DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

HYDROLOGIC INVESTIGATONS
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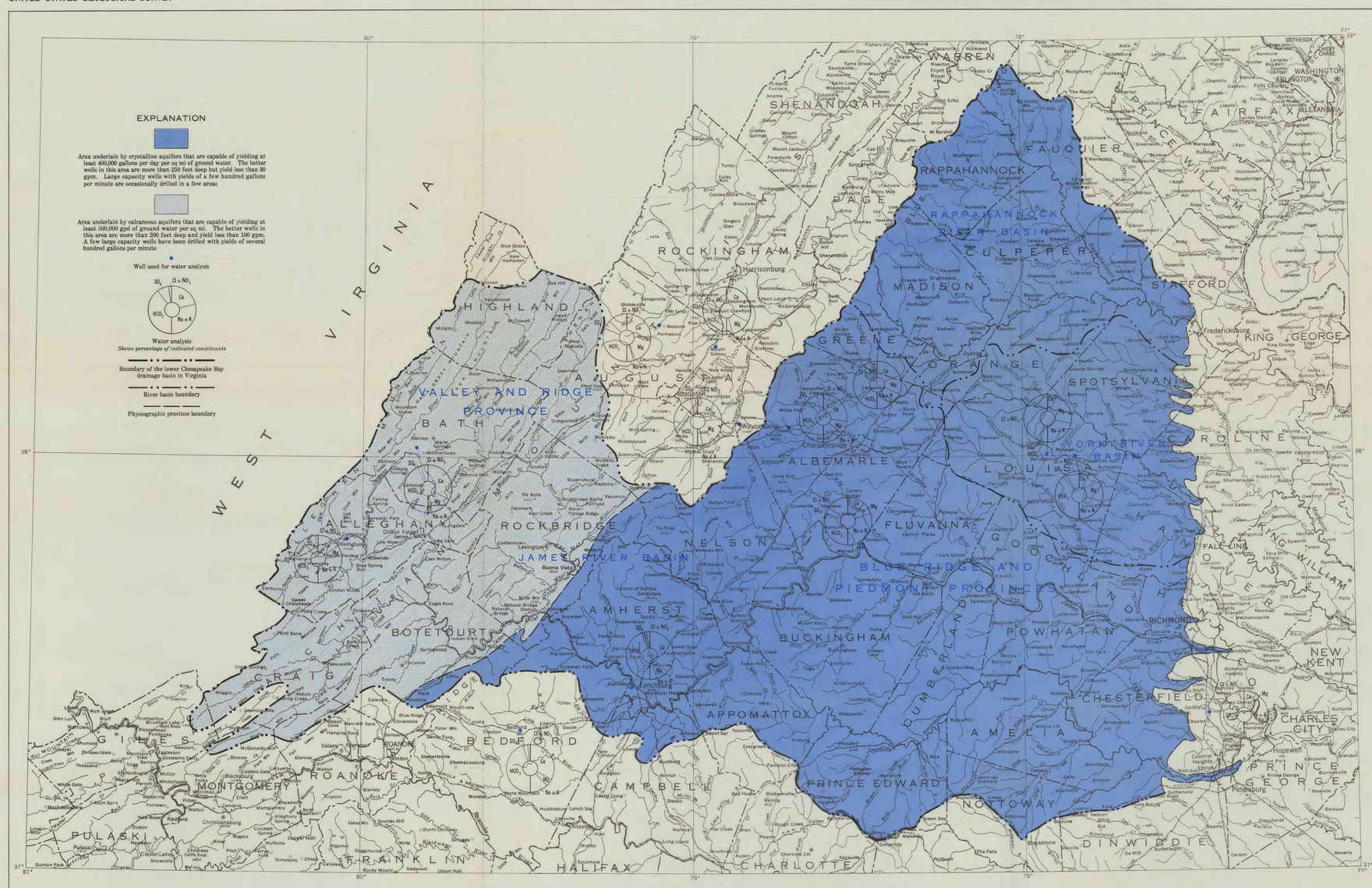
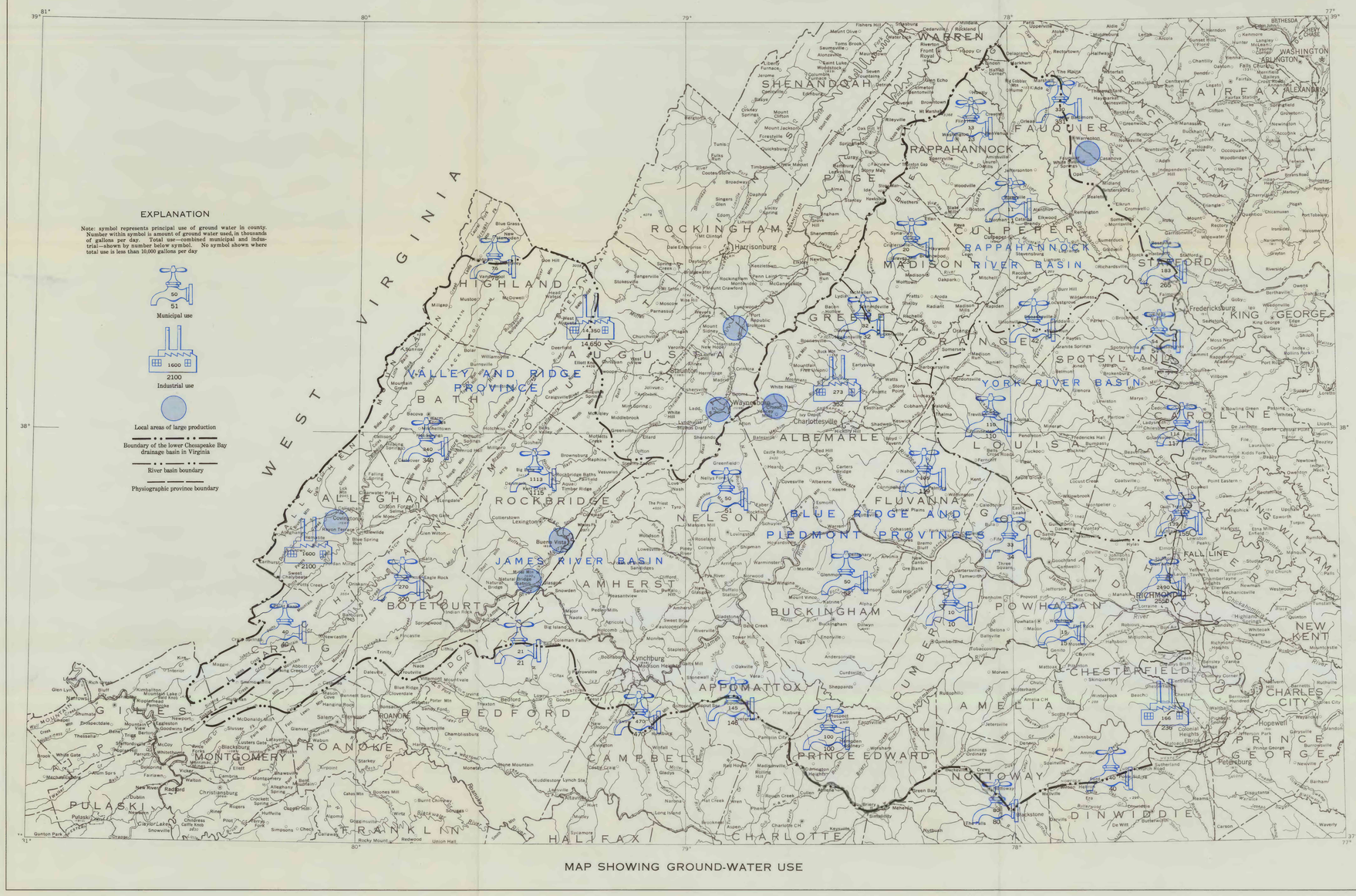


MAP SHOWING AVAILABILITY AND QUALITY OF GROUND WATER



MAP SHOWING GROUND-WATER USE

INTRODUCTION

The information contained herein was compiled from a variety of sources. No new field studies were made, instead broad interpretations were made of existing widely scattered information.

Officials of the Virginia Division of Mineral Resources, Virginia Division of Water Resources, and other State and local governmental offices have furnished very useful unpublished information from their files. Without the help and cooperation of these offices this study would have been most difficult and of limited value.

PHYSIOGRAPHY

The total relief of the terrane drained by the James, York, and Rappahannock Rivers is about 4,500 feet. The topography varies from the relatively flat or rolling Coastal Plains on the east to the rugged Appalachian Mountains near the western boundaries of Bath and Highland Counties of Virginia.

The James, York, and Rappahannock River basins include about 16,700 square miles. The area west of the Fall Line covered by this report includes about 10,800 square miles.

The Valley and Ridge province in the western part of the basin is underlain by folded Paleozoic limestones, dolomites, calcareous shales, and some sandstones, (table 1). Valleys mantled by residuum and alluvium, have been eroded in the soluble calcareous rocks. The ridges are underlain by more resistant sandstones.

The Blue Ridge and Piedmont provinces, in the James and Rappahannock River basins consist of about 8,000 square miles of hard dense rocks, (table 2). The Blue Ridge province in this area, only a few miles wide but more than 100 miles long, is topographically a low, narrow, steep-sided ridge. The Blue Ridge has little or no soil cover or weathered rock mantle and is a catchment area for the headwater streams of the Rappahannock River and a few tributaries of the James River.

East of the Blue Ridge, the topography of the Piedmont province is rolling. This characteristic topography, broken only by a few isolated ridges, extends eastward to the west edge of the Coastal Plain province. As a consequence of long erosion in a region of low relief, the residual soil cover ranges from zero to more than 100 feet in thickness. This mantle, or saprolite as it is called, masks the true topographic form of the unweathered rock by subduing the steeper slopes and filling in the topographic lows.

HYDROLOGY

The hydrologic cycle (Leopold and Langbein, 1960) and its relation to the occurrence of ground water is the controlling factor in the amount of ground water available.

The total water resources of an area are generally indicated by the average annual precipitation over a period of years. The water supply has long been recognized as a principal limiting factor to man's development in the arid regions, but even in the humid regions the quantity and quality of water are now becoming limiting factors of economic development.

Although the James, York, and Rappahannock River basins are areas of almost uniform precipitation and runoff, short-time variations are great enough to often cause serious problems to water users whose supplies are dependent upon average ("normal") precipitation.

Yields of ground water to wells in the three basins range from a few gallons a minute to as much as several hundred gallons per minute depending upon different geological environments. The effect of geology on the occurrence, movement, and quality of ground water is complex and in many areas detailed studies may be necessary if more than a minimum quantity of water is to be developed.

In the crystalline rocks west of the Fall Line, water moves and is stored in fissures and cracks. The storage capacity of these rocks is frequently only a fraction of a percent of the total volume of the rock mass or aquifer. Wells penetrating these aquifers yield only small to modest quantities of water. In the Valley and Ridge province, where calcareous rocks predominate, the primary fractures of the rocks are frequently enlarged by solution so that the storage capacity is greater and water moves more freely. Many (but not all) wells in calcareous rocks are highly productive. Specific locations where solution along the fractures in the aquifer has occurred are limited in area and number. Detailed geohydrologic work is necessary to delineate suitable well fields.

CHEMICAL QUALITY OF GROUND WATERS

Ground-water quality is dependent on rock type. Wells developed in the calcareous terranes generally yield a moderately hard calcium bicarbonate type water whereas wells developed in the crystalline terranes of the Piedmont and Blue Ridge provinces yield a somewhat softer sodium bicarbonate water.

It is noted in table 2 that one or more analyses from each type aquifer indicates that the water analyzed exceeded the maximum acceptable concentration for a given constituent for treated water for public water supply use.

In general, the ground water of the upper James, York, and Rappahannock River basins is of good quality and suitable for public water supplies (table 3). It should be noted that in most cases where the upper limit of a given chemical element of the raw ground water exceeds the maximum acceptable level for a finished drinking water this excess is found in only one or two water samples.

TABLE 3.—*Suitability of untreated ground water for public supply*

Number of determinations	Chemical characteristics	Range in concentrations (ppm) Min	Avg	Max	Maximum concentration in standards[3] (ppm)
	Valley and Ridge physiographic province (carbonate type rocks)				
13	pH (units)	6.6	7.5	8.6	
20	Hardness	20	207	649	
19	Iron	.01	.9	[1]5.6	0.3
17	Bicarbonate	70	227	354	
23	Sulfate	2	37.6	200	250
21	Chloride	.8	11	70	250
11	Nitrate	0	11.6	[2]84	4.5
4	Fluoride	.0	.15	.2	[1]1.2
	Piedmont physiographic province (crystalline type rocks)				
38	pH (units)	6.0	6.8	8.5	
44	Hardness	10	92	543	
43	Iron	.01	.84	[1]13	0.3
40	Bicarbonate	6	86.5	322	
27	Sulfate	.1	50	[4]468	250
50	Chloride	.1	14	81	250
29	Nitrate	.1	12	[2]68	45
24	Fluoride	.1	.6	[3]4.4	1.2

[1] Ten analyses exceeded acceptable concentrations.
[2] One analysis exceeded acceptable concentrations.
[3] Annual mean daily max. temp. at Lexington, Va. was 86.9°F for 65 years record.
[4] Two analyses exceeded acceptable concentrations.
[5] Three analyses exceeded acceptable concentrations
[6] Standards are for treated water—raw water can frequently be treated to comparable quality

TABLE 1.—*Geologic units in the Ridge and Valley province of the James River basin and their water-bearing properties*

Age		Units	Thickness (feet)	Lithology	Water-bearing properties
Recent and Pleistocene(?)		Alluvium	0-100	Clay, sand, gravel, cobbles, and boulders.	At base of Blue Ridge where adjacent streams, some localities have moderate yields.
Mississippian		Pocono Formation	0-500	Sandstone and conglomerate, thick bedded, some coal.	Occurs only at high elevations in few localities, not important as an aquifer.
Devonian	Upper	Hampshire Formation	500 - 2,000	Red shale and red sandstone with beds of gray and brown rocks.	Supplies of 5 to 20 gpm are generally available from wells as much as 250 feet deep. Larger supplies are rare but do occur locally. Red shales yield water high in iron. Limestones yield hard water.
		Chemung Formation	2,000- +	Greenish, poorly fissile mudrock with layers of sandstone.	
		Brallier Shale	2,000 - 4,000	Soft, thinly laminated, shale with thin beds of fine-grained, greenish sandstone.	
	Middle	Romney Shale	500 - 1,000	Black fissile shale, with some interbedded sandstones and clayey limestones.	
	Lower	Oriskany Sandstone	50-150	Calcareous, thick-bedded, coarse-grained sandstone.	
		Helderberg Limestone	200 - 500	Thick-bedded limestone and nodular, cherty, impure limestones.	No known large supplies from these formations. Small supplies are available.
Silurian	Cayuga Group	Tonoloway Limestone Wills Creek Shale Bloomsburg Red Beds	500 - 650	Black limestones, thin-bedded, interbedded fissile red, green and yellow shale; medium-bedded sandstone, gray or greenish, friable sandstones.	
	Middle	McKenzie Formation Clinton Formation			
	Lower	Tuscarora Quartzite	50-400	Thin- to thick-bedded sandstone and fissile shale; white, quartzose sandstone; thick-bedded quartzite.	Wells generally shallow and of small yield, not important as an aquifer.
Ordovician	Upper	Juniata Formation	150	Red, gray, and green mudrock and red sandstone.	Not important as aquifers.
		Oswego Sandstone	200-300	Brownish sandstone, thick-bedded.	
		Martinsburg Shale	1,500-3,000	Calcareous dark shales and interbedded green sandstone and limestone.	Wells shallow but generally have sustained yields of less than 10 gpm. Water generally is highly mineralized. Locally high in iron and sulphur.
	Middle	Chambersburg Limestone	200 - 400	Dark-colored thin-bedded limestone, some nodular layers.	These limestones probably surest source of moderate to small supplies of ground water. Locally large supplies of as much as 500 gpm have been obtained. Water hard to very hard. Contains little mineral matter other than that which causes hardness.
		Athens Shale	600 - 5,000	Black fissile shale, changing to black, thin-bedded, compact conchoidal limestone and pure argillaceous bluish limestone.	
		Stones River Group	250 - 1,000	Dark medium-coarse-grained limestone. Contains black chert, with compact glassy limestone, and some sandstone.	
	Lower	Beekmantown Group	800 - 3,200	Chert, dolomite, and limestone overlying thick-bedded gray dolomite.	
Cambrian	Upper	Conococheague Limestone	1,200 - 2,000	Thick-bedded blue limestone, dolomite with some sandstone and clay laminae.	
	Middle	Elbrook Dolomite	2,700 - 3,400	Thick-bedded, medium coarse dolomite with thinly laminated finely crystalline bluish-gray dolomite.	
	Lower	Waynesboro Formation	1,500-2,000	Red mudstone, shale, limy sandstone dolomite and limestones.	In local areas these are the best aquifers in the Ridge and Valley province. Large capacity industrial wells located adjacent to base of Blue Ridge Mountains.
		Tomstown Dolomite	1,500-2,000	Medium-thick-bedded dolomite with thin limestone beds.	
Cambrian(?)		Erwin Formation	2,000 - 4,100	Sandstone, shale, quartzite, schist, and slate.	Small yields of less than 15 gpm are common. Water soft, low in mineral content.
Precambrian		Crystalline rocks		Greenstone and granitic rocks.	

TABLE 2.—*Geologic units in the Blue Ridge and Piedmont provinces of Virginia and their water-bearing properties*

Age		Units	Lithology	Water-bearing properties
Quaternary		Alluvium	Sand, gravel, and clay on flood plains of modern streams.	Small ground-water supplies from shallow bored and dug wells.
Triassic		Diabase	Igneous rocks—sills and dikes, diabase and gabbro.	Small supplies from drilled and dug wells.
	Newark Group	Newark Group undivided	Arkosic sandstone and red shale, conglomerates, and coal beds.	Drilled wells yield as much as 80 gpm at depth of 400 feet or more. Water hard.
Ordovician		Arvonia Slate	Slate, phyllite, and schist with garnet metacrystals and conglomerates.	Water-bearing properties of rocks much more uniform than in lithology. Permeabilities vary from place to place according to structural deformation rather than lithology. Ordinarily yield few gallons to few tens of gallons per minute. Yields of 50 gpm or more in a number of localities and a few hundred gallons per minute in a few locations. No large area can be delineated where single wells producing as much as 100 gpm can be drilled.
Cambrian(?)	Chilhowee Group	Erwin Formation	Sandstone and quartzite, thick bedded, well sorted, grayish to white.	
		Hampton Formation	Sandstone, shale and quartzite.	
		Unicoi Formation	Conglomerate, shale, and quartzite and basalt flows.	
Paleozoic(?)	Evington Group	Slippery Creek Greenstone Volcanics of W. R. Brown (1953)	Muscovite, chlorite, paragonite, quartz, phyllite, and schist interbedded with graywacke, volcanic greenstone, and marble.	
		Mount Athos Formation		
		Peller Schist of W. R. Brown (1953)		
		Arch Marble of W. R. Brown (1953)		
		Joshua Schist of W. R. Brown (1953)		
		Candler Formation		
Precambrian		Catoctin Formation	Basic lava flows, schist, and gneiss composed of chlorite, plagioclase, amphibole, and epidote.	
		Swift Run Formation	Sandstone, graywacke, andesite tuff, and greenstone.	
		Lynchburg Formation	Phyllite, quartzite, graywacke and conglomerate.	
	Lynchburg, Blue Ridge, and Pedlar Groups of W. R. Brown (1958)	Lovingston Granite Gneiss	Biotite granite, biotite gneiss and biotite quartz monzonite.	
		Marshall Gneiss of W. R. Brown (1958)	Biotite, quartz, feldspar granite, gneiss, and quartz monzonite.	
		Monacta Gneiss of W. R. Brown (1958)	Biotite hornblende gneiss.	
		Petersburg Granite	Microcline, biotite granite and chloritic granodiorite.	
		Shelton Granite Gneiss of C. B. Brown (1937)	Granite gneiss, augen gneiss, and mylonite.	
		Amphibolite and amphibolite rich foliate	Amphibolite and amphibolite rich foliate.	
		Granite	Biotite and muscovite granite, granodiorite and quartz monzonite.	
		Granite gneiss and hornblende gneiss	Interlayered mica, quartz, feldspar gneiss, and hornblende feldspar mica gneiss.	
		Greenstone volcanics	Basic lava flows, tuff and slate commonly altered to chlorite-bearing rocks.	
		Hornblende gabbro, gneiss and talc	Amphibole chlorite schist, chloritic hornblende gneiss.	

GROUND-WATER USE

The development and use of the ground-water resources of the upper James, York, and Rappahannock River basins are small relative to total amount of water available, largely because ground water can be obtained only from low yield wells in many areas. Water-use records compiled by State and Federal agencies indicate that industrial and public ground-water developments have tapped only about 1 percent of the potentially available ground water.

Studies of ground-water increments to streamflow show that the calcareous aquifers that underlie the part of the James River basin in the Valley and Ridge physiographic province have a potential yield of 500,000 gpd (gallons per day) per square mile. Therefore, more than 1 billion gallons of ground water should be available each day for industrial or municipal use in that part of the James basin. Water-use records, however, indicate that in the 7 counties that fall within this part of the basin less than 20 mgd (million gallons per day) have been developed for industrial and municipal use.

The crystalline rocks underlying those parts of the James, York, and Rappahannock River basins that lie within the Blue Ridge and Piedmont physiographic provinces are capable of yielding 400,000 gpd, of ground water per square mile. Therefore, in the crystalline rock areas about 3 billion gpd are available in the ground. It is emphasized, however, that even though this amount of water is available, wells in these rocks generally have small yields and the amount of water that can be feasibly recovered is limited by the number of wells that could be drilled economically. Water-use records from the 27 counties within this area, however, indicate that less than 6 mgd are pumped for industrial and municipal use.

Areas of high yield

Wells developed in crystalline and calcareous rocks normally do not have relatively high yields. This generalization is particularly true of wells developed in the upper James, York, and Rappahannock River basins, where most of the wells yield less than 100 gpm (gallons per minute).

Where especially favorable hydrogeologic conditions occur, there are exceptions to this general rule. For example, in small areas near the municipalities of Buena Vista, Glasgow, and Covington in the upper James River basin and in similar areas outside the basin near Waynesboro, Grottoes, Elkton, and Roanoke, wells with higher yield have been developed. Undoubtedly there are other areas within this calcareous terrane where large yield wells might be developed, but as yet such areas have not been adequately identified and/or tested.

Well fields developed in the high-yield areas have two or more of the following physical characteristics: (1) The well field is located between sizable perennial streams and the western slope of the Blue Ridge Mountains, (2) all but one of the well fields (Buena Vista), are developed in carbonate aquifers, (3) the well fields have been developed at or near the sites of perennial springs, (4) the well fields have multiple producing horizons between 30 and 700 feet deep, (5) the wells are adjacent to perennial streams and have pumping levels that are below stream level, (6) most of the large-capacity wells are more than 200 feet deep and are 12 inches or more in diameter.

In the crystalline rock terranes of the Blue Ridge and Piedmont provinces, high-capacity wells are much less common than in the calcareous terranes. Records indicate that wells yielding more than 75 gpm are the exception rather than the rule. However, higher-than-average-yield wells may be developed where a favorable combination of geologic and hydrologic characteristics is present.

In local areas near Cronet in Albemarle County and near Warrenton in Fauquier County (just outside of the Rappahannock River basin) well fields have been developed which produce unusually large quantities of water from the crystalline aquifers. Sufficient criteria have not been developed, to help locate new high producing areas. However, it is believed that one criterion may be a location in or immediately adjacent to draws and valleys which have developed along fault or fissure zones. Records indicate that wells in such depressions generally yield more water than wells on the adjacent hill top or valley slope. However, all such depressions do not necessarily constitute a large water-producing area. There are undoubtedly other factors which are not yet understood, controlling the occurrence of ground water in fissured rock.

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GROUND-WATER RESOURCES OF THE JAMES, YORK, AND RAPPAHANNOCK RIVER BASINS OF VIRGINIA, WEST OF THE FALL LINE

By
George D. DeBuchananne

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