EFFECT OF URBANIZATION ON THE WATER RESOURCES OF

WARMINSTER TOWNSHIP, BUCKS COUNTY, PENNSYLVANIA

Ronald A. Sloto and Drew K. Davis

U.S. GEOLOGICAL SURVEY

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

Multiply inch-pound units	By	To obtain SI units
inch (in)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon (gal)	3.785 0.003785	liter (L) cubic meter (m^3)
million gallons (Mgal)	3,785	cubic meter (m^3)
gallon per minute (gal/min)	0.06309 0.00006309	liter per second (L/s) cubic meter per second (m^3/s)
million gallon per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
million gallon per square mile ($Mgal/mi^2$)	1,461	cubic meter per square kilometer (m^3/km^2)
million gallon per day per square mile [$(Mgal/d)/mi^2$]	0.0169	cubic meter per second per square kilometer [$(m^3/s)/km^2$]
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer [$(m^3/s)/km^2$]

EFFECT OF URBANIZATION ON THE WATER RESOURCES OF WARMINSTER TOWNSHIP, BUCKS COUNTY, PENNSYLVANIA

By Ronald A. Sloto and Drew K. Davis

ABSTRACT

Rapid suburban development occurred in Warminster Township and the surrounding area after World War II, resulting in a large population dependent on ground water. In 1980, approximately 2.7 billion gallons of ground water was pumped by public water suppliers and government facilities. Pumping wells can cause drawdown as far as 2,500 feet updip, downdip, or along strike even if the wells do not penetrate the same strata. Pumping wells have lowered base flow; a stream-gain-and-loss study showed that water lost from Little Neshaminy Creek was about 60 percent of the water pumped from wells near the stream. Net ground-water infiltration to sewers was about 830 million gallons in 1979, a wet year, and about 250 million gallons in 1980, a dry year. Estimated water budgets for 1979 and 1980 indicate evapotranspiration can range from 20 to 26 inches per year (1.0 to 1.2 million gallons per day per square mile) and recharge can range from 8 to 18 inches per year (0.4 to 0.9 million gallons per day per square mile). In a year with average precipitation (45 inches or 2.1 million gallons per day per square mile), evapotranspiration is about 24 inches (1.1 million gallons per day per square mile) and recharge about 11 inches (0.5 million gallons per day per square mile). Ground-water development in the area influenced by pumping is at its practical limit for years of average recharge, but as much as 1.1 million gallons per day of additional water may be obtained by drilling and pumping wells in areas of Warminster Township not affected by pumping.

The concentration of most dissolved constituents increased in water from seven wells, sampled at the onset of ubranization in 1953 and 1956 and again in 1979. Ground-water contamination by volatile organic compounds, especially trichloroethylene and tetrachloroethylene, has made water from some wells unsuitable for public supply. The concentration of lead in 26 samples of ground water ranged from 0 to 55 micrograms per liter, with a median of 17 micrograms per liter; this is above the reported national median and the median in nearby Chester County. High concentrations of sulfate and dissolved solids in ground water are probably caused by restricted ground-water circulation and may be reduced by long-term pumping, which flushes the aquifer. Effluent from sewage treatment plants has degraded the quality of low streamflow.

INTRODUCTION

Rapid and continuing urbanization of southeastern Pennsylvania has resulted in a large population dependent on ground water. Many water suppliers in the area must rely on ground water because adequate surface-water supplies do not exist. Water-use restrictions are increasing in frequency as water suppliers experience shortages. Waste water that once recharged the ground-water reservoir through septic systems is now exported by sewers from the basins where it is pumped. Organic chemical contamination has locally made some ground water unsuitable for public supply without expensive treatment.

Purpose

This investigation by the U.S. Geological Survey, in cooperation with the Warminster Municipal Authority, has three purposes: (1) to determine how urbanization has affected ground water and low streamflow in Warminster Township and parts of the surrounding municipalities; (2) to describe the hydrologic system; and (3) to assess the availability of ground water.

Description of the Project Area

Warminster Township is 5 miles north of Philadelphia in southeastern Pennsylvania. The project area (fig. 1), 65 mi^2 (square miles), includes Warminster Township and parts of the surrounding municipalities in Bucks and Montgomery Counties.

Warminster Township is in the Triassic Lowlands section of the Piedmont physiographic province (Greenman, 1955, p.3). The Triassic Lowlands are characterized by low rolling hills. Altitude ranges from 140 to 380 feet. The township is drained by tributaries to Little Neshaminy Creek to the north and by tributaries to Pennypack Creek to the south. Both of these streams are tributaries to the Delaware River.

The area has a modified humid continental climate. Average monthly temperature recorded by the National Oceanic and Atmospheric Administration at Georgetown School ranges from -1°C in January to 23°C in July. The average annual temperature is 11°C.

Population and Land Use

Before World War II, Warminster Township was farms and woodlands. From 1800 to 1920, the population fluctuated between 500 and 1,000; between 1920 and 1940, it grew to almost 2,000 (fig. 2).

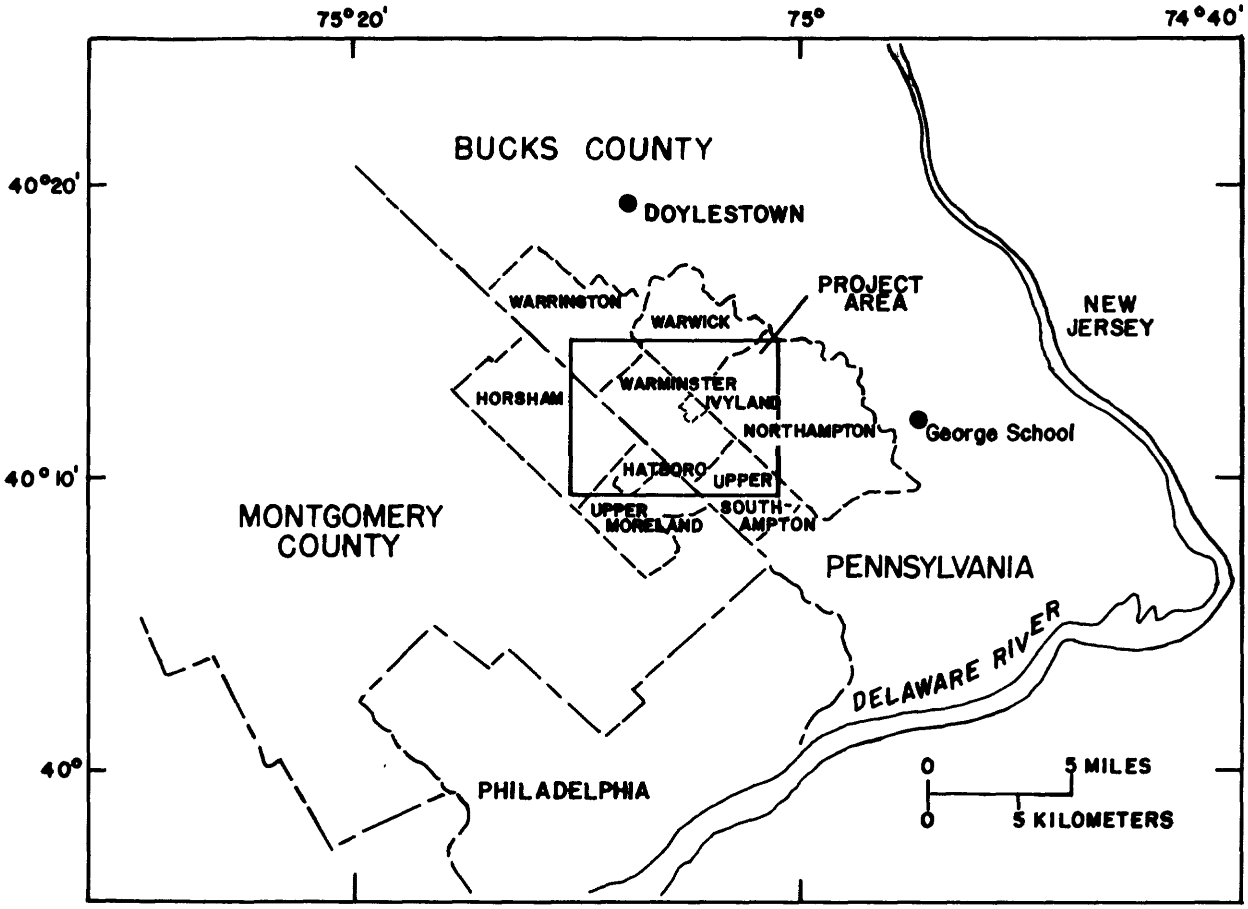


Figure 1.--Location of project area.

Industrial growth in Bucks County and subsequent suburban development increased rapidly after World War II. Warminster Township became a prime site for suburban expansion because of its favorable location. From 1940 to 1950, the population increased 350 percent, and in each of the next two decades it doubled. As the population grew, farms and woodlands became suburban housing developments. Domestic wells and septic systems were replaced by public water and sewers. Population growth slowed considerably from 1970 to 1980 because most of the available land had been developed.

Previous Investigations

Hall (1934) briefly described the water-bearing characteristics of the geologic formations of southeastern Pennsylvania. Greenman (1955) discussed the ground-water resources of Bucks County. Rima, Meisler, and Longwill (1962) described the geology and hydrology of the Stockton Formation in southeastern Pennsylvania. Parker and others (1964) discussed the water resources of the Delaware River basin. Newport (1971) summarized the ground-water resources of Montgomery County.

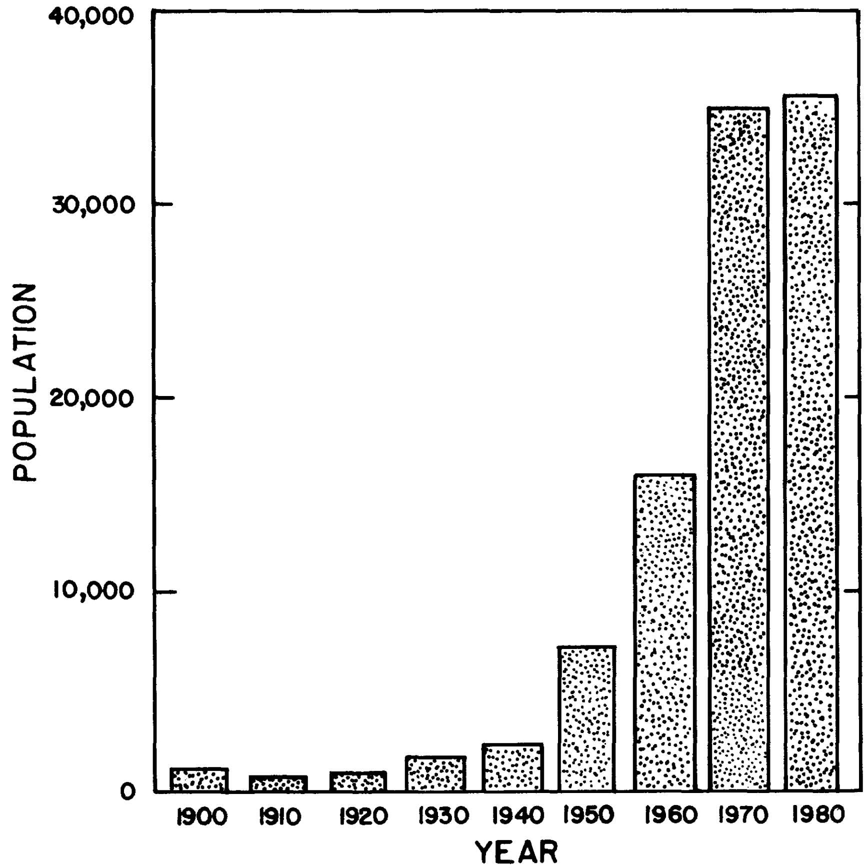


Figure 2.--Population of Warminster Township, 1900-80.

Acknowledgements

The cooperation of well owners, local, county, state, and federal officials is gratefully acknowledged. The authors wish to thank well owners, municipal water and sewer authorities, private water suppliers, the U.S. Naval Air Development Center, the U.S. Naval Air Station, the U.S. Environmental Protection Agency, the Pennsylvania Department of Environmental Resources, the Bucks County Planning Commission, the Bucks County Health Department, and W. Rollin Rabb and Son Artesian Wells for their assistance and for supplying data.

Well-Numbering System

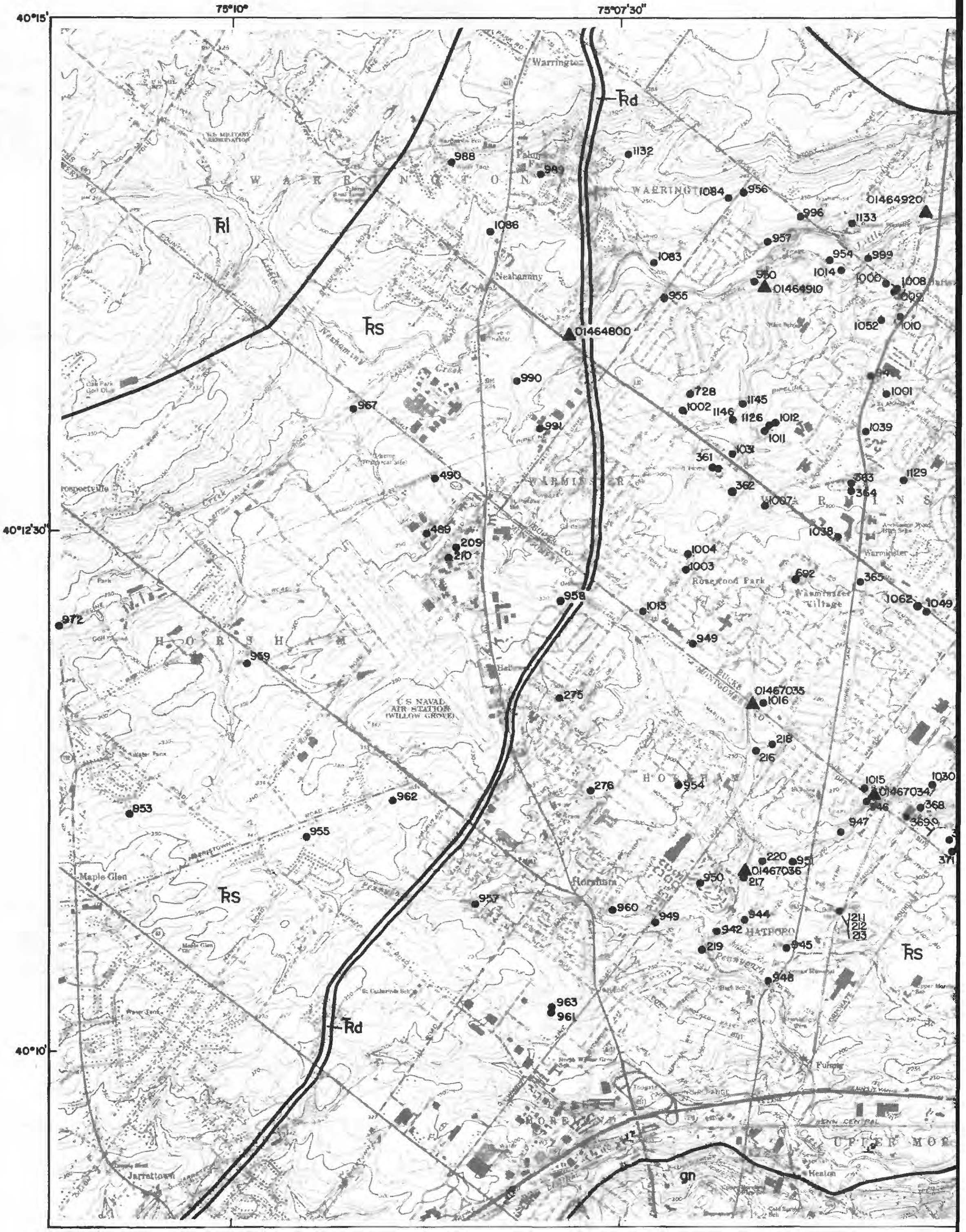
The well-numbering system used in this report is a county abbreviation followed by a sequentially assigned number. A well having the prefix Bk is located in Bucks County. A well having the prefix Mg is located in Montgomery County. The wells are listed in numerical sequence in table 12 and their locations are shown in figure 3. Missing numbers are those assigned to wells located in parts of these counties not included in this study.

Surface-Water Stations

The location of surface-water stations is shown in figure 3. Station numbers, names, and drainage areas are given in table 1. Station number 01467036 was a continuous record station 1978-81. The other stations were established as low-flow partial-record stations and water-quality sampling sites for this study (1978-80).

Table 1.-- Surface water stations

Station no.	Station name	Drainage area (mi^2)
01464800	Little Neshaminy Creek at Neshaminy	25.5
01464910	Little Neshaminy Creek tributary at Warminster	1.5
01464920	Little Neshaminy Creek at Hartsville	30.2
01464930	Little Neshaminy Creek tributary at Traymore	4.34
01464940	Little Neshaminy Creek tributary at Jacksonville	2.77
01467032	Southampton Creek at Davisville	1.12
01467033	Southampton Creek tributary at County Line Road near Lacey Park	.90
01467034	Pennypack Creek tributary at Bonair	1.18
01467035	Middle Branch Pennypack Creek tributary at Warminster Village	.92
01467036	Pennypack Creek tributary at Hatboro	4.36

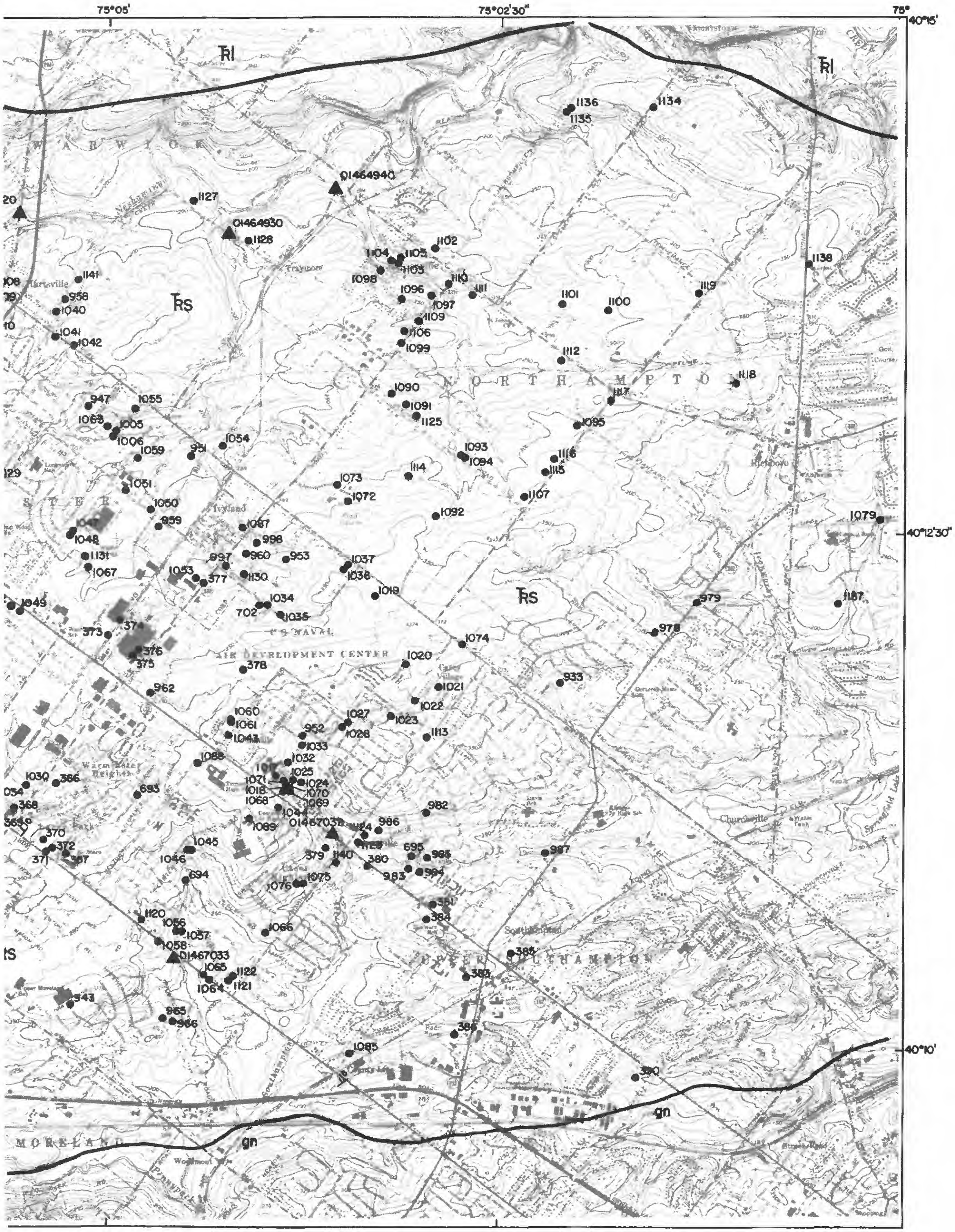


Base from U.S. Geological Survey
Hatboro and Ambler Quadrangles, 1:24,000, 1966

0 1 MILE
0 1 KILOMETER
CONTOUR INTERVAL 10 FEET

National Geodetic Vertical Datum of 1929

Figure 3.--Geologic map showing locations of selected wells and surface-water stations.



CORRELATION OF MAP UNITS

T̄Rd		Upper Triassic	TRIASSIC
T̄Rl / T̄Rs	Newark Group		
gn			PRECAMBRIAN

DESCRIPTION OF MAP UNITS

T̄Rd DIABASE - Medium to fine grained dark gray, occurs as a dike

T̄Rl LOCKATONG FORMATION - Argillite, mudstone, and shale, dark grey to black, thick bedded

T̄Rs STOCKTON FORMATION - Sandstone, fine to course grained, arkosic, middle member; conglomerate lower member

gn GNEISS - Medium grained crystalline, light-gray felsic to dark-gray mafic; partly sedimentary and partly igneous origin

GEOLOGIC CONTACT

10 Strike and dip of bedding

▲01464800 Stream gaging station and number

●1129 Well and number

PUBLIC WATER SUPPLIES

All the municipal authorities, private water suppliers, industries, and government facilities obtain their water supply from wells. In 1980, water suppliers and government facilities pumped 2.7 billion gallons of ground water (table 2). Pumpage data in table 2 does not include water pumped to waste to control the spread of organic chemical contamination. Most municipalities purchase or sell water through distribution system interconnections. In 1980, for example, the Warminster Municipal Authority purchased 98.5 million gallons and sold 48.5 million gallons of water through distribution system interconnections, for a net purchase of 50 million gallons.

Ground water pumpage in Warminster Township in 1980 was 1,240 million gallons. The Warminster Municipal Authority pumped 1,060 million gallons. The Warminster Heights Development Corporation, the U.S. Naval Air Development Center, and industries pumped 152 million gallons. About 25 million gallons was pumped by households and small commercial and industrial ground-water users.

As population and industrial growth increased, the demand for water increased. In 1960, the population of Warminster Township was 15,944 and ground-water pumpage was 124 million gallons, a per capita use of 21 gallons per day per person. In 1980, the population was 35,467 and ground-water pumpage was 1.06 billion gallons, a per capita use of 82 gallons per day per person. Between 1960 and 1980, population increased 122 percent, ground-water pumpage increased 755 percent, and per capita use increased 290 percent. Annual ground-water pumpage by the Warminster Municipal Authority from 1960-80 is shown in figure 4.

Table 2.--Ground-water pumpage in 1980 by public water suppliers and government facilities

	Number of wells	Ground-water pumpage (Mgal)
Hatboro Water Authority	10	571.7
Horsham Township Authority	13	386.7
Northampton Municipal Authority	5	205.3
Warminster Heights Development Corporation	2	66.5
Warminster Municipal Authority	14	1,063.4
Warrington Municipal Authority	2	106.0
Warrington Water Company	2	3.3
U.S. Naval Air Development Center	3	65.4
U.S. Naval Air Station	3	108.6
Upper Southampton Municipal Authority	4	142.6
Total	58	2,719.5

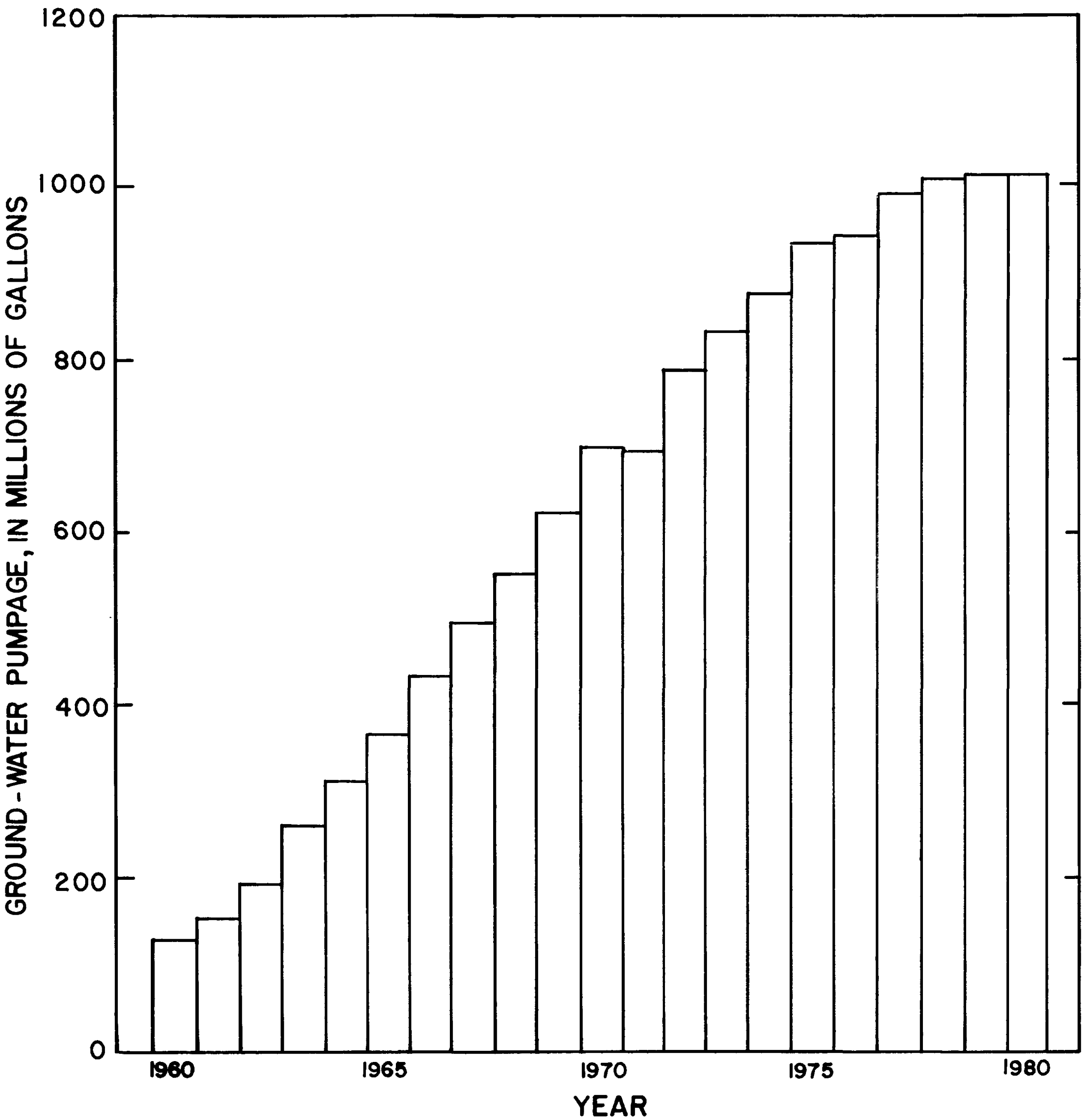


Figure 4.--Annual ground-water pumpage by the Warminster Municipal Authority, 1960-80.

GEOLOGY

The Stockton Formation of Late Triassic age underlies most of the area (fig. 3). It lies unconformably over Precambrian gneiss to the south and is overlain by the Lockatong Formation, also of Late Triassic age, to the north. The western part of the area has been intruded by a diabase dike.

The Stockton Formation is composed of sediments eroded from highlands to the south. Rima and others (1962, p. 9) divided the Stockton into three members in Montgomery County. The lower arkose member is characterized by abundant coarse-grained arkosic (composed of unsorted quartz and feldspar grains) sandstone and arkosic conglomerate. The middle arkose member, which underlies most of Warminster Township, is characterized by an abundance of fine- and medium-grained arkosic sandstones. The highest yielding wells in the Stockton Formation tap this member. In the lower and middle members, the sandstones are interbedded with siltstone and shale. Geologic logs from selected wells are given in table 15.

Lithologic units in the Stockton Formation are as thick as 120 feet and can grade from fine grained to coarse grained in short lateral distances. Cross-bedding, lensing, and pinch-and-swell structures are common (McLaughlin, 1959, p.65). Because beds commonly pinch out or grade laterally into beds of different texture and color, individual beds are generally not traceable for any appreciable distance (Rima and others, 1962, p. 8). The Stockton is extensively faulted and is cut by a well-developed system of joints.

The dip of the Stockton Formation ranges from 7 to 16° north to northwest, and averages 12°. The thickness of the Stockton near the Bucks-Montgomery County border is about 6,000 feet (Rima and others, 1962, p. 9).

HYDROLOGY

Precipitation

Average annual precipitation (1889-1980) recorded 5 miles north of the project area by the National Oceanic and Atmospheric Administration at Doylestown, Pennsylvania, is 45.16 inches. Precipitation ranged from 30.20 inches in 1965 to 67.08 inches in 1889. The 1951-80 normal precipitation is 41.90 inches, which is 3.26 inches less than the average for the period of record (fig. 5). Precipitation is fairly evenly distributed throughout the year with slightly more during July and August (fig. 6).

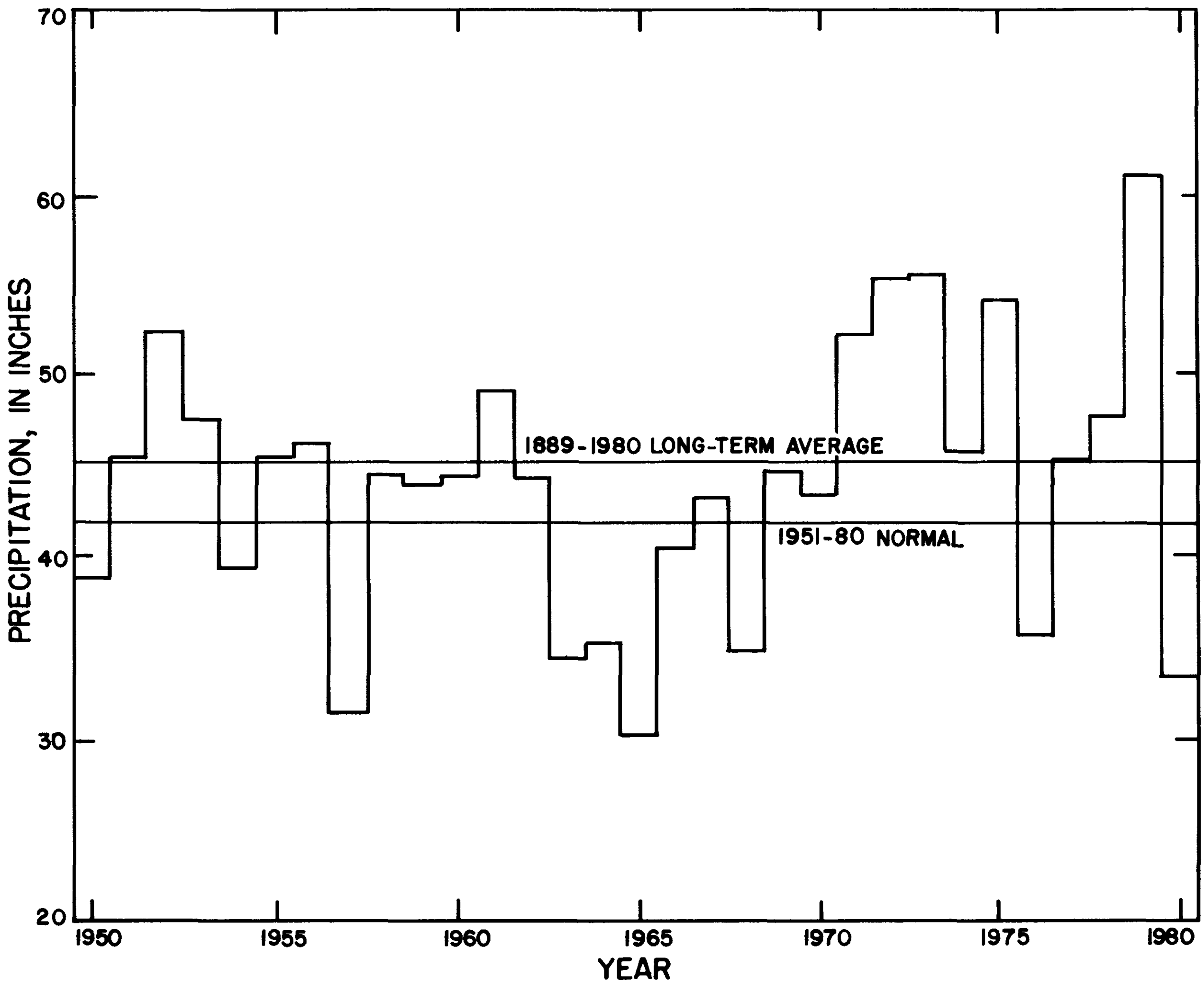


Figure 5.--Annual precipitation at Doylestown, 1950-80.

Ground Water

Part of the water from precipitation percolates downward through soil and rock until it reaches the zone of saturation, where all voids are filled with water. When the upper surface of the saturated zone is not confined by an impermeable layer and is free to rise and fall in response to recharge to and discharge from the aquifer, it is called the water table. All dug wells and most shallow drilled wells are water-table wells.

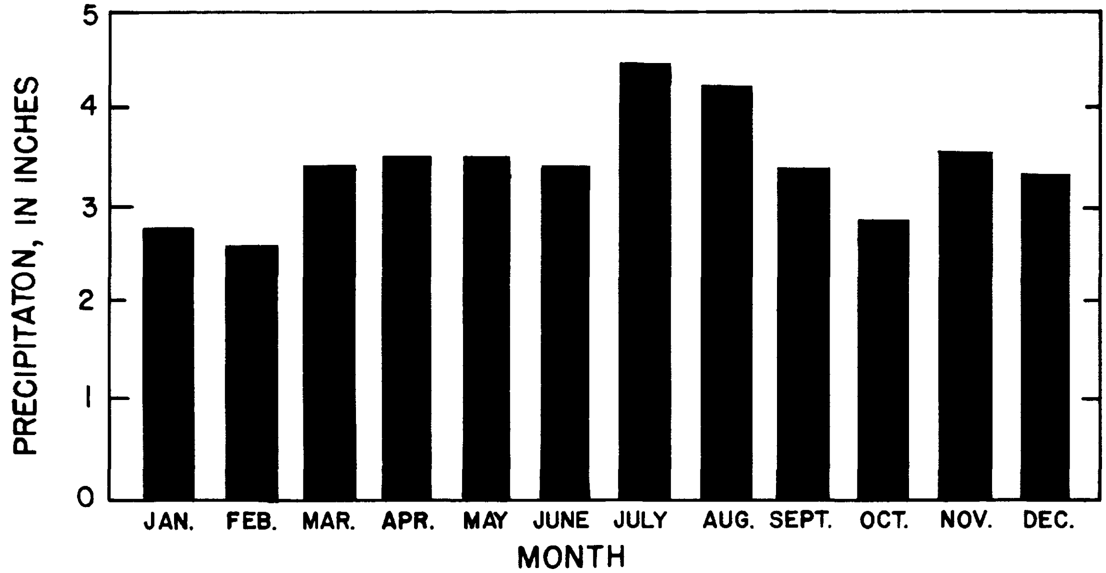


Figure 6.--Normal monthly precipitation at Doylestown, 1951-80.

At depth, water is confined under pressure greater than atmospheric. This confinement is caused by vertical changes in permeability that result from the cementing material in some zones being less susceptible to removal by solution, gradations in the textures of the sediments, and varying degrees of fracturing (Greenman, 1955, p.28). If the hydrostatic pressure is sufficient, the well will flow at the surface. Water levels in deep wells respond to changes in pressure. Most of the water pumped from the Stockton Formation is pumped from water-bearing zones in which water is under pressure greater than atmospheric. In areas of heavy pumping, this pressure may be considerably reduced.

Ground water moves through the intergranular openings in the weathered zone and through a network of interconnecting joints and fractures in unweathered rock. Some water may move through pores in the rock where the cement has been removed and the permeability has increased.

Most deep wells penetrate several major water-bearing zones. Well Bk-1129, for example, penetrated major water-bearing zones at 125, 170, 210, and 305 feet. Each zone usually has a different hydraulic head. The hydraulic head in a deep well is the composite head of the several water-bearing zones it penetrates. Where differences in hydraulic head exist between water-bearing zones, water in the well flows in the direction of decreasing head.

Internal flow, caused by differences in head between water-bearing zones, was measured in five wells. Flow in wells Bk-692, Bk-956, and Bk-957, which are in a recharge area, was measured by injecting a brine slug and measuring its direction and rate of movement. Three brine slugs injected in well Bk-692 at depths of 70, 96, and 150 feet below land surface moved downward at the rate of 9.9 gal/min (gallons per minute). The brine slug injected at 150 feet did not move past 160 feet; and brine slugs injected at 180, 200, and 236 feet did not move, indicating no water movement below 160 feet. Water in Bk-956 moved downward at the rate of 2.6 gal/min at 80 feet, 0.5 gal/min at 108 feet, and 1.3 gal/min at 180 feet. Water in Bk-957 moved downward at the rate of 1.3 gal/min at 80 feet and 2.9 gal/min at 160 feet. Well Bk-1129, in a discharge area, was flowing at the surface at the time of geophysical logging. A dye slug released at 180 feet moved up the well at 48 gal/min, and one released at 300 feet did not reach the surface. Fluid resistivity and temperature logs suggest downward movement from about 245 feet to a water-bearing zone at 305 feet. Well Bk-1146, in a discharge area, was also flowing at the surface. Water moved upward at the rate of 23.7 gal/min at 156 feet and 13.8 gal/min at 280 feet.

Water-Level Fluctuations

Water levels have a seasonal trend, generally rising during the non-growing season when evapotranspiration is low and declining during the growing season when evapotranspiration is high. The seasonal water-level fluctuation in well Bk-1020, monitored by the Bucks County Planning Commission, is shown in figure 7.

The degree of influence on ground-water levels caused by pumping municipal and industrial wells depends upon several factors, including the number of pumping wells nearby, the distance to them, their pumping rates, and local aquifer characteristics. Well Bk-1058, in an area not influenced by pumping wells, had a 5.45-foot range in water-level fluctuation during 1980. Well Bk-1087, in an area influenced by pumping wells, had a 61.63-foot range in water-level fluctuation during 1980.

Well Bk-1067 is 2,500 feet from production well Bk-959. On January 8, 1980, Bk-959 began pumping on a 12-hour per day cycle. The water level in Bk-1067 fluctuated 0.8 feet in response to the pumping cycle of Bk-959 (fig.8).

Ground-water overdevelopment occurs when, over the long term, more water is pumped from an aquifer than can be replenished by recharge. Long-term hydrographs show overdevelopment as a declining trend in water levels. Although no long-term static water-level records are available, pumping water-level data are available for most Warminster Municipal Authority wells for 1971-80. The pumping water level for the last day of each month for well Bk-955 during 1971-80 and the monthly precipitation at Doylestown are shown in figure 9. Well Bk-955 was chosen because it had the most complete record. Hydrographs from the other Warminster Municipal Authority wells show a similar pattern. The hydrographs for these wells do not show overdevelopment; they show a decline in the pumping water level when precipitation is low and a rise in the pumping water level when precipitation is high.

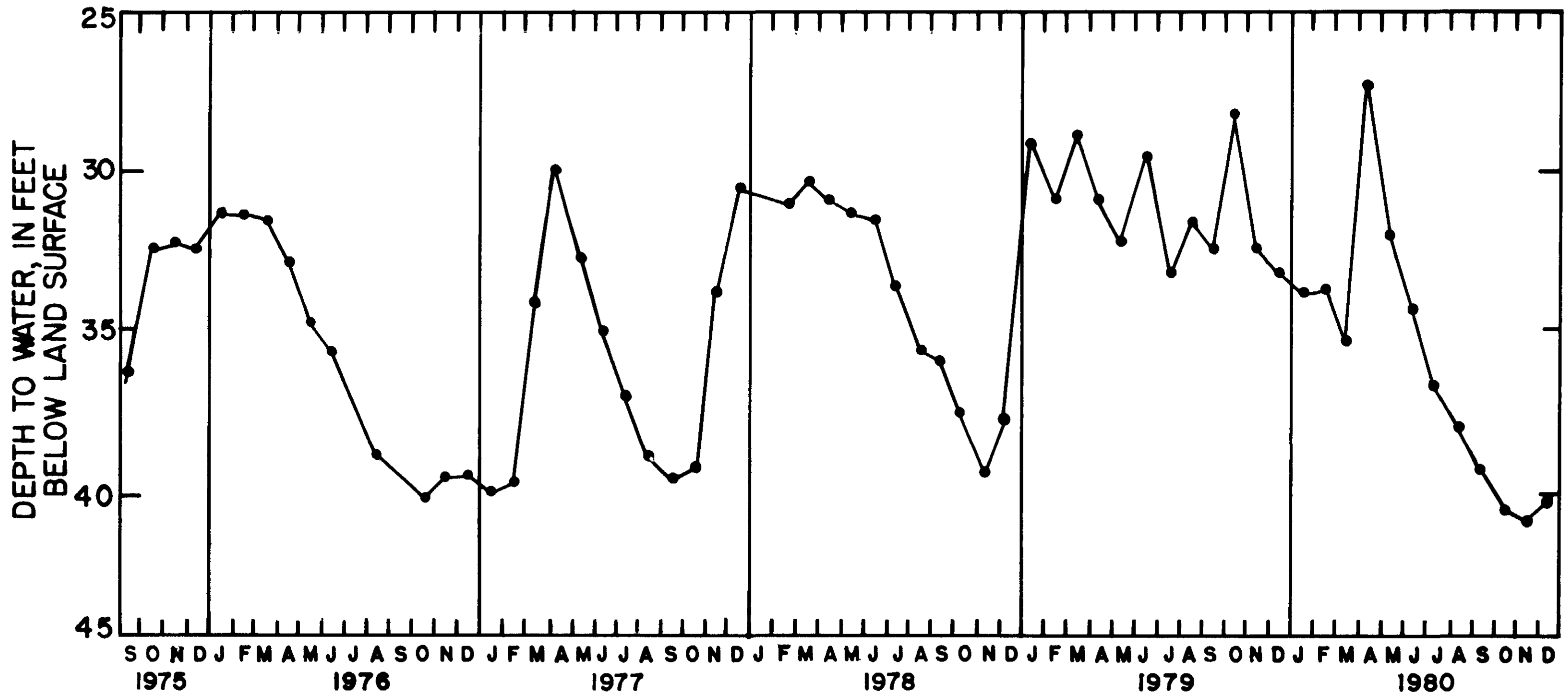


Figure 7.--Water-level fluctuations in well Bk-1020, September 1975 to December 1980. Water levels are those at midmonth. Data was provided by the Bucks County Planning Commission.

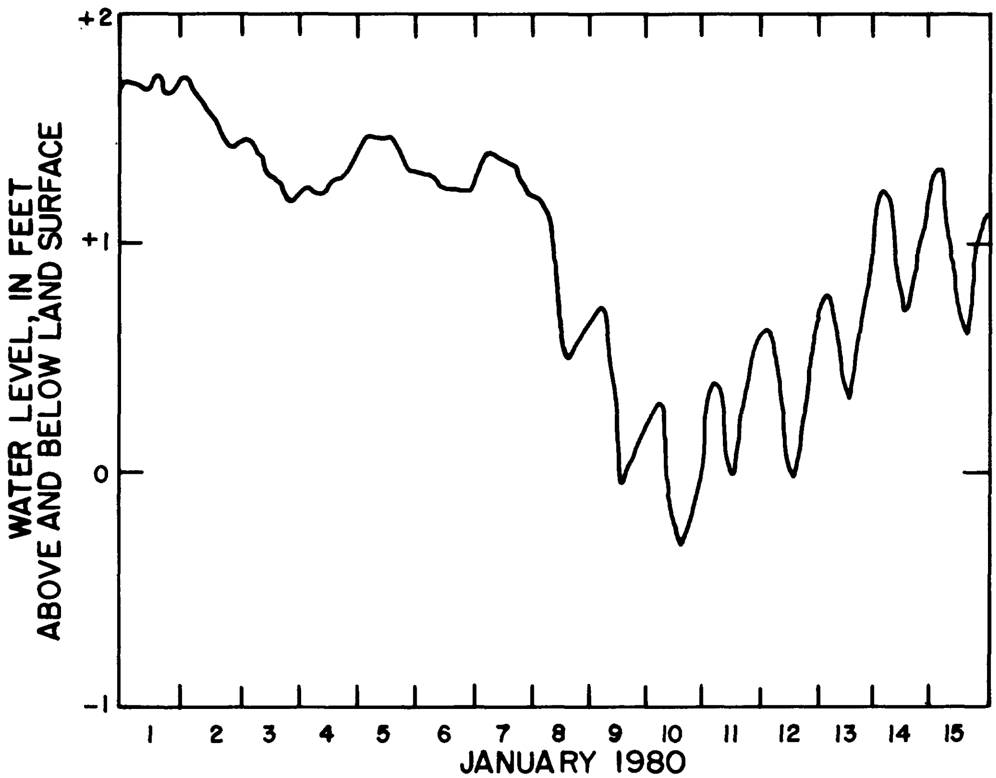


Figure 8.--Hydrograph of well Bk-1067, January 1-15, 1980.

Well Yield

Yields of drilled wells range from 8 to 700 gal/min with a median of 145 gal/min. The yield of a well is related to the number and size of water-bearing openings that it intersects. The number and size of water-bearing openings depends upon the degree of fracturing and the susceptibility of the cementing material to solution. Generally, the size and frequency of water-bearing openings decrease with depth because of the weight of the overlying rock.

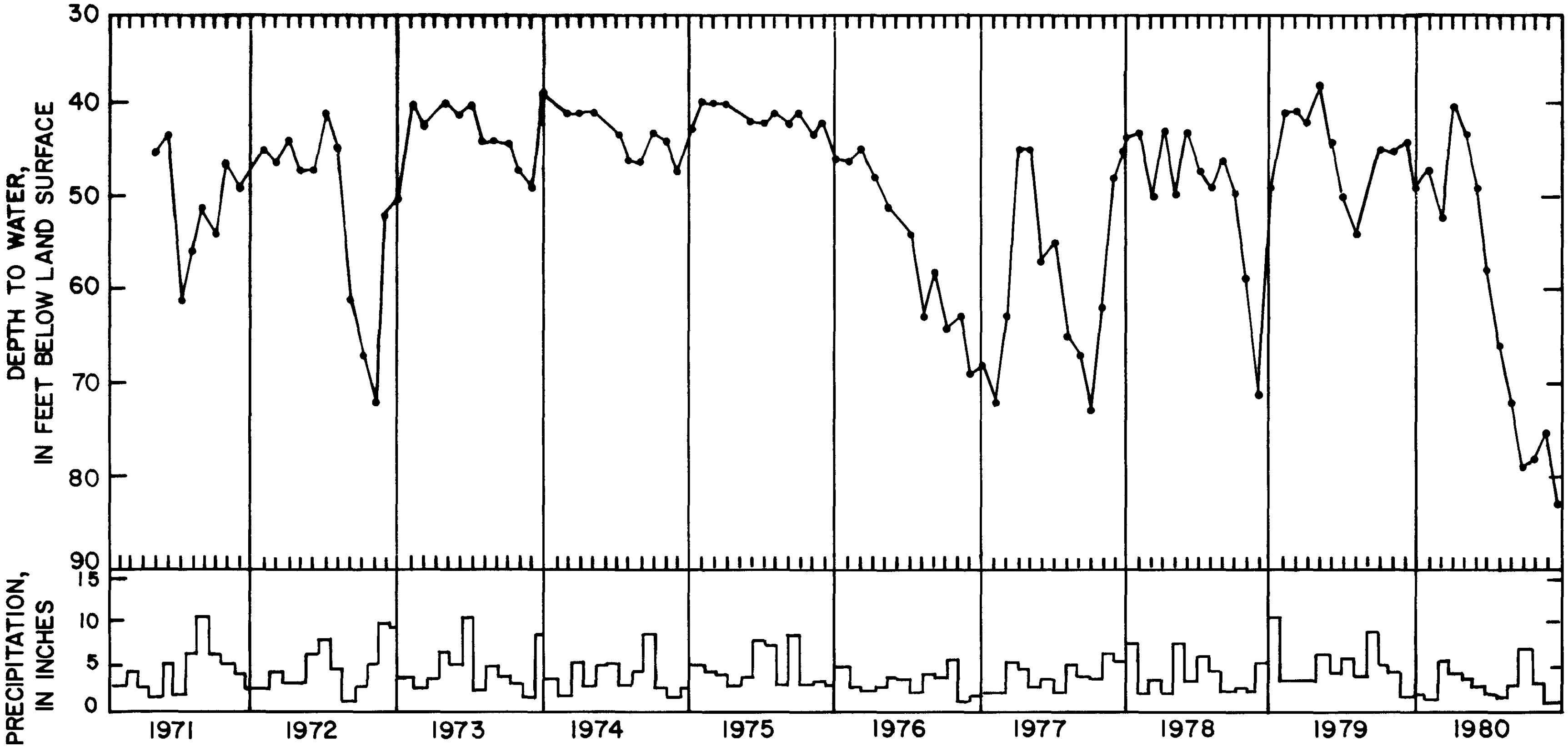


Figure 9.--Pumping water level in well Bk-955 and precipitation at Doylestown, 1971-80.

Evaluation of Aquifer Tests

Some of the assumptions that aquifer test theory is based on are: (1) the aquifer is homogeneous, isotropic, and of infinite areal extent, (2) the discharging well fully penetrates the aquifer and receives water from the entire thickness of the aquifer, and (3) transmissivity is constant at all times and at all places (Ferris and others, 1962, p. 91). Hydraulic conditions in the Stockton Formation do not satisfy any of these assumptions. The Stockton Formation contains an alternating sequence of materials of different hydraulic properties. Calculations of transmissivity and storage coefficients from aquifer tests for wells in the Stockton can, at best, be considered only an estimate of the hydraulic properties of the aquifer in the vicinity of the pumping well. Wells in the Stockton Formation generally penetrate several water-bearing zones, each of which has different hydraulic characteristics. Aquifer test results, therefore, reflect the combined hydraulic properties of the water-bearing zones penetrated by the well. Aquifer tests are useful for evaluating the effects of pumping on the pumped well and nearby wells and for evaluating the hydraulic connection between a stream and the aquifer.

Four aquifer tests were conducted during this study. The locations of the pumped wells are shown in figure 10. Results from the aquifer tests showed that drawdown caused by a pumping well occurred in observation wells downdip, updip, or along strike, even if the wells did not penetrate the same strata. Measurable drawdown can reach laterally as far as 2,500 feet. Drawdown in well Bk-1067 (fig. 8) caused by pumping well Bk-959, which is 2,500 feet away, was 0.8 feet.

Well Bk-957 was pumped at 300 gal/min during December 18-20, 1979. Well Bk-956 was an observation well 1,650 feet downdip. By projecting the 12° dip, the top uncased 20 feet in Bk-957 are the same strata as the bottom 20 feet in Bk-956. Drawdown in Bk-956 after 50 hours was 3.9 feet. The drawdown in Bk-956 began 30 minutes after Bk-957 began pumping and stopped when Bk-957 stopped pumping; recovery in Bk-956 began 95 minutes later. No drawdown was observed in well Bk-1084, a 46 foot well 1,850 feet downdip from Bk-957.

Well Bk-1059 was pumped at 309 gal/min for 71 hours during December 14-17, 1979. Well Bk-951, a production well 1,450 feet away along strike, was pumping 350 gal/min during the test. The drawdown in Bk-951 caused by pumping Bk-1059 was 6.5 feet. Three observation wells updip from the pumped well penetrate different strata than the pumping well. The drawdown in well Bk-1050, which is 1,100 feet updip, was 7.3 feet. Well Bk-959, which is 2,050 feet updip, was flowing at the start of the test and had a water level 2.42 feet below top of casing at the conclusion of the test. The water level in Well Bk-1067, which is 3,600 feet updip, showed no drawdown.

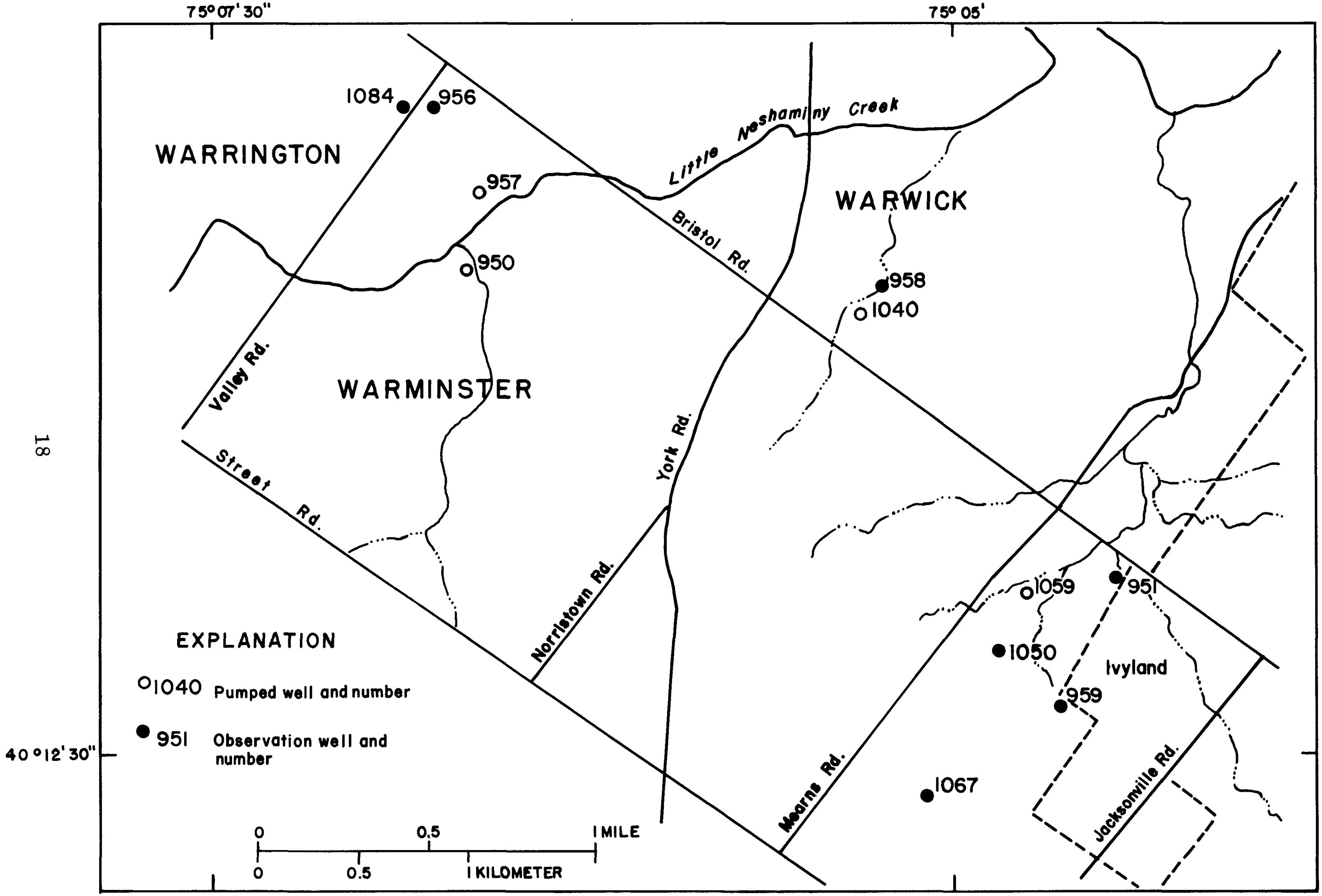


Figure 10.--Locations of aquifer tests.

Well Bk-950 was pumped at 235 gal/min during January 17-18, 1980. The drawdown in well Bk-957, an observation well 1,150 feet downdip, was 3.3 feet after 18 hours and had not stabilized. The water level in well Bk-956, an observation well 2,500 feet downdip, showed no drawdown.

Well Bk-1040 was pumped at 309 gal/min during December 10-13, 1979. The drawdown in well Bk-958, an observation well 500 feet downdip, was 26.5 feet after 60 hours.

Ground-Water Infiltration to Sewers

Most sewer lines are not watertight, and some exchange of water between sewers and the ground-water system probably occurs. Infiltration of ground water into sewers can occur when the water table is above the sewer line, and leakage from sewers to the ground-water system can occur when the water table is below the sewer line. Infiltration and leakage probably occur simultaneously, but each occurs in different areas depending on whether the water table is above or below the sewer line. The general relation between the average daily discharge from the Warminster municipal sewage treatment plant, the level of the water table in dug well Bk-1003, and monthly precipitation at Doylestown is shown in figure 11.

A comparison of discharge from the Warminster municipal sewage treatment plant and ground-water pumpage by sewer-system users (table 3) indicates infiltration into and leakage from the sewer system. Ground-water pumpage was adjusted for water purchased from and sold to surrounding municipalities. Most of Warminster Township is sewered. The storm-sewer system discharges directly to streams and is not connected to the sanitary-sewer system. The level of the water table in dug well Bk-1131, daily precipitation at Doylestown, discharge from the Warminster municipal sewage treatment plant, and water use by sewer-system users are shown in figure 12 for May, June, and July, 1980. Well Bk-1131 is not in a sewered area. Discharge from the sewage treatment plant shows the same declining trend as the water table; it appears to be only minimally influenced by precipitation part of the time. Water use by sewer-system users is less than the discharge from the sewage treatment plant in May 1980; table 3 shows a net infiltration of 25 million gallons to the sewer system. In mid-June 1980, water use becomes greater than the sewage treatment plant discharge; table 3 shows a net leakage of 8 million gallons from the sewer system. For most of July 1980, water use is more than the discharge from the sewage treatment plant; table 3 shows a net leakage of 14 million gallons from the sewer system. In 1979, a wet year, about 830 million gallons of ground water infiltrated into the sewer system. In 1980, a dry year, about 300 million gallons of ground water infiltrated into the sewer system, and about 50 million gallons leaked from the sewer system; the net infiltration was about 250 million gallons.

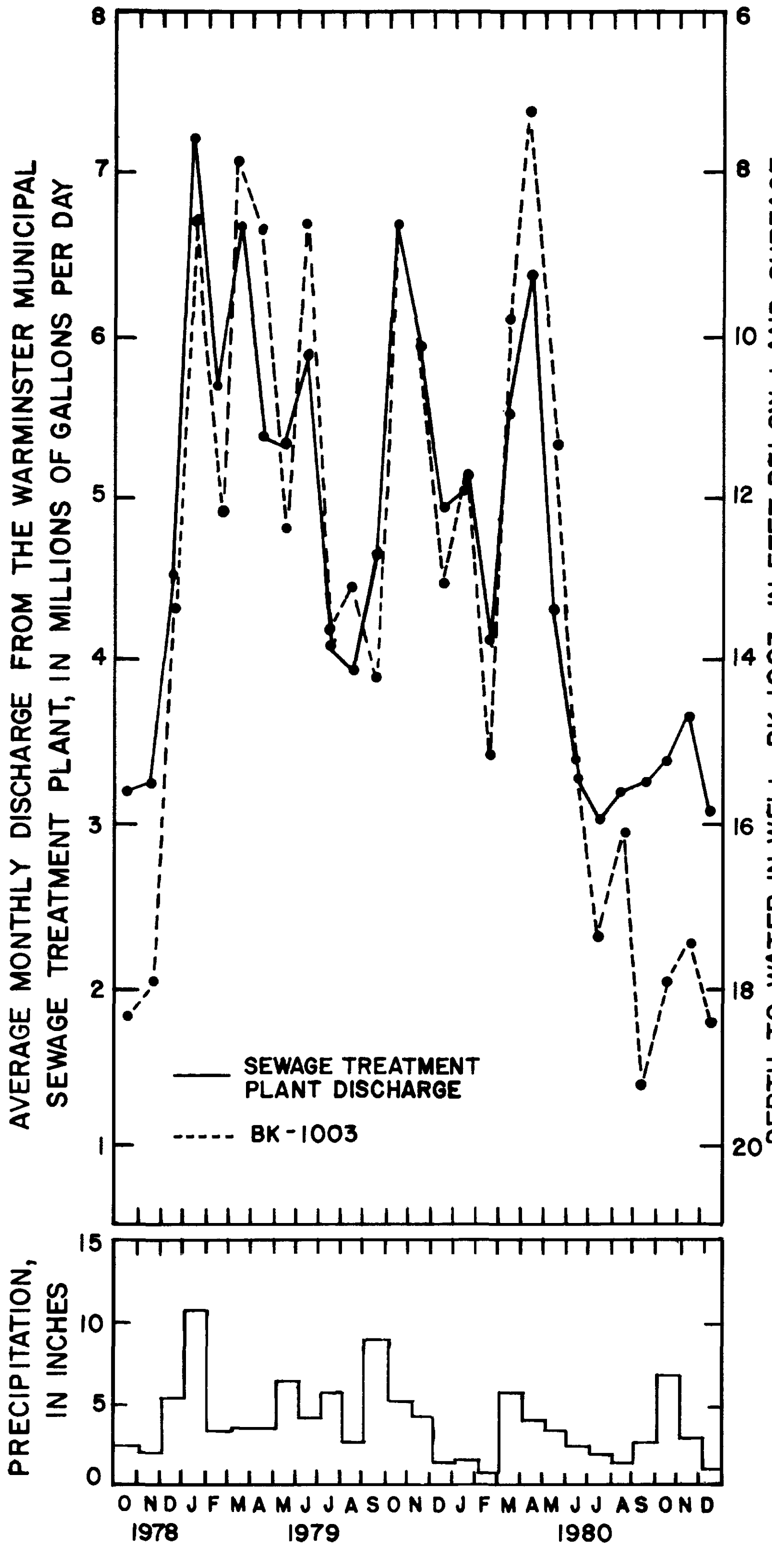


Figure 11.--Relation between discharge from the Warminster municipal sewage treatment plant, the water level in dug well Bk-1003, and monthly precipitation at Doylestown.

Table 3.--Comparisons of discharge from the Warminster sewage-treatment plant and ground-water pumpage by sewer-system users

Date	Discharge from Warminster sewage-treatment plant (Mgal)	Ground-water pumpage by sewer-system users (Mgal)	Net infiltration (+) into or leakage (-) from sewer system (Mgal)
1979			
January	223	101	+122
February	158	88	+70
March	206	101	+105
April	161	101	+60
May	164	103	+61
June	176	102	+74
July	126	100	+26
August	117	94	+23
September	143	99	+44
October	200	93	+107
November	178	95	+83
December	148	90	+58
Total	2,000	1,167	+833
1980			
January	157	97	+60
February	122	90	+32
March	173	97	+76
April	191	98	+93
May	133	108	+25
June	99	107	-8
July	94	108	-14
August	98	102	-4
September	97	100	-3
October	105	99	+6
November	110	98	+12
December	94	111	-17
Total	1,473	1,215	+258

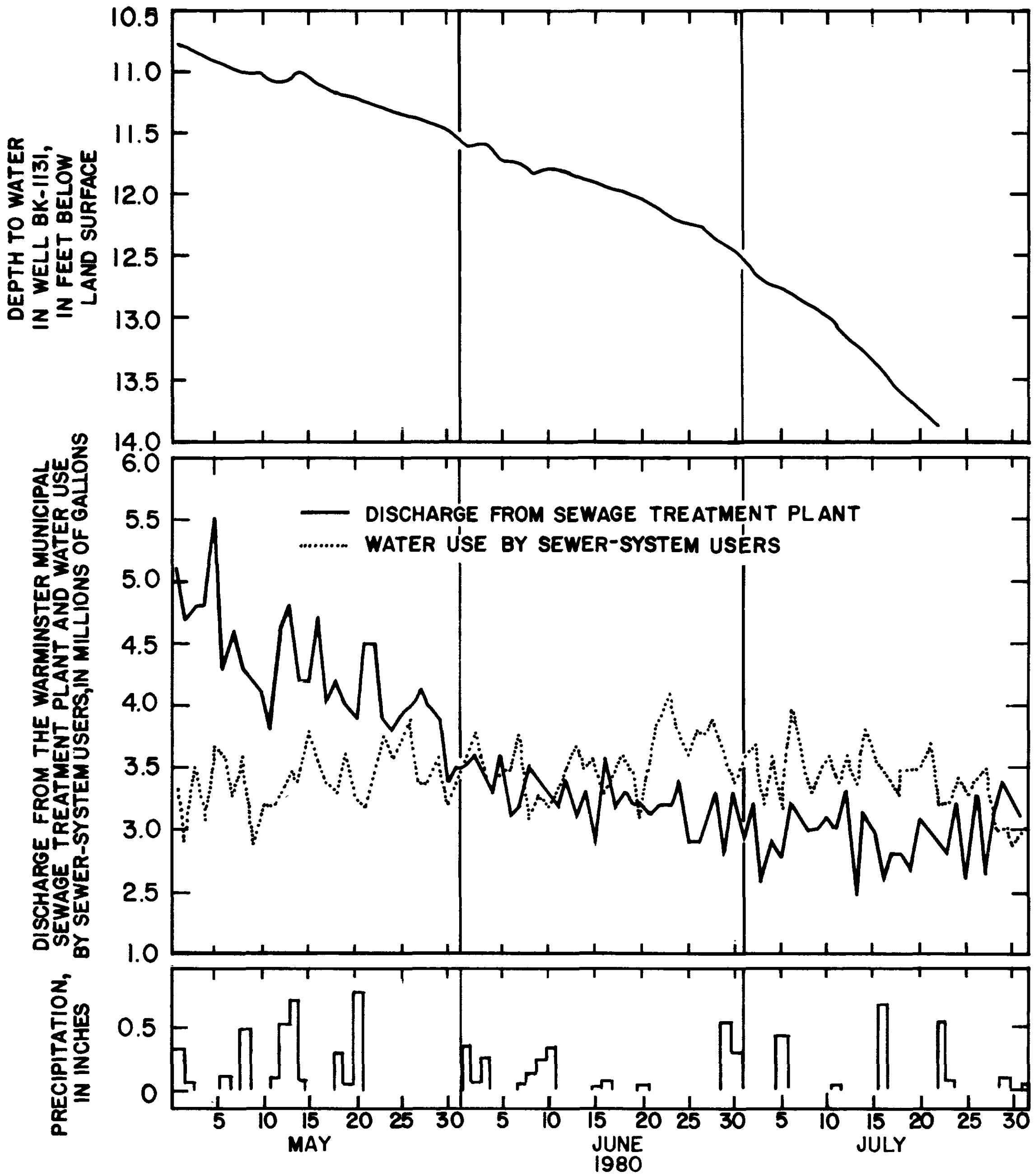


Figure 12.--Relation between the level of the water table in dug well BK-1131, daily precipitation at Doylestown, discharge from the Warminster municipal sewage treatment plant, and water use by sewer-system users in May, June, and July 1980.

Surface Water

Urbanization has increased the area covered by buildings, streets, and paved surfaces. Storm sewers rapidly drain these impervious areas, and many studies (Anderson, 1970, for example) have shown that urban development causes an increase in the magnitude of peak discharges. Peak discharges for three small basins (fig. 13) are compared. These basins are in areas of similar geomorphologic and climatic characteristics, but the degree of urbanization differs. Flippo (1977, pl. 1) includes all three basins in the same flood-frequency region. A tributary to Pennypack Creek at Hatboro (station 01467036) drains a 4.36 mi^2 urban area. From August 1977 to September 1980, 15 peak discharges at this station exceeded 350 ft^3/s (cubic feet per second); the highest was 1,120 ft^3/s. In comparison, Marsh Creek near Glenmoore (station 01480675) in Chester County, is a rural basin with a drainage area (8.57 mi^2), almost twice that at station 01467036. During the same period, only one peak discharge at this station exceeded 350 ft^3/s; that discharge was 794 ft^3/s. Pickering Creek near Chester Springs (station 01472174) in Chester County drains a 5.98 mi^2 basin changing from rural to suburban. During the same period, four peak discharges at this station exceeded 350 ft^3/s; the highest was 1,080 ft^3/s. Idéally, peak discharges should be compared before and after urbanization, but only 3 years of record are available at the Hatboro gaging station. The comparison of these three basins, however, tends to confirm conclusions made by other studies that urban development causes higher peak discharges.

During dry periods, streamflow is sustained by base flow, which is ground-water discharge to streams. Urbanization has caused a reduction in base flow because of an increase in impervious area that reduces ground-water recharge, by the pumpage of ground water that would have been discharged to streams, and by the infiltration of ground water to sewers. Base flow at four surface-water stations (fig. 14) in 1979 and 1980 are given in table 4. No effluent is discharged nor are any wells pumped to waste into these streams. Discharges are given in $(ft^3/s)/mi^2$ (cubic feet per second per square mile), so that flow at the stations can be compared. No production wells are in or adjacent to the 2.77 mi^2 basin above station 01464940 and only a small part of this basin is sewered. Three production wells are adjacent to the 1.50 mi^2 basin above station 01464910. In August and September 1980, the stream was dry at this station. Two production wells are in and one is adjacent to the 0.90 mi^2 basin above station 01467033. One production well is in the 0.92 mi^2 basin above station 01467035. These three basins are sewered. Base flow at station 01464940 is the highest, at least in part, because streamflow in that basin is not affected by ground-water pumping and only a small part of the basin is sewered.

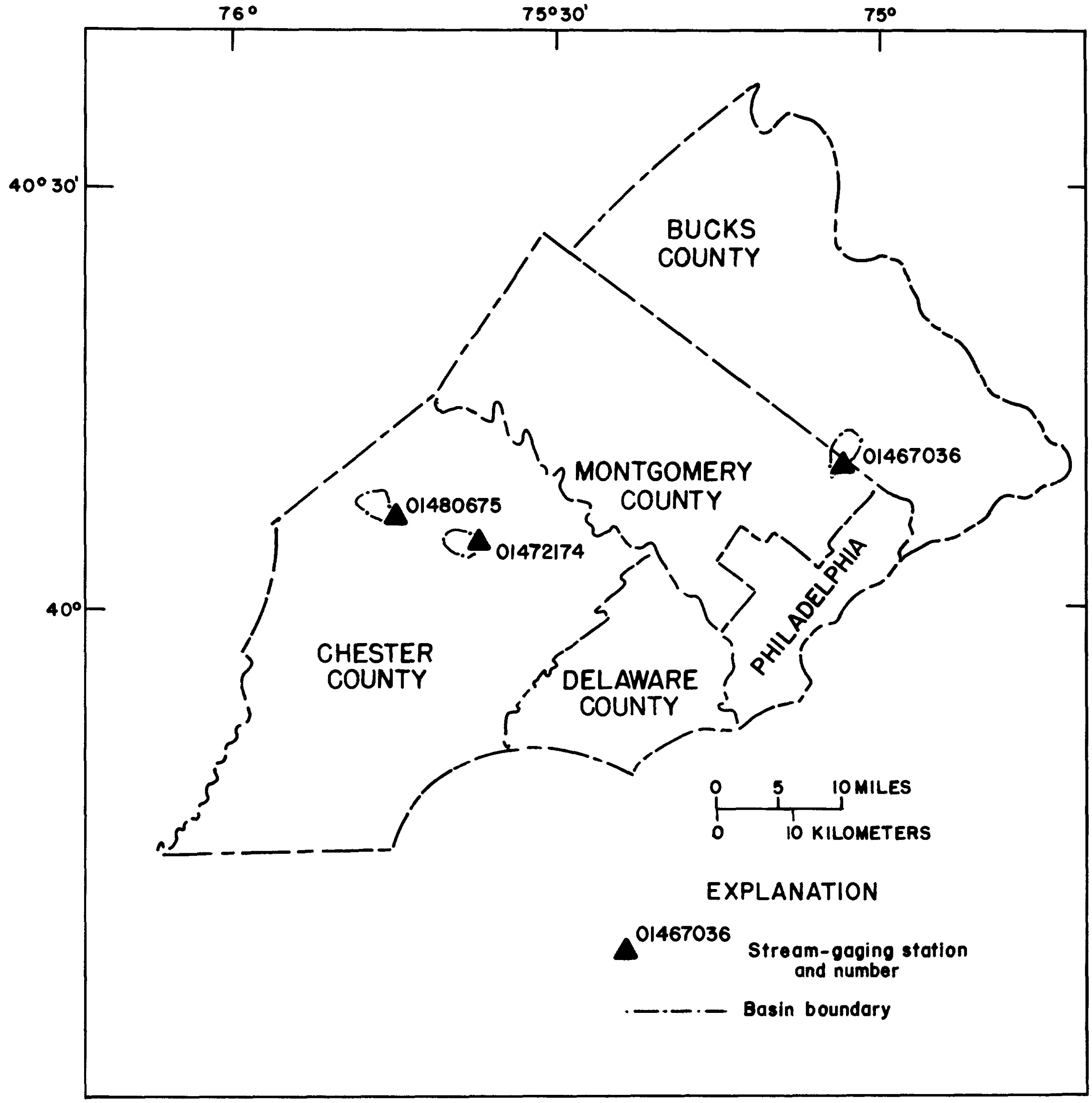


Figure 13.--Locations of selected stream-gaging stations in Chester and Montgomery Counties, Pennsylvania.

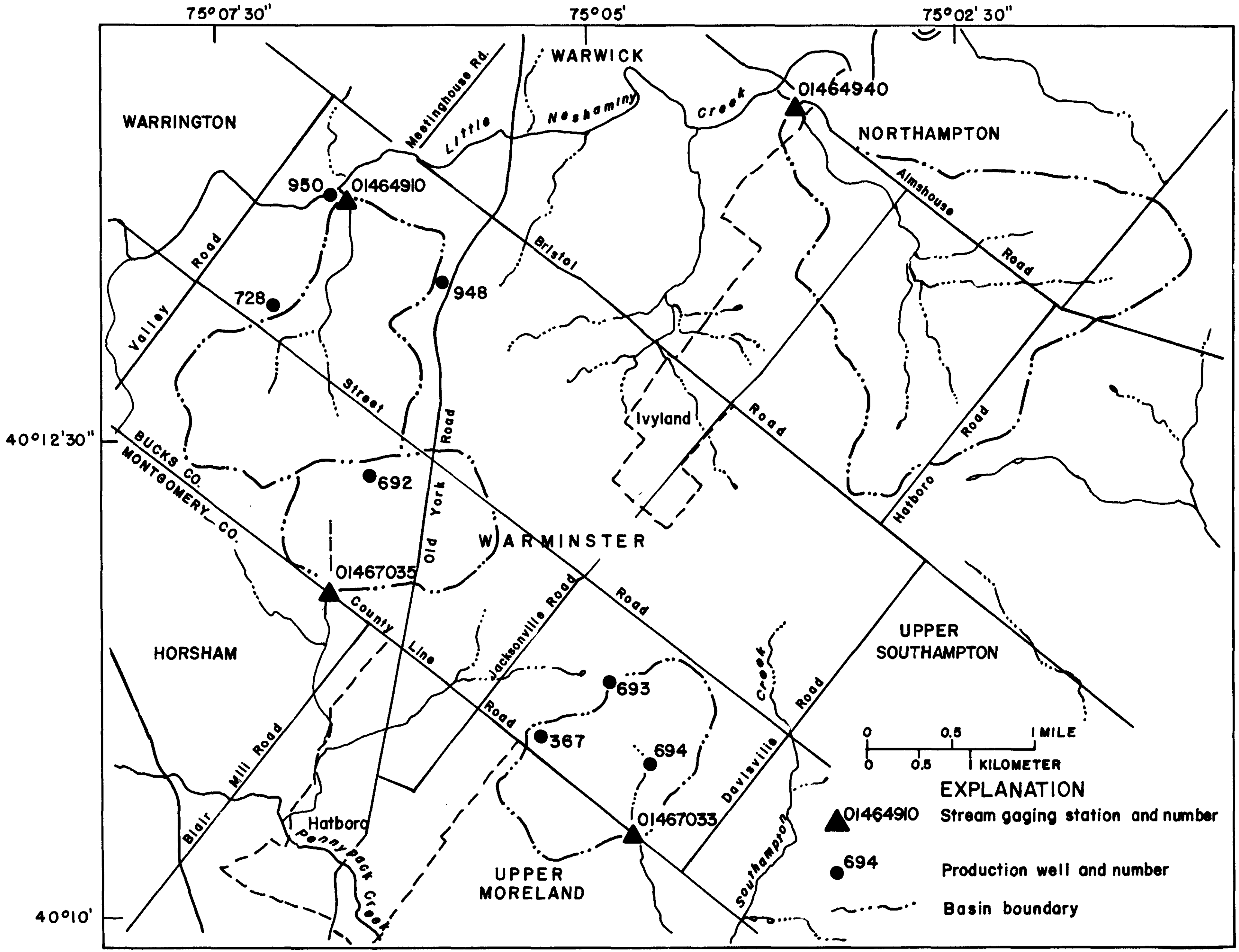


Figure 14.--Locations of selected small drainage basins.

Table 4.--Low-flow discharge at selected surface-water stations

Date of measurement	Discharge $[(ft^3/s)/mi^2]$ at surface water stations[1]			
	01464940	01464910	01467033	01467035
4/23/79	1.43	0.66	0.68	-
10/30/79	1.70	-	.61	-
11/2/79	-	.57	-	0.28
4/21/80	-	-	1.28	.41
4/22/80	-	.85	-	-
5/27/80	.81	.17	-	-
5/29/80	-	-	.23	-
8/11/80	.08	0	.07	.07
9/20/80	-	0	<.01	-
9/24/80	.03	0	-	-

[1] See figure 3 for locations of stations.

Ground Water-Surface Water Relationship

Under pre-pumping conditions, ground-water discharge would constitute 45 to 60 percent of the annual surface-water flow, depending on precipitation. Because of pumping, ground-water discharge now constitutes only about 40 percent of the annual surface-water flow. Pumping, especially during dry periods, can cause streams to go dry by diverting ground water that would have been discharged to the streams and by lowering the water table below the stream bed, causing streamflow to infiltrate into the aquifer. Recharge is induced, causing water to flow from the stream into the aquifer, when pumping reverses the hydraulic gradient between the aquifer and the stream. To induce recharge, the stream and the aquifer must be hydraulically connected. The pumping wells must be close to the stream and pumped at a rate sufficient to reverse the hydraulic gradient. The tributary to Little Neshaminy Creek at station 01464910 (fig. 14) is 200 feet from production well Bk-950. During most of July through October 1980, this tributary was dry near Bk-950, but was flowing in its upper reaches which are not close to a pumping well.

To determine how pumping wells affect streamflow, a gain and loss study of Little Neshaminy Creek was made. The study was made on a 1.42 mile reach of the creek between Street Road and the Warminster municipal sewage treatment plant on November 14, 1980. No rain had fallen for 7 days, and the stream was at base flow. Stream discharge was determined from the stage-discharge relationship of the nonrecording gage at station 01464800 and measured by a current meter at four downstream sites (fig. 15).

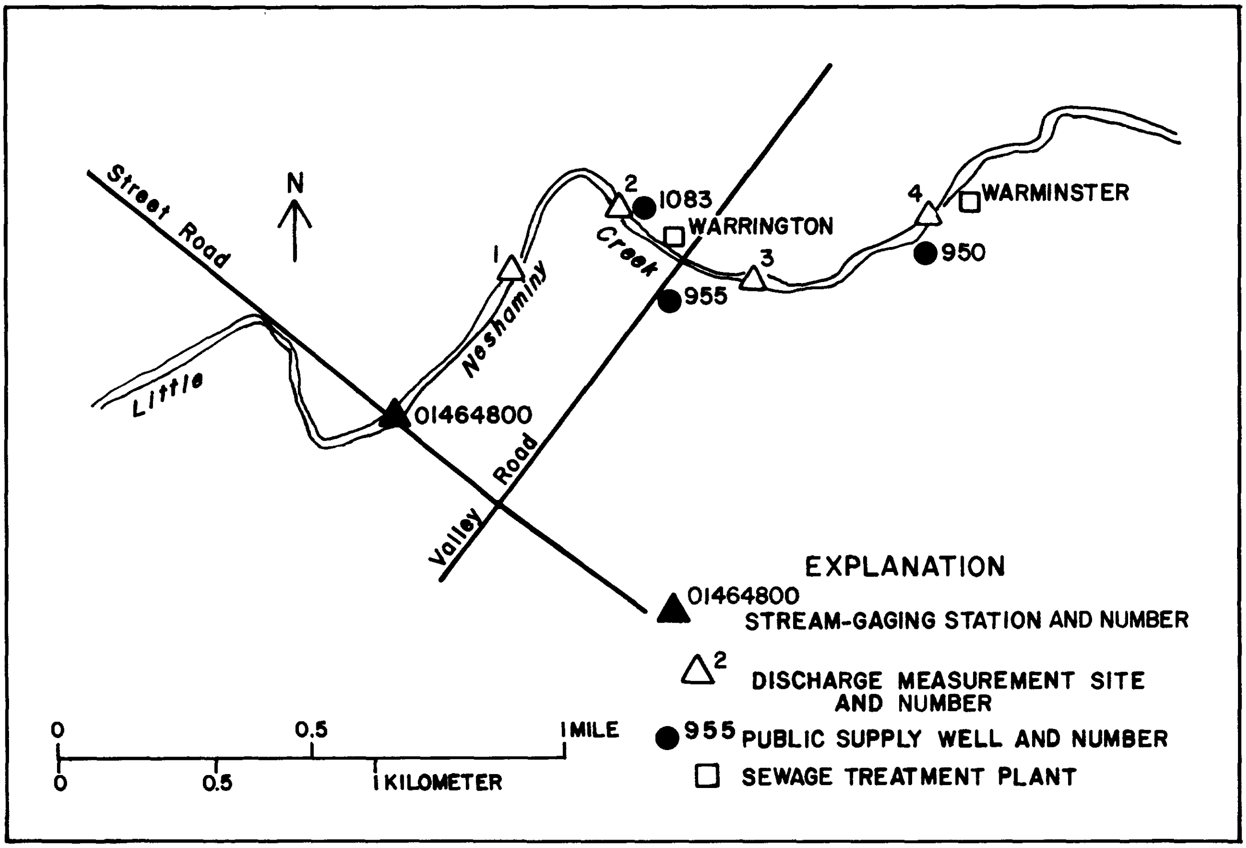


Figure 15.--Discharge measurement sites and public supply wells along Little Neshaminy Creek.

Measurements were made within a 3-hour period, during which gage height at station 01464800 did not change. Three public supply wells along this reach had a combined daily withdrawal of 1.02 million gallons at the time of the study. All tributaries to the creek along the measured reach were dry. The Warrington Township sewage treatment plant was discharging water to the creek between sites 2 and 3. The discharge of the creek is given in table 5.

Little Neshaminy Creek lost water along each segment measured, except between sites 2 and 3, where the Warrington Township sewage treatment plant discharges into the stream. Streamflow loss for this segment was estimated by the average loss in the segments upstream and downstream. In the reach between station 01464800 and site 4, the creek lost 0.9 ft^3/s, or 0.6 Mgal/d. This is equal to about 60 percent of the water pumped from the wells near the stream.

Table 5.--Discharge of Little Neshaminy Creek, November 14, 1980

Station or site	Discharge (ft^3/s)
01464800	3.87
1	3.31
2	3.14
3	3.81
4	3.74

Aquifer tests show that streams do not act as barriers to the effects of pumping. Well Bk-950 was pumped at 235 gal/min during January 17-18, 1980. Observation well Bk-957 is 1,100 feet away on the opposite side of Little Neshaminy Creek. After 18 hours, the drawdown in Bk-957 was 3.3 feet and had not stabilized. Well Bk-1040 was pumped at 309 gal/min during December 10-13, 1979. Observation well Bk-958 is 500 feet away on the opposite side of a tributary to Little Neshaminy Creek. Drawdown in Bk-958 after 60 hours was 26.5 feet.

Interbasin Transfer of Water

Sewer systems installed during urbanization have caused an interbasin transfer of water in Warminster Township, resulting in an increase in the flow of Little Neshaminy Creek and a decrease in the flow of Pennypack Creek. Before urbanization, water was pumped from domestic wells and waste water was disposed of by onsite septic systems. As Warminster Township became urbanized, these were replaced by public water wells and sewers. In 1980, approximately 250 million gallons of water pumped from wells in the Pennypack Creek basin in Warminster Township was discharged to Little Neshaminy Creek as treated sewage. This transfer is equal to 20 percent of the ground water pumped in Warminster Township. Some water pumped from wells in the Pennypack Creek basin near the drainage divide may be induced ground-water flow from the Little Neshaminy Creek basin; however, some water pumped from wells in the Little Neshaminy Creek basin near the drainage divide may be induced ground-water flow from the Pennypack Creek basin.

Water Budget

A water budget is an estimate of water entering and leaving a basin, plus or minus changes in storage, for a given period of time. Water enters as precipitation and leaves as streamflow, ground-water underflow, diversion of ground water from the basin where it was pumped, and evapotranspiration, plus or minus interbasin flow and changes in ground-water and soil-moisture storage. The water budget is complicated by several factors. Ground-water pumping has probably shifted most ground-water divides so that they do not coincide with surface-water divides. Few wells are available for water-level measurements, so a detailed water-level map cannot be constructed to show the ground-water divides. As a result, estimates of interbasin flow are difficult. In addition, pumping wells withdraw large quantities of water, making changes in ground-water storage difficult to determine.

Water budgets for 1979 and 1980 were estimated for the 4.36 mi^2 basin above continuous record station 01467036. Precipitation was measured at the Doylestown station. Ground-water pumpage was determined from records of wells in and outside the basin near the surface-water divide. Pumpage was adjusted based on the distance of the well from the divide to account for interbasin flow of ground water caused by pumping. The average annual water-level change in 13 observation wells was multiplied by an assumed specific yield of 1 percent to estimate the change in ground-water storage. The average change in water level was +2.13 feet in 1979 and -10.30 feet in 1980. Soil moisture is generally at field capacity during the winter. Because the period for the water budget begins and ends in winter, the change in soil moisture is equal to zero. Estimates of ground-water infiltration to the Warminster sewer system were used for the part of the basin (58 percent) in Warminster Township. Based on interviews with sewer authority officials, ground-water infiltration to sewers in the part of the basin in Hatboro and Horsham Township was estimated to be half that in Warminster Township because of better grouting and water proofing of sewers. After all other components in the water budget were estimated, the residual was assumed to be evapotranspiration.

The simplified annual water budget is expressed as:

$$P = R_t + ET + GP + L + \Delta GWS$$

where
- P = precipitation,
- R_t = streamflow,
- ET = evapotranspiration,
- GP = ground-water pumpage,
- L = net leakage to sewers, and
- ΔGWS = increase in ground-water storage.

Estimated water budgets for 1979 and 1980, expressed in inches of water, are:

	P	=	R_t	+	ET	+	GP	+	L	+	ΔGWS
1979	61	=	25	+	26	+	6	+	4	+	0
1980	35	=	12	+	20	+	3	+	1	-	1

Precipitation was 35 percent above average in 1979 and 23 percent below average in 1980. Ground-water pumpage in 1980 was half of the 1979 pumpage because several public-supply wells in the basin were removed from service due to organic chemical contamination. The water budgets for 1979 and 1980 give the approximate range of values for the components. Evapotranspiration, for example, can be expected to range from 20 to 26 inches per year.

A water budget was estimated for the basin for an average year, based on the water budgets for 1979 and 1980. Assuming no ground-water pumping, no ground-water infiltration to sewers, and no change in ground-water storage, the estimated water budget for an average year is:

$$P = R_t + ET$$
$$45 = 21 + 24$$

Average annual evapotranspiration estimated for Warminster Township is lower than the average for Bucks County, most of which is rural. Evapotranspiration is estimated by the Bucks County Planning Commission (1976, p. 13) to be 27 inches per year. Evapotranspiration in Warminster Township has probably been reduced by an increase in impervious areas and as a result of lowered water levels caused by ground-water pumping.

Evapotranspiration

If enough water is available to supply the needs of plants and to maintain soil moisture at saturation, evaporation from the soil and transpiration by plants proceeds at a maximum rate called potential evapotranspiration. The rate of actual evapotranspiration is usually less than the potential rate because potential evapotranspiration usually exceeds the quantity of water available from precipitation. During times of no precipitation, water for evapotranspiration comes from soil moisture. Soil moisture is replenished when precipitation exceeds evapotranspiration.

Monthly potential evapotranspiration at Philadelphia and monthly precipitation at Doylestown for 1979 and 1980 are compared in figure 16. Philadelphia was chosen because mean monthly temperature is used to compute potential evapotranspiration and Philadelphia is the nearest temperature station with complete record for 1979-80. Doylestown is the nearest precipitation station. Potential evapotranspiration was computed by Thornthwaite's equation (Thornthwaite, 1944) with Criddle's adjustment (Criddle, 1958). Potential evapotranspiration for 1979, a wet year, was 30 inches; evapotranspiration in the water budget was 26 inches. Potential evapotranspiration for 1980, a dry year, was 31 inches; evapotranspiration in the water budget was 20 inches. Actual evapotranspiration was greater in 1979, a wet year, and was closer to potential evapotranspiration.

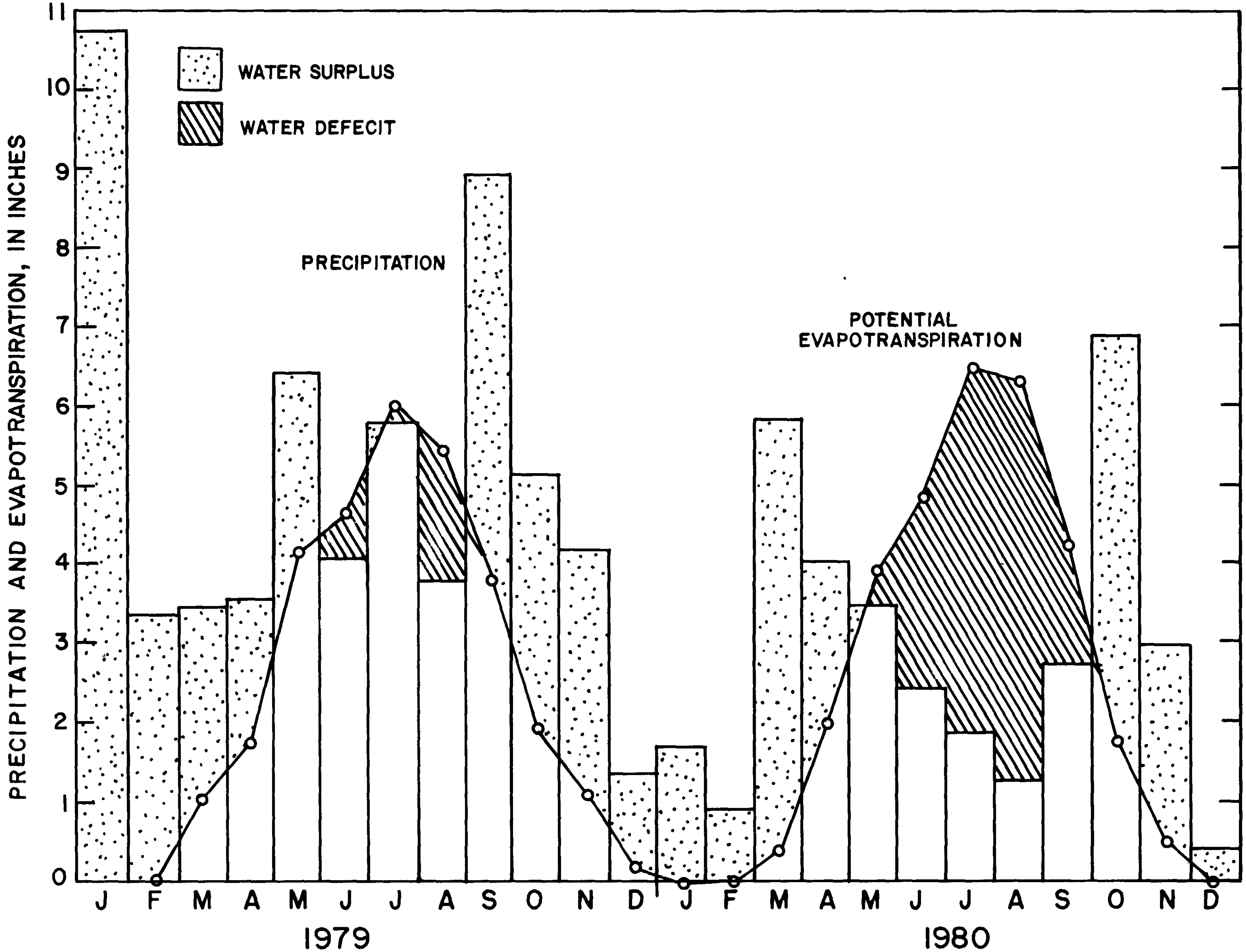


Figure 16.--Potential evapotranspiration at Philadelphia and precipitation at Doylestown, 1979-80.

Recharge

Precipitation that infiltrates and is not evaporated, transpired, or used to replenish soil moisture recharges the ground-water system. Recharge for 1979 and 1980 was estimated by adding base flow, ground-water pumpage, ground-water infiltration to sewers, and the change in ground-water storage. Base flow was determined by hydrograph separation. The other components are taken from the water budgets. Recharge was estimated by:

$$I = R_{gw} + GP + L + \Delta GWS$$

where

I = recharge,
R_{gw} = base flow (ground-water runoff),
GP = ground-water pumpage,
L = net leakage to sewers, and
ΔGWS = increase in ground-water storage.

Recharge for 1979 and 1980, expressed in inches of water, is:

	I	=	R_{gw}	+	GP	+	L	+	ΔGWS
1979	18	=	8	+	6	+	4	+	0
1980	8	=	5	+	3	+	1	-	1

Recharge can be expected to range from 8 inches or 0.4 $(Mgal/d)/mi^2$ (million gallons per day per square mile) in a dry year to 18 inches or 0.9 $(Mgal/d)/mi^2$ in a wet year. The recharge in an average year, based on the water budgets and recharge for 1979 and 1980, is estimated to be 11 inches, or 0.5 $(Mgal/d)/mi^2$.

Ground-Water Availability

Drought

During a drought, the quantity of recharge available to the ground-water system is reduced. Ground-water levels are gradually lowered as water is withdrawn from storage. As water levels decline and the aquifer is dewatered, well yields decrease. Pumping rates also decrease because of a loss in pump efficiency with lowered water levels. The crisis in a drought is reached when well yield becomes less than the demand for water.

The impact of the 1980-81 drought and future droughts may be more severe than historical droughts for four reasons: (1) a larger population has a larger water demand; (2) per capita use of water has historically increased; (3) urbanization has decreased ground-water recharge; and (4) chemical contamination has reduced the quantity of water suitable for public supply. As the demand for water increases, the margin between the demand and the ability to withdraw water from the aquifer narrows. This makes drought conditions seem to occur more frequently.

Current Ground-Water Availability

An estimate of the quantity of ground water available to the Warminster Municipal Authority well field was based on pumpage and water-level declines during May 1 to July 28, 1980. Data show water levels were normal to above normal in May 1980. From May 1 to July 28, 1980, observation well hydrographs show a continuous water-level decline. (See fig. 7.) During this 89-day period, the Warminster Municipal Authority pumped 275 million gallons of water from 13 wells. The withdrawal, in millions gallons per foot of water-level decline, was computed for each well for this period except for well Bk-1129, which began pumping on July 28. Withdrawal ranged from 0.08 to 2.9 million gallons per foot of water-level decline. These rates were used to compute the additional quantity of water available from the wells, under conditions of no recharge, with the available drawdown between the July 28 pumping water levels and the depth of the pumps. Available drawdown in the wells ranged from 27 to 98 feet. The average depth of the wells in the Warminster well field is 430 feet, and the pumps are set at an average depth of 182 feet below land surface. Data on the depth of water-bearing zones for the Warminster wells are not available. Assuming data for depths of water-bearing zones for other deep wells are typical, the pumps are set with about half of the water-bearing zones above and half below the pumps. Therefore, constant hydraulic characteristics with depth is assumed. Based on the available drawdown, an additional 950 million gallons of water would be available to the Warminster well field.

The yield of the Warminster Municipal Authority well field with time, assuming no recharge, was determined. The additional quantity of water available to each well was divided by the average pumping rate for that well from May 1 to July 28, 1980, to determine how many days the well could be pumped at that rate with the drawdown available. The yield of the well field was plotted against time (fig. 17). Assumptions are normal water levels on the first day, a 3.1 Mgal/d initial pumping rate, no change in pump depth, and no additional pumping wells. The points at 0 and 89 days are actual pumpage. The Warminster well field can yield over 3 Mgal/d for up to 63 days and over 2 Mgal/d for up to 280 days, assuming no recharge.

The quantity of water pumped from May 1 to July 28, 1980, plus the estimated additional water available equals approximately 1.2 billion gallons in storage available to the Warminster Municipal Authority well field. This is about equal to the pumpage by the Warminster Municipal Authority in 1980.

The area of influence of the Warminster Municipal Authority well field was estimated. The area of influence of a well is defined as the land area that has the same horizontal extent as the part of the water table or other piezometric surface that is perceptibly lowered by the withdrawal of water (Meinzer, 1923, P. 61). Because the proximity of many pumping wells causes their areas of influence to overlap, radius of influence was used to determine the area influenced by closely-spaced wells. A radius of influence of 2,500 feet was assumed, based on aquifer tests. The actual radius of influence of a well depends on its pumping rate and schedule, duration of pumping, local aquifer characteristics, and recharge.

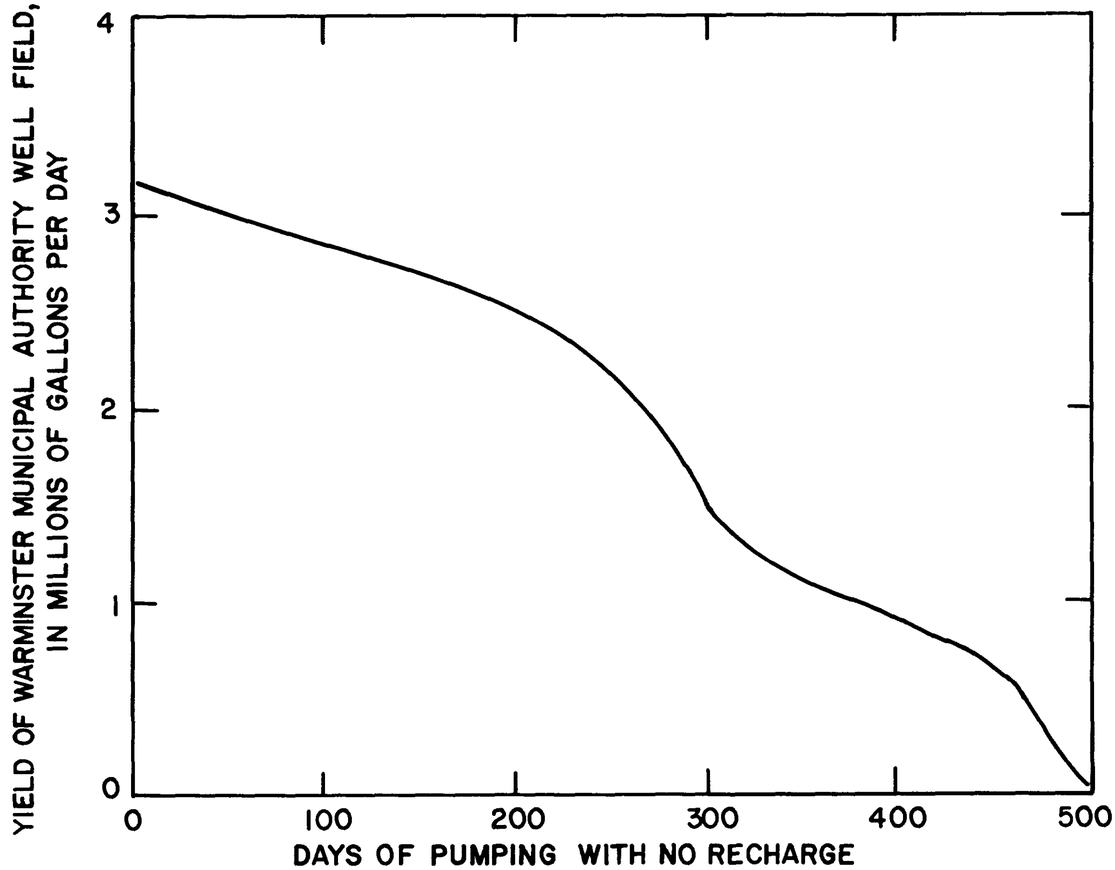


Figure 17.--Yield of the Warminster Municipal Authority well field with time, assuming no recharge.

Assuming a radius of influence of 2,500 feet for each well, the Warminster Municipal Authority well field withdraws water from a 7.9 mi^2 area (fig. 18). The Stockton Formation is not an isotropic and homogeneous aquifer, and cones of depression caused by pumping are probably not symetrical as shown in figure 18. Aquifer test data to show the actual shape or dominant anisotropy are not available, so symmetrical cones of depression are assumed for convenience. Pumpage from the well field in 1980 by the Warminster Municipal Authority was 1.06 billion gallons. This is equal to 0.37 (Mgal/d)/mi^2 or 7.7 inches of recharge. Two other public supply wells within the area of influence and several others just outside of it withdrew another 0.6 inches. Induced recharge from Little Neshaminy Creek was estimated to be 1.4 inches. Total pumpage from the Warminster Municipal Authority well field, therefore, is equal to about 7 inches of recharge.

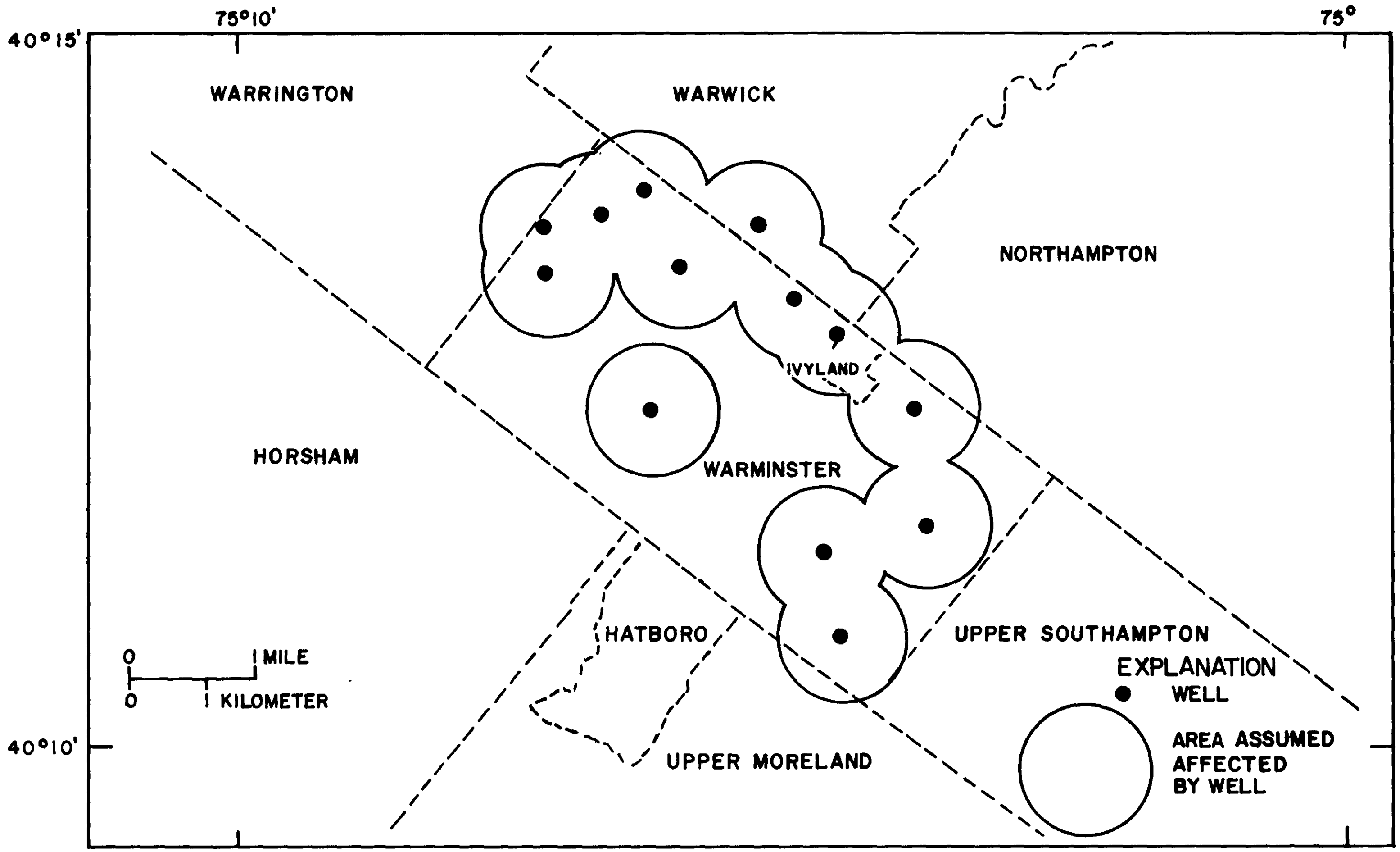


Figure 18.--Area assumed affected by the Warminster Municipal Authority well field.

In 1979, recharge was about 18 inches. Ground-water pumpage was 7 inches and about 4 inches of ground water infiltrated into sewers. This left 7 inches which was added to aquifer storage and discharged as base flow. In 1980, recharge was about 8 inches. Ground-water pumpage was 7 inches and about 1 inch of water infiltrated into sewers. This accounts for all of the recharge. However, ground water was discharged to streams. Based on the water budget for 1980, about 1 inch, or 140 million gallons of water, was withdrawn from storage.

Development of ground water in the area influenced by the Warminster Municipal Authority wells is at its practical limit for years of average recharge. In an average year, recharge is 11 inches, ground-water withdrawal is 7 inches, and ground-water infiltration to sewers is 3 inches, leaving 1 inch for ground-water discharge to streams. Current ground-water development cannot meet demand in years of below average recharge. Withdrawal of more water from additional wells in the area of influence would deplete ground water faster during a drought; additional wells would have to be drilled outside the area of influence.

Availability of Additional Ground Water

Assuming a radius of influence of 2,500 feet, the area influenced by major production wells is 21.7 mi^2 (fig. 19). Ground-water withdrawal is about 7.1 Mgal/d or 0.33 $(Mgal/d)/mi^2$. Additional water can be obtained by drilling wells outside the area of influence. New wells, however, would have to be drilled at least 3,000 feet from present wells to minimize interference.

Additional water can be obtained in Warminster Township by drilling new wells outside the area of influence shown in figure 19. Assuming a 2,500 foot radius of influence and the 0.37 $(Mgal/d)/mi^2$ current pumping rate of the Warminster well field, an additional 400 million gallons of water per year, or 1.1 Mgal/d, may be available. The actual quantity may be less because suitable sites for wells may not be obtainable, yields may not be high enough, or the water may be of unsuitable quality.

Increasing Ground-Water Availability

Locating wells close to major streams will increase water availability by inducing recharge from the stream. Pumping wells near smaller streams may cause streamflow to be severely reduced. Pumping wells near a stream with a flow of at least several cubic feet per second, such as Little Neshaminy or Pennypack Creek, can induce recharge from the stream without adversely affecting its flow most of the time.

Ground-water infiltration to sewers can be significant (as much as 4 Mgal/d). If this infiltration can be reduced or eliminated, more ground water would be available for withdrawal by wells.

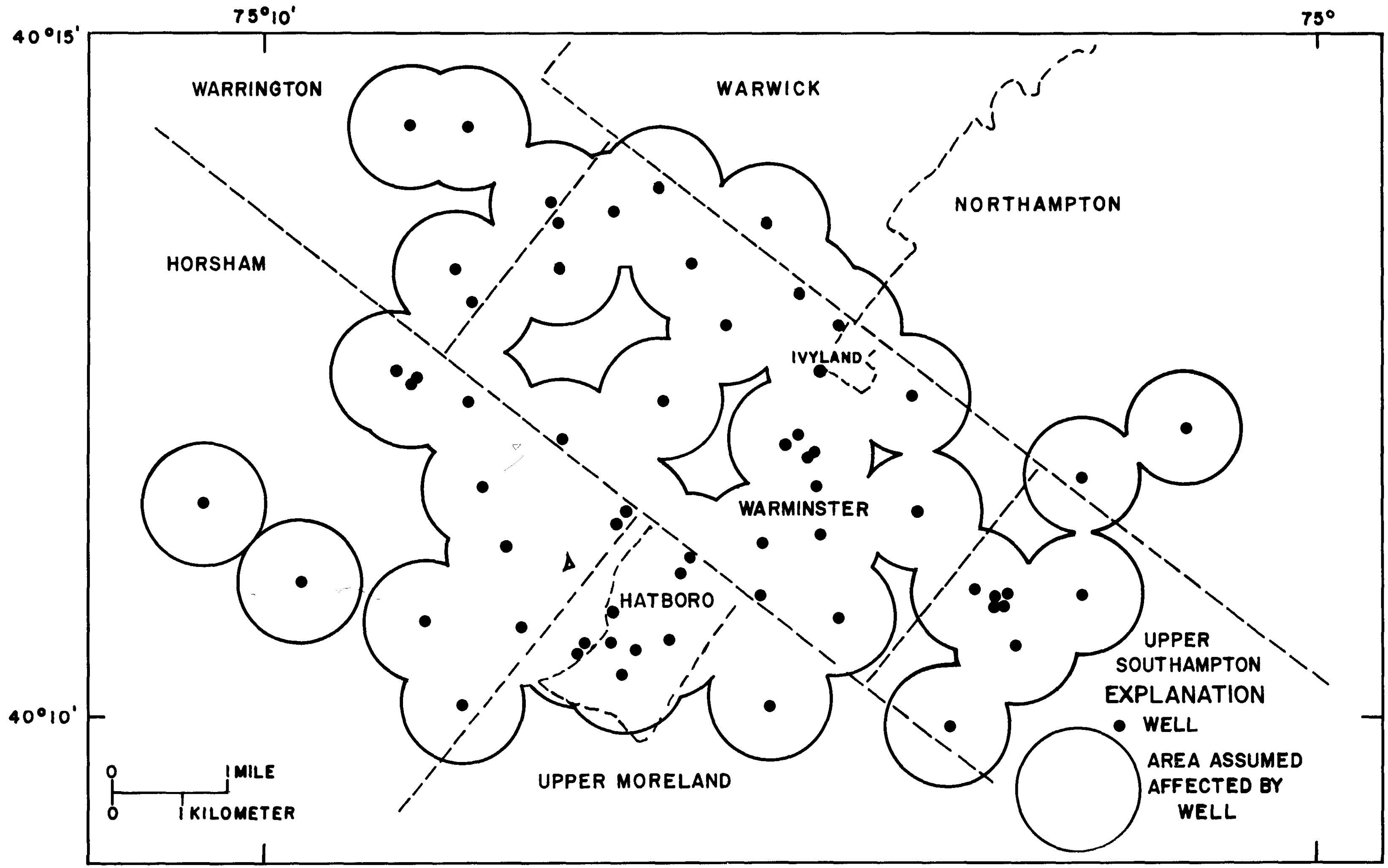


Figure 19.--Area assumed affected by pumping wells.

Additional water can be made available to the ground-water system by artificial recharge of treated sewage or industrial cooling water that does not contain objectionable constituents. Water may be recharged by spray irrigation, subsurface tile fields, recharge basins, or injection wells. Another alternative might be to pump recharge water into a stream along which several wells have been drilled. Pumping the wells would induce recharge from the stream.

SUMMARY OF THE EFFECTS OF URBANIZATION ON THE HYDROLOGIC SYSTEM

Urban growth has caused many changes to the hydrologic system. Some of the results of the change from rural to urban conditions are summarized below:

1. Ground-water withdrawal has increased sharply.
2. Per capita water use has increased.
3. Ground-water pumping has affected water levels in urbanized areas. Interference caused by a pumping well can reach laterally as far as 2,500 feet.
4. Ground-water pumping and infiltration to sewers has reduced the base flow of streams by intercepting water that formerly would have discharged to streams.
5. Pumping wells near streams has reversed the hydraulic gradient, inducing water from the stream into the aquifer.
6. When the water table is high, ground water can infiltrate into sewers. When the water table is low, sewers can leak water to the ground-water system.
7. Large areas of impervious surface have probably caused the magnitude of peak discharges from storm runoff to increase.
8. The quantity of evapotranspiration has been reduced by large areas of impervious surface and by ground-water pumping.
9. Ground water pumped in one basin and discharged into a stream in a different basin has changed the hydrologic regimen in both basins.

WATER QUALITY

The quantity and kinds of substances in water determine its quality. Some of these substances are carried to the earth's surface by precipitation, but most are leached from soil and rock. The quality of water is commonly altered by urbanization. Among the substances added to water by urbanization are organic compounds, trace metals, chloride, nitrate, and phosphate. Organic compounds and trace metals in water are generally the result of leakage, spills, or improper disposal of waste materials. Chloride and nitrate are found naturally in water, but high concentrations generally indicate pollution. Chloride can come from industrial waste, road salt, and sewage. Sources of nitrate can be fertilizers, animal waste, and sewage. Phosphates are used in detergents and are found in sewage.

Ground-Water Quality

Organic Compounds

Some wells have been contaminated by volatile organic compounds, making the water unsuitable for public supply. Maximum reported concentrations of volatile organic compounds found in ground water in the project area are listed in table 6. Organic compounds usually enter the ground-water system by spills, leakage from storage tanks, discharge from septic tanks, or improper disposal.

Two of the most common volatile organic compounds found in ground water are trichloroethylene (TCE) and tetrachloroethylene, also called perchloroethylene (PCE). These compounds are halogenated hydrocarbons and are stable, mobile, and nonflammable. They are not naturally found in ground water. They are heavier than water, only slightly soluble in water, and tend to move downward in an aquifer. Trichloroethylene and tetrachloroethylene are related compounds and are commonly found together.

Trichloroethylene is a commercial solvent and industrial metal degreaser. It became a common degreasing agent in the 1920's and began to be used in the dry cleaning industry in the 1930's (Petura, 1980). It is also used as a septic-tank cleaner, paint and varnish remover, and in the manufacture of other organic chemicals and pharmaceuticals. Trichloroethylene affects the human central nervous system and can cause depression, headache, nausea, dizziness, tremors, and blurred vision. It is a confirmed animal carcinogen (Council on Environmental Quality, 1981, p. 46; p. 64).

Tetrachloroethylene is commonly used in dry cleaning, degreasing metals, and as a solvent. It can cause human central nervous system depression, dizziness, headache, and fatigue. It also is a confirmed animal carcinogen (Council on Environmental Quality, 1981, p. 46; p. 64).

In 1979, some wells in central Montgomery County were found to be contaminated by trichloroethylene as the result of industrial spills. Public water suppliers in southeastern Pennsylvania began testing for and finding volatile organic compounds in well water. In September 1979, the Warminster Municipal Authority removed two wells from service, and the Upper Southampton Authority removed three wells from service because of trichloroethylene and tetrachloroethylene contamination. The Hatboro Water Authority removed five wells from service in October and one in November. In October, the Warminster Heights Development Corporation found volatile organic compounds in both of their wells, and the Warrington Water Company removed two of their four wells from service because of trichloroethylene contamination. In October, the Environmental Proection Agency (EPA) began testing municipal, industrial, and domestic wells for volatile organic contamination. In November, the U.S. Naval Air Development Center removed three wells from service. The Horsham Township Authority removed one well from service in January 1980 and another in April 1980. The locations of wells sampled for trichloroethylene and tetrachloroethylene are shown in figure 20. Data were provided by the Bucks County Health Department, EPA, and municipal water authorities.

Table 6.--Maximum reported concentrations[1] of volatile organic compounds in ground water

Compound	Maximum reported concentration (μg/L)
Benzene	2
Bromodichloromethane	240
Bromoform	250
Carbon tetrachloride	50
Chlorobenzene	500
Chloroform	500
p Dichlorobenzene	0.1
1,1-Dichloroethane	24
1,2-Dichloroethane	370
1,1-Dichloroethylene	660
cis-1,2-Dichloroethylene	11,000
trans-1,2-Dichloroethylene	51
1,2-Dichloropropane	250
trans-1,3-Dichloropropylene	4.7
Methyl chloride	9.3
Tetrachloroethane	2.6
Tetrachloroethylene (PCE)	26,000
1,1,1-Trichloroethane	900
Trichloroethylene (TCE)	87,000

[1] Data provided by the U.S. Environmental Protection Agency.

Volatile organic compounds can be removed from water by aeration or by adsorption on granular activated carbon or synthetic resins. Contaminated wells are usually abandoned because treatment is expensive. The loss in water supply is made up by increasing the pumpage of uncontaminated wells and by purchasing water through distribution system interconnections.

Contamination of ground water by other organic compounds, primarily gasoline and fuel oil, has been reported. Sources are generally leakage from underground storage tanks.

Inorganic Constituents

During this study (1979-81), 26 wells were sampled for chemical analysis. Forty five analyses were available from previous U.S. Geological Survey investigations and the Pennsylvania Department of Environmental Resources, making a total of 71 analyses for 57 wells. Results of chemical analyses are given in table 13.

In areas not contaminated by organic compounds, ground-water quality is generally good. High concentrations of iron and manganese are the most common water-quality problems. Dissolved constituents exceeding U.S. EPA (1977) limits for public water supplies are summarized in table 7.

Table 7.--Summary of dissolved constituents in ground water exceeding U.S. Environmental Protection Agency (1977) limits

	Limit	Number of wells sampled	Number of wells exceeding limit
Manganese	50 μg/L	38	11
Iron	300 μg/L	56	7
Dissolved solids	500 mg/L	50	2
Sulfate	250 mg/L	52	2
Lead	50 μg/L	26	1
Nitrate as nitrogen	10 mg/L	57	1

One well sampled in 1953 and six wells sampled in 1956 by Rima and others (1962, p. 105-109) were sampled again in 1979. Well Bk-366 was sampled in 1953 and wells Bk-376, Bk-692, Bk-694, Bk-695, Mg-210, and Mg-219 were sampled in 1956. The concentrations of dissolved constituents in water from these wells in 1953 and 1956 compared with concentrations in 1979 are shown in table 8. The median concentrations of all dissolved constituents except sulfate, iron, and silica have increased.

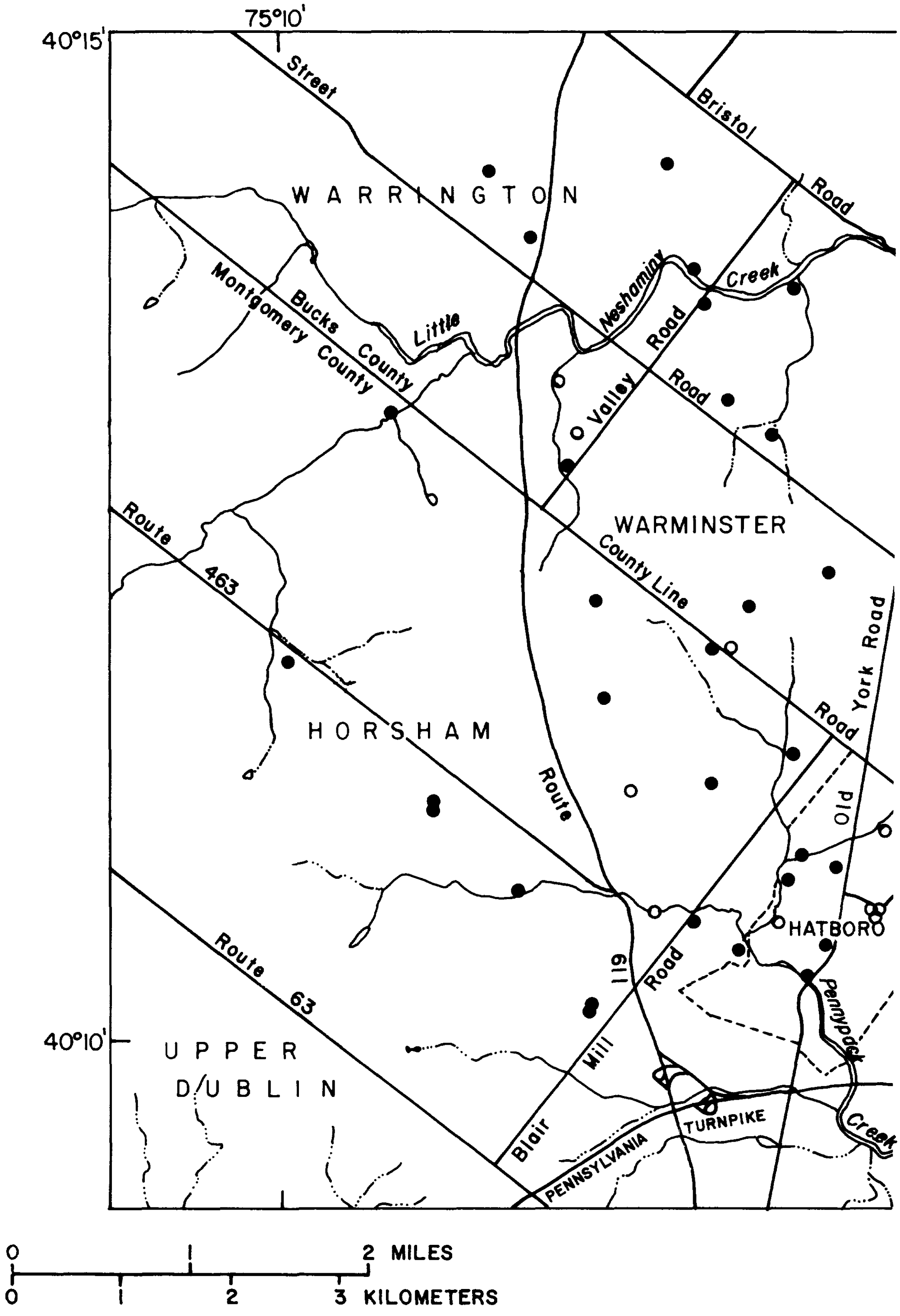
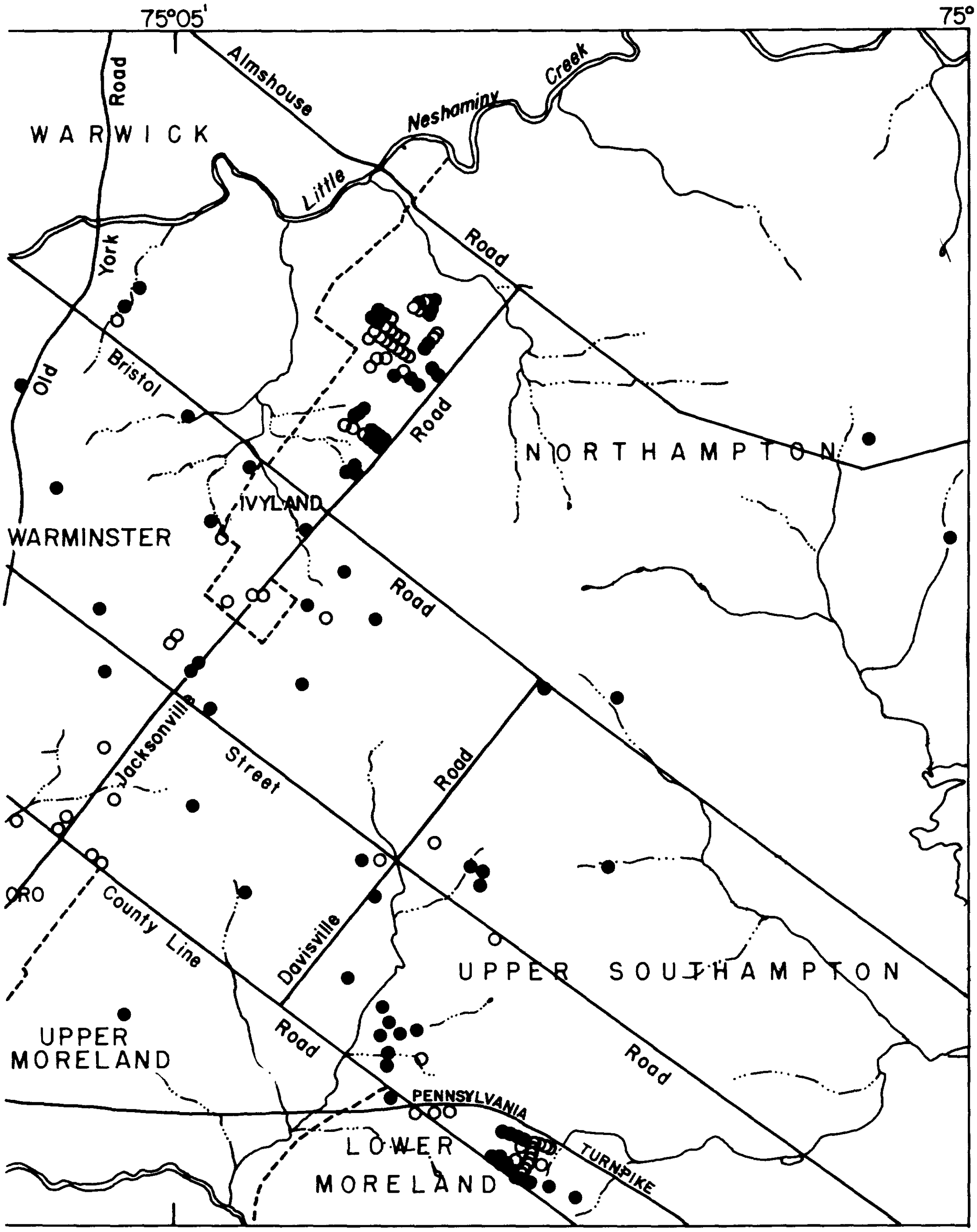


Figure 20.--Location of wells sampled for trichloroethylene and tetrachloroethylene. Data were provided by the Bucks County Health Department, the U.S. Environmental Protection Agency, and municipal water authorities.



EXPLANATION

○ Well where concentration of trichloroethylene is equal to or greater than 4.5 micrograms per liter or concentration of tetrachloroethylene is equal to or greater than 3.5 micrograms per liter.

● Well where concentration of trichloroethylene is less than 4.5 micrograms per liter and concentration of tetrachloroethylene is less than 3.5 micrograms per liter.

Table 8.--Comparisons of concentrations[1] of selected dissolved constituents in water from seven wells before and after urbanization

	Concentration before urbanization (1953, 1956)		Concentration after urbanization (1979)	
	Range	Median	Range	Median
Dissolved solids	177-251	202	208-305	249
Calcium	29-40	31	23-50	42
Magnesium	3.2-16	7	5.7-18	11
Sodium + potassium	8.3-19	14	14-21	18
Chloride	4.3-19	11	13-30	17
Sulfate	20-35	30	26-36	28
Nitrate as nitrogen	.14-9.7	2.9	.04-7.7	3.7
Iron	.02-46	.49	0-.14	<.010
Silica	13-29	26	22-29	24
Hardness as $CaCO_3$	91-140	130	81-190	150
Hardness, noncarbonate	0-58	28	14-55	37

[1] Concentrations are in milligrams per liter.

Lead

The concentration of lead exceeded the EPA (1977) limit of 50 μg/L in water from one well. Concentrations of lead ranged from 0 to 55 μg/L, with a median of 17 μg/L. This median concentration is higher than reported nearby and national median values. In water from 59 wells in nearby Chester County, concentrations of lead ranged from 0 to 8 μg/L, with a median of 2 μg/L (McGreevy and Sloto, 1976, p. 127). Fishman and Hem (1976, p. 38) reported that 80 percent of 353 ground-water samples collected in the United States contained less than 10 μg/L lead.

Lead has been added to the environment primarily by the combustion of leaded gasoline (Cannon, 1976, p. 74). Although lead is nearly insoluble in water, lead compounds in automobile exhaust have increased its availability for solution. Warminster Township is highly urbanized and traversed by several heavily traveled roads. The Stockton Formation is not known to contain elemental lead or lead ore in the project area.

Sulfate

Water from some wells in the Stockton Formation contains a high concentration of sulfate, which is probably derived from sulfate minerals in the formation. Ground water having a high sulfate concentration also contains a high concentration of calcium. This suggests gypsum (hydrated calcium sulfate) or anhydrite (calcium sulfate) as a possible source of sulfate.

Although some wells yielding water high in sulfate are close together, no relation between sulfate concentration and geographical distribution, topography, the presence of the diabase dike, or well depth was found. Data for wells yielding water high in sulfate from the Triassic formations generally indicate high sulfate concentrations at depth. However, data for wells in the project area do not show that the concentration of sulfate increases with depth or that deeper wells have water with higher sulfate concentrations. Well Bk-987 is 709 feet deep; the sulfate concentration is 12 mg/L. The sulfate concentration in water from well Mg-967 was 469 mg/L at 50 feet. Well Mg-972 is 285 feet deep; the sulfate concentration was 500 mg/L at 170 feet.

The range and median concentrations of sulfate and dissolved solids for 51 wells grouped into four depth intervals are given in table 9. If more than one chemical analysis was available for a well, the most recent one was used. Wells between 500 and 709 feet deep have the lowest median sulfate concentration. Wells less than 200 feet deep have the lowest median dissolved-solids concentration.

Table 9.--Comparison of sulfate and dissolved-solids concentrations with well depth

Depth of well (feet)	Number of wells	Sulfate (mg/L)		Dissolved solids (mg/L)	
		Range	Median	Range	Median
Less than 200	13	21-45	33	136-294	205
200-350	14	14-460	34	201-857	272
350-500	11	15-200	40	159-498	278
500-709	13	9-150	30	186-420	249

High concentrations of sulfate and dissolved solids are probably caused by poor or restricted ground-water circulation. Well Bk-728 was sampled in 1957, 1973, and 1979. In 1957, the water contained 725 mg/L of sulfate and 1330 mg/L of dissolved solids. In 1973, the sulfate concentration was 258 mg/L, and the dissolved-solids concentration was 576 mg/L. By 1979, the sulfate concentration had decreased to 200 mg/L and the dissolved-solids concentration to 498 mg/L. The concentrations of both sulfate and dissolved solids in water from Bk-728 have been reduced by pumping over a long period of time because pumping has flushed the aquifer in the vicinity of the well.

Quality of Low Streamflow

Chemical analyses of 17 samples from nine surface-water stations during two periods of low flow were made during this study. Station locations are shown in figure 3. One sample was taken at each station on October 17, 1979, during a high base-flow period. One sample was taken at each station, except 01464910 because of zero flow, on July 15, 1980, during a low base-flow period. The analyses are given in table 14.

The concentrations of selected dissolved constituents in water at eight surface-water stations in 1979 and 1980 are compared in table 10. Station 01464910 is not included in the comparison because there was no flow during sampling in 1980. Median concentrations of most constituents were higher in 1980, when precipitation was below average, than in 1979, when precipitation was above average. The discharge of the streams was lower during the 1980 sampling. Median concentrations of sulfate, nitrate, and lead were lower in 1980. The median concentration of lead was significantly lower; it was 1 μg/L in 1980 and 44 μg/L in 1979.

Table 10.--Comparisons of concentrations[1] of selected dissolved constituents in low streamflow for eight surface-water stations in 1979 and 1980

Constituent	Concentration October 17, 1979		Concentration July 15, 1980	
	Range	Median	Range	Median
Dissolved solids	169-219	190	188-515	238
Calcium	22-33	25	25-51	39
Magnesium	7.5-11	8.6	8-19	10
Chloride	12-27	19	16-89	27
Sulfate	33-42	39	18-88	38
Nitrate as nitrogen	2.2-7	3.2	1.2-11	2.4
Orthophosphate as phosphorus	0-2.3	.06	.15-24	.30
Phosphorus	.02-.96	.05	.03-6.5	.12
Lead	0-59	44	0-6	1

[1] Concentrations are in milligrams per liter except lead, which is in micrograms per liter.

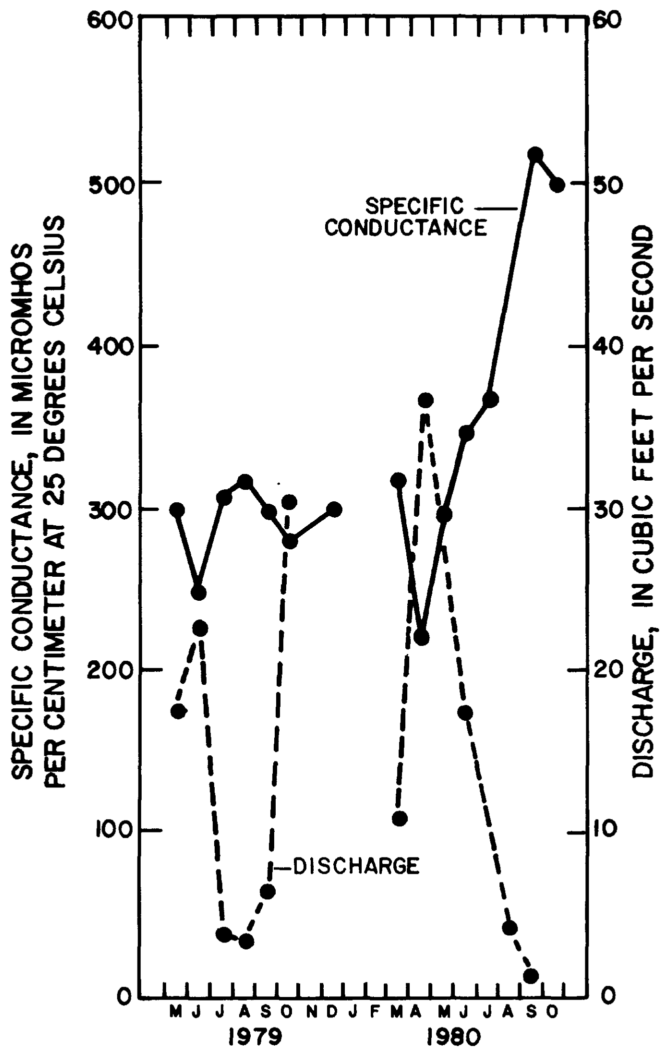


Figure 21.--Relation of stream discharge and specific conductance at station 01464800 on Little Neshaminy Creek, May 1979 to October 1980.

Due to dilution, the concentration of dissolved constituents generally decreases as stream discharge increases. This is shown in figure 21, which compares the discharge at station 01464800 with specific conductance. The other stations show a similar pattern. The approximate dissolved solids concentration in milligrams per liter can be calculated by multiplying the specific conductance by 0.63.

Two sewage treatment plants discharge effluent between stations 01464800 and 01464920. A comparison of the analyses of water from these stations shows significant increases in nutrients and other constituents at the downstream site (01464920). The increase in orthophosphate concentration, for example, was 1,400 percent in the 1979 samples and 2,000 percent in the 1980 samples.

Relation of Ground Water and Low Streamflow Quality

The quality of low streamflow and ground water are generally similar because low streamflow is ground water discharged to streams. Biesiecker and others (1968, p. 152) state that in the Triassic formations, ground-water quality and the quality of many uncontaminated first-order streams are similar. The concentrations of selected dissolved constituents in ground water and low streamflow from the Stockton Formation are compared in table 11. Surface water stations 01464800 and 01464920 are not included in the comparison because 50 and 42 percent, respectively, of their basins are underlain by the Lockatong Formation. If more than one analysis was available for a well, the most recent one was used. Median concentrations of dissolved solids, calcium, magnesium, sodium, chloride, sulfate, nitrate, and silica are similar for ground water and low streamflow.

SUMMARY OF THE EFFECTS OF URBANIZATION ON WATER QUALITY

Urbanization has caused changes in the quality of both ground water and low streamflow. Some of these changes are summarized below:

1. Contamination of ground water by volatile organic compounds has made water from some wells unsuitable for public supply.
2. The median concentration of most dissolved constituents in water from wells sampled before urbanization (1953, 1956) increased after urbanization (1979).
3. The median concentration of lead in ground water is above the reported national median and the median in nearby Chester County.
4. Pumping of wells can flush the aquifer, lowering concentrations of sulfate and dissolved solids.
5. Low-flow surface-water quality has been degraded by effluent discharged by sewage treatment plants.

Table 11.--Comparisons of concentrations[1] of selected dissolved constituents in ground water and low streamflow

Constituent	Ground water			Low streamflow		
	Number of samples	Concentration		Number of samples	Concentration	
		Range	Median		Range	Median
Dissolved solids	50	136-498	245	13	169-338	201
Calcium	34	12-110	37	13	22-51	31
Magnesium	34	5.7-20	11	13	7.5-19	14
Sodium	26	7.5-20	14	13	11-22	14
Chloride	55	2.8-69	15	13	12-42	19
Sulfate	50	9-200	32	13	18-88	38
Nitrate as nitrogen	56	.04-17	2.7	13	1.5-7	2.8
Orthophosphate as phosphorus	41	0-.67	.03	13	0-1.2	.15
Phosphorus	24	0-.22	.07	13	.02-.47	.04
Organic carbon	25	.6-3.8	1.9	7	2.5-5.2	2.7
Silica	34	10-33	23	13	8.5-19	18
Lead	25	0-55	22	13	0-48	11

[1] Concentrations are in milligrams per liter, except lead, which is in micrograms per liter.

SUMMARY

The project area, about 65 mi^2, includes Warminster Township and parts of the surrounding municipalities in Bucks and Montgomery Counties. It is underlain by the Stockton Formation, which consists of sandstone interbedded with siltstone and shale, dipping an average of 12° north to northwest. Average annual precipitation is 45.16 inches.

Rapid suburban development accompanied industrial growth after World War II. From 1940 to 1970, the population of Warminster Township increased 1,765 percent. Municipalities are dependent upon local ground-water supplies. In 1980, ground-water pumpage was 2.7 billion gallons.

Ground water moves through the intergranular openings of the weathered zone and through a network of interconnecting joints, fractures, and solution openings in unweathered rock. Most deep wells penetrate several water-bearing zones. Downward internal flow, caused by differences in head between water-bearing zones, was measured under non-pumping conditions in three wells. Upward flow was measured in one well, and one well, flowing 48 gal/min at the surface, showed indications of downward flow at depth.

The water level in most deep wells represents the composite of several water-bearing zones. Levels have a seasonal trend, rising during the non-growing season and declining during the growing season. Levels are influenced by the pumping of municipal and industrial production wells.

Results of aquifer tests show that drawdown can occur in observation wells updip, downdip, or along strike, even if the wells do not penetrate the same strata. A pumping well can cause measurable drawdown as much as 2,500 feet away.

Ground water can infiltrate into sewers when the water table is high, and water can leak from sewers when the water table is low. Net ground-water infiltration to sewers was about 830 million gallons in 1979 and about 250 million gallons in 1980.

Ground-water pumping and infiltration to sewers has reduced the base flow of streams. Pumping near streams reverses the hydraulic gradient and induces recharge from the stream into the aquifer; however, streams do not act as barriers to drawdown caused by pumping. A gain and loss study on a reach of Little Neshaminy Creek showed a loss of 0.6 Mgal/d, equal to about 60 percent of the water pumped from wells near the stream.

Water budgets were estimated for the 4.36 mi^2 basin above station 01467036 for 1979, a wet year, and 1980, a dry year. Evapotranspiration was 26 inches [1.2 (Mgal/d)/mi^2] in 1979 and 20 inches [1.0 (Mgal/d)mi^2] in 1980. Recharge was 18 inches [0.9 (Mgal/d)mi^2] in 1979 and 8 inches [0.4 (Mgal/d)mi^2] in 1980. In a year of average precipitation [45 inches or 2.1 (Mgal/d)mi^2], evaportranspiration is estimated to be 24 inches [1.1 (Mgal/d)mi^2] and recharge 11 inches [0.5 (Mgal/d)mi^2].

About 1.2 billion gallons of ground water is available in storage to the Warminster Municipal Authority well field. The Warminster well field could yield over 3 Mgal/d for up to 63 days and over 2 Mgal/d for up to 280 days under conditions of no recharge. Ground-water development in areas influenced by pumping wells is at its practical limit for years of average recharge and cannot meet demand in years of below average recharge. As much as an additional 1.1 Mgal/d of water may be available to the Warminster Municipal Authority by drilling and pumping new wells in areas not affected by pumping. New wells would need to be drilled at least 3,000 feet from present wells to minimize interference. Water availability can be increased by locating wells near larger streams, where they can induce recharge from the stream into the aquifer, by reducing ground-water infiltration to sewers, or by artificial recharge.

Contamination by volatile organic compounds has made water from some wells unsuitable for public supply. Reported concentrations of two of the most common volatile organic compounds are as high as 87,000 µg/L for trichloroethylene and 26,000 µg/L for tetrachloroethylene. Many wells were abandoned by water suppliers, government facilities, and industries in 1979 and 1980 because of organic compound contamination.

One well sampled in 1953 and six wells sampled in 1956 at the onset of urbanization were sampled again in 1979. The median concentrations of most dissolved constituents in the water from these wells increased.

The concentration of lead in well water ranged from 0 to 55 µg/L, with a median concentration of 17 µg/L. This is above the reported national median and the median in nearby Chester County.

The source of high sulfate concentrations in water from some wells is probably sulfate minerals, such as gypsum or anhydrite, in the underlying sedimentary rock. Chemical analysis data show a reduction in sulfate and dissolved-solids concentrations with time in water from a pumping well, suggesting flushing of the aquifer.

Low streamflow sampled at eight sites in 1980, a dry year, had a higher median concentration of most dissolved constituents than low streamflow sampled at nine sites in 1979, a wet year. The concentration of dissolved solids increases as stream discharge decreases. Effluent from sewage treatment plants has degraded the quality of low streamflow.

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Table 12.—Record of selected wells

Location: Lat - Long, Latitude and longitude in degrees and minutes of the southeast corner of a 1-minute quadrangle within which the well is located.

Use: C, commercial; H, domestic; I, irrigation; N, industrial, P, public supply; R, recreation; T, institutional; U, unused; Z, other.

Topographic setting: F, flat; H, upland; S, slope; V, lowland.

TABLE 12.--RECORDS OF SELECTED WELLS--CONTINUED

WELL NUMBER	LOCATION LAT-LONG	OWNER	DRILLER	YEAR COMPLETED	USE	ALTITUDE OF LAND SURFACE (FEET)	TOPO-GRAPHIC SETTING
							BUCKS
BK- 361	4012-7506	CHRIST'S HOME		1910	P	280	S
362	4012-7506	CHRIST'S HOME FARM	JOHN O'DONNELL & SON	1924	P	290	S
363	4012-7506	CHRIST'S HOME	JOHN O'DONNELL & SON	1915	P	300	S
364	4012-7506	CHRIST'S HOME	JOHN WILEY	1932	H	300	S
365	4012-7506	WARMINSTER HOSIERY CO		1938	U	295	V
366	4011-7505	WARM. HEIGHTS DEV. CORP.	RULON AND COOK, INC.	1975	P	280	F
367	4010-7505	WARM. HEIGHTS DEV. CORP.	RIDPATH AND POTTER COMPANY	1943	P	300	H
368	4011-7505	V LA ROSA		1950	U	290	V
369	4011-7505	V LA ROSA		1950	N	290	V
370	4011-7505	FISCHER & PORTER		1940	U	300	V
371	4010-7505	FISCHER & PORTER	GEORGE REMPFER	1948	N	300	V
372	4010-7505	FISCHER & PORTER	WILLIAM STOTHOFF CO.	1952	U	300	V
373	4012-7504	U.S. NADC	JOHN WILEY	1941	N	330	V
374	4012-7504	U.S. NADC	JOHN WILEY	1941	H	330	F
375	4011-7504	U.S. NADC	RIDPATH AND POTTER COMPANY	1942	H	340	S
376	4011-7504	U.S. NADC	RIDPATH AND POTTER COMPANY	1942	H	335	F
377	4012-7504	U.S. NADC	JOHN O'DONNELL & SON	1948	H	320	F
378	4011-7504	U.S. NADC	JOHN O'DONNELL & SON	1949	H	360	H
379	4010-7503	C W INDUSTRIES		1928	N	260	S
380	4010-7503	LYNCH WILLIAM		1926	N	230	V
381	4010-7502	PENNA FROSTED FOODS CORP		1946	N	260	S
383	4010-7502	HYZER LEWELLEN	HARRY L. WEISS	1945	U	240	V
384	4010-7502	UPPER SOUTHAMPTON AUTH		1942	U	260	V
385	4010-7502	UPPER SOUTHAMPTON AUTH	GEORGE REMPFER	1948	U	250	F
386	4010-7502	BELWIN HOSIERY		1900	N	235	S
390	4009-7501	BUX FRED	JOHN WILEY	1926	U	210	S
692	4012-7506	WARMINSTER AUTH		1954	P	300	F
693	4011-7504	WARMINSTER AUTH	WILLIAM STOTHOFF CO.	1955	P	340	H
694	4010-7504	WARMINSTER AUTH	WILLIAM STOTHOFF CO.	1955	P	252	S
695	4010-7503	UPPER SOUTHAMPTON AUTH		1954	P	258	S
702	4012-7504	U.S. NADC			H	338	S
728	4013-7507	WARMINSTER AUTH	WILLIAM STOTHOFF CO.	1957	P	260	H
933	4011-7502	NORTHAMPTON AUTH		1963	P	275	V
947	4013-7505	WARMINSTER AUTH	WILLIAM STOTHOFF CO.	1962	P	235	V
948	4013-7505	WARMINSTER AUTH	WILLIAM STOTHOFF CO.	1963	P	277	S
949	4011-7507	WARMINSTER AUTH	WILLIAM STOTHOFF CO.	1962	P	290	S
950	4013-7506	WARMINSTER AUTH	WILLIAM STOTHOFF CO.	1964	P	205	V
951	4012-7504	WARMINSTER AUTH	WILLIAM STOTHOFF CO.	1965	P	240	S
952	4011-7503	WARMINSTER AUTH	WILLIAM STOTHOFF CO.	1965	P	290	W
953	4012-7503	WARMINSTER AUTH	WILLIAM STOTHOFF CO.	1966	P	315	S
954	4013-7506	WARMINSTER AUTH	WILLIAM STOTHOFF CO.	1967	P	200	S
955	4013-7507	WARMINSTER AUTH	WILLIAM STOTHOFF CO.	1967	P	213	S
956	4014-7506	WARMINSTER AUTH		1970	U	240	V
957	4013-7506	WARMINSTER AUTH		1975	U	200	V
958	4013-7505	WARMINSTER AUTH	C. S. GARBER & SONS, INC.	1955	P	200	V
959	4012-7504	WARMINSTER AUTH	WILLIAM STOTHOFF CO.	1972	U	258	V
960	4012-7503	GOLF FARM	RULON AND COOK, INC.	1968	I	280	S
962	4011-7504	U.S. NADC	RULON AND COOK, INC.	1976	P	350	S
978	4012-7501	NORTHAMPTON AUTH	MOODY DRILLING CO., INC.	1970	U	304	S

WELL DEPTH BELOW LAND SURFACE (FEET)	CASING DEPTH (FEET)	CASING DIAMETER (INCHES)	DEPTH(S) TO WATER-BEARING ZONE(S) (FEET)	STATIC WATER LEVEL DEPTH BELOW LAND SURFACE (FEET)	STATIC WATER LEVEL DATE MEASURED (MO/YR)	REPORTED YIELD (GPM)	SPECIFIC CAPACITY (GPM/FT) /RATE(GPM)	HARDNESS (MG/L)	SPECIFIC CONDUCTANCE (MICROMHOS AT 25 DEG C)	PH	WELL NUMBER
COUNTY											
80		6		50							BK- 361
150	12	6		28	01/24						362
161	12	6		90	07/46						363
200		6									364
56		6		15							365
300	40	8		8	09/75	340		119	350	6.2	366
300	56	8		36	11/43	115					367
600		6		70							368
236		6		70							369
190	15	6		69	10/46						370
474		8		58	12/48		0.40 / 80				371
600		8		58	10/52		0.35 / 70				372
250		8		86	10/43	120	1.8 /125				373
250		8		68	10/43	150		111		7.3	374
600		8		70	10/43	120	1.7 /164				375
592		8		63	10/43	125		171	400	6.7	376
352	62	6			01/48	28	2.4 / 76				377
278											378
270		6									379
128	20	8		24	01/46		3.6 / 50				380
324	29	8		67	01/46						381
57		6		9	02/53						383
225	90	8									384
359	50	8		12	08/48	70		84	250	6.3	385
28				12							386
193		6		25	07/46						390
300	63	10		13	03/56			136	345	6.5	692
324	49	10		27	05/56			205	480	7.0	693
329	41	10		19	12/55			222	440	7.1	694
502	52	10		38			0.63 / 90	120	335	6.2	695
202											702
364	50	10		4	06/57	200		806		7.2	728
608	31	8									933
398	71	10		16	06/62			205	510	7.5	947
516	88	10		24	07/63	175	0.96 /164	188	440	7.5	948
466	80	10		19	09/62		1.1 /175	188	410	7.1	949
460	62	10		6	07/64	275	17 /600	205	470	7.3	950
528	57	10			06/65		8.1 /503	154	380	7.4	951
623	55	10		7	08/65		0.78 /170				952
601	50	10		4	06/66		0.72 /167	137	295		953
469	62	10		6	02/67		1.9 /268	188	400	6.9	954
530	60	10		12	04/67			222	480	7.0	955
422	50	8		52	09/78						956
402	50	8		45	04/78	350		378		7.7	957
107	22	12						205	560	7.1	958
250	70	10			01/72		8.8 /420	188	420	7.4	959
400	40	6		6	01/67						960
400	62	6		34	04/68						962
575	35	8		21	07/70						978

TABLE 12.--RECORDS OF SELECTED WELLS--CONTINUED

WELL NUMBER	LOCATION LAT-LONG	OWNER	DRILLER	YEAR COMPLETED	USE	ALTITUDE OF LAND SURFACE (FEET)	TOPO-GRAPHIC SETTING
							BUCKS
BK- 979	4012-7501	NORTHAMPTON AUTH	MOODY DRILLING CO., INC.	1971	P	228	V
982	4011-7502	UPPER SOUTHAMPTON AUTH		1958	U	300	S
983	4010-7503	UPPER SOUTHAMPTON AUTH		1961	P	246	S
984	4010-7503	UPPER SOUTHAMPTON AUTH		1963	P	232	S
985	4014-7502	UPPER SOUTHAMPTON AUTH		1963	P	267	S
986	4011-7503	UPPER SOUTHAMPTON AUTH		1963	P	284	S
987	4010-7502	UPPER SOUTHAMPTON AUTH	WILLIAM STOTHOFF CO.	1965	P	193	V
988	4014-7508	WARRINGTON W. C.		1960	P	365	S
989	4014-7508	WARRINGTON AUTH	RULON AND COOK, INC.	1964	P	315	S
990	4013-7508	WARRINGTON AUTH	W. ROLLIN RAAB	1973	P	222	V
991	4013-7508	WARRINGTON AUTH	RULON AND COOK, INC.	1966	P	263	S
996	4014-7506	GUBICZA WENDEL			H	235	S
997	4012-7504	BEARN ROBERT		1970	H	311	H
998	4012-7504	VARNEY JOSEPH	F. E. BUEHLER & SON	1970	H	290	S
999	4013-7505	WALTHER S			H	200	S
1000	4013-7505	RUTH RONALD			U	248	S
1001	4013-7505	BOSTON			H	269	H
1002	4013-7507	MILLER PAVING			H	270	H
1003	4012-7507	CAMPEAU & MACNEIL			U	305	H
1004	4012-7507	BENITO B			I	302	H
1005	4013-7504	KEEBLE	CARSON BROS.	1974	H	249	S
1006	4012-7504	NIXON CHARLES	JOSEPH J. GUENTHOER	1973	H	251	S
1007	4012-7506	CHRIST'S HOME		1954	R	288	S
1008	4013-7505	BUSHNELL			H	244	S
1009	4013-7505	BUSHNELL			U	244	S
1010	4013-7505	WRIGHT		1957	H	264	H
1011	4013-7506	MCNEIL RICHARD	RULON AND COOK, INC.	1964	H	260	S
1012	4013-7506	MILLER PAVING			H	278	S
1013	4012-7507	SERRILL			H	299	H
1014	4013-7506	BROOKS			H	205	S
1015	4011-7505	WOLVERTON J			H	262	S
1016	4011-7506	POWELL RON			H	265	V
1017	4011-7503	PICCOLI RAYMOND			H	348	H
1018	4011-7503	BETZ FRED	CARSON BROS.	1974	H	330	S
1019	4012-7503	U.S. NADC	RULON AND COOK, INC.	1967	H	360	S
1020	4012-7503	U.S. NADC	HARRISBURG'S KOHL BROS.	1968	U	370	H
1021	4011-7502	WOLF ROBERT		1959	H	355	H
1022	4011-7503	JOHNSON			H	350	S
1023	4011-7503	WARMINSTER AUTH	WILLIAM STOTHOFF CO.	1972	U	350	S
1024	4011-7503	SHAPIRO ED	JOSEPH J. GUENTHOER	1971	H	309	S
1025	4011-7503	DICKSON	JOHNSON & GROSS	1968	H	320	H
1027	4011-7503	HOY H			H	319	S
1028	4011-7503	HOY H			U	314	S
1030	4011-7505	WARMINSTER AUTH			Z	260	V
1031	4012-7506	GRACE CHURCH		1963	H	260	S
1032	4011-7503	SINKLER EARL			H	312	S
1033	4011-7503	SINKLER EARL			U	293	S
1034	4012-7504	ANDRE			H	338	S
1035	4012-7503	MUNRO CRAIG			H	335	S
1036	4012-7503	MCKELVIE JAMES		1955	H	345	S

WELL DEPTH BELOW LAND SURFACE (FEET)	CASING DEPTH (FEET)	CASING DIAMETER (INCHES)	DEPTH(S) TO WATER-BEARING ZONE(S) (FEET)	STATIC WATER LEVEL DEPTH BELOW LAND SURFACE (FEET)	STATIC WATER LEVEL DATE MEASURED (MO/YR)	REPORTED YIELD (GPM)	SPECIFIC CAPACITY (GPM/FT) /RATE(GPM)	HARDNESS (MG/L)	SPECIFIC CONDUCTANCE (MICROMHOS AT 25 DEG C)	PH	WELL NUMBER
COUNTY -- CONTINUED											
217	33	8									BK- 979
445	65	10		43	02/58		0.27 / 47	192		7.2	982
500	55	10		34	09/61		1.4 /210	150		6.7	983
642	52	10		32	05/63		0.66 /108	105		7.3	984
703	52	10		75	06/63		1.00 /167				985
682	56	10		20	02/64		0.69 /122			7.2	986
709	59	10			04/65		0.50 /115				987
500	66	10		80	06/60		0.75 / 90	200		7.3	988
619	43	8		123	01/65	160	1.7 /160	188		7.8	989
550	60	8		10			6.7 /175				990
300	58	8		6	03/66		3.5 /225				991
		6		18	07/78						996
110	30	6	65 90 100	20							997
135	37	6	70	30	12/71						998
125				17	07/78						999
				26	07/78						1000
	22	6		20	07/78						1001
		6		26	07/78						1002
20				11	07/78						1003
		6		22	07/78						1004
115	53	6	72 110								1005
155	31	6	65 140	30	10/73			139	300	6.7	1006
105	20	6									1007
								139	340	6.8	1008
				15	07/78						1009
90								86	240	6.0	1010
145	38	6		25	01/64			139	340	7.5	1011
								86	240	8.4	1012
								86	250	6.3	1013
								139	310	7.6	1014
80								86	280	7.2	1015
									280	6.4	1016
				25	07/78			86	270	5.1	1017
215	42	6	80 180								1018
385	62	8									1019
400	57	10	120 280	40	04/68						1020
104								171	420	4.1	1021
								205	500	4.8	1022
600	60	8		16	09/78						1023
140	30	6		37	07/78			86	260		1024
102	33	6		35	01/68						1025
70								103	260	5.6	1027
20				14	07/78						1028
				9	07/78						1030
								154	420	6.3	1031
152								154	420	6.3	1032
30				15	08/78						1033
70								120	265	6.9	1034
								86	205	6.1	1035
								68	170	5.5	1036

TABLE 12.--RECORDS OF SELECTED WELLS--CONTINUED

WELL LOCATION NUMBER	LAT-LONG	OWNER	DRILLER	YEAR COMPLETED	USE	ALTITUDE OF LAND SURFACE (FEET)	TOPO-GRAPHIC SETTING
							BUCKS
BK-1037	4012-7503	MCKELVIE H			H	345	S
1038	4012-7506	JONES C			H	310	H
1039	4013-7505	MORROW C			H	275	S
1040	4013-7505	WARMINSTER AUTH	W. ROLLIN RAAB	1978	P	210	V
1041	4013-7505	DOAN GEORGE	W. ROLLIN RAAB		H	235	S
1042	4013-7505	ZIMMERMAN HARRY			H	245	S
1043	4011-7504	KING JOHN	HARRY L. WEISS		H	345	S
1044	4011-7503	GILLIE RICHARD			H	345	S
1045	4010-7504	BURG JOHN		1951	U	290	S
1046	4010-7504	BURG JOHN			H	290	S
1047	4012-7505	SCARPILL JOHN		1959	H	289	S
1048	4012-7505	SCARPILL JOHN			U	292	S
1049	4012-7505	GRADWELL FRANK		1935	H	315	H
1050	4012-7504	HABERMEHL C			I	263	S
1051	4012-7504	STOVER R			U	265	S
1052	4013-7505	DUFFY C			C	264	S
1053	4012-7504	SMITH C			H	265	S
1054	4012-7504	RADELBACK HERBERT	F. E. BUEHLER & SON	1973	H	250	S
1055	4013-7504	MCMAHON L		1960	H	233	V
1056	4010-7504	GERMAN CLUB	JOHN WILEY	1937	R	235	S
1057	4010-7504	GERMAN CLUB		1950	H	235	S
1058	4010-7504	WARMINSTER AUTH		1972	U	215	S
1059	4012-7504	WARMINSTER AUTH	W. ROLLIN RAAB	1977	P	238	V
1060	4011-7504	PASSMORE BARRY		1963	H	347	S
1061	4011-7504	PASSMORE BARRY			U	347	S
1062	4012-7505	SMITH ELMER	F. E. BUEHLER & SON	1970	H	315	S
1063	4013-7505	GUERRELLI R	W. ROLLIN RAAB	1974	H	242	S
1064	4010-7504	WOOLLEY GEORGE	F. E. BUEHLER & SON	1973	H	210	S
1065	4010-7504	CUNNINGHAM EDWARD			H	209	S
1066	4010-7504	HANFUS JOHN			H	262	S
1067	4012-7505	WARMINSTER AUTH	W. ROLLIN RAAB	1978	U	289	W
1068	4011-7503	ASTERING	JOSEPH J. GUENTHOER	1973	H	340	S
1069	4011-7503	KELLY R	JOSEPH J. GUENTHOER	1974	H	330	S
1070	4011-7503	KLINGERS C	MILLER PUMP SERVICE, INC.	1976	H	315	S
1071	4011-7503	CARTER S	CARSON BROS.	1975	H	325	S
1072	4012-7503	GOLF FARMS	RULON AND COOK, INC.	1966	C	300	S
1073	4012-7503	GOLF FARMS			U	299	S
1074	4011-7502	WOLSTENHOLMES J			H	365	H
1075	4010-7503	DOUGHERTY MICHAELS			U	247	S
1076	4010-7503	DOUGHERTY MICHAEL			H	247	S
1079	4012-7500	NORTHAMPTON AUTH			P	248	V
1083	4013-7507	WARRINGTON AUTH	W. ROLLIN RAAB	1973	P	203	V
1084	4014-7506	HARRIS ARTHUR			U	249	S
1085	4009-7503	UPPER SOUTHAMPTON AUTH	WILLIAM STOTHOFF CO.	1966	P	207	V
1086	4013-7508	WARRINGTON W. C.	RULON AND COOK, INC.		P	270	V
1087	4012-7504	WARMINSTER AUTH		1972	U	273	V
1088	4011-7504	TENNENT SCHOOL		1954	T	362	H
1089	4011-7504	JOHNSVILLE SCHOOL			T	359	H
1090	4013-7503	BERNARD C	JOSEPH J. GUENTHOER	1973	H	285	S
1091	4013-7502	MANDES C	JOSEPH J. GUENTHOER	1973	H	270	S

WELL DEPTH BELOW LAND SURFACE (FEET)	CASING DEPTH (FEET)	CASING DIAMETER (INCHES)	DEPTH(S) TO WATER-BEAR-ING ZONE(S) (FEET)	STATIC WATER LEVEL DEPTH BELOW LAND SURFACE (FEET)	STATIC WATER LEVEL DATE MEASURED (MO/YR)	RE-PORTED YIELD (GPM)	SPECIFIC CAPACITY (GPM/FT) /RATE(GPM)	HARD-NESS (MG/L)	SPECIFIC CONDUCTANCE (MICROMHOS AT 25 DEG C)	PH	WELL NUMBER
COUNTY -- CONTINUED											
								86	220	5.5	BK-1037
								188	520	6.1	1038
				22	08/78			222	580	7.0	1039
400	60	12	102 150 200 218 240 315	25	09/78						1040
90	40	6						137	520	4.7	1041
								120	360		1042
44	12	6		11	08/78			103	260	5.8	1043
129								51	170	5.6	1044
21				9	08/78						1045
50								137	300	7.5	1046
								188	320	7.8	1047
				3	08/78						1048
40		8		8	08/78			205	690	5.8	1049
								171	380	7.1	1050
				36	08/78						1051
								68	225	6.0	1052
20				16	09/78						1053
85				18	09/78						1054
44								205	420	6.9	1055
275		10									1056
200											1057
500				25	09/78						1058
400	66	12	164 235 294	8	09/78			154	340		1059
115	60	6		21	09/78			205	380	7.7	1060
95	40	6	50 92					171	520	5.6	1062
130	100	6		40	06/74						1063
155	40	6	60 115 145	12	06/73						1064
								6	180	6.0	1065
								120	320	6.1	1066
400	60	8		12	10/78			205	460	8.3	1067
110	36	6	48 77 97	30	07/78		0.50 / 20				1068
200	31	6	70 110 150 185	40	06/74						1069
135	69	6	120 130	40	02/76						1070
155	36	6	72 150								1071
								154	300	7.8	1072
		6		26	10/78						1073
				20	10/78			103	340	5.9	1074
				14	10/78						1075
132	30	6		18				171	400	7.1	1076
500	70	12									1079
300	40	8		19	01/74						1083
				36	12/78						1084
700	60	10		12	01/80						1085
420	56	8									1086
400				7	03/79						1087
216	31	8									1088
											1089
170	33	6	47 85 160	16	03/79			137	310	7.7	1090
110	29	6	41 78 93	4	06/79			171	335	7.9	1091

TABLE 12.--RECORDS OF SELECTED WELLS--CONTINUED

WELL LOCATION NUMBER	LAT-LONG	OWNER	DRILLER	YEAR COMPLETED	USE	ALTITUDE OF LAND SURFACE (FEET)	TOPO-GRAPHIC SETTING
							BUCKS
BK-1092	4012-7502	EISENHARD C			H	330	S
1093	4012-7502	WISNIOSKI		1979	U	290	S
1094	4012-7502	WISNIOSKI			H	295	S
1095	4013-7502	ST VINCENT CH			H	305	S
1096	4013-7503	O M FELLOWSHIPS			H	188	S
1097	4013-7502	O M FELLOWSHIPS			H	225	S
1098	4013-7503	MARK ANTHONY	ANTHONY DOMINIANI JR.	1968	H	210	S
1099	4013-7503	FRISCHMANN CHARLES			H	270	S
1100	4013-7501	TANNER C	CARSON BROS.		H	320	S
1101	4013-7502	SOLLYBROS FARM			H	285	S
1102	4013-7502	MILLER GEORGE	F. E. BUEHLER & SON	1968	H	250	S
1103	4013-7503	KING ROBERT	ANTHONY DOMINIANI JR.	1969	H	210	S
1105	4013-7503	CAMERON JAMES	ANTHONY DOMINIANI JR.	1966	H	220	S
1106	4013-7503	ANDERSON			H	262	S
1107	4012-7502	HAIST			H	323	S
1109	4013-7503	HENDERSON ROBERT			H	240	S
1110	4013-7502	UNGERER GEORGE	W. ROLLIN RAAB	1974	H	235	S
1111	4013-7502	BROWN W			H	238	S
1112	4013-7502	TRAIL ROBERTA			H	275	S
1114	4012-7503	HUFF			H	313	S
1115	4012-7502	GABLER			H	320	S
1116	4012-7502	KRAUSE			H	317	H
1117	4013-7501	KENNY			H	312	S
1118	4013-7501	EDWARDS			H	325	H
1119	4013-7501	DUNLAP	HARRY L. WEISS	1949	H	335	H
1120	4010-7504	EICHER			U	243	S
1121	4010-7504	PAHL W			H	208	S
1122	4010-7504	THESEN			H	212	S
1123	4011-7503	FORNICOLA			H	248	S
1124	4011-7503	STACKPOLE FRED			H	252	S
1125	4013-7503	RINK JOHN	JOSEPH J. GUENTHOER	1973	H	270	V
1126	4013-7506	MCNEIL RICHARD			Z	272	S
1127	4014-7504	ALDERFER			H	195	V
1128	4013-7504	CORNELL ALVIN			H	205	S
1129	4012-7505	WARMINSTER AUTH	W. ROLLIN RAAB	1980	P	270	F
1130	4012-7504	WARMINSTER AUTH	W. ROLLIN RAAB	1980	U	300	F
1131	4012-7505	WARMINSTER AUTH			U	290	F
1132	4014-7507	WARRINGTON AUTH	W. ROLLIN RAAB		P	255	S
1133	4014-7506	NESHAMINY-WARWICK PRES CH	W. ROLLIN RAAB	1974	H	205	S
1134	4014-7501	KILLOUGH			H	322	S
1135	4014-7502	WESSER			H	265	S
1136	4014-7502	FELDMAN			H	275	S
1137	4012-7500	NORTHAMPTON AUTH		1979	P	200	V
1138	4013-7500	NORTHAMPTON AUTH			U	370	H
1140	4010-7503	MIKOWSKI			H	235	S
1141	4013-7505	WARMINSTER AUTH	W. ROLLIN RAAB	1980	P	195	V
1145	4013-7506	WARMINSTER AUTH	W. ROLLIN RAAB	1980	U	245	V
1146	4013-7506	WARMINSTER AUTH	W. ROLLIN RAAB	1981	U	245	V

WELL DEPTH BELOW LAND SURFACE (FEET)	CASING DEPTH (FEET)	CASING DIAMETER (INCHES)	DEPTH(S) TO WATER-BEARING ZONE(S) (FEET)	STATIC WATER LEVEL DEPTH BELOW LAND SURFACE (FEET)	STATIC WATER LEVEL DATE MEASURED (MO/YR)	REPORTED YIELD (GPM)	SPECIFIC CAPACITY (GPM/FT) /RATE(GPM)	HARDNESS (MG/L)	SPECIFIC CONDUCTANCE (MICROMHOS AT 25 DEG C)	PH	WELL NUMBER
COUNTY -- CONTINUED											
				10	06/79			154	335	7.9	BK-1092
24				5	05/79						1093
		6		14	05/79			120	285	6.2	1094
160		6		20	05/79			205	450	7.1	1095
								137	320	7.0	1096
								154	320	7.7	1097
113	56	6	35 69 87 92 110	30	09/68		0.14 / 10	86	300	5.9	1098
								103	290	5.8	1099
				28	06/79			86	270	6.3	1100
				23	06/79			120	265	6.7	1101
157	42	6	60 125 157				0.31 / 30	68	215	5.9	1102
128	50	6	56 85 126	28	01/69		0.58 / 30	137	295	7.9	1103
125	52	6	65 94 115	40	07/66		0.40 / 20				1105
				18	06/79			103	340	5.7	1106
				10	06/79			137	345	6.3	1107
								103	300	6.4	1109
80	45	6	25 30 45 70	15	06/79		0.75 / 15	154	325	7.4	1110
								137	380	5.8	1111
				13	06/79			154	400	5.9	1112
				24	06/79			68	235	6.0	1114
								205	570	5.9	1115
								137	450	5.5	1116
								103	340	5.6	1117
								68	245	5.4	1118
		6						103	350	5.8	1119
		6		26	07/79						1120
								68	200	5.6	1121
140								519	160	5.4	1122
								171	420	6.6	1123
								103	350	6.1	1124
96	31	6	38 78 90					137	320	7.6	1125
245								86	220	9.1	1126
45								51	140	5.5	1127
								103	280	6.4	1128
400	50	8	125 168 210 305 360					120	280	7.9	1129
400	50	8	140 158 232 280 376	4	02/80						1130
23				3	03/80						1131
380	209	10		19	05/80			137	330		1132
								137	340	7.2	1133
200								86	240	7.2	1134
				60	10/79			171	360	7.7	1135
								137	305	7.7	1136
400	60	10									1137
530	60	10									1138
								188	440	7.4	1140
400								154	380	8.0	1141
350	20	6						395	395	8.2	1145
460	132	12	58 78 116 190 224 364								1146

TABLE 12.--RECORDS OF SELECTED WELLS--CONTINUED

WELL NUMBER	LOCATION LAT-LONG	OWNER	DRILLER	YEAR COMPLETED	USE	ALTITUDE OF LAND SURFACE (FEET)	TOPO-GRAPHIC SETTING
							MONTGOMERY
MG- 209	4012-7508	U.S. NAS	F. L. BOLLINGER & SONS	1942	P	310	F
210	4012-7508	U.S. NAS		1942	P	310	F
211	4010-7506	HATBORO AUTH		1900	U	250	S
212	4010-7506	HATBORO AUTH			U	250	S
213	4010-7506	HATBORO AUTH			U	250	S
216	4011-7506	HATBORO AUTH		1947	P	250	V
217	4010-7506	HATBORO AUTH		1948	P	220	V
218	4011-7506	HATBORO AUTH		1952	P	225	V
219	4010-7507	HATBORO AUTH		1953	P	217	V
220	4010-7506	HATBORO AUTH		1956	U	225	V
275	4011-7507	HORSHAM AUTH	WILLIAM STOTHOFF CO.	1955	P	345	S
276	4011-7507	HORSHAM AUTH	WILLIAM STOTHOFF CO.	1955	U	300	S
489	4012-7508	U.S. NAS		1957	P	290	S
490	4012-7508	U.S. NAS		1957	P	280	S
942	4010-7506	HATBORO AUTH		1959	P	211	V
943	4010-7505	HATBORO AUTH		1965	P	272	H
944	4010-7506	HATBORO AUTH	F. L. BOLLINGER & SONS	1964	P	220	V
945	4010-7506	HATBORO AUTH	F. L. BOLLINGER & SONS	1964	P	225	S
946	4011-7505	HATBORO AUTH		1969	P	240	V
947	4011-7506	HATBORO AUTH			P	245	V
948	4010-7506	HATBORO AUTH	W. ROLLIN RAAB	1971	P	202	V
949	4010-7507	HATBORO AUTH			P	220	V
950	4010-7507	HATBORO AUTH	W. ROLLIN RAAB	1972	P	250	S
951	4010-7506	HATBORO AUTH	W. ROLLIN RAAB	1971	U	258	S
953	4011-7510	HORSHAM AUTH		1960	P	333	S
954	4011-7507	HORSHAM AUTH	WILLIAM STOTHOFF CO.	1963	P	302	H
955	4011-7509	HORSHAM AUTH	WILLIAM STOTHOFF CO.	1965	P	335	S
957	4010-7508	HORSHAM AUTH	W. ROLLIN RAAB		P	265	V
958	4012-7507	HORSHAM AUTH	WILLIAM STOTHOFF CO.	1968	P	320	H
959	4011-7509	HORSHAM AUTH	F. L. BOLLINGER & SONS	1973	P	290	V
960	4010-7507	HORSHAM AUTH		1973	P	225	V
961	4010-7507	HORSHAM AUTH	F. L. BOLLINGER & SONS	1973	P	273	S
962	4011-7509	HORSHAM AUTH			P	320	V
963	4011-7507	HORSHAM AUTH	F. L. BOLLINGER & SONS	1973	U	277	S
965	4010-7504	BALL DAVID			H	220	S
966	4010-7504	NICHOLSON			H	215	S
967	4013-7509	HORSHAM AUTH		1971	U	225	V
972	4012-7511	HORSHAM AUTH	F. L. BOLLINGER & SONS	1975	P	248	V

WELL DEPTH BELOW LAND SURFACE (FEET)	CASING DEPTH (FEET)	CASING DIAMETER (INCHES)	DEPTH(S) TO WATER-BEARING ZONE(S) (FEET)	STATIC WATER LEVEL DEPTH BELOW LAND SURFACE (FEET)	STATIC WATER LEVEL DATE MEASURED (MO/YR)	REPORTED YIELD (GPM)	SPECIFIC CAPACITY (GPM/FT) /RATE(GPM)	HARDNESS (MG/L)	SPECIFIC CONDUCTANCE (MICROMHOS AT 25 DEG C)	PH	WELL NUMBER
COUNTY -- CONTINUED											
397	52	10		48	08/45			120	360	7.6	MG- 209
	43	10				183		171	420	6.9	210
250	38	8									211
250	38	10									212
250	38	10									213
299		10		56		300	4.1 /300				216
288	30	10		25	04/50	211	1.5 /211				217
306				24		375	3.1 /375				218
300	40	10					2.4 /235	137	395	6.6	219
475	43	10		3		110	0.41 /110				220
354	40	10		27			0.96 /100	152	350	6.5	275
342	46	10						130		7.7	276
350		10									489
330		10									490
300	40	10									942
500	260	6									943
300	41	10									944
300	41	10									945
300	40	10									946
300											947
301	47	10									948
300											949
375	70	10									950
335	70	10									951
468	61	10									953
478	48	10									954
600	51	10									955
602	70	10					0.61 /152				957
271	50	10									958
400	30	6	53 85 165 330								959
400	40	8		6	01/73						960
400	40	6	80 140 200 220								961
400	16	22									962
400			80 180 220 260	11	10/73						963
		6		31	07/79			120	340	6.6	965
								86	285	6.2	966
330	38	8	53 65 75 125 225 380			230		513	1100	7.0	967
285	44	16	135 160 170 250 270			700	17 /700	262	574	7.8	972

TABLE 13.--CHEMICAL ANALYSIS OF WATER FROM SELECTED WELLS

WELL NUMBER	DATE OF SAMPLE	SOLIDS, RESIDUE AT 180 DEG. C DIS-SOLVED (MG/L)	SPE-CIFIC CON-DUCT-ANCE (UMHOS)	PH (UNITS)	TEMPER-ATURE (DEG C)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)	SODIUM+ POTAS-SIUM DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	SULFATE DIS-SOLVED (MG/L AS SO4)	NITRO-GEN, NITRATE DIS-SOLVED (MG/L AS N)	NITRO-GEN, NITRITE DIS-SOLVED (MG/L AS N)	PHOS-PHORUS, ORTHO, DIS-SOLVED (MG/L AS P)	PHOS-PHORUS, DIS-SOLVED (MG/L AS P)
BUCKS COUNTY																
BK- 366	53-04-08	185	310	7.2	12.0	29	16	8.1	8.6	.5	11	35	3.40	--	--	--
	79-07-24	233	350	6.2	15.0	23	5.7	19	21	1.6	22	31	7.70	<.010	.060	.070
374	56-12-05	201	324	7.0	13.0	34	12	--	11	--	15	46	1.70	--	--	--
376	56-12-05	209	315	7.8	13.0	33	12	--	19	--	4.3	30	.14	--	--	--
	79-10-22	249	400	6.7	16.0	41	15	17	19	1.9	14	28	.04	.010	.040	.060
377	56-12-05	180	274	8.0	12.0	33	11	--	8.7	--	2.8	20	.14	--	--	--
384	74-05-14 1/	208	--	6.6	--	--	--	--	9.4	--	18	27	5.10	--	.010	--
385	53-04-08	160	202	6.5	13.0	20	6.2	14	16	2.2	9.0	39	.34	--	--	--
	56-08-16	159	204	8.0	--	20	5.7	--	18	--	18	28	.09	--	--	--
390	53-09-07	136	220	6.5	12.0	12	9.0	13	16	2.6	11	39	2.30	--	--	--
692	56-08-17	202	292	8.0	--	30	7.0	--	14	--	16	30	9.71	--	--	--
	79-07-25	287	420	6.7	16.0	43	11	16	17	1.1	30	31	4.10	.010	.060	.120
693	74-08-26 1/	244	--	7.3	--	--	--	--	12	--	13	36	5.10	--	.010	--
694	56-08-16	177	279	8.2	--	40	6.0	--	8.3	--	8.5	23	2.71	--	--	--
	79-07-25	286	440	7.1	14.5	50	15	12	14	1.7	17	26	3.60	<.010	<.010	.050
695	56-08-16	251	277	8.0	--	31	3.2	--	10	--	13	34	4.30	--	--	--
	79-10-23	208	335	6.2	14.0	39	5.9	17	19	1.8	13	36	3.80	.010	.070	.080
728	57-12-30 2/	1330	--	--	--	310	9.0	--	--	--	--	720	--	--	--	--
	73-10-01	576	--	7.5	--	118	--	--	23	--	7.0	258	.84	--	.010	--
	79-07-26	498	680	7.4	14.5	110	11	14	16	1.8	13	200	.33	.020	<.010	<.010
933	74-07-10 1/	362	--	7.4	--	--	--	--	21	--	16	105	2.80	--	<.010	--
947	79-07-25	334	510	7.5	14.5	49	18	16	18	1.6	21	79	3.80	<.010	<.010	.060
948	74-05-14 1/	420	--	6.9	--	--	--	--	--	--	--	111	2.60	--	--	--
949	74-05-14 1/	278	--	7.4	--	--	--	--	.2	--	12	24	1.80	--	.020	--
950	74-12-04 1/	212	--	7.8	--	--	--	--	3.4	--	14	18	2.80	--	.010	--
	79-07-26	195	470	7.3	14.5	52	16	13	14	.9	22	61	3.80	.010	.030	.080
951	74-12-04 1/	340	--	7.9	--	--	--	--	14	--	18	54	4.20	--	.010	--
	79-07-31	314	380	7.4	13.5	36	15	12	13	1.1	15	36	3.90	.010	.030	.080
952	70-01-06 1/	--	--	8.1	--	--	--	--	--	--	4.0	--	.20	--	--	--
953	75-02-06 1/	--	--	7.8	--	--	--	--	--	--	5.5	--	1.70	--	<.010	--
954	75-02-06 1/	--	--	7.1	--	--	--	--	--	--	18	--	2.40	--	.010	--
955	75-02-06 1/	--	--	7.7	--	--	--	--	--	--	13	--	1.60	--	.010	--
957	74-02-21 1/	400	--	7.1	--	--	--	--	13	--	17	108	4.30	--	.070	--
	79-09-19	439	690	7.2	13.0	93	19	19	20	1.0	23	150	2.30	<.010	.010	.030
958	75-02-06 1/	321	--	7.3	--	--	--	--	8.7	--	42	30	4.50	--	.010	--
	79-07-25	245	560	7.1	14.0	56	15	24	25	1.0	69	44	3.20	.010	.020	.070
959	75-02-06 1/	--	--	8.1	--	--	--	--	--	--	13	--	.10	--	.010	--
	79-07-31	389	420	7.4	14.0	50	14	13	15	2.0	17	39	.95	.030	<.010	.030
978	74-03-28 1/	186	--	8.0	--	--	--	--	.7	--	7.5	9.0	.50	--	.010	--
979	75-02-03 1/	251	--	7.5	--	--	--	--	8.5	--	9.5	14	1.80	--	.020	--
982	73-01-08 1/	265	--	7.4	--	--	--	--	--	--	9.5	57	3.20	--	.010	--
983	75-01-14 1/	226	--	6.8	--	--	--	--	3.2	--	15	18	1.00	--	.010	--
984	74-10-01 1/	188	--	7.3	--	--	--	--	6.0	--	8.0	12	.93	--	.010	--
985	75-01-14 1/	246	--	6.7	--	--	--	--	6.0	--	15	22	2.90	--	.010	--
986	69-12-08 1/	--	--	8.0	--	--	--	--	--	--	12	--	3.00	--	--	--
987	73-07-19 1/	190	--	7.5	--	--	--	--	9.7	--	5.7	12	.57	--	.010	--
988	74-01-10 1/	330	--	7.8	--	--	--	--	15	--	20	30	1.70	--	<.010	--
989	73-07-23 1/	360	--	7.3	--	--	--	--	--	--	14	80	1.40	--	.010	--
990	69-04-14 1/	--	--	7.8	--	--	--	--	--	--	10	--	.80	--	--	--
991	74-12-09 1/	270	--	7.0	--	--	--	--	6.9	--	15	56	2.20	--	.020	--
1011	79-08-03	181	340	8.8	16.0	33	13	11	13	1.5	23	25	3.10	<.010	.040	.060
1024	79-07-25	170	260	6.7	15.5	23	8.6	11	12	.9	15	33	2.70	.010	<.010	.090
1041	79-07-30	239	380	6.2	16.0	32	7.9	20	22	2.0	42	34	3.80	.010	<.010	.030
1046	79-07-26	181	--	--	--	32	12	7.5	8.0	.5	4.7	30	.13	<.010	.010	.070
1050	79-08-03	235	405	7.0	16.0	42	14	14	15	1.2	25	45	5.70	<.010	.080	.110
1055	79-07-27	294	420	7.0	15.0	50	14	14	15	.9	15	40	4.50	.010	.030	.070
1094	79-07-27	179	300	6.9	15.0	29	11	10	12	1.9	9.7	42	3.60	.010	.030	.080
1098	79-07-24	205	300	5.8	17.0	30	11	14	15	.9	22	30	6.80	<.010	.220	.220
1125	79-07-31	276	320	7.6	14.0	35	11	8.7	9.8	1.1	11	21	3.70	<.010	.070	.070
1128	79-10-23	169	280	6.4	14.0	27	8.0	11	12	.8	11	27	6.60	.000	.090	.090
1140	79-08-08	233	440	7.4	15.0	59	11	10	11	1.3	17	26	17.0	<.010	.040	.050
MONTGOMERY COUNTY																
MG- 209	56-06-08	225	350	7.5	14.4	31	20	--	8.1	--	8.0	40	1.70	--	--	--
210	56-06-08	217	317	7.2	12.2	31	14	--	15	--	19	20	2.20	--	--	--
	79-10-22	305	420	6.9	14.0	42	18	15	16	1.2	17	28	1.90	.010	.070	.080
212	56-06-27	274	367	8.2	12.2	39	6.5	--	27	--	17	50	3.80	--	--	--
216	56-06-27	264	343	8.4	12.8	38	11	--	17	--	14	25	2.90	--	--	--
217	56-06-27	279	403	7.6	13.9	31	10	--	39	--	8.5	70	1.50	--	--	--
218	56-06-27	274	407	8.2	12.2	41	10	--	29	--	11	64	2.50	--	--	--
219	56-06-27	197	286	8.0	13.0	40	5.2	--	18	--	10	23	2.90	--	--	--
	79-10-23	220	395	6.6	12.0	44	9.2	16	18	1.5	19	27	3.70	.010	.040	.050
275	56-08-17	187	300	7.8	13.9	36	10	--	8.6	--	9.0	15	5.00	--	--	--
967	79-08-07	857	1100	7.8	13.0	190	16	31	32	1.0	5.4	460	.07	.010	.010	<.010

ND = NOT DETECTED
1/ ANALYSIS BY PENNSYLVANIA DEPARTMENT OF ENVIRONMENTAL RESOURCES
2/ ANALYSIS BY PRIVATE LABORATORY

IRON, DIS- SOLVED (UG/L AS FE)	MANGA- NESE, DIS- SOLVED (UG/L AS MN)	SILICA, DIS- SOLVED (MG/L AS SIO2)	FLUO- RIDE, DIS- SOLVED (MG/L AS F)	CARBON, ORGANIC DIS- SOLVED (MG/L AS C)	ALKA- LINITY FIELD (MG/L AS CACO3)	HARD- NESS (MG/L AS CACO3)	HARD- NESS, NONCAR- BONATE (MG/L CACO3)	CADMIUM DIS- SOLVED (UG/L AS CD)	CHRO- MIUM, DIS- SOLVED (UG/L AS CR)	COPPER, DIS- SOLVED (UG/L AS CU)	LEAD, DIS- SOLVED (UG/L AS PB)	MERCURY DIS- SOLVED (UG/L AS HG)	SELE- NIUM, DIS- SOLVED (UG/L AS SE)	ZINC, DIS- SOLVED (UG/L AS ZN)	WELL NUMBER
680	--	13	.0	--	94	140	44	--	--	--	--	--	--	--	BK- 366
<10	4	22	<.1	2.9	33	81	48	<2	20	85	34	<.5	<1	20	
170	0	25	.1	--	82	130	52	--	--	--	--	--	--	--	374
520	0	28	.1	--	135	130	0	--	--	--	--	--	--	--	376
140	870	29	.1	1.7	150	160	14	1	<10	2	0	.1	--	--	
130	0	27	.1	--	121	130	6	--	--	--	--	--	--	--	377
90	<10	--	.1	--	39	90	51	--	--	--	--	--	--	--	384
480	--	28	.1	--	54	75	21	--	--	--	--	--	--	--	385
--	--	33	.1	--	58	73	15	--	--	--	--	--	--	--	
2300	--	10	.1	--	32	67	35	--	--	--	--	--	--	--	390
--	--	22	.1	--	46	100	58	--	--	--	--	--	--	--	692
<10	<10	24	.1	2.9	98	150	55	<2	<20	4	8	<.5	--	--	
230	<10	--	.4	--	86	130	44	--	--	--	--	--	--	--	693
460	0	21	.1	--	97	130	28	--	--	--	--	--	--	--	694
<10	<10	22	<.1	1.7	160	190	27	<2	<20	5	40	<.5	--	--	
46000	3600	29	.1	--	50	91	41	--	--	--	--	--	--	--	695
10	40	25	.1	3.1	85	120	37	2	<10	12	9	.2	--	--	
--	--	--	--	--	90	810	720	--	--	--	--	--	--	--	728
142	120	--	.1	--	108	340	230	--	--	--	--	--	--	--	
80	70	17	.1	2.2	120	320	200	ND	20	<2	24	<.5	--	--	
<10	<10	--	.1	--	94	190	96	--	--	--	--	--	--	--	933
<10	<10	18	.1	1.4	110	200	86	ND	<20	5	45	<.5	--	--	947
110	<10	--	.1	--	87	--	--	--	--	--	--	--	--	--	948
30	<10	--	.1	--	112	160	48	--	--	--	--	--	--	--	949
20	<10	--	.1	--	91	130	39	--	--	--	--	--	--	--	950
<10	<10	23	.1	2.2	110	200	86	2	<20	4	31	<.5	--	--	
55	<10	--	.1	--	102	170	68	--	--	--	--	--	--	--	951
20	8	21	.1	1.9	110	150	42	ND	<20	4	6	<.5	--	--	
100	--	--	--	--	119	140	21	--	--	--	--	--	--	--	952
105	--	--	--	--	46	82	36	--	--	--	--	--	--	--	953
30	--	--	.2	--	86	130	44	--	--	--	--	--	--	--	954
7	--	--	.1	--	102	160	58	--	--	--	--	--	--	--	955
90	30	--	.1	--	85	210	130	--	--	--	--	--	--	--	957
30	20	21	.1	1.5	140	310	170	ND	<20	ND	ND	<.5	--	--	
490	15	--	.0	--	77	160	83	--	--	--	--	--	--	--	958
<10	<10	23	<.1	3.1	100	200	100	<2	<20	3	38	<.5	--	--	
20	--	--	.1	--	107	140	33	--	--	--	--	--	--	--	959
<10	40	20	.1	2.6	170	180	13	2	<20	3	55	<.5	--	--	
215	40	--	.1	--	102	120	18	--	--	--	--	--	--	--	978
50	20	--	.1	--	110	130	20	--	--	--	--	--	--	--	979
60	60	--	.1	--	95	180	85	--	--	--	--	--	--	--	982
130	110	--	.1	--	84	120	36	--	--	--	--	--	--	--	983
60	160	--	.1	--	73	88	15	--	--	--	--	--	--	--	984
80	60	--	.1	--	76	120	44	--	--	--	--	--	--	--	985
0	--	--	--	--	117	160	43	--	--	--	--	--	--	--	986
50	90	--	.4	--	97	99	2	--	--	--	--	--	--	--	987
80	<10	--	.1	--	170	200	30	--	--	--	--	--	--	--	988
<10	30	--	.4	--	121	230	110	--	--	--	--	--	--	--	989
600	--	--	--	--	125	200	75	--	--	--	--	--	--	--	990
80	20	--	.1	--	85	160	75	--	12	150	--	--	--	--	991
<10	2	20	<.1	1.1	94	140	42	2	<20	36	ND	<.5	--	--	1011
<10	<10	22	<.1	2.0	55	93	38	<2	<20	44	12	<.5	--	--	1024
170	30	15	<.1	2.9	48	110	64	ND	<20	63	22	<.5	--	--	1041
70	270	22	.1	2.1	110	130	19	ND	<20	4	33	<.5	<1	80	1046
20	8	24	<.1	1.1	95	160	68	<2	<20	26	4	<.5	--	--	1050
<10	<10	23	<.1	1.1	130	180	53	ND	<20	<20	5	<.5	--	--	1055
20	2	14	.1	2.2	65	120	53	2	<20	67	23	<.5	--	--	1094
<10	<10	25	<.1	1.9	63	120	57	<2	20	3	26	<.5	<1	50	1098
1	1	19	.1	.6	120	130	13	ND	<20	19	48	<.5	--	--	1125
10	3	25	.1	1.9	58	100	42	3	<10	31	11	.1	--	--	1128
50	3	21	<.1	.7	140	190	53	<2	20	17	ND	<.5	--	--	1140
70	--	23	.1	--	118	160	42	--	--	--	--	--	--	--	MG- 209
20	--	27	.1	--	112	140	23	--	--	--	--	--	--	--	210
10	2	29	.1	1.6	150	180	29	0	<10	3	41	.1	--	--	
150	--	22	.1	--	93	120	31	--	--	--	--	--	--	--	212
100	--	32	.1	--	120	140	20	--	--	--	--	--	--	--	216
200	--	24	.1	--	113	120	5	--	--	--	--	--	--	--	217
40	--	29	.1	--	115	140	29	--	--	--	--	--	--	--	218
110	--	26	.1	--	112	120	9	--	--	--	--	--	--	--	219
0	4	23	.1	3.8	110	150	38	0	<10	6	0	.2	--	--	
--	--	23	.1	--	103	130	28	--	--	--	--	--	--	--	275
140	170	18	.1	1.0	110	540	430	<2	<20	<2	ND	<.5	--	--	967

TABLE 14.--CHEMICAL ANALYSIS OF WATER FROM SELECTED SURFACE-WATER SITES. STATION NAMES ARE GIVEN IN TABLE 1.

STATION NUMBER	DATE OF SAMPLE	DISCHARGE, IN CUBIC FEET PER SECOND	SOLIDS, RESIDUE AT 180 DEG. C DIS-SOLVED (MG/L)	SPE-CIFIC CON-DUCT-ANCE (UMHOS)	PH (UNITS)	TEMPER-ATURE (DEG C)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)	SODIUM+ POTAS-SIUM DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	SULFATE DIS-SOLVED (MG/L AS SO4)	NITRO-GEN, NITRATE DIS-SOLVED (MG/L AS N)	NITRO-GEN, NITRITE DIS-SOLVED (MG/L AS N)	PHOS-PHORUS, ORTHO, DIS-SOLVED (MG/L AS P)
01464800	79-10-17	29.7	169	280	--	12.0	22	8.0	15	17	2.1	19	36	2.20	.000	.050
	80-07-15	1.24	237	370	7.2	23.0	32	11	21	--	3.1	31	41	1.20	.040	.340
01464910	79-10-17	2.41	179	245	7.5	12.0	23	7.7	14	16	2.0	18	38	4.80	.010	.140
01464920	79-10-17	49.1	213	355	7.0	14.0	25	9.3	23	26	3.1	27	41	6.20	.340	.740
	80-07-15	4.40	515	850	7.4	23.0	45	15	84	--	9.9	89	74	11.0	1.10	7.00
01464930	79-10-17	9.04	169	285	7.0	11.0	24	7.8	13	15	2.1	12	39	3.50	.010	.050
	80-07-15	.15	306	480	7.4	19.0	51	9.6	19	--	4.2	23	88	3.20	.021	.380
01464940	79-10-17	6.45	189	280	7.1	12.0	22	8.1	13	15	2.2	18	39	7.00	.010	.020
	80-07-15	.33	188	300	7.6	20.0	25	8.3	13	--	2.0	19	33	4.50	.010	.110
01467032	79-10-17	--	172	270	7.1	14.5	23	7.5	13	15	1.6	17	38	2.80	.000	.000
	80-07-15	--	222	340	7.6	20.0	33	9.2	14	--	2.0	23	35	1.90	.000	.050
01467033	79-10-17	.99	201	320	7.1	14.0	28	9.0	15	17	2.2	19	42	3.60	.000	.010
	80-07-15	.01	238	400	7.2	20.0	36	8.0	22	--	2.1	42	29	1.90	.000	.060
01467034	79-10-17	2.61	219	340	7.3	--	33	11	16	18	1.8	23	41	2.90	.000	.010
	80-07-15	.31	334	500	8.1	22.0	45	19	22	--	2.4	37	50	2.80	.010	.080
01467035	79-10-17	.57	190	310	7.5	15.0	31	9.3	13	15	1.9	15	33	2.70	.000	.020
	80-07-15	.03	225	360	8.9	23.5	41	13	11	--	1.4	16	18	1.50	.010	.050

STATION NUMBER	DATE OF SAMPLE	PHOS-PHORUS, DIS-SOLVED (MG/L AS P)	IRON, DIS-SOLVED (UG/L AS FE)	MANGA-NESE, DIS-SOLVED (UG/L AS MN)	SILICA, DIS-SOLVED (MG/L AS SIO2)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	CARBON, ORGANIC DIS-SOLVED (MG/L AS C)	ALKA-LINITY FIELD (MG/L AS CACO3)	HARD-NESS (MG/L AS CACO3)	HARD-NESS, NONCAR-BONATE (MG/L CACO3)	CADMIUM DIS-SOLVED (UG/L AS CD)	CHRO-MIUM, DIS-SOLVED (UG/L AS CR)	COPPER, DIS-SOLVED (UG/L AS CU)	LEAD, DIS-SOLVED (UG/L AS PB)	MERCURY DIS-SOLVED (UG/L AS HG)	SELE-NIUM, DIS-SOLVED (UG/L AS SE)	ZINC, DIS-SOLVED (UG/L AS ZN)
01464800	79-10-17	.090	60	60	14	.2	2.9	41	88	47	1	<10	2	0	.2	--	--
	80-07-15	.340	20	230	8.4	.6	--	83	130	42	4	20	6	1	.1	0	4
01464910	79-10-17	.140	20	20	18	.1	2.6	31	89	58	0	<10	2	11	.3	--	--
01464920	79-10-17	.960	80	50	17	.2	5.8	50	100	51	1	<10	14	40	.3	--	--
	80-07-15	6.50	90	90	21	.4	--	130	170	44	5	10	29	1	.1	0	30
01464930	79-10-17	.060	30	30	17	.1	2.8	39	92	53	0	<10	2	48	.2	--	--
	80-07-15	.470	20	90	8.5	.1	--	74	170	93	4	20	4	0	<.1	0	10
01464940	79-10-17	.060	20	20	18	.1	2.5	24	88	64	0	<10	0	50	.2	--	--
	80-07-15	.100	20	40	14	.1	--	52	97	45	3	20	1	1	<.1	0	4
01467032	79-10-17	.020	30	70	19	.1	3.1	36	88	52	2	<10	0	52	.2	--	--
	80-07-15	.030	10	10	12	.1	--	78	120	42	5	10	2	1	<.1	0	8
01467033	79-10-17	.040	10	9	19	.1	2.5	53	110	54	0	<10	2	13	.2	--	--
	80-07-15	.050	10	20	16	.1	--	76	120	47	6	20	1	0	<.1	0	20
01467034	79-10-17	.040	30	60	18	.1	2.8	69	130	59	0	20	2	59	.2	--	--
	80-07-15	.140	10	20	17	.2	--	130	190	61	6	160	6	0	<.1	1	10
01467035	79-10-17	.030	30	30	18	.1	5.2	72	120	44	0	<10	1	23	.2	--	--
	80-07-15	.040	10	4	17	.1	--	130	160	26	4	10	1	6	<.1	0	9

Table 15.--Geologic logs of selected wells

Well Bk-1129

Description	Depth (feet)
Soil; sandstone, brown, medium grained.	0 - 20
Sandstone, dark gray brown, medium grained.	20 - 40
No sample.	40 - 50
Sandstone, reddish brown, fine grained.	50 - 60
Sandstone, brown, very fine to fine grained; some siltstone.	60 - 80
Sandstone, light brown to brown, medium to coarse grained, some fine grained.	80 - 100
Sandstone, light brown to brown, medium grained.	100 - 110
Sandstone, brown, fine grained.	110 - 120
Sandstone, brown, fine grained, siltstone, blue-green (water-bearing zone at 125 ft).	120 - 130
Sandstone, reddish brown, fine grained.	130 - 140
Sandstone, light gray to dark gray, coarse grained.	140 - 170
Sandstone, reddish brown, fine to very fine grained; siltstone, reddish brown (water-bearing zone at 168-172 ft).	170 - 180
Sandstone, light gray through brown, medium to coarse grained, some fine grained (water-bearing zone at 210 ft).	180 - 210
Sandstone, reddish brown, fine grained; siltstone, reddish brown.	210 - 220
Sandstone, reddish brown, fine grained.	220 - 230
Sandstone, dark gray-brown, fine grained; siltstone,	
Sandstone, dark gray-brown, fine grained.	240 - 250
Sandstone, light gray, medium and coarse grained, iron stained.	250 - 260
Sandstone, light to dark gray, coarse grained.	260 - 280
Sandstone, reddish brown, fine grained.	280 - 290
Sandstone, dark gray and brown, fine grained (water-bearing zone at 305-309 ft).	290 - 310
Sandstone, light gray, coarse grained; sandstone, brown, fine grained.	310 - 330
Sandstone, reddish brown, fine grained.	330 - 340
Sandstone, dark gray brown, fine grained.	340 - 350
Sandstone, dark gray, medium grained (water-bearing zone at 360 ft).	350 - 360
Sandstone, brown and reddish brown, fine grained.	360 - 380
Siltstone, reddish brown; sandstone, brown, fine grained.	380 - 390
Sandstone, brown, fine grained.	390 - 400

Table 15.--Geologic logs of selected wells--continued

Well Bk-1130

Description	Depth (feet)
Sandstone, light brown, fine grained, micaceous	40 - 50
Sandstone, light brown, fine to medium grained, iron stained.	50 - 70
Sandstone, light brown, fine grained; sandstone, light gray, medium grained.	70 - 80
Sandstone, reddish brown to gray brown, fine grained; sandstone, pink, coarse grained.	80 - 90
Sandstone, light pinkish gray, coarse grained; sandstone, reddish brown, fine grained.	90 - 110
Sandstone, reddish brown, fine grained.	110 - 120
Sandstone, pinkish gray, coarse grained, calcite veins present.	120 - 130
Sandstone, brown, fine grained; sandstone, light to dark pinkish gray, medium grained (water-bearing zone at 140 ft).	130 - 140
Sandstone, light gray, coarse grained; sandstone, reddish brown, fine grained; siltstone, green-red.	140 - 150
Sandstone, brown and light gray, fine and coarse grained (water-bearing zone at 158 ft).	150 - 160
Sandstone, light gray, very coarse grained.	160 - 170
Sandstone, white, medium to coarse grained; sandstone, gray and brown, fine grained.	170 - 180
Sandstone, dark gray and dark brown, fine grained, micaceous.	180 - 220
Sandstone, dark gray to gray, fine to medium grained.	220 - 230
Sandstone, brown, fine grained, calcite present (water-bearing zone at 232 ft).	230 - 270
Sandstone, brown and gray, fine grained; sandstone, gray, medium to coarse grained (water-bearing zone at 280 ft).	270 - 280
Sandstone, gray, medium grained, sandstone, brown and dark gray, fine grained.	280 - 290
Sandstone, brown, fine to very fine grained; siltstone, brown.	290 - 330
Sandstone, gray brown, fine to medium grained.	330 - 340
Sandstone, gray, fine grained; sandstone, white and gray, coarse grained.	340 - 350
Sandstone, white, light gray, dark gray, medium to coarse grained.	350 - 370
Sandstone, gray-brown, very fine to fine grained. Siltstone, brown (water-bearing zone at 376 ft).	370 - 380
Sandstone, pinkish gray and gray, medium grained; siltstone, brown.	380 - 390
Sandstone, gray-brown, fine grained.	390 - 400

Table 15.--Geologic logs of selected wells--continued

Well Bk-1141

Description	Depth (feet)
Soil; sandstone, reddish brown, fine to medium grained.	0 - 20
Sandstone, brown, fine to medium grained, mica present, some siltstone.	20 - 30
Sandstone, brown, medium grained, mica and clear quartz grains present.	30 - 40
Sandstone, gray with some buff and brown, medium grained, feldspar and mica present.	40 - 50
Sandstone, brown with some buff and gray, medium to coarse grained, calcite coatings.	50 - 60
Sandstone, reddish brown, fine grained.	60 - 70
Sandstone, reddish brown, fine grained; some grayish brown, medium to coarse grained.	70 - 80
Sandstone, reddish brown, fine grained.	80 - 90
Sandstone, brown, fine to medium grained, mica present.	90 - 100
Sandstone, brown and grayish brown, medium to coarse grained.	100 - 110
Sandstone, reddish brown, fine grained.	110 - 120
Sandstone, reddish brown and brown, fine to medium grained, some coarse grained; mica present.	120 - 130
Sandstone, brown, grayish brown, light gray and buff, fine to coarse grained.	130 - 140
Sandstone, light gray and brownish gray, coarse and very coarse grained.	140 - 150
Sandstone, light gray, brownish gray and brown, coarse and very coarse grained, composed of quartz and feldspar.	150 - 160
Sandstone, reddish brown and brownish gray, fine to medium grained, calcite present. Sandstone, light gray, coarse grained.	160 - 170
Sandstone, brown, fine to medium grained, calcite present. Siltstone, brown.	170 - 180
Sandstone and siltstone, brownish gray, very fine to fine grained.	180 - 190
Sandstone, grayish brown and brownish gray, medium grained, calcite present.	190 - 200
Sandstone, light gray, dark gray, yellow, reddish brown, and brown, coarse and very coarse grained, chalcopyrite present.	200 - 210
Sandstone, grayish brown, buff, and red, medium to coarse grained, limestone present.	210 - 220
Sandstone, grayish brown, medium to coarse grained.	220 - 230
Sandstone, grayish brown, fine to coarse grained.	230 - 240
Sandstone, brownish gray, medium grained, calcite coatings present.	240 - 250

Table 15.--Geologic logs of selected wells--continued

Well Bk-1141--continued

Description	Depth (feet)
Sandstone, grayish brown and brown, fine to coarse grained.	250 - 260
Sandstone, light gray to dark brownish gray, medium to coarse grained, calcite present.	260 - 270
Sandstone, grayish brown, light gray and dark gray, fine to coarse grained.	270 - 280
Sandstone, light gray, coarse grained and reddish brown, very fine to fine grained.	280 - 290
Siltstone and sandstone, reddish brown, very fine grained.	290 - 330
Sandstone, reddish brown and dark gray brown, fine to medium grained.	330 - 340
Siltstone and sandstone, reddish brown, very fine grained.	340 - 370
Sandstone and siltstone, reddish brown and bluish gray brown, fine to very fine grained; mica present.	370 - 400