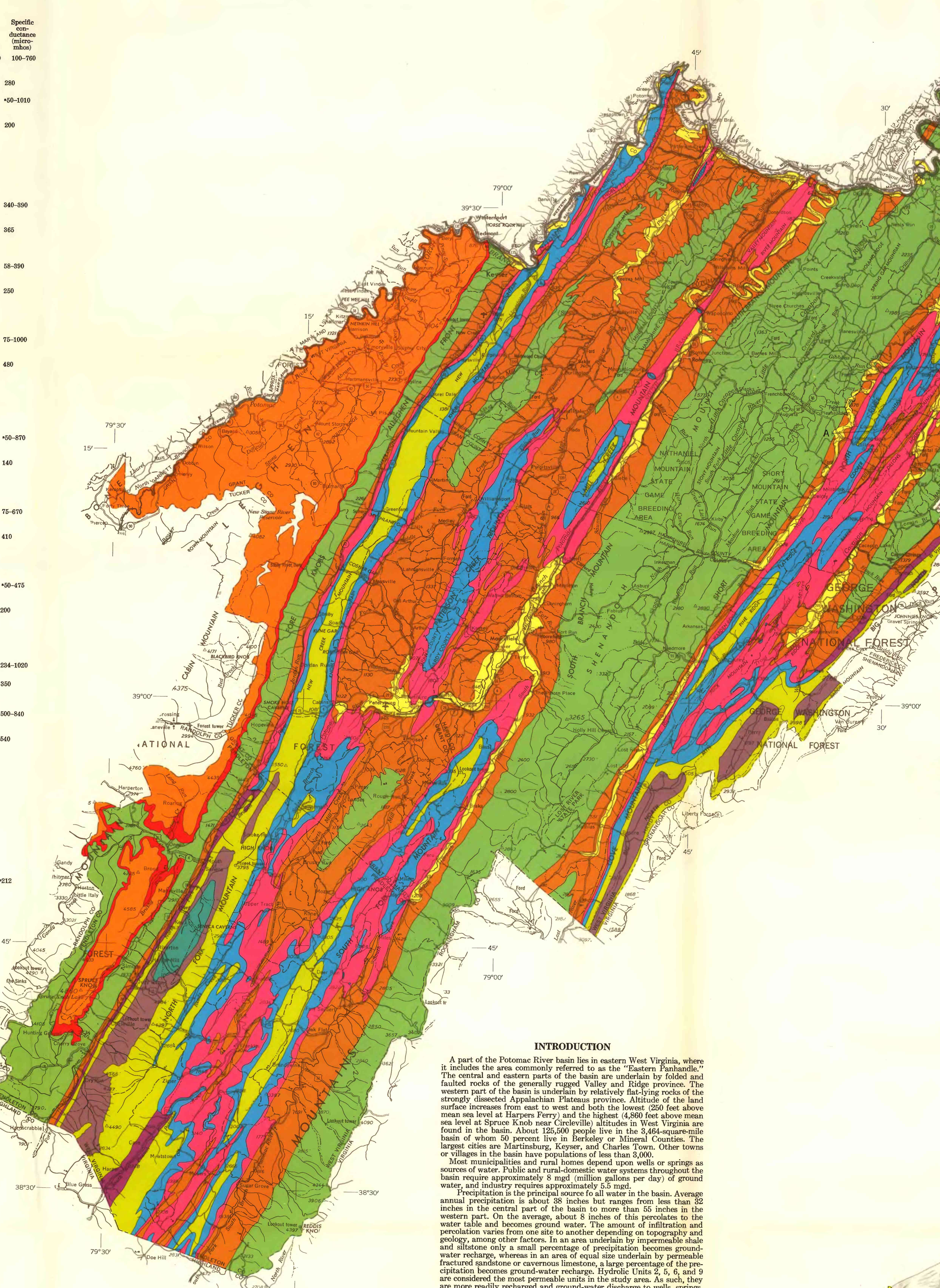
Table 1.—Summary of data regarding hydrologic units and ground water.

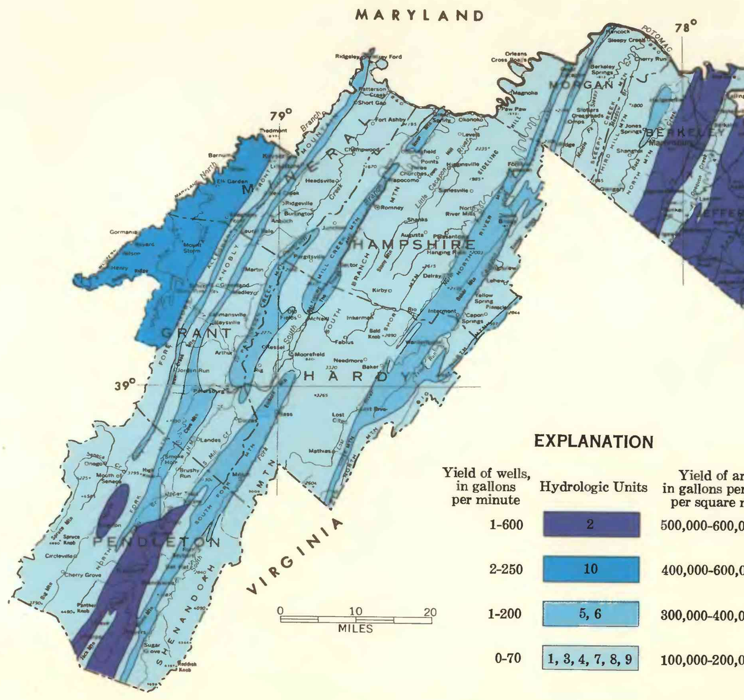
Description	*Rock units	Range of thickness (feet)	Hydrologic unit		Well depths (feet)	Well yields (gpm)	Water-quality parameters: Iron (mg/l)	Chloride (mg/l)	Hardness (mg/l)	Specific conductance (micromhos)
Unconsolidated stream deposits are mainly silt and clay containing some lenses of sand and gravel. Significant saturated thicknesses of alluvium are generally found only near major streams. Many alluvium deposits are on terraces and are unsaturated.	Alluvium	0–35	11	Range	4–35	0–40	[a]0.1–3.0	2.0–72	[a]51–290	100–760
				Median			0.4	[a]8	[a]136	280
Analysis of drill logs by Overbeck (1954, p. 50–51) for drill holes penetrating these formations in Garrett County, Maryland, indicate that 20 to 35 percent of the Conemaugh Group (and Monongahela? Group) is sandstone (including siltstone), about 50 percent of the Allegheny Formation is sandstone, and 55 to 70 percent of the Pottsville Group is sandstone. The remaining percentages of each formation are shale, clay, some limestone, and coal. Most of the coal beds are in the Conemaugh and Allegheny. Occasional thin beds of limestone (less than 5 feet thick) occur in all of the formations above the Pottsville. Beds of clay are often found at the base of coal deposits. The Mauch Chunk consists of thin-bedded sandstones, siltstones, and noncalcareous red or green shales.	Monongahela Group Conemaugh Group Allegheny Formation Pottsville Group Mauch Chunk Group	0–180 780–840 150–200 350–450 500–800	10	Range	12–325	2–250	0.1–[b]5	[a]8–56	[a]17–200	[a]50–1010
				Median	60	[a]30	0.5	[a]8	110	200
The Greenbrier Group is mainly limestone; however, approximately the upper 100 feet is usually a reddish calcareous shale. The basal 300 feet is mostly blue, gray, or reddish limestone. At greater depth, the limestone beds become more massive. This limestone is thickest and purest in Pendleton County but decreases in thickness and probably becomes more sandy in the northern part of the basin.	Greenbrier Group	100–300	9	Range			[a]0.1	1.3–6	[a]160–200	340–390
				Median			[a]0.1	[a]6	180	365
The Pocono Group is a gray, hard, massive sandstone with some shale beds. The upper 300–400 feet of the Hampshire Formation is maroon to reddish brown siltstone and shale. The lower part is nearly all fine-grained, well-cemented, hard, massive red sandstone with some shale. The Chemung is nearly always a rusty yellowish brown. The top half of the formation is thin-bedded, hard, blocky sandstone. The bottom half is principally thin-bedded, siltstone and shale with a massive sandstone member present at its base in the easternmost areas.	Pocono Group Hampshire Formation Chemung Group	200–600 1200–3000 1200–3500	8	Range	18–640	1–75	[a]0.1–30	1–80	34–156	58–390
				Median	130	10	0.4	[a]8	85	250
The Brallier Formation is a greenish-gray shale, siltstone, and sandstone. Sandstone and siltstone may constitute about 35 percent of the formation. The lower 50 to 400 feet of this formation (the Harrell Shale) is black shale. Below, lie the brown sandy shales of the Mahantango Formation which contains only occasional sandstone beds. Many concretions are normally found near the contact with the underlying Marcellus Formation. The Marcellus is a black carbonaceous, clayey, fissile shale which contains considerable pyrite and minor amounts of siltstone. Perhaps 50 to 150 feet from the base of this formation is one or two beds of limestone each having a thickness of 20 to 40 feet (Reger, D. B., 1924, p. 320). Large limestone concretions are near the base of this formation at places.	Brallier Formation (includes Harrell Shale) Mahantango Formation Marcellus Formation Needmore Shale	1500–2300 300–1000 500–900	7	Range	5–962	0–75	0.1–[b]6	2–1270	15–6370	75–1000
				Median	75	8	[a]1	[a]8	170	480
This unit is composed of sandstone sandwiched between two layers of generally soft calcareous chert. The upper chert layer ranges in thickness from zero to 100 feet. The Oriskany Sandstone is a medium- to thick-bedded brown-to-white sandstone. In places the rocks contain very hard silica cement; in other places they contain softer carbonate cement; in still other places they are friable and completely devoid of cement. The lower Shriver Chert ranges in thickness from near zero in Morgan County to 312 feet in Pendleton County.	Oriskany Sandstone Shriver Chert	100–500	6	Range	10–552	1–150	0.1–1.0	[a]8–85	[a]17–476	[a]50–870
				Median	100	15	[a]0.2	[a]8	[a]85	140
The upper part of the Helderberg Group consists of thin-bedded, light-colored, cherty limestone. The middle part is shaly and thin-bedded. The bottom part is massive-bedded relatively pure limestone. The underlying gray, flaggy, thin beds of the Tonoloway Formation contain some silica and dolomite and grade downward into the flaggy limestone and calcareous shales of the Wills Creek Shale. The basal 25–100 feet consists of red or green sandy shales and one hard sandstone bed.	Helderberg Group Tonoloway Formation Wills Creek Formation Williamsport Sandstone	300–600 200–400 200–400 60–100	5	Range	13–420	2–200	0.01–6.5	1.1–43	6–390	75–670
				Median	100	20	[a]0.1	[a]8	[a]200	410
The McKenzie Formation is a bluish-gray, wavy-bedded, flaggy limestone and limy shale. The adjacent Clinton Group is predominately red shale with thin beds of sandstone and occasional limestone layers. The underlying thick-bedded Tuscarora Sandstone varies in color from gray to pink and is extremely hard and resistant to weathering. In Pendleton County vertical beds of Tuscarora sandstone form spectacular walls of rock. The red beds of the Juniata Formation consist of thin-bedded blocky sandstone and shale. In places this formation is underlain by thick-bedded gray Oswego Sandstone.	McKenzie Formation Clinton Group Tuscarora Sandstone Juniata Formation Oswego Formation	150–400 300–600 50–300 500–1000 100–200	4	Range	32–265	0–40	[a]0.1–5	1.1–[b]8	6–258	[a]50–475
				Median	100	8	0.3	[a]8	[a]100	200
The upper part of this unit largely consists of blocky, sandy shale with interbedded sandstone. Downward, the rocks grade into thin-bedded shale and near the base of the unit are generally calcareous with some beds of limestone. However, the unit contains little limestone in Hardy County.	Martinsburg Formation	1500–2300	3	Range	28–175	2–50	0.1–10	1–121	111–540	234–1020
				Median	65	20	2	15	250	350
The Trenton-Black River Group is shaly near its contact with the Martinsburg Formation. Downward, it grades into a hard, thin-bedded, blue-black limestone. The St. Paul Group consists of thin-bedded quite pure limestone that becomes more massive and higher in silica and dolomite toward its base. The Beekmantown Group contains abundant chert in its upper part. The remainder consists of occasional beds of very pure limestone and beds of dolomite and limestone which are often high in silica, especially near the base. The high silica content continues into the underlying Conococheague Formation. This formation is largely limestone, but contains some banded sandstone and characteristically contains beds of oolite throughout. The Elbrook Formation is mainly thin-bedded limestone and calcareous shale. However, massive beds of dolomite occur and chert is abundant throughout. The adjacent Waynesboro Formation is a mass of siliceous limestone, sandstone, sandy shale, and some dolomite. However, some very pure limestone beds do occur. The upper beds of the Tomstown Dolomite are massive, banded, hard limestones and dolomites. Below these beds, there are massive beds of siliceous dolomite with thin beds of relatively pure limestone. Considerable amounts of shale occur near the base of the formation.	Trenton and Black River Groups St. Paul Group Beekmantown Group Conococheague Formation Elbrook Formation Waynesboro Formation Tomstown Dolomite	400–500 500–800 2000–2500 1500–1800 2200–2500 1500–1600 1000	2	Range	11–705	1–630	0.1–0.7	3–24	216–636	500–840
				Median	150	35	[a]0.2	[a]8	290	540
The Antietam Formation is generally a thick-bedded quartzite and a sandstone that is calcareous in places. The adjacent Harpers Formation is an intensely folded and uniform sandy shale. The underlying Weverton-Loudoun Formation is mainly quartzite that varies in color from nearly white to purplish black and in some places resembles dark-gray granular granite. The basal part of this unit is formed by greenish-gray schist of the Catoctin Formation.	Antietam Formation Harpers Formation Weverton-Loudoun Formation Catoctin Formation	500 1200 500–600	1	Range	18–212	1–45	[a]0.1	[a]5	[a]100	[a]212
				Median	150	7				

* Names are those used by the West Virginia Geological and Economic Survey.
[a] Less than value shown.
[b] More than value shown.

Significance of water quality parameters given in table 1.

Iron	Concentrations of more than 0.3 mg/l generally cause staining and adversely affect the taste of coffee and tea.
Chloride	Concentrations of more than 250 mg/l cause salty taste.
Hardness	Soft water 0–60 mg/l Moderately hard water 60–120 Hard water 120–180 Very hard water more than 180
Specific conductance	For most ground water 0.6 times specific conductance equals total dissolved minerals, in milligrams per liter. For most ground water high in sulfate 0.9 times specific conductance equals total dissolved minerals, in milligrams per liter.





EXPLANATION

Yield of wells, in gallons per minute	Hydrologic Units	Yield of area in gallons per day per square mile
1-500	2	500,000-600,000
2-250	10	400,000-600,000
1-200	5, 6	300,000-400,000
0-75	1, 3, 4, 7, 8, 9	100,000-200,000

A. AVAILABILITY OF GROUND WATER

Ground water is generally available throughout the basin; however, the quantity available varies from one aquifer to another and from one place to another within a given aquifer. The largest ground-water supplies are available from sandstone and carbonate-rock aquifers containing secondary openings such as faults, joints, or solution cavities within the zone of saturation. Less ground water is available from shale and siltstone aquifers which in places contain almost no secondary openings. Although nearly all rocks contain fewer secondary openings with increased depth below land surface, the decrease is marked in shales. The shale beds are less competent, or more "plastic," than sandstone or carbonate rock beds, and at depth the weight of the overlying rock squeezes openings shut. The lack of secondary openings dramatically affects the yield of deep wells. Some wells have been drilled in the shales of Unit 7 to depths of about 900 feet without obtaining a usable quantity of water. In contrast, a gas well near Springfield, penetrating limestone of Unit 2 at a depth of about 10,600 feet, produced 16 gpm.

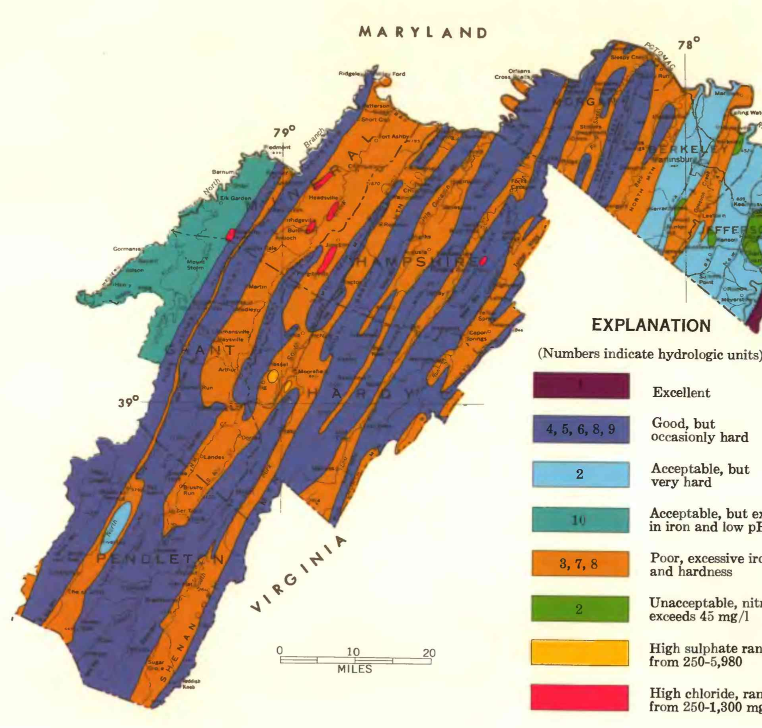
Dry wells have also been drilled to depths of 500 feet in ridges and 200 feet in upland valleys underlain by Hydrologic Units 5 and 6 without penetrating the water table. Dry wells in these units are due not to the lack of secondary openings but to the fact that the water table is extremely deep because of underground drainage. Water can be obtained from these units if the well can be drilled and cased into or through Unit 6. Well construction is made difficult by caving sand and rock where Unit 6 is composed of alternating layers of cemented and friable sand.

Problems may also arise when wells are constructed in permeable weathered zones in carbonate-rock aquifers. These zones commonly contain residual clay and caverns. When the wells are pumped at high rates, the clay contributes to turbidity. Also, lowering the water table removes support of clay plugs in the roofs of water filled caverns in the bed rock, and the plugs may collapse to cause sinkholes at the land surface.

The ranges of well yields shown on the map are based on reported and measured yields of inventoried wells. The ranges of areal yields are based on ground-water runoff values obtained from streamflow analysis and on baseflow measurements. Because the streamflows analyzed were for the 1969 water year when ground-water recharge was below normal, the ranges shown on the map have been adjusted upward to approximate the values for an "average" year.

The areal yields shown indicate the amount of ground water that annually discharges from each square mile of aquifer as streamflow. The discharge ranges from about 60 to 85 percent of total streamflow from streams draining shale and limestone areas, respectively. Because ground water discharged to streams is only a part of total annual ground-water recharge (the other part is lost to evapotranspiration), the areal yields shown on the map are only a relative index as to the quantity of ground water available for development from the various parts of the basin.

Records for some observation wells in the study area show that maximum and minimum ground-water levels virtually have not changed over the last 14 years. Thus, ground-water storage is about the same today as it was years ago. However, local increases in ground-water storage have been caused by works of man such as dams. Other works such as wells, mines, and tunnels have locally drained ground water and decreased ground-water storage, although elsewhere similar abandoned works become filled with water and locally increase ground-water storage. In still other places blasting for highway construction has increased work permeability, which in turn permits more water to enter the ground.



EXPLANATION

(Numbers indicate hydrologic units)

	Excellent
4, 5, 6, 8, 9	Good, but occasionally hard
2	Acceptable, but very hard
10	Acceptable, but excessive in iron and low pH
3, 7, 8	Poor, excessive iron and hardness
2	Unacceptable, nitrate exceeds 45 mg/l
	High sulphate ranges from 250-5,980
	High chloride, ranges from 250-1,300 mg/l

B. SUITABILITY OF CHEMICAL QUALITY OF GROUND WATER FOR DOMESTIC OR PUBLIC SUPPLIES

The quality of ground water in approximately one half of the basin is suitable for domestic uses; however, much of the water in the other half of the basin is undesirable because of low pH or high iron, hardness, nitrate, chloride, or sulfate content.

Comparison of the water-quality map and the hydrogeologic map shows that water quality is closely related to geology. For example, Hydrologic Unit 2, largely carbonate rocks, generally yields very hard water and is locally contaminated by nitrate, probably where surface water moves directly to the water table through solution cavities. Hydrologic Unit 7, predominantly shale, yields water generally containing excessive iron and hardness. In the broad major synclinical basins, wells tapping this unit may obtain water containing excessive chloride or sulfate, especially where the wells are more than 200 feet deep and located on valley flats. Hydrologic Unit 10, composed of sandstone, shale, and numerous beds of coal, yields ground water that is commonly acidic and may contain excessive iron and sulfate. Hydrologic Units 4, 5, and 6, predominantly limestone and sandstone, yield water that is of good quality but occasionally hard, especially where the water is derived from limestone.

The dissolved minerals in ground water vary with time as well as with geologic formation. Water samples collected monthly from observation wells indicate that the dissolved mineral content generally reaches a maximum in the fall and winter when ground-water recharge begins and reaches a minimum in the spring and summer as ground-water recharge diminishes.

Specific conductance (see table 1) is an indirect measurement of the dissolved mineral content. For most water in the basin, 0.6 times specific conductance in micromhos approximately equals the dissolved mineral content in milligrams per liter. For water high in sulfate, the dissolved mineral content is more nearly 0.9 times the specific conductance.

The ground water in the basin can generally be classified as calcium carbonate bicarbonate water. However, water from some of the shales, limestones, and coal-bearing rocks is more nearly a calcium sulfate type. At times water from parts of Unit 4 and from warm springs at Berkeley Springs approaches a sodium chloride type, as does water from deep gas wells. Most of the water from Unit 7 is of the calcium carbonate bicarbonate type; however, in places calcium sulfate, sodium chloride, and sodium carbonate bicarbonate types are also present.

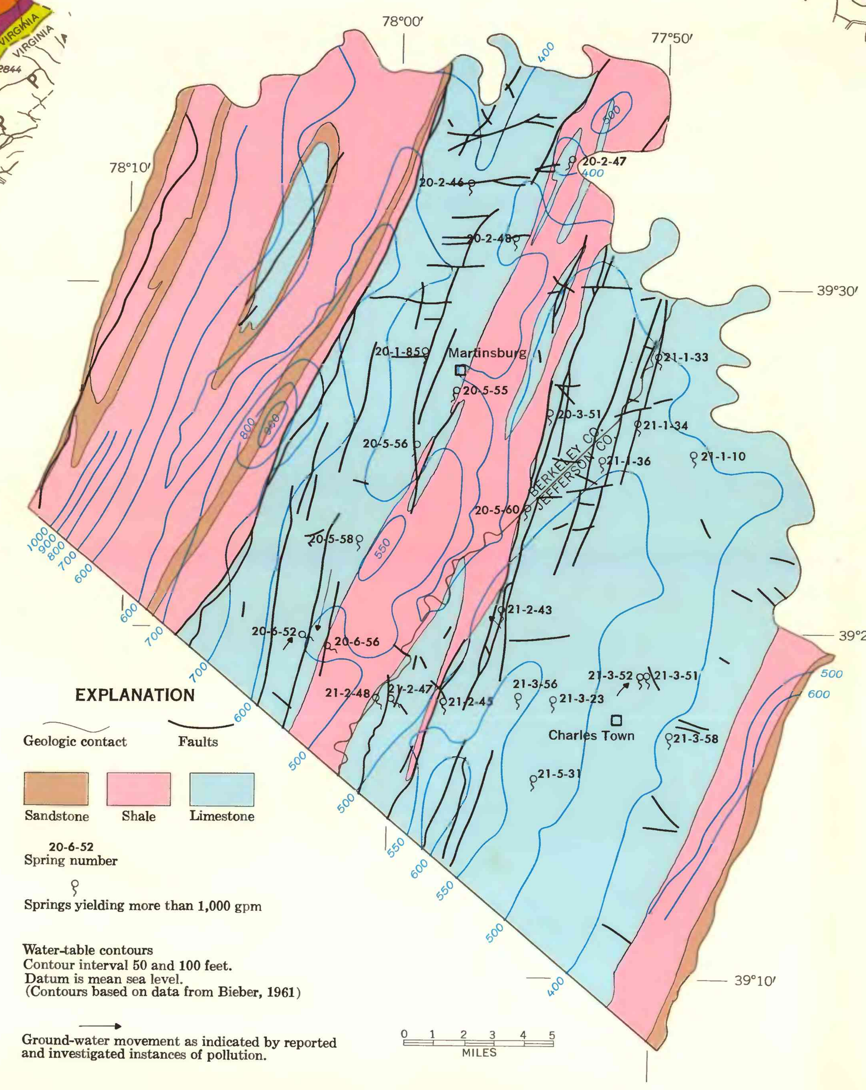
AVERAGE CHEMICAL CHARACTERISTICS OF GROUND WATER

(All data reported in milligrams per liter except pH.)

Hydrologic Unit	1	2	3	4	5	6	7	8	9[1]	10	11
Silica (SiO_2)	11	16		7.9	7.6	7.8	15	17	4.1	6.5	5.4
Iron (Fe)	.2	.4	3.4	2.3	.2	.1	1.5	.4[2]	.1	.5[2]	.4[2]
Calcium (Ca)	8.5	98		25	49	33	94	23	28	30	32
Magnesium (Mg)	4.5	21		9.2	8.1	4.1	126	12	2.2	7.4	4.4
Sodium (Na)		8.6		40	1.6	1.8	347	9.6	1.4	.8	5.0
Potassium (K)		4.4		1.4	1.4	1.3	2.5	.8	.6	1.8	2.1
Bicarbonate (HCO_3)	76	321	208	168	155	86	218	134	86	79	90
Sulfate (SO_4)	12	50	144	16	19	25	473	5.9	60	19	28
Chloride (Cl)	4.0	18	38	9.4	2.4	1.6	296	3.6	2.4	32	4.7
Nitrate (NO_3)	.5	20	7.9	.4	3.1	4.7	4.7	.4	3.2	1.0	4.0
Dissolved solids		445	325	210	168	134	1,030	172	100	148	131
Hardness as $CaCO_3$ (Ca, Mg)	61	328	226	93	160	78	558	102	78	106	99
pH	7.2	7.5	7.1	7.8	7.8	7.1	7.3	7.3	6.8	7.3	7.1

[1] Averages computed from data reported by Friel and others, 1967, p. 103.
[2] Average based on analysis made at sampling site.

The temperature of naturally occurring ground water in the basin is generally within a degree or two of the average annual air temperature. Ground-water temperature in the Allegheny Mountain section is about 9°C (48°F), whereas ground-water temperature throughout the rest of the basin is about 13°C (55°F). Exceptions are found at Berkeley Springs, where the temperature of water from warm springs ranges from about 19° to 23°C (66° to 73°F) and at the base of Ice Mountain where the temperature of water from a small spring is about 9°C (49°F).



EXPLANATION

Geologic contact — Faults

Sandstone — Shale — Limestone

20-4-33 Spring number

Springs yielding more than 1,000 gpm

Water-table contours
Contour interval 50 and 100 feet.
Datum is mean sea level.
(Contours based on data from Bieber, 1961)

Ground-water movement as indicated by reported and investigated instances of pollution.

C. WATER-TABLE CONTOURS, LARGE SPRINGS, AND FAULTS IN BERKELEY AND JEFFERSON COUNTIES

Ground water in the area moves downslope approximately perpendicular to the water-table contours to places of discharge at streams or springs. Twenty-five of the largest springs in the area are shown on the map. Of these, about two-thirds are on or near mapped faults. Apparently the faults are zones of increased permeability that act as drains collecting water along their length from tributary faults, fractures, sinkholes, and solution channels. Ground water entering the fault zone moves down gradient along the fault to the point of discharge at a spring. Many smaller springs not shown are also on faults.

INTRODUCTION

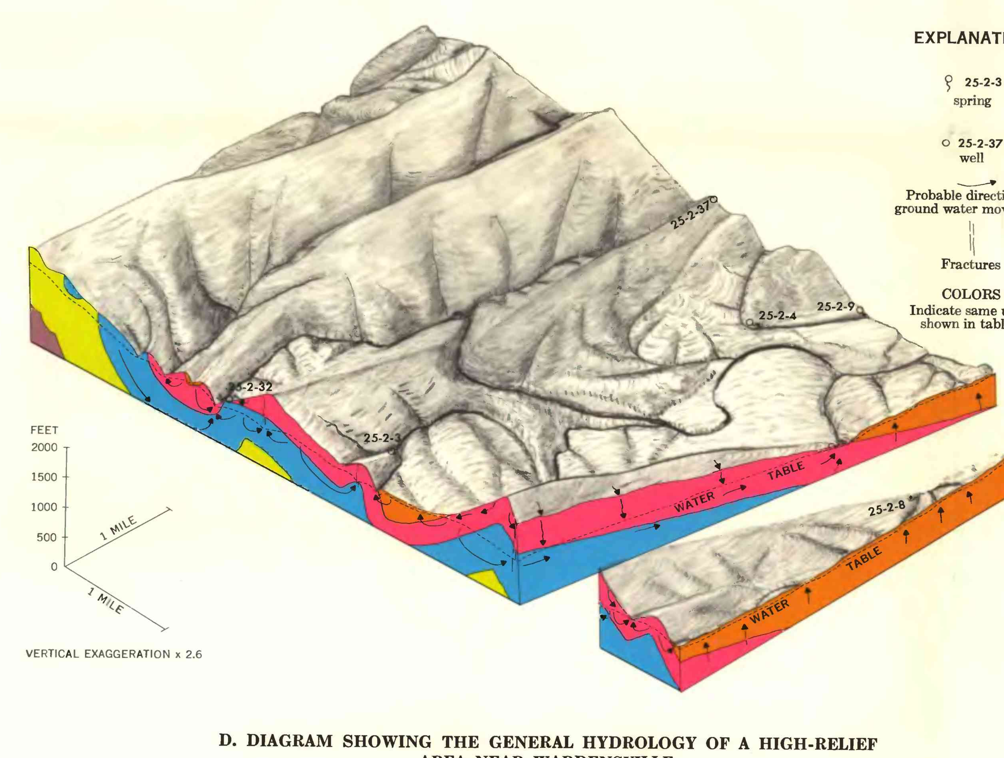
A part of the Potomac River basin lies in eastern West Virginia, where it includes the area commonly referred to as the "Eastern Panhandle." The central and eastern parts of the basin are underlain by folded and faulted rocks of the generally rugged Valley and Ridge province. The western part of the basin is underlain by relatively flat-lying rocks of the strongly dissected Appalachian Plateaus province. Altitude of the land surface increases from east to west and both the lowest (250 feet above mean sea level at Harpers Ferry) and the highest (4,860 feet above mean sea level at Spruce Knob near Circleville) altitudes in West Virginia are found in the basin. About 125,000 people live in the 3,464-square-mile basin of whom 50 percent live in Berkeley or Mineral Counties. The largest cities are Martinsburg, Keyser, and Charles Town. Other towns or villages in the basin have populations of less than 3,000.

Most municipalities and rural homes depend upon wells or springs as sources of water. Public and rural-domestic water systems throughout the basin require approximately 8 mgd (million gallons per day) of ground water, and industry requires approximately 5.5 mgd.

Precipitation is the principal source of all water in the basin. Average annual precipitation is about 38 inches but ranges from less than 32 inches in the central part of the basin to more than 55 inches in the western part. On the average, about 8 inches of this percolates to the water table and becomes ground water. The amount of infiltration and percolation varies from one site to another depending on topography and geology, among other factors. In an area underlain by impermeable shale and siltstone only a small percentage of precipitation becomes ground-water recharge, whereas in an area of equal size underlain by permeable fractured sandstone or cavernous limestone, a large percentage of the precipitation becomes ground-water recharge. Hydrologic Units 2, 5, 6, and 9 are considered the most permeable units in the study area. As such, they are more readily recharged and ground-water discharge to wells, springs, and streams is greater.

Scale 1:250,000

TRANSVERSE MERCATOR PROJECTION



EXPLANATION

25-2-3 spring

Probable direction of ground-water movement

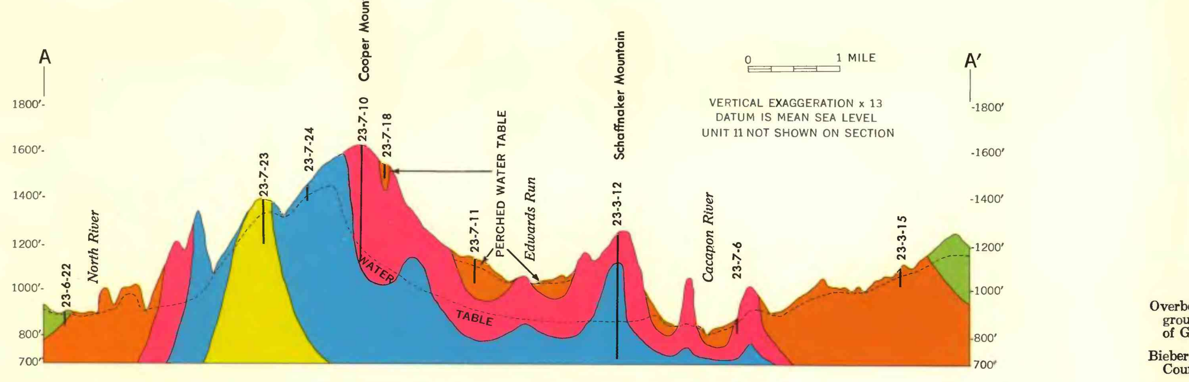
Fractures

COLORS
Indicate same units shown in table 1

VERTICAL EXAGGERATION x 2.6

D. DIAGRAM SHOWING THE GENERAL HYDROLOGY OF A HIGH-RELIEF AREA NEAR WARDENSVILLE

The block diagram shows the location of four large springs at or near the nose of plunging anticlines near Wardensville. The yield of the springs ranges from 70 gpm at spring 25-2-8, to 15,000 gpm at spring 25-2-3. Springs such as 25-2-9 are probably on fractures normal to the trend of the ridges. The probable location of the water table and the direction of ground-water movement are indicated on the diagram.



VERTICAL EXAGGERATION x 11
DATUM IS MEAN SEA LEVEL
UNIT 11 NOT SHOWN ON SECTION

E. EAST-WEST SECTION (A–A') THROUGH THE CENTRAL PART OF THE STUDY AREA SHOWING WELLS AND THE APPROXIMATE GEOLOGY, STRUCTURE, AND WATER TABLE

The rocks of the study area are folded into a series of northeast-trending anticlines and synclines. The ridges are underlain by the more resistant rocks, generally sandstone, and the valleys are underlain by the less resistant rocks, generally shale. The water table usually lies less than 100 feet below land surface except in some areas underlain by Hydrologic Units 5 and 6. These units characteristically underlie ridges in the basin. Because the sandstone is in places fractured and friable and the limestone is fractured and cavernous, both are more permeable than the shale units. Permeability is generally greatest along northeast-trending bedding planes, fractures, and faults. Thus, water moves northeastward or southwestward through these ridges to discharge at springs in gaps cut through the ridges or at the nose of anticlines where Units 5 and 6 plunge beneath the overlying shale. Perched water tables are common in small synclinal beds of shale overlying "dry" beds of Units 5 and 6. Perched water tables also overlie locally impermeable beds in Units 5 and 6.

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Charlottesville, Va.; W. Va. 1956
Baltimore, Md.; Va.; W. Va.; Pa. 1957

Hydrologic units based on 1968 geologic map of West Virginia compiled by Dudley H. Cardwell, Robert B. Erwin, and Herbert P. Woodward.

(Note: This summary is also PLATE 1 in the report, "Water Resources of the Potomac River Basin, West Virginia.")

GROUND-WATER HYDROLOGY OF THE POTOMAC RIVER BASIN, WEST VIRGINIA

By
W. A. Hobba, Jr., E. A. Friel, and J. L. Chisholm
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
WEST VIRGINIA GEOLOGICAL AND ECONOMIC SURVEY
AND THE WEST VIRGINIA DEPARTMENT OF NATURAL RESOURCES
1973

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