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GROUND-WATER RESOURCES OF MONROE COUNTY, PENNSYLVANIA

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U.S. GEOLOGICAL SURVEY

Open-File Report 79-414

Prepared in cooperation with the

Topographic and Geologic Survey,

Pennsylvania Department of Environmental Resources

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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, SECRETARY

GEOLOGICAL SURVEY

H. William Menard, Director

CONTENTS

CONTENTS--(continued)

CONTENTS--(continued)

ILLUSTRATIONS

TABLES

GROUND-WATER RESOURCES OF MONROE COUNTY, PENNSYLVANIA

By

Louis D. Carswell and Orville B. Lloyd, Jr.

ABSTRACT

Monroe County is on the eastern border of Pennsylvania and includes much of the area popularly called the Poconos. It is an area long used for outdoor recreation and includes a part of the Delaware Water Gap National Recreation Area.

Water resources in the county are derived from precipitation. The Lehigh and Delaware Rivers, bordering the northwestern and southeastern parts, respectively, are the drains for surface-water and ground-water discharge and are essentially unused for water supply.

Water budgets were calculated for average conditions when annual precipitation is 45 in. Sixty percent of this or 27 in. runs off and 65 percent of that runoff or 17 in. moves through the ground-water reservoir. Evapotranspiration varies little between wet and dry years and averages 18 in.

Bedrock consists of Silurian and Devonian sedimentary rocks, which are intensely deformed by folding in the southeastern third of the county and are moderately deformed in the remainder. During the Pleistocene Epoch, glaciers repeatedly advanced across most of the county. The last of these advances deposited a terminal moraine that extends across the southwestern part of the county. The glaciers eroded pre-existing deposits, veneered the upland, and filled valleys with unconsolidated deposits that changed surface-water drainage and altered ground-water gradients.

Water occurs in fractures and solution openings in the consolidated rocks and in intergranular openings in the unconsolidated rocks and weathered calcareous sandstones. Water that reaches the water table moves down the hydraulic gradient to points of discharge, moving both laterally and vertically away from ground-water divides and toward streams. The thickness of the fresh-water system is 800 ft or more, but little water is yielded to wells by aquifers more than 500 ft below land surface. Ground-water recharge is 600 to 650 (gal/min)/mi^2; and about 1.6 billion gallons per square mile is stored in the ground-water reservoir.

Currently the most productive wells are in consolidated-rock aquifers; however, specific-capacity data suggest that wells in the unconsolidated deposits have potentially larger yields. Well yield is affected primarily by the distribution, size, and interconnection of the water-bearing openings and by topographic location, available recharge, well-depth, location within the flow system, pumping rate and duration of pumping, and interference from other pumping wells. Potential yields of properly located, drilled, and developed wells have been calculated for the aquifers. The median yields calculated from specific capacity data from the unconsolidated deposits, are 200 gal/min; from the Bloomsburg Formation, 100 gal/min; and from the Poplar Gap Member of the Catskill Formation, 70 gal/min. Median yields of the other units range from 15 to 40 gal/min. In general, enough water for domestic use can be obtained throughout the county. Large-scale development and consumptive use of the ground water will diminish baseflow of the streams.

The temperature of water measured in wells ranges from 44° to 57°F and is largely dependent on altitude of the land surface and depth to the producing zone. Hardness of water in the noncarbonate rocks averages 3 to 4 grains per gallon, or about half that of the carbonate rocks. Water from most of the bedrock aquifers is low in dissolved solids, acidic, and soft. In carbonate rocks, the water tends to be hard and slightly alkaline. Excessive amounts of iron and manganese are encountered in water from the unconsolidated deposits and, locally, from the Catskill and Shawangunk Formations.

INTRODUCTION

Monroe County is on the eastern border of Pennsylvania (fig. 1) and includes much of the mountainous area popularly called the Poconos. It is an area long used for outdoor recreation by people from metropolitan

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Figure 1.--(Caption on next page) belongs near here.

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areas in the northeastern United States. The establishment of the Delaware Water Gap National Recreation Area, a part of which is on the eastern border, is expected to increase the use of the county as a recreational center. There are more than 200 hotels, motels, and camps,and the resort industry is the largest single industry. Outdoor recreation is the largest principal use of the land. Farming is the dominant land use in the southern half. There are more than one hundred industrial plants employing 4,700 people. In addition, 3,700 people are employed at Tobyhanna Army Depot, which is the largest single employer. The county is transected from east to west by Route I-80 and from north to south by Route I-380 and Pennsylvania State Route 33. Stroudsburg, in the eastern part is the major urban center.

Figure 1.--Map of Pennsylvania showing location of Monroe County and physiographic divisions.

The resident population according to the 1970 census was 45,422, but summer visitors raise the population to more than 100,000. Projected seasonal population figures show an approximate fourfold increase by the year 2000 (Moody and Associates and E. C. Hess Associates, 1973, p. 31, and Roy F. Weston, Inc., 1970, p. 47). During the first half of the century many of the summer visitors were concentrated in resorts. Since 1950, however, there has been a steady decline of the old resorts and a rapid increase in the purchase of recreational lots and in the construction of seasonal or second homes, many are in recreational subdivisions or communities. A few of the subdivisions provide water supply and sewage disposal; however, the vast majority of people in recreational subdivisions and rural areas have their own wells and on-lot sewage disposal.

Approximately 20 small private water systems serve developments and resorts and derive their supply mainly from wells and springs. The urban areas of Stroudsburg and East Stroudsburg are supplied by surface water. The Borough of Delaware Water Gap is supplied mainly from wells.

Current total water use amounts to about 8 Mgal/d and per capita use is 75 gal/d. Moody and Associates and E. C. Hess Associates (1973) estimate the per capita use will increase to about 100 gal/d by the year 2000 and total water use will be about 35 Mgal/d, or more than a fourfold increase.

Purpose and Content

The rapidly increasing population will require water at an increasing rate. In anticipation of this need, the U.S. Geological Survey, in cooperation with the Pennsylvania Topographic and Geologic Survey, began this study as a part of their continuing program to investigate the ground-water resources of Pennsylvania. The report describes the significance, occurrence, movement, availability, and quality of ground water in the county.

Acknowledgements

The cooperation, information, and access to private and public property provided by land owners, companies, municipalities, and State and Federal agencies are gratefully acknowledged. Well drillers provided data on well locations and construction. Of particular help were the written reports of well construction and testing provided by Moody and Associates. The Pennsylvania State Game Commission gave permission to have an observation well drilled on State Game Land 214.

The well and quality of water data collected by S. W. Lohman (1937) has been incorporated into the U.S. Geological Survey's automatic data processing system and has been freely used with appreciation in writing this report.

Assistance in geophysical logging and in pumping and packer tests was provided by W. C. Roth, E. S. Cibort, R. L. Morningstar, and G. N. Griffin. Eugene H. Hess of the Pennsylvania Topographic and Geologic Survey facilitated the review of well records.

GEOLOGY

Bedrock in Monroe County is composed of sandstone, conglomerate, siltstone, shale, and small amounts of carbonate rock. These rocks have been intensely deformed by folding in the southeastern third and gently folded throughout the rest of the county. The rocks are cut by systematic sets of joints and fracture cleavage. During the Pleistocene Epoch glacial ice advanced across most of the county, leaving a veneer of unconsolidated deposits that modified the surface of the land.

The geology of Monroe County has been mapped in detail by personnel of the Pennsylvania Topographic and Geologic Survey and the U.S. Geological Survey. The mapping has resulted in a series of reports and maps that are listed in the selected bibliography. Those interested in details of stratigraphy, structure, glacial geology, geomorphology, and mineral resources are referred to these reports and maps.

The stratigraphic nomenclature used in this report is that of the Pennsylvania Topographic and Geologic Survey and does not necessarily conform with established usage of the U. S. Geological Survey.

Consolidated Rock

The consolidated rocks that immediately underlie Monroe County are of Silurian and Devonian age and are briefly described in table 1. The geologic map (fig. 2) accompanying this report was compiled by W. D. Sevon, J. B. T. M. Berg of Pennsylvania Geological Survey and J. B. Epstein of U.S. Geological Survey and shows the areal distribution of the units described in table 1.

Table 1.--Description of rock units in Monroe County (belongs near here).

Table 1.--Description of rock units in Monroe County.

System	Series	Group	Formation and member		Description	Thickness Feet
DEVONIAN	Upper		Catskill Formation: Duncannon Member		Characterized by red color, composed of grayish-red to medium-gray conglomerate, sandstone, siltstone and shale, possesses a well-developed joint system, forms hill and ridges on the Pocono Plateau.	850 - 968
			Poplar Gap Member		Medium-gray sandstones and conglomerate and minor red shales and siltstones, rare calcareous lenses, generally has a well-developed joint system. Equivalent to the Clarks Ferry, Berry Run, and Sawmill Run Members to the west in Carbon County, forms ridges north-west of the Pocono Plateau escarpment.	850 - 1,700
			Packerton Member		Greenish-gray to medium-gray fine-to medium-grained sandstone conglomeratic sandstone and conglomerate, rare calcareous lenses, forms low cliffs at the Pocono Plateau escarpment, possesses a well-developed joint system.	300 - 500
			Long Run Member		Member characterized by its red color, consists of alternating gray sandstone and red siltstone and shale. Forms the slope on the east and south of the Pocono Plateau below the Packerton and the core of the Weir Mountain syncline in the southwest part of the county.	2,360 - 3,500
			Beaverdam Run Member		Gray to greenish-gray sandstone with lesser amounts of greenish-gray siltstone and shale, contains marine fossils, has a well developed joint system. Characterized by lack of red strata, forms a low ridge.	0 - 963
			Walcksville Member		First characteristically red dominantly non-marine member of the Catskill Formation. Alternating greenish and gray sandstone and red shales, intertongues with both the Beaverdam Run and Towamensing members.	645 - 1,825

Table 1.--Description of rock units in Monroe County (continued)

System	Series	Group	Formation and member	Description	Thickness Feet
DEVONIAN	Upper	Catskill Fm.	Towamensing Member	Medium-gray fine-to medium-grained sandstone with interbedded silty shale and siltstone, arranged in cycles and intertongues to some degree with overlying Walcksville Member, gradational contact with Trimmers Rock Formation.	0 - 300
			Trimmers Rock Formation	Gray and olive-gray massive and fissile siltstones with minor shales. (Upper third is a ridge forming quartzitic sandstone.) Gradational contact with Mahantango Formation, grades upward into the Towamensing Member of the Catskill Formation, possesses a well-developed joint system.	600 - 1,700
	Middle	Hamilton	Mahantango Formation	Medium-dark-gray siltstone and shale, bedding largely masked by cleavage, thickens to the west.	1,825 - 2,400
			Marcellus Formation	Grayish-black, carbonaceous, fissile shale and silty shale, underlies the valleys from Bushkill to Scotia and most of the valley north and south of the Weir Mountain Syncline, joints have no pronounced orientation, grades upward through about 200 feet to the Mahantango.	800
		Silurian-Devonian, undifferentiated		Structurally complex sequence of carbonates, shales, siltstones, with minor calcareous sandstone and conglomerate.	
			Buttermilk Falls Limestone	Medium-gray argillaceous limestone, limestone, and calcareous argillite, thins to 80 feet (24 meters) in western part of the county.	270
			Palmerton Sandstone	Light-gray, massive, friable coarse to very coarse-grained, partly conglomerate sandstone, disappears in eastern part of the county.	0 - 110
			Scoharie Formation	Medium-gray, argillaceous siltstone, thins to the west.	100
	Lower		Esopus Formation	Medium dark-gray silty shale and siltstone, thins to the west.	181

Table 1.--Description of rock units in Monroe County (continued)

System	Series	Group		Formation and member	Description	Thickness Feet
DEVONIAN	Lower	Oriskany	Silurian-Devonian undifferentiated	Ridgeley Formation	Light-gray, fine-to coarse-grained calcareous sandstone and quartz pebble conglomerate, with minor beds of siltstone, limestone, and chert.	8 - 50
DEVONIAN	Lower	Oriskany	Silurian-Devonian undifferentiated	Shriver Chert	Weathered, white to orange chert, sandstone and conglomerate.	25 - 45
DEVONIAN	Lower	Helderberg	Silurian-Devonian undifferentiated	Port Ewen Shale	Medium-dark-gray calcareous shaly siltstone and silty shale.	150
DEVONIAN	Lower	Helderberg	Silurian-Devonian undifferentiated	Minisink Limestone	Dark-to medium-gray argillaceous limestone.	14 - 4
DEVONIAN	Lower	Helderberg	Silurian-Devonian undifferentiated	New Scotland Formation	Medium-to dark-gray calcareous shale and argillaceous limestone.	63 - 81
DEVONIAN	Lower	Helderberg	Silurian-Devonian undifferentiated	Coeymans Formation	Gray, argillaceous and arenaceous limestones, calcareous sandstone and conglomerate.	53 - 112
SILURIAN	Upper		Silurian-Devonian undifferentiated	Rondout Formation	Gray calcareous shale, argillaceous limestone and dolomite.	25 - 37
SILURIAN	Upper		Silurian-Devonian undifferentiated	Decker Formation	Conglomerate, calcareous sandstone and siltstone, argillaceous and arenaceous limestone and dolomite.	87
SILURIAN	Upper		Silurian-Devonian undifferentiated	Bossardville Limestone	Dark-gray argillaceous limestone.	100
SILURIAN	Middle & Upper			Poxono Island Formation	Olive-gray to green calcareous and dolomitic shale and dolomite, sandstone and siltstone.	700
SILURIAN	Middle & Upper			Bloomsburg Formation	Red, green and gray sandstone, siltstone, and shale and minor conglomeratic sandstone.	1,500
SILURIAN	Lower & Middle			Shawangunk Formation	Quartzose sandstone and conglomerate with some siltstone and shale forms the crest of Kittatinny and Blue Mountains.	1,400
ORDIVICIAN	Middle and Upper			Martinsburg Formation	Dark-gray to grayish-black claystone slate, underlies a small area between the northern end of Blue Mountain and Kittatinny Mountain, near Blue Mountain Pines.	

Unconsolidated Rock

The unconsolidated deposits of sand, gravel, silt, and clay that overlie the bedrock are the direct result of glaciation. Epstein and others (1974, p. 207) state "In the Lehighton and Palmerton quadrangles south of Stony and Chestnut Ridges, there is evidence for three and possibly four separate periods of glaciation." However, most maps of the distribution of glacial deposits in Monroe County indicate only two glacial advances. An early advance, of probable Illinoian age, covered most of the county, and a second advance, of late Wisconsinan age, covered about 75 percent. The extent of other advances is unknown because of the pervasive effects of erosion and deposition resulting from the last advance of ice.

The glacial deposits can be broadly subdivided into unstratified and stratified deposits. The unstratified deposits are till, which is composed of unsorted mixtures of boulders, sand, gravel, silt, and clay, largely of local origin and deposited directly from the ice sheet as ground or end moraine. Till masks the bedrock in most of the area and is as much as 125 feet thick in the terminal moraine. It reaches a maximum thickness of about 300 feet where it fills valleys formed before the last advance of the ice sheet.

Stratified deposits of poorly to well-sorted sand, gravel, silt, and clay were transported and deposited by glacial meltwater. These deposits were formed in contact with the ice, by streams flowing from the glacier, as outwash in flood plains and deltas, and as fine sediment in lakes and ponds formed as a consequence of glaciation. Epstein and Epstein (1967, p. 35) report extensive lake deposits in the area west of Saylorsburg, and Bucek (1971) indicates similar deposits in the general area of the Stroudsburg-Pocono airport. Peat formed in many of these lakes and slowly filled them (Cameron, 1970).

The effect of glaciation was to erode preexisting deposits, veneer much of the county with till, partially fill valleys, displace surface water divides, and alter the existing aquifers by changing gradients and divides and creating new aquifers in the valley fill. In areas covered with till, the capacity for infiltration of precipitation is generally poor, whereas in areas of outwash, it is generally good. Where outwash deposits are below the water table, they form a significant ground-water reservoir. Such deposits occur in the valleys of the Lehigh and Delaware Rivers, in the broad valley underlain by the Marcellus shale extending from Bushkill to Saylorsburg, around the Weir Mountain syncline, and in the valleys that drain the eastern and southern slopes of the Pocono Plateau.

Recent alluvium has been deposited on flood plains of the rivers and creeks, and colluvium covers the upper slopes of Kitattinny and Blue Mountains and the southern and eastern upper slopes of the Pocono Plateau. A landslide has been mapped in northern Chestnuthill Township, (Berg, 1975 p. 51).

Structure

Monroe County lies within two physiographic provinces, the folded Appalachian Mountain section of the Valley and Ridge province and the Pocono Plateau section and glaciated Low Plateau section of the Appalachian Plateaus province (fig. 1). Each province is characterized structurally by differing type and degree of deformation; however, the general alignment of structural of the entire area is persistent and is approximately N60° to 70°E. The rocks of the Pocono Plateau section dip northwest at progressively gentler dips away from the transition zone that separates the Pocono Plateau section from the folded Appalachian Mountain section.

The rocks of the Pocono Plateau section have been gently folded and contain few faults. In contrast, the rocks of the folded Appalachian Mountain section are intensely deformed by folding and faulting. The crests of Blue Mountain and Kittatinny Mountain form the southeast boundary of the county. These mountains are parts of a single narrow sinuous ridge supported by the upturned resistant rocks of the Shawangunk Formation. The Shawangunk dips steeply to the northwest and is locally overturned. The sinuosity of the ridge is a reflection of minor anticlinal and synclinal folds. Other structural features in the section are the Weir Mountain syncline and the Lehighton anticline in the southwest and smaller folds that occur throughout the area. Both the Plateau section and Appalachian Mountain section have systematic joints and cleavage and exhibit fracture traces and lineaments.

Fractures

The major sets of systematic fractures that cut the consolidated rock in Monroe County dip very steeply and in places are vertical. Two major sets exist, one oriented parallel to the regional structural grain (longitudinal fractures) and having a strike to N50° to 70°E, the other major set is at right angles to the structural grain (transverse fractures) and strikes N20° to 30°W. Several minor sets of fractures form oblique angles to the structural grain, such as N20° to 30°E and N28° to 40°W. Much of the water in the bedrock is stored in and transmitted through the openings along these fractures and along bedding planes. These openings are believed to become fewer and tighter with increasing depth below the land surface.

Porosity and Hydraulic Conductivity

Primary porosity and hydraulic conductivity are low in the consolidated rocks. Secondary porosity and hydraulic conductivity have been developed along fractures and bedding planes in the clastic rocks, especially in the carbonate rocks as the result of solution. The principal cementing material binding the clastic grains of the sedimentary rocks is, chlorite, sericite, hematite, and silica; all are comparatively insoluble in ground water. Exceptions to the above generalization are the sandstone beds of the Oriskany, Palmerton, Decker, and Coeymans Formations. These rocks have carbonate cement that is comparatively soluble in ground water. Where the carbonate cement has been weathered or removed by circulating ground water, a moderately large amount of porosity and hydraulic conductivity is developed. Wells in these sandstones then may need well screens to prevent caving.

In the southwestern part of the county, between Saylorsburg and Kunkletown on Chestnut and Cherry Ridges, residual white clay deposits and saprolites have formed in the limy shales and shaly limestones of Silurian and Devonian age. These deposits are beyond the southwestern limit of the late Wisconsin Glaciation. If similar deposits existed to the northeast, they were removed by glacial erosion. The extent and thickness of these deeply weathered deposits is unknown; however, according to Epstein and Hosterman (1969, p. 95), 182 ft of clay was penetrated by an exploratory borehole without reaching unweathered rock, and a recently drilled water well 3 mi south of Saylorsburg penetrated 400 ft of these deposits. Presumably, the depth to which carbonate has been leached extends below the interval of white clay into a zone of highly weathered rock, and there is a possibility that a significant ground-water reservoir has been formed in the secondary porosity produced by weathering beneath the area where the saprolite has been formed.

Summary of Water-Bearing and Water-Quality Characteristics of the Aquifers

The important water-bearing and water-quality characteristics of the aquifers are discussed in the following pages and summarized in figure 2. Yield characteristics are derived from the specific capacities shown on table 6, using an assumed drawdown of 25 ft for the unconsolidated aquifers and of 50 ft for the consolidated aquifers.

Figure 2.--Belongs near here (caption on next page)

Unconsolidated Rocks

Sand and Gravel

Saturated sand and gravel deposits constitute the most potentially productive aquifers. The thickest such deposits are found in the river valleys (fig. 3). If a storage capacity of 15 percent and an average

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Figure 3.--Belongs near here (caption on next page).

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saturated thickness of 65 feet is assumed, the unconsolidated deposits shown on figure 3 store about 70 billion gallons of water. In addition to this stored water, these deposits probably receive about 8 billion gallons of water per year as recharge from precipitation on the basis of water budget estimation. Further, because of their valley location, most of the ground-water discharge flows through these deposits. Thus, tremendous volumes of water could be withdrawn from the unconsolidated materials. If large withdrawals are planned, careful consideration should be given to the potential effect on stream flow.

Figure 2.--Bedrock geologic and hydrologic map of Monroe County.
(Back of report).

Figure 3.--Map showing saturated thickness of valley-fill unconsolidated glacial deposits in Monroe County. (Back of report).

Test drilling can be used to find the areas underlain by coarse, well-sorted, saturated deposits where high-yielding wells can be developed. Specific-capacity data indicate that one of every four wells located, drilled, and developed for high yield will probably produce 400 gal/min or more, with 25 ft of drawdown after 24 hours of pumping. In general the chemical quality of the water is good, but excessive concentrations of iron and manganese may be encountered. Dissolved solids average less than 100 mg/L, and the water will be acidic and soft. Because the unconsolidated deposits lie at the surface, they are particularly vulnerable to the degradation of the water quality.

Consolidated Rocks

Catskill Formation

The sandstones and siltstones of the Catskill Formation crop out or are covered only by unconsolidated deposits over about 70 percent of the county (fig. 2). Most of the recreational and resort areas are on the Catskill Formation and depend on it for their water supply. On the average, one of every four wells located, drilled, and developed for high yield will probably produce about 75 gal/min or more, with 50 ft of drawdown after 24 hours pumping. Wells in the Poplar Gap Member will probably produce about 215 gal/min, but only about 30 gal/min from the Towamensing Member. Chemical analyses of water from wells in the Catskill Formation indicate that dissolved solids concentration averages about 100 mg/L. The water is soft and acidic, and locally contains excessive concentrations of iron and manganese.

Trimmers Rock Formation

The siltstone of the Trimmers Rock Formation crops out or is covered only by unconsolidated deposits over a little more than 3 percent of the county. Specific-capacity data indicate one out of every four wells located, drilled, and developed for high yield produce 90 gal/min or more, with 50 ft of drawdown after 24 hour pumping. The chemical quality of water from these rocks is very similar to that from the Catskill Formation. Dissolved solids average about 110 mg/L, and the water is soft and acidic.

Mahantango Formation

The siltstone of the Mahantango Formation crops out or is covered only by unconsolidated deposits over 8.5 percent of the county. About 25 percent of the wells located, drilled, and developed in this formation for high yield will probably produce 70 gal/min or more, with 50 ft of drawdown after 24 hours of pumping. Water from wells in the Mahantango is much like that from wells in the Catskill and Trimmers Rock Formations. Dissolved solids average about 100 mg/L, and the water is generally soft and acidic.

Marcellus Formation

The shale of the Marcellus Formation crops out or is covered only by unconsolidated deposits over a little less than 5 percent of the county. This formation lies beneath a broad valley that is partly filled with thick saturated deposits of unconsolidated material. The combination of topographic position and the presence of the overlying saturated deposits makes it possible to develop very productive wells in what might otherwise be a rather poor aquifer. One of every four wells located, drilled, and developed for high yield will probably produce 110 gal/min or more, with 50 ft of drawdown after 24 hours of pumping. Dissolved solids in water from wells in the Marcellus Formation average about 100 mg/L. The water is soft to moderately hard and slightly acidic to neutral.

Silurian-Devonian Undifferentiated

The limestone, dolomite, calcareous shale and sandstone formations of this unit crop out or are covered only by unconsolidated deposits over about 9 percent of the County. Moderately large yields can be developed from wells in most of the formations in this unit. About one in four of the wells located, drilled, and developed for high yield will probably produce 160 gal/min or more, with 50 ft of drawdown after 24 hours pumping. In the purer carbonate rocks, like the Buttermilk Falls and the Poxono Island Formations, higher yields can be expected. Dissolved solids in water from wells throughout this unit range from about 100 to 400 mg/L and average about 250 mg/L. The water ranges from moderately hard to very hard and from slightly acidic to slightly alkaline. Higher concentrations of dissolved solids, hardness-causing constituents, and alkalinity are found in water from wells in the purer carbonate rocks.

Bloomsburg Formation

The sandstones, siltstones, and shales of the Bloomsburg Formation crop out or are covered only by unconsolidated deposits over a little more than 3 percent of the county. This formation occurs on the northern flank of Kittatinny and Blue Mountains and is covered to a great extent by saturated talus and colluvial deposits derived from the weathered conglomerate and sandstones of the Shawangunk Formation, that forms the crests of the mountains. The Bloomsburg Formation is the most productive consolidated-rock aquifer. One of every four wells located, drilled, and developed for high yield will probably produce 250 gal/min or more, with 50 ft of drawdown after 24 hours of pumping. The concentration of dissolved solids in water from the Bloomsburg Formation averages about 100 mg/L. In addition, the water is soft or moderately hard and slightly acidic.

Shawangunk Formation

The conglomerate and quartzose sandstone of the Shawangunk Formation crop out or are covered only by unconsolidated deposits over less than 2 percent of the county. Because these rocks form the relatively uninhabited crests of Kittatinny and Blue Mountains they are used very little for water supply. Thus, very little data are available to appraise their water-bearing and water-quality characteristics. Data from well Mo-199, drilled at Mount Minsi for the National Park Service, indicate water levels may be very deep, possibly greater than 200 ft and yields small, possibly less than 5 gal/min. The concentration of dissolved solids in water from well Mo-199 was only about 50 mg/L, but the concentrations of iron and manganese (6.2 and 0.43 mg/L, respectively) far exceeded the maximums (0.3 and 0.05 mg/L, respectively, recommended by the U.S. Environmental Protection Agency (1975). In summation, water from these rocks is probably very soft, acidic, and corrosive.

WATER BUDGET

Water budgets were calculated for seven drainage basins. (See Figure 4 and table 2). The period 1960-75 was used to represent

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Figure 4.--(Caption on next page) belongs near here.

Table 2.--Belongs near here.

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normal climatic conditions, as it is similar to the average conditions of the much longer period 1921-50 used by Parker and others (1964) in their study of the Delaware River basin. The period from 1963-66 represents dryer-than-normal and from 1972-75 represents wetter-than-normal conditions.

Figure 4.--Map showing drainage basins and gaging stations.

Table 2.--Water budgets for selected drainage basins
(units in inches)

	BASIN NAME						
	Bushkill	Brodhead Creek	Lehigh River	Tobyhanna Creek	Pohopoco Creek	Aquashicola Creek	Area-weighted average 2/
USGS Gaging station	4395	4425	4475	4477.2	4500	4505	
Drainage area (square miles)	117	259	92	118	109	77	
AVERAGE VALUES FOR 1960-75							
(P) Precipitation 1/	44.82	45.45	43.88	46.36	46.00	42.72	45.09
(R) Runoff	26.33	28.20	26.03	28.91	26.33	25.29	27.22
(WL) Water loss	18.49	17.25	17.85	17.45	19.67	17.43	17.87
AVERAGE VALUES FOR 1963-66 (4 dry years)							
(P) Precipitation 1/	35.89	36.46	34.34	36.99	36.57	33.32	36.20
(R) Runoff	16.38	17.79	17.22	19.46	16.76	16.11	17.46
(WL) Water loss	19.51	18.67	17.12	17.53	19.81	17.21	18.74
AVERAGE VALUES FOR 1972-75 (4 wet years)							
(P) Precipitation 1/	53.03	56.25	54.33	57.42	55.75	52.31	55.23
(R) Runoff	37.15	40.32	35.84	40.22	37.69	34.79	38.37
(WL) Water loss	15.88	15.93	18.49	17.20	18.06	17.52	16.86

1/ Precipitation was contoured then area weighted for each basin.

2/ Area weighted average is for the 5 stations shown and is presumed to be representative of the county.

3.

The water budgets were determined on a calendar year basis from the following equation and assume the system is in a steady-state condition:

$$P = R + WL$$

where P = Precipitation (rain and snow)

R = Runoff (overland runoff and ground-water discharge)

WL = Water loss (primarily evaporation and transpiration)

Precipitation

Precipitation is about 45 in. per year. More than 50 in. falls annually in the west-central part near Long Pond. Between 41 and 45 in. falls annually in the northern part (fig. 5).

Figure 5.--Belongs near here.

Average annual precipitation was about 9 in. below normal (45 in.) from 1963 through 1966 and about 10 in. above normal from 1972 through 1975 (table 3). The areal distribution of the precipitation during these two periods was similar to that shown on figure 5; the largest amounts occurred near Long Pond and smallest amounts along the northern and southern boundaries of the county.

Figure 5.--Map showing average annual precipitation 1960-75.

Runoff

Average annual runoff from 1960 to 1975 ranged from about 25 in. in the Aquashicola Creek basin to 29 in. in the Tobyhanna Creek basin. (See figure 4 and (table 3). The average annual runoff from the area was 27 in., or 60 percent of the average annual precipitation. During the 1963-66 and 1972-75 average runoff varied almost directly with the difference in average annual precipitation. From 1963 through 1966, annual runoff, like precipitation, was 9 in.below normal; from 1972 through 1975 they were both between 10 and 11 in. above normal. Runoff amounted to about 50 percent of precipitation during the dry period and about 70 percent of precipitation during the wet period.

Water Loss

Nearly all the net water losses listed for the budget periods were caused by evaporation and transpiration. Other net losses probably amount to less than 2 in. per year and are probably a result of flow of ground water below the base streams and out of the basin. The data in table 3 indicate the average amounts of water lost annually are fairly constant. Regardless of the amount of annual precipitation, 16 to 20 in. were lost to evaporation and transpiration. These water losses are fairly small, only amounting to about 40 percent of precipitation, as compared with those determined in south-central Pennsylvania, where water losses were about 65 percent of precipitation (Lloyd and Growitz, 1977). The small losses are largely a result of the low average annual temperature (about 48°F) in the relatively high average altitudes in Monroe County. More than 50 percent of the county is more than 1,000 ft. above sea level, and the highest altitudes on the Pocono Plateau are more than 2100 ft above sea level.

GROUND WATER

Contribution To Runoff

Streamflow hydrograph separations indicate that about two-thirds of the average annual runoff in Monroe County flows through the rocks and unconsolidated sediments (the ground-water reservoir) before it is discharged to the streams. Streamflow hydrographs for all the basins were separated into overland flow and ground-water discharge components by a method described by Linsley, Kohler, and Paulhus (1958, p. 156-157). The data in table 3 indicate there is only a small amount of variation (on the average ± 5 percent) in the proportion of ground-water contribution to streamflow. This is true for all possible comparisons

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Table 3.--Belongs near here.

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of basins and weather conditions listed in the table.

Recharge

The data in tables 2 and 3 indicate that during normal periods when precipitation was approximately normal (45 in.), recharge was between 16 and 19 in./yr, or 530-630 (gal/min)/mi^2. When the annual precipitation was 9 in. below normal, recharge was 10 to 13 in./yr or 330-430 (gal/min)/mi^2; and when the annual precipitation was 10 in. above normal, recharge was 25 to 30 in. or 830-990 (gal/min)/mi^2.

Table 3.--Ground-water contribution to streamflow for selected basins.

Basin name and gaging station number	1963 Precipitation 9 inches below normal			1969 Precipitation Approximately normal			1973 Precipitation 10 inches above normal			1963, 1969, 1973 basin average		
	Total runoff (inches)	Ground-water contribution (inches)	Percent ground water	Total runoff (inches)	Ground-water contribution (inches)	Percent ground water	Total runoff (inches)	Ground-water contribution (inches)	Percent ground water	Total runoff (inches)	Ground-water contribution (inches)	Percent ground water
Bushkill 4395	16.75	12.01	72	26.28	16.55	63	39.74	27.83	70	27.59	18.80	68
Brodhead Creek 4425	17.16	11.67	68	26.80	16.82	63	44.60	30.47	68	29.52	19.65	66
Lehigh River 4475	15.56	10.98	71	23.91	16.17	68	38.42	25.50	66	25.96	17.55	68
Tobyhanna Creek 4477.2	19.01	13.54	71	29.54	18.80	64	45.47	29.99	66	31.34	20.78	67
Pohopoco Creek 4500	15.96	10.38	65	27.88	16.07	58	40.91	31.29	76	28.25	19.25	67
Aquashicola Creek 4505	15.04	11.90	79	23.29	16.91	73	36.07	25.71	71	24.80	18.17	74
Average weighted area	16.79	11.76	70	26.58	16.90	64	41.89	29.04	69			

Recharge occurs throughout the upland areas at rates dependent on the composition and texture of surface materials and on the slope of the land surface. It is largely precluded from the upper steep slope of the Pocono escarpment, where bedrock is much exposed, but is facilitated along the base of the escarpment in the talus and glacial outwash. The talus along the lower flanks of Kittatinny and Blue Mountain is also a good recharge area and is probably largely responsible for the high yielding wells reported from the Bloomsburg Formation in this area. Kames and kame terraces along the flanks of the major valleys are also good recharge areas. Areas of low recharge result from housing developments and shopping centers, where large areas of the land surface are covered by impermeable surfaces and where storm drainage and snow melt are removed as rapidly as possible.

Occurrence and Movement

The water table is a subdued expression of the surface topography. In most of Monroe County the upper surface of this saturated zone is

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Figure 6.--Belongs near here

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in unconsolidated materials (glacial deposits or weathered bedrock) that blanket the bedrock and typically range in thickness from 30 ft to more than 300 ft. Water occurs in and moves through void spaces of the unconsolidated materials. In unweathered bedrock, whether lying beneath unconsolidated materials or at land surface (as along the escarpment of the Pocono Plateau), water occurs in and moves through fractures and solution openings.

Figure 6.--Map showing generalized ground-water divides and direction of ground-water flow at and near the top of the zone of saturation in Monroe County.

Three types of flow systems have been recognized in the consolidated rocks of the county -- local, intermediate, and regional. Much of the water in the shallow part of the aquifer moves laterally through local flow systems to points of discharge in nearby streams. The divides separating local ground-water flow systems generally coincide with surface-water divides, particularly at the water table. However, variations in recharge and discharge during the year, or in pumping of wells may change position of ground-water divides.

Measurements of water levels in the shallow and deep parts of wells in the area using packers (see Appendix A) indicate that water also moves vertically into the deeper flow systems. The regional flow system discharges westward and southwestward to the Lehigh River in the western third of the county and eastward and southeastward to the Delaware River elsewhere. The intermediate flow system discharges to the major tributaries of these two rivers. Only a small amount of the water that reaches the ground-water reservoir passes beneath the local basins and into the deeper parts of the aquifer.

As water moves through the aquifer along flow paths from recharge to discharge areas there is a progressive decrease in the potential energy in the flow system which is measured as a progressive decrease in hydraulic head regardless of the actual direction of flow. The decline in hydraulic head is the loss of energy caused by the frictional resistance to flow in moving the water through the rock or through joints and fractures to areas of discharge. The maximum head loss in the flow systems in Monroe County is about 1700 ft in a distance of about 15 miles. This maximum head loss is the difference between the water table in the eastern part of the Pocono plateau (altitudes above 2000 ft) and the discharge area along the Delaware River (300 ft in altitude). In vertical sections through the aquifer of a particular site the head change from the top of the zone of saturation to the base of the regional flow system can be as much as 400 ft in areas where there is an abrupt and large topographic break such as along Kittatiny Mountain and east and southern front of the Pocono plateau. In most of the county the head difference between the top and the bottom of the fresh-water flow systems is on the order of tens of feet.

Most deep water wells in bedrock have only a few tens of feet of casing and the remaining uncased part of the well typically penetrates several different water bearing zones that are each under a different hydraulic head. Because of the comparitively small resistance to flow in the open borehole, these wells act as short circuts in the natural flow system (analogous to short circuits in electrical systems). Water flows through the wells from zones of higher head (producing zones) to those of lower head (thieving zones) and a cone of depression of hydraulic head develops around the producing zone and a recharge cone develops in the vicinity of the thieving zone. These short circuits in the natural flow system may connect local, intermediate, and regional flow systems and transmit water from one system to another. Short-circuited flow was measured in over 30 wells by geophysical logging techniques. Figure 7 shows the direction and amount of flow in 5 of these wells.

Figure 7.--(Caption on next page) belongs near here.

Figure 7.-- Diagramatic cross section from Thornhurst to East Stroudsburg showing generalized flow paths and direction and amount of flow measured in wells.

In valley bottoms, particularly in those that are major drains or discharge areas for the flow system, the deepest water-bearing zones generally have the highest hydraulic heads. Thus, upward flow occurs in wells drilled into these zones and may result in flowing wells. However, water from the deeper zones may discharge into shallow zones and give no obvious indication of the flow within the wells at land surface. The amount of flow depends on the difference in head between the water-bearing zones penetrated and on the location and hydraulic conductivity of the zones. In comparison with nearby shallow wells, the deep wells that have upward flow have higher water levels, their water temperature is higher, and their water generally contains more dissolved solids.

When a well penetrates progressively higher heads at greater depths, the resultant higher, composite water level increases the amount of drawdown available to the well when it is pumped, and decreases the energy required to lift the water from the well. Such upward flow is not always advantageous, for it may transmit water containing relatively large amounts of dissolved solids into shallow aquifers that contain small concentrations of dissolved solids.

Downward flow occurs in wells where the deep zones have lower heads than the shallow zones. Such flow occurs in wells on hilltops throughout Monroe County, particularly near ground-water divides, such as along the Pocono Plateau escarpment, Kittatinny Mountain and Blue Mountain. Generally the deepest wells in these areas also have the deepest water levels.

Downward flow can also have a substantial effect on the amount of ground water available to wells, if the deep zones transmit much more water than the shallow zones. The composite water level in the well is controlled by these deep zones, and may lie between 100 ft and 400 ft below the top of the zone of saturation. Such deep water levels reduce the amount of drawdown available and require more pump power to lift the water from the well. In addition, the water flowing downward, out of the well into the deep zones may be considered lost potential well yield. This loss can be minimized by setting the pump opposite the major thieving zone. The cone of depression in deep wells with downward flow may locally dewater the upper part of the zone of saturation and cause nearby shallow wells to go dry or have a diminished yield.

Some wells that penetrate two or more flow systems (local, intermediate, or regional), may have complex flow within the borehole. The direction of flow in such wells can be upward in one part of the hole and downward in another part of the borehole (see fig. 7); however, the flow is always from higher to lower heads. In areas such as the central part of the Pocono Plateau between Pocono Pines and Trout Lake, the deeper producing zones, which may lie more than 500 ft below land surface, have a comparatively high hydraulic head. This area lies approximately midway between the highest areas of recharge, in the vicinity of the village of Tobyhanna, where altitudes may be as much as 2100 ft, and the Lehigh River, to which the ground-water flow system in the northwest part of the county drains, at an altitude of 1400 ft. Here, local relief is typically 100 ft, and comparatively minor differences in the altitude of water table can cause a reversal of the direction of flow in wells.

Changes in Flow Systems

The flow of water through a well bore from a producing to a thieving zone accelerates movement of the water through the flow system by creating a short circuit in the system, and locally alters the distribution of hydraulic heads. The water level in a well that penetrates two or more producing zones having different hydraulic heads is a composite water level and is close to the head of the major producing zone. In public-supply wells that were studied, the median flow between producing and thieving zones was 1.5 gal/min (2,160 gal/d) and the maximum flow measured was 56 gal/min (80,600 gal/d). The domestic wells studied had a median flow of 1 gal/min (1440 gal/d). These domestic wells had a median depth of 320 feet or about twice that of the average domestic well. To put some perspective on the effects on the hydrologic system by flows of this size, 1 gal/min is slightly larger than the average amount of recharge per acre, which is 1200 to 1400 gal/day, and considerably more water than most domestic households use in a day.

The drilling of a large number of wells, one or more per acre, may significantly alter the fresh water flow system by accelerating the movement of water down the hydraulic gradient to points of discharge and by causing local changes in potentiometric surfaces. In addition, when water nearly in equilibrium with conditions in one part of the ground-water flow system is rapidly transferred to a different part of the system, one that has different pressures, temperatures, and chemical equilibria, either deposition or solution of minerals may occur in the new environment. All such short-circuits affect the system and many short-circuits may significantly alter it.

Water-bearing Zones

In most wells, very few zones more than 500 ft below land surface yield large quantities of water. However, drilling to depths below 500 ft may increase the yield of the wells as the surging action of the drill develops the shallower zones; that is, mud forced into these zones as they were initially penetrated is now washed out as a result of the continued drilling.

Depth of Fresh-water Circulation

Fresh water probably circulates deeper than 800 ft below land surface throughout the county. Borehole-flow measurements made in deep wells (see Appendix, table 12) indicate downward flow as deep as 700 ft.

Water temperature gradients measured in the deep wells generally approached the regional geothermal gradient at depths greater than about 400 ft below land surface. This indicates that the largest amounts of ground-water circulation occur less than 400 ft below land surface and only small amounts circulate below that depth.

Availability

Because precipitation is abundant and relatively small amounts of water are lost to evaporation or transpiration, more water flows through the ground-water reservoir in Monroe County each year than in most other parts of the state. Average ground-water recharge is estimated at close to 1 gal/min per acre or about 600 (gal/min)/mi^2 almost twice the amount estimated for the northcentral, southcentral, and westernmost parts of Pennsylvania (Becher, 1970). In addition to the plentiful recharge, the depth of the fresh-water circulation system appears to be as deep as, if not deeper, than that in most of the other fractured-rock areas in the state. Thus, the aquifers in Monroe County probably store more water than similar rocks elsewhere in Pennsylvania.

Rock Type

Data in table 4 indicate the relative capacity of the different rock types and formations to yield water to wells. The specific capacity

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Table 4.--Belongs near here.

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of wells finished in the unconsolidated sand and gravel deposits is about 10 times larger than that of wells finished in the consolidated, fractured sandstones, siltstones, and shales. This difference would be greater if the wells in the unconsolidated material were finished with screens and were developed. However, most of the wells producing from the unconsolidated material have no screens and the water enters only through the open end of the casing at the bottom of the well. The average capacity of the coarse-grained and well-sorted unconsolidated rocks should be between 10 to 100 times larger than the consolidated rocks except in the carbonate rocks.

Table 4.-- Specific capacities of domestic wells in selected water-bearing rocks, determined by one-hour pumping tests

Formation or aquifer	Number of wells	Estimated saturated thickness of the overburden (feet) Median	Specific capacities 1/ (in gallons per minute per foot of drawdown) exceeded by indicated percentage of wells. 90%	75%	50%	25%	10%
			Median				
UNCONSOLIDATED ROCKS							
Pleistocene sand & gravel	20	74	0.45	0.78	2.85	7.0	20.0
CONSOLIDATED FRACTURED ROCKS							
Catskill Formation	101		0.04	0.08	0.22	0.67	1.63
Duncannon Member	14	--	.04	.12	.22	.50	5.0
Poplar Gap Member	19	--	.24	.35	.67	2.18	8.0
Long Run Member	62	--	.03	.06	.19	.35	1.0
Walcksville Member	18	--	.03	.04	.12	.30	1.11
Towamensing Member	10	--	.03	.06	.10	.27	.44
Trimmers Rock Formation	11		.03	.08	.18	.81	1.50
Mahantango Formation	23	12	.03	.06	.20	1.00	4.00
Marcellus Formation	25	57	.03	.07	.36	1.00	1.50
Silurian and Devonian Undifferentiated	16	39	.03	.06	.38	1.50	4.00
Bloomsburg Formation	15	37	.10	1.00	2.00	5.30	16.50
All consolidated rock formations listed above	191	--	.03	.08	.26	1.00	2.82
Devonian sandstones	101	--	.04	.08	.25	.67	1.63
Devonian siltstones	32	--	.03	.06	.18	.81	3.00
Devonian shales	27	--	.03	.07	.28	.86	1.33
Silurian and Devonian carbonates	10	--	.07	.20	.38	3.50	7.50

1/ Most specific capacities calculated from data reported by drillers.
-- indicates no saturated overburden.

Despite the wide range (two orders of magnitude) in the specific capacities of wells in the fractured rocks, fairly consistent differences occur from one formation to another. Wells in the Bloomsburg Formation generally produce between 3 and 20 times more water than wells in the other consolidated rocks. Those in the Poplar Gap member of Catskill Formation are 2 to 7 times better than the average well in the other members. The poorest wells occur in the Walcksville and Towamensing members of the Catskill. In addition, carbonate rocks in the Silurian- and Devonian-undifferentiated unit yield more water to wells than most of the clastic rocks.

Topography

The data in table 5 indicate a relationship between topographic

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Table 5.--(Caption on next page) belongs near here.

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position and the specific capacity of domestic wells. The highest specific capacities were obtained from wells in valleys and the lowest, from wells on hilltops. Data compiled for wells in all formations show those in valleys are more than six times as productive as those on hilltops. For the Catskill Formation, wells in valleys are more than three times as productive as those on hilltops. Data are inadequate to make the same analysis for the other formations; however, the same trends seem probable.

Table 5.--Relation between specific capacities of domestic wells and topographic position.

Formation or aquifer	Number of wells	Estimated saturated thickness of the overburden (feet)	Specific capacity of wells after one-hour of pumping (gallon per minute per foot drawdown)
		Median	Median
All formations			
Hilltop	37	0	0.11
Hillside	126	0	0.19
Valley	69	46	0.70
Catskill Formation			
Hilltop	23	0	0.11
Hillside	76	0	0.21
Valley	21	37	0.37

The relationship of specific capacity to topographic position is caused by the following factors: (1) The valleys are underlain by rock that is less resistant to erosion and more permeable than the rock forming the hillsides and hilltops. (2) The saturated thickness of the unconsolidated deposits is generally greatest in the valleys and least on the hillsides and hilltops. (3) Hydraulic heads decrease with depth on hilltops and increase with depth in valleys, that is, ground-water gradients are away from wells on hilltops and towards wells in valleys.

Saturated Thickness of Unconsolidated Deposits

The saturated thickness of the unconsolidated deposits was estimated to be about equal to the difference between the casing depth, which generally extends to the bedrock, and the depth to the static water level below land surface at selected well sites. The data in table 5 shows the relationship between estimated saturated thickness of the unconsolidated deposits and the specific capacity of wells compiled by topographic position of all formations and by formation regardless of topographic positions. In general, the data indicate the most productive wells are those with the thickest saturated unconsolidated deposits. Figure 3 shows the location and distribution of some of the thickest unconsolidated deposits in Monroe County. The median specific capacity of the wells in the shales of the Marcellus Formation and the sandstones and siltstones of the Bloomsburg Formation would probably be lower if it were not for the large amounts of water stored in the thick, saturated deposits of unconsolidated material that overlie these formations. When wells are pumped, water from these unconsolidated deposits leaks downward to replace water withdrawn from the bedrock and thereby sustains the well yields.

Pumping Rate and Duration

Long-term pumping-test data indicate that specific capacity decreases as the pumping rate or duration of pumping or both increases. The decrease in capacity as the pumping rate increases is due to an increase in the turbulence, or friction of the water entering the borehole, and, possibly, to dewatering of some of the producing zones. The effect is greater in wells in the poorer aquifers. The decrease in specific

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Figure 7.--Belongs near here (Caption on next page).

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capacity between 1 hour and 24 hours of continuous pumping ranged from 11 percent for the well in the Bloomsburg Formation to 78 percent for the wells in the Catskill Formation. The average decrease for all the wells was about 57 percent.

Figure 7.--Relation between specific capacity and rate and duration of pumping for selected wells.

The specific capacities of wells that are pumped continuously will decrease until (1) recharge to the ground-water reservoir has been increased by an amount equal to the pumping rate, (2) the natural discharge from the ground-water reservoir has been decreased by an amount equal to the pumping rate, or (3) the sum of the increased recharge and decreased natural discharge is equal to the pumping rate. In general, there is more opportunity both to increase recharge and decrease natural discharge close to the major streams. Because most ground-water recharge is routed to the major streams at a rate of about 600 (gal/min)/mi^2 the largest amounts of ground-water should be available to wells near these streams. By contrast, the smallest opportunity to increase recharge and decrease natural discharge generally occurs near the basin divides. Here, both the recharge and available drainage areas are very small and all the recharge that does occur moves away from the divides. Consequently, the smallest amounts of ground water would be available to wells drilled in these areas.

Changes in specific capacity with increasing time or pumping rate may also occur when the water level in the well is drawn below a producing zone, which then drains into the well and is no longer progressivley stressed, by the increasing drawdown in the well.

Thieving zones may become producing zones with increased drawdown.

When nearby wells penetrate several producing zones, some of which are in common with a pumped well and others which are not, the nearby wells may recharge the pumped well through the common zones.

Estimated Potential Well Yield

Table 6 shows the estimated potential yield of wells in all the

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Table 6.--Belongs near here.

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formations for which specific capacity information was compiled. Properly developed and screened wells drilled in valley bottoms in thick deposits of sand and gravel or that penetrate major water-bearing zones deeper than 50 ft below the water table, will generally have more available drawdown and, therefore, a better chance of obtaining the higher potential yields shown.

Table 6.--Estimated potential well yield for the major aquifers.

Aquifer	Estimated potential yield in gallons per minute after				
	2/90%	75%	50%	25%	10%
Unconsolidated Rocks					
Sand and gravel	25	75	200	400	750
Consolidated Fractured Rocks					
Catskill Formation	3	10	25	75	175
Duncannon Member	5	15	25	55	225
Poplar Gap Member	25	40	70	215	300
Long Run Member	3	7	20	40	110
Walcksville Member	3	5	15	35	120
Towamensing Member	3	7	10	30	50
Trimmers Rock Formation	3	9	25	90	160
Mahantango Formation	3	7	20	70	225
Marcellus Formation	3	7	40	110	165
Silurian and Devonian undifferented	3	7	30	160	300
Bloomsburg Formation	5	50	100	265	400

1/ Assuming 25 ft available drawdown for unconsolidated rocks and 50 ft available drawdown for consolidated fractured rocks.

2/ Percent of wells in which yield is equaled or exceeded.

Potential Effect of Ground-water Pumpage On Streamflow

If pumpage from the ground-water reservoir exceeds the average recharge of about 650 Mgal/day, the annual streamflow will be reduced to about 1/3 the present rate and will consist almost entirely of overland runoff. In addition, the runoff will be intermittent, and substantial amounts will occur only for short periods of time (1 to 4 days) after each storm. Ground-water withdrawals and consumption in excess of about 650 Mgal/day would mine water from the ground-water reservoir. Current pumpage (1976) is about one percent of the recharge. The above discussion describes general conditions and assumes that ground-water withdrawals would be distributed evenly throughout the county. However, the same conditions can occur locally when ground-water withdrawal and consumption or exportation approaches and exceeds local recharge

Quality

Temperature

The temperature of the ground water varies directly with the average annual air temperature, from the highest parts of the Pocono Plateau to the lowest parts of the Delaware River valley. At a depth beneath the river, the temperature of the ground water appears to be related directly to the geothermal gradient.

Figure 8.--(Caption on next page) belongs near here.

Figure 8 was compiled from an analysis of 25 temperature logs of deep wells. The plots represent an average of all the water temperatures that were logged at the altitude of each point. Each point represents the temperature of the water at about 300 ft below the water table. The air temperature gradient (1°F for each 260 ft change in altitude) was estimated from plots of average annual air temperatures and altitudes at Tobyhanna and Stroudsburg. The geothermal gradient (1°F for each 100 ft of depth below the water table) was estimated from a study of temperature logs made in segments of deep wells where there was no ground-water flow.

Figure 8.--Ground-water temperature, air-temperature, and geothermal gradients in Monroe County.

In general, the temperature of the water 300 ft below the water table is about 1°F warmer than the average annual air temperature at land surface. Closer to the water table air and water temperatures will be more coincident. This temperature of ground-water near the top of the zone of saturation ranges from about 45° or 46°F where land-surface altitudes are near 2,000 ft to about 52 to 54 °F where land surface altitudes are 300 to 400 ft.

Specific Conductance and Hardness

Specific conductance and hardness determinations of ground water are summarized by formation in table 7. The specific

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Table 7.--Belongs near here.

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conductance ranged from 57 to 750 micromhos. Water from the unconsolidated deposits and from consolidated sandstones, siltstones, and shales had a median specific conductance of about 200 micromhos. The water in the carbonate rocks had a conductance of about 370 micromhos.

The total hardness ranged from 1 to 19 grains per U.S. gallon. The median hardness of water in the different noncarbonate formations ranged from 1 to 5 grains and had a composite median of 3 grains per U.S. gallon; that from the carbonate rocks had a median of 8 grains per U.S. gallon.

Table 7.--Specific conductance and total hardness of ground water.

Formation or aquifer	Total hardness as $CaCO_3$ in grains per U.S. Gallon 1/			Specific conductance in micromhos at 25° Celsius		
	Number of samples	Range of values	Median value	Number of samples	Range of values	Median value
Unconsolidated Rocks						
Sand and gravel	3	2-2	2	2	75-160	117
Consolidated Rocks						
Catskill Formation	24	1-5.5	3	27	60-300	160
Trimmers Rock Formation	6	2-5	3.5	6	120-215	168
Mahantango Formation	2	1-4	2.5	3	57-210	200
Marcellus Formation	4	2-9	4	3	110-390	160
Silurian-Devonian undifferentiated	8	5-19	8	9	200-750	370
Bloomsburg Formation	2	3-7	5	3	180-320	220
Shawangunk Formation	1	-	1	1	-	65
Devonian sandstones	24	1-5.5	3	27	60-300	160
Devonian siltstones	9	1-6	4	10	57-215	178
Devonian shales	5	2-9	4	4	110-390	168
Silurian-Devonian carbonate rocks	8	5-19	8	9	200-750	370

1/ Multiply grains by 17.1 to convert to milligrams per liter.

Specific conductance can be used to estimate both the dissolved-solids content and the hardness of the water. Data from 37 wells indicate that if the specific conductance is multiplied by 0.6, the approximate dissolved-solids content is obtained; and if the conductance is divided by 40, the approximate hardness is obtained.

Chemical Analyses

The results of 58 chemical analyses of water from 45 wells are shown in table 8. The median concentration of dissolved constituents is given by formation in table 9.

Table 8.--Belongs near here.

Table 9.---Belongs near here.

Excessive concentrations of iron (greater than 0.3 mg/L) were found in water from 20 percent of the wells sampled in the unconsolidated deposits of sand and gravel and in the Catskill Formation. Data from the unconsolidated deposits were not sufficient to calculate the percentage of the wells that exceeded the recommended limits of manganese; however, high concentrations of manganese in these waters appears to be a common problem. The highest concentrations of iron and manganese were reported for the one well in the Shawangunk Formation.

In general, the water from all the aquifers has low concentrations of dissolved solids. Thus, wherever the dissolved solids concentrations of water exceed about 150 to 200 mg/L in the noncarbonate aquifers, and 350 to 400 mg/L in the carbonate aquifers, contamination should be suspected.

Table 8.--Chemical analyses of ground water.
(Constituents in milligrams per liter)

Aquifer: See table of well records and geologic maps for explanation of ~~symbols~~. aquifer abbreviations

Data Source: U, U.S. Geological Survey; C, Commercial Laboratory.

MONROE COUNTY

Date of collection	Aquifer	Data source	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate as Nitrogen (N)	Phosphate (PO_4)	Sum of dissolved constituents	Total Hardness
12/17/53	Dcpg	U	4.7	0.04	-	4.0	1.0	-	1.8	14	1.0	3.0	0.0	0.4	-	29	17
12/28/53	Dcpg	U	4.3	0.03	-	4.0	1.0	-	1.9	14	1.0	3.5	.0	.2	-	24	17
7/03/57	Dcpg	U	5.1	.26	-	4.0	.5	-	2.3	11	3.3	1.3	.1	.6	-	29	15
12/18/60	Dcpg	U	5.6	.36	-	2.8	1.5	-	1.4	7	7.7	.8	.0	.5	-	26	20
3/13/62	Dcpg	U	7.1	.02	-	2.9	1.5	.9	.5	12	.6	1.9	.0	.7	-	25	17
11/19/63	Dcpg	U	5.1	.14	.02	2.0	1.0	-	1.6	10	.4	1.9	.0	.8	-	21	10
12/18/58	Dcpg	U	6.0	.73	.0	4.4	1.2	-	1.6	12	2.0	2.2	.0	1.6	-	32	22
3/13/62	Dcpg	U	7.1	1.0	.01	3.7	1.9	1.8	.5	10	1.9	3.8	.1	1.6	-	34	26
11/19/63	Dcpg	U	5.4	.11	.02	6.4	1.9	2.0	.0	13	.4	8.1	.1	1.6	-	38	37
10/21/69	Dcpg	U	5.0	.04	.01	4.9	1.8	2.0	.5	10	3.3	6.0	.0	1.8	-	36	31
7/03/57	Dcpg	U	10	.49	.0	22	3.0	-	3.2	77	6.3	1.6	.0	.8	-	86	71
12/18/58	Dcpg	U	7.8	.06	.0	21	3.6	-	2.5	78	5.5	1.2	.0	.5	-	83	70
8/24/60	Dcpg	U	7.9	.04	.0	31	3.0	2.8	.5	110	5.0	2.6	.0	.9	-	111	90
8/06/64	Dcpg	U	7.1	.03	-	22	3.4	2.6	.5	78	5.0	2.9	.1	.6	-	85	74
9/22/30	Dcpg	U	-	-	-	3.0	-	2.0	-	10	2.0	3.0	-	1.4	-	-	-
9/22/30	Dcpg	U	-	-	-	5.0	-	-	-	20	2	1.0	-	.2	-	-	-
7/03/57	Dcpg	U	4.5	.01	.0	10	1.0	-	3.9	26	5.8	2.5	.1	1.7	-	47	37
8/24/60	Dcpg	U	6.0	.1	.0	7.3	2.3	2.0	.5	26	5.0	2.0	.0	1.2	-	43	34
9/23/30	Dm	U	-	-	-	36	4.9	-	6.0	109	26	5.0	-	.0	-	-	131
9/23/30	Qg	U	-	-	-	10	-	-	7.0	42	4.0	1.0	-	.0	-	-	-
9/23/30	Dm	U	11	.05	-	9.2	2.1	4.0	.2	24	14	1.8	-	.4	-	56	44

Date of collection	Aquifer	Data source	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate as Nitrogen (N)	Phosphate (PO_4)	Sum of dissolved constituents	Total Hardness
9/22/30	Qg	U	-	-	-	3.0	-	-	2.0	11	2.0	1.0	-	.02	-	-	-
10/08/68	Qg	U	5.9	4.6	.19	3.3	.7	.8	.3	10	.9	2.5	-	.04	0.0	24	14
12/04/68	Ds	U	10	.27	.01	21	3.9	5.2	.8	72	20	1.4	.0	.0	-	98	79
9/28/70	Ss	U	5	6.2	.43	2.3	3.0	1.5	4.6	12	12	2.2	.3	.0	-	37	26
5/25/71	Ds	U	7.4	.10	.02	32	2.6	3.0	1.8	84	34	1.2	.1	.07	.0	124	113
3/06/73	Dmh	U	9.5	-	-	6.1	1.6	2.0	.2	21	5.5	1.5	.1	-	-	37	27
9/19/72	Dmh	U	-	-	-	-	-	-	.55	-	-	-	-	1.8	-	-	-
	Qg	U	-	-	-	-	-	-	-	35	-	2.0	.0	.6	-	46	40
9/18/69	Sb	C	-	.25	.0	9.4	4.6	-	-	60	.0	1.0	.6	.0	-	61	-
12/04/48	Dclr	C	-	1.8	-	-	-	-	-	52	-	5.0	-	1.1	-	-	46
	Dcpg	C	-	.0	.0	-	-	-	-	27	-	1.0	.0	.0	-	54	32
3/22/65	Dclr	C	-	.0	-	-	-	-	-	51	-	1.0	-	-	-	76	34
8/20/71	Dcpg	C	-	-	-	25	-	-	-	115	58	5.0	-	.07	-	124	84
6/14/73	Dcpg	C	7.0	.53	.05	13	2.9	1.0	.2	71	4.0	2.0	.25	.21	-	-	44
7/09/73	Dcpg	C	8.0	.21	.05	-	-	-	.02	68	20	4.0	.32	.15	-	-	60
2/18/71	Dbf	C	-	.0	.0	-	-	-	-	185	38	5.0	-	.59	-	248	176
4/23/71	Dbf	C	-	.02	.0	-	-	-	-	156	29	5.0	-	.41	-	198	160
2/06/71	Dbf	C	-	.0	.0	-	-	-	-	198	38	9.5	-	.40	-	276	202
4/15/71	Sp	C	-	1.0	.0	-	-	-	-	122	77	10	-	.28	-	390	234

PIKE COUNTY

Date of collection	Aquifer	Data source	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate as Nitrogen (N)	Phosphate (PO_4)	Sum of dissolved constituents	Total Hardness
1/03/72	Dtr	C	-	.11	.05	-	-	-	-	32	1.0	2.0	.1	.1	-	55	33
12/15/72	Dtr	C	-	.05	.07	-	-	-	-	98	5.0	1.0	-	.1	-	123	86
10/06/72	Qg	C	-	.1	.1	-	-	-	-	30	1.0	4.0	-	.1	-	116	29
10/13/72	Dmh	C	-	.1	.1	-	-	-	-	99	-	6.0	-	.1	-	131	64
11/15/72	Dtr	C	-	.13	.16	-	-	-	-	112	2.0	4.0	-	.1	-	112	56
11/02/72	Dtr	C	-	.05	.06	-	-	-	-	76	2.0	1.0	-	.1	-	108	68
12/28/72	Dtr	C	-	.10	.05	-	-	-	-	102	-	-	.1	.1	.03	118	71
9/28/72	Dcpg	C	-	.1	.1	-	-	-	-	105	8.0	3.0	-	.1	-	-	90
9/27/72	Dcpg	C	-	.1	.1	-	-	-	-	126	6.0	9.0	-	.1	-	-	64

WAYNE COUNTY

Date of collection	Aquifer	Data source	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate as Nitrogen (N)	Phosphate (PO_4)	Sum of dissolved constituents	Total Hardness
7/13/72	Dcpg	C	14	.06	.05	2.9	7	4.9	.5	134	20	2.0	.25	.15	-	-	103
6/01/73	Dcpg	C	8.4	.09	.05	26	2	4.2	1.2	107	1.0	6.0	.44	.18	-	-	10[illegible]
1/18/73	Dcpg	C	-	.12	.05	-	-	6.1	-	105	10	4.0	-	.1	-	124	9[illegible]
1/26/73	Dcpg	C	-	.1	.05	-	-	1.0	-	87	7.0	6.0	-	.15	-	141	88
4/16/73	Dcpg	C	-	.06	.09	-	-	4.3	-	102	10	4.0	-	.1	-	119	110
4/05/73	Dcpg	C	-	.1	.05	-	-	3.1	-	105	7.0	4.0	-	.1	-	118	90
5/18/73	Dcpg	C	.1	.1	.05	11	2	24	.85	117	1.0	8.0	.01	.06	-	-	38
2/15/73	Dcpg	C	-	.1	.05	-	-	5.5	-	76	5.0	2.0	-	.1	-	110	64

Table 9.--Median concentration of dissolved constituents in ground water.

(Concentrations in milligrams per liter)

Formation or aquifer	Number of samples	Silica (SiO_2)	~~Total~~ Iron (Fe)	~~Total~~ Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Sum of dissolved constituents
Unconsolidated Rock															
Sand and gravel	5	5.9	2.3	.15	7	-	-	2	11	1.5	2	-	.1	-	70
Consolidated Rock															
Catskill Formation 1/	35	6	.05	.02	5	1.9	2.8	.7	14	5	3	.1	2.8	-	100
Trimmers Rock Formation	5	-	.1	.07	-	-	-	-	-	2	1.5	.05	.1	-	112
Mahantango Formation	3	9.5	-	-	6.1	1.6	2	.02	21	5.5	3.7	.1	4	.55	85
Marcellus Formation	2	11	-	-	23	3.5	4	3	67	20	3.5	-	.9	-	-
Sil.-Dev. Undivided															
Carbonates 2/	4	-	.02	.0	-	-	-	-	-	38	7	-	-	-	260
Noncarbonates 3/	2	8.5	.18	.02	26	3.2	4.1	.9	78	27	1.3	.05	.15	-	111
Bloomsburg Formation	1	-	.25	.00	9.4	4.6	-	-	-	.0	1	.6	.0	-	61
Shawangunk Formation	1	5	6.2	.43	2.3	3	1.5	4.6	12	12	2.2	.3	.00	-	53

1/ Most analyses are ~~for~~ of water from the Poplar Gap Member.

2/ Analyses are ~~for~~ of water from the Buttermilk Falls and Poxono Island Formations.

3/ Analyses are ~~for~~ of water from the Esopus and Scoharie Formations.

SUMMARY

The average annual precipitation in Monroe County is 45 in. of which 27 in. leaves the area as streamflow and sixty-five percent of this streamflow is water that has moved through the ground-water reservoir. Evaporation and transpiration consume 18 in. of the precipitation.

Water is stored and transmitted through intergranular openings in the unconsolidated rock and in joints, fractures, and solution openings in the consolidated rock. The unconsolidated deposits of sand and gravel store 70 billion gallons of water or about 10 times as much as they receive as direct recharge each year. The fresh-water flow system in the consolidated rock locally extends to depths of more than 800 ft and stores one trillion gallons of water or five times the annual ground-water discharge.

There are local, intermediate, and regional flow systems. Most of the annual recharge is transmitted through the local systems to nearby streams and comparatively small amounts pass through the intermediate and regional flow systems.

Wells in the consolidated rock act as short-circuits within and between flow systems. Water flows through the well from producing zones of higher hydraulic head to those of lower head. The flow may be up or down the well or upward in one part of the well and downward in another part. The effect of the flow is to accelerate the movement of water towards points of discharge, redistribute hydraulic heads, change the top of the zone of saturation in the vicinity of the well, and transfer water rapidly from one environment to another. The short-circuited flow of one gal/min is equal to more than the daily recharge of an acre of land. Most of the wells in which borehole velocity measurements were made had flows in excess of one gallon per minute.

The specific capacity of wells drilled in valleys averages six times that of wells on hilltops. Deep wells drilled in the uplands near large topographic breaks penetrate producing zones having hydraulic heads as much below the top of the zone of saturation. Because of the extra lift required, the cost of producing water from these zones having the comparitively low heads is much greater than from shallow zones whose hydraulic heads are close to that of the local water table. Current pumpage of ground water is about one percent of recharge.

Ground-water temperatures range from 45°F for water from shallow depths on the Pocono Plateau to 57°F for water deep in the flow system near the Delaware River. The water temperature is directly related to the mean annual air temperature, which decreases with increasing altitude. Hardness of water in the noncarbonate rocks averages 3 to 4 grains per gallon, or about half of that in of the carbonate rocks. Water from most of the bedrock aquifers is low in dissolved solids; it is acidic, and soft. In carbonate rocks, the water tends to be hard and slightly alkaline. Excessive amounts of iron and manganese are encountered in water from the unconsolidated deposits and, locally, in water from the Catskill and Shawangunk Formations.

Assuming 24 hours of pumping and 50 ft of drawdown, 1 of every 4 wells constructed for large yields will produce 250 gal/min from the Bloomsburg, 160 gal/min from the Silurian-Devonian-undivided unit, 110 gal/min from Marcellus, 75 gal/min from the Catskill, 90 gal/min from the Trimmers Rock, and 70 gal/min from the Mahantango. Assuming 24 hours of pumping and 25 ft of drawdown, 1 of every 4 wells constructed for large yield will produce 400 gal/min from the unconsolidated sand and gravel.

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GLOSSARY

Anticline: A fold in rocks in which the strata dip outward away from the axis of the fold. Opposite from syncline.

Aquifer: A formation, group of formations, or part of a formation from which water is collectable in usable quantities.

Bedding: Layers of sedimentary rocks of the same or different lithology.

Bedrock: A general term for the rock, usually solid, that underlies soil or other unconsolidated or semiconsolidated superficial material.

Carbonate rocks: Rock composed primarily of minerals that contain the carbonate radical (CO_3^{-2}). In the study area the rocks are limestone ($CaCO_3$) and dolomite ($Ca\ Mg\ (CO_3)_2$).

Cleavage: Breaks or splits in rock along definite, parallel, closely spaced planes, may be highly inclined to the bedding planes.

Colluvium: A general term applied to loose and incoherent deposits, usually at the foot of a slope or a cliff and brought there chiefly by gravity.

Deformation: Any change in the original form or volume of rock masses produced by earth forces; folding, faulting, and solid flow are common modes of deformation.

Dip: The angle at which a bed or any planar feature is inclined from the horizontal.

Fault: A surface or zone of fracture in rock along which movement has taken place.

Fracture: A general term for any break in rock due to mechanical failure by stress, including cracks, joints, and faults.

Fracture traces: Fracture traces are natural linear features consisting of topographic (including straight stream segments), vegetational, or soil-tonal alignments, which are visible primarily on aerial photographs, and are expressed continuously for less than a mile.

Geothermal gradient: The temperature gradient in the outer part of the earth's crust, which is about 1°F for each 100 ft in depth. Movement of water through the fresh water flow system alters the thermal gradient, and movement of water in wells often completely obscures the gradient.

Ground water: That part of the subsurface water in the zone of saturation.

Ground-water discharge: Release of ground water in springs or seeps or wells from the ground-water reservoir.

Ground-water recharge: Addition of water to the ground-water reservoir by infiltrating precipitation or seepage from streambed.

Ground-water reservoir: See aquifer.

Hydraulic conductivity (or Permeability): The capacity of a porous rock, sediment or soil to transmit a fluid without impairment of the medium; it is a measure of the relative ease of fluid flow under pressure.

Joints: Fractures in rock, generally more or less vertical or transverse to bedding, along which no appreciable movement has occurred.

Lithology: A term used to mean the description of rocks. Also to mean the composition and texture of rock.

Porosity: The ratio of the aggregate volume of interstices in a rock or soil to its total volume. It is usually stated as a percentage.

Reported well yield: The short term discharge of a well as reported by well drillers in gallons per minute.

Saturated zone: That part of the water-bearing material in which all voids are completely filled with water under pressure equal to or greater than atmospheric.

Sericite: A variety of the mica muscovite.

Solution cavity: Any void, generally an enlargement in the fracture opening, caused by solvent action of water in limestone or dolomite.

Specific capacity: The yield of a well, in gallons per minute, divided by the drawdown of water level in the well, in feet, for some specific period of pumping.

Specific conductance: Specific conductance is a measure of the capacity of a substance to conduct electrical current. It is measured in micromhos per centimeter and is equal to 10,000 divided by the electrical resistivity, in ohm meters. Waters having small amounts of dissolved solids have low conductances whereas waters having comparatively large amounts of dissolved solids have high conductances.

Static water level: The water level in a well when the well is not being pumped and when the water level is unaffected by any prior pumping of the well or nearby wells.

Storage coefficient: The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.

Structure: The sum of the attitudes, arrangements, or relative positions of the rocks (features produced in the rock by movements after deposition, and commonly after consolidation of the rock) of an area.

Surface water: That water on the surface of the earth. Surface water is generally a combination of overland runoff and ground-water discharge, the proportions varying from almost 100 percent overland runoff during periods of high intensity rain to 100 percent ground-water discharge during periods of little or no rain.

Syncline: A fold in the rocks in which the strata dip toward the axis. Opposite from anticline.

Terminal moraine: A deposit of unsorted sediments formed across the course of a glacier at its farthest advance.

Till: Nonsorted, nonstratified material, ranging in size from clay to boulders; carried or deposited directly by ice.

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

Water table: That surface in an unconfined ground-water body at which the pressure is atmospheric.

Zone of saturation: The zone below the water table in which all openings are saturated.

APPENDIX A

Geophysical Logs and Packer Tests

Geophysical logs were made for 35 wells in Monroe County and adjacent parts of Pike and Wayne Counties. Locations of these wells are shown on figure 9; and table 11 indicates the type of logs made

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Figure 9.--(Caption on next page) belongs near here.

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and identifies the wells in which packer tests were made. Table 12

Table 12.--Belongs near here.

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shows the result of the packer tests. The geophysical logs were temperature, fluid conductivity, caliper, electric, gamma ray, neutron, and borehole velocity. These logs and their application to the study of ground water are briefly described in the following paragraphs.

For more detailed information on logging, the reader is referred to "Application of borehole geophysics to water-resources investigations," by Keys and MacCary (1971).

Figure 9.--Location of wells in which geophysical logs and packer tests were made in Monroe County and parts of Pike and Wayne Counties.

Table 11.--Geophysical logs and packer tests

Well number	Mo-214	Mo-215	Mo-216	Mo-225	Mo-226	Mo-227	Mo-234	Mo-235	Mo-236	Mo-237	Mo-238	Mo-239	Mo-240	Mo-241	Mo-242	Mo-243	Mo-244	Mo-245	Mo-305	Mo-416	Wn-116	Wn-119	Wn-120	Wn-121	Wn-122	Wn-123	Wn-124	Pi-200	Pi-201	Pi-203	Pi-204	Pi-205	Pi-206	Pi-207	Pi-208
Well depth	290	170	223	524	421	655	697	616	346	568	575	170	224	1052	420	720	705	324	572	534	540	750	759	652	505	526	323	799	789	804	459	684	458	609	804
LOGS																																			
Temperature	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Fluid conductivity	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Caliper		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Electric				X		X	X	X	X	X				X	X		X	X		X	X	X	X	X	X	X	X	X	X		X	X		X	X
Gamma	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Neutron	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
Borehole velocity	X			X	X	X	X	X X	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Packer tests				X					X		X		X			X	X		X			X	X	X	X	X		X							

Well number	Altitude of LSD (feet above msl)	Well depth (feet)	Flow in well[1] (gal/min)	Composite water level below LSD (feet)	Packer setting below LSD (feet)	Duration of test[2] (minutes)	Change in water level above packer (feet)	Change in water level below packer (feet)	Specific capacity gallons per minute per foot of drawdown above packer	Specific capacity gallons per minute per foot of drawdown below packer
Mo-227	990	655	.3-.4 ↓	125	215	120	+4.24	-2.33	0.16	0.13
Mo-236	1,985	346	5.0 ↑	12	176	40	-0.5	+1.38	10	3.6
Mo-238	1,790	575	0.5 ↓	3.6	240	20	-0.11	0		
					140	20	-0.28	+.03		
Mo-243	530	720		93	105	75	+0.56	0		
Mo-244	520	705	0.6-0.8 ↕	66	100	480	+9.30	-0.44		
					280	120	-0.15	+0.25		
Mo-416	1,785	534	4.0 ↑	41.1	120	120	-5.76	+10.17	0.66	0.39
Wn-119	1,820	750	0.3 ↓	56.7	110	135	+1.54	-0.02		
			0.4 ↓	56.7	270	125	+1.8	-0.08		
Wn-120	1,860	759	2 ↓	13.5	120	130	+1.45	-1.05		
				13.5	160	23	+0.5	-136.1	2.67	0.01
Wn-121	1,780	652	1-2 ↓	17.0	210	60	+1.75	-1.2	0.57	1.66
Wn-122	1,740	505	2-0.5 ↑	2.7	120	80	-2.45	+4.71	0.82	0.25
Wn-123	1,900	526	12 ↓	90	220	120	+70	-5.2	0.17	3.0
Pi-200	1,180	799	2.0 ↓	25	120	110	+2.4	-9.0	0.83	0.22

1/ Arrow indicates direction of flow: ↓ down, ↑ up. Flow recorded at packer installation depth before packer was installed.

2/ Tests were not run long enough for water levels to come to equilibrium.

Caliper: The caliper log gives a continuous record of borehole size. These logs are useful in determining the location and extent of openings in the sides of the borehole caused by caving, fracturing, and solution.

Electric: (1) Electric resistivity logs form a continuous record of the resistance to the flow of an electrical current from points within the borehole to an electrical ground at land surface. Sandstone units containing fresh water have a high resistance, shales low. This log is useful for determining lithology and stratigraphic correlations and the presence of water-producing fractures in rocks of low porosity.

(2) Spontaneous potential logs record small differences in voltage that develop at the contacts of the borehole fluid, the shale or clay and the water in the aquifer. The logs are used for determining lithology chiefly shale and clay content.

Fluid conductance: Fluid-conductance logs record the conductivity of the water in the borehole. Changes in conductivity readings reflect differences in the dissolved solids in the water and therefore, indicate changes in chemical quality of the water in the well. Because water in different producing zones is often of different quality, the logs help to define producing zones.

Gamma: Natural-gamma logs indicate the amount of natural gamma radiation given off by the rocks surrounding the borehole. In general, shales give off more radiation than sandstones or carbonate rocks typically because of their potassium content. Consequently, the logs are useful in determining lithology and in making stratigraphic correlations.

Neutron: Neutron logs are made by lowering a neutron source and detector into the borehole. Hydrogen atoms slow the neutrons so that they are captured by other elements. In zones in the borehole where the surrounding rock is porous and saturated, more neutrons are captured and fewer neutrons reach the detector. The logs are useful in determining differences in porosity in the rocks surrounding the borehole.

Temperature: Temperature logs record the temperature throughout the borehole. Possibly the most useful log in that it outlines producing and thieving zones and, in conjunction with local knowledge of temperature gradients, indicates the direction of flow of water in the borehole. Where flow occurs in a well that penetrates water-bearing zones having different heads, it is indicated by slopes steeper than 1°F per 100 ft. In general, the flow of water in the well distorts the temperature log so as to mask the changes in conductance of heat to be expected between rocks of different lithological composition.

Velocity: Borehole velocity measurements were made by injecting a concentrated solution of electrolyte (table salt) into the well and tracing its movement by repeatedly running fluid-conductance logs and recording the time of travel of the peak of the anomaly caused by the brine. These measurements help define producing zones and intervals in wells where flow takes place. They also can be used in conjunction with test pumping to outline producing zones and to determine the percent of total yield produced from each individual zone.

Packer tests: Packer tests were made in 12 wells by lowering a packer to depths that had been selected by geophysical logging, and inflating the packer. The packer consists of a steel cylinder covered with a rubber sleeve which is inflatable with nitrogen gas. Measurements were made of the water levels above and below the packer prior to and after inflation. Because of physical limitations of the equipment, the packer could not be placed much more than 200 ft below the static water level in any well. Thus, in most cases, only heads in the upper part of the flow system were measured.

In summary, each geophysical log measures a different characteristic of the rocks surrounding the borehole or the water in and near the borehole. In general, each log adds information valuable in the interpretation of the other logs, and the hydrologic system penetrated by the borehole. Temperature, fluid conductance, electric, neutron, and caliper logs often indicate producing and thieving zones in boreholes. The boreholes velocity logs show the direction and amount of water movement in the borehole. Packer tests indicate the head differences in the hydrologic system penetrated by the borehole, those head differences control the direction and amount of movement.

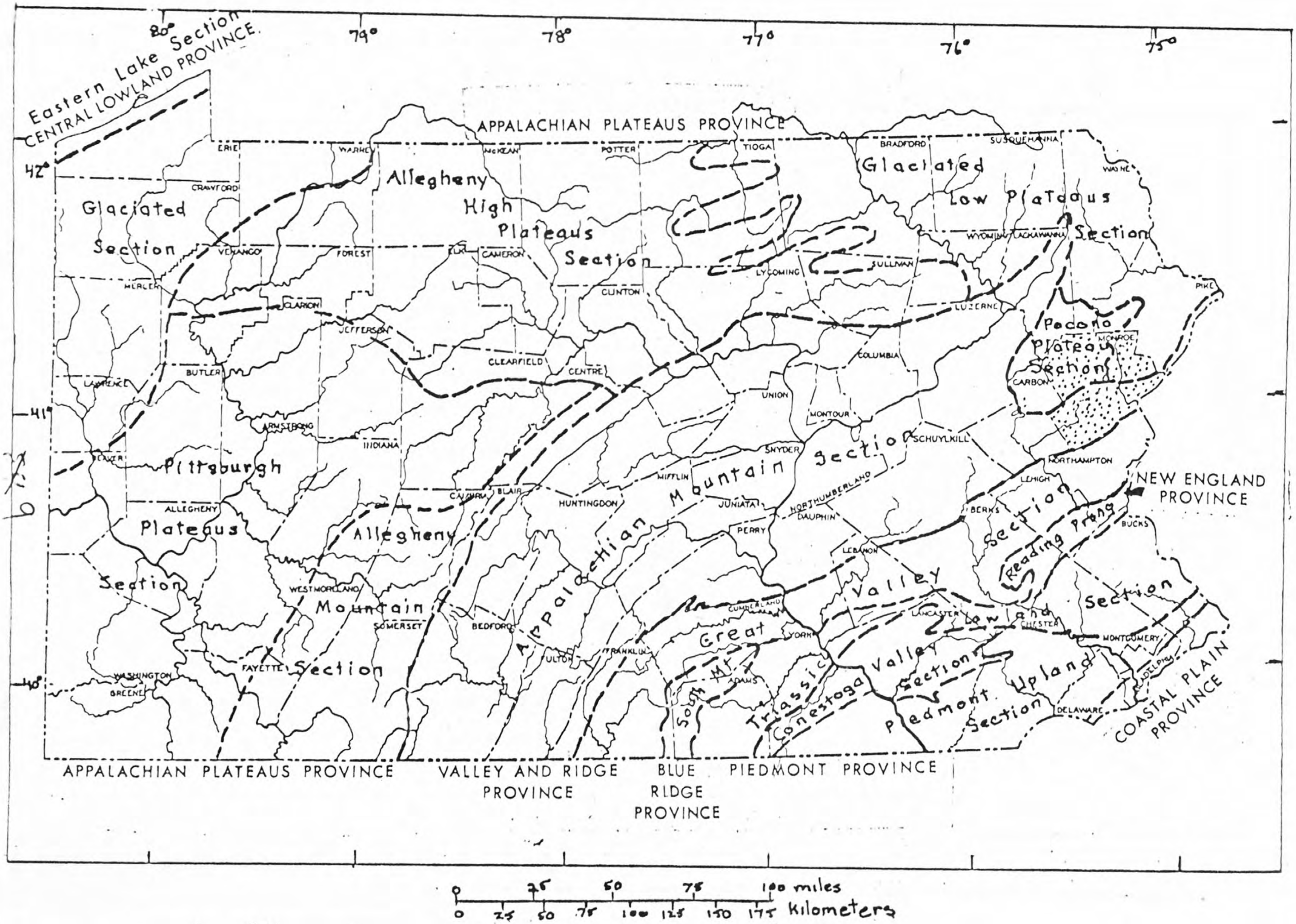

Figure 1. Location of Monroe County and physiographic divisions.

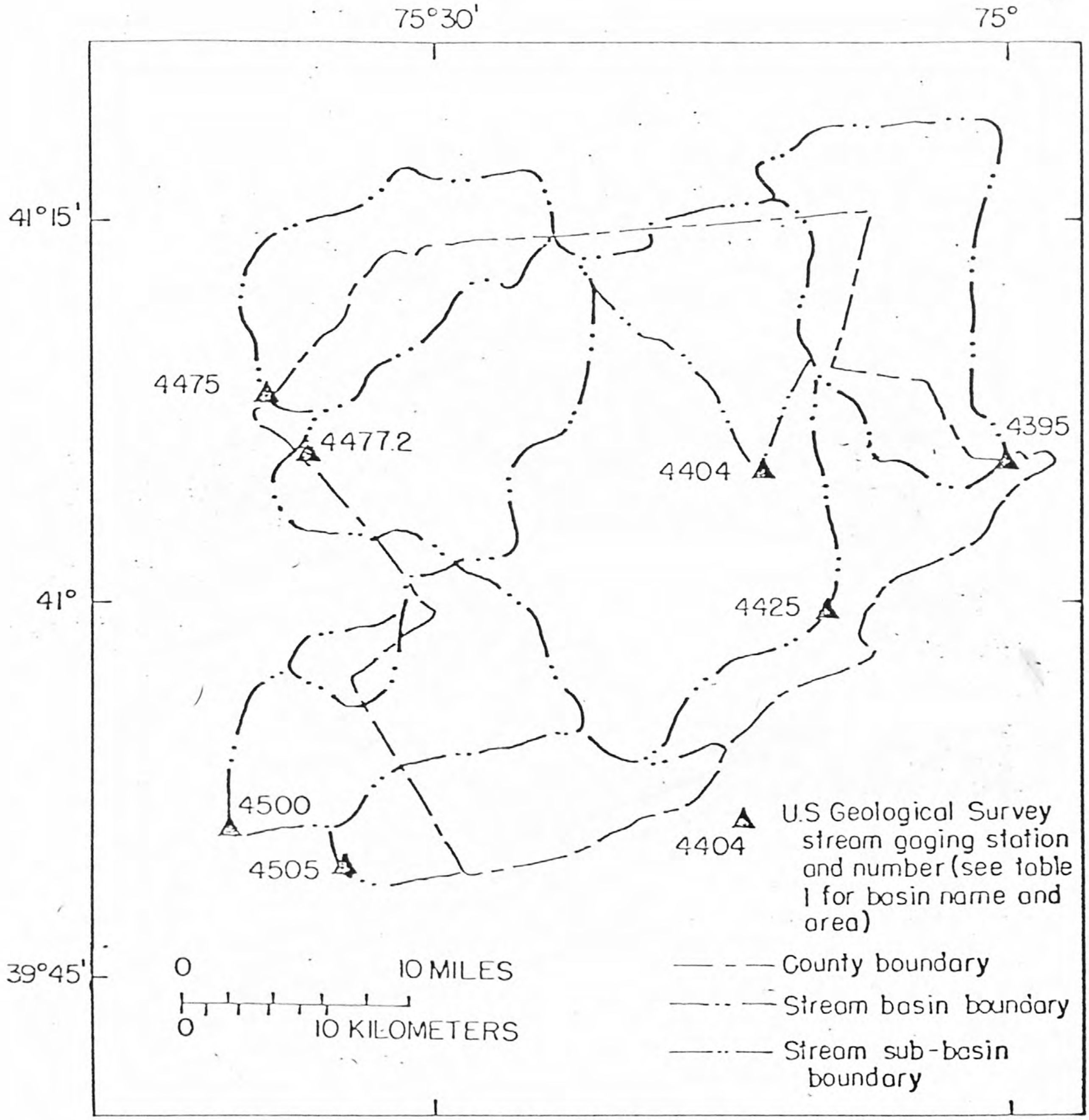

Figure 4.--Stream basins and gaging stations.

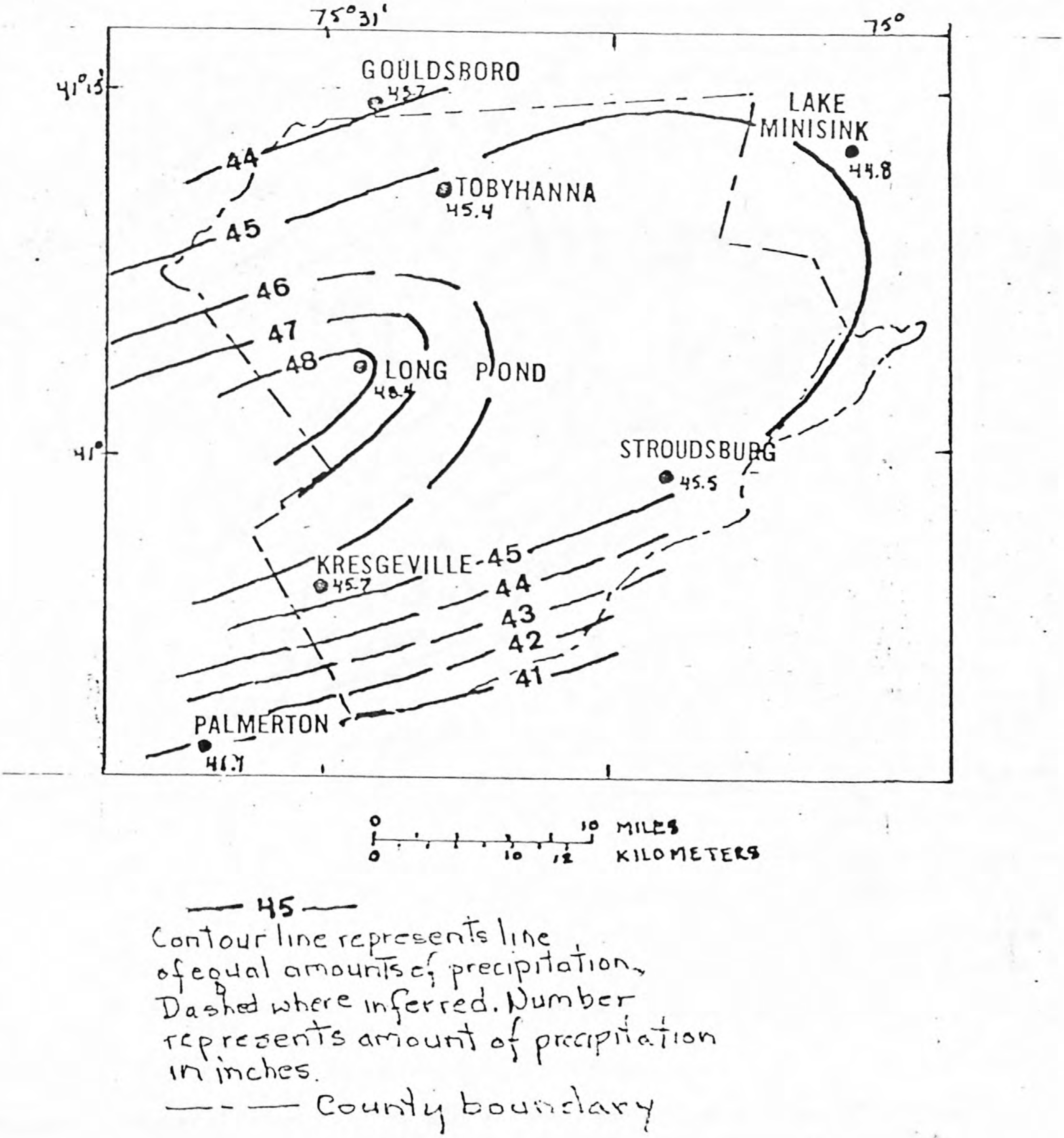

Figure 5.--Average precipitation 1960-75.

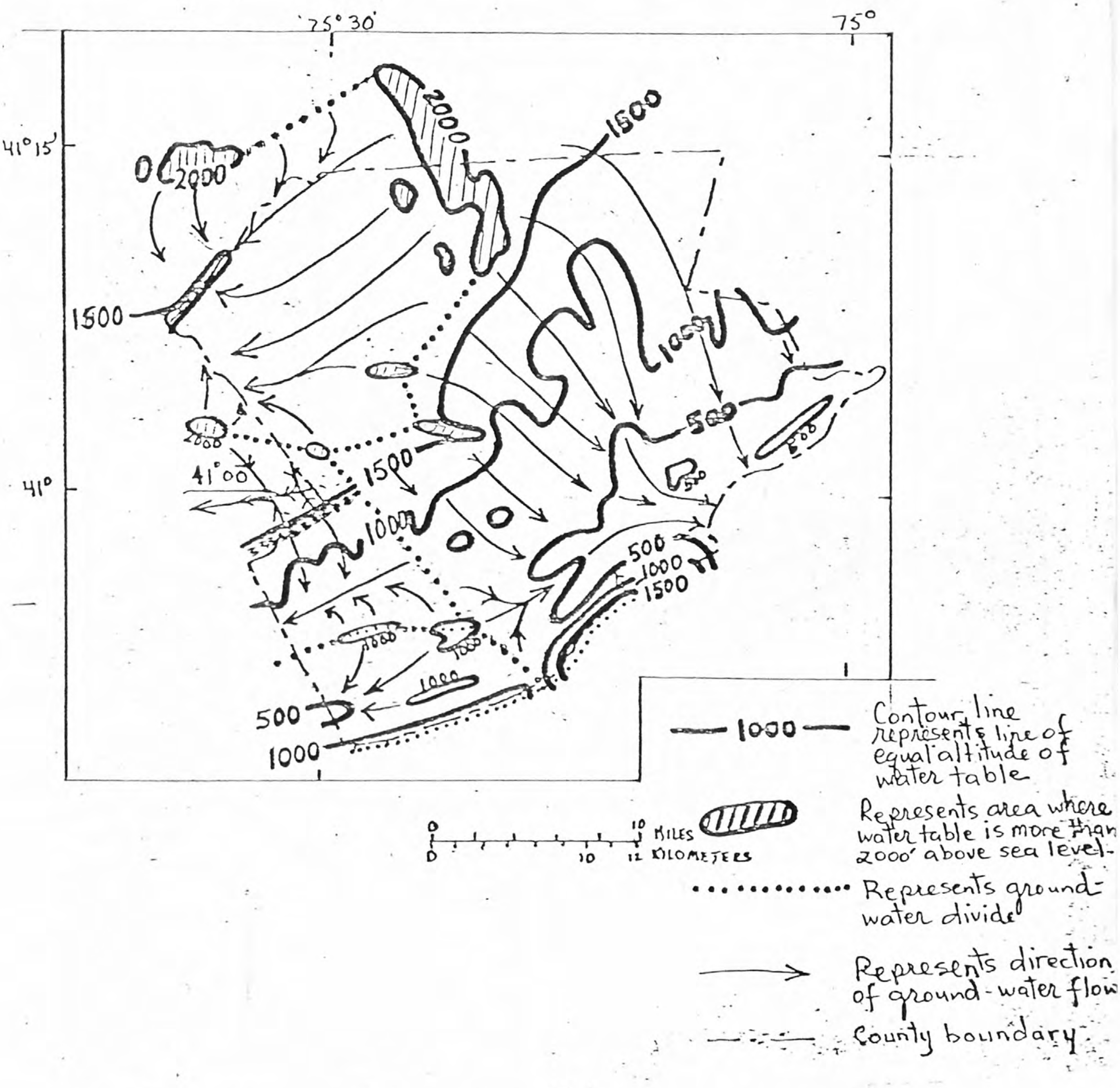

Figure 6.--General shape of the top of the zone of saturation, location of ground-water divides, and direction of ground-water flow.

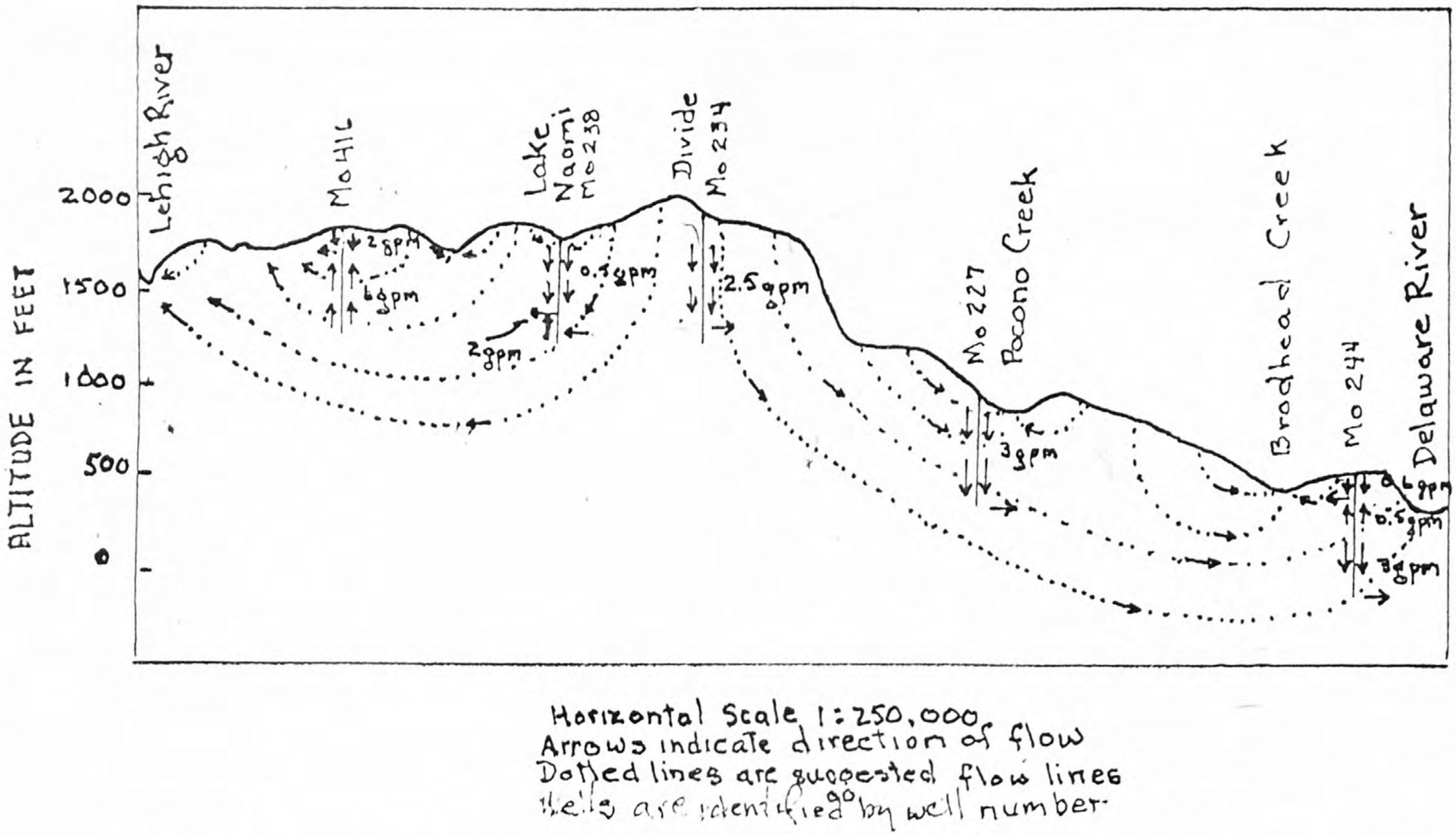

Figure 7.--Diagramatic cross-section from Thornhurst to East Stroudsburg showing generalized flow paths and direction and amount of flow measured in wells.

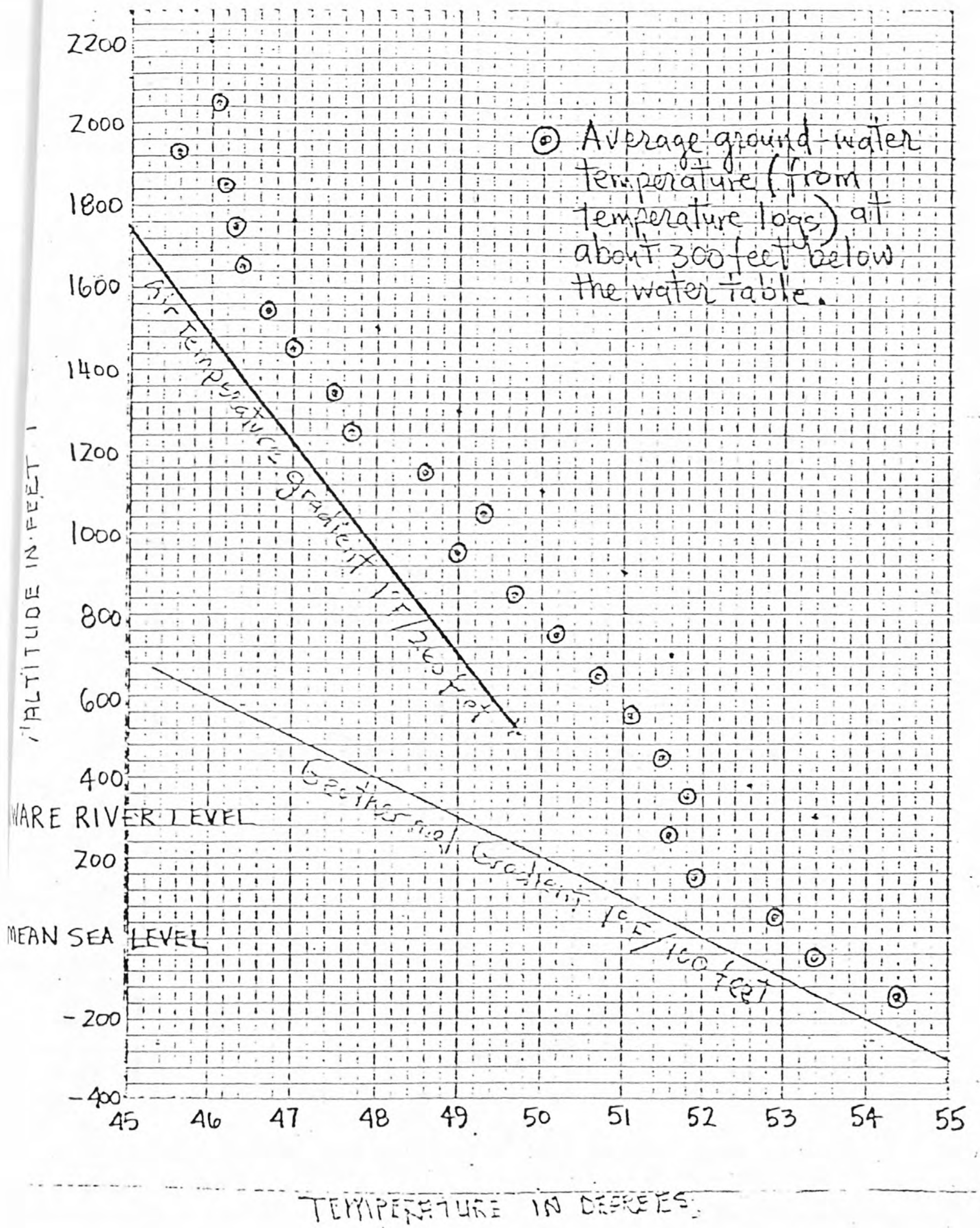

Figure 8. Ground-water temperature, air-temperature and geothermal gradients in Monroe County.

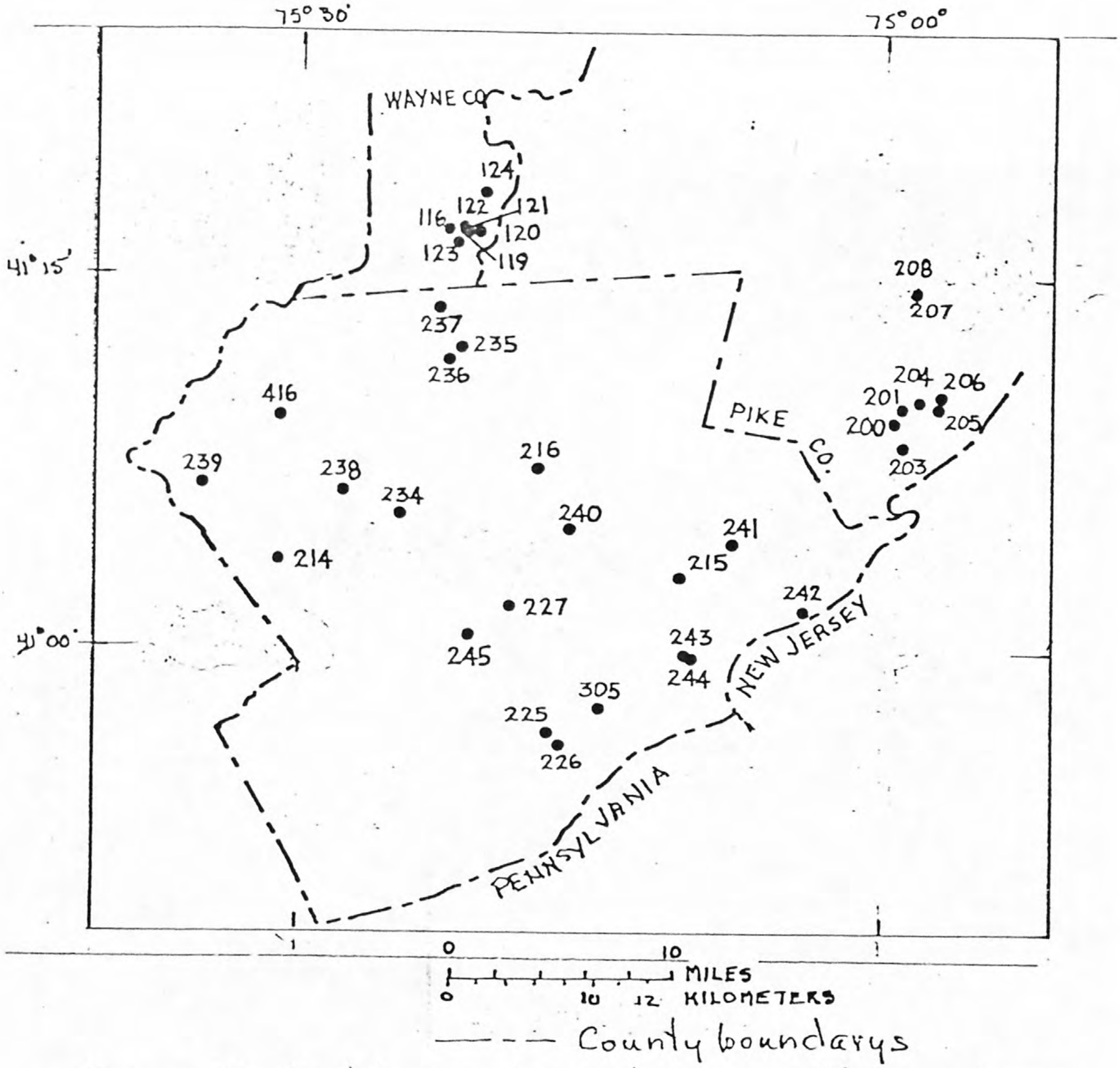

Figure 9. Location and county sequential number of wells in which geophysical logs and packer tests were made in Monroe County and parts of Pike and Wayne Counties.