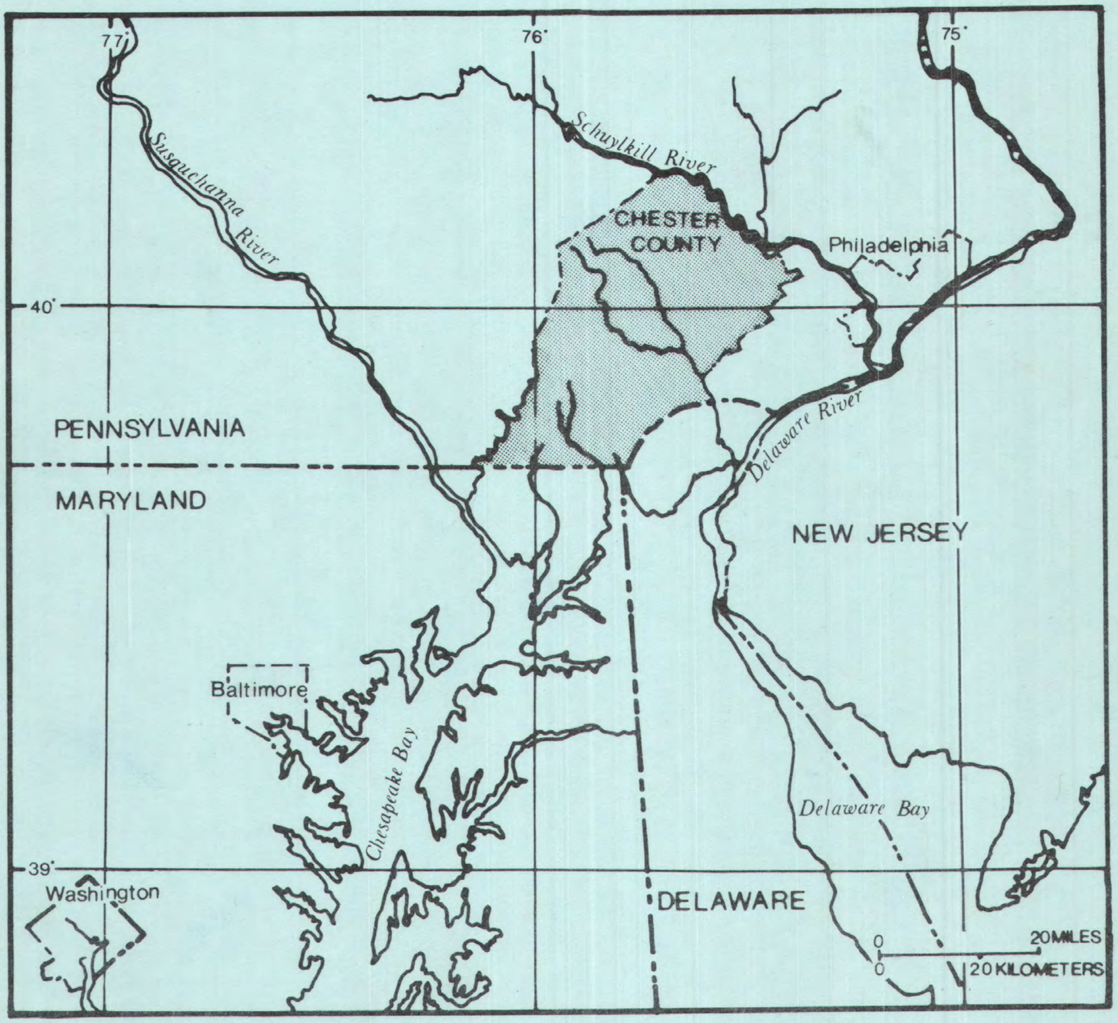
GROUND WATER RESOURCES OF CHESTER COUNTY, PENNSYLVANIA

U. S. GEOLOGICAL SURVEY
WATER-RESOURCES INVESTIGATIONS 77-67
OPEN-FILE REPORT



Prepared in Cooperation with the
CHESTER COUNTY WATER RESOURCES AUTHORITY

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Fifty gallons per minute (3 liters per second) or more may be obtained from wells in almost all parts of the county, but not at all locations. Adequate exploration to find fracture or solution openings is required. Five hundred gallons per minute (30 liters per second) or more may be obtained from some of the carbonate rocks. Linear features are visible on 1:1,000,000-to 1:24,000-scale aerial imagery. Many linear features, but not all, have geologic or hydrologic significance, and some may indicate fractured rock that might be tapped by wells. Dissolved-solids concentration of most ground water is less than 500 milligrams per liter. Chemical-quality problems are predominantly caused by acidity, iron and manganese, or nitrate. Base (ground-water) runoff during a near-average year, 1968, was about 420 million gallons per day (18 cubic meters per second).

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By Laurence J. McGreevy and Ronald A. Sloto

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Chester County Water Resources Authority

September 1977

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

V. E. McKelvey, Director

Open-File Report

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GROUND-WATER RESOURCES OF CHESTER

COUNTY, PENNSYLVANIA

By Laurence J. McGreevy and Ronald A. Sloto

ABSTRACT

Chester County is an area of about 760 square miles (1,970 square kilometers) in the Piedmont of southeastern Pennsylvania. Rocks of the county include: (1) Precambrian metamorphic and igneous rocks; (2) upper Precambrian to lower Paleozoic metamorphic rocks, predominantly metamorphosed sedimentary rocks; (3) upper Precambrian and lower Paleozoic sedimentary rocks that are moderately metamorphosed; and (4) Upper Triassic sedimentary and igneous rocks. Overlying the bedrock is a generally thick zone of unconsolidated weathered rock.

Most wells derive water from fractured rock. Intergranular permeability is present only in the weathered zone and in some of the sedimentary rock. Solution of carbonate rock and weathering increase the permeability.

Reported yields range from 0 to 1,800 gallons per minute (114 liters per second). Yields from carbonate rock, particularly the Cockeysville Marble and Ledger Formation, are generally higher than yields from other units. The difference in yield between nearby wells in the same unit, however, may be greater than the difference in yield between wells in different units. Exceptionally high yields of 100 gallons per minute (6 liters per second) or more were reported in almost all parts of the county and from almost all units, as were exceptionally low yields of 5 gallons per minute (0.3 liters per second) or less.

The estimated number of wells that would be needed in an area to yield 1 million gallons per day (0.04 cubic meters per second) continuously are indicated on a map. The estimates are based on evaluation of data on reported yields of more than 1,900 wells, on specific capacity for almost 900 wells, and on estimates of long-term specific capacity from 97 pumping tests. Yields that might be obtained by intensive exploration of an aquifer were estimated. These yields were then reduced by half to approximate the long-term average yield.

Aerial imagery of various kinds was evaluated as a potential aid in the study. The imagery included: side-scanning radar, infrared scanning, Skylab photography, Landsat imagery, and aerial photographs from various altitudes. These provided images at scales of 1:1,000,000; 1:250,000; 1:100,000; 1:60,000; and 1:24,000. The Landsat and Skylab images give an overview of the geology and structure of the area that is not available from other sources.

Straight or gently curved linear features are visible on all scales of aerial imagery that were examined, and most have geologic and hydrologic significance. Many linear features indicate fracture zones where fractured rock might be tapped by wells. Linear features were mapped from Landsat imagery and from 1:60,000 aerial photos. The mapped features are generally topographic lows, and most indicate zones of weakness in the rock.

Most ground water moves from where it enters the ground in upland areas and hillsides to the nearby valleys, where it is discharged to streams. Ground-water levels fluctuate in response to precipitation and evapotranspiration. Water levels generally decline during the growing season and recover during the rest of the year.

A water-budget analysis for the county indicates that an average of about 1,650 million gallons of water per day or 72 cubic meters per second enter and leave the area. The basin yield from the county during a near-average water year (1968) was 620 million gallons per day (27 cubic meters per second). Base flow, ground-water outflow, accounts for about 420 million gallons per day (18 cubic meters per second) and direct (storm) runoff about 200 million gallons per day (9 cubic meters per second).

The dissolved-solids concentration of most ground water in the county is less than 500 milligrams per liter. Chemical-quality problems are predominantly caused by acidity, iron and manganese, or nitrate. Hardness is sometimes a problem.

About 7 billion gallons (26 cubic hectometers) of water was withdrawn from the ground in Chester County in 1974. Almost 60 percent of this water was for self-supplied domestic users. Public supplies accounted for another 30 percent. In all, almost two-thirds of the residents of the county depend upon ground water for household use.

INTRODUCTION

Purpose and Scope

This report provides basic information on the ground-water resources of Chester County, Pennsylvania, which is an area of about 760 square miles (1,970 square kilometers) in southeastern Pennsylvania. (See cover.) It discusses the availability and quality of the water in the water-bearing units in the county and the relation of the ground water to surface water. The study was done by the U. S. Geological Survey in cooperation with the Chester County Water Resources Authority.

Fieldwork for the study was done during 1973-75. Well and spring data on which interpretations and conclusions are based were published separately in a basic-data report (McGreevy and Sloto, 1976). The report contains a map giving well and spring locations and includes tables of data on selected wells and springs. The location map is included in this report as plate 1. Also contained in the basic-data report are hydrographs of water levels in selected wells; chemical analyses of ground water including major ions, nutrients, and trace metals; and detailed descriptive logs of five wells. A seepage study of several streams crossing Chester Valley is given by McGreevy (1974) in an open-file report.

Acknowledgments

The cooperation of the residents of Chester County and of local, county, state, and federal officials is gratefully acknowledged. The authors are particularly indebted to the Chester County Planning Commission, which furnished base-map materials, and to well and spring owners, the Pennsylvania Topographic and Geologic Survey, and well drillers, who furnished essential information.

Units of Measurement

Factors for converting English units used in this report to International System or metric units are:

Multiply English unit	By	To obtain metric unit
inches (in)	25.4	millimeters (mm)
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
square miles (mi^2)	2.590	square kilometers (km^2)
gallons (gal)	3.785	liters (L)
	.003785	cubic meters (m^3)
million gallons	3,785	cubic meters (m^3)
	.003785	cubic hectometers (hm^3)
gallons per minute (gal/min)	.06309	liters per second (L/s)
	.06309	cubic decimeters per second (dm^3/s)
	.00006309	cubic meters per second (m^3/s)
million gallons per day (Mgal/d)	.04381	cubic meters per second (m^3/s)
million gallons per square mile	1,461	cubic meters per square kilometer (m^3/km^2)
	.001461	cubic hectometers per square kilometer (hm^3/km^2)
million gallons per day per square mile [$(Mgal/d)/mi^2$]	.0169	cubic meters per second per square kilometer [$(m^3/s)/km^2$]

Chemical concentrations are given in milligrams per liter (mg/L) or in micrograms per liter (ug/L). One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than about 7,000 milligrams per liter, the values are numerically the same as parts per million.

Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by use of the equation: °F = 1.8(°C) + 32. For example, 50°F = 1.8(10°C) + 32. Water temperatures are reported to the nearest 0.5°C. Air temperatures are given in degrees Fahrenheit followed by degrees Celsius in parentheses.

Topography and Drainage

Chester County lies within the Piedmont Province of the Appalachian Highlands. The county is mostly uplands formed of hard crystalline rocks that have been deeply weathered and have been shaped into rolling hills. The uplands slope gently to the southeast. The highest point is in the northwest at the top of Welsh Mountain, which reaches an altitude of 1,071 feet (326 m). The uplands are divided into two almost equal parts by Chester Valley, which trends northeast across the middle of the county. This narrow valley was formed of more easily eroded limestone and dolomite.

Lowlands border the Schuylkill River in the northeastern part of the county. These lowlands were formed by erosion of sandstone and shale, which are less resistant than the crystalline rocks of the uplands. The lowest point is on the east edge of the lowlands, where the Schuylkill River leaves the county. The altitude here is 66 feet (20 m).

Almost all Chester County streams have their headwaters within the county. The drainage basins are shown in plate 2. French, Pickering, and Valley Creeks are the principal tributaries flowing into the Schuylkill River. Brandywine Creek drains the interior of the county and flows into the Christina River. Its basin, which drains 38 percent of the county, is the largest. Darby, Crum, Ridley, and Chester Creeks flow into the Delaware River. Octoraro Creek and its tributaries flow into the Susquehanna River. Elk and Northeast Creeks flow into Chesapeake Bay. Red Clay and White Clay Creeks flow into the Christina River, which then flows into Delaware Bay.

Climate

Chester County has a modified humid continental climate characterized by warm summers and moderately cold winters. Climatological data used in this report were collected at 8 stations by the National Weather Service (formerly the U.S. Weather Bureau): Chadds Ford, Coatesville, DeVault, Glenmoore, Honey Brook, Phoenixville, West Chester, and West Grove.

The normal annual temperature is 53°F (11.5°C). This is the average of the normals for the three stations (Coatesville, Phoenixville, and West Chester) recording temperature during the normal period 1941-70 The normal temperature for January, the coldest month, is 31°F (0.5°C). The normal temperature for July, the warmest month, is 75°F (24°C).

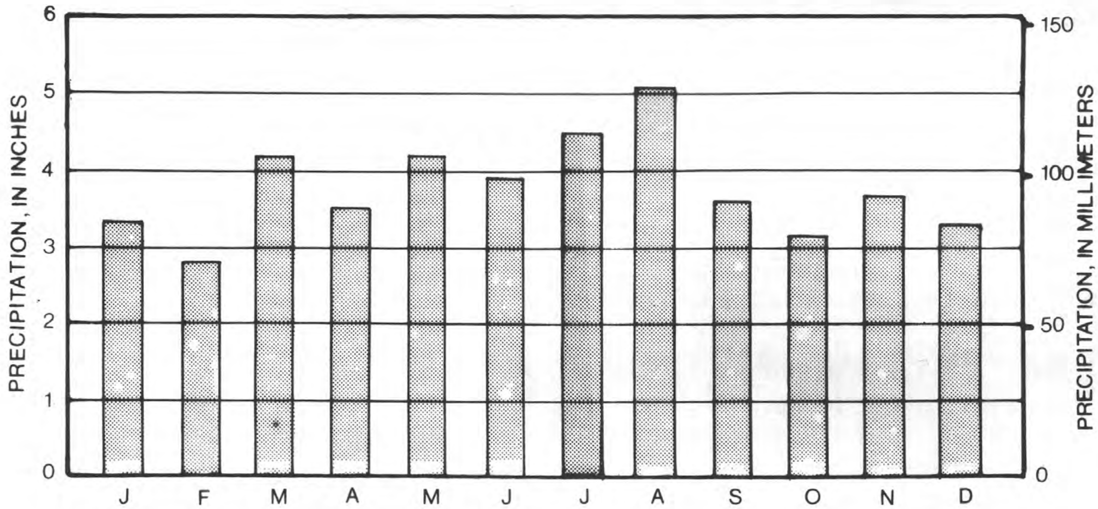

Figure 1.--Four-station average of normal monthly precipitation (Coatesville, Phoenixville, West Chester, and West Grove) 1931-60.

Precipitation is generally distributed evenly throughout the year. Normal monthly precipitation is shown in figure 1. This is the average of the normals for the four stations (Coatesville, Phoenixville, West Chester, and West Grove) recording precipitation during the normal period 1931-60. Normal yearly precipitation for Chester County is 45.41 inches (1,153 mm) based on the average of those four stations during the normal period 1931-60. The normals ranged from 45.03 inches (1,144 mm) at West Grove to 46.03 inches (1,169 mm) at West Chester. The 1931-60 normal is used because it is closer to a long-term average than the 1941-70 normal, which includes the drought years 1961-65. At the West Chester station, the long-term average for 115 years of record is 46.83 inches (1,189 mm) per year and the 1931-60 normal is 46.03 inches (1,169 mm) per year, whereas the 1941-70 normal is only 43.13 inches (1,096 mm) per year (fig. 2).

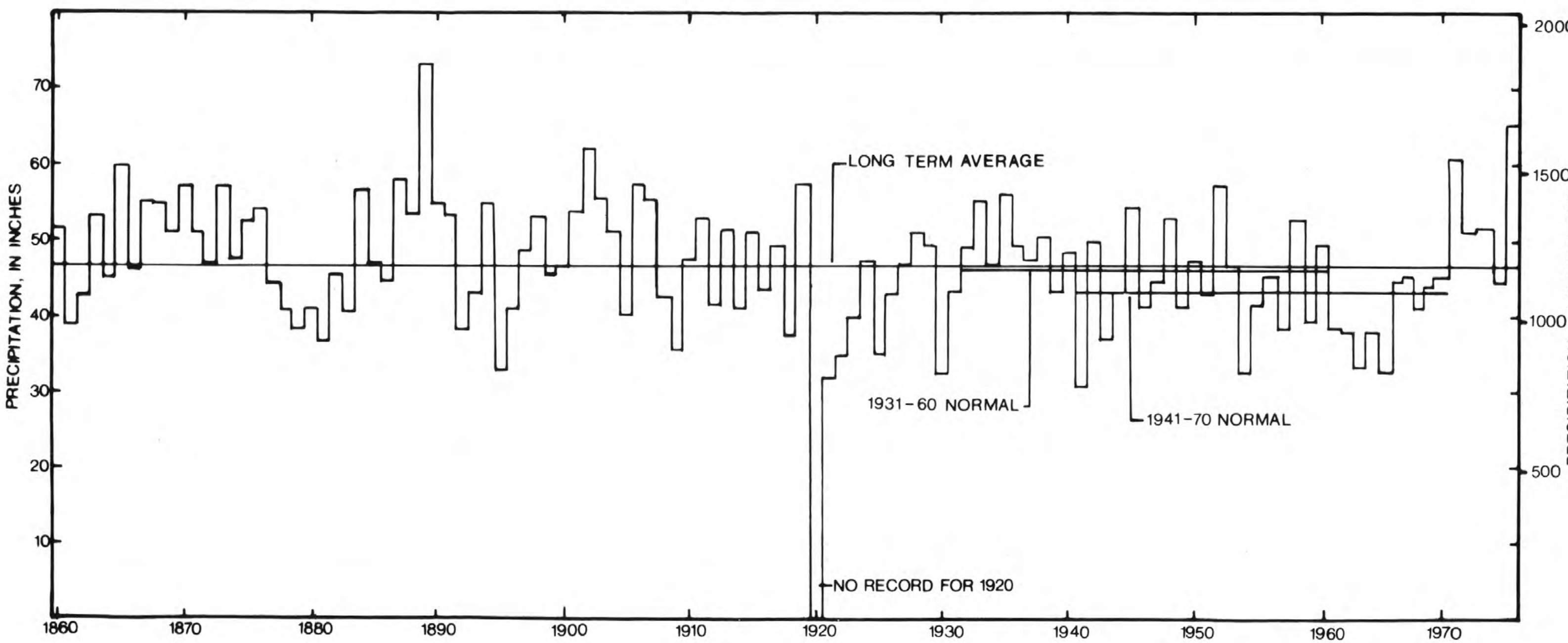

Figure 2.--Annual precipitation at West Chester, 1860-1975.

Population and Land Use

The population of Chester County in 1970 was 278,000 (Chester County Planning Commission, 1970). Forty-five percent of the population was classified as urban, 48.5 percent as rural, nonfarm, and 6.5 percent as rural, farm. About three-fifths of Chester County's land in 1970 was devoted to agriculture. One third was classified as vacant land, woodlands, and parks. Eight percent was classified as residential and 0.7 percent as industrial. The amount of residential land is rapidly increasing at the expense of agricultural land and woodland. The Chester County Planning Commission estimates the 1975 population at 315,000.

Previous Investigations

The geology of Chester County was mapped by Bascom and others (1909), Bascom and Miller (1920), Knopf and Jonas (1929), Bascom and Stose (1932), and Bascom and Stose (1938). McKinstry (1961) made structural interpretations of part of the county. Higgins (1972) reinterpreted the age and regional relations of some of the units.

Water resources on a basinwide scale for the Delaware River were covered by Parker and others (1964) and for the Schuylkill River by Biesecker, Lescinsky, and Wood (1968).

Miller, Troxell, and Leopold (1971) discussed the hydrology of Pickering Creek and upper East Branch Brandywine Creek basins. Olmsted and Hely (1962) described the relationship between ground water and surface water in the Brandywine Creek basin.

Ground water was discussed generally by Hall (1934), as part of his report on southeastern Pennsylvania. A detailed investigation of the central part of Chester County was made by Poth (1968). Groundwater occurrence in the Triassic sedimentary rocks of northern Chester County and adjacent areas is described by Rima and others (1962), Longwill and Wood (1965), and Biesecker, Lescinsky, and Wood (1968).

GEOLOGIC SETTING

The bedrock formations of Chester County are Precambrian, lower Paleozoic, and Triassic in age and are mapped and described on plate 2. They may be divided into four general groups: (1) Precambrian metamorphic and igneous rocks, which are mostly gneiss and igneous rock of similar composition; (2) upper Precambrian to lower Paleozoic metamorphic rocks, which are predominantly metamorphosed sedimentary rocks, mostly schist; (3) upper Precambrian and lower Paleozoic sedimentary rocks, some of which may correlate with group (2) above. These are mostly moderately metamorphosed limestone, dolomite, and quartzite; and (4) Upper Triassic sedimentary and igneous rocks, which are mostly shale, sandstone, conglomerate, argillite (indurated siltstone or mudstone), and diabase.

The bedrock is generally deeply weathered, and a zone of unconsolidated weathered rock covers most of the area. Minor alluvial and slope-wash deposits are present locally, but in this report they are not distinguished from the unconsolidated weathered rock.

The geologic structure consists of a series of extremely complicated anticlines and synclines that trend northeast, approximately parallel to Chester Valley. Major faults also trend northeast and may be normal, reverse, or thrust. Minor normal faults generally trend north or northeast. Triassic sedimentary rocks unconformably overlie older rocks in the northern part of the county. They generally strike east to southeast and dip north to northeast 10° to 20°.

Except for slight modification, the terminology used for the geologic units in this report are those of the Pennsylvania Topographic and Geologic Survey (Gray and others, 1960) and the Chester County Planning Commission (1973). The nomenclature does not necessarily follow the usage of the U. S. Geological Survey.

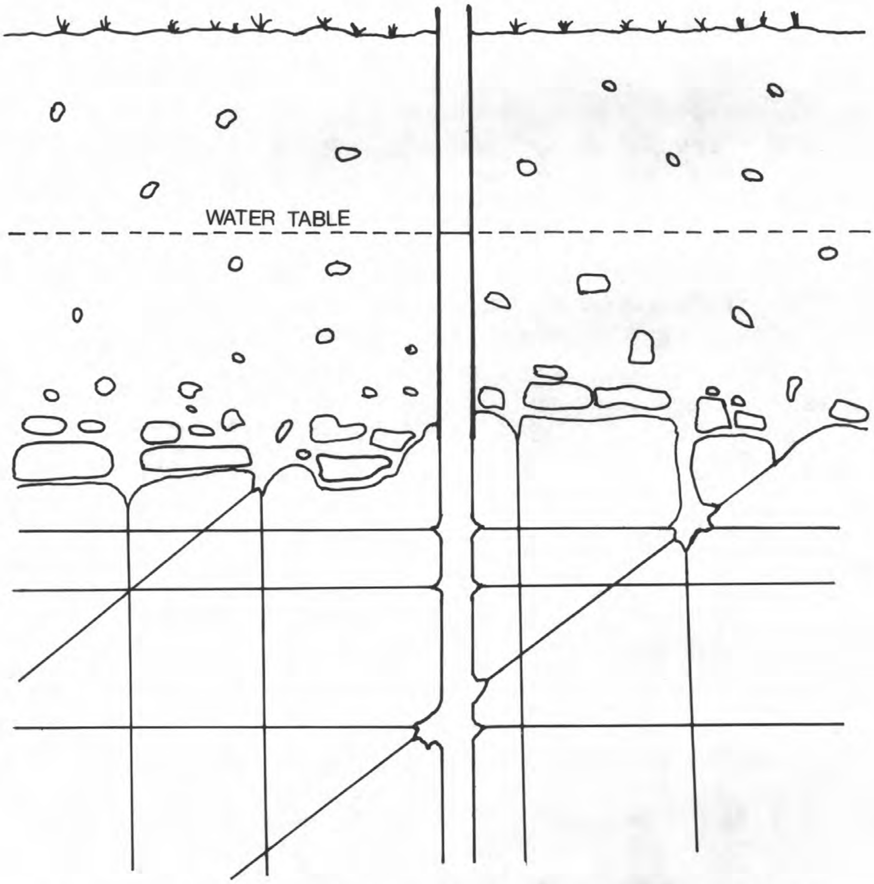

Figure 3.--Sketch of well tapping fractured rock.

GROUND WATER

Water-Bearing Units

All the geologic units in Chester County are water bearing. The units are composed of crystalline rock or highly indurated sedimentary rock and contain water where the rock has been fractured, decomposed by weathering, or dissolved. Intergranular permeability is present only in intensely weathered rock, in some of the Triassic sedimentary rock, and in some of the quartzitic rock. The water-bearing units and their reported yields are listed in table 1.

Fracturing

Most wells in Chester County obtain water from fractured rock. (See fig. 3.) Fractures are common as a result of various natural stresses. Permeability of fractured rock depends on the number of fractures per unit area, the size of the fracture opening, and the interconnection of the fractures.

Weathering

Weathered rock is particularly significant to the hydrology of Chester County because it contains a considerable amount of water in storage. Weathering has been continuous in this area for millions of years; as a result, the weathered zone is exceptionally thick and extensive.

Weathering is a mechanical and chemical breakdown of rock by the actions of air, water, temperature, and biological activity. The process works progressively downward from the surface, where a soil is eventually formed, to the deep fractures, where circulating water slowly alters the rock. The change in the rock with depth is gradational. The upper part of the weathered zone is unconsolidated and grades from decomposed rock and soil to a crumbly, gravel-like material, where pieces of sand-to boulder-size rock remain in place in a clayey matrix. This zone generally has moderate to low permeability, but it is porous and has large storage capacity. Below the unconsolidated zone, the rock is generally solid; however, some minerals are heavily weathered, particularly along fractures. Permeability and storage capacity of the solid fractured rock generally decrease with depth as the degree of weathering decreases. The highest permeability probably occurs where the unconsolidated and solid rock merge. In this transitional area, openings in rock are formed or enlarged by the weathering process, but decomposition is incomplete and the openings are not plugged with clay. Storage capacity, however, is small because the rock has little porosity.

The thickness of the unconsolidated weathered rock ranges from zero to a few hundred feet. Such material was logged to a depth of 323 feet in well CH-2328 in graphitic gneiss (McGreevy and Sloto, 1976, table 7). Because most wells in Chester County have well casing set in the upper few feet of solid rock, casing depth usually indicates the thickness of the unconsolidated zone. Based on median casing depths, the average thickness of the unconsolidated weathered rock is about 60 feet (18 m) for graphitic gneiss, 50 feet (15 m) for carbonate rock, less than 20 feet (6 m) for diabase, and about 40 feet (12 m) for most other units. For Triassic sedimentary rock, the average thickness of the unconsolidated zone is probably less than the median casing depth of about 40 feet (12 m); the zone probably averages less than 30 feet (9m) in thickness.

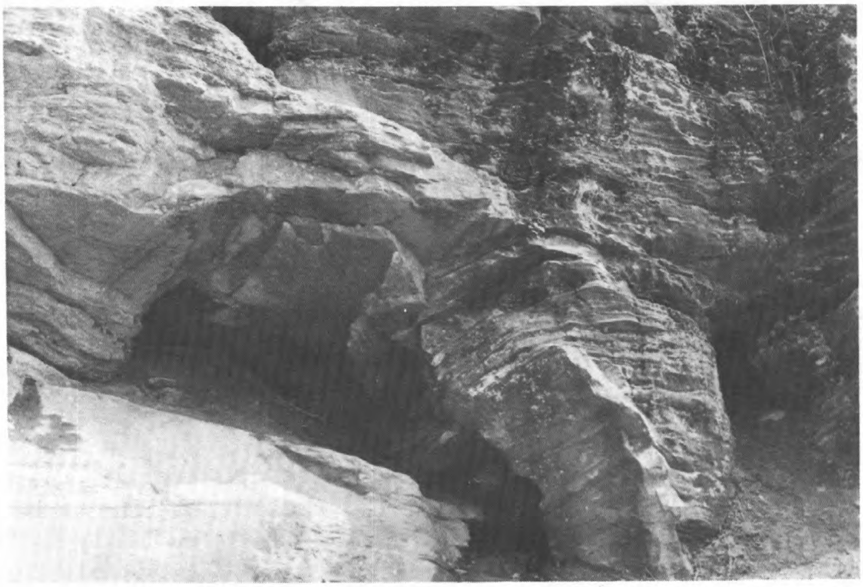

Figure 4.--Solution openings in carbonate rock (Cockeysville Marble). (Vertical distance at center of photograph is about 10 feet or 3 meters.)

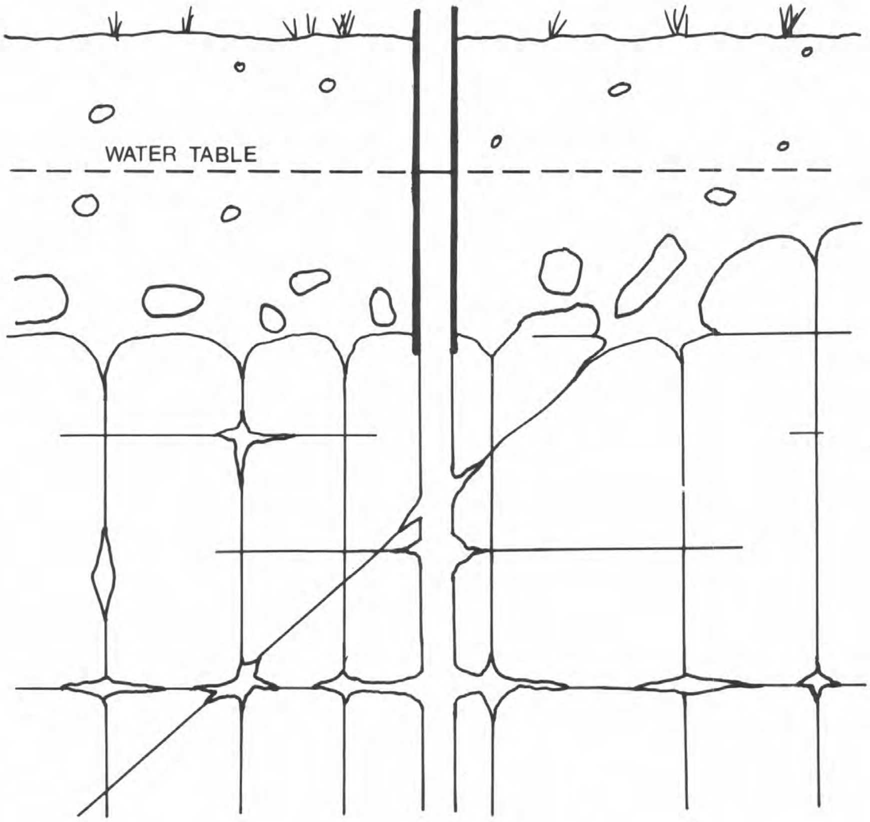

Figure 5.--Sketch of well tapping solution openings in fractured carbonate rock.

Solution of Carbonate Rock

Permeability of carbonate rock is predominantly a result of solution. As water moves through carbonate rock along fractures or other openings, it dissolves the rock and enlarges the openings. (See figures 4 and 5.) Where solution has been active, as in a fractured zone, permeability may be high; elsewhere, the same unit may be nearly impermeable.

Table 1.--Summary by aquifer of the reported yields of wells

Aquifer	Number of wells	Range of yield (gal/min)	Yield equalled or exceeded by the indicated percentage of wells (gal/min)				
			Percentage of wells				
			90	80	50	20	10
Diabase	4	0.5- 40	-	-	9	-	-
Triassic sedimentary rock	155	4 -1,300	8	10	20	80	150
Brunswick Formation	62	5 -1,300[a/]	8	10	15	80	150
Quartz-pebble conglomerate	19	5 - 100	-	-	12	-	-
Lockatong Formation	7	5 - 32	-	-	12	-	-
Stockton Formation	67	4 - 800	7	10	25	85	200
Carbonate rock	205	0 -1,800	4	10	35	150	330
Conestoga Limestone	45	0 -1,000[b/]	1	3	16	100	150
Elbrook Formation	34	0 -1,200	3	5	18	75	330
Ledger Formation	39	0 -1,125	5	15	100	258	725
Kinzers Formation	1	10	-	-	-	-	-
Vintage Dolomite	10	0 - 665	-	-	30	-	-
Cockeysville Marble	74	4 -1,800	10	20	73	200	350
Franklin Limestone	2	75 - 225	-	-	-	-	-
Quartzitic rock	119	.3- 110	4	6	15	30	50
Antietam and Harpers Formations	16	4 - 35	-	-	12	-	-
Chickes Quartzite	72	.3- 100	3	5	14	30	37
Setters Formation	31	1 - 100	4	12	20	50	80
Serpentinite	30	2 - 80	4	5	11	30	50

Table 1.--Summary by aquifer of the reported yields of wells--(Continued)

Aquifer	Number of wells	Range of yield (gal/min)	Yield equalled or exceeded by the indicated percentage of wells (gal/min)				
			Percentage of wells				
			90	80	50	20	10
Schist	683	0 - 400	4	6	15	30	60
Peters Creek Schist	110	0 - 312[c/]	4	5	10	20	30
Wissahickon Formation							
Chlorite phase	118	0 - 230	2	5	13	35	60
Mica phase	455	0 - 400	5	8	15	30	70
Gneissic rock	714	0 - 650	3	6	18	44	75
Pegmatite	3	7 - 35	-	-	-	-	-
Gabbro	24	3 - 100	6	10	15	30	60
Anorthosite	44	3 - 225	6	17	30	60	100
Quartz monzonite	62	1 - 180	5	8	24	50	75
Granodiorite	129	0 - 167	3	5	19	40	60
Gabbroic gneiss and gabbro	179	.5- 300	4	6	19	40	80
Granite gneiss	191	0 - 300	3	6	15	40	70
Graphitic gneiss	82	0 - 650	1	4	15	50	100

a/ One yield exceeded 224 gal/min

b/ One yield exceeded 220 gal/min

c/ One yield exceeded 70 gal/min

Permeability of Triassic Sedimentary Rock

The permeability of Triassic sedimentary rock differs from bed to bed and also laterally within the same bed due mostly to changes in lithology. The permeability may be intergranular or due to fracturing. Intergranular permeability depends on grain size, sorting, and cementing.

The most permeable beds are generally loosely cemented sandstone or conglomerate that may have both intergranular and fracture permeability. The least permeable beds are shale and argillite, which have little or no intergranular permeability, but which may have some permeability where fractured.

Well Information

Basic information on many of the wells in Chester County is contained in the report by McGreevy and Sloto (1976). Much of these data are summarized in tables in this section. Reported yields of about 1,900 wells are summarized in table 1. Depth to water for about 1,600 wells and well depth for about 2,100 wells are summarized in table 2.

Reported Yield

Reported yields are shown on plate 3 and are summarized by aquifer in table 1. Well yields commonly reflect the type of well use, as drilling generally continues only until a sufficient yield is obtained. Most of the data in table 1 pertain to household wells; the yields of such wells may not be the maximum available. With proper exploration, yields greater than the median (50 percent) in table 1 can probably be obtained from aquifers in most areas. Yields from carbonate-rock units, particularly the Cockeysville Marble and Ledger Formation, are generally higher than yields from other units. The Stockton and Brunswick Formations have the next highest yields. The difference in yield between nearby wells in the same unit, however, may be greater than the difference in yield between wells in different units. Exceptionally high yields of 100 gal/min (6 l/s) or more were reported in almost all parts of the county and from almost all units, as were exceptionally low yields of 5 gal/min (0.3 l/s) or less. (See pl. 3.)

Table 2.--Summary of data on depth of wells and depth to water

Unit	Number of wells	Range (feet)	Depth equalled or exceeded by the indicated percentage of wells (feet)				
			Percentage of wells				
			90	80	50	20	10
Depth of wells							
Diabase	5	78- 225	--	--	90	--	--
Triassic sedimentary rock	160	16- 902	80	95	125	260	400
Carbonate rock	237	16- 605	55	70	120	240	340
Quartzitic rock	140	16- 490	70	85	120	210	250
Serpentinite	31	40- 310	45	65	100	125	220
Schist	781	13-1,004	65	80	120	201	300
Gneissic rock	770	10- 550	55	70	100	200	250
Depth to water below land surface							
Diabase	3	22- 52	--	--	--	--	--
Triassic sedimentary rock	77	flowing- 165	1	8	17	38	60
Carbonate rock	181	flowing - 112	5	10	18	35	50
Quartzitic rock	102	flowing - 140	10	18	30	50	63
Serpentinite	23	5- 60	7	10	18	36	44
Schist	649	flowing - 110	6	12	25	42	50
Gneissic rock	604	flowing - 105	6	10	24	39	46

Reported Specific Capacities

Specific-capacity data, mostly reported by drillers, were obtained for almost 900 wells. The data are contained in the report by McGreevy and Sloto (1976, table 1) and are summarized in table 3. Specific capacity $(\frac{Q}{s})$ relates well yield (Q) to drawdown (s) and is expressed in gallons per minute per foot of drawdown, (gal/min)/ft. Specific capacity values may be converted to liters per second per meter, (L/s)/m, by multiplying by 0.207.

Specific capacity decreases as the duration of pumping increases. As a well is pumped at a particular discharge, the drawdown continues to increase, though at a gradually diminishing rate. Most of the reported data are for tests made by pumping with air. For this method of testing, drawdowns are not measured directly, but are estimated by assuming that drawdown is to the depth of the water-bearing zone or to the bottom of the well. As a result, the estimates of drawdown are generally high and cause the computed specific capacity to be erroneously low. These lower specific-capacity values can be considered to represent pumping periods longer than the actual tests. Thus, although most of the reported data are for tests of less than 1 hour, the reported values probably more nearly represent specific capacity after a few hours of pumping.

Results of Pumping Tests

Long-term (24-hour) specific capacity values were estimated from results of pumping tests of 94 wells. The tests were run by the U.S. Geological Survey, by well drillers, by the Green Valleys Association, and by well owners. The rate of increase in drawdown with time at a particular discharge was determined from a plot of drawdown against the log of time since pumping began. The values are expressed as $\frac{Q}{\Delta s}$ where Q is the discharge (in gallons per minute) and Δs is the change in drawdown (in feet) per log cycle of time (in minutes). Transmissivity (T), in square feet per day, has the relation, $T=35 \frac{Q}{\Delta s}$ (Ferris and others, 1962, p.100). From Johnson and others (1966, fig. 10), the more conservative 24-hour specific capacity values have an approximate relation, $T=300 \frac{Q}{s}$. Comparing these relations gives the approximate relation used to estimate long-term specific capacity:

$$300 \frac{Q}{s} \simeq 35 \frac{Q}{\Delta s}$$

$$\frac{Q}{s} \simeq 0.1 \frac{Q}{\Delta s}$$

The above comparison is based on well performance. Although the formulas defining transmissivity assume uniform conditions that are not usually present in the fractured-rock aquifers, each well <u>performs as if</u> the transmissivity in the vicinity of the well were a particular value. The estimates of long-term specific capacity from pumping tests are listed in table 4 and summarized in table 3.

Table 3.--Summary of specific-capacity data

Unit	Number of values	Range of specific capacity [(gal/min)/ft]	Specific capacity equalled or exceeded by the indicated percentage of wells [(gal/min)/ft]				
			Percentage of wells				
			90	80	50	20	10
Reported specific capacity							
Triassic sedimentary rock	47	0.08 -18	0.2	0.3	1.0	4.9	7.5
Carbonate rock	86	.002-90	.04	.1	1.8	9.0	25
Quartzitic rock	46	.002- 5	.04	.06	.3	.7	1.7
Serpentinite	18	.01 -38	.02	.1	.4	1.3	15
Schist	378	.002-38	.05	.09	.3	1.3	3.0
Gneissic rock	293	.001-50	.03	.07	.3	1.3	3.0
Long-term (24-hour) specific capacity estimated from pumping tests							
Triassic sedimentary rock	5	.05 - 2.4	-	-	1.0	-	-
Carbonate rock	14	.01 -44	.02	.8	3.9	15	32
Quartzitic rock	3	.008- .4	-	-	.2	-	-
Schist	57	.005- 6.6	.01	.02	.3	1.2	2.1
Gneissic rock	18	.02 - 3.8	.06	.08	.5	2.2	2.9

Table 4.--Long-term (24-hour) specific capaity estimated from pumping tests

Aquifer	Well number	Specific capacity (gal/min)/ft
Brunswick Formation	181	1.0
Stockton Formation	152	2.4
	1499	1.2
	1554	.5
	1597	.3
Conestoga Limestone	1023	.03
Elbrook Formation	209	7.1
	211	4.9
	2148	1.1
Ledger Formation	2147	1.3
	2361	4.2
Vintage Dolomite	765	.01
Cockeysville Marble	10	15
	56	0.8
	57	3.7
	172	44
	1989	19
	2125	1.2
Harpers Formation	1074	.2
Chickies Quartzite	1067	.008
Setters Formation	644	.4
Peters Creek Schist	169	.9
	749	.05
	776	.01
	868	.2
	880	.005
	979	1.1
	981	1.9
	983	1.4
	1000	.02
	1004	.3
	1015	3.0
	1037	3.2
	1056	.006
	1069	1.6
Wissahickon Formation		
Chlorite phase	735	.03
	781	3.0
	799	.03
	817	.6
	837	.01
	853	1.0
	882	.02
	883	.03
	932	.3
	970	.5
	1019	6.6
	1040	2.0
	1042	1.0
	1073	.5

Table 4.--Long-term (24-hour) specific capacity estimated from pumping tests -(Continued)

Aquifer	Well number	Specific capacity (gal/min)/ft	Aquifer	Well number	Specific capacity (gal/min)/ft
Wissahickon Formation			Gabbro	1959	.6
Chlorite phase					
(continued)	1078	.006	Quartz monzonite	227	.5
	1999	1.0			
	2169	.1	Granodiorite	2273	.4
	2196	.1			
	2334	.3	Gabbroic gneiss and		
	2336	.3	gabbro	560	1.2
				609	1.7
Wissahickon Formation					
Mica phase	179	.4	Granite gneiss	618	.2
	180	.03		636	.8
	562	.5		660	2.4
	569	.6		661	.03
	619	.1		704	.3
	646	.01		705	2.2
	718	.09		904	.07
	726	.09		974	1.0
	731	.08		1062	.3
	756	.01		1064	2.8
	775	.05		1080	.5
	777	.9		1717	.06
	809	.01			
	877	.03	Graphitic gneiss	1204	3.9
	948	.02			
	951	1.9			
	1018	1.3			
	1922	3.6			
	1994	.006			
	2009	.8			
	2187	.5			

Potential Yield

Data on yield and specific capacity were used to estimate potential yields that might be obtained with adequate exploration. Potential yield is expressed on plate 2 in terms of the number of wells required to yield 1 Mgal/d (0.04 m^3/s) continuously. Ranges in the number of such wells are indicated for each geologic unit. The larger number of the range for each unit is based on the reported yield exceeded by only 10 percent of the wells (table 1). It is assumed that such a yield can be obtained with adequate exploration. The smaller number of the range for each unit is based on the yield estimated from the value that was exceeded by only 10 percent of the specific capacities, assuming 100 feet (30 m) of drawdown. The yield estimated from this specific-capacity value is near the maximum yield reported for each unit and is assumed to be as great a yield as can be expected. (Exceptional wells have greater yields, but such yields cannot normally be expected.) The yield values obtained were then arbitrarily reduced by half to approximate the long-term average continuous yield. The number of such wells required to yield 1 Mgal/d (0.04 m^3/s) was computed, and geologic units that have approximately the same ranges were grouped together on plate 2. Use of this plate is discussed further in the section on exploration for ground water.

The units capable of the highest potential yields (1-5 wells per 1 Mgal/d on plate 2) are the Elbrook and Ledger Formations, and the Cockeysville Marble. The Elbrook and Ledger Formations are present in the county principally in Chester Valley, and the Cockeysville Marble occurs in the southern part of the county. Well data indicate that small areas of unmapped Cockeysville Marble may be present in a few valleys adjacent to mapped areas. Because topographic lows are characteristic of areas underlain by the marble, lows that extend beyond mapped areas are logical places to explore for the high-yielding marble.

Use of Aerial Imagery in Ground-Water Exploration

Types of Coverage

Aerial imagery of various kinds were evaluated as potential aids in the ground-water study. The imagery and approximate scales are:

Side-scanning radar imagery at scales of 1:250,000 and 1:125,000.

Infrared scanning at 1:24,000 for about a fourth of the area and at 1:48,000 for the rest.

Skylab photography, stereoscopic coverage at 1:1,000,000 in color, color infrared, and four bands in black and white that cover the visible spectrum and near visible part of the infrared spectrum.

Landsat - 1 and 2 (ERTS-1 and 2) scanned imagery, stereoscopic coverage at 1:1,000,000 and some enlargements to 1:250,000 -- four bands in black and white that cover the visible spectrum and near visible part of the infrared spectrum, and false-color composites.

Aerial photography:

1:100,000-scale, stereoscopic coverage in black and white infrared and in color infrared.

1:60,000-scale, stereoscopic coverage in black and white -- visible spectrum.

1:24,000-scale, stereoscopic coverage in black and white -- visible spectrum.

Aircraft-flown scanning, infrared and radar, were generally not as useful as other imagery because they did not provide stereoscopic coverage and because the scale was distorted by unstable aircraft speed and direction. As a result, mapping and interpretation of linear features is difficult.

Satellite scanning from Landsat-1 and 2 provide stereoscopic coverage of the county. (See fig. 6.) Landsat images from various dates from 1972 to 1975 were examined.

Skylab photography is at the same scale and provides the approximate photographic equivalent of the Landsat images. It is also available in color and color infrared. The detail of the photography is better than that of the Landsat scanning, but coverage is available for only one date.

One of the most impressive things about the Landsat and Skylab images is how much can be seen. The images give an overview of the geology and structure of the area that is not available from other sources. The whole area can be seen as a unit and it can be seen at many different times and under different conditions.

The aerial photographs (at 1:100,000, 1:60,000, and 1:24,000) and the satellite imagery (at 1:1,000,000 and 1:250,000) give five distinct scales of information. Each scale of imagery emphasizes particular features that are not as apparent at the other scales.

Mapping of Linear Features

Straight or gently curved linear features are visible on all scales of aerial imagery and most have geologic and hydrologic significance. Most of the linear features are related to variations in topography, vegetation, soil, and land use that, in turn, are related to variations in geology. The most apparent linear features at all scales are those related to rock type. Most noticeably, carbonate rock tends to form valleys and quartzitic rock tends to form ridges. Variations within a particular rock type may also be seen where part of a unit weathers and erodes more easily than other parts. Linear features may also indicate faults or fractures. (Compare the linear features of figure 7 and the stereopair of figure 6 with the geologic map of plate 2.)

Many linear features indicate fractures or fracture zones where (unlike faulting) little or no movement has occurred. Wells located on such features have increased chances of tapping fractured rock and tend to have higher yields than other wells (Nutter, 1974). During the study, five wells were drilled at sites on linear features identified on aerial imagery and verified in the field as probable fracture zones. Yield information on these wells is given in the following table.

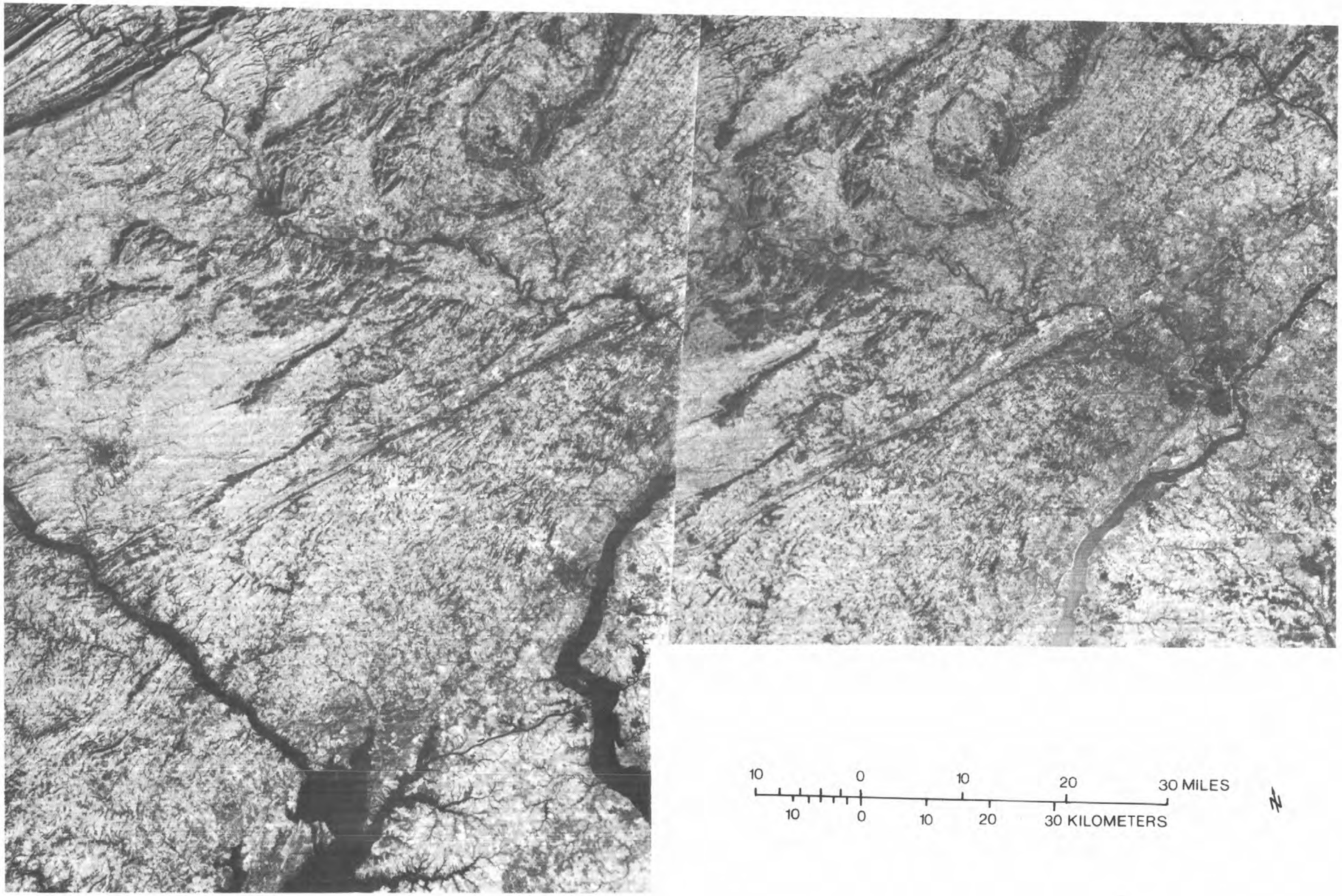

Figure 6.--Landsat-1 stereopair of Chester County and surrounding area. (Left side is band 7, January 9, 1973; right side is band 5, February 13, 1973; NASA Goddard Space Flight Center, through the EROS Data Center.) Refer to index map on cover for location.

Well number	Yield (gal/min)	Aquifer	Percent of wells in aquifer that have higher yields
CH-1922	300	Wissahickon Formation, mica phase	1
1959	100	Gabbro	0
2217	75	Franklin Limestone	-
2273	40	Granodiorite	20
2328	60	Graphitic gneiss	15

Plate 3 shows principal linear features that were visible on 1:60,000-scale aerial photographs. The mapped features that are shown are generally topographic lows, and most indicate zones of weakness in the rock. Some features can be interpreted as fracture zones and some as stratigraphic variations, but many can not be interpreted without field study. Most of the linear features shown on plate 3 were not studied in the field.

The mapping of linear features from 1:60,000-scale aerial photographs (pl. 3) and from satellite images (fig. 7) provide an overview of large-scale features. Investigations of potential well sites, however, would also include both field study and study of more detailed aerial photographs. Many short linear features (less than 1 mile or 1.6 km), commonly called fracture traces, are visible on 1:24,000-scale photographs, but may not be apparent on the 1:60,000-scale photographs.

Linear features and reported well yields are shown on a topographic base on plate 3. Many wells that have higher than average yields are located on the mapped linear features, but many others are not. Some of these high-yield wells that are not located on the mapped features are situated in topographic lows, such as draws, which are susceptible to being mapped on 1:24000-scale photographs as fracture traces.

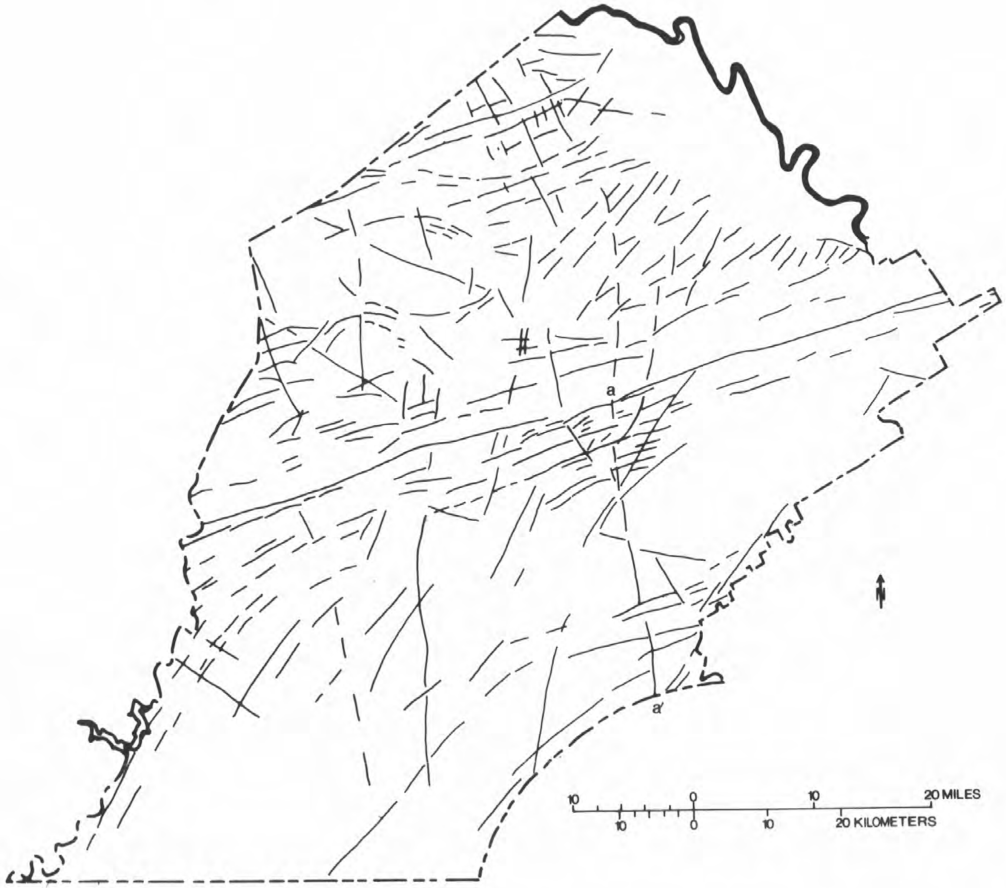

Figure 7.--Linear features of Chester County visible on various Landsat-1 and -2 images, 1972-75. (a-a′, linear feature explained in text.)

Figure 8A.--Fractures at different attitudes in phyllite of the Wissahickon Formation.

Figure 8B.--Irregularly spaced fractures and zone of concentrated fracturing in gneiss of the Wissahickon Formation. (Diameter of larger tree trunk is about 3 inches or 80 millimeters.)

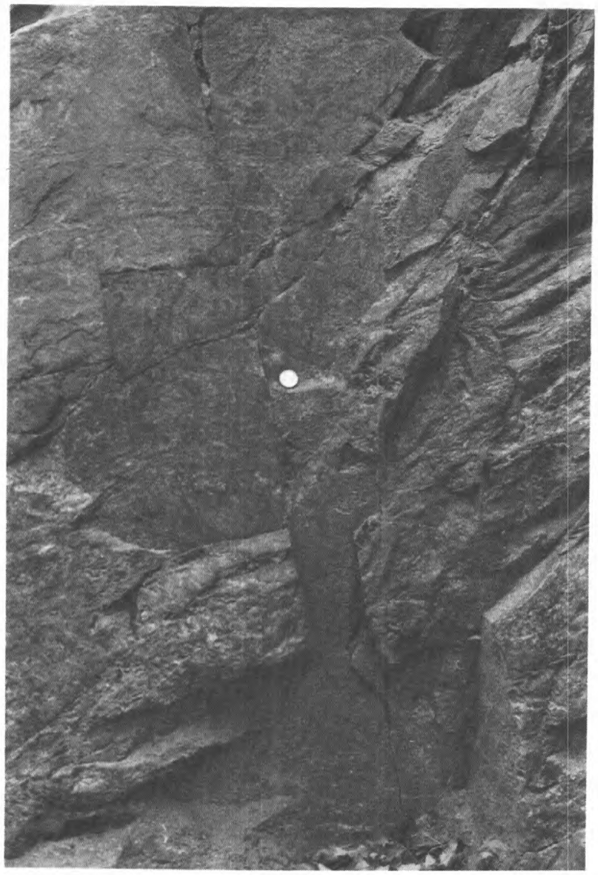

Figure 8C.--Close-up of gneiss of the Wissahickon Formation. (Nickel indicates scale.) Note the gross similarity of the appearance of the linear features to those of satellite imagery (Fig. 6).

Figure 8.--Fractured crystalline rock.

Linear features visible in outcrops and hand specimens of rock are clues to interpretation of aerial imagery. Most are fractures, but some are related to changes in rock or mineral type, to differential resistance to weathering, or to coincidental alinement of unrelated features. The fractures are irregularly spaced and some may be concentrated in zones. Several sets of parallel fractures may be present, each oriented at a different attitude. Photographs of selected outcrops of fractured crystalline rock are shown on figure 8.

The linear feature marked a-a' on figure 7 was examined at several locations in the field. The feature is an apparent alinement of various segments, some of which are draws, stream channels, and topographic lows that probably indicate fracture zones. Other segments of the feature, however, are apparently unrelated to fracturing and the alinement is apparently only coincidental.

Movement of Ground Water

The source of ground water is precipitation. Some water from precipitation runs across the ground to streams, some soaks into the ground, and some evaporates. Much of the water that soaks in is held in the soil and used by plants. Excess water in the soil moves downward to the water table and recharges the ground-water reservoir.

Most ground water in Chester County moves from where it enters the ground in uplands and hillsides to the nearby valleys, where it is discharged to the streams. Streams in the county, with rare exception, act as drains for the ground-water reservoir. Deep interbasin ground-water flow may occur, but it is probably a negligible part of the movement. Even in carbonate-rock areas, almost all ground-water movement is between interstream drainage divides and the adjacent streams.

The general direction of ground-water movement is indicated by water-level contour lines on plate 4. The lines connect points of equal hydraulic head. Ground water moves generally perpendicular to these lines, from areas of higher head (higher altitude) toward areas of lower head (lower altitude).

In most of the county, water-level contours generally represent the water table. In areas of the Triassic sedimentary rocks in the vicinity of the Schuylkill River, however, the contours represent the head of confined water that is tapped by most wells in that area. Much of the 100-foot (30 m) water-level contour along the Schuylkill River north of Valley Creek shows a head above land surface.

For a few short reaches of some streams, the water table is below land surface, and the streams lose water to the ground-water system. This generally occurs where permeability of the bedrock underlying a stream increases abruptly, as where the streams entering Chester Valley flow onto carbonate rock. A reconnaissance of seepage to and from several streams crossing Chester Valley was made November 13-14, 1973 (McGreevy, 1974), to investigate potential stream loss to carbonate rock. The study showed that some streams lose a little water in short reaches as they enter the valley, but they gain significantly from ground-water discharge through the rest of the valley. The water-table profile in Chester Valley (McGreevy, 1974, fig. 2) and the water-level contour lines of plate 4 indicate that the general direction of ground-water movement in the valley is from interstream divides to the local streams. At the time of the seepage study (a time of negligible direct runoff from precipitation), one-third to two-thirds of the streamflow leaving Chester Valley was gained within the valley. Significant interbasin flow of ground water is unlikely.

Water-Level Fluctuations

Water-levels in Chester County fluctuate mostly in response to precipitation and evapotranspiration. Precipitation is irregular but not seasonal (fig. 1). Hydrographs based on daily water levels show sharp rises in ground-water levels caused by individual precipitation events. (McGreevy and Sloto, 1976, fig. 2). Seasonal trends in water levels, however, are primarily the result of reduction of recharge during the growing season caused by evapotranspiration. Water levels generally decline during the growing season from midspring to midfall and recover during the rest of the year. Water levels for 1974, shown in figure 9 and in McGreevy and Sloto (1976, fig. 1), and water levels for 1963-65 for well CH-1018 (formerly number 956-555-1) in Poth (1968, pl. 3), indicate the general seasonal trend. Levels in June and July 1975 (fig. 9) rose during the growing season because of exceptionally high precipitation. Man-made modification of seasonal trends by discharge to wells or recharge from irrigation occurs only locally.

The bar graph shown on figure 9 indicates the relation of the water level to precipitation and runoff. The difference between total runoff and precipitation represents water eventually used by evapotranspiration. The bar graph is not a monthly water budget, however, because change of storage in the soil moisture zone and in the ground water reservoir are not taken into account. The average annual changes in storage are negligible (table 5), but monthly changes may be large.

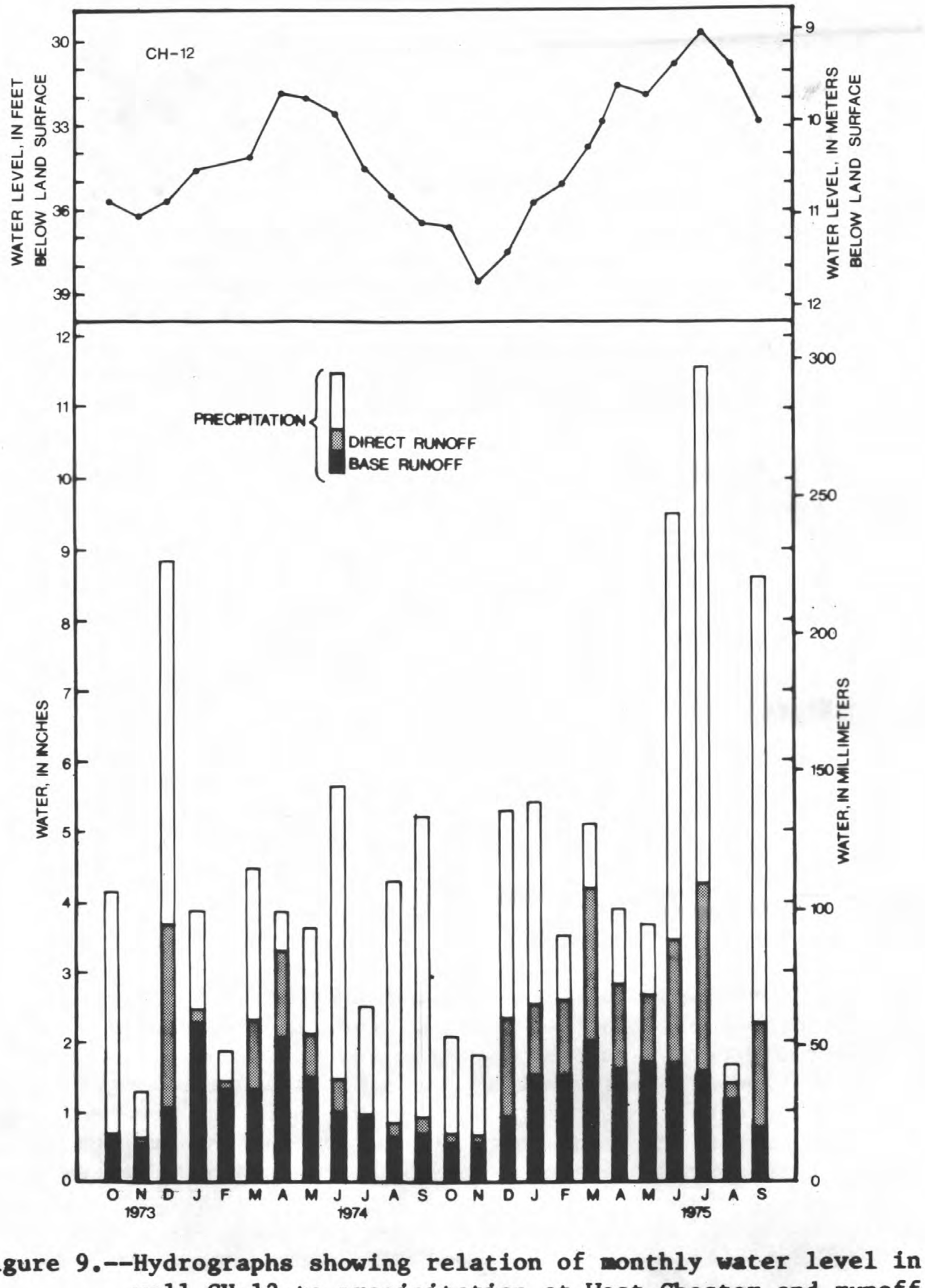

Figure 9.--Hydrographs showing relation of monthly water level in well CH-12 to precipitation at West Chester and runoff of East Branch Brandywine Creek below Downingtown (station 01480870), 1974-75 water years.

Water levels also have long-term fluctuations that depend on variations in annual precipitation. Figure 10 shows the water level at the end of the water year (September 30) compared to annual precipitation for water years 1955-75. The general relation is apparent.

Storage

In Chester County, water occupies most of the open space in the rock below the water table. This constitutes the ground water reservoir. Although a relatively small amount of water flows through the reservoir (water recharged from rainfall and discharged to streams), a much larger amount of water is contained in transient storage. This storage can be used just as storage in a surface reservoir. For restricted periods, more water can be withdrawn from storage than is being replenished. Water can be withdrawn in times of need and replenished during times of less need. However, water cannot be withdrawn from storage continuously without replenishment, or water levels will decline and streamflow will be reduced.

The exact amount of ground water in storage is unknown, but its approximate magnitude can be determined from estimates of specific yield and saturated thickness. Specific yield is the amount of water that will drain from a rock under gravity and is generally expressed as percentage by volume.

In Chester County, most ground water is stored in the unconsolidated weathered rock near the land surface. The average saturated thickness of this zone is estimated from the median depth of casing, which usually indicates the approximate depth to solid rock, and the median depth to water. In Triassic rocks, including diabase, the unconsolidated weathered material is thin, and casing depths are not a reliable guide to thickness; the unconsolidated zone probably lies above the water table and is unsaturated. In carbonate rock the estimated saturated thickness of the unconsolidated zone averages 35 feet (11 m), and in all other units it averages about 15 feet (5 m). A conservative estimate of the specific yield for this zone is 8 percent. (Olmsted and Hely, 1962, p. 18, estimated 7.5 to 10 percent).

Storage also occurs in fractures and solution openings in the upper 200 feet (60 m) of the consolidated rock in most units and the upper 500 feet (150 m) in Triassic sedimentary rock. (Deeper storage exists, but is assumed to be negligible.) The estimated specific yield is 0.5 percent for the carbonate rock and Triassic sedimentary rock and 0.2 percent in other rocks.

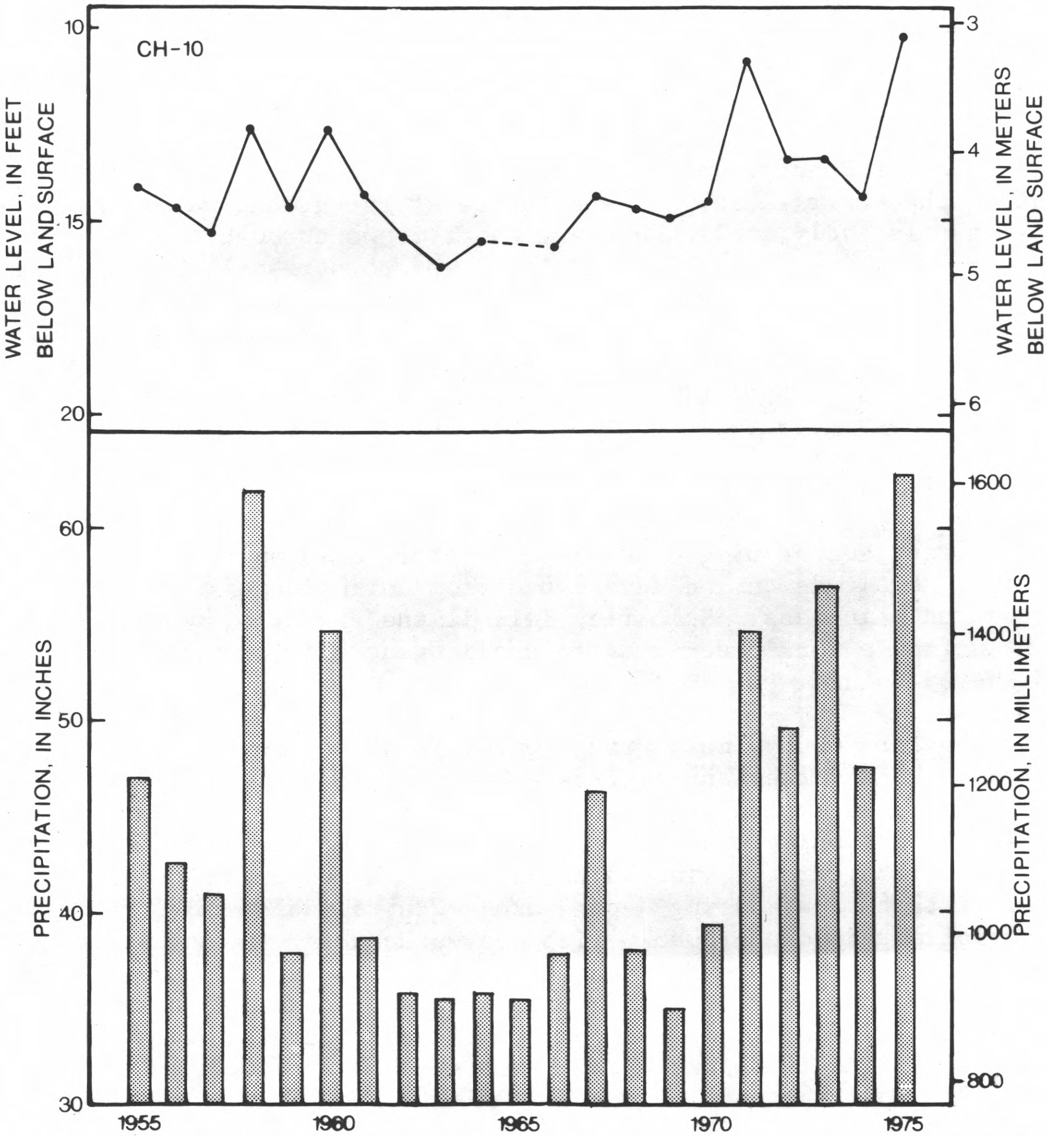

Figure 10.--Relation of water level at end of water year in well CH-10 to annual precipitation at West Grove, water years 1955-75.

The amount of ground water in storage in Chester County is estimated as:

Unit	Storage		Area	Total storage
	Feet of water	Million gallons per square mile	(Square miles)	(Million gallons)
Diabase	0.4	80	4	300
Triassic sedimentary rock	2.5	500	66	33,000
Carbonate rock	3.8	800	52	42,000
Other rock	1.6	300	638	190,000
Total storage in county (rounded)				300,000

WATER-BUDGET ANALYSIS

A water budget is a statement of the balance between water entering and leaving an area. A long-term average water budget for Chester County is given in table 5. Inflow to the county equals outflow plus or minus change in storage. When averaged over a long term, the change in storage is assumed to be negligible. Inflow items are precipitation, runoff (streamflow), ground-water underflow, and imported water. Outflow items are evapotranspiration, runoff, consumptive use, ground-water underflow, and exported water.

Long-term average runoff data are available only for Brandywine Creek at Chadds Ford, where 54 years of record are available. As figure 11 indicates, runoff at Chadds Ford for the 1968 water year was very near the long-term (54-year) average. Runoff for the entire county for the 1968 water year (table 6) is, therefore, used as the estimate of long-term average runoff for the water budget.

Precipitation data are available for the same 54-year period of record for only the West Chester weather station. The average annual precipitation at West Chester for this period was 45.4 inches (1,150 mm), which is only about 1 percent less than the 1931-60 normal of 46.03 inches (1,169 mm). Thus, the 1931-60 normal for Chester County weather stations is assumed to approximate the long-term (54-year) average precipitation. The average of the normals for Coatesville, Phoenixville, West Chester, and West Grove (45.41 inches or 1,153 mm) was used to estimate long-term average precipitation for the water budget. (See discussion of climate).

Estimates obtained from the Chester County Water Resources Authority (D.C. Yaeck, written commun., 1975,) and the Pennsylvania Department of Environmental Resources (Stephen Runkle, written commun., 1975) indicate that consumptive use of water has averaged less than 20 Mgal/d (0.9 m^3/s). Evapotranspiration is not estimated directly, but is assumed to equal the inflow minus runoff and consumptive use. Imported and exported water are negligible in this analysis.

Ground-water underflow is assumed to be negligible in the water-budget analysis. The ground-water yield of most basins in the county is measured in the streams as part of the runoff, and the small amount of underflow is negligible. In a few areas, such as parts of the Schuylkill River basin and the Pequea Creek basin, underflow may be significant. However, estimates of runoff (tables 6 and 7) are based on rates per square mile determined at gages where underflow is negligible; thus, underflow from such areas is included (approximately) in the estimate for runoff.

Most items in the water budget may be affected by man, and the budget may change in the future. Consumptive use may increase, as may importation of water for public supply and exportation of water through sewer systems. Changes in land use may occur that could affect evapotranspiration and runoff.

Table 5.--Water-budget analysis for Chester County

	Inflow (Mgal/d)	Outflow (Mgal/d)
Precipitation (Estimated long-term average)	1640	-
Runoff (Estimated long-term average)	10	630
Consumptive use (Estimated maximum long-term average)	-	20
Evapotranspiration (Inflow less runoff and consumptive use)	-	1000
Change in storage, ground-water underflow, and imported and exported water	Negligible	Negligible
	1650	1650

BASIN YIELD

The basin yield (total water yield of a basin) is included in the water budget as runoff and consumptive use. The consumptive use estimate amounts to only 3 percent of the runoff and is much less than the possible error of the runoff figures. Therefore, runoff will be considered equal to basin yield in this section.

Runoff includes direct runoff from precipitation and base runoff. The base runoff is mainly ground-water discharge to streams and provides an estimate of the amount of water moving through the ground-water system.

Basin yield or runoff is given in table 6 for major drainages and some sub-basins for a near-average year (1968 water year) following a near-average year, for a low-yield year (1966 water year) following a low-yield year, and for a high-yield year (1973 water year) following a high-yield year. Figure 11 shows the mean annual discharge of Brandywine Creek at Chadds Ford for water years 1963-74 and indicates the relation of the mean discharge for the 1966, 68, and 73 water years to the long-term (54-year) average.

Streamflow hydrographs are available for 15 stations for the 1973 water year, 13 stations for the 1968 water year, and 9 stations for the 1966 water year. The hydrographs were separated into components of direct (storm) runoff and base runoff (ground-water outflow). The separations were made by rough visual approximation, which attempted to average the base runoff through the storm periods rather than try to define it precisely. The results look similar to hydrograph separations illustrated in Olmsted and Hely (1962, fig. 2), which were derived from base-flow recession curves. Several more sophisticated methods of hydrograph separation are available, but even these leave questions about precision and interpretation. Probably too many uncertainties and variables are involved to hope to derive precise values.

Estimates of direct and base runoff for the various basins (table 6) are based on evaluation of the hydrographs. Where record is not available, estimates are based on correlation with gaged areas. The basin yield map of plate 2 shows the drainage areas used to compile table 6 and indicates basin yields for the near-average water year, 1968.

Table 6.--Basin yield for water years 1966 (low yield), 1968 (near-average yield), and 1973 (high yield)

Drainage basin	Drainage area (square miles)	Water year	Runoff[1/] Total Mgal/d/mi²	Total Mgal/d	Base Mgal/d/mi²	Base Mgal/d	Direct Mgal/d/mi²	Direct Mgal/d
Schuylkill River								
French Creek and other drainage above Pickering Creek	107.9	1966	0.50	54.0	0.26	28.1	0.24	25.9
		1968	.69	74.4	.45	48.5	.24	25.9
		1973	1.40	151.1	.81	87.4	.59	63.7
Pickering Creek and other drainage between Valley and Pickering Creeks	41.5	1966	.60	24.9	.32	13.3	.28	11.6
		1968	.80	33.2	.50	20.8	.30	12.4
		1973	1.57	65.2	.80	33.2	.77	32.0
Valley Creek and other drainage below Valley Creek	31.3	1966	.60	18.8	.32	10.0	.28	8.8
		1968	.85	26.6	.52	16.3	.33	10.3
		1973	1.48	46.3	.80	25.0	.68	21.3
Outflow from county	180.7	1966	-	98	-	52	-	46
		1968	-	134	-	85	-	49
		1973	-	263	-	146	-	117

Inflow to county, French Creek	6.9	1966	-	3.5	-	1.8	-	1.7
		1968	-	4.8	-	3.1	-	1.7
		1973	-	9.7	-	5.6	-	4.1
Basin yield from county	173.8	1966	-	94	-	50	-	44
		1968	-	129	-	82	-	47
		1973	-	253	-	140	-	113
Delaware River								
Outflow and basin yield from county -- Darby, Crum, Ridley, and Chester Creek drainages	56.9	1966	.61	35	.38	22	.23	13
		1968	1.05	60	.75	43	.30	17
		1973	1.61	91	.99	56	.62	35
Brandywine Creek								
West Branch above gage at Coatesville	45.8	1966	.50	23	.27	12	.23	11
		1968	.68	31	.45	20	.23	11
		1973	1.33	61	.76	35	.57	26
East Branch above gage near Downingtown	60.6	1966	.56	34	.30	18	.26	16
		1968	.76	46	.50	30	.26	16
		1973	1.48	90	.76	46	.72	44
Above gage at Chadds Ford	287	1966	.52	149	.32	92	.20	57
		1968	.89	255	.64	183	.25	72
		1973	1.36	390	.85	245	.51	145

Table 6.--Basin yield for water years 1966 (low yield), 1968 (near-average yield), and 1973 (high yield)-(Continued)

Drainage basin	Drainage area (square miles)	Water year	Runoff[1/] Total Mgal/d/mi²	Total Mgal/d	Base Mgal/d/mi²	Base Mgal/d	Direct Mgal/d/mi²	Direct Mgal/d
Brandywine Creek -(Continued)								
Below Chadds Ford	4.3	1966	.52	2.2	.32	1.4	.20	.8
		1968	.89	3.8	.64	2.7	.25	1.1
		1973	1.36	5.8	.85	3.6	.51	2.2
Outflow from county	291.3	1966	-	151	-	93	-	58
		1968	-	259	-	186	-	73
		1973	-	396	-	249	-	147
Inflow to county, West Branch and Delaware County	3.5	1966	-	1.9	-	1.0	-	.9
		1968	-	2.6	-	1.5	-	1.1
		1973	-	4.4	-	2.1	-	2.3
Basin yield from county	287.8	1966	-	149	-	92	-	57
		1968	-	256	-	184	-	72
		1973	-	392	-	247	-	145
Christina River								
Outflow from county -- Red Clay, White Clay, and Christina River drainages	98.2	1966	.45	44.2	.24	23.6	.21	20.6

		1968	.81	79.5	.52	51.1	.29	28.4
		1973	1.41	138.5	.91	89.4	.50	49.1
Inflow to county, White Clay drainage	1.1	1966	-	.5	-	.3	-	.2
		1968	-	.9	-	.6	-	.3
		1973	-	1.6	-	1.0	-	.6
Basin yield from county	97.1	1966	-	44	-	23	-	21
		1968	-	79	-	51	-	28
		1973	-	137	-	88	-	49
Chesapeake Bay								
Outflow and basin yield from county -- Big Elk, Little Elk, and Northeast Creek drainages	62.3	1966	.44	27	.22	14	.22	13
		1968	.80	50	.50	31	.30	19
		1973	1.30	81	.80	50	.50	31
Susquehanna River								
Outflow and basin yield from county (inflow negligible) -- Conestoga, Pequea, and Octoraro Creek drainages	80	1966	.48	38	.26	21	.22	17
		1968	.64	51	.42	34	.22	17
		1973	1.26	101	.68	55	.58	46

Table 6.--Basin yield for water years 1966 (low yield), 1968 (near-average yield), and 1973 (high yield)-(Continued)

Drainage basin	Drainage area (square miles)	Water year	Runoff[1/] Total Mgal/d/mi²	Total Mgal/d	Base Mgal/d/mi²	Base Mgal/d	Direct Mgal/d/mi²	Direct Mgal/d
Total basin yield from county (rounded)	760	1966	.5	390	.3	220	.2	170
		1968	.8	620	.5	420	.3	200
		1973	1.4	1,100	.8	640	.6	420

1/ Insignificant figures are carried to prevent the accumulation of round-off errors. All values are approximate--probably accurate within 10 to 20 percent.

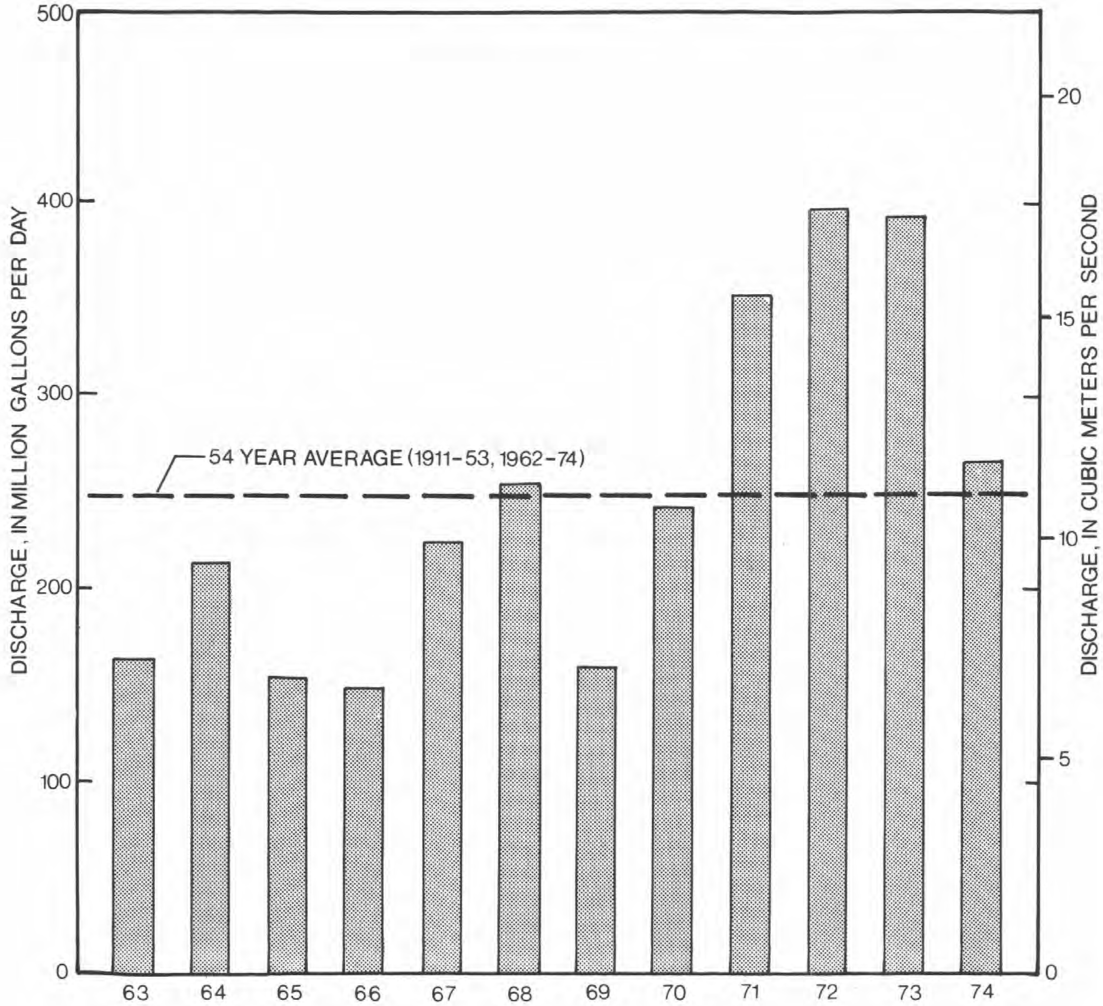

Figure 11.--Mean annual discharge of Brandywine Creek at Chadds Ford, water years 1963-74.

WATER QUALITY

The chemical quality of water is determined by the kind and amount of substances dissolved in it. These dissolved substances may come from several sources. Precipitation may dissolve gases and solid particles in the atmosphere and carry them to the land surface. Mineral constituents may be dissolved by solution and chemical breakdown during the weathering process as water percolates through soil and rock. The activities of man may alter the natural quality of ground water in many ways. Chemical constituents may be added from fertilizers, septic tank effluents, surface or subsurface waste disposal, and road salt. Man may also induce changes in water quality by changing land use. The presence of nitrate and chloride concentrations in ground water in Chester County that are significantly greater than in water in surrounding areas may indicate contamination.

Field Data

Determinations of specific conductance, pH, and hardness were made in the field. Field data are given by McGreevy and Sloto (1976, table 1) and summarized in table 7. Locations of the sampling sites are shown on plate 5.

Specific Conductance

Specific conductance, expressed in micromhos per centimeter (cm) at 25°C, is a measure of the ability of water to conduct an electrical current. Specific conductance is proportional to the amount of dissolved solids present in water. A good approximation of dissolved solids in milligrams per liter may be calculated by multiplying the specific conductance by 0.65. Average ratios of dissolved solids to specific conductance were computed for several aquifers from the chemical analyses given by McGreevy and Sloto (1976, table 3).

Aquifer	Ratio
Stockton Formation	0.63
Conestoga Limestone	0.63
Elbrook Formation	0.61
Ledger Formation	0.61
Chickies Quartzite	0.66
Serpentinite	0.56
Peters Creek Schist	0.66
Wissahickon Formation,	
Chlorite phase	0.60
Mica phase	0.66
Cockeysville Marble	0.61
Anorthosite	0.71
Quartz monzonite	0.86
Granodiorite	0.65
Granite gneiss	0.72
Graphitic gneiss	0.60

Field determinations of specific conductance were made at 742 wells. Specific conductances ranged from 15 micromhos per cm for a sample from the Chickies Quartzite to 1,150 micromhos per cm for a sample from a well near the contact of the mica phase of the Wissahickon Formation and the Cockeysville Marble. The ranges and median values for all the aquifers are given in table 7.

Table 7.--Summary of field determinations of pH, hardness, and specific conductance of ground water

	pH			Hardness (mg/L as $CaCO_3$)			Specific Conductance (micromhos per cm at 25°C)		
	Number of wells	Range	Median	Number of wells	Range	Median	Number of wells	Range	Median
Diabase	3	6.0-7.3		3	50-80	-	3	130-210	-
Triassic sedimentary rock	43	5.3-8.0	6.7	51	10-330	110	45	20-860	300
Brunswick Formation	15	5.3-7.6	6.3	21	10-250	130	16	70-680	320
Quartz-pebble conglomerate	5	5.4-7.1	5.8	5	10-90	30	5	20-280	110
Lockatong Formation	1	7.2	-	1	160	-	1	400	-
Stockton Formation	22	5.6-8.0	7.2	24	30-330	110	23	120-860	300
Carbonate rock	50	5.4-8.0	7.3	56	30-520	210	54	120-1,110	430
Conestoga Limestone	13	5.4-7.6	7.1	14	30-520	250	13	140-1,100	500
Elbrook Formation	9	7.1-8.0	7.4	10	160-300	260	9	360-960	560
Ledger Formation	10	7.0-7.8	7.4	11	160-470	260	11	360-1,000	510
Kinzers Formation	1	7.5	-	2	90-150	-	2	325-350	-
Vintage Dolomite	5	7.0-7.6	7.3	5	80-280	90	5	180-700	250
Cockeysville Marble	11	6.2-7.8	6.9	13	40-250	130	13	120-600	310
Franklin Limestone	1	7.4	-	1	140	-	1	330	-

Quartzitic rock	44	4.9-7.1	5.8	48	10-160	30	48	15-410	130
Antietam and Harpers Formations	8	5.0-6.8	5.7	8	10-60	30	7	30-350	130
Chickies Quartzite	27	4.9-6.6	5.7	29	10-90	30	30	15-400	100
Setters Formation	9	5.9-7.1	6.3	11	30-160	80	11	100-410	240
Serpentinite	8	7.3-9.1	8.1	13	40-250	140	13	105-510	350
Schist	270	4.8-7.9	6.1	299	10-420	40	301	20-1,150	120
Peters Creek Schist	70	4.8-7.6	6.0	71	10-140	40	71	45-500	120
Wissahickon Formation									
Chlorite phase	52	5.0-7.6	6.0	60	10-180	40	60	20-400	120
Mica phase	148	5.1-7.9	6.1	168	10-420	30	170	25-1,150	120
Gneissic rock	253	5.5-8.3	6.3	280	10-260	60	278	40-810	160
Pegmatite	2	5.8-6.1	-	2	10-90	-	2	80-250	-
Gabbro	8	6.0-7.2	6.4	8	30-230	40	8	90-600	170
Anorthosite	21	5.6-6.6	6.3	21	10-260	40	21	50-810	110
Quartz Monzonite	25	5.5-7.3	6.1	26	10-210	40	25	40-600	110
Granodiorite	41	5.6-8.3	6.2	43	10-210	60	41	60-450	160
Gabbroic gneiss and gabbro	51	5.9-7.1	6.4	55	10-160	60	56	50-360	180
Granite gneiss	85	5.7-7.7	6.4	104	30-180	60	104	60-480	180
Graphitic gneiss	20	5.6-7.4	6.3	21	10-180	60	21	50-420	180

Descriptions of the amount of dissolved solids in ground water, as used in this report, are defined as follows:

Description	Specific Conductance (micromhos per cm at 25°C)	Dissolved Solids (mg/L)
Very low	0-150	0-100
Low	151-250	101-160
Moderate	251-750	161-500
High	More than 750	More than 500

Specific conductance data indicate that the dissolved-solids concentration tends to be moderate in water from Triassic sedimentary rock and carbonate rock and very low to low in water from quartzite, schist, and gneissic rock.

The U. S. Public Health Service (1962) recommends that waters containing more than 500 mg/L of dissolved solids (about 750 micromhos per cm at 25°C) not be used for drinking if other, less mineralized supplies are available. This limit was set primarily by consideration of taste. The limit was exceeded in water from nine wells, which is about 1 percent of the wells sampled.

pH

pH is a measurement of hydrogen ion activity in water expressed in logarithmic units. A pH number indicates whether a water is acidic or basic based on a scale 0-14. Neutral water has a pH of 7. Water with a pH less than 7 is acidic; water with a pH greater than 7 is alkaline. Field determinations were made at 671 wells. The pH values ranged from 4.8 in the Peters Creek Schist to 9.1 in serpentinite. The ranges and median values for all the aquifers are given in table 7. The U. S. Public Health Service (1962) does not set a limit for pH of drinking water.

Acidic waters tend to be corrosive and may damage plumbing. Many cases of green or blue stains in sinks and bathroom fixtures as the result of corrosion of copper piping by acidic water were both observed and reported. In some places, the water caused pipes to leak and ruined valves. Damage to appliances such as washing machines was also reported. Some of the acid-water problems can be alleviated by the use of plastic pipe for plumbing or by the installation of a commercially available neutralizer.

Hardness

Hardness in water is caused by the presence of alkaline earths, chiefly calcium and magnesium. Hard water is generally not considered to pose a health problem. It can, however, create problems by causing soap to leave curd deposits or not lather or cleanse properly. It can also cause incrustations in boilers, pipes, and cooking utensils.

Field determinations of hardness were made at 750 wells. Ranges and median values are given in table 7. Ground water in the county ranges from soft to very hard, according to the following classification:

Description	Hardness (mg/L)
Soft	0-60
Moderately hard	61-120
Hard	121-180
Very hard	More than 180

Laboratory Analyses

Water samples from 151 wells and springs were analyzed in the laboratory to determine major ions and nutrients. Trace-element concentrations were determined for 58 of these wells and springs. Results of the analyses are given by McGreevy and Sloto (1976, tables 3 and 4). Locations of the sampling sites and the type of analysis are indicated on plate 5.

Major Ions and Nutrients

Major cations are calcium, magnesium, sodium, and potassium. Major anions are bicarbonate, sulfate, chloride, and nitrate. Carbonate is not present in water with a pH of less than 8.0 and is not a major ion in the ground water. It was found in very small concentrations in only three samples.

Results of analysis for nitrogen and phosphorus compounds (nutrients) in ground water from Chester County are given by McGreevy and Sloto (1976). As with most ground water, the samples analyzed contained little phosphorus or forms of nitrogen other than nitrate.

Sources of nitrate in ground water include biological activity within the upper soil zones, fertilizers, animal wastes, and sewage. Nitrate, as used in this report, is expressed in terms of dissolved nitrate as nitrogen. The U. S. Public Health Service (1962) recommends that the nitrate concentration of drinking water not exceed 10 mg/L as nitrogen (45 mg/L as nitrate). Concentrations greater than the recommended limit can be harmful to infants. Ten percent of the samples analyzed in the laboratory had nitrate concentrations above 10 mg/L as nitrogen. Plate 5 shows sampling locations and nitrate concentrations for those samples that exceed the recommended limit.

Iron and Manganese

Both iron and manganese can cause a brownish color on laundry and add a bitter taste to water. The U. S. Public Health Service (1962) recommends a limit for drinking water of 0.3 mg/L for iron and 0.05 mg/L for manganese. Both limits were exceeded in about 20 percent of the samples analyzed in the laboratory.

Trace Elements

Analyses for trace elements include aluminum, arsenic, barium, boron, cadmium, chromium, cobalt, copper, lead, lithium, mercury, nickel, selenium, silver and zinc. None of the concentrations of these elements exceeded the U. S. Public Health Service (1962) recommendations for drinking water. Mercury and silver were not detected in any of the samples.

Generalized Ground-Water Quality

The dissolved-solids concentration of most ground water in the county is very low to moderate. The general composition is indicated by representative diagrams on plate 5. Calcium, magnesium, and bicarbonate are the principal ions in most of the water. Chemical-quality problems are predominantly caused by acidity, iron and manganese, or nitrate. Hardness is sometimes a problem.

Mineralized zones in the bedrock contain various metals such as lead and zinc, but excessive amounts of these and other trace elements were not found in water samples from 58 wells and springs. Incidents of lead poisoning from water are known in the study area, but the source of lead may have been the plumbing and not the ground water. Some older homes in the county may still have lead pipes, lead-lined storage tanks, or joints of lead-based solder. Acidic ground water, which is common in the county, may dissolve undesirable amounts of lead from such plumbing systems.

Water samples from 92 household wells and springs were tested for bacterial contamination. Two wells were found to be contaminated. Bacterial contamination is probably not widespread, but the results indicate that unsafe supplies are in use in the county.

Temperatures measured in the field and reported by drillers indicate that the temperature of ground water in Chester County ranges from 9°C to 15°C.

Quality Areas

Chester County has been divided into eight ground-water quality areas on plate 5. The locations of all sampling sites are also shown on the plate. The water-quality areas are generalizations based on laboratory analyses and field determinations, and where data are lacking, it is assumed that water-quality boundaries follow geologic boundaries. Ranges and median values of field determinations are given for each area. Chemical-quality diagrams show the proportions of major ions in samples from selected wells.

Geologic Units

The chemical quality of ground water in Chester County is associated more closely with rock type than with any other factor. Chemical analyses of water from the same geologic unit are generally similar. However, within the same unit, the mineral composition of the rock can vary enough to produce different kinds of water, as the ranges in table 7 indicate.

The following are generalized descriptions of the chemical quality of water from the geologic units. Descriptions are based on field determinations (table 7) and laboratory analyses (McGreevy and Sloto, 1976, tables 3 and 4). The limits referred to are those recommended by the U.S. Public Health Service (1962, p. 7, 8).

Diabase

Water from wells in diabase is generally acidic, moderately hard, and contains a low amount of dissolved solids. Two water samples from the diabase were analyzed in the laboratory. Iron in one sample exceeded the recommended limit.

Brunswick Formation

Water from the Brunswick Formation is generally acidic. In the quartz-pebble conglomerate, the water is generally soft and very low in dissolved solids. In the shale and sandstone, it is generally hard and contains a moderate amount of dissolved solids. Water from three wells in the Brunswick Formation were analyzed and none of the results exceeded recommended limits.

Lockatong Formation

One sample was collected from a well in the Lockatong Formation. The water had a pH of 7.2, a hardness of about 170 mg/L, and a specific conductance of 400 micromhos per cm at 25°. The analytical results did not indicate the presence of any constituents above recommended limits.

Stockton Formation

Water from the Stockton Formation is generally alkaline, moderately hard, and contains a moderate amount of dissolved solids. Water from nine wells in the Stockton was analyzed in the laboratory. Water from two wells exceeded the recommended limit for manganese, one for iron, and one for sulfate. The U.S. Public Health Service (1962) has a recommended sulfate limit of 250 mg/L.

Carbonate rocks

Water from the carbonate-rock aquifers is generally alkaline, hard to very hard, and contains a moderate amount of dissolved solids. Twenty-three samples from wells in the carbonate rocks were analyzed in the laboratory. Of the four samples from the Conestoga Limestone, half exceeded the recommended limits for iron and nitrate. Two of the five samples from the Elbrook Formation exceeded the limit for nitrate, and one exceeded the limit for dissolved solids. Four samples from the Ledger Formation and one sample from the Kinzers Formation were analyzed; however, no values exceeded recommended limits. Two samples from the Vintage Dolomite were analyzed; iron in one sample exceeded the recommended limit. Fifteen samples from the Cockeysville Marble were analyzed; manganese in one sample exceeded the recommended limit.

Antietam and Harpers Formations

Water from the Antietam and Harpers Formations is generally acidic, soft, and very low in dissolved solids. Three samples from wells in the Harpers were analyzed. Two samples exceeded the limit for manganese and one exceeded the limit for iron. Two samples exceeded the recommended limit for nitrate of 10 mg/L as nitrogen and the third sample had a nitrate concentration of 9.6 mg/L as nitrogen. Water from a spring in the Antietam Formation was analyzed, and the results did not exceed recommended limits.

Chickies Quartzite

Water from the Chickies Quartzite is generally acidic, soft, and very low in dissolved solids. Six samples were analyzed in the laboratory. Half of the samples exceeded the limit for iron, and one-third exceeded the limit for manganese. One sample exceeded the limit for nitrate.

Serpentinite

Water from the serpentinite is generally alkaline, hard to very hard, and contains a moderate amount of dissolved solids. Magnesium usually makes up 50 to 90 percent of the anions, and bicarbonate usually makes up 65 to 90 percent of the cations. Six samples from the serpentinite were analyzed. One sample exceeded the limit for iron.

Gabbro

Water from the gabbro is generally acidic, soft, and low in dissolved solids. Three samples were analyzed, and results did not exceed recommended limits.

Peters Creek Schist

Water from the Peters Creek Schist is generally acidic, soft, and very low in dissolved solids. Nine samples were analyzed. Three samples exceeded the limit for nitrate, two exceeded the limit for iron, and one exceeded the limit for manganese.

Wissahickon Formation

Water from the Wissahickon Formation is generally acidic, soft, and very low in dissolved solids. Seven samples from the chlorite phase were analyzed. One sample exceeded the limit for iron. Twenty-two samples from the mica phase were analyzed. Four samples exceeded the limits for iron and manganese. Field tests in an area about 2 miles (3 km) south of Avondale in New Garden Township, which is designated as area 8 on plate 5, showed abnormally high specific conductance compared to the surrounding area. A well in this area was sampled and the chemical analyses showed both nitrate and dissolved solids above recommended limits.

Setters Formation

Water from the Setters Formation is generally acidic, moderately hard, and contains a low amount of dissolved solids. Five samples from the Setters were analyzed. In two samples the nitrate concentration exceeded the recommended limit.

Anorthosite and quartz monzonite

Wells in both the anorthosite and quartz monzonite yield a calcium bicarbonate water of similar quality. The water is generally acidic, soft, and very low in dissolved solids. Five samples from anorthosite and seven from quartz monzonite were analyzed. One sample from the quartz monzonite exceeded the limit recommended for nitrate.

Granodiorite

Water from the granodiorite is generally acidic, moderately hard, and contains a low amount of dissolved solids. Ten samples were analyzed. Water from one well and one spring exceeded the limit for iron, and water from one well exceeded the limit for manganese.

Gabbroic gneiss and gabbro

Water from the gabbroic gneiss and gabbro is generally acidic, moderately hard, and low in dissolved solids. Six samples were analyzed. One sample had an iron concentration greater than the recommended limit.

Granite gneiss

Water from the granite gneiss is generally acidic, moderately hard, and contains a low amount of dissolved solids. Fifteen samples were taken from 14 wells and analyzed in the laboratory. Fifty-four percent of the samples exceeded the limit recommended for iron. Forty percent exceeded the nitrate limit. Thirty-three percent exceeded the limit for manganese. One well had a chloride concentration in excess of the 250 mg/L recommended limit.

Graphitic gneiss

Water from the graphitic gneiss is generally acidic, moderately hard, and contains a low amount of dissolved solids. The major ions are calcium and bicarbonate. Six samples were analyzed. One sample exceeded the limit recommended for iron, and one sample exceeded the limit recommended for nitrate.

Relation of Ground-Water and Surface-Water Quality

Streamflow during fair weather periods (base runoff) is derived primarily from ground-water discharge. Therefore, the chemical quality of the base runoff is related to the chemical quality of the ground water. Partial chemical analyses and biological data for streamflow at 50 stations in Chester County, collected from 1969-74, are given by Lium (1976). Locations of the stations are shown on plate 5. Samples collected by Lium in the fall of 1973, 1974, and 1975 during base-runoff conditions were analyzed for major ions, nutrients, and trace elements. Complete results of the analyses are published in the annual series, "Water Resources Data for Pennsylvania" (U.S. Geological Survey, 1974; 1975a,b).

Diagrams showing concentrations of major ions in samples from selected wells and streams are shown on plate 5. The similarity of most diagrams in the same ground-water quality area, whether from wells or streams, indicate the close relation of ground-water and surface-water quality during base-runoff conditions.

The drainage basin of Indian Run, a tributary to the East Branch of Brandywine Creek, covers approximately 2 square miles (5 km^2) and is mostly underlain by anorthosite. Relative concentrations of major ions in water from two wells tapping anorthosite are compared by diagrams in figure 12 with water from a surface-water sampling site. All samples have similar proportions of major ions, although the concentration in the stream is a little higher. Dissolved-solids concentration of water from the wells is about 60 mg/L and that of water from the stream is about 90 mg/L.

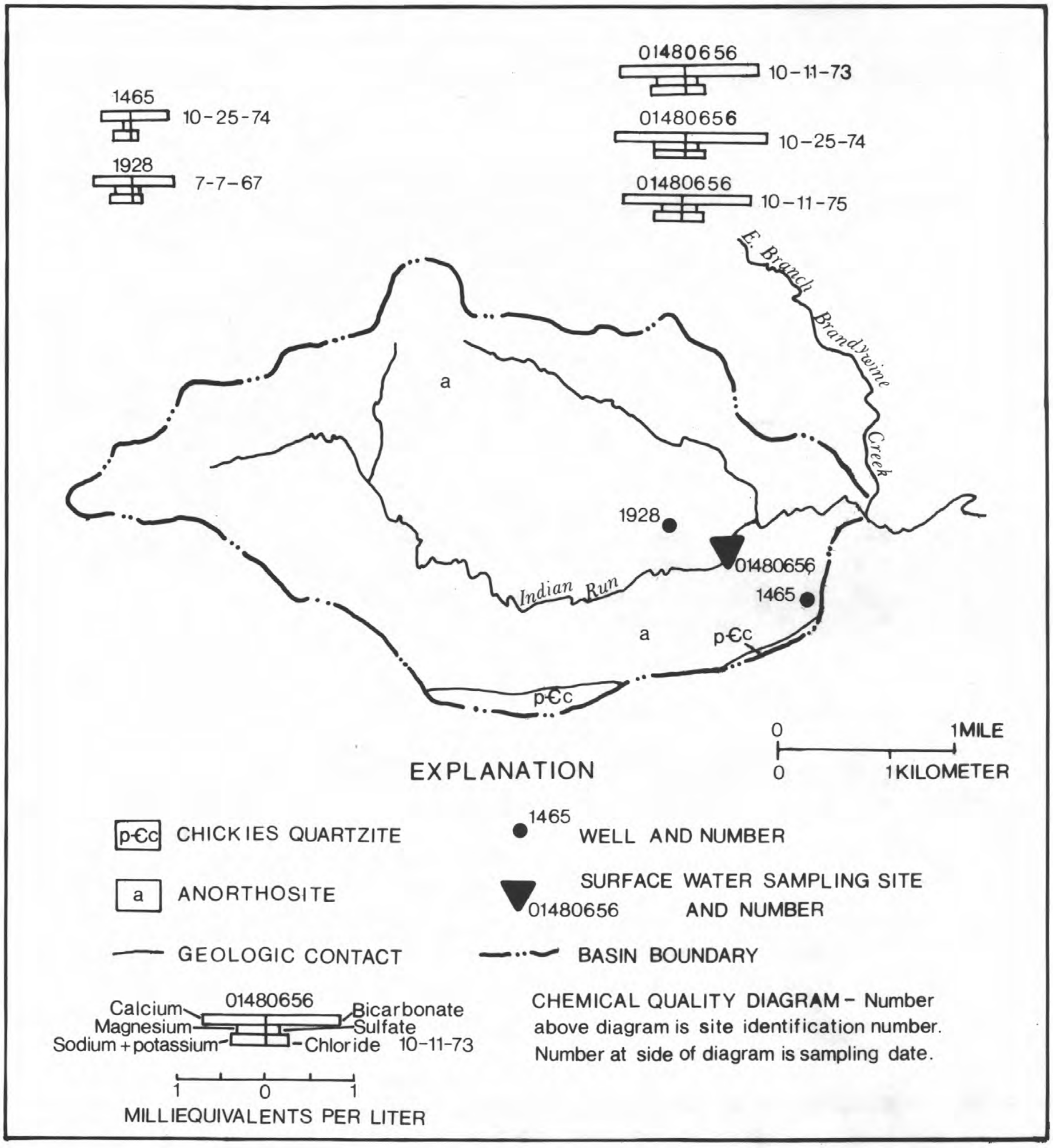

Figure 12.--Relation of major ions in ground and surface waters at selected sites in the Indian Run drainage basin.

Water quality in an area where man has affected the quality of streamflow and shallow ground water is illustrated in figure 13.. The general natural quality of water in the area is indicated on the figure by the nitrate values and the chemical-quality diagrams for water from the East Branch of Chester Creek (station 01476835) and from wells CH-351, CH-619, and CH-1459. The much higher chloride and somewhat higher nitrate concentrations in water from Goose Creek (station 01476840) and well CH-2322 indicate pollution. The station on Goose Creek is downstream from sites of industrial and municipal waste disposals. Well CH-2322 is shallow and is apparently affected by local septic systems. Although well CH-2322 is near Goose Creek, it is probably not affected by the creek because the stream most likely does not lose water in this reach.

Concentrations of selected trace elements in ground and surface waters were compared. Trace-element data were available for 81 surface-water samples from 49 stations. The samples were collected by Lium during base-runoff conditions in October 1973 and October 1974. These data were compared with data for 58 ground-water samples from 55 wells and 3 springs. The ground-water samples were collected mostly in October 1974. (See McGreevy and Sloto, 1976, table 4.)

Concentrations of arsenic, cadmium, chromium, cobalt, lead, and nickel were generally less than 10 ug/L in both ground and surface water. Concentrations of copper and zinc, however, were generally higher in water from wells than from springs or surface water. This may be the result of trace amounts of these metals being leached from copper pipes and galvanized pressure tanks.

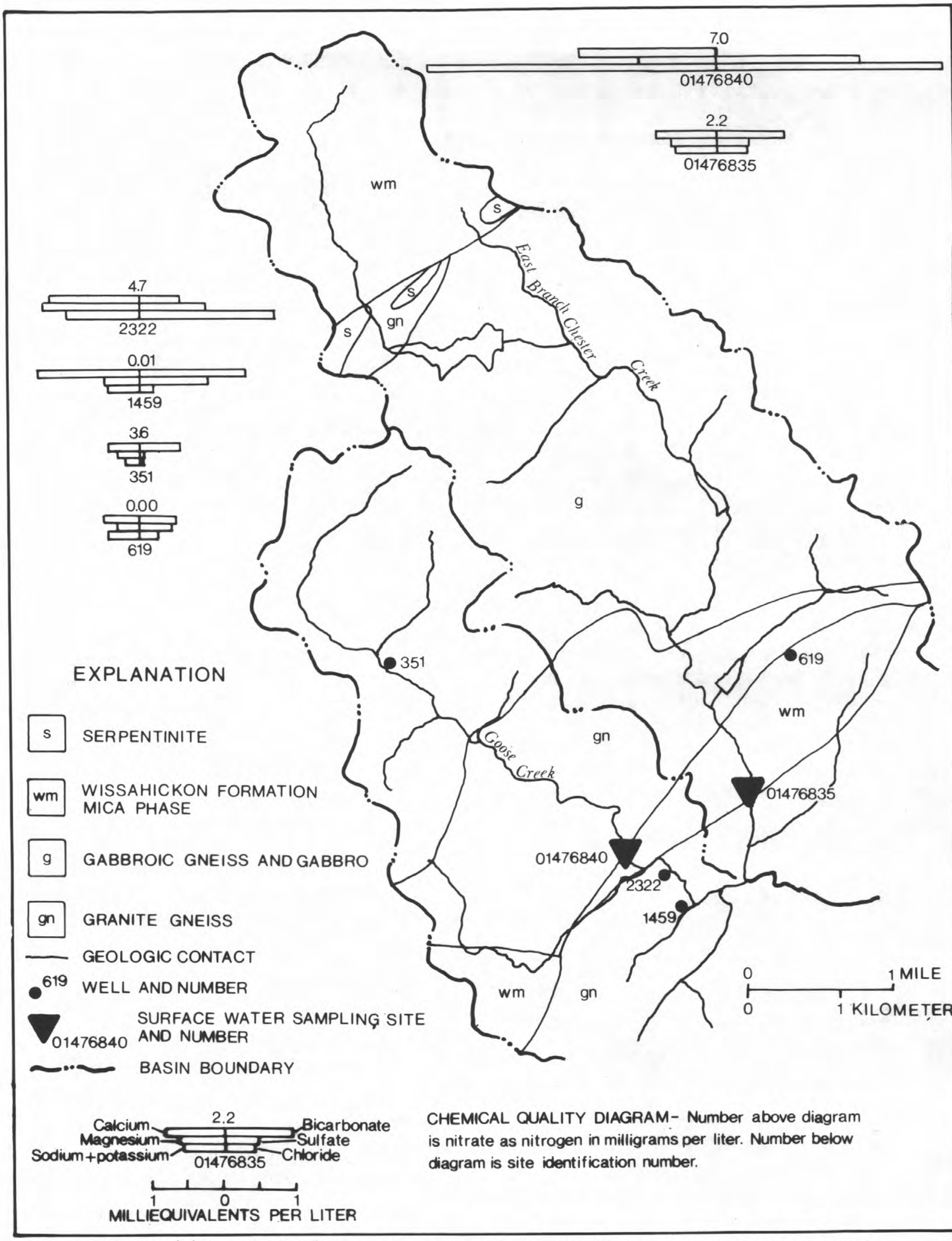

Figure 13.--Major ions in ground and surface waters at selected sites in the Goose Creek and East Branch of Chester Creek drainage basins.

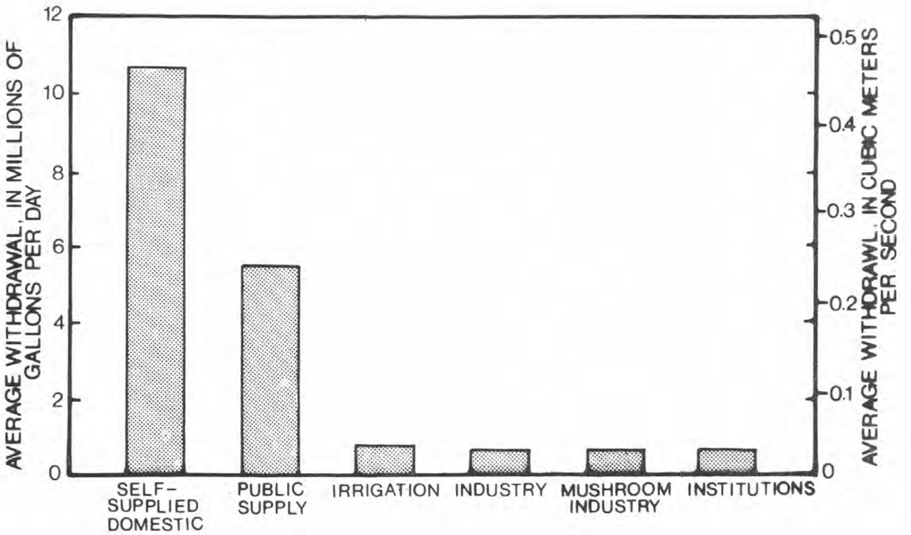

Figure 14.--Ground-water use, 1974.

GROUND-WATER USE

In 1974 approximately 7 billion gallons (26 hm^3) or an average of 19 million gallons per day (0.8 m^3/s) of ground water was used in Chester County. Almost 60 percent of this water was pumped from wells and springs by self-supplied domestic users. Public supplies accounted for another 30 percent. The rest was used by irrigation, industry, institutions, and mushroom growers and processers. This usage is shown in figure 14.

About 48 percent of the population is self-supplied with ground water. Another 13 percent is supplied by public water companies that obtain their water from wells. Thus, about three-fifths of the residents of Chester County depend upon ground water for household use.

Public Supplies

Public water systems provided water for 162,500 persons (52 percent of the residents) in Chester County in 1974. Wells and springs supplied about 28 percent of the water; the rest came from surface sources. The sources of water can be broken down as follows:

Ground water	5.5 Mgal/d
Surface water	14.5 Mgal/d
No breakdown available	0.6 Mgal/d
Total	20.6 Mgal/d

Public water companies serve the more densely populated areas of the county. In addition, many residential developments in rural areas are served by small water companies. These smaller companies use wells for their source of supply and usually provide water to only one development. Public water supply data for 1974 are listed in table 8, and areas served are shown on plate 6.

Per capita water use ranges from 49 gallons (180 L) per person per day to 200 gallons (760 L) per person per day. High per capita rates are found in the more densely populated areas because public water companies serve commerce and industry in addition to households. The lower per capita rates are found in areas where public water companies serve only private residences.

Most of the various federal, state, and county institutions in Chester County have their own water-supply systems. Their main source of supply is wells, from which 250 million gallons (0.95 hm^3) of water was pumped in 1974.

Self-Supplied Residential Users

People who live in parts of the county not served by public water companies are self-supplied by wells or springs. Generally, each home has its own well or spring, although in places several homes share the same well. In 1974, 3.87 billion gallons (15 hm^3) or 10.6 million gallons per day (0.46 m^3/s) of ground water was withdrawn by these self-supplied residential users. This estimate is based on the average residential use reported by public suppliers.

Industrial Use

An inventory made to determine the use of ground water by industry in 1974 indicates that 75 percent of Chester County's industries are connected to a public water system. Twenty percent of the industries pump their own ground water and five percent use surface sources. These industries are located in areas where public supplies are not available. A few of the companies on public supply also pump small amounts of ground water for use in cooling.

Ground water pumped by industries amounted to 250 million gallons (0.95 hm^3) in 1974. This water was used in manufacturing processes, cooling, and for boiler supplies.

The annual usage of ground water by industry has been declining in recent years for two reasons. As it becomes available, many industries are tying into public water systems. Also, a growing number of industries are now using closed-water systems in which the same water is recycled. In these systems only small amounts of water are added as needed to maintain the necessary quantity.

The mushroom industry in Chester County depends heavily upon ground water. A survey by the Chester County Water Resources Authority indicated that the industry used 240 million gallons (0.9 hm^3) of ground water in 1974. Eighty million gallons (0.3 hm^3) was used to prepare the compost in which mushrooms are grown and to water the crop. Another 160 million gallons (0.6 hm^3) was used to process and can the mushrooms.

Table 8.--Public-water systems, 1974

Name	Source of water	Well or spring number or stream	Quality			Amount of water used, 1974		Estimated population served, 1974	Per capita use (gallons per day per person)
			Dissolved solids (mg/L)	pH	Hardness (mg/L as $CaCO_3$)	Average daily (gallons per day)	Total (million gallons)		
Atglen Borough	2 springs	Sp-31	-	-	-	43,700	16	740	59
		Sp-32	-	-	-				
	2 wells	CH-1061	-	-	24				
		CH-1062	115	7.8	60				
Avondale Borough	2 wells	CH-2150	300	7.5	220	110,000	40.2	1,025	107
		CH-2151	265	7.4	170				
Chatwood Water Company	1 well	CH-2164	215	6.4	110	15,000	5.5	238	63
Citizens Utilities Home Water Company	Surface	Schuylkill River	-	-	-	598,000[a/]	218	4,600	130
	1 well	CH-2149[b/]	140	7.3	68				
Coatesville	Surface	Brandywine Creek	-	-	-	2,410,000	880	17,000	135
Downingtown Borough	Surface	Brandywine Creek	-	-	-	1,200,000	438	7,500	160
Exton Water Works	2 wells	CH-1315	284	7.7	100	60,000	21.9	685	88
		CH-1316	348	7.5	186				
Fox Knoll Water Company	1 well	CH-2153	-	-	-	4,000	1.5	70	57
Franklin Water Company	1 well	CH-1778	112	-	34	16,400	6	227	72
Friendship Water Company	1 well	CH-2152	220	5.6	76	18,000	6.6	249	72

Great Valley Water Company									
Milltown Tank	4 wells					542,100	198	9,048	60
Firethorn		CH-1453	110	6.5	30				
Grand Oak		CH-1454	-	-	-				
Oakbourne		CH-644	140	-	105				
Johnny's Way		CH-1714	-	-	-				
Boot Road Tank	3 wells	CH-1451	-	-	-	260,400	95	2,500	91
		CH-1452	76	6.1	30				
		CH-1716	90	6.2	44				
Pomona Park	1 well	CH-1457	60	7.2	100	52,600	19.2	967	54
Westtown Woods	2 wells	CH-668	-	-	-	11,300	4.1	203	55
		CH-1448	-	-	-				
Highland Glen	1 well	CH-1449	140	6.2	64	55,400	20.2	613	90
Mt. Bradford	1 well	CH-1450	138	6.4	60	6,100	2.2	70	87
Radley Run	2 wells	CH-1458	-	-	-	71,300	26	637	112
		CH-1718	-	-	-				
Chadds Ford Knoll	2 wells	CH-1461	-	-	-	26,700	9.8	333	80
		CH-1462	-	-	-				
Hammorton	1 well	CH-1447	102	6.3	60	51,300	18.7	588	87
Thornbury	1 well	CH-1460	124	7.2	106	6,300	2.3	81	78
Edgewood Chase	1 well	CH-1455	125	7.1	53	14,700	5.4	189	78
Dilworthtown Oak	1 well	CH-1717 b/	302	7.3	110	0	0	0	0
Total	20 wells					1,100,000	401	15,299	72
Hedgerow	1 well	CH-1997	154	7.1	80	2,100	0.8	39	54

Table 8.--Public-water systems, 1974 -(Continued)

Name	Source of water	Well or spring number or stream	Quality			Amount of water used, 1974		Estimated population served, 1974	Per capita use (gallons per day per person)
			Dissolved solids (mg/L)	pH	Hardness (mg/L as $CaCO_3$)	Average daily (gallons per day)	Total (million gallons)		
Honey Brook Borough	5 wells	CH-1242	81	6.9	54	142,500	52	1,226	116
		CH-1243	32	5.8	8				
		CH-1244	146	7.4	80				
		CH-1245	180	7.9	100				
		CH-2217[b/]	221	7.4	137				
Kennett Square Borough	Surface	Red Clay Creek	-	-	-	600,000	219		
	1 well	CH-45	185	-	130	325,000	119		
Total						925,000	338	5,000	185
Landenberg Manor	1 well	CH-2000	132	6.0	24	8,400	3.1	84	100
Lionville Water Company	4 wells	CH-260	88	6.4	43	350,000	127.8	4,764	73
		CH-261	142	6.2	61				
		CH-1228	224	7.8	92				
		CH-1298[b/]	-	7.0	144				
Locust Knoll Water Company	1 well	CH-1998	152	6.9	82	8,000	2.9	158	51

Malvern Borough	4 springs	Sp-27	-	-	-	330,000	120	3,100	106
		Sp-28	-	-	-				
		Sp-29	-	-	-				
		Sp-30	-	-	-				
	7 wells	CH-320	49	6.3	14				
		CH-321	110	7.0	59				
		CH-322	45	6.2	17				
		CH-2168	-	-	-				
		CH-2169[b/]	-	-	-				
		CH-2170[b/]	-	-	-				
		CH-2237[b/]	-	-	-				
Octoraro Water Company	Surface	Octoraro Creek	-	-	-	920,000	336	4,600	200
Oxford Borough	5 wells	CH-75	80	6.2	-	301,000	110	3,658	82
		CH-526	68	-	28				
		CH-2186	170	7.2	-				
		CH-2187	100	6.7	44				
		CH-2189	179	6.3	124				
Philadelphia Suburban Water Company	Surface	Schuylkill River	-	-	-	2,230,000	814		
		Pickering Creek	-	-	-				
		Perkiomen Creek	-	-	-				
	3 wells	CH-207	-	-	-	1,850,000	675		
		CH-209	-	-	-				
		CH-2199[b/]	-	-	-				
Total						4,080,000[a/]	1,489	38,850	105
Phoenixville Borough	Surface	Schuylkill River	-	-	-	3,600,000[a/]	1,314	18,000	200
Pottstown Borough	Surface	Schuylkill River	-	-	-	200,000[a/]	73	1,700	118
Southeastern Chester County Authority	Surface	Octoraro Creek	-	-	-	147,600	53.9	1,600	92
Uwchlan Water Company	1 well	CH-1204	190	7.6	92	9,000	3.3	125	72

Table 8.--Public-water systems, 1974 -(Continued)

Name	Source of water	Well or spring number or stream	Quality: Dissolved solids (mg/L)	Quality: pH	Quality: Hardness (mg/L as $CaCO_3$)	Amount of water used, 1974: Average daily (gallons per day)	Amount of water used, 1974: Total (million gallons)	Estimated population served, 1974	Per capita use (gallons per day per person)
West Bradford Water Company									
Marshalton Manor	2 wells	CH-2171	200	5.9	40	8,000	2.9	165	49
		CH-2172	86	5.9	38				
Marshalton Woods	4 wells	CH-2173	194	6.1	66	15,000	5.5	228	66
		CH-2175	154	6.5	52				
		CH-2176	58	6.3	26				
		CH-2177	56	6.1	25				
Colonial Woods	3 wells	CH-2178	-	-	-	400	.2	7	59
		CH-2179	-	-	-				
		CH-2180	-	-	-				
Total	9 wells					23,400	8.6	400	59
West Chester Area Municipal Authority	Surface	East Branch Brandywine Creek	-	-	-	2,200,000	803		
		East Branch Chester Creek	-	-	-	1,000,000	365		
	9 wells	CH-16	176	6.4	94	200,000	73		
		CH-2002	100	7.1	62				

		CH-2003	60	6.2	40				
		CH-2004	160	7.4	120				
		CH-2005	124	6.5	24				
		CH-2006	200	6.8	7				
		CH-2007	300	6.5	132				
		CH-2009 b/	179	7.3	83				
		CH-2010 b/	204	7.1	100				
Total						3,400,000	1,240	25,500	135
West Grove Borough	3 wells	CH-2165	185	7.4	125	130,000	47.4	2,200	59
		CH-2166	180	7.2	100				
		CH-2167	190	6.9	108				
Whitford Water Company	3 wells	CH-242	96	6.1	56	460,000	168	3,850	120
		CH-263	124	7.9	124				
		CH-264	132	8.0	132				

a/ Use in Chester County only.

b/ Well not in service in 1974.

Irrigation

Data from an irrigation survey made by the Chester County Water Resources Authority indicate that 300 million gallons (1.1 hm^3) of ground water was used for irrigation in 1974. The largest use was for horticulture, especially the rose-growing industry. The second largest use of irrigation water was for nursery stock. The amount of ground water used by agriculture for irrigation is largely dependent on precipitation during the growing season. In a dry year, water use is much greater than in a wet year.

EXPLORATION FOR GROUND WATER

Additional ground-water supplies may be obtained in Chester County, but there are certain natural limitations on well yield and basin yield. The following paragraphs discuss some of the steps or considerations in exploration for ground water in the county.

Initial well yield that may be expected in the areas available for exploration may be evaluated with the aid of table 1 and plates 2 and 3. Using scientific exploration techniques (assuming the area available is large enough), a well yield in the highest 10 percent of table 1 could probably be obtained; however, a yield in the highest 20 percent is more assured. A well or well field in Chester County cannot be pumped constantly at the initial (near maximum) yield. Consequently, the initial yield would probably need to be two or three times as great as the expected continuous yield (long-term average rate of use) of the proposed well or well field.

For each area considered for exploration, an estimate of the number of wells needed to produce the required yield may be obtained by using plate 2. The plate indicates the approximate number of wells needed to yield 1 Mgal/d (0.04 m^3/s) continuously. If the yield required for a proposed well field is 10 percent of 1 Mgal/d (0.04 m^3/s), then the estimated number of production wells needed for the well field would be 10 percent of the number of wells indicated by the plate. Plate 2 is generalized and contains assumptions that may not apply to a particular situation. Assumptions are that a large enough area is available for exploration and for installation of the required number of wells, that the most likely sites are tested by drilling, and that production wells are properly developed.

If a sufficient continuous yield can be expected from a proposed well or well field, then an evaluation of the ground-water yield of the basin supplying the well field is necessary. The approximate drainage area that will supply the proposed well field can be estimated roughly from the topographic map (pl. 3), and the expected yield per square mile can be computed. Estimates of the ground-water yield for various basins are given in table 6 as base runoff per square mile. Comparison of the expected yield per square mile and near-average (1968) base runoff per square mile provides a basis for estimating roughly the magnitude of potential long-term effects of the pumping. The amount of consumptive use and where the unconsumed water is to be returned to the system needs to be considered also.

Suppose, for example, that a well field in the Chesapeake Bay drainage basin is planned to have a yield of 1 Mgal/d (0.04 m^3/s) and that the water is to be exported from the area. The drainage area that would supply the well field is estimated to be 2 mi^2 (5.2 km^2). This amounts to a use of 0.5 (Mgal/d)/mi^2 [0.008 (m^3/s)/km^2]. From table 6, the amount of water going through the ground-water system (base runoff) in a near-average year is about 0.5 (Mgal/d)/mi^2 [0.008 (m^3/s)/km^2]. Theoretically, after storage has stabilized at some future time, the well would intercept all of the water going through the ground-water system in that drainage area, and streams in the area would flow only during storms. Such drastic reduction of streamflow has occurred in other parts of the country, but is unlikely in most of this area because of the generally low to moderate permeability of the aquifers. Instead, well yield would probably decline seriously before this extreme condition would be reached, and another source would have to be found to supply some of the required water.

Well CH-45 in the Red Clay Creek drainage basin supplies 0.3 Mgal/d (0.01 m^3/s) to a public-water system (table 8). Unconsumed water is not returned to the system in the area supplying the well. The drainage area supplying the well is 2.5 square miles (6.5 km^2). This amounts to a use of 0.12 (Mgal/d)/mi^2 [0.002 (m^3/s)/km^2]. From table 6, the amount of water going through the ground-water system in a near-average year is 0.52 (Mgal/d)/mi^2 [0.009 (m^3/s)/km^2]. In this case, long-term effects of the pumping on streamflow and ground-water levels should be moderate.

Carbonate-rock aquifers offer possibilities for the largest well yields; however, there are potential problems associated with pumping large amounts of water from wells in carbonate-rock areas. One problem is that water-level declines may induce collapse of weathered carbonate rock or residual materials,particularly where the rock is loaded by heavy structures or water bodies. When water levels are lowered by pumping, hydrostatic support given by the water may be removed. The weakened materials may collapse and sinkholes may form. (See Nutter, 1973, p. 21-23.)

Another potential problem is that some of the areas in which carbonate rocks occur have insufficient natural drainage area to supply large yields continuously. Water-level decline induced by pumping may alter the ground-water drainage divides and increase the drainage area supplying a well or well field. In areas where the divides are in permeable carbonate units, as in parts of Chester Valley, altering divides may increase the supply enough to balance large yields. Where the divides are in units of low permeability, less increase can be expected.

Interference may be a problem for some wells tapping Triassic sedimentary rock. Most water in the Triassic rock is semiconfined. The water is under pressure and water levels in wells stand above the level of the water-bearing beds. Pumping such a well reduces the pressure in the aquifer. The pressure reduction is transmitted rapidly, and water levels in wells several thousand feet from a pumped well may be affected within a very short time. The initial response may be quite rapid because it reflects pressure change rather than dewatering. Such pressure reduction may also induce leakage of water from overlying unconfined beds, and these materials may eventually be dewatered.

The amount of interference depends on the discharge and the degree of interconnection between wells. Wells tapping the same beds or the same fracture zones would have the most interference. Effects are not symmetrical, and a distant well in one direction may be affected more than a nearby well in a different direction. Interference caused by pumping a household well is generally small.

Interference may also occur between wells tapping aquifers other than the Triassic sedimentary rock, but the magnitude will generally be less. Interference is likely between nearby wells tapping the same fracture or solution zone, but effects in other wells will usually not be noticed.

Water-quality requirements may be compared with plate 5. The map indicates the general quality most likely in an area. It also gives sampling locations and types of quality data available in the report by McGreevy and Sloto (1976). The water-quality areas are generalized, however, and water quality may differ considerably between nearby wells in the same quality area. Ground-water quality would be influenced by land use; thus, anticipated changes in land use should be evaluated.

After an area has been evaluated and it has been judged that there may be sufficient water of suitable quality, exploration for drilling sites can begin. Most of the rock will not yield much water unless it has been altered by fracturing or weathering or by solution of carbonate rocks. Consequently, some sign of rock alteration would be sought. Topographic, magnetic, textural, vegetal, or other natural variations may give a clue to alteration of the rock. Topographic lows -- such as draws, valleys, or depressions -- were apparently eroded more easily than surrounding rock. Thus, they indicate possible zones of weakness in the rock. Topographic highs may indicate more solid rock. Linear features that appear to be fracture traces or other signs of weak rock may be seen on the ground or on aerial photographs. Magnetic, seismic, or electrical surveys may detect other variations in the rock that may not be visible at the surface.

Test wells in rocks of Chester County, except the Triassic sedimentary rock, would generally be drilled to less than 300 feet (90 m). If little water has been found by that depth, testing another site may be more productive than drilling deeper.

Test wells in Triassic sedimentary rock would usually be drilled deeper than 300 feet (90 m). Seventeen wells, 400 to 902 feet (120 to 275 m) deep, had a median yield of 200 gal/min (13 L/s). Particular beds or sequences of beds have greater permeability than others, and yields depend on tapping the permeable beds rather than on well depth. Depths to favorable beds may sometimes be estimated from information on nearby wells or from interpretation of the local geology.

CONCLUSIONS

Moderate supplies of water, 50 gal/min (3 L/s) or more, may be obtained from wells in almost all parts of the county, but not at all locations. Adequate exploration to find fracture or solution zones is required. Large yields, 500 gal/min (30 L/s) or more, may be obtained from some of the carbonate rocks, particularly the Cockeysville Marble and the Ledger Formation.

Ground-water quality is generally good. The dissolved-solids concentration is mostly low to moderate (less than 500 mg/L). Chemical-quality problems are caused predominantly by acidity, iron and manganese, nitrate, or hardness.

Basin yield or total water yield from the county averaged 0.8 (Mgal/d)/mi^2 [0.014 (m^3/s)/km^2] during a near-average water year, 1968. Of this, 0.5 (Mgal/d)/mi^2 [0.008 (m^3/s)/km^2] was base flow (ground-water outflow). Base flow during a low-yield water year, 1966, was 0.3 (Mgal/d)/mi^2 [0.005 (m^3/s)/km^2] and during a high-yield water year, 1973, was 0.8 (Mgal/d)/mi^2 [0.014 (m^3/s)/km^2].

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