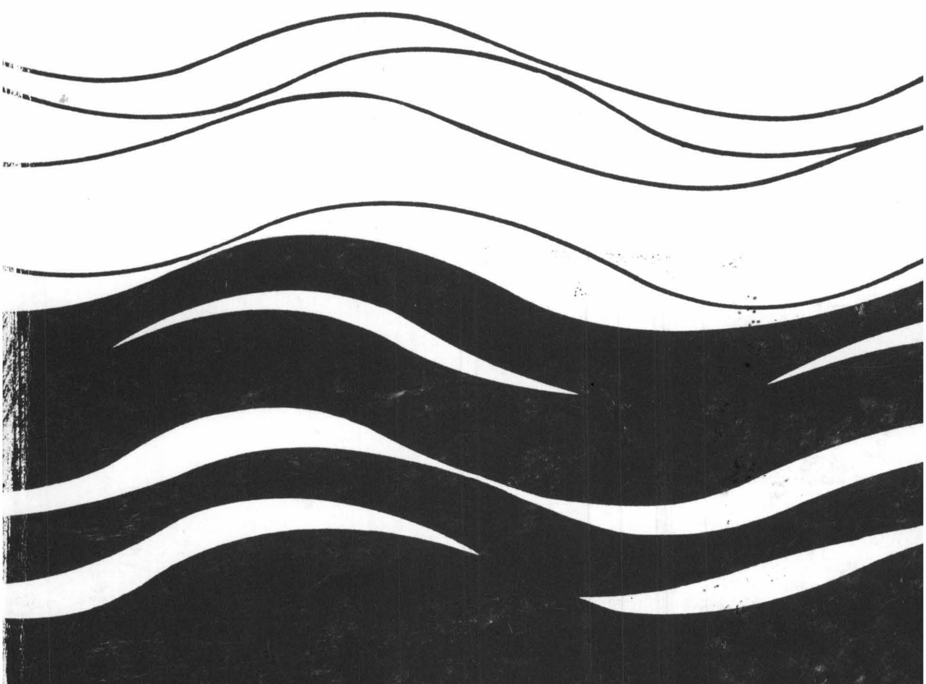
Rock Type and Minimum 7-Day/10-Year Flow in Virginia Streams

Reed W. Smith



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ABSTRACT

This study investigates the direct relationship between rock type and minimum 7-day/10-year flow ($Q_{7,10}$) for Virginia streams. These streams behave predictably during the low-flow condition because of the stream recharge from specific rock types: the flow in the minimum 7-day/10-year condition generally relates to the drainage basin size and the rock type of the upstream watershed. This report presents an effective method of estimating the minimum 7-day/10-year flow for ungauged streams.

This method was developed from geologic base maps for Virginia and streamflow data for the minimum 7-day/10-year flow from U.S. Geological Survey gauging stations. A specific relationship for flow rate to drainage basin size was identified for seven rock types, including metavolcanic rock, Triassic sandstone rock, igneous rock, Lynchburg Formation conglomerates, carbonate rock, and unconsolidated sedimentary material.

Additional information demonstrates a method for estimating minimum 7-day/10-year flows for drainage basins with more than one rock type. Calculations add flows from each rock type in the drainage basin, based upon adding net drainage area flow rates for each rock type.

Key Words: Minimum 7-Day/10-Year Flow, 7-Day/10-Year Low Flow, $Q_{7,10}$, Virginia Streamflows, Streamflows, Streams, Geohydrology

INTRODUCTION

With the advent of P.L. 92-500 and subsequent federal laws related to sewer and sewage treatment, much new construction has occurred with effluent design criteria dependent upon stream flow at the drought condition—the minimum 7-day/10-year flow ($Q_{7,10}$). The minimum 7-day/10-year flow data are available for many streams in Virginia; however, problems occur when trying to estimate minimum 7-day/10-year flows on ungauged streams. This report attempts to develop a rational method of estimating the minimum 7-day/10-year flow for ungauged streams in Virginia.

One comprehensive report projecting the minimum 7-day/10-year flow for gauged streams was written by Singh and Stall [1974]. This effort describes plotting of the minimum 7-day/10-year flow versus drainage area for hydrologically similar areas in Illinois. These areas are not described further by the authors, and the curves were derived based upon the results of plotting data for hydrologically similar watersheds.

A similar study involving minimum 7-day/10-year flow data was developed by the U.S. Geological Survey (USGS) [Riggs, 1972]. This USGS manuscript states that "the principal terrestrial influence on low flows is geology (the lithology and structure of the rock formations). . . ."

This report relates the low stream flows in Virginia streams to the rock type that occurs in a gauged basin by developing minimum 7-day/10-year flow versus drainage area curves for each rock type (carbonate, shale, schist, gneiss). Further, a method has been developed to estimate the minimum 7-day/10-year flow for watersheds that are composed of dissimilar rock types.

The purpose of this study is to demonstrate an effective method of minimum 7-day/10-year flow estimation so as to properly construct sewage treatment plants or estimate safe surface water withdrawals for water systems.

FACTORS IN DEVELOPMENT OF GEOLOGY-HYDROLOGY CURVES—MINIMUM 7-DAY/10-YEAR FLOW

I. General

A. Categories of Rock

With the premise that the minimum 7-day/10-year flow can be related to the rock type within a waterhsed, an attempt has been made to develop geology-hydrology curves at the minimum 7-day/10-year flow for several rock types. The rock types used in each curve are listed in *Table 1.*

The information used in the development of these curves consists of geologic base map information as well as minimum 7-day/10-year flow information supplied by state and federal agencies. Additional information was obtained concerning springs and their yields so as to properly study the streamflows for watersheds containing carbonate rock.

B. Minimum 7-Day/10-Year Flow

The data generated for minimum 7-day/10-year flow were from records of gauging stations utilizing a water-stage recorder. In Virginia, a 1970 publication on low flows was available; however, it was determined that more current data (through 1974 water year) were available by treating the water records data from the HISARS computer program available through the Virginia Water Resources Research Center, Blacksburg, Virginia *(Table 2).* Only gauge data for gauges with 20 or more years of record were used, and the minimum 7-day/10-year flow was computed by the log-Pearson III method of analysis.

In Maryland, North Carolina, and West Virginia, the publications relating to the minimum 7-day/10-year flow were used. In this case as well, only gauge data for gauges with 20 or more years of record were used.

The method of analysis of minimum 7-day/10-year flow for these states was the following: West Virginia, Bumbel's limited distribution of the smallest value; Maryland, log-Pearson Type III; North Carolina, Graphical Method. The log-Pearson Type III is considered similar to graphical representations.

C. Geologic Base Maps

The Geologic Map of Virginia, 1963 (scale 1:500,000) was used to determine the rock type within a watershed. It may be possible to develop better-fitting curves and to cull extraneous data by using USGS quadrangle geology maps of Virginia; however, the relevance of the relationships has been established based upon the use of the Map of Virginia (scale 1:500,000). *Table 3* shows the listing of geologic formations from the Map of Virginia and the rock category *(Table 1)* to which it pertains.

D. Spring Flow Data

Spring flow data used for this report were from dry weather flows of 1962 and 1963 measured by the Bureau of Surveillance and Field Studies, Virginia State Water Control Board, for several springs in Virginia. Additionally, a curve was developed relating the 1963 field measurements to a report of yields of 566 springs in Virginia as measured during 1928 [Collins et al., 1930]. Spring flows were only used to develop "base curves" for carbonate rock.

II. Flow Curves by Rock Type

The gauge data for the state were perused so as to develop minimum flow and drainage area information that would establish geology-hydrology curves for the several categories. Originally, the research was limited to the state of Virginia; however, after exhausting the data, it was obvious that additional data points would be needed for the metavolcanic rock category in order to establish curves with a large enough population so as to be relevant. Thus, information from North Carolina and Maryland was used for this rock type. In addition, the shale and sandstone curves developed for the Western Potomac of Virginia also contained data from nearby tributaries of the Potomac in West Virginia. Data for the Big Sandy basin shales and sandstones were supplemented with data from the Elk and Little Kanawha in West Virginia. Additional information from North Carolina and Maryland streams was used where relevant to Virginia stream basins.

GEOLOGY-HYDROLOGY CURVE DEVELOPMENT

The methodology for developing data was as follows. All gauge station records for stations in state(s) where minimum 7-day/10-year flow data were available were reviewed. Those gauges with less than 20 years of record were eliminated since the data are less reliable for these gauges. Basins with more than one category of rock as defined in *Table 1* (i.e., carbonate and shale) were eliminated.

Data were used from carbonate, shale, or sandstone formations where spring values were known, but if springs were known to exist and their yields were unknown, the gauge data were not used. No attempt was made to determine sewage flows to streams at low flow or to determine the evaporation loss rate of impoundments.

In an attempt to update old data in Virginia, additional data for the minimum 7-day/10-year flow were generated by statistical treatment of data available in the Virginia Water Resources Research Center HISARS computer program (log-Pearson III method). It is impossible to determine reliably all cases where flow was diverted or regulated; however, if regulation or diversion was indicated by gauge records, the data for that gauge were not used.

I. Metavolcanic Rock

Metavolcanic rock—tuffs, breccias, and flows—are found locally in Virginia, Maryland, and North Carolina. Using the methodology previously described, data from only one station could be found in Virginia; therefore, it was necessary to develop a metavolcanic curve by utilizing gauge data from nearby streams in Maryland and North Carolina for this rock type. In North Carolina, the gauge data were for felsic volcanics and for mafic volcanics of the Precambrian or lower Paleozoic Age. In Virginia and Maryland, the gauge stations recorded flows of the Catoctin Formation (late Precambrian Age). *Table 4* shows the data developed for the seven gauge stations found to be located within the metavolcanic rock type. Note that the metavolcanic rock does not yield large quantities of water during dry weather periods. As can be seen, for a 350-square-mile drainage area, the net stream is only approximately 3.5 cubic feet per second.

Figure 1 is a plot of these data showing a linear curve of minimum 7-day/

10-year flow versus drainage area as plotted on cube root paper. This rock type is found in Virginia on the eastern slope of the Blue Ridge Mountains and in large beds in the Rappahannock and Eastern Potomac watersheds. One of the more notable streams containing metavolcanic rock is the Occoquan River, a Northern Virginia water supply source.

II. Triassic Sandstone Rock

The Triassic Age sandstone of the Newark Group in Virginia was assumed to exhibit a separate behavior from other rock types, and an attempt was made to plot gauge data for this porous sandstone rock. The rock type is found to occur mostly on the Eastern Potomac with some isolated occurrences of the rock type farther south in Campbell and Pittsylvania counties. Only two gauging stations were found for streams that flowed completely through the Triassic sandstone rock *(Table 5).* A plot of these two points and the zero point was generated, however, to show a curve for the Triassic sandstone *(Figure 2).* It has been observed in evaluating the discharges from streams in Maryland and Virginia that the Triassic sandstone does not yield large quantities of water during the low flow periods. A stream that contains a large bed of sandstone of the Triassic Age is the Occoquan River in Virginia. Another is the Monocacy River in Maryland and Pennsylvania.

This rock formation occurs mostly in Culpeper, Fauquier, Prince William, Loudoun, and Fairfax counties, with limited occurrences in Chesterfield, Pittsylvania, Campbell, and Cumberland counties. The ability to establish conclusively a relationship for this rock type is hampered by lack of data.

III. Igneous Rock

Gauge data for igneous rock formations in Virginia were originally used to establish a base curve for granite, gneiss, and granite gneiss rock and separately for schist and granite schist rock; however, the two curves were combined after it was found that they exhibited similar flow-rate curves. The rock types found in this category include the Wissahickon schists and granite gneisses, quartz diorite, hornblende, gabbro, gneiss, granite and hornblende gneiss, granite gneiss, granite, amphibolite and amphibolite-rich foliates, the Virginia Blue Ridge Complex, Leatherwood granite, Melrose granite, Petersburg granite, Redoak granite, Shelton granite gneiss, Virgilina Group schist, the Old Rag Formation, the Pedlar Formation, Robertson River Formation, Striped Rock granite, Roseland anorthosite, and the Arvonia Formation.

While trying to relate the minimum 7-day/10-year flow to drainage area for these rock types, it was discovered that a wide variability existed in the data and that with the ranges in value apparent, the data could not readily be used to estimate flows in ungauged streams. The data were plotted separately for each applicable river basin in Virginia. The Rappahannock, York, Eastern Potomac, and Chowan basins exhibited similar geology-hydrology curves. The James Basin and the Roanoke (Staunton) Basin each exhibited a distinct minimum 7-day/10-year flow to drainage area relationship. Thus, three curves were developed with data as shown in *Tables 6, 7,* and *8. Figures 3, 4,* and *5* show the geology-hydrology curves generated. It is apparent that although similar, the metamorphosed materials do not yield as well in the Eastern Potomac, Rappahannock, York, and Chowan basins as they do in the James Basin and in the Roanoke (Staunton) River Basin. There is no readily apparent explanation for this; however, it is known that these materials are generally impervious and that they contain water only as a result of secondary porosity brought about by fracture. Further, the complex factors associated with stream recharge during dry weather periods are not well understood, and it is possible that there is some yield of water in the soil/rock interface during the dry weather periods. These rocks are known for their weathered overburden, which can be extremely thick in some areas or which may not exist in others. It could be that the yield of these streams is as much related to the thickness of the weathered material as it is to the general classification of rock type.

Correspondence with H. C. Riggs, USGS, Reston, Virginia, has suggested that the scatter in the curves may be related to dissimilar evapotranspiration rates. These rock types occur generally in the Blue Ridge and Piedmont provinces of Virginia, and as a classification, they cover the major portion of the state.

IV. Lynchburg Formation Conglomerates

The Lynchburg Formation is found to exhibit flow characteristics separate from any other rock category in Virginia for the minimum 7-day/10-year flows. This category has the highest flow rate to discharge basin relationship of any rock type in Virginia: characteristically, a drainage basin of 100-square-mile size would yield in excess of 25 cfs flow. Seven gauging stations are located in the Lynchburg Formation and are located in Carroll, Grayson, Floyd, Patrick, and Franklin counties. The Lynchburg Formation does outcrop in other areas in Virginia and extends in a long, narrow band up the east side of the Virginia Blue Ridge through Bedford, Amherst, Nelson, Albemarle, Green, Madison, and Culpeper counties. *Table 9* and *Figure 6* show the gauge data and curve for this rock type. The Lynchburg Formation consists mainly of phyllite, quartzite, graywacke, and conglomerate.

V. Shale and Sandstone Rock Interbeds

Within Virginia, Maryland, and West Virginia are large interbeds of shale and sandstone of Pennsylvanian, Mississippian, Silurian, Devonian, and Permian ages. The geologic maps of these three states were perused in an effort to develop separate curves for shale and sandstone; however, not one gauged watershed could be separated because of the method by which these formations are mapped. Thus, the geology-hydrology curve has been developed for sandstone and shale together. As expected, there is some scatter in the data. However, the values of low flow tend to be extremely low when compared to limestone or gneiss and schist curves.

In Virginia, the shale and sandstone interbeds are not folded in the Big Sandy River Basin (Cumberland Plateau—Buchanan, Dickenson, and Wise counties); however, throughout the Valley and Ridge Province of Virginia, massive folding has occurred. Thus, two curves were developed—one describing the geology-hydrology relationship for massively folded beds of shale and sandstone *(Table 10* and *Figure 7)* and the other describing the geology-hydrology relationship for flat-lying beds of shale and sandstone *(Table 11* and *Figure 8).* The massively folded sandstone and shale rock yield slightly higher values for flow than do the non-folded beds when comparing flows for the same basin size.

VI. Limestone and Dolomite (Carbonate) Rock

Within Virginia, carbonate rock types occur generally west of the Blue Ridge Mountains and in the Valley and Ridge Province. Because of the massive folding that has occurred in the Appalachian region, it is difficult to find gauge data representative of carbonate rock only. However, five watersheds have been found that contain carbonate rock, and net streamflows have been developed for these streams by subtracting dry weather measurements of spring flow from the minimum 7-day/10-year flow value. The spring flow data were taken directly from unpublished measurements of August 1962 and August and September 1963 spring flows, based upon measurements made by the Bureau of Surveillance and Field Studies, Virginia State Water Control Board, Charlottesville, Virginia. In addition, a relationship was established between the 1963 low flow information and the more complete information available in Collins et al. [1930]. The resulting data are presented in *Table 12* and plotted in *Figure 9.* Note in *Figure 9* that the carbonate curve has a large slope for drainage areas above 10 square miles and produces large quantities of water for these relatively small basin sizes.

VII. Unconsolidated Sedimentary Material

The unconsolidated sedimentary materials occur in the eastern sections of Virginia and cover an area generally considered to be in the Coastal Plain Province. The formations involved include the Tertiary Formations of the Chesapeake Group and the Pamunkey Group. *Table 13* shows the stream data available for these rock types.

As can be seen from *Figure 10,* the unconsolidated sedimentary materials are not large producers of surface water during drought periods. Three gauges yielded markedly higher flows as compared to the data from the other five gauges. The cause of these disparate points is considered to be the influence of tidal action during low flow.

The gauge on the Blackwater River near Franklin is reversed during low flow periods by tidal action as reported in the USGS Water-Data reports (published each year). Note the height above mean sea level for the three gauges as reported in *Figure 10* and that their absolute flows are inversely related to the height of the gauge above mean sea level.

Figure 11 graphically represents the minimum 7-day/10-year flow for unconsolidated sedimentary material as plotted against datum of gauge above mean sea level. There is an inverse relationship between ΔH and streamflow for drainage basins with a gauge datum of 35 feet or less.

DEVELOPING MINIMUM 7-DAY/10-YEAR FLOW DATA FOR STREAMS WITH MORE THAN ONE ROCK CATEGORY

I. General

Most of the Virginia streams for which there are gauge data flow through rock types that are hydrologically dissimilar. However, the flow in these streams is predictable by adding the contribution from each rock category. Several streams in Virginia for which minimum 7-day/10-year flow data were known and which flowed through more than one rock category were studied. It was found generally that the additions of the minimum 7-day/10-year flow for drainage basin size of each rock category yielded a sum which approximated the actual gauge value for the minimum 7-day/10-year flow. *Table 14* shows the comparison of the estimated and actual values of the minimum 7-day/10-year flow, with actual calculations shown in *Table 15.*

II. Special Conditions

Several special conditions affecting the actual minimum 7-day/10-year flow in Virginia streams were found to exist.

1. The flow of springs in carbonate category basins was a large determinant in the total flow during dry weather periods. Unfortunately, the dry weather spring yields for Virginia streams are poorly documented.

2. Triassic Age sandstone is porous and an aquifer and in all cases where a predominantly large-yielding drainage basin flowed for a portion of its length through this rock type, the streams appeared to yield considerably less than the projected value for the rock category. Streams found to exhibit this behavior were: Sandy River near Danville, Banister River near Danville, Falling River near Brookneal, Roanoke Creek near Saxe, and Appomattox River near Farmville. No rate of loss through the streambed could be developed for these streams.

CONCLUSIONS AND RECOMMENDATIONS

1. In Virginia, there is a direct comparable relationship between the geologic rock categories studied and their rate of discharge during low flow periods (as approximated by $Q_{7, 10}$).

2. Streams flowing through unconsolidated sedimentary material, Triassic sandstone, shale and sandstone interbeds, or metavolcanic rock do not have high yields for their drainage area size.

3. Streams flowing through metamorphosed sedimentary and igneous rock, Lynchburg conglomerates, and carbonate rock exhibit markedly high values for flow as compared to their basin size.

4. The presence of springs greatly influences the minimum 7-day/10-year flow of streams flowing through carbonate rock.

5. Minimum 7-day/10-year flows can be estimated for streams with dissimilar rock types by the addition of streamflows for each rock type found within the stream drainage area.

6. Gauge stations should be constructed for streams flowing through metavolcanic and Triassic sandstone rock types so that additional information on the minimum 7-day/10-year flow can be developed.

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FIGURES

FIGURE 1
Metavolcanic Rock—Geology-Hydrology Curve

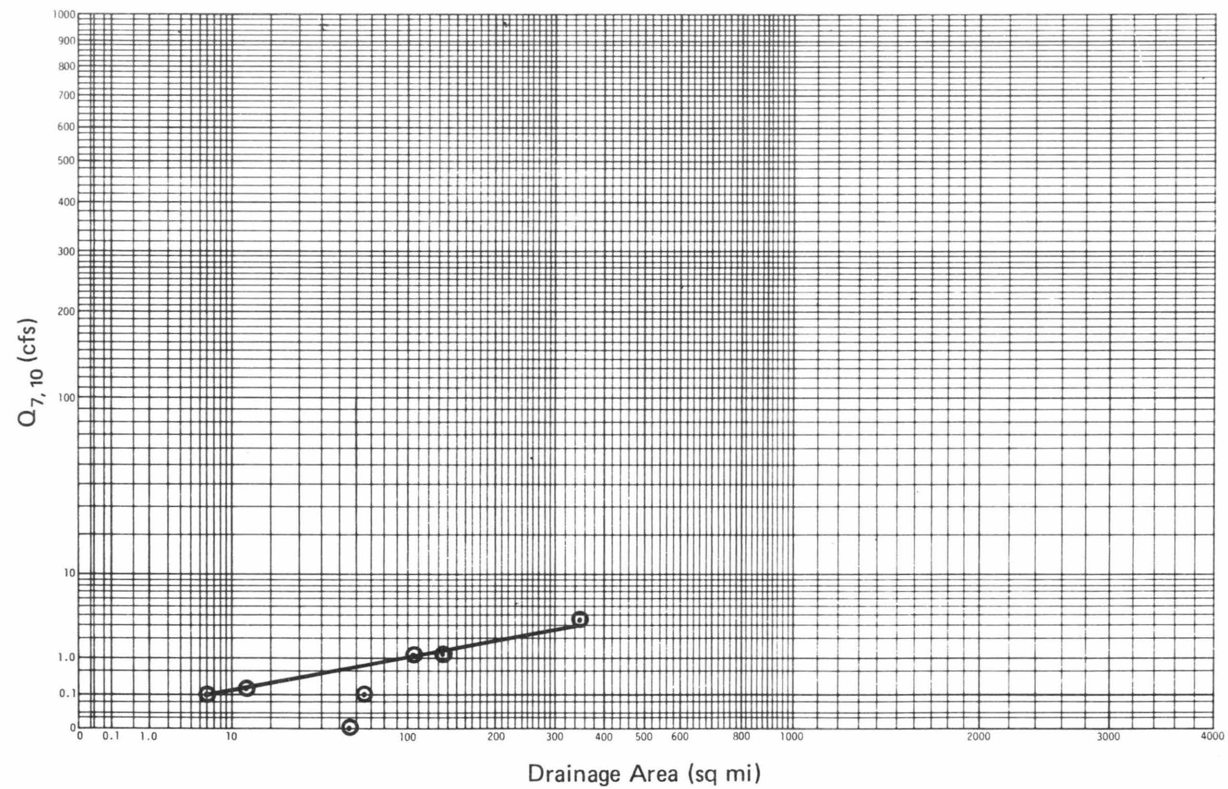


FIGURE 2

Triassic Sandstone and Shale Rock—Geology-Hydrology Curve

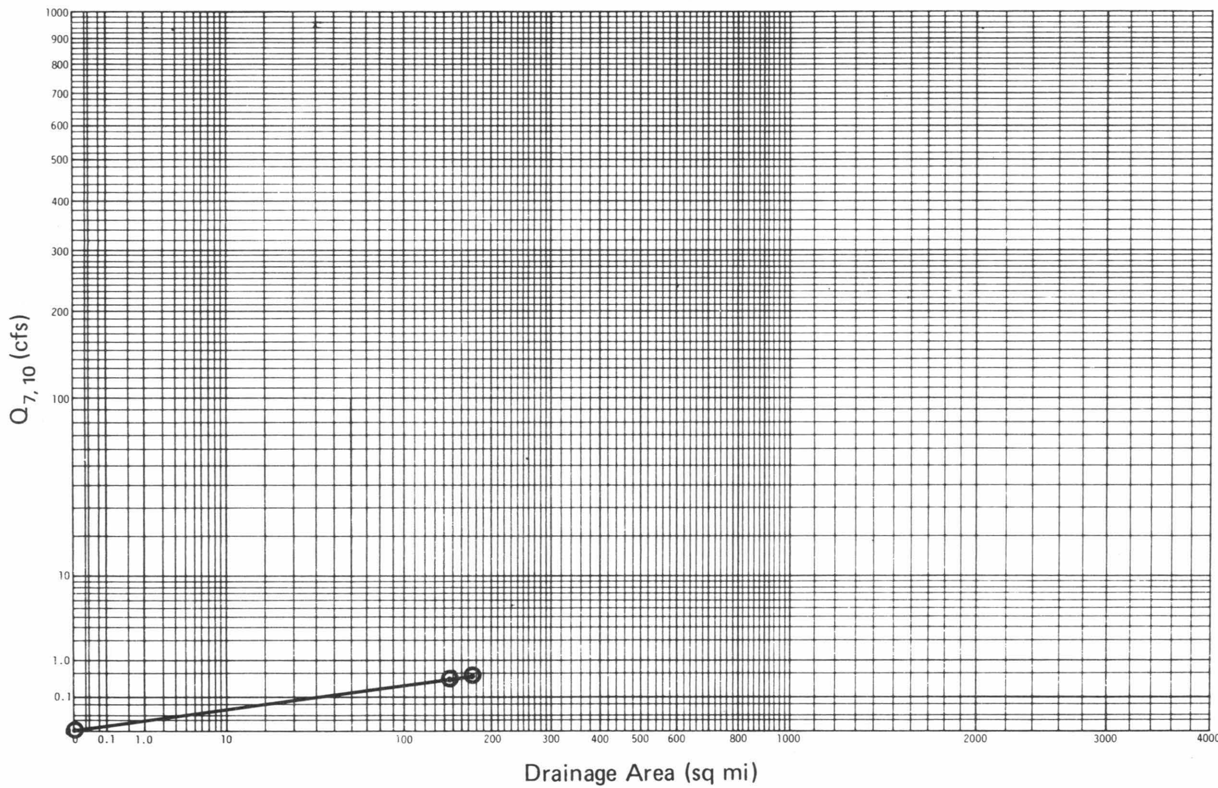


FIGURE 3

Igneous Rock—Eastern Potomac, York, Rappahannock, and Chowan Basins, Virginia, Geology-Hydrology Curve

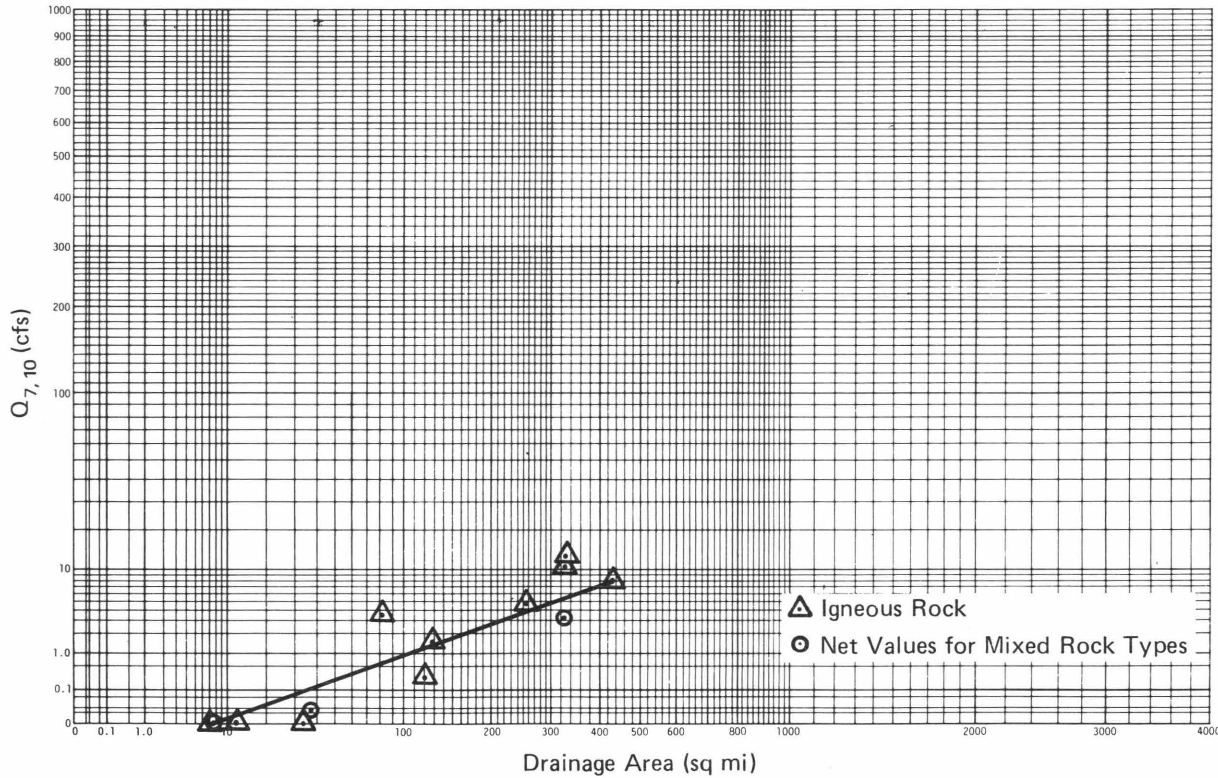


FIGURE 4
Igneous Rock—James River Basin Geology-Hydrology Curve

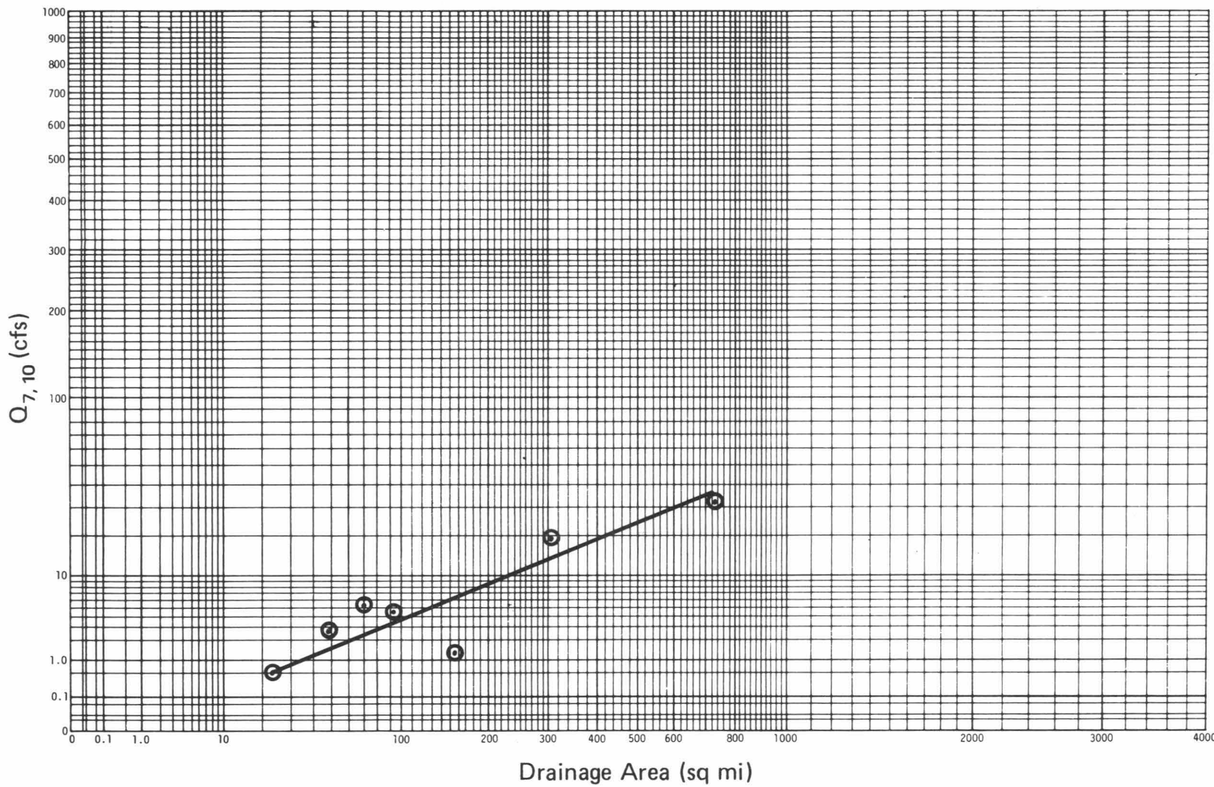


FIGURE 5
Igneous Rock—Roanoke River Basin Geology-Hydrology Curve

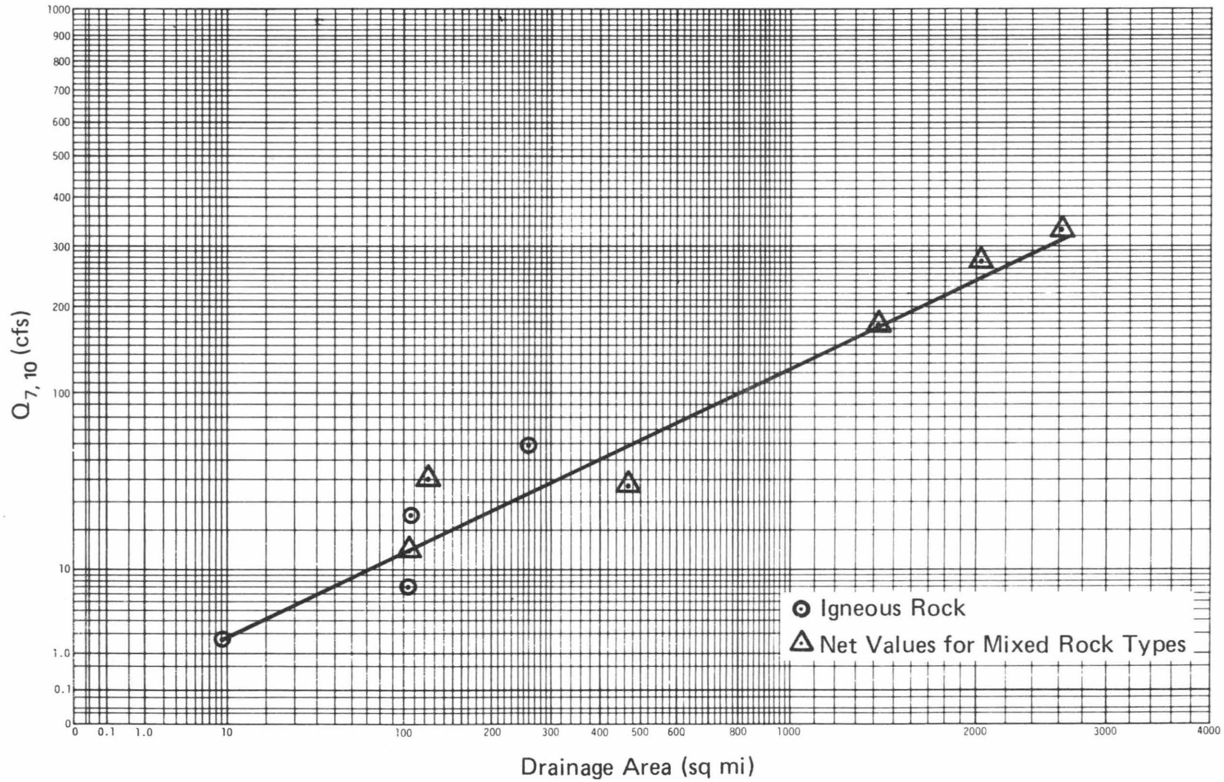


FIGURE 6

Lynchburg Formation Conglomerates—Geology-Hydrology Curve

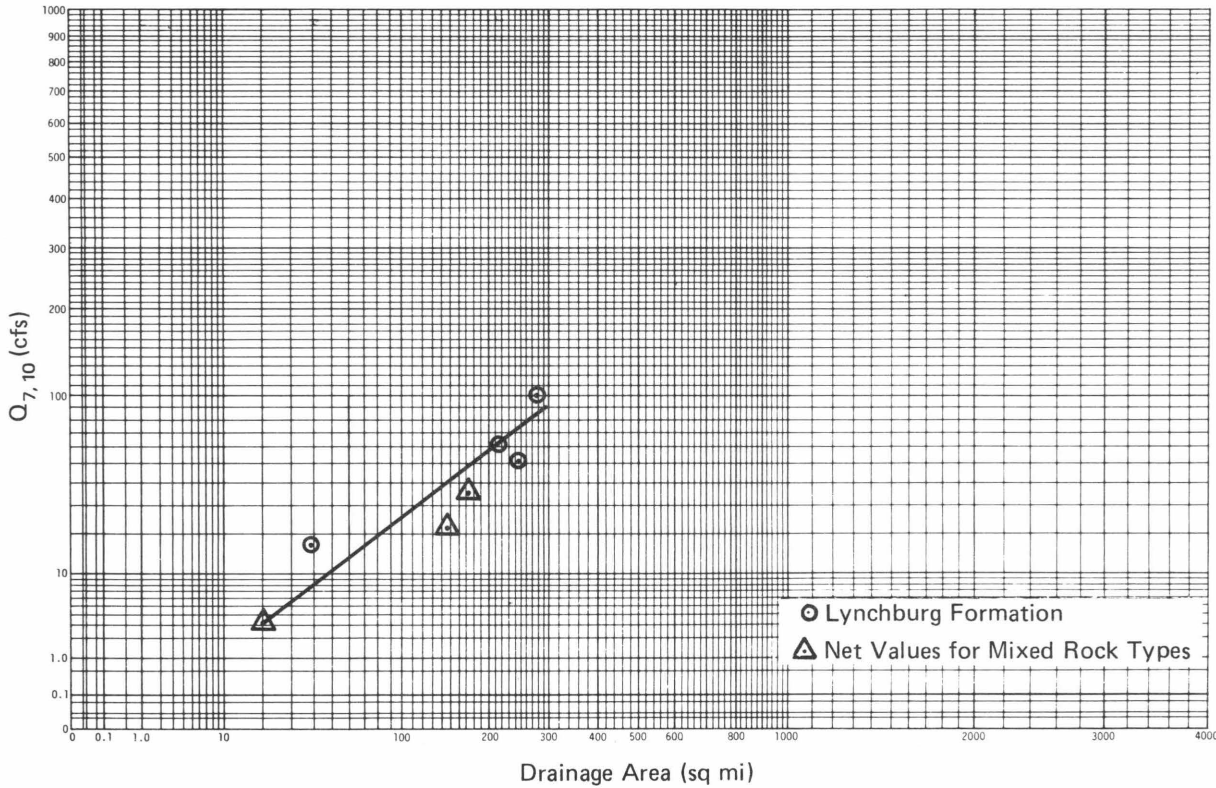
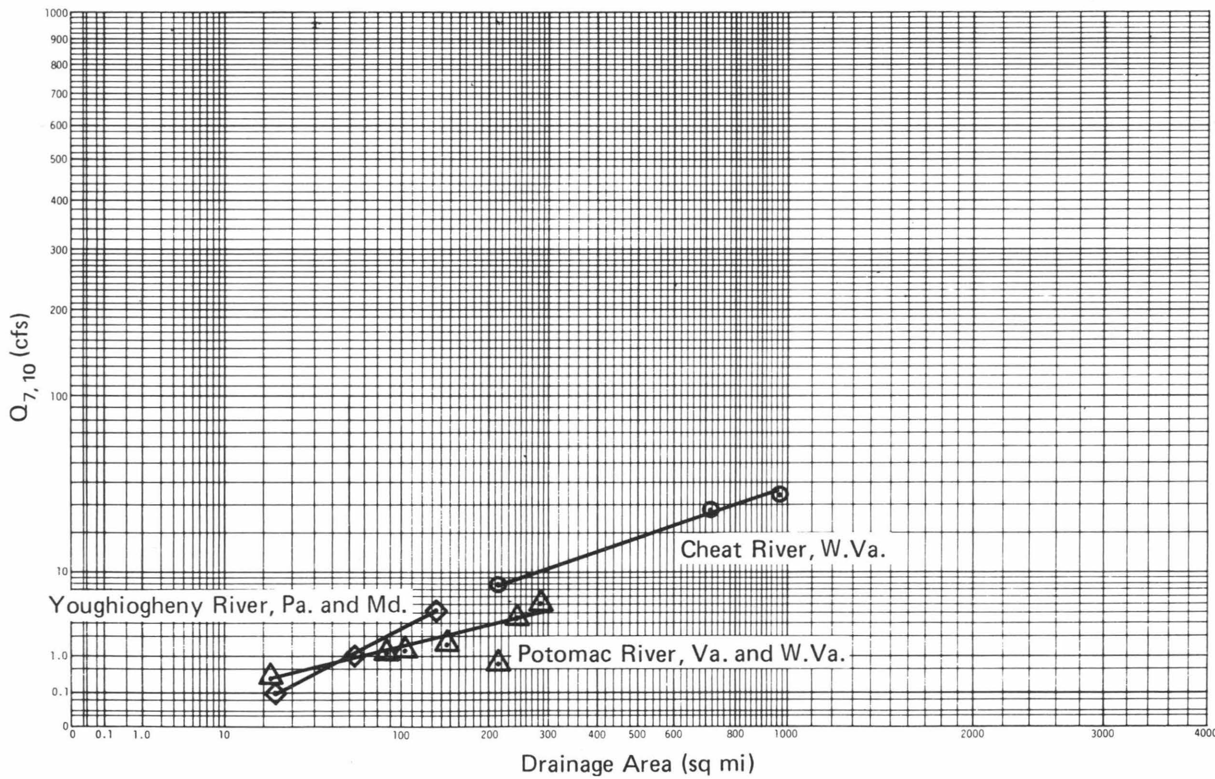


FIGURE 7

Shales and Sandstones of Pennsylvanian, Permian, Silurian, Devonian, and Mississippian Ages, Massive Folding—Geology-Hydrology Curve



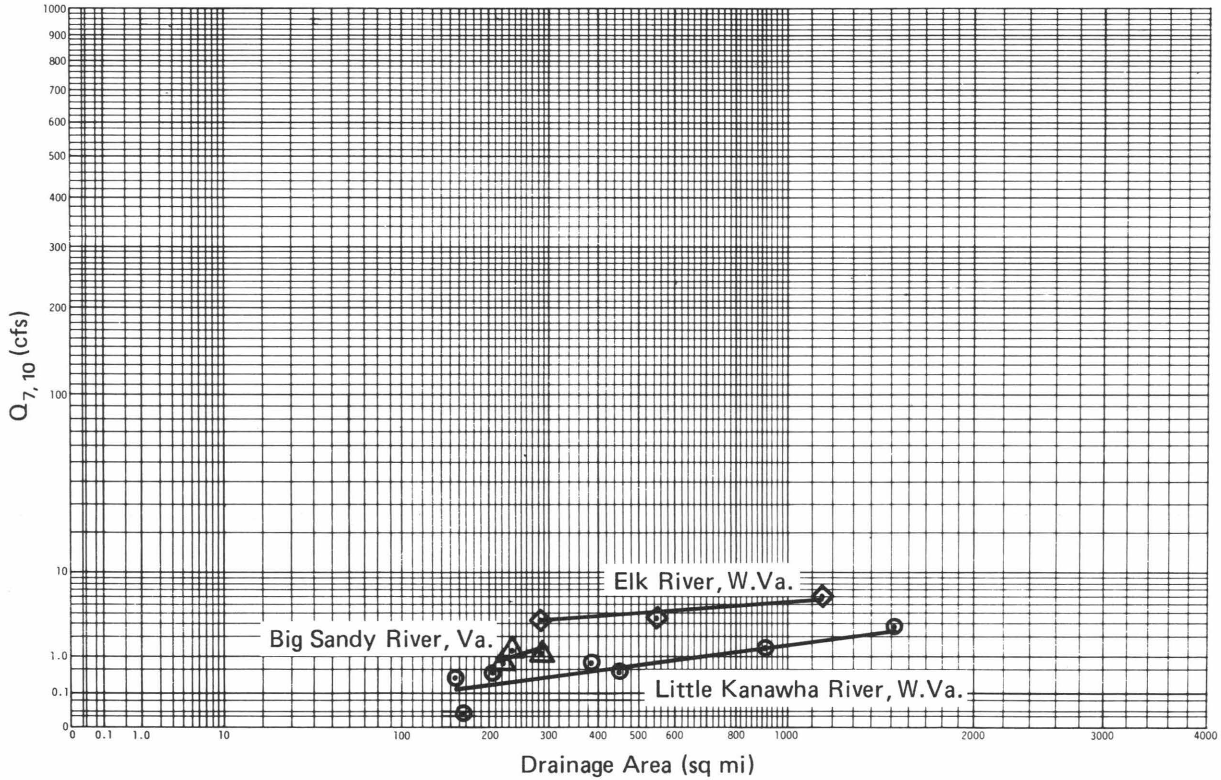


FIGURE 8

Shales and Sandstones of Pennsylvanian, Permian, Silurian, Devonian, and Mississippian Ages, Nonfolded Bedding—Geology-Hydrology Curve

FIGURE 9
Limestone and Dolomite Rock—Geology-Hydrology Curve

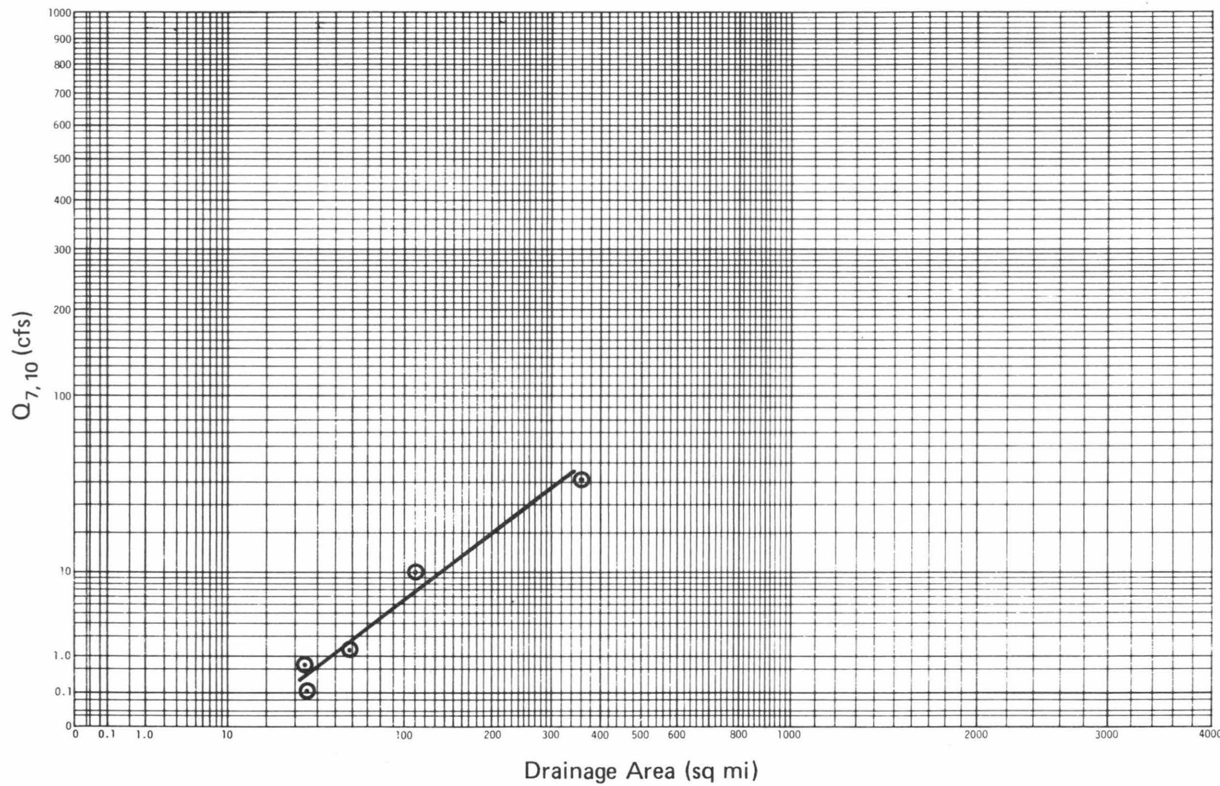


FIGURE 10

Unconsolidated Sedimentary Materials in Virginia— Geology-Hydrology Curve

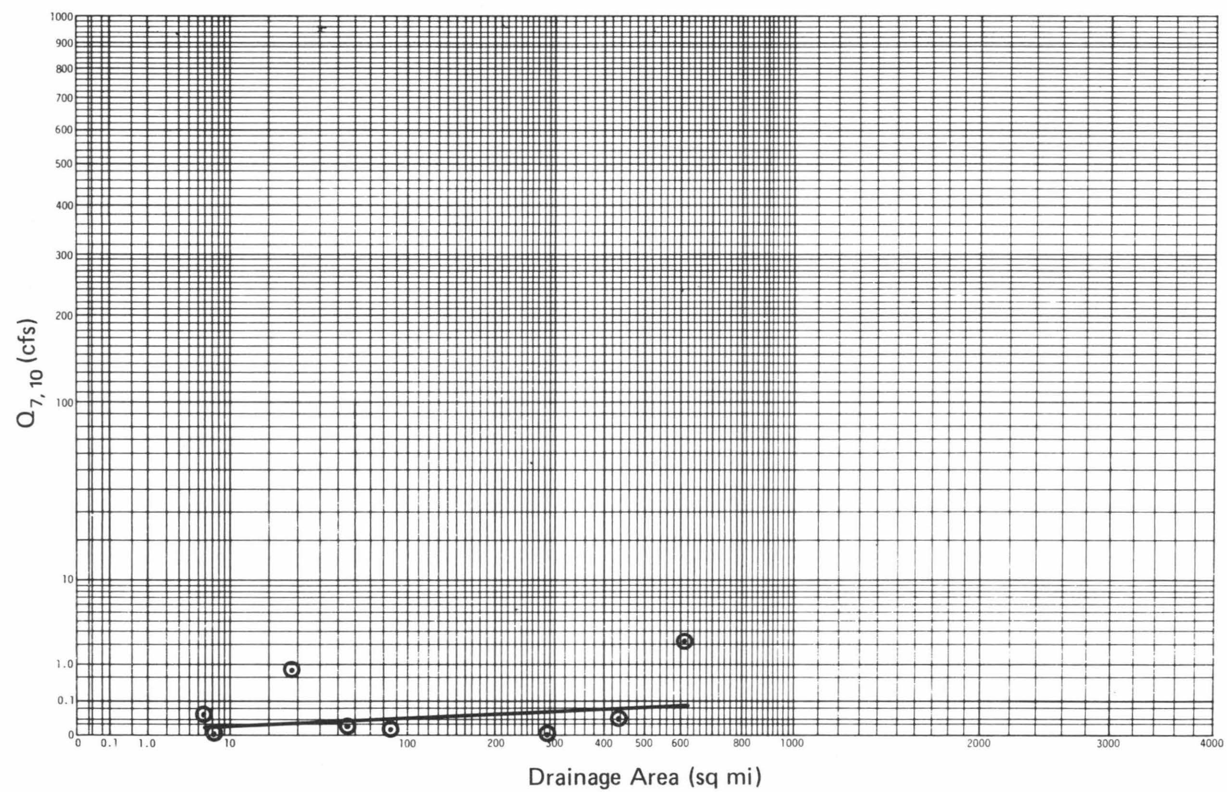
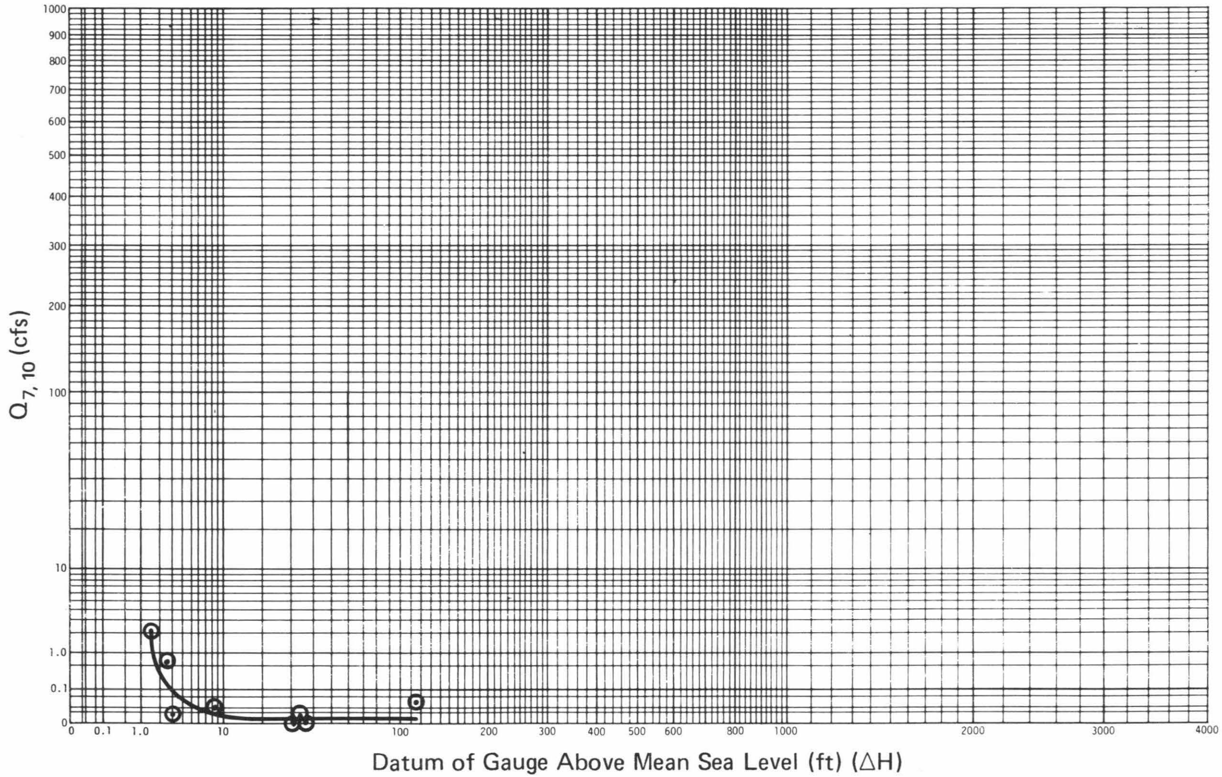


FIGURE 11

Unconsolidated Sedimentary Material—Minimum 7-Day/10-Year Flow versus Datum of Gauge Above Mean Sea Level



TABLES

TABLE 1

Rock Categories Used in Geology-Hydrology Curve Development for Minimum 7-Day/10-Year Flow in Virginia

Metavolcanic Rock
Metamorphosed volcanics, metarhyolite, metabasalt

Triassic Sandstone
Triassic sandstones

Igneous Rock
Granite, granite gneiss, gneiss, gabbro, diorite, syenite, amphibolite, schist, slate, phyllite

Lynchburg Formation Conglomerates
Phyllite, quartzite, graywacke, conglomerate

Shale and Sandstone Interbeds
Shale, sandstone, siltstone

Carbonate Rock
Limestone (limestone and marble), dolomite

Unconsolidated Sedimentary Material
Tertiary, quaternary, and cretaceous sediments

TABLE 2

Minimum 7-Day/10-Year Flow Data Developed from HISARS Program for Virginia Streams (from Virginia Water Resources Research Center)

Station	Minimum 7-Day/10-Year Flow (cfs)	Years of Record
James River at Cartersville	574.31	49
Fine Creek at Fine Creek Mills	0.48	28
James River and Kanawha Canal at Richmond	234.43	36
Buffalo Creek near Hampden-Sydney	5.28	27
Appomattox River at Farmville	19.46	48
Appomattox River at Mattoax	32.38	47
Deep Creek near Mannboro	1.33	26
Appomattox River near Petersburg	57.77	38
Chickahominy River near Providence Forge	5.45	32
Nottoway River near Burkeville	0.04	27
Nottoway River near Rawlings	3.11	21
Nottoway River near Stony Creek	13.59	43
Stony Creek near Dinwiddie	0.52	27
Nottoway River near Sebrell	28.71	32
Blackwater River near Dendron	0.00	32
Blackwater River at Zuni	0.05	31
Blackwater River near Franklin	2.11	28
North Meherrin River near Lunenburg	0.12	26
Meherrin River near Lawrenceville	14.72	45
Meherrin River at Emporia	18.63	23
Fontaine Creek near Brink	0.00	20
New River near Galax	385.66	44
Back Creek near Mountain Grove	3.09	22
• Jackson River at Falling Spring	63.09	50
• Dunlap Creek near Covington	10.43	45
• Potts Creek near Covington	16.66	34
• Cowpasture River near Clifton Forge	53.16	48
• James River at Lick Run	181.71	48
Meadow Creek at New Castle	1.92	23
Johns Creek at New Castle	7.69	46
• Craig Creek at Parr	30.28	48
• Catawba Creek near Catawba	2.04	30
• James River at Buchanan	268.74	63
Calfpasture River above Mill Creek at Goshen	1.63	35
• Maury River at Rockbridge Baths	12.53	44

(continued)

<u>TABLE 2</u> (continued)

Station	Minimum 7-Day/10-Year Flow (cfs)	Years of Record
Kerrs Creek near Lexington	574.31	49
Maury River near Lexington	43.37	33
Maury River near Buena Vista	57.52	35
James River at Holcombs Rock	394.74	47
James River at Bent Creek	441.48	48
Tye River near Lovingston	4.40	34
Piney River at Piney River	2.85	23
Buffalo River near Norwood	37.23	21
Rockfish River near Greenfield	2.85	31
James River at Scottsville	499.87	49
Hardware River below Briery Run near Scottsville	5.24	34
Slate River near Arvonia	8.63	48
Rivanna River at Palmyra	26.72	38
Willis River at Flanagan Mills	6.75	47
Chestnut Creek at Galax	17.24	29
New River at Ivanhoe	418.33	44
Reed Creek at Grahams Forge	50.94	54
Big Reed Island Creek near Allisonia	100.59	41
New River at Allisonia	709.50	44
Little River at Graysonton	67.75	45
New River at Radford	911.41	41
New River at Eggleston	876.92	59
Walker Creek at Bane	31.51	35
Wolf Creek near Narrows	22.03	43
New River at Glen Lyn	1,114.06	46
Levisa Fork near Grundy	1.30	32
Russell Fork at Haysi	1.17	48
Pound River below Flannagan Dam near Haysi	0.77	48
Opequon Creek near Berryville	1.23	30
North River near Stokesville	0.21	27
North River near Burketown	38.59	45
Middle River near Grottoes	52.00	46
South River near Waynesboro	23.14	21
South River at Waynesboro	26.00	23
South River at Harriston	46.34	30
South Fork Shenandoah River near Lynwood	150.53	43
South Fork Shenandoah River at Front Royal	239.89	43
North Fork Shenandoah River at Cootes Store	0.72	49
North Fork Shenandoah River at Mt. Jackson	17.64	29
North Fork Shenandoah River near Strasburg	65.80	49

TABLE 2 (continued)

Station	Minimum 7-Day/10-Year Flow (cfs)	Years of Record
Cedar Creek near Winchester	4.01	35
Passage Creek near Buckton	1.16	41
Happy Creek at Front Royal	0.16	25
Accotink Creek near Annandale	1.04	26
Cedar Run near Warrenton	0.12	22
Cedar Run near Catlett	0.00	22
Broad Run at Buckland	0.75	22
Bull Run near Manassas	0.36	23
Occoquan River near Occoquan	8.38	23
South Fork Quantico Creek near Independent Hill	0.00	22
Rappahannock River near Warrenton	2.23	31
Rush River at Washington	0.00	20
Hazel River at Rixeyville	5.30	31
Rappahannock River at Remington	9.78	31
Mountain Run near Culpeper	0.53	24
Rapidan River near Ruckersville	4.03	31
Robinson River near Locust Dale	8.71	30
Rapidan River near Culpeper	18.68	43
Rappahannock River near Fredericksburg	45.00	64
Cat Point Creek near Montross	0.02	30
Piscataway Creek near Tappahannock	0.79	22
Dragon Swamp near Church View	0.01	30
Roanoke River at Lafayette	22.78	28
Roanoke River at Roanoke	39.64	56
Roanoke River at Niagara	79.49	46
Blackwater River near Union Hall	30.50	37
Roanoke (Staunton) River near Toshes	141.54	36
Pigg River near Toshes	66.13	32
Goose Creek near Huddleston	21.36	43
Roanoke (Staunton) River at Altavista	215.03	42
Big Otter River near Evington	27.06	37
Roanoke (Staunton) River at Brookneal	311.13	49
Falling River near Naruna	13.86	44
Cub Creek at Phenix	6.99	26
Roanoke (Staunton) River at Randolph	376.24	29
Roanoke Creek at Saxe	1.21	25
Roanoke (Staunton) River near Clover	433.21	22
N. Mayo River near Spencer	25.10	44

(continued)

TABLE 2 (continued)

Station	Minimum 7-Day/10-Year Flow (cfs)	Years of Record
Smith River near Philpott	60.89	26
Smith River at Bassett	89.49	35
Smith River at Martinsville	107.50	44
Sandy River near Danville	14.60	44
Dan River at Danville	434.61	39
Dan River at Paces	406.57	23
Georges Creek near Gretna	1.78	24
Banister River at Halifax	39.08	46
Hyco River near Denniston	0.83	25
Beaverdam Swamp near Ark	0.00	24
North Anna River near Doswell	8.76	45
Hudson Creek near Boswells Tavern	0.00	25
South Anna River near Ashland	10.87	43
Pamunkey River near Hanover	35.13	32
Totopotomoy Creek near Atlee	0.06	25
Mattaponi River near Bowling Green	0.27	31
Mattaponi River near Beulahville	16.44	32
South Fork Holston River at Riverside	18.67	41
South Fork Holston River at Vestal	71.41	42
North Fork Holston River at Seven Mile Ford	26.30	32
North Fork Holston River near Meadowview	39.61	21
North Fork Holston River near Saltville	23.28	52
North Fork Holston River near Gate City	57.19	43
Clinch River at Richlands	15.25	29
Copper Creek near Gate City	18.20	24
Clinch River at Speers Ferry	97.78	52
Powell River near Jonesville	22.70	43
Goose Creek near Leesburg	2.17	44
Difficult Run near Great Falls	2.54	38

TABLE 3
Map of Virginia Rock Types and Applicable Geology-Hydrology Curve

Unconsolidated Sedimentary Material
Cretaceous – all formations
Tertiary – all formations
Quaternary – all formations

Triassic Sandstones
Newark Group Triassic – Newark Group

Sandstones and Shale
Pennsylvanian – all formations
Mississippian – Pennington Group, Bluefield Formation, Fido sandstone, Maccrady and Price Formations, Pocono Formation, Mississippian-Devonian shales
Devonian – Hampshire Formation, Chemung Formation, Brallier Formation
Silurian – Clinton Formation, Tuscarora Formation
Cambrian – Rome Formation, Chilhowee Group

Igneous
Paleozoic – Arvonia Formation
Precambrian – Virginia Blue Ridge Complex, Old Rag Formation, Pedlar, Robertson River, Roseland anorthosite, Striped Rock granite, granite gneiss
Paleozoic and Precambrian Formations of Uncertain Age Relationship – Leatherwood granite, Melrose granite, Petersburg granite, Redoak granite, Shelton granite gneiss, Virgilina Group (slate grouping)
Formations of Uncertain Age – amphibolite and amphibole-rich foliates, granite, granite gneiss, granite and hornblende gneiss, hornblende gabbro and gneiss, intrusive rock, metamorphosed sedimentary rocks, quartz, diorite
Triassic – igneous rocks

Lynchburg Formation Conglomerates
Paleozoic – Lynchburg Formation, Mechums River Formation

Metavolcanic Rock
Paleozoic – Catoctin Formation, Mount Rogers Volcanic Group
Formations of Uncertain Age – Greenstone volcanics, metamorphosed volcanic and sedimentary rocks

(continued)

TABLE 3 (continued)

Limestone and Dolomite

Formations of Uncertain Age – limestone and marble
Mississippian – Cove Creek limestone, Newman limestone, Greenbriar limestone
Ordovician – Ordovician Formations, Middle and Upper, undivided; Ordovician Formations, Middle, undivided; Knox Group; Mascot, Kingsport, and Longview Formations; Beekmantown Formation; Chepultepec Formation; Beekmantown and Chepultepec Formations; Concocheague Formation
Cambrian – Honaker dolomite, Elbrook Formation, Shady Formation

TABLE 4
Metavolcanic Geology-Hydrology Data

Stream and Location	Drainage Area (sq mi)	Minimum 7-Day/10-Year Flow (cfs)
Bear Creek at Robbins, N.C.	134.0	1.2
Sapony Creek near Nashville, N.C.	64.8	0.1
Big Bear Creek near Richfield, N.C.	55.7	0.0
Little River near Star, N.C.	105.0	1.1
Uwharrie River near Eldorado, N.C.	347.0	3.5
Happy Creek near Front Royal, Va.	13.8	0.2
Owens Creek at Lantz, Md.	5.9	0.1

TABLE 5
Triassic Sandstone – Geology-Hydrology Data

Stream and Location	Drainage Area (sq mi)	Minimum 7-Day/10-Year Flow (cfs)
Bull Run near Manassas, Va.	147.0	0.4
Monocacy River at Bridgeport, Md.	173.0	0.5

TABLE 6

Igneous Rock — Eastern Potomac, Rappahannock, York, and Chowan Basins

Stream and Location	Drainage Area (sq mi)	Minimum 7-Day/10-Year Flow (cfs)	Net Drainage Area (sq mi)	Net Minimum 7-Day/10-Year Flow (cfs)
Rappahannock Basin				
Hazel River at Rixeyville, Va.*	286.0	5.30	254.0	4.90
Rappahannock River near Warrenton, Va.*	192.0	2.20	129.0	1.60
Rappahannock River at Remington, Va.*	616.0	9.80	430.0	8.00
Rapidan River near Ruckersville, Va.*	111.0	4.00	82.0	3.60
Rush River at Washington, Va.*	14.7	0.00	12.6	0.00
York Basin				
South Anna River near Ashland, Va.*	393.0	10.90	327.0	10.20
Potomac Basin				
Goose Creek near Leesburg, Va.*	338.0	2.20	120.0	0.30
Cedar Run near Warrenton, Va.*	13.0	0.10	7.0	0.00
Cedar Run near Catlett, Va.*	93.5	0.00	7.0	0.00
S.F. Quantico Creek near Independent Hill, Va.	7.5	0.00	7.5	0.00
Chowan Basin				
Nottoway River near Rawlings, Va.	323.0	3.10	323.0	3.10
Nottoway River near Burkeville, Va.	38.0	0.04	38.0	0.04
North Meherrin River near Lunenburg, Va.*	56.0	0.12	34.0	0.00
Meherrin River near Lawrenceville, Va.	553.0	14.70	336.0	12.60

*These streams contained both the metavolcanic rock category and the igneous rock category from which the metavolcanic values for $Q_{7,10}$ were subtracted so as to obrain a net yield of the igneous rock type.

TABLE 7
Igneous Rock — James River Basin

Stream and Location	Drainage Area (sq mi)	Minimum 7-Day/10-Year Flow (cfs)
Tye River near Lovingston, Va.	92	4.40
Fine Creek at Fine Creek Mills, Va.	23	0.50
Buffalo Creek near Hampden-Sydney, Va.	70	5.30
Appomattox River at Farmville, Va.	306	19.50
Appomattox River at Mattoax, Va.	729	32.30
Deep Creek near Mannboro, Va.	156	1.33
Piney River at Piney River, Va.	48	2.80

TABLE 8
Igneous Rock — Roanoke River Basin

Stream and Location	Drainage Area (sq mi)	Minimum 7-Day/10-Year Flow (cfs)	Net Drainage Area (sq mi)	Net Minimum 7-Day/10-Year Flow (cfs)
North Mayo River near Spencer, Va.	108.0	25.1	108.0	25.1
Georges Creek near Gretna, Va.	9.2	1.8	9.2	1.8
Mayo River near Price, N.C.	260.0	59.0	260.0	59.0
Cub Creek at Phenix, Va.	102.0	7.0	102.0	7.0
Sandy River near Danville, Va.*	113.0	14.6	105.0	14.6
Banister River at Halifax, Va.*	552.0	39.1	469.0	38.1
Roanoke River at Roanoke, Va.	388.0	39.6	—	—
Roanoke River at Niagara, Va.†	511.0	79.6	123.0	40.0
Roanoke (Staunton) River at Altavista, Va.†	1,802.0	215.0	1,414.0	175.4
Roanoke (Staunton) River at Brookneal, Va.†	2,420.0	311.1	2,032.0	271.5
Roanoke (Staunton) River at Randolph, Va.†	3,000.0	376.2	2,612.0	336.6

*These streams contained both the metavolcanic rock category and the igneous rock category from which the metavolcanic values for $Q_{7,10}$ were substracted so as to obtain a net yield of the igneous rock type. $Q_{7,10}$ was determined using *Table 4.*
†Values for the Roanoke River below Roanoke were obtained by subtracting the drainage area and flow of that gauge from the downstream gauges. Most of this drainage area is schist or gneiss.

TABLE 9
Lynchburg Formation Conglomerates

Stream and Location	**Drainage Area (sq mi)**	**Minimum 7-Day/10-Year Flow (cfs)**
Chestnut Creek at Galax, Va.	39	17.20
Smith River near Philpott, Va.	212	60.90
Big Reed Island Creek near Allisonia, Va.	278	100.59
Reed Creek at Grahams Forge, Va.	247	50.94
Blackwater River near Union Hall, Va.*	147	22.50
Pigg River near Toshes, Va.*	172	36.10
Goose Creek near Huddleston, Va.*	20	3.10

*Flows for these gauges were from both the Lynchburg Formation and from igneous materials. The flows from the igneous materials were subtracted out of the $Q_{7, 10}$ based upon the flows as per *Figures 4* and *5.*

TABLE 10
Shale and Sandstone Rock Interbeds (Massively Folded Rock)

Stream and Location	**Drainage Area (sq mi)**	**Minimum 7-Day/10-Year Flow (cfs)**
North River near Stokesville, Va.	23.4	0.2
Passage Creek near Buckton, Va.	87.0	1.1
N.F. Shenandoah River at Cootes Store, Va.	215.0	0.7
Calfpasture River at Goshen, Va.	147.0	1.6
Shavers Fork at Parsons, W.Va.	214.0	8.0
Cheat River near Parsons, W.Va.	718.0	28.0
Cheat River near Rowlesburg, W.Va.	972.0	34.0
Casselman River at Grantsville, Md.	62.5	1.0
Big Piney Run near Salisbury, Pa.	24.5	0.1
Youghiogheny River near Oakland, Md.	134.0	4.3
S.F. South Branch Potomac at Brandywine, W.Va.	102.0	1.3
S.F. South Branch Potomac near Moorefield, W.Va.	283.0	5.0
Back Creek near Jones Spring, W.Va.	243.0	3.5

TABLE 11

Pennsylvanian, Permian, Silurian, Devonian, and Mississippian Ages (Flat-Lying Beds)

Stream and Location	Drainage Area (sq mi)	Minimum 7-Day/10-Year Flow (cfs)
Russell Fork at Haysi, Va.	286.0	1.17
Levisa Fork near Grundy, Va.	235.0	1.30
Pound River near Haysi, Va.	221.0	0.77
Little Kanawha River at Burnsville, W.Va.	155.0	0.37
Little Kanawha River at Glenville, W.Va.	386.0	0.77
Steer Creek at Grantsville, W.Va.	166.0	0.04
Little Kanawha at Grantsville, W.Va.	913.0	1.39
W.F. Little Kanawha River at Rocksdale, W.Va.	205.0	0.52
Little Kanawha River at Palestine, W.Va.	1,515.0	2.92
Hughes River at Cisco, W.Va.	452.0	0.46
Elk River at Centralia, W.Va.	281.0	3.20
Elk River at Sutton, W.Va.	543.0	3.50
Elk River at Queen Shoals, W.Va.	1,145.0	6.00

TABLE 12
Limestone and Dolomite Rock

Stream and Location	Drainage Area (sq mi)	Minimum 7-Day/10-Year Flow (cfs)	*1963 Low Flow of Springs (cfs)	Net 7-Day/10-Year Flow (cfs)
Catawba Creek near Catawba, Va.	34.0	2.04	1.37	0.67
Kerrs Creek near Lexington, Va.	34.0	4.88	4.76	0.12
Opequon Creek near Berryville, Va.	58.0	1.23	0.00	1.23
Middle River near Grottoes, Va.	360.0	52.00	10.74	41.26
Copper Creek near Gate City, Va.	106.0	18.20	7.91	10.30

*Some flows are taken from 1928 spring flow values as shown in Collins et al. [1930] and adjusted by curves shown in Rod W. Smith, P.E., *Geologic Considerations Used to Forecast the Sustained Dry Weather Yield of Springs in the Ridge and Valley Physiographic Province of Virginia* [unpublished].

TABLE 13
Unconsolidated Sedimentary Material — Geology-Hydrology Data

Datum of Gauge Above Mean Sea Level	Stream and Location	Drainage Area (sq mi)	Minimum 7-Day/10-Year Flow (cfs)
30.99	Blackwater River near Dendron, Va.	285.0	0.00
8.56	Blackwater River at Zuni, Va.	448.0	0.05
1.56	Blackwater River near Franklin, Va.	613.0	2.11
36.43	Beaverdam Swamp near Ark, Va.	7.1	0.00
2.93	Cat Point Creek near Montross, Va.	45.0	0.02
116.33	Totopotomoy Creek near Atlee, Va.	5.9	0.06
2.50	Piscataway Creek near Tappahannock, Va.	28.1	0.79
34.00	Dragon Swamp near Church View, Va.	84.9	0.01

TABLE 14
Comparison of Estimated and Actual Minimum 7-Day/10-Year Flow Data for Virginia Streams

Stream and Location	Estimated Minimum 7-Day/10-Year Flow (cfs)	Actual Minimum 7-Day/10-Year Flow (cfs)
Hardware River at Scottsville	5.95	5.24
Rockfish River near Greenfield	3.30	2.85
Pigg River near Sandy Level	73.00	66.10
Big Otter River near Evington	44.50	27.10
Falling River near Naruna	21.70	13.90
Roanoke Creek at Saxe	17.95	1.20
Mattaponi River near Bowling Green	2.10	0.27
Pamunkey River near Hanover	23.90	35.10
Roanoke River at Lafayette	22.50	22.80

TABLE 15
Calculations for Minimum 7-Day/10-Year Flow for Selected Virginia Streams

Stream and Location	Drainage Area (sq mi)	Minimum 7-Day/10-Year Flow (cfs)
Hardware River at Scottsville (James River)		
Drainage Area = 116 sq mi		
$Q_{7,10}$ = 5.24 cfs		
Rock Type		
Schist and granite (James River)	71	3.00
Metavolcanic	23	0.25
Triassic sandstone	4	0.00
Lynchburg conglomerate	18	2.70
Total	116	5.95

(continued)

TABLE 15 (continued)

Stream and Location	Drainage Area (sq mi)	Minimum 7-Day/10-Year Flow (cfs)
Rockfish River near Greenfield		
Drainage Area = 95 sq mi		
$Q_{7,10}$ = 2.85 cfs		
Rock Type		
Metavolcanic	25	0.3
Gneiss (James River)	70	3.0
Total	95	3.3
Pigg River near Sandy Level		
Drainage Area = 394 sq mi		
$Q_{7,10}$ = 66.13 cfs		
Rock Type		
Lynchburg conglomerate	161	42
Schist and gneiss (Roanoke River)	233	31
Total	394	73
Big Otter River near Evington		
Drainage Area = 325 sq mi		
$Q_{7,10}$ = 27.1 cfs		
Rock Type		
Lynchburg conglomerate	43	7.5
Gneiss (Roanoke River)	282	37.0
Total	325	44.5
Falling River near Naruna		
Drainage Area = 172 sq mi		
$Q_{7,10}$ = 13.9 cfs		
Rock Type		
Lynchburg conglomerate	33	5.60
Triassic sandstone	18	0.05
Gneiss and schist (Roanoke River)	118	16.00
Metavolcanic	3	0.05
Total	172	21.70

TABLE 15 (continued)

Stream and Location	Drainage Area (sq mi)	Minimum 7-Day/10-Year Flow (cfs)
Roanoke Creek at Saxe		
Drainage Area = 162 sq mi		
$Q_{7,10}$ = 1.2 cfs		
Rock Type		
Metavolcanic	20	0.25
Gneiss and schist (Roanoke River)	133	17.50
Triassic sandstone	9	0.20
Total	162	17.95
Mattaponi River near Bowling Green		
Drainage Area = 251 sq mi		
$Q_{7,10}$ = 0.27 cfs		
Rock Type		
Granite gneiss (York)	144	1.8
Unconsolidated sedimentary	79	0.0
Metavolcanic	28	0.3
Total	251	2.1
Pamunkey River near Hanover		
Drainage Area = 1,072 sq mi		
$Q_{7,10}$ = 35.1 cfs		
Rock Type		
Unconsolidated sediment	80	0.1
Metamorphosed sediment (York)	850	23.0
Metavolcanic	142	0.8
Total	1,072	23.9
Roanoke River at Lafayette		
Drainage Area = 257 sq mi		
$Q_{7,10}$ = 22.8 cfs		
Rock Type		
Shale and sandstone (folded)	152	2.4
Granite gneiss (Roanoke River)	45	6.5
Carbonate	60	2.0
Spring flows	–	11.6
Total	257	22.5

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