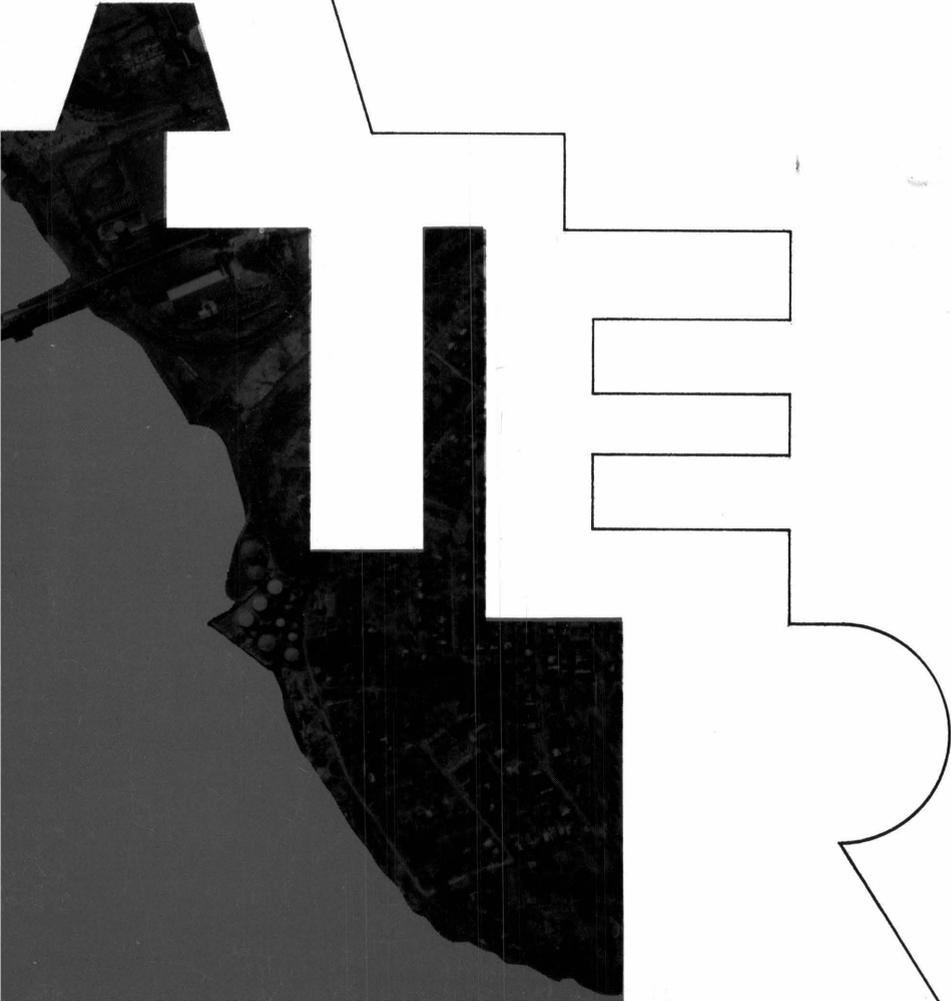


Bulletin 25:

**GEOLOGIC CONTROL OF RAINFALL-RUNOFF RELATIONS
IN THE PEAK CREEK WATERSHED, PULASKI AND
WYTHE COUNTIES, VIRGINIA**

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AND WYTHE COUNTIES, VIRGINIA

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The work upon which this report is based was supported in part by funds provided by the United States Department of the Interior, Office of Water Resources Research, as authorized under the Water Resources Act of 1964.

Water Resources Research Center
Virginia Polytechnic Institute
Blacksburg, Virginia
May 1969

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PREFACE

During the course of 36 years of field work in the Appalachian region, the writer has had many occasions to witness flood phenomena and to derive many other less spectacular data pointing toward one general conclusion, namely, that the bedrock geology of a given area in the Appalachian region largely determines the relative topographic relief and elevation, the nature of thickness of much of the soil and mantle rock, fabric of terrane, steepness of slopes, intricacy of dissection, the nature of the cover of vegetation, and, thereby, the amount of runoff relative to rainfall. Bedrock geology by its local control of relief and general control of elevation even affects climate and rainfall. It is difficult to understand why this self-apparent fact has not been more widely appreciated—at least qualitatively, if not quantitatively. Many parameters enumerated above are obviously partial controls of local runoff and also of ease of ingress of precipitation into the soil, mantle rock, and bedrock, but none exert the profound effect of bedrock geology.

Although of preponderant importance, the control of runoff exerted by bedrock geology is, of course, not complete. Local bedrock conditions do not control the amount of precipitation or intensity of periods of precipitation. Seasonal and daily changes in temperature and atmospheric pressure and many other meteorological conditions play a dominant part. One of the capricious vagaries of nature is the unending variation in the distribution of precipitation in time and space. Rainfall-runoff relations for cloudbursts are significantly higher than for a rain of lesser intensity, which may release the same amount of water onto the earth over a longer period of time. Runoff from snowfalls varies not only with the snow accumulation but with the nature of melting conditions. Despite these situations, year in and year out, the annual runoff derived from a given quantity of precipitation is nevertheless primarily a function of the bedrock geology, especially in areas such as the Folded Appalachians of western Virginia where the topographic elevation, local relief, and nature of land forms strongly reflects the varied nature and attitude of the succession of strata. However, there are relatively little quantitative data to substantiate these qualitative generalizations.

In 1946 and from time to time from then to 1959, the writer was involved in the scientific study of the headwaters of Peak Creek preparatory to construction of Gatewood Dam and Reservoir by the Town of Pulaski. His first familiarity with the area of impoundment was gained in 1936 while he was engaged in field study of a portion of Pulaski and Wythe counties for the Virginia Geological Survey (Cooper, 1939). During the summer of 1936, it was noted that Peak Creek upstream from Pulaski was a dry stream bed much

of the time with only immediate, short-lived, surface discharge occasioned by storms during the relatively dry, warm, summer months. This observed condition led the writer to sense the relatively high runoff factor for that drainage area, but the impression was wholly a qualitative conclusion.

Support for the bond issue necessary to enable the Town of Pulaski to build a dam on Peak Creek to create Gatewood Reservoir was insufficient to obtain an affirmative vote until 1957. Construction of the dam started in April, 1958, and was completed in December, 1959. Prior to the passage of the municipal bond issue, many citizens argued that there simply was not enough water discharged by Peak Creek to fill the reservoir. To the astonishment of nearly everyone, Gatewood Reservoir, draining approximately 16 square miles of rugged mountain land, filled and overflowed the spillway only 12 days after initial closing of the discharge gates of the dam. This remarkable fact bore additional testimony to the relatively high runoff factor for the Peak Creek watershed above Gatewood Dam.

The logical cause for the inordinately high runoff of Peak Creek demonstrated by the rapid initial filling of Gatewood Reservoir is the preponderance of relatively impervious shales and shaly sandstones comprising the succession from the base of the Devonian Millboro Shale to the highest preserved beds of the Price Formation (Table 1). Upon formation of the Virginia Water Resources Research Center, the writer applied for and obtained a grant to undertake a quantitative study of the runoff characteristics of the various kinds of bedrock in the watershed of Peak Creek above Gatewood Dam.

Numerous sources of information about accumulation and analysis of rainfall-runoff data were consulted. References found particularly helpful were reports by Butler (1957), Carter and Anderson (1963), Chow (1964, secs. 4, 8-15, 18), Corbett and others (1943), Foster (1948, p. 293-348), Horton (1933, p. 446-460), Johnstone and Cross (1949), Grover and Harrington (1966, Kazmann (1965), Lindsley and others (1949, p. 59-283; 387-465; 1958, p. 52-122, 149-245), Mead (1919, p. 156-200, 309-390, 432-544), Meyer (1928, p. 203-511), Wisler and Brater (1949, p. 15-286, 359-398). As explained subsequently in this report, the stream-level gaging and determination of current flow measurements followed procedures and utilized types of instruments used by the U. S. Geological Survey.

Much of the field work on the project was done by Ellis Koch in 1966-1967. Unfortunately his current flow studies were not accurate enough

to allow development of valid hydrographs, and his gage records had to be later re-evaluated by taking more current readings using the more sensitive Nyrpic current meter. In 1967-1968 the field work on the project was conducted by David Aronson who refined the hydrographs. Ann Waybright aided in recalculation of daily runoff values based on the improved hydrographs for the seven stations. The generous cooperation of Mr. C. King, Mr. Forrest Sharritz, Mrs. Ruby Crockett, Mr. Sam Peak, Mr. L. A. Rutherford, Mr. F. W. Stevens and the U. S. Forest Service, property owners who allowed rain and stream gages to be placed on their properties during the two year period, is gratefully acknowledged. Fred Webb, Jr., a former graduate student in geology at Virginia Polytechnic Institute supervised the construction of the gaging installations.

During the study Dr. James Wiggert of the V.P.I. Department of Civil Engineering, was very helpful and offered many suggestions on procedures. Especially helpful techniques in measuring current flow were obtained from S. G. Anderson of the U. S. Geological Survey's Water Resources Office in Marion, Virginia. The officials of the Town of Pulaski were very cooperative in aiding investigations.

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INTRODUCTION

Investigation of the rainfall-runoff coefficient for the Peak Creek watershed above Gatewood Dam in Pulaski and Wythe counties, Virginia, was undertaken by rain and runoff gaging of four easily recognized hydrogeologic terranes--each of which is composed of a part of the stratigraphic succession that possesses distinctive hydrologic characteristics. Studies of (1) sample plots of individual hydrogeologic terranes, (2) areas embracing two different terranes, (3) three different terranes, and (4) of the entire drainage area which embraces all four terranes provides overwhelming evidence that rainfall-runoff coefficients for sandstone shale terranes are higher by 40 to 80 per cent than for other hydrogeologic terranes.

In smaller watersheds in which hydrogeologic terranes with unusually high runoff factors predominate, gross underestimations of water impoundment possibilities in western Virginia are likely to be incurred if the rule-of-thumb runoff coefficient of .30 to .33 is used.

Geologic maps can serve very usefully as a base for deriving estimated probable rainfall-runoff coefficients for terranes similar to the four described in the study of the Peak Creek watershed. Runoff from Appalachian limestone dolomite terranes is almost one-third that of shale-sandstone hydrogeologic terranes in the same watershed.

Shale-sandstone hydrogeologic terranes in the Appalachian region provide a relatively greater runoff and water of better quality than that from any other terrane. This basic fact should be of considerable value in re-evaluating local watersheds in western Virginia, which is believed necessary to obtain realistic appreciation of the true potential of many small watersheds for impoundment.

OBJECTIVES

The objectives of the projected investigation of rainfall-runoff relations in the upper portion of the Peak Creek watershed were: (1) to obtain quantitative values for rainfall-runoff relations on all the major hydrogeologic terranes¹ of the succession exposed in the watershed, (2) to investigate the practical utility of a detailed geologic map in predicting expected runoff that would be generated in a typical small drainage area amenable to gaging by standard hydrologic methods, which embraces a diverse succession of strata including limestones and dolomites, hill-making shales and interbedded sandstones, ridge-making quartzites and sandstones. The writer's qualitative impressions of the high runoff characteristics of Peak Creek were first gained from his field studies of 1936 (Cooper, 1939), but they were reinforced later by the geologic mapping done by his doctoral student, Fred Webb, Jr., in the Crockett Cove area of Bland and Wythe counties. In spite of the fact that our combined studies covered completely the area of Pulaski's Gatewood impoundment watershed, additional Appalachian watersheds were examined in search for the one best suited for quantitative gaging of rainfall-runoff relations. The result of this preliminary search indicated clearly that the upper portion of Peak Creek above Gatewood Dam was the ideal watershed for quantitative evaluation of geologic control of runoff because (1) the watershed contains an exceptionally wide range of bedrock formations ranging from the Middle Cambrian Honaker Dolomite to the Middle Mississippian Price Formation (Table 1), (2) the watershed is completely covered by detailed geologic maps, (3) Gatewood Dam forms an ideal place for monitoring the entire discharge of the drainage area, (4) the area was conveniently located with respect to the Blacksburg campus of Virginia Polytechnic Institute and (5) access to the watershed is sufficiently restricted to provide reasonable security for gaging installations.

¹A hydrogeologic terrane is defined as an association of bedrock formations which are essentially indistinguishable in their effect on surface and subsurface movement of natural waters.

METHODS OF STUDY

Using available geologic maps, the total areas of each hydrogeologic unit in the Peak Creek watershed can be determined by planimetry. In the folded Appalachians, it is not possible to find a suitable place for gaging stations that will monitor all the water falling on and running off of a given hydrogeologic terrane; hence it is necessary to gage representative sample watershed plots to determine their rainfall-runoff characteristics.

By the use of simple proportion, the total runoff expected from a given hydrogeologic terrane can be estimated by applying the rainfall-runoff coefficient determined on the representative sample plot to the total area underlain by that hydrogeologic unit within a watershed. Certain qualified assumptions are necessary in order to determine the rainfall-runoff coefficients of hydrogeologic terranes. In order to gage the runoff from an area underlain by any given hydrogeologic unit, it is ideally desirable that the sample drainage area be gaged to measure only the discharge water generated on that hydrogeologic terrane. If the sample area is representative for a specific hydrogeologic terrane, the rainfall-runoff coefficient of the sample area should apply equally well to other portions of the area underlain by the same hydrogeologic unit.

If it is impossible to measure separately the runoff generated on each separate hydrogeologic terrane, and if two different hydrogeologic terranes are involved, one of which can be separately gaged and its rainfall-runoff sufficiently determined, then by gaging the combined runoff from two hydrogeologic terranes, the runoff coefficient for the second one can be determined by subtraction.

Gaged drainage areas of known size, embracing a number of the same hydrogeologic terranes but containing one different hydrogeologic terrane, may provide enough information to derive a rainfall-runoff coefficient for the unique area underlain by the different hydrogeologic terrane.

As shown in Table 1, there are four distinct hydrogeologic terranes, in descending stratigraphic order:

1. Devonian-Mississippian shales and sandstones comprising the Price, Parrott, Broadford, and Brallier formations--all predominantly of the distinctive Portage lithofacies, the Millboro-Needmore clay shales ranging in color from black to green-gray, which floor synclinal valleys and lap up on the lower slopes of Silurian sandstone ridges such as Cove Mountain and cover all of numerous lower ridges.
2. Middle Devonian to basal Silurian ridge-making formations, including the Huntersville Chert, Ridgely Sandstone, Rocky Gap Sandstone, Keefer Sandstone, rose Hill Formation (red hematitic, gray sandstones, and variegated shales), and the ridge-making Tuscarora Formation composed primarily of orthoquartzite, which crop out on the middle and upper portions of the dipslopes of Appalachian ridges.
3. Ordovician sandstones, shales, and impure limestones comprising the Juniata Formation, Martinsburg Formation, and Bays Formation, which crop out on the Middle and upper slopes of Cove and Tract mountains.
4. Ordovician and Cambrian carbonate rocks and interrelated shaly rocks, comprising the Witten, Wassum and Chatham Hill limestones; the Rich Valley Formation composed of black limestone and calcareous black shales; the Fetzer, Lenoir and Mosheim limestones, the Knox Dolomite group (including the Mascot and Kingsport dolomites). Longview limestones and dolomites, Chepultepec limestones and intercalated sandstones, Nolichucky shales and limestones, and Honaker Dolomite-- which collectively underlie much of the cleared grazing land in the head of Crockett Cove which is drained by Peak Creek.

The Cambro-Ordovician limestone and dolomite terrane doubtless could be subdivided in many areas into at least two hydrogeologic units if the Nolichucky Shale, which is only 80 feet thick in the area of study, were sufficiently thick to provide an effective impermeable curtain wall between the overlying Knox Group and the subjacent Honaker Dolomite. But because of the thinness of the Nolichucky and very limited areal extent of the Nolichucky Formation in Crockett Cove, it seemed unsound to try to

Table 1. Strata exposed in Peak Creek watershed above Gatewood Dam, Pulaski and Wythe Counties, Virginia.

Geologic System	Formation Name	Stratigraphic Thickness	Character of Strata	Hydrogeologic Terranes Recognized in this Study
Mississippian	Price Formation	800'	Sandstone and shale	DEVONIAN- MISSISSIPPIAN SANDSTONES AND SHALES
	Parrott Formation	400'	Shaly sandstone	
	Broadford Sandstone	300'	Sandstone and shale	
	Brallier Formation	1,800'	Shale and thin sandstones	
	Millboro Shale	700'	Black, gray, and buff shale	
Devonian	Huntersville Chert	40'	Gnarled chert; glauconitic sandstones	SILURIAN- DEVONIAN SANDSTONES
	Oriskany Sandstone	6'	Rusty-brown sandstones	
Silurian	Rocky Gap Sandstone	45'	Gray friable sandstone	ORDOVICIAN SANDSTONES AND LIMESTONES
	Keefe Sandstone	40'	Hard orthoquartzite	
	Rose Hill Formation	115'	Red sandstone, variegated shales	
	Tuscarora Formation	90'	Hard orthoquartzite	
	Junjata Formation	250'	Red & green sandstones & shales	
	Martinsburg Formation	1,300'	Black shale & impure shelly limestone	
	Bays Formation	200'	Red shales & sandy beds	
Ordovician	Chatham Hill Ls.	350'	Shell limestones & calcarenites	CAMBRIAN- ORDOVICIAN LIMESTONES AND DOLOMITES
	Rich Valley Fm.	900'	Black shales & limestones	
	Effna Limestone	0-50'	Reefy limestones, local in occurrence	
	Fetzer Limestone	20'	Impure, rusty, fossiliferous ls.	
	Lenoir-Lincolshire Limestones Knox Dolomite Group	100' 2,700'	Black, impure, cherty limestone Dolomites, intercalated zones of dolomitic sandstone & limestone	
Cambrian	Nolichucky Shale	80'	Shale & shaly dolomite	
	Honaker Dolomite	1,000'+	Fine-grained dolomite	

monitor separate surface discharge from the beds above and below the Nolichucky. As thin as the Nolichucky is there are probably many dip joints and undetected minor tear faults with offsets normal to strike of the beds, which are greater than the thickness of the Nolichucky. Thus, the entire Chatham Hill-Honaker succession of predominantly carbonate rocks should probably be studied as a unit.

In attempting to obtain reliable runoff coefficients for various units, it seemed advisable to ignore the divide limiting the watershed boundary of Peak Creek and to gage two areas outside the Peak Creek watershed to offer superior conditions for monitoring discharge from portions of the headwaters of Cove Creek which drains a large part of Crockett Cove just west of the boundary of the Peak Creek watershed. Because of the close proximity of Crockett Cove just west of the boundary of the Peak Creek watershed, because of the close proximity of Drainage Areas 5 and 7 (Table 2) to the Peak Creek watershed and because of the fact that identical stratigraphic successions to those in monitored drainage areas 5 and 7 occur with the headward part of Crockett Cove, which is drained by Peak Creek, the gaging data and calculated runoff coefficients for the two are surely applicable for parts of the same hydrogeologic terranes drained by Peak Creek. The sites for Gaging Stations 5 and 7 are also ideal for cross-sectional channel determinations and current flow measurements. Gaging Station 8 is especially valuable for accurate discharge measurements since all the waters of the East Fork of Cove Creek embracing 14.104 square miles passes through the box flumes under the highway bridge beside the gaging station.

The study was directed primarily at the determination of the rainfall-runoff characteristics of four major hydrogeologic terranes which define the four characteristic topographic fabrics of any typical area of the Folded Appalachians:

- a. the Devonian-Mississippian sandstone-shale successions intricately dissected land characteristically occupying synclines or synclinoria;
- b. the rugged steep dip slopes of Appalachian hogbacks whose crests are upheld by Tuscarora quartzites and which are characterized by bold series of flatirons made by the Keefer, Helderberg-Oriskany, and Huntersville formations;
- c. the intricately dissected outcrop slopes of Appalachian hogbacks, made in descending stratigraphic order by the Juniata, Martinsburg, and Bays formations; and

- d. the rolling, cleared valley regions underlain by limestone and dolomite of Middle Cambrian to Middle Ordovician age.

In the region between James River and the Tennessee line, these four topographic-geologic subdivisions are readily recognizable even though the lithology and the stratigraphic names applied to the succession of strata vary slightly from place to place.

Table 2. Summary of rainfall-runoff data related to geologic terranes in the Peak Creek watershed and adjacent areas in Wythe and Pulaski Counties, Virginia.

Gaging Sta. (Locations on Pl. 1)	Data Collec- tions Period	Area of Drainage			Rainfall		Runoff		Description of Hydrogeologic Terranes and per cent of Area Underlain by Each Terrane
		Square Miles	Acres	Square Inches	Volume in Cubic in.	Inches	Volume in Cubic in.	Runoff Coeff.	
1	7/20/66 to 6/20/68	0.418	267.804	1.68×10^9	59.34	9.80×10^9	30.92	4.34×10^{10}	.5221 Devonian-Mississippian shales and sandstones, 100.00 per cent
2	7/20/66 to 6/20/68	0.0632	40.48	2.53×10^8	59.34	15×10^{10}	19.80	2.97×10^{10}	.3337 Devonian-Mississippian shales and sandstones, 100.00 per cent
4	12/4/66 to 6/20/68	1.349	864.135	5.41×10^9	38.04	20.6×10^{10}	8.2	8.2×10^{10}	.3983 Devonian-Mississippian shales and sandstones, 74.30 per cent Silurian-Devonian sandstones, 25.70 per cent
5	11/18/66 to 6/20/68	0.948	607.23	3.8×10^9	50.75	19.2×10^{10}	13.75	5.2×10^{10}	.2709 Cambrian-Ordovician limestones and dolomites, 100.00 per cent
6	7/20/66 to 6/20/68	2.46	1578.798	9.86×10^9	68.04	67.09×10^{11}	37.66	3.195×10^{11}	.4909 Devonian-Mississippian shales and sandstones, 12.92 per cent Cambrian-Ordovician limestones and dolomites, 35.60 per cent Ordovician sandstones, shales, and limestones, 51.48 per cent

Table 2. Continued.

Gaging Sta. (Locations on Pl. 1)	Data Collec- tions Period	Area of Drainage		Rainfall		Runoff		Description of Hydrogeologic Terranes and per cent of Area Underlain by Each Terrane		
		Square Miles	Square Acres	Square Inches	Volume in Cubic in.	Inches	Volume in Cubic in.		Runoff Coeff.	
7	7/20/66 to 6/20/68	15.909	10193.68	6.39x10 ¹⁰	70.5	4.47x10 ¹²	37.60	2.4x10 ¹²	.5342	Devonian-Mississippian shales, and sandstones, 84.40 per cent Cambrian-Ordovician limestones and dolomites, 5.51 per cent Ordovician sandstones, shales and limestones, 7.79 per cent Silurian-Devonian sandstones, 2.12 per cent
8	7/20/66 to 6/20/68	14.104	9036.83	5.656x10 ¹⁰	70.28	3.975x10 ¹²	26.33	1.489x10 ¹²	.3746	Devonian-Mississippian shales and sandstones, 22.10 per cent Cambrian-Ordovician limestones and dolomites, 58.93 per cent Ordovician sandstones, shales and limestones, 18.97 per cent
									.52-.5700	Devonian-Mississippian sandstones and shales, 100.00 per cent Silurian-Devonian sandstones and chert 100.00 per cent Ordovician sandstones, shales, and lime- stones, 100.00 per cent Cambrian-Ordovician limestones and dolomites, 100.00 per cent
									.2147	
									.6410	Representative Runoff Coefficients for Hydrogeologic Terranes which are unmixed.
									.2709	

DESCRIPTION OF GAGING STATIONS

A survey of the Peak Watershed was made in an attempt to determine the best places for gaging runoff. Eight locations were chosen, as shown on Plate 1. It will be noted that three of the eight stations are located actually outside of, but very close to, the Peak Creek watershed. The locations outside the drainage basin were selected because one offered an exceptionally good location for monitoring the valley limestones and dolomites; another afforded a local drainage area embodying Devonian-Mississippian sandstone and shale valleys and bordering typical dip slopes of Cove Mountain, and another offered an excellent site for gaging a relatively large area embracing three hydrogeologic terranes. The other stations were designed to cover various parts of the Peak Creek watershed. Station 7 gaged the discharge water released continuously through gates in Gatewood Dam into the downstream channel which could be very precisely defined and which was unaffected by significant underflow. Station 6 monitored the entire head of Crockett Cove and was situated to record stream flow where there was essentially no underflow. Station 1 was a particularly good place to monitor a sub-watershed entirely within the extensive Devonian-Mississippian sandstone-shale hydrogeologic terrane. Drainage basin 2 proved too small to be of much value, and the surface flow from the area was lessened by considerable underflow moving through a valley fill of loose shale chips and slabby pebbles of sandstone.

Two of the stations established within the Peak Creek watershed were selected because bedrock was showing along the bed of the drainage channels and underflow was thought to be minimal. Actually, however, subsequent observations established that despite the showings of bedrock in these drainage channels, there was considerable underflow at Station 2. In both of these locations the valley flats, originally thought to have been cut by minor tributaries, are actually alluvial fills of sandstone-shale fragments, whose bottoms reach below the foundations of the gaging stations. The amount of underflow in Station 2 amounts to about one-fourth of the surface discharge, and in the area drained by Gaging Station 1, the underflow amounts to probably no more than one-tenth of the surface discharge.

Gaging Station 3, intended to monitor discharge of a limited area of mountain slope, failed to record any measurable surface flow and contributed nothing of value to the study.

The essential features of the seven gaging stations yielding significant hydrologic data are recorded in Table 2. Drainage areas 1, 2, 3, and 4 are entirely forested except portions along the streams.

Drainage basins 6 and 8 are partially cleared and the area drained by Gaging Station 5 is largely cleared. Station 7, which measures the discharge of the entire watershed above Gatewood Dam, of course, supplied the most valuable information of any station.

All gaging stations were outfitted with Leupold-Stevens A35 water level recorders mounted inside a weathertight plywood, metal-covered housing (Pl. 2). The recorders measured water levels inside an 18-inch corrugated steel pipe anchored into the ground as shown in Figure 2. Rainfall gages installed beside the water level recorders were security-proof non-recording rain gages. Current flow measurements were correlated with gage heights under varying conditions of stream discharge and from these data hydrographs for each station were derived.

Rain gages were prevented from freezing by adding a known volume of commercial ethylene glycol anti-freeze liquid. Bimonthly or weekly inspections were made of recording stations.

RESPONSE OF PEAK CREEK TO HEAVY RAINS

Peak Creek ordinarily is a stream characterized by low discharge, but the flow is extremely sensitive to rains of even 0.5 inches. The maximum discharge measured was on March 18, 1968, when the average flow for a 24 hour period was 183 second feet. Figure 3 summarizes the typical performance characteristics of Peak Creek during the period of study. The vagaries of discharge indicate a stream with an unusually high runoff coefficient.

SUMMARY OF HYDROLOGIC AND GEOLOGIC DATA

As shown in Table 2, the runoff coefficients of the four hydrogeologic terranes defined in Table 1 vary from .2147 to .641. The highest runoff coefficient is that of the hydrogeologic terrane composed of the Juniata, Martinsburg, and Bays formations; the lowest is for the Silurian-Devonian sandstone succession (Tuscarora to Huntersville formations).

The predominant hydrogeologic terrane, composed of Devonian-Mississippian sandstones and shales (Needmore to Price formations), constitutes essentially all of Watershed 1. The runoff coefficient, 52.21, is slightly lower than that for the entire watershed above Gatewood Dam. This disparity doubtless arises from the underflow which is moderately low at Gaging Station 1 but considerably higher at Station 2. Based upon the visible signs of moving water in the stilling well at Gaging Station 1 when the recorder was measuring no flow, the unmonitored underflow is estimated to be about 10 per cent of the calculated runoff coefficient, .5221. The rainfall-runoff coefficient for the Devonian-Mississippian sandstone shale hydrogeologic terrane would be approximately .57 if all underflow at Station 1 had been cut off.

The runoff coefficient for the Juniata-Martinsburg-Bays succession was derived by analysis of Watershed 6 wherein three hydrogeologic terranes occur. Watershed 5 provided a reliable source of data for calculating the runoff coefficient for Cambrian-Ordovician limestones and dolomites, .271, and the runoff coefficient for the Devonian-Mississippian hydrogeologic terrane as determined from monitored drainage area 1 is .5221. The runoff coefficient for the Ordovician sandstone-limestone-shale terrane can be derived by calculating the portion of the annual precipitation that falls on the Devonian-Mississippian terrane and, knowing its runoff coefficient as obtained from data supplied by Gaging Station 1, the total annual runoff for the 12.92 per cent of Watershed 6, underlain by Devonian-Mississippian sandstones and shales, can be calculated. The same can be done for the Cambrian-Ordovician limestone-dolomite hydrogeologic terrane whose runoff coefficient, .271, was calculated from data obtained from Gaging Station 5 and which can be applied to the 35.60 per cent of Watershed 6 underlain by that hydrogeologic terrane. By subtraction of the volume of the rainfall and runoff generated on the Devonian-Mississippian sandstone-shale and also from the Cambrian-Ordovician limestone dolomite terranes can be subtracted from the total runoff of Watershed 6 to yield the total runoff generated on 51.48 per cent of the total local watershed underlain by Ordovician sandstones, shales and limestones. By calculating the volume of annual precipitation

falling on 51.48 per cent of the total watershed area gaged at Station 6, the runoff for the Ordovician sandstone-shale-limestone succession can be calculated. The coefficient .641 reflects the essentially impervious nature of the succession and the steep slopes which encourage rapid runoff.

The same hydrogeologic terranes are also involved in Watershed 8. Knowing the average rainfall for the watershed, the percentage area of each of the three terranes, and using the coefficients obtained from Gaging Stations 1, 5, and 6, the total runoff was calculated for each of the three terranes. Their sum varies less than 3 percent from the total gaged discharge record at Station 5. This close approximation offers substantial corroboration of the accuracy of runoff coefficients derived from data supplied by Stations 1, 4, and 5.

SIGNIFICANCE OF FINDINGS

As shown in Table 3, (Rich and Payne, 1954, p. 607) rainfall-runoff coefficients for some large rivers in central and western Virginia approximate the values .30 to .33 which constitute the range of values commonly

Table 3. Rainfall-runoff coefficients for some large rivers in Virginia.^a

Name of River	Location of Gaging Station	Drainage Area (square miles)	Average Runoff Coefficient
Appomattox River	Farmville	306	.297
Shenandoah River	Millville, West Virginia	3040	.313
South Fork, Shenandoah River	near Luray	1377	.317
Roanoke River	Altavista	1802	.331
Dan River	South Boston	2730	.328

^aRich and Payne (1954, pp. 6-7).

taken by engineers in the estimated runoff for evaluation of all watershed impoundment projections in this region of the United States. The figures cited by Rich and Payne (1954, *ibid.*) agree with most other rainfall-runoff coefficients cited in government records on discharge of principal rivers. So far as known, no one has previously attempted to develop anywise reliable data allowing for more accurate estimation of runoff in small drainage basins where no specific gaging data are locally available. In order to do so, one would have to know the rainfall-runoff characteristics of different kinds of bedrock. As a matter of fact the obvious control of runoff by bedrock geology is largely unexplored. The present study presents data that should be of considerable significance in evaluating the impoundment possibilities of other watersheds in the Appalachian Valley and Ridge Province.

In the Folded Appalachians, bicarbonate hardness varies greatly with the bedrock geology. Devonian-Mississippian sandstones and shales yield water of remarkably low total hardness, e.g. Hogans Hollow Reservoir of the Town of Pulaski, whose waters have only about 30 ppm of total dissolved

solids (Table 4). Limestone waters utilized by some western Virginia towns and cities have hardness ranging up to nearly 300 ppm of total dissolved solids. The correlation between water quality and bedrock geology in western Virginia points toward sandstone-shale terranes as the principal source of water of excellent quality. This fact is so well known that the general public commonly refers to "freestone waters" occurring in shale valleys which are also locally known as "Poor Valleys."

Water of excellent quality in the Folded Appalachians is almost restricted to synclines or synclinoria in which Devonian to Mississippian strata underlie nearly all the local drainage basins. The area of these shale valleys varies greatly from place to place, but most of the shale valleys accessible for municipal water supply development comprise areas of less than 150 square miles, and many of them contain less than 50 square miles, under existing frames of evaluation of these impoundment areas, the rule-of-thumb runoff factor of .30 to .33 is invariably taken to determine the runoff that can be impounded. Naturally, shale valleys are sought whenever possible because such watersheds yield water of good quality. The smaller the area of such watersheds, the more likely they are to be rejected as economically infeasible impoundment sites simply because the runoff estimated by the traditional runoff coefficient .30 to .33 is too limited to meet municipal needs.

The present study indicated that the actual rainfall-runoff coefficient for typical shale valleys in western Virginia, as exemplified by the Peak Creek watershed impoundment area of the Town of Pulaski, Virginia, are actually in the general range of .50 to .57. The establishment of a quantitative base for a determination of the rainfall-runoff coefficient predominantly shale-sandstone watershed, which is significantly higher than the .30 to .33 runoff factors, long-used in evaluating stream impoundment possibilities, poses the need for systematic re-evaluation of these impoundment areas, particularly small ones, which heretofore were passed over as being too small and housing too limited runoff. The use of the .30 to .33 rainfall-runoff factors is so ingrained in planning and evaluating water supplies that impoundment reservoirs have come to be classed on the basis of their acreage. For watersheds of the general type of Peak Creek above Gatewood Dam, which are predominantly or wholly floored with Devonian and/or Mississippian sandstones and shales, a runoff factor of .52 to .57 is probably much more realistic than the lower rule-of-thumb figures.

Of course, further gaging of similar small watersheds needs to be done in order to broaden the corroboration of the rainfall-runoff factors derived in the study of Peak Creek. The potential economic impact of such further

Table 4. Quality of surface water supplies and raw-water storage capability of selected towns and cities in Virginia.^a

Town/City	Quality of Water In PPM			Turbidity (1.0 = the turbidity produced by 1 ppm diatomaceous earth in pure H ₂ O)	Raw Water Storage in Millions of Gallons	Capacity of Filter Plant in Millions of Gallons Per Day	1954 Population
	Total Dissolved Solids	Hardness as CaCO ₃					
Alexandria	74	47		0.6	1,750	8.8	61,787
Bristol	194	178		0.0	5	2.0	15,954
Charlottesville	22	10		---	1,000	3.0	25,969
Covington	74	61		1.0	none	2.0	5,860
Danville	69	36		0.5	3,000	9.0	35,066
Harrisonburg	18	8		0.0	none	2.0	10,870
Lynchburg	39	15		.7.0	600	8.0	47,727
Marion	67	64		0.0	none	1.5	6,982
Martinsville	76	40		0.5	1,500	5.0	17,251
Newport News	110	68		0.5	1,754	20.0	42,358
Norfolk	111	71		0.5	9,700	48.0	213,513
Pulaski (1960)	40	14		0.5	1,500	3.0	14,224
Radford	74	49		0.5	none	2.0	9,026
Roanoke	86	69		---	7,020	7.5	91,921
Salem	131	127		0.0	none	2.0	6,823
Waynesboro	96	86		0.0	none	3.6	12,357

^aLohr and Love, 1954, p. 563-590; and from the Town of Pulaski.

studies and correlative re-evaluations of impoundment possibilities need to be appreciated in order to derive realistic water impoundment budgets for the local, low-hardness water resources available for future utilization.

The present study points up a new and hitherto unused technique in evaluating medium and small watersheds in areas where the bedrock geology, as it does in the Folded Appalachians, basically determines their runoff characteristics. The present study supplies four quantitatively derived rainfall-runoff coefficients for many hydrogeologic terranes: (1) synclinal shale-sandstone valleys, (2) dip-slope areas of Appalachian ridges, (3) outcrop slope areas of such ridges, and (4) extensive limestone-dolomite valleys. Comparable hydrogeologic terranes can be recognized over wide areas in western Virginia south of James River and west of the Blue Ridge. The rainfall-runoff coefficients of the four hydrogeologic terranes as defined in this paper for the Peak Creek watershed, therefore, probably have wide utility.

One seeking preliminary evaluation of the impoundment possibilities in any similar drainage basin in a large portion of western Virginia can obtain a much more accurate estimation of rainfall-runoff coefficients by:

1. utilizing the best geologic base maps available for the watershed in order to determine the percentage of the total watershed area, which is composed of each of the established hydrogeologic terranes previously described;
2. obtaining relevant rainfall data from established stations for calculating annual volumes of runoff;
3. determining the total annual volume of water precipitated on each of these four terranes;
4. employing the runoff factors derived in the present study to determine the predictable runoff for each terrane by utilizing the available rainfall data; and
5. by weighing the runoff of each hydrogeologic terrane according to its relative size and its specific runoff coefficient, deriving therefrom an overall composite watershed rainfall-runoff coefficient that is much closer to actual runoff performance than can be obtained by the rule-of-thumb precedures for estimating stream discharge.

Under existing procedures for evaluating stream discharge by a blanket factor applied to bedrocks of all types, the maximum feasible productivity of drainage basins for future municipal use can not be determined. For example, if a shale valley watershed of 8 square miles is considered too limited in area to yield adequate runoff as calculated by employment of the .30 to .33 figures, the drainage area may easily supply sufficient runoff to equal that of a basin with an area of 11.368 square miles based on employment of the arbitrary .30 to .33 rainfall-runoff coefficient.

The employment of geologic maps in deriving meaningful runoff estimates for different bedrock in watersheds embracing multiple hydrogeologic terranes provides additional justification for the continued and, if possible, accelerated program of geologic mapping. Geologic maps long regarded as mainly of value as a base of information for evaluating mineral resources, probably have greater potential use in large sectors of the United States as a means of determining the amount of water that can be recovered on a continuing basis for the area. If an Appalachian watershed contains one or more of the hydrogeologic terranes described and quantified in the Peak Creek area above Gatewood Dam, and if it has been mapped geologically in reasonable detail, rainfall data, percentage of area underlain by these terranes can be employed to determine probably much more accurate estimates of impoundable runoff than could be derived by the usual, standard methods employed.

RECOMMENDATIONS FOR FUTURE STUDIES

The close correlation of the amount of runoff per unit area with the character of the bedrock needs further exploration in order to disclose just how many of the fundamental parameters of runoff are basically determined by bedrock geology. One special relationship that needs further exploration quite as much as gaging of runoff is investigation of possible control of rainfall patterns by the bedrock geology. The writer believes that the effect of bedrock on runoff is far more complicated than generally supposed, and, indeed, there are strong reasons for believing that a greater quantity of precipitation actually falls on shale-sandstone terranes as a direct function of their relatively higher elevation and fabric. The consummate effect of many patches of steep slopes may encourage rapid runoff perhaps as much or more than the impervious nature of the rock itself.

Drainage basins in western Virginia suggested for study similar to that described in this report include:

1. Passage Creek draining the interior of the Massanutten Mountains in Shenandoah County;
2. Mill Creek upstream from Gala, Botetourt County;
3. Stuart Run upstream from Millboro in Bath County;
4. Johns Creek above New Castle in Giles and Craig Counties;
5. Craig Creek in Botetourt and Craig Counties;
6. Bradshaw Creek above Ironto in Montgomery and Roanoke Counties;
7. South Fork of Roanoke River above Alleghany Springs;
8. Back Creek upstream from Starkey in Roanoke County;
9. Walker Creek upstream from Little Walker Gap in Giles County;
10. Laurel Creek upstream from Broadford in Smyth and Tazewell Counties;
11. Hunting Camp Creek above Bastian in Bland County;

12. Lick Creek north of the Saltville fault in Smyth and Bland Counties;
13. Tumbling Creek in Washington, Smyth, and Russell Counties upstream from the crossing of the outcrop of the Tonolowag Limestone; and
14. Bear Creek north of Adkins, Smyth County, Virginia

Locations of these areas are shown on Butt's Valley Map of Virginia.

All of the above areas offer water of excellent quality, and probably because of the overwhelming predominance of Devonian-Mississippian sandstones and shales, these basins probably have much higher runoff factors than .30 to .33.

Also, local precipitation patterns in rough terrane appear to vary greatly with elevation. The higher the elevation the greater the local rainfall. The writer is inclined to believe that with further study of various identifiable hydrogeologic terranes in a given area of diverse types of bedrock, it may be found that bedrock is truly the basic parameter governing not only local variations in runoff but also even local variations in rainfall. The fundamental limitation of the investigation of the hydrogeology of the Peak Creek watershed was the limited number of rainfall measurements. In future studies involving Appalachian hogback ridges, it is suggested that rain gages be placed in test areas in increments of 100 feet of change in elevation—with 12 to 20 rain gages measuring precipitation at different elevations in the same basin.

In areas where the Cambrian Nolichucky Formation or the likewise shaly Elbrook Formation occurs, it may be possible to separate Cambrian-Ordovician-limestone-dolomite terrane into at least two subdivisions—one above and the other below the intercalated shaly rock which may act as an effective curtain-wall deterrent to freedom of ground water movement.

Also the amount of underflow in limestone terranes may be monitored by stream gaging if the gage stations are placed in locations just downstream from contacts between limestone or dolomite with shale. Further investigation may suggest ways for estimating underflow which is obviously a part of the water budget that is very difficult to inventory by present procedures. Water runoff studies made without detailed knowledge of bedrock geology are of limited value except, of course, in areas where the soil

cover is unusually thick and the bedrock is primarily concealed. In such areas the soils have to be studied as hydrogeologic terranes.

In making gaging measurements by the methods used in the present study the desired degree of reliability of studies probably cannot be achieved in much less than a two-year period of record accumulation. Any such study made should provide for numerous rainfall recorders located over a maximum range of elevation in each basin being gaged for runoff. Such studies, if initiated in the years just ahead, could provide an attractive body of quantitative data that could be of great value in promoting the development of western Virginia where supplies of water of high quality are relatively abundant.

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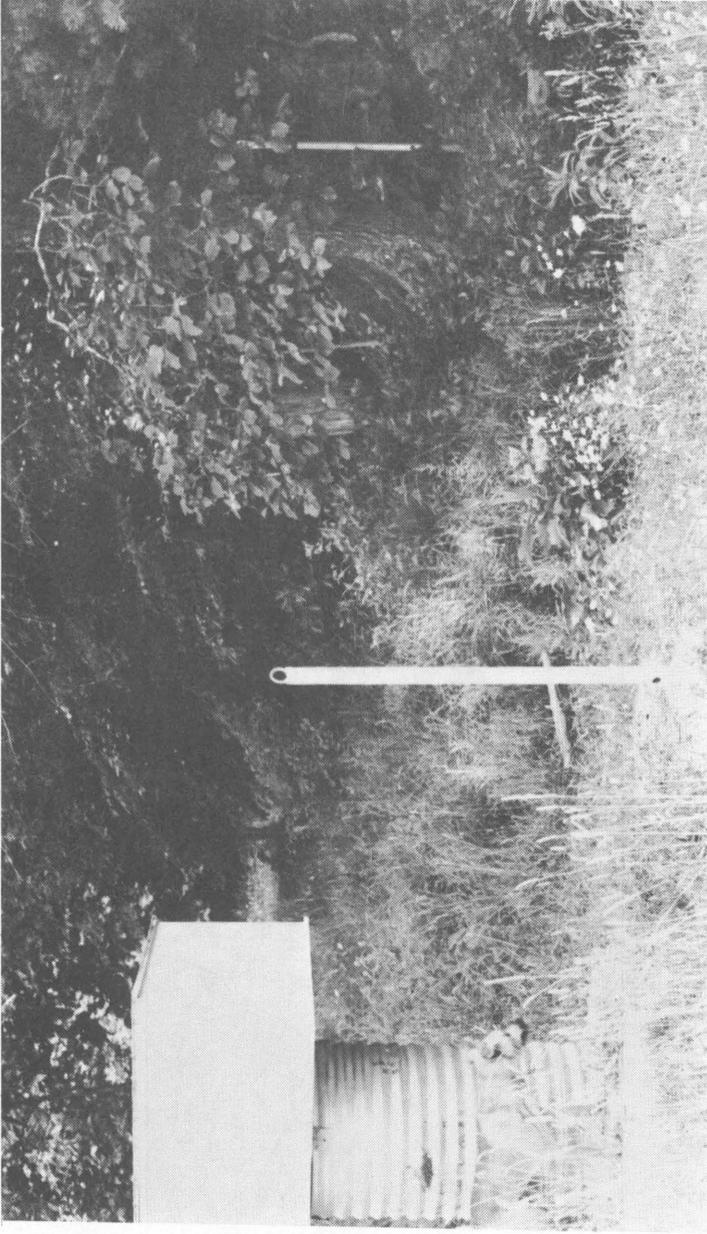


PLATE 2A. Gaging station for drainage area 1, Pulaski and Wythe counties, Virginia, showing loop stanchions for tag line used in establishing cross section of channel.

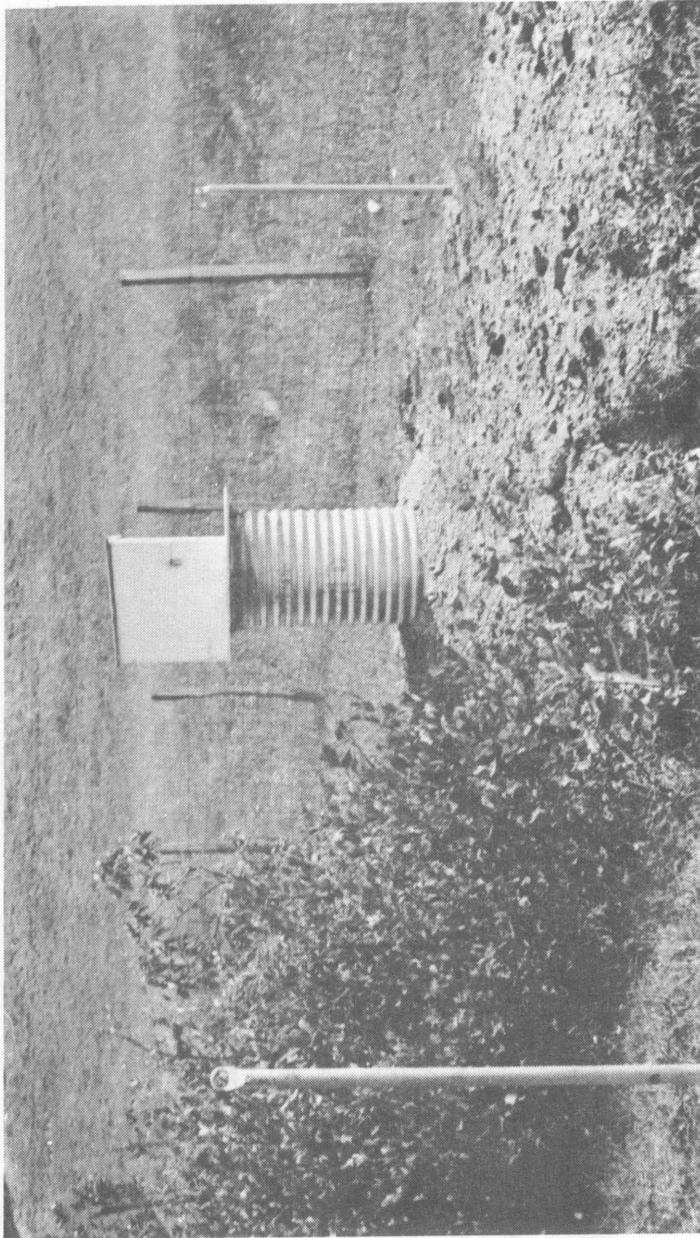


PLATE 2B. Gaging station for drainage area 2, Pulaski and Wythe counties, Virginia; showing loop stanchions for station.



PLATE 3A. Location of gaging station for drainage area 4 on West Fork of Miller Creek, Wythe County, Virginia.

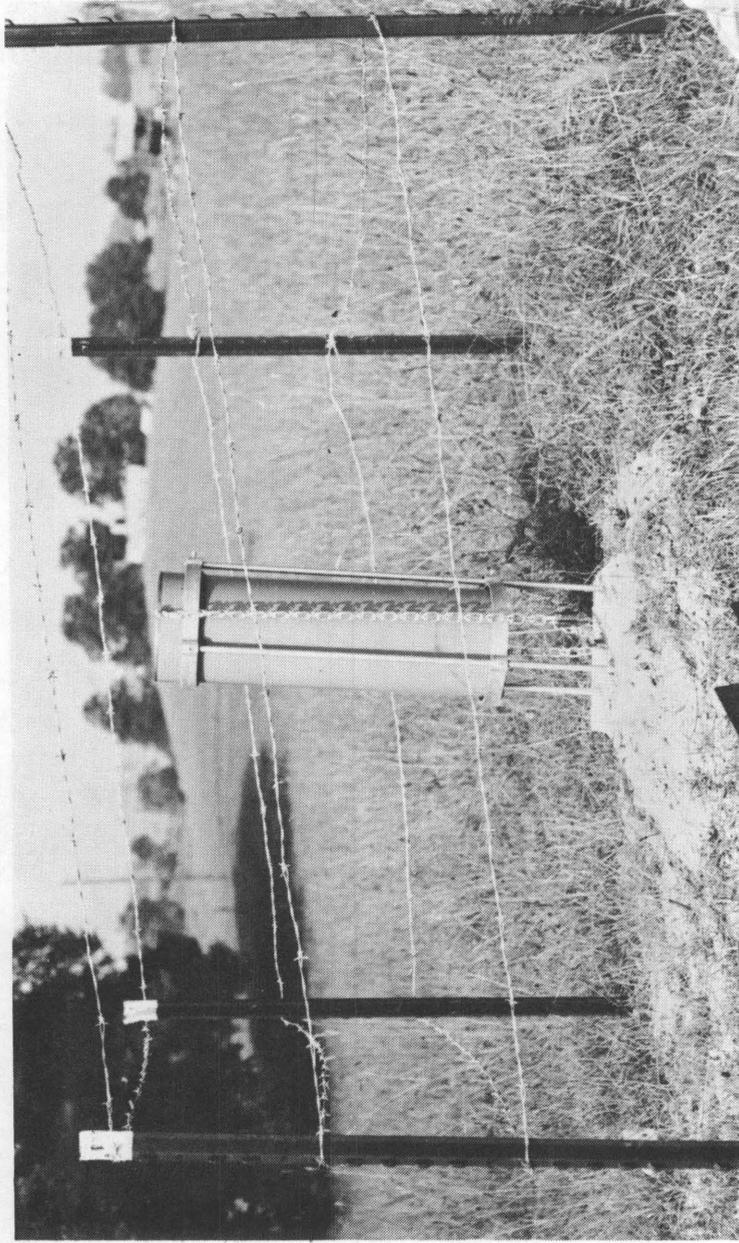


PLATE 3B. Rain gage installation near gaging station for drainage area 5 (Pl. 1).

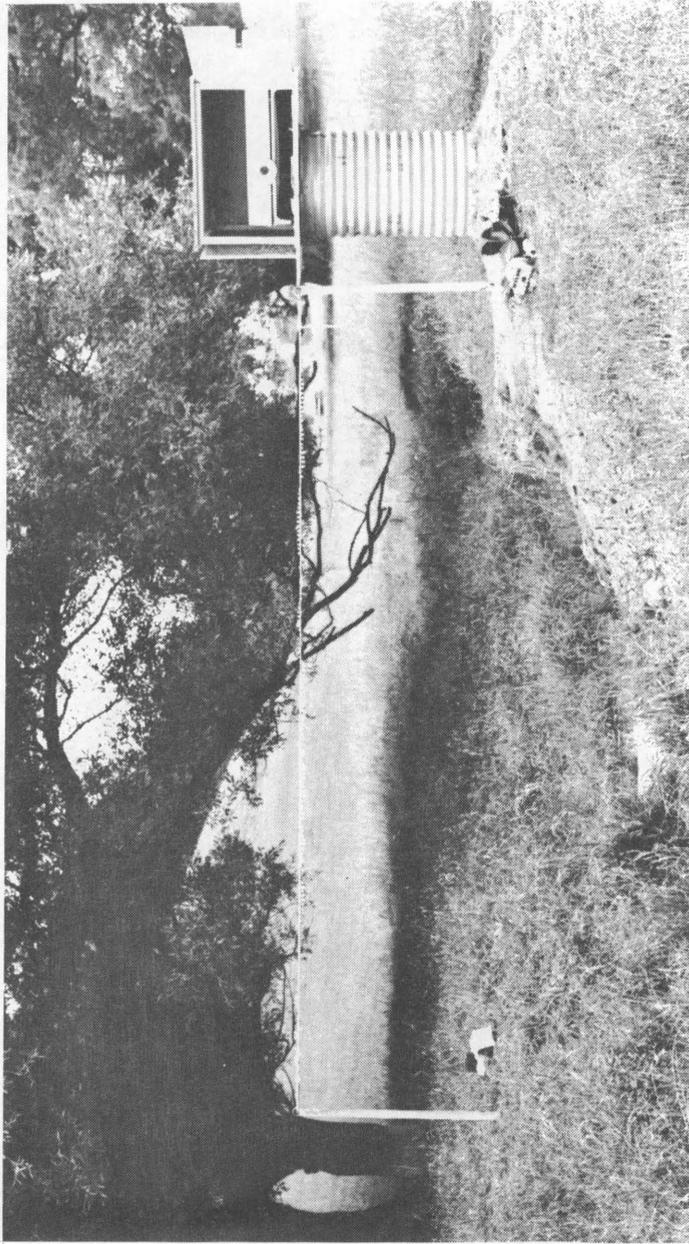


PLATE 4A. Gaging station for drainage area 5 on West Fork of Cove Creek, Crockett Cove, Wythe County, Virginia; showing stilling well pipe, enclosure for gage height recorder, and tag line for precise definition of stream channel.



PLATE 4B. Point determination of contour of stream channel at gaging station for drainage area 5 using tag line and plumb bob.

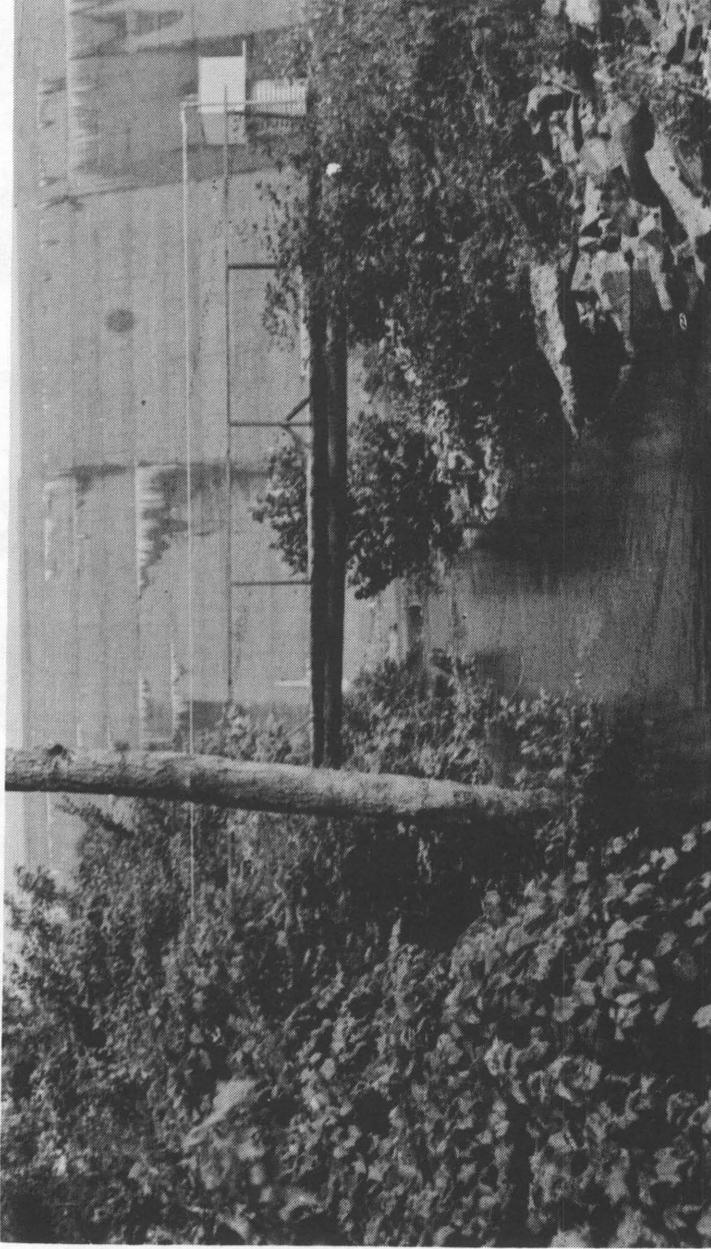


PLATE 5A. Location of gaging station below Gatewood Dam, which monitors all discharge from Peak Creek watershed impoundment area, Pulaski County, Virginia.

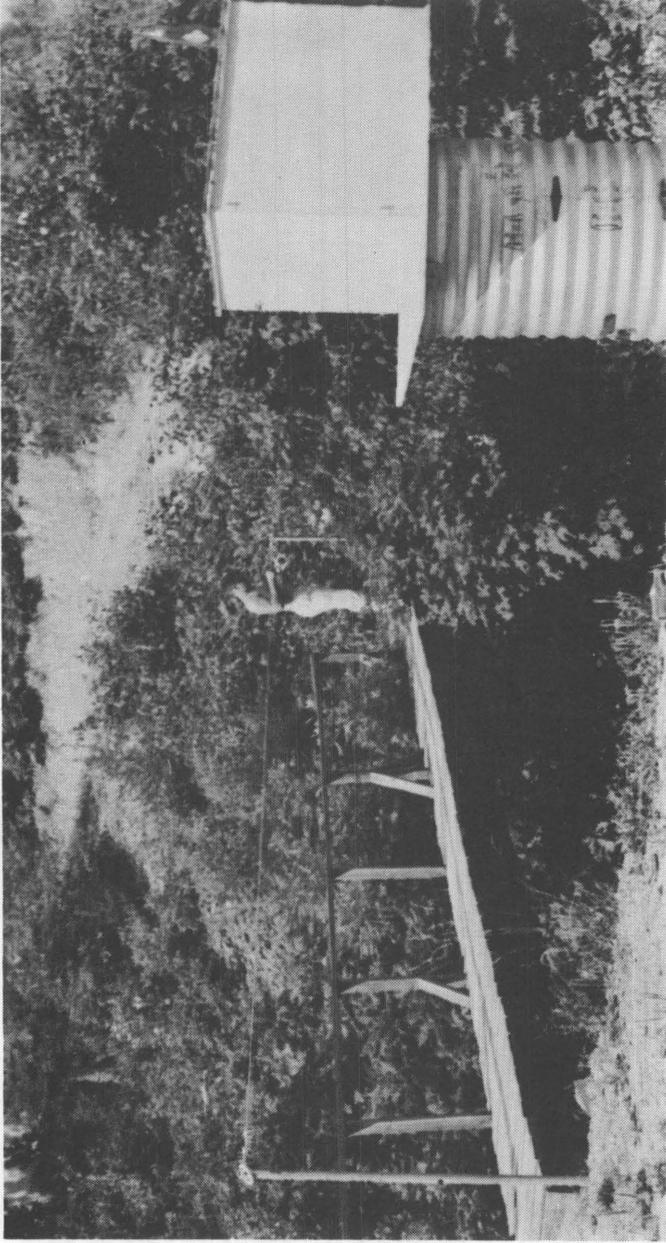


PLATE 5B. Close-up view of stilling well and recorder and tag line being used to contour channel of Peak Creek, gaging station 7 below Gatewood Dam, Pulaski County, Virginia. Note fixed reference line being tagged at one inch intervals.

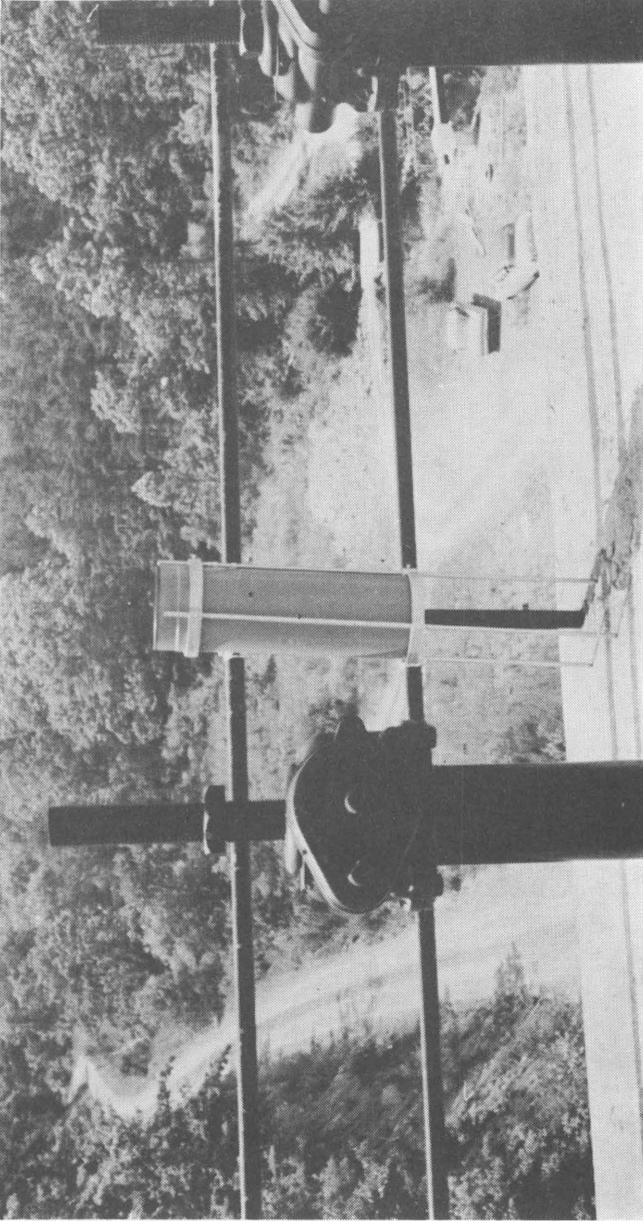


PLATE 6A. Rain gage for drainage area 7 embracing Peak Creek watershed above Gatewood Dam, installed on the dam near gate release valves.

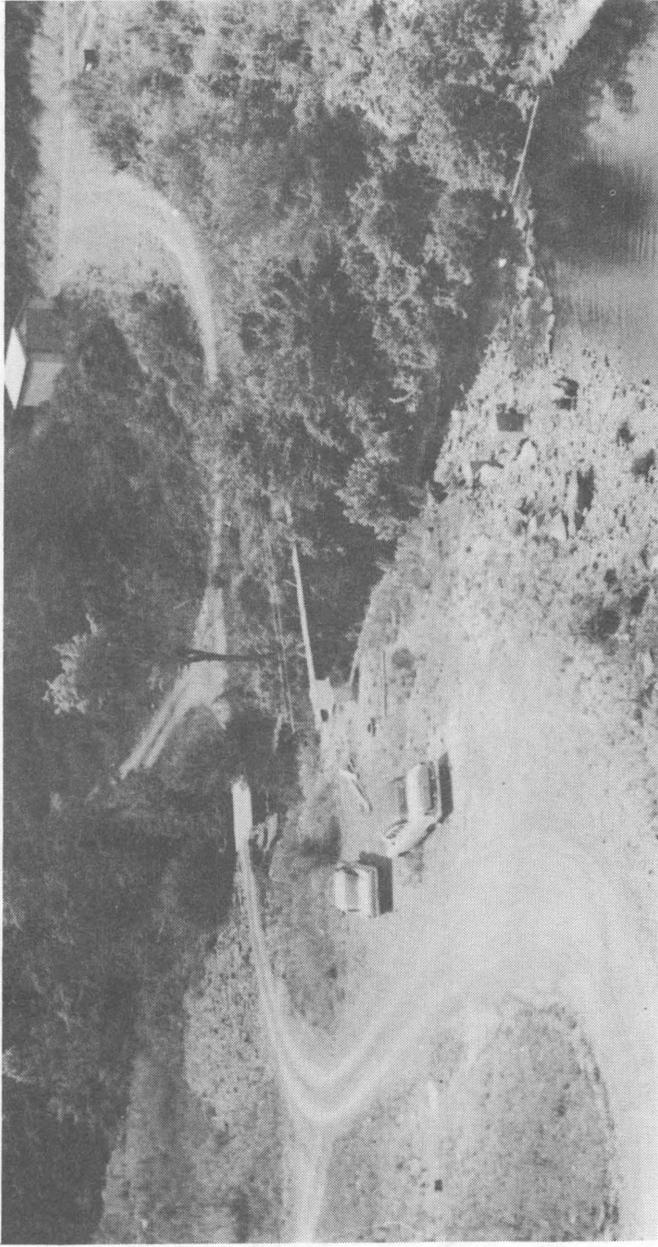


PLATE 6B. General view of Peak Creek channel below Gatewood Dam. All water released in channel from dam for downstream pick-up and pumping to filter plant and all water flowing over spillway is monitored at gage station 7.

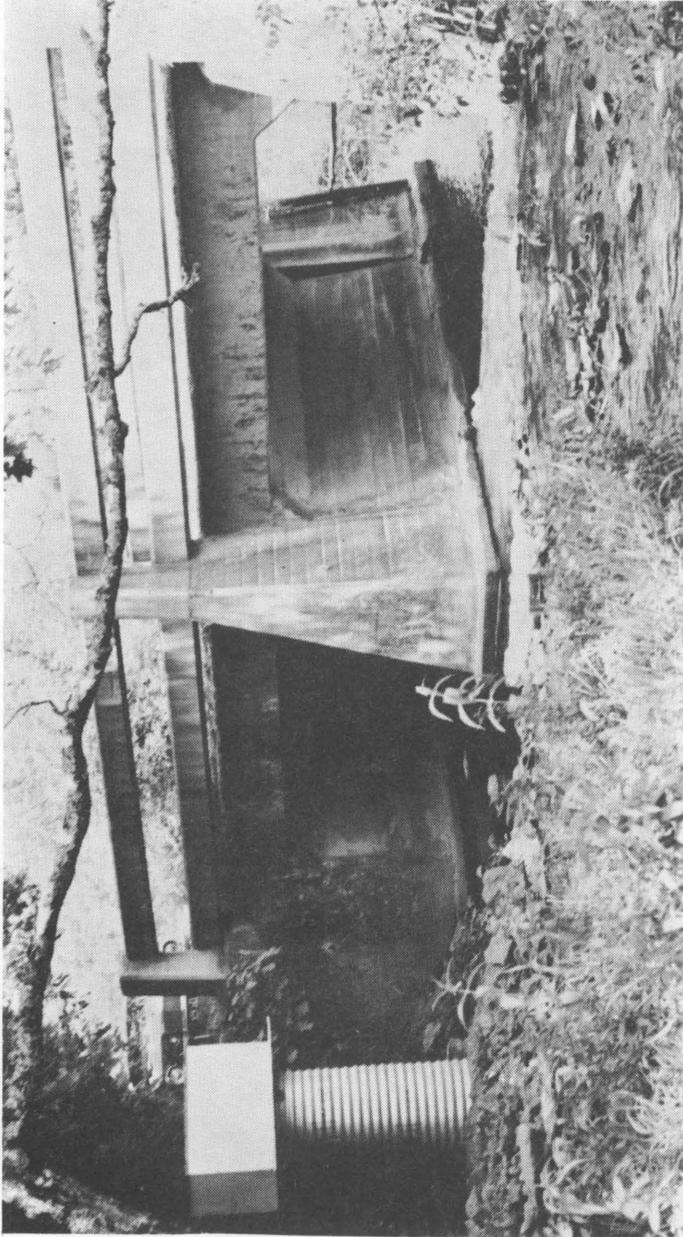


PLATE 7. Location of gaging station and definition of cross section of stream channel under highway bridge of Road 603 over East Fork of Cove Creek, Crockett Cove, Wythe County, Virginia.

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