Ground Water in the Piedmont Upland of Central Maryland

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2077

Prepared in cooperation with the U.S. Environmental Protection Agency

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By CLAIRE A. RICHARDSON

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FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM (SI) UNITS

[Factors for converting inch-pound units to international system (metric) units are shown to four significant figures.]

Multiply inch-pound unit	*By*	*To obtain SI units*
foot (ft)	0.3048	meter (m)
gallon (gal)	3.785	liter (L)
gallon per day (gal/d)	3.785	liter per day (L/d)
gallon per minute (gal/min)	.06309	liter per second (L/s)
gallon per minute per foot (gal/min)/ft	.207	liter per second per meter ((L/s)/m)
inch (in.)	25.4	millimeter (mm)
million gallons (Mgal)	3785	cubic meters (m^3/d)
million gallons per day (Mgal/d)	3785	cubic meters per day (m^3/d)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)

GROUND WATER IN THE PIEDMONT UPLAND OF CENTRAL MARYLAND

By CLAIRE A. RICHARDSON

ABSTRACT

This report, describing ground-water occurrence in a 130-square-mile area of the central Maryland Piedmont, was originally designed for use by the U.S. Environmental Protection Agency in replying to a request for designation of the aquifers to be the sole or principal source of ground water. However, the information contained in the report is pertinent to other crystalline-rock areas as well.

The study area is underlain chiefly by crystalline rocks and partly by unaltered sandstones and siltstones.

The ground water is derived from local precipitation and generally occurs under water-table conditions. Its movement is restricted by the lack of interconnected openings, and most ground water occurs within 300 feet of the land surface. Hydrographs indicate no long-term change in ground-water storage.

A few wells yield more than 100 gallons per minute, but about 70 percent of 286 inventoried wells yield 10 gallons per minute or less; most specific capacities are less than 1.0 gallon per minute per foot.

The ground-water quality is generally satisfactory without treatment, and there are no known widespread pollution problems.

Estimated daily figures on ground-water use are as follows: 780,000 gallons for domestic purposes; 55,000, for commercial purposes; and 160,000, for public supply. Although part of the area is served by an existing surface-water supply and could be served by possible extension of it and of other public-supply water mains, much of the rural population is dependent on the ground water available from private wells tapping the single aquifer that underlies any given location. Neither the ground-water conditions nor this dependence on individual wells is unique to the study area, but, rather, applies to the entire Piedmont province.

INTRODUCTION

PURPOSE OF THE INVESTIGATION

The purpose of this study is to describe the geohydrologic system in a specified area of the central Maryland Piedmont. The report was originally designed for use by the U.S. Environmental Protection Agency in replying to a petitioner who had requested that the aquifers of the area be designated as the sole or principal source of ground water, as defined under Section 1424(e) of the Safe Drinking Water Act. However, the information assembled for this report can be applied to other crystalline-rock areas beyond the bounds of the study area itself.

SCOPE OF THE INVESTIGATION

The report includes a geographic and geologic description of the area; information on the occurrence and availability of ground water; a summary definition of the term "aquifer" as it applies to the study area; and chapters on the quality of the ground water, on ground-water use, and on alternative water supplies.

In covering these topics, it was necessary to consider the nature, source, and estimated quantities of water recharging and discharging from the aquifer; the nature of ground-water movement and the ranges in transmissivity and storage; water-level fluctuations; factors that affect well yield; general chemical character of the ground water and possible sources of pollution; and estimates of present and projected water use in the specified area.

The project was not set up as a field study: The descriptions and conclusions are based chiefly on information that was already in the files of the Geological Survey's Maryland offices. However, as no field studies had been done in the area since 1963, a limited well inventory was done. Also, it was necessary to update other information, particularly that on population, climate, and water use.

LOCATION AND DESCRIPTION OF THE STUDY AREA

THE GEOGRAPHIC SETTING

The study area lies in the central part of Maryland and consists of approximately 130 mi^2 in parts of four counties (fig. 1). By far the largest part of the area is in northwestern Montgomery County; the remainder consists of smaller sections of Frederick, Carroll, and Howard Counties. The study area also comprises parts or all of seven drainage basins (fig. 1). Table 1 gives the approximate size of each basin.

TABLE 1.—*Areas, in square miles, of the drainage basins in the study area*

[Numbers preceding basin name refer to map locations (fig. 1)]

Name of basin	Approximate area	Percent of total area
1. Seneca Creek	37	28
2. Little Monocacy River	17	13
3. Little Bennett Creek	24	18
4. Bennett Creek	20	15
5. Fahrney Branch	8	6
6. Patuxent River	16	12
7. Patapsco River	10	7
Total	132	[1]99

[1]Partial figures do not add to 100 percent because of rounding.

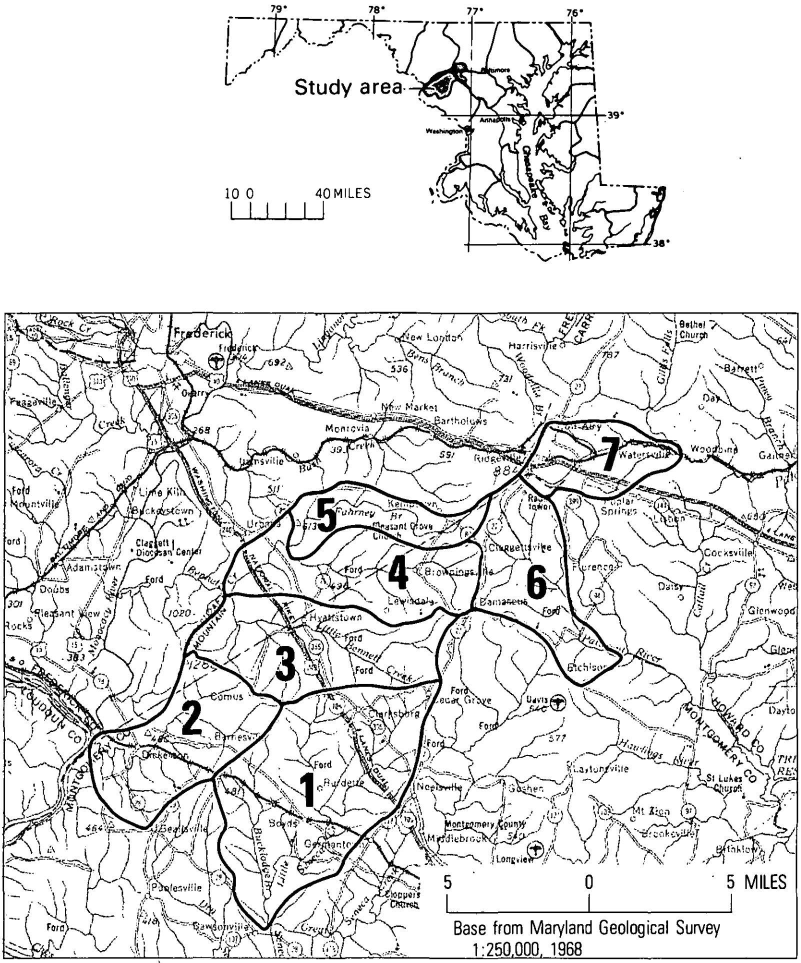

FIGURE 1.–Location of the study area and of drainage-basin boundaries. (Numbers refer to basins listed in table 1.)

PHYSIOGRAPHY AND TOPOGRAPHY

The entire study area lies in the Piedmont province, which extends from southern New York near the mouth of the Hudson River southward to Alabama. In Maryland, as elsewhere, the Piedmont is a rolling upland cut by many streams and small tributaries. The study area is the headwaters for a number of streams, such as the Monocacy, Patuxent, and South Branch of the Patapsco, that become major rivers of the State in their lower courses; within the study area, however, these streams are modest in size.

In places, the slopes of some valley walls are fairly steep, but in most of the area, hilltops are rounded and some valley floors are quite level.

The only true "mountain" – a monadnock named Sugar Loaf, whose summit is 1,282 ft above sea level – is in southeastern Frederick County. Hilltops are generally about 400 ft in altitude in the southern part of the area and about 700–800 ft in the northern part. As might be expected, the lowest altitudes are also in the southern part, where 250–300-ft levels occur in the valley of Seneca Creek.

CLIMATE

The climate is moderate and rather humid. Although there are several long-term weather stations in Montgomery County, norms and departures from normal are not published for these stations. However, records from the station at Unionville in eastern Frederick County, 7 mi north-northwest of Mount Airy, may be used to show monthly variations in precipitation and temperature (U.S. Department of Commerce, 1941–77). The average precipitation at Unionville is 39.0 inches per year, the greatest quantity in May through August and the least in January and February. The graphs in figure 2 show the range in precipitation over the last four full years of record and the monthly averages for this station. Since the record began in July 1940, the monthly values have ranged from 0.14 in. in December 1955 to 16.26 in. in June 1972 (a result of Hurricane Agnes). The yearly totals have ranged from 29.5 in. in 1941 to 57.5 in. in 1942. Computations based on about 40 interrupted years of record for the Boyds station in the southern part of the study area indicate an estimated average annual precipitation of 38.79 in., a figure that agrees very well with that for Unionville. However, Schwiesow and others (1970, p. 24) indicated that the average annual precipitation for the north-central areas of Maryland, including Montgomery, Howard, Carroll, and Frederick Counties, was 42 in. during 1929–68, and Dingman and Meyer (1954, p. 38) used a figure of 43.5 in. based on measurements at Takoma Park and Germantown during 1933-49. The differences are probably related to the periods of record.

The average annual temperature at Unionville is 52° F (degrees Fahrenheit) (about 11° C (degrees Celsius)), the coldest months being the period December through February and the warmest July and August. The average monthly temperatures generally range from 31° F (–0.6° C) to 74° F (23.3° C). Computations are not available for the Boyds station in Montgomery County, but the temperature there is commonly 2 to 3 degrees warmer than at Unionville: the average annual temperature is 54° F (12.2° C).

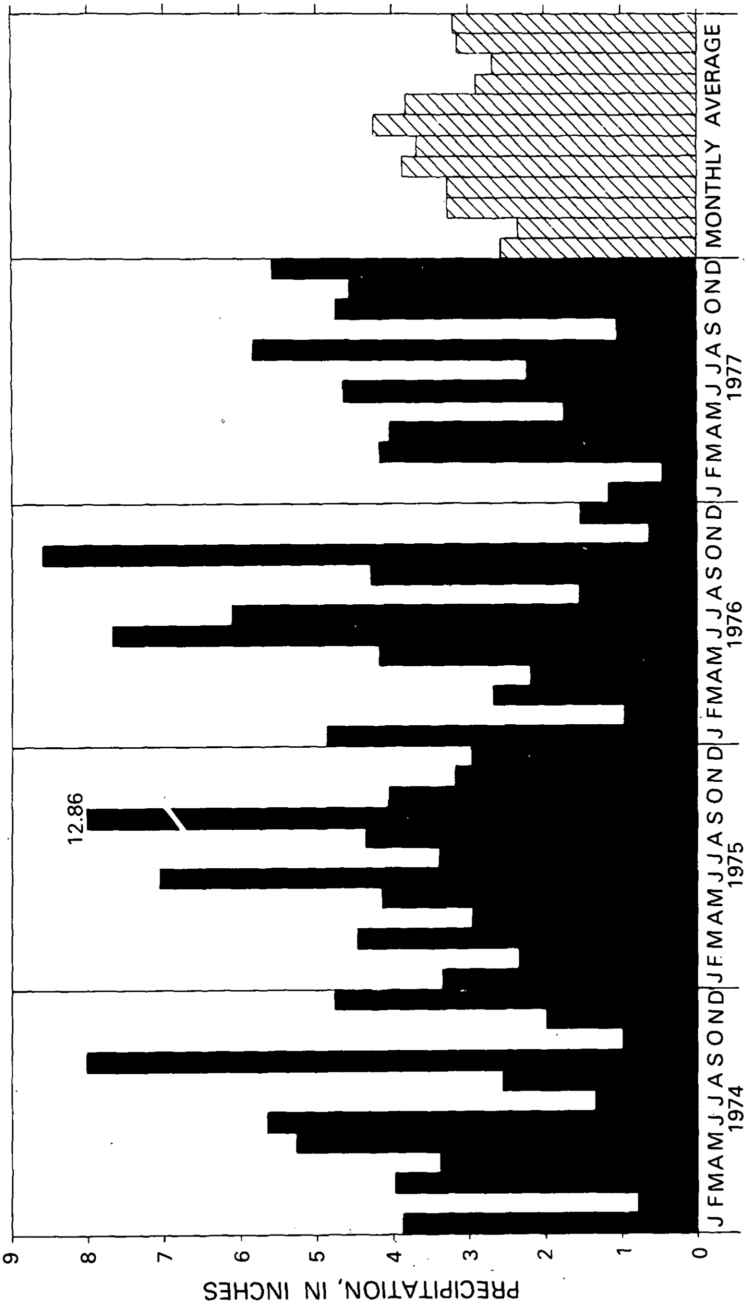

FIGURE 2.—Precipitation for 1974–77 and monthly norms, Unionville, Frederick County.

GEOLOGY OF THE AREA

Almost all the rocks are closely folded metamorphosed sedimentary rocks of late Precambrian or early Paleozoic age. These rocks were originally mud and sand and have been subsequently altered to phyllite, schist, and quartzite. The exact thickness of the individual units is not known, but Hopson (1964, p. 128) stated that the complete section of stratified crystalline rocks, as represented in Howard and Montgomery Counties, forms a "sequence on the order of 25,000 feet thick." Associated with these rocks are minor occurrences of mafic volcanic rocks, chiefly metabasalt.

Overlying the metamorphic rocks in the southwestern part of the area are more than 2,200 ft of younger and unmetamorphosed red and gray sandstones and siltstones of Triassic age. These sedimentary rocks generally dip from 5 to 10 degrees westward but locally dip as much as 20 degrees. Intrusive into these rocks are Triassic diabase dikes and sills, represented in the study area by a dike a mile west of Dickerson that runs north-south for about 3 mi and by a 3-mi^2 sill immediately south and west of Boyds.

The overburden, that is, the soil, saprolite, and alluvium that overlies bedrock, is generally between 20 and 40 ft thick. However, outcrops, drillers' logs, and lengths of well casings indicate that in many places rock is at or less than 20 ft from the land surface. On the other hand, well-casing lengths of 100–125 ft indicate that some uncommonly thick sections of overburden do occur.

According to Froelich's (1975a) map showing the thickness of overburden, only two areas where the overburden is fairly uniform in thickness are as large as several square miles. Both of these areas are in the southwestern part of the study area, both are underlain chiefly, but not entirely, by Triassic sedimentary rocks, and in both areas rock is reported to be generally within 20 ft of the land surface.

Belts of thinner and thicker overburden trend north-northeast, conforming to the regional geologic structure. Overburden is generally thinner in the valleys than on hilltops.

The long Piedmont history of deposition, orogeny, metamorphism, and erosion has resulted in an extremely complex geology whose stratigraphy and structure are not completely understood. Furthermore, the stress and strain to which the rock materials have been subjected have resulted in the formation of joints, fractures, and faults, the extent of which is not thoroughly known. However, the major structures in the area are known to trend northeast-southwest.

To appreciate this complex geology, one has only to compare the geologic maps that pertain to the area, no two of which agree. The latest Montgomery County map was done by Cloos and Cooke in 1953. The terminology and identification of geologic formations agree only in part with the map of adjacent Frederick County published in 1938 (Jonas and Stose). The authors of the Maryland State geologic map of 1968 (Cleaves and others), faced with somehow resolving the differences on a single map, also had to deal with more recent work by other geologists. Figure 3 shows their attempt to reconcile these problems. Table 2 lists the formations that occur in the study area and gives a brief description of each.

In the maps for Montgomery County, Froelich did not include a geologic map as such. He did make a bedrock map (Froelich, 1975b), which shows only rock types or lithology and is more useful for a ground-water study than is a map showing the formations, almost all of which include more than one rock type. Unfortunately, there are no corresponding maps for the adjacent counties, but Froelich's map was used for this project, as most of the study area is in Montgomery County. For the other counties, a combination of drillers' logs and the State geologic map was used to determine rock type.

Issue might be taken with Froelich's map where the Harpers Phyllite of Cloos' map and the Urbana Phyllite of the State map seem to be interpreted as predominantly quartzite, but including some phyllite; a

TABLE 2.–*Geologic units in the study area*

Age	Geologic unit and lithology[1]
Triassic	DIABASE SILLS AND DIKES Sills: greenish gray to black, medium grained; dikes: greenish gray to black, medium to fine grained; local contact metamorphic aureoles. NEW OXFORD FORMATION Red, maroon, and gray sandstone, siltstone, and shale.
Late Precambrian and early Paleozoic	URBANA PHYLLITE Dark gray to green sericite-chlorite phyllite, metasiltstone, and quartzite; thin lenses of impure marble and calcareous phyllite occur locally. SUGARLOAF MOUNTAIN QUARTZITE Massive white quartzite interbedded with softer sericitic quartzite, slate, and phyllite. SAMS CREEK FORMATION Grayish-green, massive to schistose, amygdaloidal metabasalt IJAMSVILLE PHYLLITE (includes Marburg Schist of former usage, Blue, green, or purple phyllite and phyllite slate, with interbedded metasiltstone and metagraywacke; flattened pumiceous blebs occur locally; also includes bluish-gray to silvery green, fine-grained, muscovite-chlorite-albite-quartz schist that has been intensely cleaved and closely folded; contains interbedded quartzite. WISSAHICKON FORMATION (undivided) Muscovite-chlorite-albite schist, muscovite-chlorite schist, chloritoid schist, and quartzite; intensely folded and cleaved.

[1]Modified from the Geologic Map of Maryland (Cleaves and others, 1968).

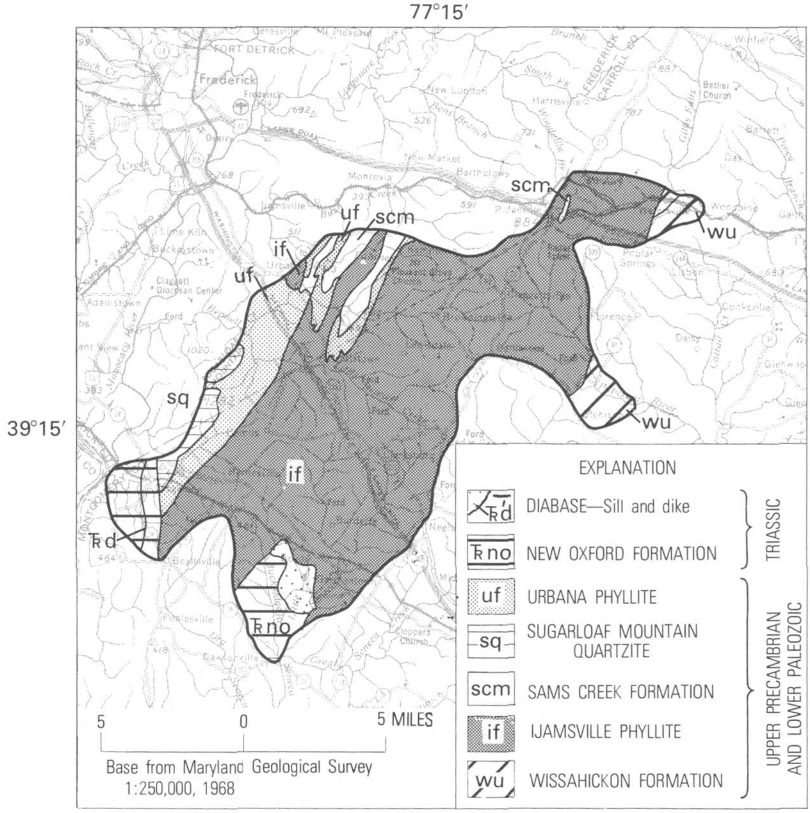

FIGURE 3.—Geology of the study area. (Geology modified from Cleaves and others, 1968).

more correct interpretation might be the reverse. Where there was a conflict in analyzing well data by rock type, the driller's log was used, rather than Froelich's map.

Froelich's rock types and their corresponding geologic units are given as follows:

Phyllite	Urbana Phyllite. Ijamsville Phyllite.
Schist	Wissahickon Formation.
Quartzite with schist	Sugarloaf Mountain Quartzite.
Mafic volcanic rocks	Sams Creek Formation.
Diabase	Triassic sills and dikes.
Sandstone and siltstone	New Oxford Formation.

THE OCCURRENCE OF GROUND WATER

SOURCE AND DISTRIBUTION OF THE WATER

Ground water is that fraction of the precipitation on the land surface that has worked its way downward by gravity through the soil and into the underlying saprolite and bedrock.

The source of ground water in the study area is precipitation on the area. As the area boundaries are drainage divides and as little if any ground water crosses the divides, the amount of water entering the area from outside the boundaries may be considered almost zero.

Precipitation is part of the hydrologic cycle. The distribution of precipitation in the local hydrologic cycle can be explained by the equation for the hydrologic budget:

$$P = E + R + \Delta S,$$

where

P = precipitation,
E = evapotranspiration,
R = total runoff, or streamflow, and
ΔS = change in ground-water storage.

PRECIPITATION

Statistical data on the amount and distribution of the precipitation in the study area are given in the section on climate, the average annual figure being 39.0 in. per year.

EVAPOTRANSPIRATION

Although a large percentage of the precipitation in a given area is evapotranspired, this fraction of the hydrologic budget is more difficult to measure than is either precipitation itself or the total runoff. It is, therefore, usually computed as a residual, by subtracting the total runoff (as streamflow) from the precipitation.

By using precipitation data for Takoma Park and Germantown in Montgomery County and streamflow data for Rock Creek in Washington, D.C., Dingman and Meyer (1954, p. 38) estimated that of a total 43.5 in. of precipitation per year, 30.9 in., or 71 percent, was evapotranspired. A similar analysis for a stream in the Baltimore and Harford Counties area (Dingman and Ferguson, 1956, p. 47–52) resulted in a somewhat different value: 25.5 in., or 60 percent. The discrepancy has been ascribed to differences in topography and stream gradient.

RUNOFF

Some precipitation runs off almost immediately to streams, but some percolates downward through the soil into the underlying rock to remain for a time before being discharged to streams as seeps and springs. The flow of a stream is the sum of both surface-water runoff and ground-water runoff. Although the total runoff can be measured fairly easily, it is somewhat more difficult to separate out the ground-water runoff. It can be assumed to be the flow of the streams in dry periods, when there is little or no precipitation and therefore no surface-water component.

According to Dingman and Meyer (1954, p. 39), the total runoff at the Rock Creek gage in Washington, D.C., is 29 percent of the average annual precipitation, or 12.6 in. Some quantitative data on ground-water runoff for the study area are given in the section on ground-water discharge.

CHANGE IN GROUND-WATER STORAGE

Ultimately, the input to and output from the rocks are essentially equal over a long period of time, and thus one element in the hydrologic-budget equation, ΔS, remains unchanged over long periods of time.

GROUND-WATER CONDITIONS

Unconfined ground water in contact with the atmosphere is said to occur under water-table conditions. The water level in a water-table well fluctuates in response to precipitation, to the demands of vegetation, and to pumping. Most of the ground water in the study area occurs under water-table conditions.

In places where ground water is confined under pressure between two impermeable zones, artesian conditions exist, and the water in an artesian well rises up in the bore above the top of the water-bearing formation. If the pressure is sufficiently great and (or) the land surface sufficiently low relative to the intake area, the water rises above the land surface, and the well is then a flowing artesian well. Under certain conditions, flowing wells may end in aquifers confined only locally by impervious subsoil.

As a few flowing wells are known to occur in crystalline-rock areas, there may be some in the project area. However, no examples were noted in this study.

Water in crystalline rock occurs in the pore spaces between the individual grains of the weathered rock material (saprolite) and (or) in the cracks and fractures of the unweathered hard rock. Figure 4 shows how water may occur in crystalline rock under water-table conditions.

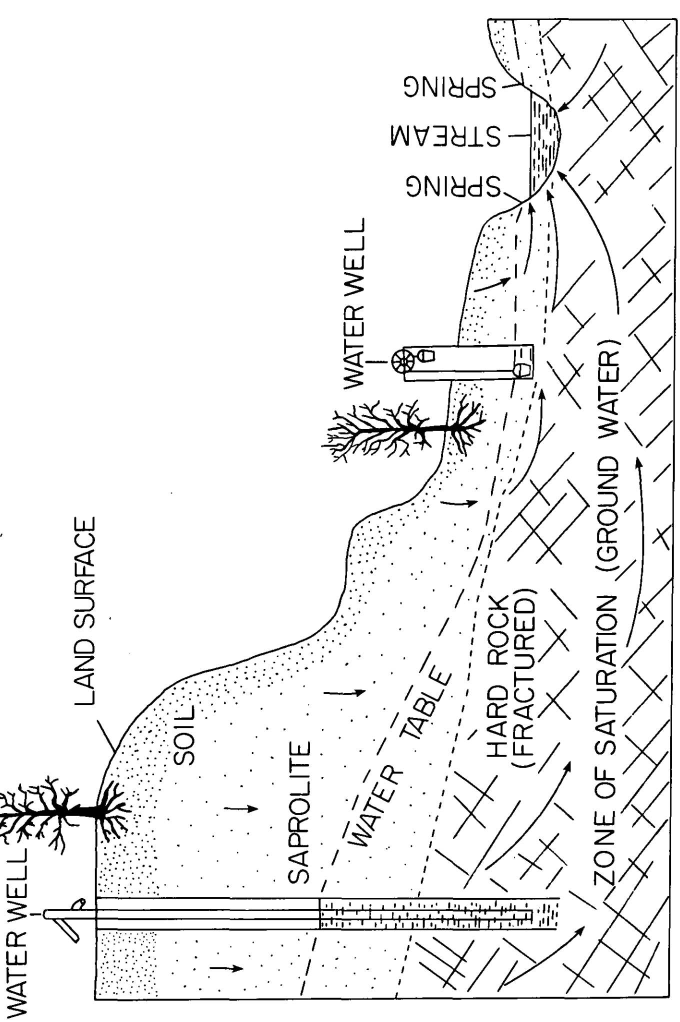

FIGURE 4.—Occurrence of ground water under water-table conditions in crystalline rock. (Adapted from Johnston and Otton, 1963, fig. 2.)

In the case of the Triassic sedimentary rocks, the primary porosity has been destroyed by compaction and cementation following deposition. However, as the sedimentary rocks have also been subjected to weathering and to the earth movements that have fractured the hard rock, ground water occurs under conditions somewhat similar to those in the older crystalline rocks. In addition, ground water also occurs along the bedding-plane partings of the sedimentary rocks, sometimes under artesian conditions.

GROUND-WATER RECHARGE

Ground-water recharge occurs when precipitation infiltrates into the aquifers. Its measurement is derived indirectly from streamflow records by analyzing streamflow hydrographs for periods of dry weather when the streamflow is derived entirely from ground water. As ground-water discharge over a long period of time equals ground-water recharge, the recharge rate may thus be determined approximately.

Based on the stream hydrograph for the Rock Creek gage in Washington, D.C., Dingman and Meyer (1954, p. 39) estimated the ground-water runoff (or effective recharge) to be 20 percent of the average precipitation of 43.5 in. per year, or about 8.5 in. This quantity is 67 percent of the total runoff. Through use of a method suggested by Ferris and others (1962, p. 132), the effective recharge in the Bennett Creek basin above Park Mills in Frederick County just outside the study area is estimated to be 11 in. On the basis of work done for a report in preparation, E. G. Otton (oral commun., 1979) determined that the effective ground-water recharge amounted to 10–11 in. in the basin of the South Branch of the Patapsco River in southern Carroll County.

Table 3 summarizes the results of several studies to determine effective ground-water recharge in areas that are near the study area and where the basins are underlain by similar rocks.

GROUND-WATER MOVEMENT

POROSITY AND PERMEABILITY

Among the important properties of rocks that relate directly to the occurrence and movement of ground water are porosity and permeability. **Porosity** is the percentage of open space in a given rock and is therefore related to the amount of water that can be stored there. **Permeability** is concerned with the interconnection between the open spaces in a given material and, hence, with that material's ability to transmit water from place to place.

TABLE 3.—*Summary of estimates of effective ground-water recharge in the Maryland Piedmont*

Drainage basin	Period of record	Annual precipitation (inches)	Area of drainage basin (mi²)	Effective ground-water recharge: Amount (inches)	Effective ground-water recharge: Percent of precipitation	Reference
Rock Creek	1933–49	43.5	62	8.5	20	Dingman and Meyer, 1954.
Little Gunpowder Falls	1927–49	42.6	36	11.3	27	Dingman and Ferguson, 1956.
Bennett Creek	[1]1976	42	62.8	11	27	Otton, E. G., 1979 (report in preparation).
South Branch of the Patapsco River	([2])	43	----	10	23	Do.
Do	([2])	43	----	11	25	Do.
Median values, all basins	----	43	----	11	25	

[1]Analysis based on flow data for 1976 water year.

[2]Method is based on use of water levels in wells and not on streamflow data (Ferris and others, 1962, p. 131).

In general, the crystalline rocks in the study area have very low porosities, as the major openings are cracks and fractures, some of which may have been slightly enlarged by solution. Because most of these openings are very small and are interconnected over only limited distances, permeability and **transmissivity**, which is the rate at which water moves through a certain section of an aquifer under a given gradient, are generally low. This situation tends to limit, for example, the effects of recharge, the movement of pollutants, and the effects of pumping wells. Nevertheless, substantial quantities of water can move through such rocks because of the total volume of rock involved.

Above the water table, ground water generally moves vertically downward. In the saturated zone, that is, below the water table, it moves laterally to natural discharge points in stream valleys. (See fig. 4.)

Although ground water can move underground for many miles, its movement in crystalline rocks, such as those in the study area, is restricted by the lack of a well-integrated network of large and interconnected openings. Studies in this and other areas of the Maryland Piedmont indicate that the zone of ground-water circulation occurs chiefly in the upper 300 ft of a saprolite and (or) bedrock section (Nutter, 1977, p. 22) and that individual water-bearing fractures probably do not extend laterally much more than a few hundred feet.

RATE OF MOVEMENT

Ground-water flow rates are difficult to measure accurately except where tracers can be used in relatively short-term or localized tests. Although some of the larger well yields might suggest that ground water can move rapidly through the rock materials, such is not the case. The movement of ground water is normally very slow, and rates usually measured are in feet per day or feet per year.

DIRECTION OF GROUND-WATER FLOW

The movement of water in fractured rock is related to the configuration of the land surface and thus to surface drainage. Under the conditions found in the study area, the ground water is generally moving downward under the influence of gravity and then laterally toward points of discharge in stream valleys, where it issues as springs and seeps. Seldom does it flow counter to topographic gradients. As pumping can divert ground-water flow and thus interrupt or alter the natural flow path in a given area, it would not be impossible for a pumped well in one basin to intersect water from an adjoining basin if a fracture zone extended beyond the basin boundaries. However, given the common ground-water conditions in crystalline rock and the limited degree of interconnection between fractures, the possibility of such an occurrence is very slight. Furthermore, in the study area pumpage is probably too low and too scattered to affect the hydrologic budget. As the several basins of the area drain in different directions, there is no one preferred direction of ground-water flow, except as described here.

GROUND-WATER DISCHARGE

GROUND-WATER RUNOFF

It is easy to understand the concept of direct surface runoff by observing the drainage into streams immediately after a heavy rainstorm or when snow melts in the spring. The contribution of ground water to the total runoff is more difficult to see and to measure. However, a reasonable estimate of ground-water runoff, or base flow, may be made by measuring the discharge of a stream and observing the flow rate during periods of very little or no precipitation. As mentioned on p. 12, Dingman and Meyer (1954, p. 39) estimated the average annual ground-water runoff to be 8.5 in., or about 20 percent of the average annual precipitation. If that same percentage is applied and the previously cited figure of 39 in. is used for the annual precipitation, then the ground-water runoff from the study area amounts to an average of 48 Mgal/d. (If the figure of 11 in., cited on page 12, is used, then this runoff figure would be considerably greater.) In any case, this fraction of the total flow of a stream is what keeps the stream flowing in periods of drought, when there is no direct surface runoff from precipitation. It is the theoretical maximum amount of water that could be pumped from a specific drainage basin on a long-term basis, assuming that all the pumped water is removed from the basin and not returned to the ground after its use.

The ground-water contribution to total runoff occurs chiefly as seeps and springs at valley heads and along stream banks. Although some springs issue from rocks as well-defined streams, most do not, and the observer sees only a small pool or collecting basin from which water discharges as a trickle or tiny stream.

In the limited time available for fieldwork in this study, it was not possible to inventory individual springs to measure discharge rates. However, a number of springs were visited, and one local resident (D. R. Maxey, oral commun., Aug. 1978) knows of at least eight farms whose sole supply is water from their own springs; a number of houses are known to be supplied by springs. Some springs are apparently reliable even in times of severe drought; others no doubt go dry in dry weather.

Probably the best known perennial spring in the study area is Parrs Spring, the ultimate source of the South Branch of the Patapsco River. It is located at the point where the boundaries of Carroll, Frederick, Howard, and Montgomery Counties meet. As the spring itself is now under the waters of a pond, it is no longer possible to see the exact source of the water or to measure its discharge.

Despite reports to the contrary, it is unlikely that any spring has an unvarying supply throughout the year. The discharge of several springs in phyllite and other crystalline rocks in Frederick County has ranged from a few to as much as 50 gal/min. The water from a spring in Brunswick, Frederick County, issues from a 4-in. pipe that has been driven into the hillside just above a small stream. The discharge of this spring has been measured at intervals since 1960. During this time, the flow has ranged from 1 to 36 gal/min, the largest flows occurring in the late spring and the smallest in late fall.

PUMPAGE

In addition to natural discharge, ground water is also discharged from pumped wells. Information on ground-water use in the study area may be found in a later section of this report.

WATER-LEVEL FLUCTUATIONS

Under the water-table conditions that generally prevail in the study area, the water level in a well represents the top of the saturated zone, which is in contact with the atmosphere. As mentioned earlier, the water table fluctuates in response to precipitation, evapotranspiration, and ground-water pumping. Water-level changes indicate periods when recharge is in excess of, or is less than, discharge: A rise in the water table occurs when recharge exceeds discharge, and a decline occurs when the reverse is true.

Regular periodic measurements of the depth to the water table in wells selected for the purpose of monitoring fluctuations show a natural cycle during the year. The water table is highest in the spring, when late winter and early spring rains have recharged the aquifers and vegetation has not yet begun to make its greatest demand on the rainfall. The water table generally declines through the summer even though it is the period of greatest precipitation, as it is also the time when evapotranspiration is greatest. Thus, the water table is commonly at its lowest in the fall or early winter, at the end of the growing season. Occasionally, when there is an exceptional storm in the summer, enough precipitation penetrates to the water table to reverse the seasonal downward trend.

In the study area, there are two observation wells in which periodic water-level measurements are made. One is a 58-ft drilled well (Mont–Be 1) near Damascus, Montgomery County. Its record began in 1949. Since that time, the water level has fluctuated over a range of about 32 ft, from a record high of 17.47 ft below land surface in April 1958 to a record low of 49.90 ft in October 1977. Figure 5 shows the last 10 years of record for this well.

The other observation well is a 46-ft dug well (Mont–Cc 14) in Barnesville, Montgomery County. Its record began in 1952. Since that time, the water level has fluctuated over a range of about 22 ft, from a record high of 23.62 ft below land surface in April 1958 to several occasions when the well has gone dry, notably during the drought of the 1960's.

Both wells are in upland areas, and therefore their water levels fluctuate over a wider range than would those of wells in valleys. Their trends are generally parallel, which is to be expected of wells in similar aquifers, similar topographic position, and areas of similar precipitation, as these wells are.

Such records indicate not only the short-term fluctuations but also the long-term trends that may exist in an area. The long records of the two observation wells in the study area and those elsewhere in the Maryland Piedmont seem to indicate no long-term rise or decline in the water table and thus no long-term change in ground-water storage.

AVAILABILITY OF GROUND WATER

WELL YIELDS

About 70 percent of 286 wells for which yield figures are available have yields of 10 gal/min or less. Only very few wells are reported to reliably yield 100 gal/min or more; three wells in or near Mount Airy have been known to yield as much as 200-300 gal/min on tests, although the sustained yields are reported to be somewhat less.

Most of the available information on well yields is obtained when the drillers test the wells at the completion of construction. The discharge is measured by noting the time it takes to fill a container of known volume. The tests usually last for 1 to 3 hours, but wells drilled for public-supply use or commercial use may be tested for 12 to 24 hours.

On some tests a well is pumped until it fails, whereupon pumping is discontinued and the rising water level is measured during at least part of the recovery. For a more useful test, the declining water level is measured at regular intervals while the well is being pumped at a constant rate, so that a curve can be plotted on a time-drawdown graph. It is desirable to also have one or more nonpumping wells nearby in which water-level measurements can be made throughout the test.

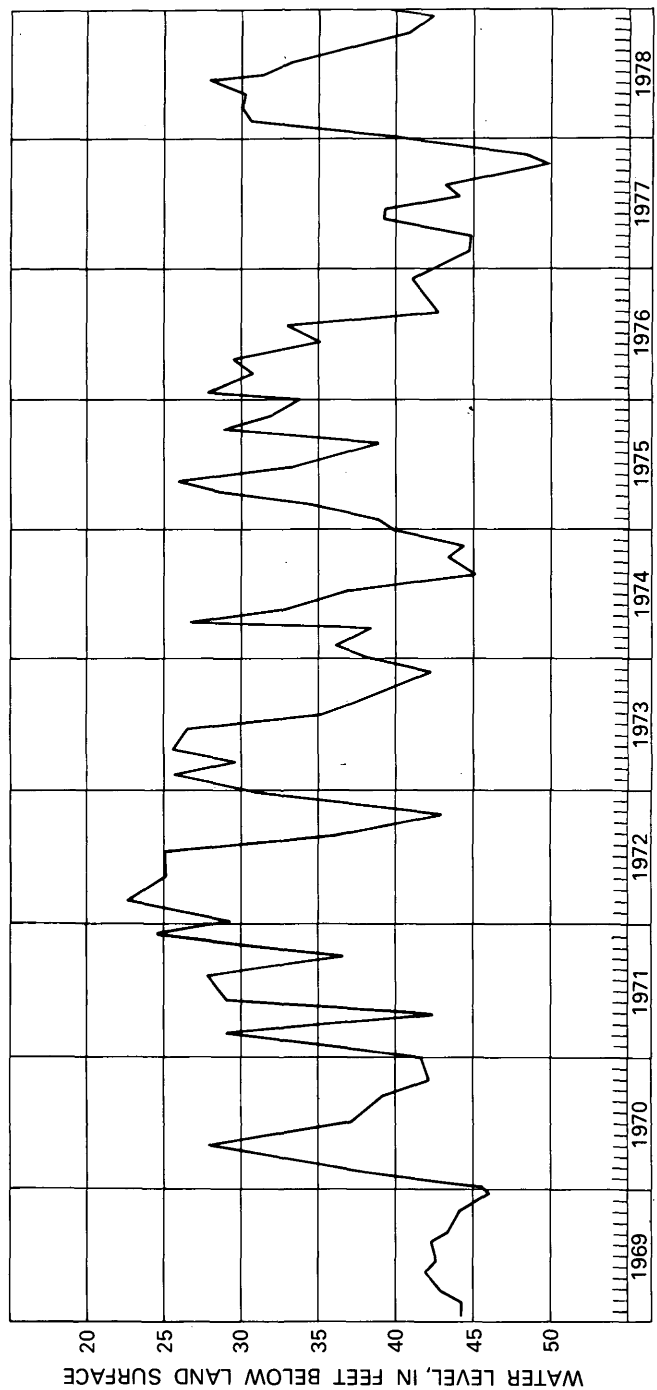

FIGURE 5.—Fluctuation of water level in observation well Mont-Be 1, 1969–78.

An aquifer test provides a means of determining quantitatively not only the yield of an individual well but also information on various hydrologic properties of the aquifer. It also permits the computation of **specific capacity**, which is the rate of discharge of water divided by the drawdown or decline of the water level, a useful figure in determining aquifer efficiency, as it takes into consideration both yield and the effect of pumping a given quantity of water. Obviously, a higher specific capacity indicates a smaller decline in water level for a given yield.

Specific capacities in most rock wells are very low, commonly less than 2.0 (gal/min)/ft of drawdown. The specific capacities for wells in the study area generally range from 0.1 to 1.0. A few wells have specific capacities from 1.0 to 5.0, and two public-supply wells have values of 10.0. The median value for 159 wells ending in the phyllite is 0.13; for 16 wells ending in the Triassic sedimentary rocks, it is 0.18. Insufficient data are available to compare values for all of the different rock types in the study area. However, analysis of specific-capacity data from other crystalline-rock areas of Maryland demonstrates the relationship between yield and several other parameters, such as rock type and topography (Nutter and Otton, 1969, p. 21–26; Nutter, 1977, p. 8–13).

No aquifer tests were run during the present study. However, such tests have been run in other areas in rocks similar to those of the study area. Table 4 gives selected aquifer-test data for crystalline-rock wells in Carroll, Frederick, Montgomery, and Washington Counties. The transmissivities in all cases are low compared with those in more productive aquifers and indicate that only limited quantities of water can be obtained. Estimates of transmissivity values for some other crystalline-rock areas in Maryland are even lower than those shown in the table (Trainer and Watkins, 1975, p. 22–23). However, in a stream valley or at the intersection of fracture traces, larger transmissivities may occur and greater well yields may be available, at least for a time. This is the case, for instance, at well Fr–Eh 1 in the original well field in the town of Mount Airy (table 4).

FACTORS AFFECTING WELL YIELD

LITHOLOGY

Given adequate recharge, that is, precipitation, the occurrence of ground water in a given area is controlled chiefly by such geologic factors as rock type; the trend of the structural features and fractures, joints, and faults; the thickness of the saprolite; and the topography. All of these factors are interrelated, and it is difficult to sort out the part that each plays in the available yield at any one place.

TABLE 4.—*Aquifer-test data for selected crystalline-rock wells*

Rock type	Well No.	Length of test (hrs)	Yield (gal/min)	Drawdown (ft)	Transmissivity[1] (ft^2/d)	Storage coefficient
Phyllite	Fr–Eh 1 (Mount Airy)	48	223	15	976	0.02
Do	Fr–Eh 10 (Mount Airy)	65	236	26	672	.0048
Do	Mont–Cd 48 (Clarksburg)	36	100	----	71	----
Schist	Car–Ec 75 (Nr. Woodbine)	6	15	----	12	----
Do	Mont–De 1 (Gaithersburg)	----	8	----	[2]414	----
Do	Mont–Cf 19 (Laytonsville)	22	150	54	307	----
Do	do	113	53	15	361	.17
Mafic rocks (metabasalt)	Wa–Al 5 (Highfield)	40	----	----	[3]414	[3].003
Do	Wa–Al 9 (Cascade)	7	53	----	428	----
Sandstone and siltstone (Triassic)	Mont–Dc 31 (Poolesville)	6?	100	----	230	----

[1]Transmissivity is the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

[2]Early stage of test only.

[3]Average.

Experience in this and other areas indicates that some rock units are more productive than others and that phyllite is one of the less productive (Dingman and Meyer, 1954, p. 25; Meyer, 1958, p. 89–91).

Table 5 shows the relationship between rock type and yield of 286 wells in or immediately adjacent to the project area. Unfortunately, a comparison of yields is not entirely valid because of the well distribution: An estimated 73 percent of the study area is underlain by phyllite and similar rocks, and in areas underlain by some rock types, there are too few wells for reliable statistical analysis. Nevertheless, when sorted by yield groups (0–5 gal/min, 6–25 gal/min, and >25 gal/min), 47 percent of the phyllite wells are in the 0–5-gal/min group, and only 8 percent are in the >25-gal/min group. In most other rock types, the larger fraction is in the 6–25-gal/min group. Brief examination of many other records for wells in the study area, but not actually inventoried in the field, further verified the frequency of low yields. Although data collected for this report substantiate the conclusions of earlier workers regarding the yield of phyllite wells, it does appear that wells yielding 15 gal/min or more are more numerous than previously realized.

TABLE 5.—*Yield of wells, in gallons per minute, by rock type*

Rock type	Yield		
	Range	Median	Number of wells
Quartzite	2.5- 50	20	7
Sandstone and siltstone	3 -100	15	21
Schist	5 - 50	7	5
Phyllite	0 -150	6	247
Mafic rocks (metabasalt)	3.5- 6	5	5
Diabase	----	2	1
Total	----	--	286

NATURE OF THE SAPROLITE

The rocks of the study area are covered almost everywhere by a mantle of soil and saprolite developed in place by weathering of the underlying rock material. The saprolite thickness varies greatly, ranging from zero where rock actually crops out to tens of feet, or, in a few places, more than 100 ft. It is generally thickest on hilltops and thinnest in valleys (Dingman and Meyer, 1954, p. 30–33; Meyer, 1958, p. 45–56). In the study area, it generally ranges from 20 to 40 ft in thickness and in Triassic rocks may seldom exceed 50 ft.

The thickness of the weathered zone can be determined by drillers' logs and sometimes by the length of the well casings, as casing is usually seated on hard rock. However, a recent Montgomery County requirement of a minimum of 40 ft of casing has altered the value of the drillers' reported casing lengths for that county.

The permeability of saprolite also varies greatly. If very clayey, it may act more as an insulating "blanket" over the rock, preventing ground-water recharge, than as a ground-water source in itself. If, on the other hand, it is porous and permeable, it may hold the largest part of the ground-water supply in a given area, especially if the underlying rock has few, if any, water-bearing fractures. Both of these conditions occur in the study area, but for this report, no study was made of a possible relation between saprolite thickness and yields of wells.

It should be noted that where the larger part of the available water supply comes from the overburden, driving the well casing down into hard rock may result in a well whose yield is totally inadequate for its intended use because the only available supply is thus cut off or drastically reduced.

STRUCTURAL GEOLOGY; FRACTURES AND JOINTS

In an area underlain by hard rock, the regional structure and the fracture pattern can control the development of the drainage pattern and also the topography. This may well be the case where tributary streams seem to have a preferred compass orientation at consistent angles to a main structure trend.

All hard rocks have been broken to some degree by earth movements. The resulting faults, joints, and fractures play an important part in the occurrence of ground water, for they permit the entry of water into the rocks where the subsequent weathering and enlargement of the openings lead to increased "storage space" and circulation of ground water. In turn, this can lead to above-average yields for wells drilled where a fracture occurs or where two fracture zones intersect. On the other hand, fault gouge that has weathered to a clayey material may retard ground-water movement in some places (Nutter and Otton, 1969, p.17).

Aerial photographs can be useful in showing some of the linear features associated with these fracture zones. The features may be revealed by straight stream stretches, linear alignment of ridges, and tonal differences in soil and vegetation. However, the interpretation of such lineations is subject to the judgment and experience of the viewer, and observation of some of these features on topographic maps may be more reliable than dependence on aerial photographs alone. Furthermore, it does not necessarily follow that all straight lines drawn between wells having above-average yields necessarily coincide with fracture traces.

The trend of the main structural features is northeast and southwest. This is borne out by what seems to be a broad southwest extension of the ridge running through Mount Airy that current geologic study may prove to be an anticline (W. P. Crowley, oral commun., 1978); by the strike and cleavage orientation, as shown on the Montgomery County geologic map (Cloos and Cooke, 1953); by a preferred stream orientation; and by the orientation of the fault separating the phyllite from the Triassic sedimentary rocks in the Bucklodge area. In addition, Froelich (1975b) shows two faults running northeast from Bucklodge that extend across the phyllite area; there may be others as well. Figure 6 shows the most conspicuous straight stream stretches and the two fault traces as plotted by Froelich on his lithologic map (1975b). It will be observed that a number of these are oriented approximately N. 30-35° E., and there appear to be several sets that are oriented at various degrees to the west of north.

So few inventoried wells in the study area seem to be located on these linear features that it is difficult to make a detailed analysis of their relation to well yield. Reliable demonstration of the concept that higher yields are obtained from wells located on linear features would

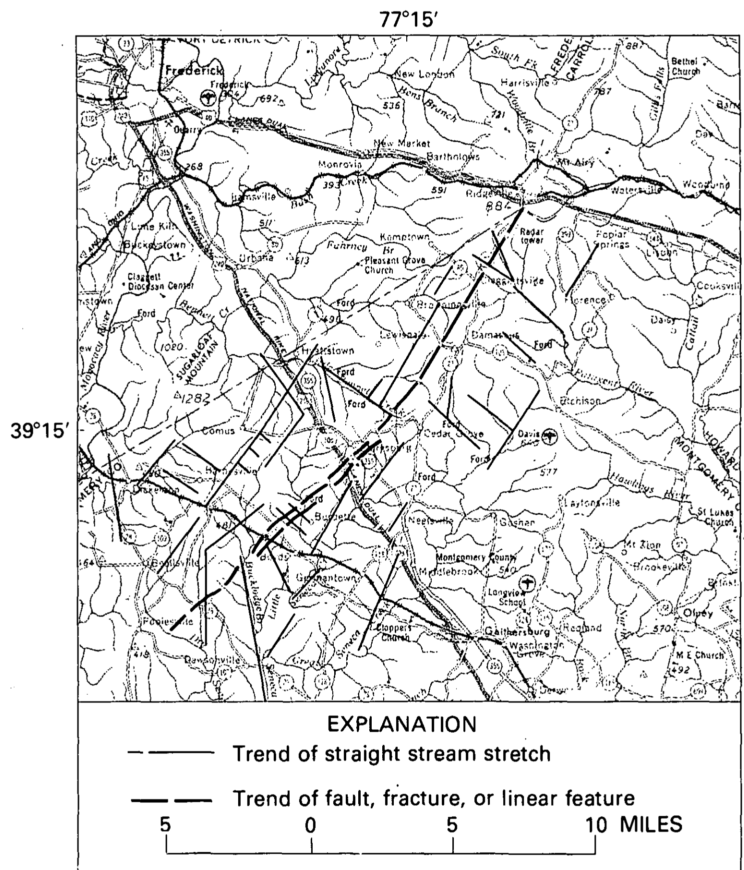

FIGURE 6.—Trend of straight stream stretches, and major faults, fractures, or linear features.

necessitate the actual drilling of test wells at selected sites that might seem favorable. However, it is probable that a well near Clarksburg that produced 100 gal/min was situated on a fracture trace. A well owned by the town of Mount Airy and located near the junction of Woodville Branch and a small unnamed branch of that stream yielded about 300 gal/min. One well in a small tributary valley of Little Bennett Creek near Thurston, Frederick County, reportedly yielded 50 gal/min from fractures at depths of 130 to 170 ft. Nutter and Otton (1969, p. 16–21), Johnston (1966, p. 30–31), and other authors document the above-average yields that can be obtained from wells in fault and fracture zones. Yet the old Damascus town wells, located in a valley near the headwaters of Magruder Branch, produced no more than 20 gal/min, indicating that mere location in a valley does not necessarily insure a large ground-water supply.

TOPOGRAPHY

Ground-water studies in various crystalline-rock areas indicate that wells in valleys and draws are generally more productive than wells on hilltops (Dingman and Meyer, 1954, p. 29–30; Dingman and Ferguson, 1956, p. 37; Meyer, 1958, p. 42-45; Nutter, 1977, p. 17–19). Nutter and Otton (1969, p. 21–22) did a somewhat more detailed analysis of well data for crystalline rocks and arrived at the same conclusion, as did Nutter (1975, p. 11–12) working in the Triassic-rock area of Maryland. In a study of Triassic rocks in Lancaster County, Pa., Johnston (1966, p. 30) noted "no well-defined relationship" between topography and well yield; however, he also stated that "the few high-yielding wells are near streams." Evidently the differences in well yields with respect to topography are not so pronounced in that area as in some others.

The reasons for larger well yields may not be the same in all valleys, but they are probably related to (1) the presence of joints and faults in stream valleys that permit better circulation of water, thus encouraging rock weathering; (2) greater available drawdown owing to shallow water levels (land surface is closer to the top of the saturated zone); and (3) the fact that ground water flows downhill toward the streams as a result of higher hydraulic head in the uplands.

On the basis of data only for wells on or near hilltops and in stream valleys, it is apparent that topography exerts a strong influence on well yields in the study area, just as it does in other crystalline-rock areas. The yields of 69 wells on hilltops range from 0.2 to 106 gal/min; the median value is 4 gal/min. The yields of 17 wells in valleys range from 2 to 50 gal/min; the median value is 15 gal/min.

WELL DEPTH

Contrary to a popular belief, it is not true that if a well is drilled deep enough, there will be an adequate supply of water. Obviously, a well must be drilled at least to the water table, or there will be no water in the hole. A well should also be drilled deep enough to allow for the fluctuation of the water table through wet and dry seasons. Furthermore, drilling a deep well does increase the available drawdown and provides for storage of water in the well bore. However, if additional water-bearing zones are not encountered, the sustained yield of a deep well will not be any greater than that of a shallower well.

Much of the ground water in the Piedmont is within 300 ft of the land surface; at greater depths, the size and number of open fractures and the degree of weathering decrease, so the chances of encountering additional water become much less. Well depths in the study area are about the same as those in other Piedmont areas of Maryland. Some wells are drilled to 500 ft or more, but usually this is done in the hope of augmenting the inadequate supply found higher up in the hole.

These comments do not always seem to apply to the unaltered Triassic sedimentary rocks. In these rocks, deeper water-bearing zones are more common than are those in crystalline rocks. In one Montgomery County well, the water-bearing zone is at 635 ft (Nutter, 1975, p. 14). Three wells at Dulles Airport in Chantilly, Va., about 15 mi south of the project area, range in depth from 860 to 1,030 ft and yielded 327 to 1,000 gal/min when drilled (Johnston, 1964).

Wells in the study area were sorted by depth group, rock type, and topographic position. When sorted by depth group (0–50, 51–150, 151–250, and >250 ft), 7 percent fall in the shallowest group, 68 percent in the 51–150-ft group, and about 12 percent in each of the deeper groups.

Well depths vary somewhat with rock type, or lithologic unit, and for some rock types, the percentage of wells in the 51–150-ft group is even greater than 68. The wells ending in the metasedimentary and unaltered sedimentary rocks are generally deeper than those ending in rocks of igneous origin (metabasalt and diabase), probably because experience has shown that these latter types are too hard and unfractured to warrant deeper drilling. Table 6 shows the median depth value and the depth range for each rock type for 354 wells located in or immediately adjacent to the study area.

The water table follows the land-surface contours in a smoothed-out curve that is deeper below hilltops than below valleys, and there is thus a relationship between well depth and topography. The depths of 78 wells located at hilltops in the study area range from 38 to 402 ft; the median value is 124. The depths of 21 wells located in valleys range from 41 to 443 ft; the median value for these wells in only 88. From

TABLE 6.—*Depth of wells, in feet, by rock type*

Rock type	Depth		Number of wells
	Range	Median	
Phyllite	10- 572	117	297
Sandstone and siltstone	50-1,004	105	31
Schist	50- 133	95	8
Quartzite	59- 443	88	9
Mafic rocks (metabasalt)	32- 146	72	6
Diabase	40- 185	63	3
Total, all wells	----	----	354

these statistics, it may be observed that although the ranges are very similar, hilltop wells are generally deeper than valley wells, primarily because it is farther to the water table.

Some deep wells have large yields, but as has been explained, this is not always cause and effect: Some wells less than 100 ft deep yield several tens of gallons per minute, and some wells more than 400 ft deep yield only a few gallons per minute. In such cases, one or more of the factors described in the preceding pages play a part in determining the well yield.

QUALITY OF THE GROUND WATER

GENERAL CHARACTERISTICS

The chemical quality of ground water is directly related to the lithology of an area, in other words, to the mineral composition of the rock material with which the water comes in contact and to the length of time the water is in contact with it. Superimposed on these natural determinants are the effects of farming, waste-disposal, and construction activities at or near the land surface.

In general, the quality of the ground water in the study area is satisfactory for most purposes, and as far as is known, ground-water use has not been deterred by water quality. For domestic and public supplies, the pH, hardness, dissolved solids, and iron and nitrate concentrations are probably the properties or constituents most commonly determined. In recent years, increased attention has been given to some of the metals such as copper, lead, and zinc.

Too few analyses are available for ground water from some rock types in the area to permit detailed assessment of the chemical character of the water. However, if analyses from wells in nearby areas are included, adequate information is available regarding ground water from the phyllite, schist, and sandstone and siltstone.

Table 7 shows the number of samples and the pH, hardness, total iron, dissolved solids, and nitrate in each of the three major rock types in or near the study area. The values are not uncommon for the types of rocks in which they occur. Most pH values range from 6.0 to 8.0. As there are no carbonate rocks, which contain large amounts of calcium and magnesium, the water is generally soft, except in some of the Triassic sandstones. Iron sometimes occurs in concentrations of more than the recommended maximum of 0.3 mg/L (milligram per liter). Where this problem exists, it can usually be remedied by the installation of a domestic water-treatment unit. However, lowering iron content as high as 13.0 mg/L, reported in one well near Germantown, Montgomery County, might prove more troublesome. In a few wells, the nitrate concentration approaches or exceeds the maximum of 45 mg/L recommended in the Environmental Protection Agency's drinking-water regulations (1975, p. 81–82). As there is no natural source of nitrate in the rocks and very little in the natural soils of the area, these high values probably indicate pollution from domestic waste-disposal systems, barnyards, or the application of fertilizers.

One of the advantages of ground water over surface water is its relatively consistent temperature, particularly in summer. Although this factor may not be of great importance to the average user, it may be for commercial firms that use it for cooling. The temperature of

TABLE 7.—*Range and median pH, hardness, total iron, dissolved solids, and nitrate, in milligrams per liter (except pH), in ground water in or near the study area*

	Phyllite	Schist	Sandstone and siltstone
pH			
Number of samples	26	6	7
Range	5.4 -8.1	6.0 -7.2	6.0 -8.3
Median	6.4	6.4	7.9
Hardness ($CaCO_3$)			
Number of samples	16	6	7
Range	4 -88	27 -93	31 -210
Median	25	32	120
Total iron (Fe)			
Number of samples	11	5	7
Range	.03-13.0	.02- .99	.02- 4.9
Median	.6	.03	.04
Dissolved solids			
Number of samples	9	5	4
Range	26 -283	76 -184	82 -402
Median	75	84	140
Nitrate (NO_3)			
Number of samples	19	6	7
Range	.6 -73	2.9 -23	.9 -39
Median	16	12	7.1

shallow ground water is generally about the same as the average annual air temperature, which in Carroll and Frederick Counties is about 53° F (11.7° C) (Meyer, 1958, p. 58). It fluctuates during the year, rising during the summer months in accordance with the higher air temperatures, but over a smaller range. Below about 50 ft, ground-water temperature generally does not fluctuate more than a few degrees, although it becomes warmer with increasing depth owing to the geothermal gradient of the Earth.

The water temperatures of wells in the report area range from 53.5° F to 77.0° F (11.9° C to 25.0° C); the median value is 60.8° F (16° C). In two springs in Brunswick, Frederick County, the observed temperature has ranged from 49.0° to 59.0° F (9.4° to 15° C) over a period of 20 years, although in any one year, the fluctuation has been only about 7 or 8° F (3.9 or 4.4° C).

POSSIBLE SOURCES OF POLLUTION

Under normal conditions, ground water flowing from a spring or pumped from a well is safe to drink, even though it may have objectionable concentrations of some minerals. However, it is possible to pollute ground water through either carelessness or ignorance.

As explained on page 14 of this report, ground water tends to move vertically down to the water table and then laterally to points of discharge. This pattern of movement permits polluted water to travel away from the immediate source of the pollution.

One of the most common ways in which ground water becomes polluted is through surface or subsurface drainage from a barnyard. Sometimes an old dug well is used as a refuse pit after a new well has been installed. A third common source of pollution is waste from septic tanks that very slowly moves toward a well, reaching it only after several years. Ground water can also be polluted from repeated applications of fertilizers. Leaking fuel tanks may contaminate ground-water supplies. Leachate from open dumps and improperly operated landfill sites is another source of pollution.

Some of these situations can take several years to develop because ground water, and therefore its contaminants, generally moves very slowly and because movement through earth materials has a "cleansing" effect–that is, some contaminants may be absorbed by the fine-grained but permeable earth materials.

Because some pollutants and contaminants are "applied" at or near the land surface, some people think that there is no connection between such occurrence and the water that is withdrawn from a well tens or hundreds of feet deep. However, as water pumped from either saprolite or rock fractures has passed vertically through soil, it has been exposed to any pollutants occurring near the surface. Furthermore, in crystalline rocks where ground-water circulation is limited, dilution with other water may also be limited.

Much remains to be learned about the movement of pollutants in ground water – not only the actual paths of ground-water movement in a given geologic environment but also the behavior of the pollutants themselves with time and with contact with earth materials.

As far as is known, no widespread cases of ground-water pollution have occurred in the study area. However, in one nearby town, a high percentage of the wells became polluted from adjacent individual waste-disposal systems. The resulting health hazard was removed by the installation of town wells and a public sewerage system. In time, natural flushing action may clear up the remaining pollution, but when the condition may have taken years in its development, it is extremely difficult to prophesy the length of time for restoration of the water quality to its original state.

GROUND-WATER USE

THE ROLE OF GROUND WATER IN THE STUDY AREA

In an area served by a public supply derived from surface-water sources, ground water and a study of its availability may seem to be of only secondary importance. However, in what is still essentially a rural area where only a small part of the area is served by a public utility, ground water is actually of paramount importance. Although the study area borders on, and in places actually includes some fairly densely populated districts, it still includes many square miles of open country and farmland, and perhaps two-thirds of the population relies on individual private wells for its water supply. However, the Washington Suburban Sanitary Commission water mains now extend beyond Damascus and thus serve part of the project area from a surface-water supply (fig. 7).

AVAILABILITY OF WATER-USE DATA

As is true for many other areas, it is difficult to obtain accurate water-use figures for the study area, especially for ground-water use. There are four main reasons for this: (1) the project boundaries do not coincide with any statistical-unit boundaries; (2) domestic wells are seldom equipped with water meters; (3) at the present time, only the largest nondomestic ground-water users are required to report their pumpage to the appropriate State agency, and only a few of these users are in the study area; and (4) there is no complete and up-to-date list of nondomestic ground-water users. However, several incomplete lists of such users in the files of the Maryland Water Resources Administra-

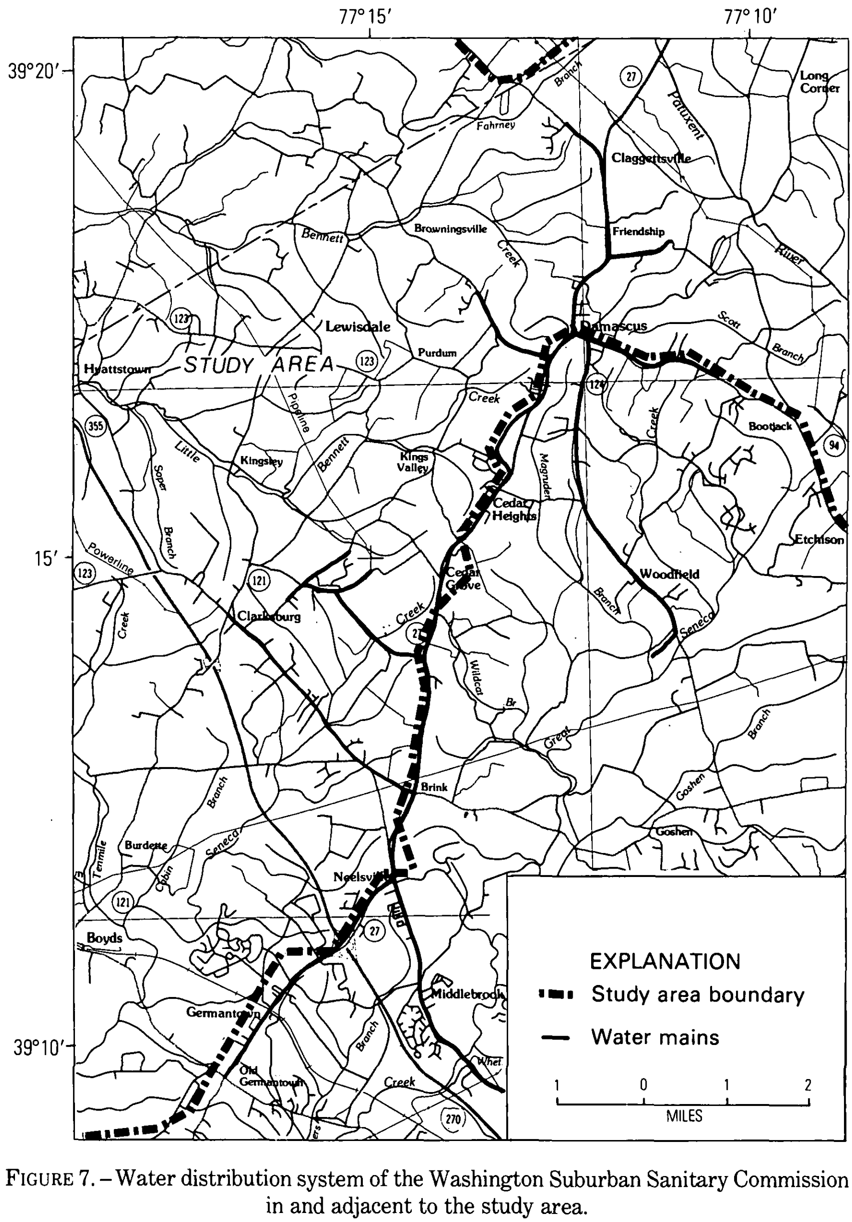

FIGURE 7. – Water distribution system of the Washington Suburban Sanitary Commission in and adjacent to the study area.

tion were combined to give a partial inventory, and, therefore, at least a minimum estimate of ground-water withdrawal.

The complexities of attempting to determine accurate water-use figures are well described in a 1977 report prepared for the Washington Suburban Sanitary Commission (WSSC) (Ecological Analysts, Inc., 1977). In this report, entitled "Water Supply Study for Montgomery and Prince George's Counties, Maryland," the consultants describe some of the variables that should be taken into account when accurate water-use figures are needed (p. 2:5–12, 3:17, and 3:41). These variables include the presence or absence of both water and sewer facilities, changes in seasonal use, the type of residential facility, economic factors, and perhaps some unknown factor labeled "an as yet undiscovered distinction among patterns of water use" (p. 3:29). The authors conclude that "although per capita approaches to water use have been traditionally used in the industry, water use is better correlated with the number of customer connections than it is with resident population" (p. 3:27).

Unfortunately, for the reasons described, some of the data for mean water use in gallons per day per connection cannot be applied throughout the project area; complete lists of "connections" are simply not available. However, where possible, WSSC statistics were used in combination with other estimates to arrive at the figures used in this report.

DOMESTIC AND FARM USE

In lieu of actual figures for ground-water use for domestic purposes, it is possible to obtain population statistics, multiply those figures by some average per capital figure, and arrive at an estimate of the total daily consumption. However, as the study area boundaries are dictated by drainage divides rather than by election district boundaries, it is impossible to use census statistics directly; the total for the part of the population that resides outside of the study area boundaries must somehow be deleted.

The Montgomery County population and housing-count map dated January 1, 1976 (Maryland-National Capital Park and Planning Commission, 1976), contains helpful information but is, of course, 2½ years old. Using a housing count also means making another estimate, namely the number of occupants per house. Statistics given on the map indicate that a reasonable figure is 3.5 persons per house, and so that figure was used in making an estimate of the population in the study area.

Unfortunately, this estimate cannot be used directly either; before ground-water-use figures can be computed, it is necessary to subtract values for the segment of the population that is served by the

Washington Suburban Sanitary Commission. The WSSC has up-to-date water-use figures for various service areas, which of course do not exactly coincide with the study area boundaries. Use figures are based on water meters and number of connections.

For the parts of Carroll, Frederick, and Howard Counties that are included in the study area, it was necessary to count houses on the latest available editions of the U.S. Geological Survey 7½-minute quadrangles, realizing that in an area of expanding suburbia, many houses are omitted on maps that are 8 years old. Furthermore, the town of Mount Airy, which straddles the Frederick-Carroll County line, is served entirely by ground water from town wells, and that segment of the population must be omitted from any house count that would otherwise duplicate water-use figures. It also happens that part of the town is outside of the study area boundary.

By taking into consideration all of the above factors, and by using 3.5 as the average number of occupants per house, the total population served by private individual wells in the study area is estimated to be at least 9,000, distributed as follows:

Carroll County	660
Frederick County	2,200
Howard County	1,400
Montgomery County	4,700
Total	8,960

Based on the growth rate in several parts of the study area from 1960 to 1970, the actual population figure is probably closer to at least 12,000. However, more accurate figures to update 8-year-old United States Census statistics and 8-year-old Geological Survey quadrangles do not seem to be available.

By using WSSC data for water use and number of connections for residential properties and then computing estimated population figures, it appears that the average per capita water use in five districts in the study area is about 65 gal/d. This is a smaller figure than the commonly used rule-of-thumb of 100 gal/d per person, which is about the same as the WSSC's statistics when commercial and other uses are included; nevertheless, the figure seems valid here. If 65 gal is used as an average daily per capita water-use figure and the population is assumed to be 12,000, then the total estimated ground water used for domestic purposes in the study area is on the order of at least 780,000 gal/d.

As the Washington Suburban Sanitary Commission serves an estimated 6,500 people in the study area and as the town of Mount Airy system serves about 2,200 people (not all living inside the study area), the total water actually used for domestic purposes in the study area is much larger than the figure cited.

No attempt was made in this study to estimate the amount of ground water used for dairy farms, for irrigation of crops in dry years, and other farm uses.

COMMERCIAL AND INSTITUTIONAL USE

The Maryland State Water Resources Administration issues appropriation permits for all ground-water users other than private homes and farms. Part of the information included on the user's permit application is an estimate of the anticipated average and maximum daily water-withdrawal rates. The quantity of water granted on the permit may be more or less than the subsequent quantity used. The total ground water used for commercial and institutional purposes was estimated by adding together all the figures given on the permits, although the agency requests only those wells producing more than 10,000 gal/d to be equipped with meters.

Examination of the Water Resources Administration's files for Montgomery County resulted in a list of commercial users, with both average and maximum daily allowable consumption rates. These figures, added with those for one commercial well in Frederick County, indicate a total commercial ground-water use averaging 31,000 gal/d, with a maximum of 55,000 gal/d in the study area. These figures must be recognized as only minimum values, as there are doubtless dozens of small users that are not listed in the files.

PUBLIC SUPPLIES

There are only three public supplies in the study area, and only one of these is a town supply derived wholly from wells.

One mobile-home trailer park in southwestern Carroll County is permitted to use an average of 30,000 gal/d and a maximum of 37,440 gal/d from wells.

The town of Mount Airy, which lies in both Frederick and Carroll Counties, is supplied by four wells, three of which are in regular use and a fourth is on standby service only (as of 1978). Two of the wells can produce about 265 gal/min, one about 65 gal/min, and the fourth about 115 gal/min.

The waterworks includes equipment for chlorinating the water, the only treatment currently being used. However, the town is considering the installation of a treatment unit that will raise the low pH of 5.6–6.1 and possibly lower the carbon dioxide content of 6 mg/L. Constituents such as iron, chloride, and dissolved solids are no problem and require no treatment. Finished water is stored in two elevated tanks, one having a capacity of 75,000 gal and another, 200,000.

The population served by the Mount Airy system is about 2,200, almost entirely residential and commercial. A sizeable proportion lies outside the study area boundaries. The two largest consumers are the elementary and middle schools at the north end of town. The largest commercial water user, a liquid fertilizer company, has its own wells and no longer uses town water.

In 1978, the town's average daily water use was between 100,000 and 150,000 gal/d, a figure considerably less than the reported capacity of the wells and also less than the amount permitted by the Water Resources Administration (R. D. Hobbs, Jr., oral commun., 1978).

The third of the three public supplies in the study area is owned by the Washington Suburban Sanitary Commission (fig. 7). This supply is obtained entirely from surface-water sources, and thus the total estimated 640,000 gal/d that it furnishes in the study area is not included in the ground-water-use statistics. Additional information on this important utility is given in the section entitled Alternative Water Supplies.

PROJECTED USE

As it is impossible to obtain any accurate current ground-water-use figures for the study area, it is easy to understand that projected figures are even more difficult to obtain. Furthermore, such figures are based on estimates of population growth and commercial development that may not proceed at the same rates as they have in even the recent past. Given the fact that at least part of the study area is located in the area of expanding suburban development that surrounds Washington, D.C., it is likely that some degree of growth will continue.

It is not in the purview of this report to discuss some of the differences of opinion or the relative merits of any particular points of view of residents, planners, real-estate agents, and developers on the general subject of development. However, these are factors that affect the growth rate of areas not yet fully developed and make it more difficult to estimate future water use.

It has already been mentioned that the study area boundaries do not coincide with any census-district boundaries. However, for several election districts of northern and western Montgomery County, the Maryland-National Capital Park and Planning Commission (1976) has assembled some population figures that show the changes since the 1970 U.S. Census:

Election district	Population		
	April 1, 1970, census	January 1, 1976, estimated	Percent change
1. Laytonsville	3,452	3,880	+2
2. Clarksburg	3,980	4,260	+7
11. Barnesville	2,266	2,390	+5
12. Damascus	6,372	7,630	+20

Whether or not the population in these districts will continue to grow at the same rates is difficult to predict. In the report prepared for the WSSC by Ecological Analysts (1977), the household population of Montgomery County in 1976 was estimated to be 599,000, and the number of single-family housing units, 130,800. Values for these same parameters implicit in the 1985 projection are 686,000 and 161,900, respectively; for 1995 (low forecast), 757,700 and 180,400; and for 2030 (low forecast), 999,000 and 210,000, respectively (tables 3–20, 3–21, and 3–22).

In any case, population growth, commercial development, and relocation of various governmental agencies to areas outside the District of Columbia are only three factors that must be considered in predicting water use and availability. Various economic factors must also be considered, to say nothing of the natural limitations on the availability of the ground-water resource itself.

One recent development will make the WSSC distribution system more flexible: It has been announced recently that a contract has been let for a new tunnel that will connect the water mains of the western and eastern parts of Montgomery County and will also permit the movement of water from the Potomac River Filtration Plant into parts of Prince George's County (Interstate Commission on the Potomac River Basin, 1978). How this will affect population distribution and, hence, water demand is difficult to say at the present time.

DESIGNATION OF AN AQUIFER IN THE STUDY AREA

An aquifer is usually defined simply as a rock unit that will produce water in usable quantities. In consolidated material, the saprolite and the underlying hard rock function as a single water-bearing unit. The water-bearing properties at any one site are dictated by a set of varying conditions involving lithology, structural geology, fracture and joint systems, topography, and well depth. The relative importance of these factors varies from place to place, as does the horizontal and vertical extent of a particular set of conditions. A given set of conditions may exist over an area as large as a part of a drainage basin or over an area only several hundred feet in diameter.

Conventionally, an aquifer has been equated with a geologic formation. This is still done, because by definition a geologic formation is a mappable unit and it is convenient to handle data from a unit having definite boundaries. However, a formation does not always consist of a single rock type, and thus the lithology, a controlling factor in water availability, may vary considerably within the formation.

An aquifer is sometimes considered to be a single rock type, such as those units delineated on Froelich's bedrock map of Montgomery County (Froelich, 1975b). As the occurrence of ground water is controlled largely by geology and lithology, this definition is perhaps more valid than is the selection of a geologic formation to represent an aquifer, and it has been used in the statistical analyses in this report. It must be remembered, however, that rock types themselves can grade both vertically and horizontally into one another and that water-bearing zones cross contacts between rock types.

In a geologic sense, the study area is underlain by only one rock type at a given location, and a well ends in whatever formation it begins. This is partly because most of the individual formations are very thick and long before a well penetrates the entire thickness of a formation, it reaches a depth where water-bearing zones are few and unproductive. An exception to this is in the nearly flat-lying Triassic sandstone and siltstone where it might be possible, though perhaps impractical, to penetrate the entire thickness of the sequence and drill into the underlying older crystalline rock. However, by far the largest part of the study area is underlain by fractured crystalline rocks, and in that part, even though conditions may vary from site to site, there is only a single aquifer at a given place from which to draw ground water. This situation exists not only in the study area but also throughout both the crystalline-rock area of Maryland and, in fact, the entire Piedmont province.

It is sometimes convenient to consider water availability on the basis of a drainage basin or subbasin because certain parameters, particularly runoff, lend themselves to measurement more easily in a basin. Ground-water runoff can be derived from total runoff, and the theoretical maximum available ground-water supply within the basin can be estimated. A basin may contain more than one geologic formation, or more than one rock type, or simply varying geologic conditions that make the availability of ground water differ from one part of the basin to another. Nevertheless, in a certain sense, the boundaries of a basin can be used to delimit an aquifer's boundaries, and the boundaries of the study area are basin boundaries.

Inherent in the concept of a sole-source aquifer is the idea that only one aquifer is available as a source of potable ground water. However, there may be no real reason why ground water must be the only water used in an area, and, therefore, the possibility of using surface water in the project area should be examined.

ALTERNATIVE WATER SUPPLIES

As has been mentioned earlier, the Washington Suburban Sanitary Commission already supplies large parts of Montgomery and Prince George's Counties with water from the Potomac and Patuxent Rivers. Although there are a few small interconnecting lines between the two systems, it is safe to say that the water supplied to the study area comes from the Potomac River.

There is no impounding dam on the Potomac; water is withdrawn through an intake structure on the north channel of the river near Watts Branch, 3 mi above Great Falls. It is piped under the Chesapeake and Ohio Canal and then pumped up 140 ft to the Potomac Filtration Plant, on the hilltop above the river. The design capacity of this plant is 240 Mgal/d. However, lacking a dam and, therefore, also a reservoir pool, the shallow depth of the river water (averaging about 3 ft) prevents this plant from operating at its full capacity. Instead, it is capable of pumping only about 180 Mgal/d so long as the river level remains above an elevation of 157 ft above sea level. If, however, a drought period drops the river level only 2 ft, then the capacity of the intake is reduced to only 80 Mgal/d. Obviously, the lack of a dam or even a low weir severely limits the availability of water from this source. However, looking ahead to a time when its request for permission to build a weir at this station is granted, the WSSC has already drawn up plans for enlarging the treatment facility to a capacity of 400 Mgal/d.

Treatment of water as it passes through the plant includes the usual steps of prechlorination, coagulation (in which alum and liquid ferric chloride are used), settling, filtration, corrosion control, and postchlorination or dechlorination. Hydrofluorosilicic acid is also added, and the processed water then flows to the filtered water reservoirs at the plant site pending withdrawal through the finished-water pumping station and into the distribution system (Washington Suburban Sanitary Commission, 1976).

The other part of the WSSC supply system is the Patuxent River, on which have been built two impounding dams, one at Brighton and one at Rocky Gorge, both on the Montgomery-Howard County line. Triadelphia Lake, above Brighton Dam, has a storage capacity of 7 billion gallons, and the T. Howard Duckett Reservoir, above Rocky Gorge Dam, 6.4 billion gallons. Water from these reservoirs supplies Prince George's County and part of Montgomery County. The nearby Patuxent Water Filtration Plant has a capacity of 65 Mgal/d. None of this water reaches the study area at the present time.

As WSSC water already serves a portion of the study area, it is a possible alternate water source. However, as already mentioned, the intake facilities at the Potomac River filtration plant pose some problems. Furthermore, under the Capital Improvements Program for 1979–84, the WSSC proposes the construction of some connecting links between existing water mains but no major additions to the system in the study area, at least prior to 1984 (Washington Suburban Sanitary Commission, undated map). Thus, for some time to come, a large part of the population in the study area will probably depend upon ground water from either private individual wells or new public-supply wells.

Nearby, but outside the study area, are three other public supplies. They are those of the District of Columbia and the City of Rockville systems, which are derived from the Potomac River, and that of the Town of Poolesville system, which is derived from wells. Each of these suppliers has its own problems in successfully serving its existing customers, but in time their service areas may be enlarged and their water mains extended to approach or reach the study area.

Although there are few sites available for large impoundments in the study area, some smaller reservoirs could possibly be constructed. One multipurpose lake is already proposed for an area immediately north of Boyds in Montgomery County. However, small surface-water impoundments that would each serve only a relatively few residents would be very costly, so use of this alternative water source would have to be evaluated very carefully.

In some areas, water is imported over considerable distances and from outside the area of actual use. This situation does not exist in Maryland, although one of the sources of Baltimore's water is the Susquehanna River, about 30 mi from the city. Some thought has been given to developing emergency ground-water supplies for the Washington metropolitan area in times of severe drought, and estimates have been made of the water-supply potential of the Coastal Plain aquifers in southern Maryland (Papadopulos and others, 1974). At the present time, it does not seem likely that such supplies will be available for the study area for some time to come, regardless of the source.

SUMMARY OF FINDINGS

1. The study area consists of about 130 mi^2 in the Piedmont area of central Maryland and includes parts of Montgomery, Frederick, Carroll, and Howard Counties.
2. The entire area is underlain by possibly 25,000 ft of closely folded metasedimentary rocks, chiefly schists and phyllites, and minor inclusions of mafic volcanic rocks. Overlying these crystalline rocks in the southwestern part of the area are more than 2,000 ft of younger, unmetamorphosed sandstones and siltstones that have been intruded by diabase.
3. The overburden is generally between 20 and 40 ft thick but ranges from 0 to about 125 ft.
4. The source of the ground water in the study area is local precipitation. Perhaps as much as 28 percent of the 39 in. of total annual precipitation, or 10–11 in., constitutes the effective ground-water recharge.

5. Ground water occurs almost everywhere under water-table conditions. It is stored in intergranular spaces in the saprolite and (or) in the cracks and fractures of the underlying hard rock.
6. Ground-water movement is greatly restricted by the degree of interconnection between openings in the rock materials. Most of the ground water in the crystalline-rock area is found within 300 ft of the land surface. Individual fractures probably do not extend laterally for much more than a few hundred feet, although some fracture zones may extend for some miles.
7. Ground water in the study area is generally moving downward by gravity and then laterally toward discharge points in stream valleys. Little, if any, crosses topographic divides.
8. Records of two observation wells in the study area exhibit the seasonal cycle of water-table fluctuations typical of the Eastern United States. In accordance with records for other Maryland Piedmont wells, there appears to be no long-term rise or decline in the water table.
9. About 70 percent of the 286 inventoried wells have yields of 10 gal/min or less. Only very few wells yield as much as 100-300 gal/min. Most specific capacities range from 0.1 to 1.0 (gal/min)/ft. Transmissivity values are also low; the highest value for the study area is 976 ft^2/day.
10. Well yield varies somewhat according to lithology. Wells ending in quartzite and in sandstone-siltstone have the highest median yield values. Those in phyllite have one of the lowest; almost half of the phyllite wells yield less than 6 gal/min.
11. The regional structural geology and the pattern of joints, fractures, and faults play an important part in the formation of the local drainage pattern and in the occurrence of ground water. Although no test drilling was done for this project, it is probable that above-average yielding wells can be completed where a fracture occurs or where two fractures intersect.
12. Wells in valleys are more productive than those on hilltops. The median yield value of 15 gal/min for valley wells is nearly four times as great as that for hilltop wells.
13. Well yield is somewhat related to depth. Additional water may be found down to about 300 ft in crystalline rocks; below that depth, the chances of finding more decrease rapidly. However, in the Triassic sedimentary rocks, water-bearing zones are sometimes encountered at two or three times that depth. Almost 70 percent of the inventoried wells are between 50 and 151 ft deep. The greatest median depth value is for wells ending in phyllite; the lowest is for those ending in metabasalt and diabase. The deepest wells are located on hilltops; the shallowest, in valleys.

14. The quality of the ground water is generally satisfactory, although iron sometimes occurs in troublesome concentrations. The few above-average nitrate values probably indicate only local pollution.
15. Ground water can be polluted from wastes from barnyards and septic tanks, from leaking fuel tanks, by application of fertilizers on nearby fields, and by leachate from open dumps and improperly operated landfill sites. However, no widespread cases of pollution are known to exist in the study area.
16. Accurate figures on ground-water use are not available, and estimates are open to revision. Domestic and farm use total about 780,000 gal/d. Commercial and institutional use totals perhaps as much as 55,000 gal/d. Approximately 160,000 gal/d is used by public supplies, specifically one trailer park and the Town of Mount Airy, part of which is outside the study area.
17. The Washington Suburban Sanitary Commission supplies about 640,000 gal/d to the study area, all from surface-water sources.
18. At least part of the study area lies in the area of suburban expansion that surrounds Washington, D.C. In the 6 years from 1970 to 1976, the population in four Montgomery County election districts that include large segments of the study area increased by 5 to 20 percent. Although continued growth is certain to take place, it is difficult to forecast the rate and, hence, also the future demand for water.
19. Alternative sources of water that could be used are the Potomac and Patuxent Rivers, involving extension of water mains of the WSSC; lesser streams where impoundments could be built; and water from additional individual wells, expansion of the Mount Airy and (or) Poolesville systems, Coastal Plain aquifers, or new public-supply wells. For various reasons, it seems that in the immediate future most new housing will be served by private individual wells and the rural population will continue to be dependent on the water available from private wells tapping the single aquifer that underlies any given location.

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