THE CULPEPER BASIN FOLIO

The Culpeper basin is a structural trough filled with sedimentary and igneous rocks of Mesozoic age that borders the eastern front of the Blue Ridge in northern Virginia. The basin extends from the Rapidan River near Madison Mills, Va., northeastward across the Potomac River and terminates just west of Frederick, Md.

This report is one of a series of earth science information maps being prepared as part of a study of the geologic and hydrologic resources of the Culpeper basin. The scale of the maps, 1:125,000 (1 inch = approximately 2 miles), permits only a regional overview or guide to evaluating hydrologic and geologic conditions that may influence certain types of land use. The maps are not intended for enlargement, nor are they, or any graphical or tabulated data included, intended to replace site investigations. Local details at a given site may differ from the general conditions portrayed on these maps and detailed studies are invariably required for site planning.

By combining the basic resource maps in a variety of ways, depending on the relevant limiting factors for any given land use, the user can derive a secondary series of maps that focus on specific problems. Potential uses of these maps and possible derivative products are discussed in the texts accompanying each map.

INTRODUCTION

The chemical quality of ground water affects its usefulness for public, industrial, and agricultural supplies. In addition, knowledge of the quality of available water can influence land-use decisions. Water for nearly every use requires a certain minimum quality, and some uses may require that the water be treated. The degree and type of treatment depend on the original quality and intended use of the water. Ground water is the source of supply for most privately owned water systems in the Culpeper basin. In addition, several municipal and industrial water requirements, such as those at Poolesville, Md., and Leesburg, the Manassas area, and Culpeper, Va., are met partly or entirely by ground water. The objectives of this report are to (1) summarize the chemical characteristics of ground water in the basin, (2) relate ground-water quality to geology and hydrology, and (3) briefly address the influence of ground water quality on land-use decisions.

A compilation of approximately 200 water-quality analyses provided the data base for this report; locations of data sites (wells and springs) are shown on the accompanying map. Some of the data were obtained from published reports and from files of the Virginia State Water Control Board (SWCB) and the U.S. Geological Survey (USGS). Additional wells were sampled where areal coverage was inadequate or specific rock types or depth ranges were not represented. The accompanying table was primarily compiled from recent samples. The cooperation of well owners and well drillers and the assistance of personnel of SWCB, Northern Regional Office, and of several county health agencies made possible the data collection needed to prepare this report. Inquiries about the data should be directed to the State Office Chief, Water Resources Division, USGS, Richmond, Va. 23220.

GEOHYDROLOGIC SETTING

The layered rocks in the Culpeper basin consist primarily of siltstone, sandstone, conglomerate, and interbedded basalt flows. These Triassic and Jurassic strata have been intruded by diabase dikes, sills, and stocks; these intrusions are surrounded by a belt of thermally metamorphosed rock (Leavy, Froelich, and Abram, 1982). A layer of weathered material from 0 to 50 feet, but commonly less than 15 feet thick, has accumulated near the land surface. This thin layer does not provide much ground-water storage capacity, nor does it act as an effective buffer between surface contaminants and the shallow underlying bedrock.

The sedimentary rocks have some porosity (void space), but neither they nor the intrusive and metamorphic rocks have any appreciable intergranular permeability. However, permeability (ability to transmit water) due to fractures, joints, and bedding-plane partings is significant, and wells that intersect these openings may be highly productive. The general reduction in the number and size of fractures and openings in the rock with increasing depth slows ground-water movement, increases residence time, and thus influences water quality. Surface connections through shallow fractures allow rapid movement of surface water into the ground.

WELL-COMPLETION METHOD AND DATA DISTRIBUTION

Virtually all water wells in the basin are completed as open holes. From 50 to 100 feet of casing (depending on local and State regulations) is seated and grouted into unweathered rock to prevent entry into the well of surface water and shallow ground water that may be contaminated. Thus, except for a few specially designed test wells, the chemical analyses on which the following discussion is based represent the "combined" quality of water from the entire section of rock penetrated by each well.

Most wells for which geologic information is available penetrate only one bedrock unit. Seventy-five percent of all data points for water quality used in this analysis are wells completed in siltstone, sandstone, or diabase, which collectively constitute 80 percent of the rocks in the basin. Only these rocks are highlighted in color on the accompanying map.

ANALYSIS AND INTERPRETATION OF DATA

GENERAL CHEMICAL CHARACTER

Ground water in the Culpeper basin is predominantly a calcium-magnesium bicarbonate type, but about 10 percent of the analyses indicate a calcium sulfate water. These latter samples are primarily from springs, deep (more than 500 feet) wells in siltstone, or wells within or adjacent to the diabase-thermally metamorphosed rock complex. The high concentrations of sulfate in water from these sources are accompanied by correspondingly high values of hardness and dissolved solids.

SELECTED CONSTITUENTS AND CHARACTERISTICS

The criteria for the chemical quality of water are commonly stated in terms of maximum allowed or recommended concentrations of specific constituents and have a wide range, depending on use of the water (U.S. Environmental Protection Agency, 1977a). Thus, detailed chemical analyses, such as those shown in the accompanying table, should be examined critically to determine if the water at a particular site is suitable for an intended use.

Dissolved solids

Dissolved-solids concentration is commonly used as an indicator of overall water quality. Excessive dissolved solids are objectionable in drinking water because of possible physiological effects, unpalatable mineral taste, as well as higher cost due to corrosion of pipes or the necessity for additional treatment. Five hundred mg/L (milligrams per liter) dissolved solids is the recommended maximum for drinking water recommended by the U.S. Environmental Protection Agency (1977b). Seventy percent of the ground-water samples included in this analysis have dissolved solids concentration less than 300 mg/L, and in 88 percent of the samples, dissolved-solids concentration is less than 500 mg/L. Generally, the highest dissolved-solids concentrations reported are from wells tapping the siltstone. Larson (1978) pointed out that in the Culpeper basin part of Fairfax County, dissolved solids concentration in water from siltstone commonly exceeds 500 mg/L, particularly in wells deeper than about 500 feet. Of the 200 analyses compiled for this study, 20 showed dissolved solids concentration greater than 500 mg/L. Sixteen of those 20 analyses were of samples from wells or springs in the siltstone. In sandstone, the other dominant rock type, 4 of 70 samples contain more than 500 mg/L dissolved solids, and only 1 of 18 samples from wells completed in diabase exceed that limit.

Hardness

Consumption of hard water has no known harmful effects on human health, and some investigators believe it to be a significant factor in reducing cardiovascular disease (Marier and others, 1979; Sauer, 1974; and Schroeder, 1966). However, values of hardness (expressed as the equivalent concentration of calcium carbonate) greater than 100 mg/L become increasingly inconvenient, causing waste of soap and encrustation of water fixtures and utensils. Applying the relative terms commonly used in describing hardness to the data on ground-water quality compiled for this study, 70 percent of the samples would be classified as either hard (121-180 mg/L as $CaCO_3$) or very hard (>180 mg/L as $CaCO_3$). Again, comparing the two dominant rock types: 73 percent of the samples from wells in siltstone are in the very hard range, whereas only 22 percent of the samples from sandstone wells are in that range. Solution of calcite cement in both siltstone and sandstone is probably the chief source of hardness in water from those rocks. A sample from one spring (No. 19S on the map and table of analyses) of the several that issue from limestone conglomerate north of Leesburg is hard (160 mg/L $CaCO_3$); water samples from 11 wells in the conglomerate range from moderately hard (61–120 mg/L $CaCO_3$) to very hard. Wells in diabase (Nos. 22–24) and thermally metamorphosed rocks (Nos. 25 and 26) yield predominantly very hard water.

Sulfate

Concentrations of sulfate greater than 250 mg/L may impart a foul taste to water and may act as a laxative to new users. Samples from 12 wells in siltstone contained dissolved sulfate concentrations that range from 280 to 2,500 mg/L. Point samples from different depths in a 1020-foot well (No. 3 on map and table) at Dulles Airport and sampling during drilling in western Fairfax County, Va., (No. 4) and near Poolesville, Md. (No. 2; see Otton, 1981) indicate that sulfate concentrations, as well as hardness and dissolved solids, increase abruptly at depths greater than about 500 feet in siltstone. (See water-quality diagram). Although the test drilling also showed that, at least locally, fractures are effective at depths greater than 500 feet, there may be a regional decrease in the number of interconnected fractures below that depth, which would result in sluggish ground-water circulation, longer residence time, and, consequently greater mineralization. However, the high sulfate values are probably due mainly to solution of gypsum ($CaSO_4 \cdot 2H_2O$) present in the rock. Horizontal seams of gypsum, from one-eighth to one-fourth inch thick and at intervals of one to 1.5 feet, were present at depths of about 475 feet and greater in core samples from a well drilled in siltstone near Manassas. Small, partly dissolved inclusions or blebs of gypsum were present in the core above 475 feet. Another source of sulfate in the ground water is pyrite (Hem, 1970, p. 162), which is concentrated in fine-grained (lacustrine?) zones within the siltstone.

The concentration of sulfate is high in some samples of water from other rock units in the Culpeper basin, but is not as pervasive as in the siltstone. Distinct zones of water of different quality may also be present in the fractured-rock aquifers. Four samples collected between 550 and 700 feet during drilling of a 1000-foot test well in sandstone (No. 13) contained very high sulfate concentrations (305 to 960 mg/L) compared to water above and below that depth interval (Leggette, Brashears and Graham, 1980, table 2).

A tendency for highly mineralized ground water to be localized at or near borders of the intrusive diabase and the adjacent thermally altered zone is indicated by analyses of samples from at least one well and from three springs. The sample from the 165-foot deep well (No. 26) contains 1400 mg/L sulfate and 2370 mg/L dissolved solids. Such highly mineralized water may result from preferential solution of hydrothermal minerals in the thermally metamorphosed zone between sedimentary rocks and diabase.

Two springs of historical interest, Sudley Spring (No. 5S) in the Manassas National Battlefield Park and the formerly commercially developed Berry Hill Spring (No. 9S) (Roberts, 1928, p. 136) south of Remington discharge highly mineralized calcium sulfate type water. The Berry Hill Spring was reported by Roberts to be a "sulphur and chalybeate (iron-salt flavored) water". Analysis of the sample taken in this study indicated an extremely high concentration of sulfate (1600 mg/L) but a relatively low iron content (0.3 mg/L). A second spring at the Manassas Battlefield Park (No. 6S) is also a calcium sulfate water, but is less highly mineralized than springs 5S and 9S.

Both the Berry Hill and Manassas Battlefield Park springs issue from siltstone, but their outlets are near the diabase-thermally metamorphosed rock-siltstone contact zone. This proximity to the intrusive body and the chemical character of the water indicate that the springs may be hydraulically connected to the contact zone and the chemically enriched water associated with it.

Iron

Iron in water in concentrations greater than 0.3 mg/L causes staining and discoloring of laundry and porcelain fixtures and may impart a bad taste. Analyses of ground water from the Culpeper basin show that iron is troublesome only locally. Most of the water sampled had concentrations of iron of 0.1 mg/L or less; the concentration of iron exceeds the recommended maximum of 0.3 mg/L (U.S. Environmental Protection Agency, 1977b) in only 10 samples (about 5 percent of all analyses).

Nitrate

Concentrations of nitrate greater than 10 mg/L (as N), the recommended maximum for drinking water (U.S. Environmental Protection Agency, 1977b) may be harmful or fatal to infants. The nitrate concentration in samples from 8 wells exceeded that recommendation. Rainwater and Thatcher (1960, p. 211) state that unpolluted water generally contains less than 10 mg/L (as N) of nitrogen compounds. Excessive nitrate concentrations in ground water are commonly attributable to contamination by domestic sewage, industrial waste, and agricultural sources such as fertilizers and effluent from feedlots, barnyards, and silos (Feth, 1966, p. 48). The specific sources of possible nitrate contamination indicated by the analyses mentioned above were not traced in this study.

Trace Metals

In addition to major inorganic constituents, samples from Berry Hill Spring (No. 9S) and from two wells were analyzed for a number of metals (arsenic, cadmium, chromium, copper, mercury, selenium, lead and zinc) that are present in trace amounts. Some of these metals are toxic to living organisms. For some metals, toxic effects may be apparent immediately if they are present in concentrations above certain limits. For others, the effect may be cumulative, and very small amounts may be ingested over a long period before toxic levels have accumulated in the body (Sauer, 1974). Trace concentrations of several of the metals were detected in the samples, but in water from only one well did any of the concentrations equal or exceed the recommended maximum levels for drinking water. The mercury content in a sample from a well at a seed cleaning plant was 2.0 micrograms per liter, which equals the recommended maximum level (U.S. Environmental Protection Agency, 1977b). Mercury contamination in this well may originate from a compound used as a seed preservative. Additional trace metal data for selected public water supply sources are available from the Virginia SWCB and the Virginia Department of Health.

WATER-QUALITY AND LAND-USE PLANNING

Two aspects of water quality are important to land-use planning. Present quality and the degree of treatment required affect the suitability of water for an intended use. The potential for change in quality might also influence the choice between land-use alternatives.

Most of the ground water (within a few hundred feet of the surface) in the Culpeper basin is suitable, with little or no treatment, for domestic, agricultural, and many industrial uses. Although water-quality conditions are generally consistent within each rock type throughout the basin, local variations can be expected. The water is commonly hard to very hard, which is somewhat detrimental to its overall quality, and concentrations of iron are troublesome locally. Deep wells in siltstone and several springs yield highly mineralized (greater than 1000 mg/L dissolved solids) calcium sulfate water.

The potential for change, particularly the degradation of water quality, is of vital concern to the land-use planner. The thin layer of weathered surficial material that overlies the fractured-rock aquifers provides only minimum protection of ground water from surface and shallow subsurface waste disposal. Contaminants can move rapidly along fractures to the ground-water body with little opportunity for attenuation. Decisions such as construction of individual domestic wells versus community supply, septic tanks versus central sewerage, and methods of disposal and (or) treatment of industrial and agricultural wastewater would necessarily be based on consideration of the potential for degradation of ground water.

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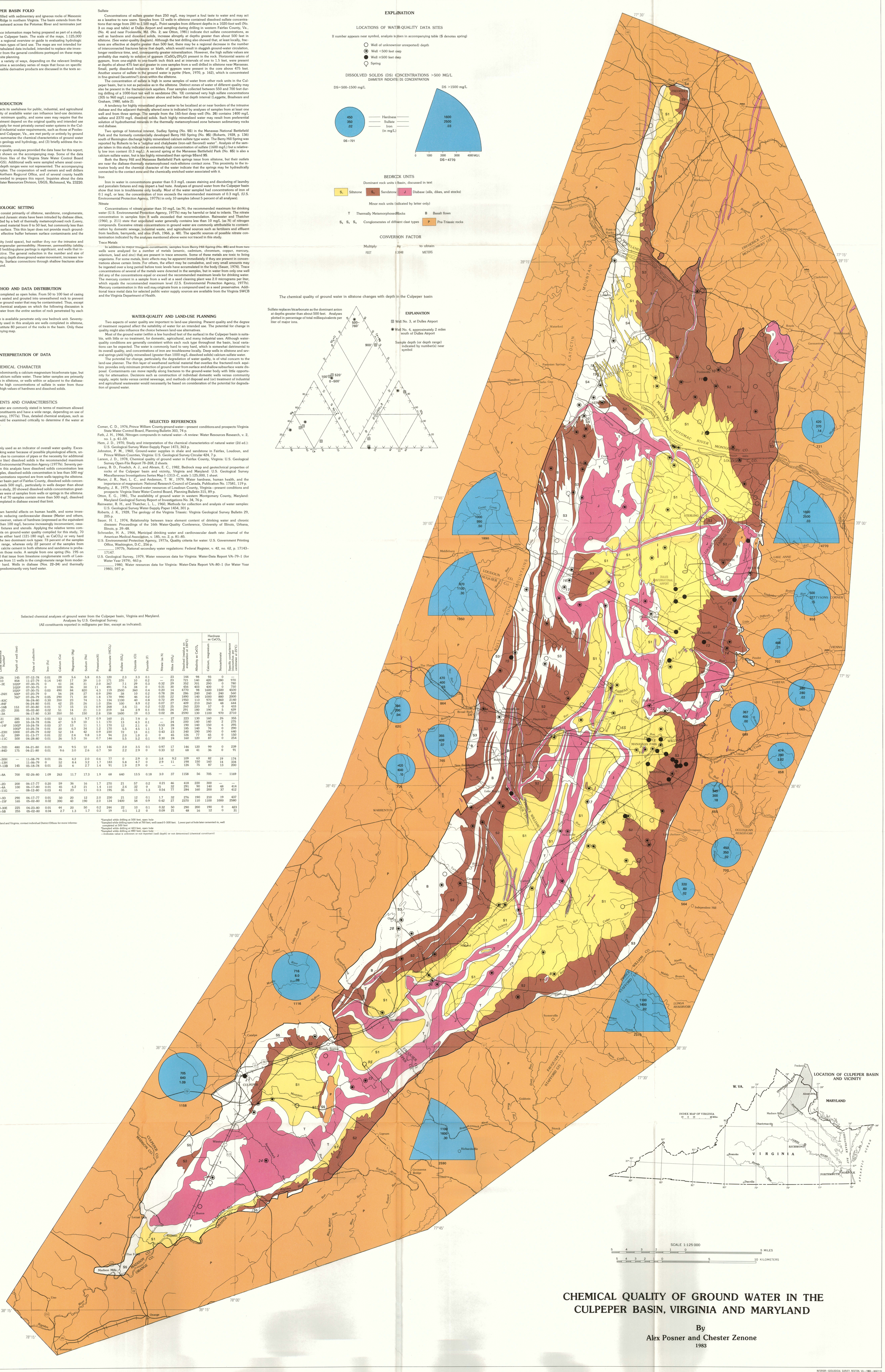
Selected chemical analyses of ground water from the Culpeper basin, Virginia and Maryland.
Analyses by U.S. Geological Survey.
(All constituents reported in milligrams per liter, except as indicated).

Bedrock unit	Map Number[1]	U.S.G.S. Local Reference Number[2]	Depth of well (feet)	Date of collection	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium(K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (as N)	Silica (SiO_2)	Dissolved residue on evaporation at 180°C)	Alkalinity as $CaCO_3$	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos per centimeter at 25°C)
SILTSTONE (S_1)	1	DB–26	145	07–12–78	0.01	28	5.6	5.8	0.5	120	2.3	3.3	0.1	—	23	144	98	93	0	—
	2	EC–10	858	11–27–79	0.14	140	17	39	1.0	171	370	10	0.2	—	23	721	140	420	280	970
	3	51V–3E	1020[a]	07–30–75	0	61	34	31	2.0	367	7.1	29	0.3	0.32	29	352	301	290	0	780
			1020[b]	07–30–75	0	100	36	30	11	491	7.6	34	0	0.31	30	456	403	400	0	750
			1020[c]	07–30–75	0.03	490	84	820	4.3	119	2500	360	0.4	0.20	14	4770	98	1600	1500	4500
	4	51V–24H	500[a]	07–20–79	0	56	24	27	0.9	290	38	10	0.2	0.78	28	286	240	240	240	560
			760[c]	07–26–79	0.05	290	71	30	1.8	170	990	46	0.2	0.05	22	1890	140	1000	880	2000
	5S	50U–83C		06–24–80	0.30	350	23	74	1.5	134	1100	40	0.8	0.72	29	1950	110	970	860	2140
	6S	50U–84F		06–24–80	0.01	62	25	26	1.0	256	100	8.9	0.2	0.07	27	409	210	260	48	644
	7	50T–16B	153	07–30–80	0.01	57	15	15	0.9	268	3.6	11	0.2	0.22	25	260	220	57	0	433
	8	50S–2D	205	05–02–80	0.02	51	14	21	1.0	219	54	2.9	0.1	0.05	24	291	180	190	5	439
	9S	48R–3A		06–17–80	0.30	350	55	150	2.8	158	1600	19	0.3	0.02	28	2590	130	1100	970	2710
SANDSTONE (S_2)	10	DC–31	285	10–18–78	0.03	53	6.1	9.7	0.9	160	21	7.9	0	—	27	223	130	160	26	355
	11	DB–47	600	10–18–78	0.06	47	5.9	10	1.1	170	13	4.3	0.1	—	24	200	140	140	2	275
	12	51V–14F	1002[a]	10–24–78	0.03	37	13	11	1.1	170	12	2.1	0	0.53	28	190	140	150	6	295
			1002[c]	10–25–78	0.01	20	6.3	34	1.2	170	5.5	4.5	1.1	1.3	19	185	140	76	0	290
	13	51V–23H	1000	07–09–79	0.02	52	14	42	0.9	230	72	13	0.1	0.43	23	340	190	190	0	640
	14	51V–5J	289	01–13–77	0.01	22	2.4	9.8	1.0	94	2.0	1.0	0	0	45	126	77	65	0	150
	15	49U–11C	500	04–28–80	0.01	26	5.3	16	0.7	146	5.5	5.2	0.1	0.30	24	160	120	87	0	254
CONGLOMERATE Schist and quartz clasts (S_2)	16	50V–70D	480	04–21–80	0.01	24	9.5	12	0.3	146	2.0	3.5	0.1	0.97	17	146	120	99	0	239
	17	50V–84D	175	04–21–80	0.01	9.6	3.0	2.6	0.7	50	2.2	2.9	0	0.33	12	68	41	36	0	91
CONGLOMERATE Limestone clasts (S_2)	18	50X–30H	—	11–08–79	0.01	26	4.2	2.0	0.6	77	0	2.9	0	3.8	9.2	109	63	82	19	174
	19S	50X–13H		11–06–79	0	52	8.4	3.2	1.7	183	5.8	4.7	0	2.9	11	198	150	160	14	334
	20	50W–13B	145	05–18–78	0.01	25	6	2.7	1.4	91	1.9	2.9	0	—	—	126	75	87	13	200
CONGLOMERATE Greenstone clasts (S_2)	21	47R–8A	700	02–26–80	1.09	263	11.7	17.3	1.9	68	640	13.5	0.18	3.0	37	1158	56	705	—	1169
DIABASE (J)	22	51U–2D	200	06–17–77	0.20	59	36	16	1.7	270	21	57	0.2	0.21	46	418	220	300	—	—
	23	48R–4A	100	06–17–80	0.01	45	6.2	21	1.4	110	2.6	32	0	15	32	291	90	140	48	414
	24	47R–11G	—	08–12–80	0.03	41	23	11	0.3	195	35	15	1.3	0.54	77	284	160	200	37	412
THERMALLY METAMORPHOSED ROCKS (T)	25	51U–3D	290	04–17–77	0.01	50	20	12	2.0	230	21	12	0.1	1.7	32	276	190	210	19	437
	26	48S–15F	165	05–02–80	0.02	390	40	190	2.0	134	1400	58	0.9	0.42	27	2370	110	1100	1000	2580
BASALT (B)	27	49U–30E	225	04–23–80	0.01	44	20	50	0.2	244	22	10	0.1	0.32	50	290	200	190	0	423
	28	48S–5B	255	05–02–80	0.04	2.7	1.3	1.7	0.2	19	0.1	1.2	0	0.09	21	48	16	12	0	31

[1]S—designates spring.
[2]Different numbering system used in Maryland and Virginia; contact individual District Offices for more information.
[a]Point sample from 100-foot depth
[b]Point sample from 520-foot depth
[c]Point sample from 900-foot depth

[a]Sampled while drilling at 500 feet, open hole
[b]Sampled while drilling open hole at 760 feet, well cased 0–500 feet. Lower part of hole later cemented-in, well completed at 500 feet
[c]Sampled while drilling at 423 feet, open hole
[d]Sampled while drilling at 880 feet, open hole
—Indicates value is unknown or not reported (well depth) or not determined (chemical constituent)



CHEMICAL QUALITY OF GROUND WATER IN THE CULPEPER BASIN, VIRGINIA AND MARYLAND

By
Alex Posner and Chester Zenone
1983

Base from U.S. Geological Survey 1:250,000
Baltimore, Charlottesville, and Washington
Lithology by Leavy, Froelich, and Abram (1982)

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