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WATER RESOURCES OF SOUTHEASTERN BUCKS COUNTY, PENNSYLVANIA

By

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CONTENTS

ILLUSTRATIONS

TABLES

INTRODUCTION

This report has been prepared as a contribution to the development of southeastern Bucks County, Pa. It summarizes available information on the water resources of this 90-square mile area and evaluates current supplies. Future development of the area may change both the available quantity and the quality of the water supply. The effective development of the area demands a continuing knowledge of the water used and the potential quantity and quality of water available from both underground and surface sources.

The area is strategically important to a great industrial section of the East. Its eastern boundary is a 26-mile segment of the Delaware River along the extreme southeastern border of Bucks County, Pa. (fig. 1). The present population of the area is about 40,000, including 24,800 in Bristol Borough and Township and 6,770 in Morrisville. The area is traversed by both the Pennsylvania and the Reading Railroads and also by U.S. Highways 1 and 13. These are main transportation routes connecting the great market outlets of Philadelphia and New York. The Delaware River is navigable from Morrisville to the sea. The area is only a short distance upstream from the Port of Philadelphia, which ranks second only to New York as the most important seaport in the United States.

The area is mostly flat, open land 10 to 60 feet above mean sea level. It contains several large industries, concentrated chiefly in the Bristol area (pl. 1). There are also scattered industries in the Morrisville, Langhorne, and Bensalem areas. However, Bucks County retains some of the characteristics of a farming region. Truck farming and gardening are still carried on to a considerable extent. Along Delaware River below Morrisville the mining of sand and gravel is an important industry.

The facts summarized in this report have been accumulated over a period of 25 years or more by Federal, State, and local agencies in connection with investigations for other purposes. Most of the data used in this report have been obtained by the United States Geological Survey in cooperation with the Pennsylvania Department of Forests and Waters, the Pennsylvania Department of Internal Affairs, the Pennsylvania Department of Commerce, and State Planning Board, the City of Philadelphia, the Corps of Engineers, and the Interstate Commission on the Delaware River Basin.

This report was prepared in the Water Resources Division of the U.S.Geological Survey by Jack B. Graham, District Geologist; John W. Mangan, District Engineer; and Walter F. White, Jr., District Chemist, under the general direction of C. G. Paulsen, Chief Hydraulic Engineer.

CLIMATE

Southeastern Bucks County probably has the mildest climate of any area in the Commonwealth. It is in the eastern coastal belt and has a typical maritime climate. Precipitation averages about the same as for Pennsylvania as a whole and is evenly distributed throughout the year. Snow is uncommon before December and after early April. Snow cover may be expected for a total of less than 30 days in any normal year. Hurricanes and tornadoes, although rare, are not unknown. Once every four or five winters a severe glaze storm will occur. Owing to proximity of the ocean, the area has relatively high humidity, averaging about 57 percent for the year. No extremely high or low temperatures occur. For only about one day in the average year is a temperature of 0° F. recorded, and the temperature in summer very rarely will rise to 100° F.

The United States Weather Bureau has maintained a precipitation-temperature station at George School for the past 41 years. George School is 2 miles north of Langhorne and just outside the northwest map boundary of plate 1. It is believed that the following records for George School are representative of the conditions of the area.

Table 1.--Precipitation and temperature at George School

Month	Precipitation (1907-49) Maximum (inches)	Precipitation (1907-49) Minimum (inches)	Precipitation (1907-49) Average (inches)	Average depth of snow (inches)	Average air temperature (1909-49) (°F)
January	7.74	1.34	3.40	7.2	31.2
February	5.85	1.26	2.79	8.2	31.4
March	8.58	.57	3.42	4.4	40.7
April	6.65	1.23	3.52	1.2	50.4
May	8.49	1.17	3.78	.0	61.3
June	9.93	.21	3.80	.0	69.5
July	16.11	.50	4.68	.0	74.2
August	11.84	1.05	4.52	.0	72.4
September	8.72	.35	3.56	.0	66.4
October	7.87	.29	3.13	.1	55.5
November	8.62	.35	3.05	.9	44.1
December	7.17	1.06	3.28	5.4	33.5
Annual	54.28	30.81	42.93	27.4	52.6

SOURCES OF WATER

Precipitation is the common source of essentially all the water contained on the surface or underground. During a typical rain some water runs over the land surface and immediately becomes part of the flow of small streams and of the Delaware River. Part of the water remains on the surface of plants and on the ground and is subsequently evaporated. Still another part enters the soil where it is held for a time and later is used by plants in the process of transpiration. Finally, that part of the rain not thus disposed of seeps deeper through the soil, reaching the ground-water zone. It then begins its slow lateral movement to out-

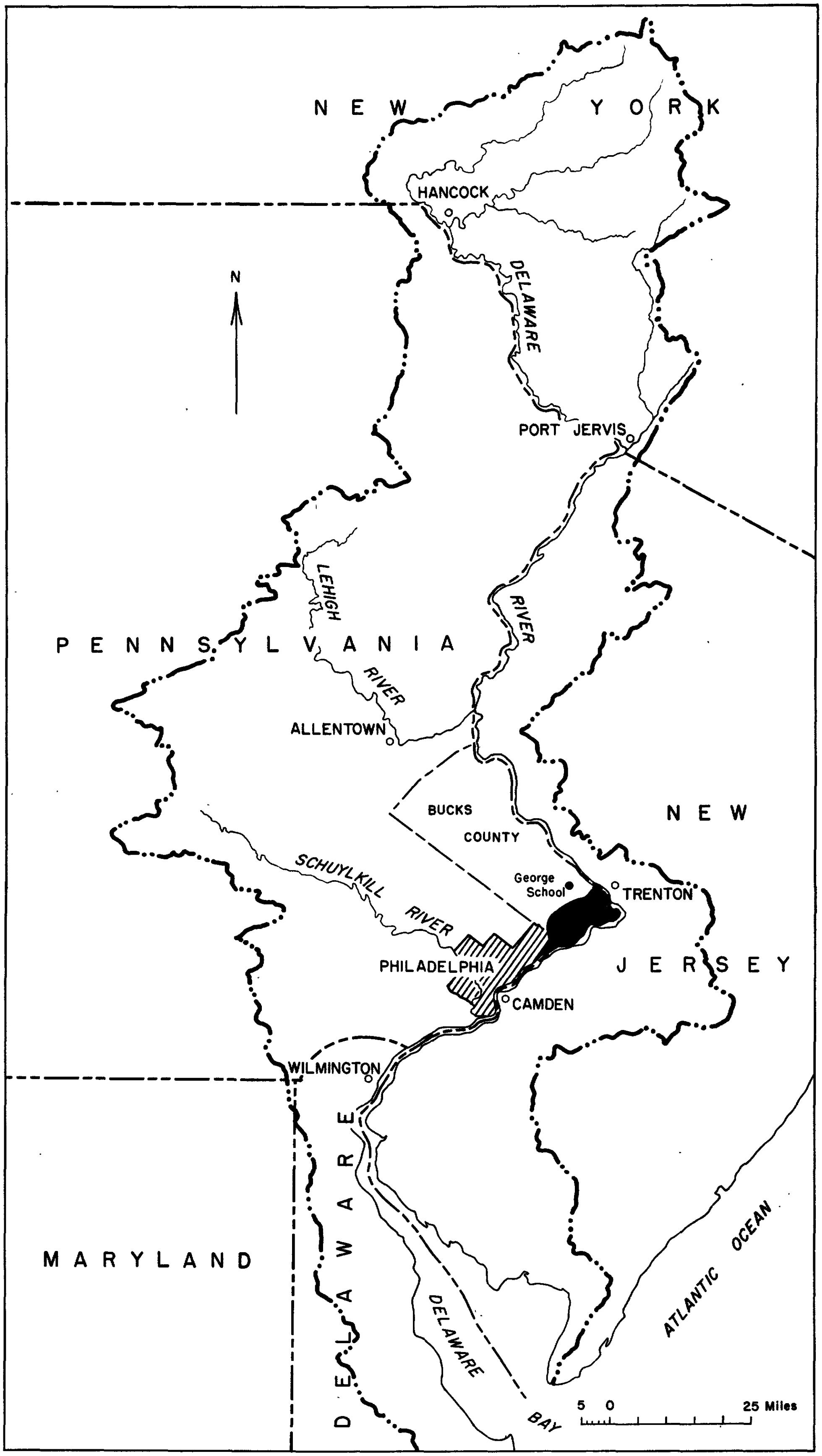

Figure 1.--Delaware River Basin showing the area covered by this report (in black)

lets in streams, springs, and wells. It is the continued discharge of this ground-water storage that keeps creeks and rivers from drying up during prolonged rainless periods. Thus, the surface-water and ground-water resources of southeastern Bucks County, as of most other areas, are very closely interrelated.

The principal sources of water of southeastern Bucks County are the Delaware River, Neshaminy, Poquessing, Mill, and Common Creeks; several small ponds and lakes (pl.1); and ground water. Obviously, (fig.1) little of the flow of the Delaware River in the Morrisville-Bristol area is derived from the nearby area; most of it comes from the upper basin. The Delaware River as it passes the area acts primarily as a conduit for waters coming from other regions. The flow of the river and the chemical character of the water, therefore, are controlled in large part by factors beyond local influences. However, nearly all the other water sources mentioned are closely related to local environmental factors. Almost all the Neshaminy Creek Basin lies within Bucks County, and the basins of both Mill and Common Creeks are entirely within the area covered by this report. Poquessing Creek drainage extends a few miles beyond the southwestern limit of the area. It is probable that essentially all the ground water in southeastern Bucks County comes from precipitation falling within the area. Contrary to a popular belief, the water flowing from the springs and pumped from wells does not come from the Pocono Mountains nor from the upper Delaware Basin. It results from the infiltration of local storm water.

SURFACE WATER

Surface water available within the area of this report is sufficient for all present uses and for all foreseeable future uses. The minimum flow of the Delaware River as it enters the area is many times the present demand of 30 to 35 million gallons a day. In fact, the flow is so great and the river so accessible that, with the exception of Neshaminy Creek, development of the small tributaries within the area is not likely to be economical so long as the flow of the river is maintained and no serious problems of quality are introduced. The various uses of water upstream and across the river in the Trenton N. J., area are not likely to change this situation.

The quality of water throughout the area is generally favorable for most uses without costly treatment. Although waste-disposal practices in recent years have threatened the water supply of the entire lower Delaware Basin, corrective measures are proving effective in reducing pollution. As in most surface waters, the chemical character of the water in the streams in the area varies in response to precipitation and to the variable effect of the soil, vegetation, topography, and use of water in the drainage basin. The Delaware River, and the smaller streams in the area have about the same chemical quality, except where affected by industrial or domestic pollution. In the zone along the river, pollution and ground-water inflow tend to alter the chemical characteristics of smaller streams. In general, however, the chemical quality of most of the surface waters can be expected to be as indicated by the range of concentrations given below.

	Parts per million (except pH)
Dissolved solids......	50-150
Hardness (as $CaCO_3$)..	30-120
Bicarbonate..........	10-70
Sulfate..............	15-50
Chloride.............	1-10
Fluoride.............	.0-.3
Nitrate..............	1-15
Color................	5-30
Iron.................	.05-.3
Silica...............	1-15
pH...................	6.0-8.0

In only a few places have major departures from these ranges been noted. These are principally in the industrialized areas near Morrisville and Bristol and in the lower sections of small streams near the Delaware River. No indication of salinity has been found in the Delaware River or its tributaries in the area covered by this report.

Sediment in the water is not a major problem in southeastern Bucks County. No records are available to show the amount of suspended sediment transported during periods of high runoff. A sediment station on the Delaware River at Morrisville has been in operation only since September 1949. The maximum sediment concentration measured was 550 parts per million (ppm), and for long periods of time the sediment concentration remained below 15 to 20 parts per million. It has been as low as 1 part per million many times.

Surface-water temperatures in the region can be expected to range from 32° F. to nearly 90° F., the monthly mean water temperature being about the same as the monthly mean air temperature.

Delaware River

The Delaware River has a drainage area of 6,780 square miles and a length of about 160 miles about Morrisville, Pa. This area lies in New York, New Jersey, and Pennsylvania. In parts of its course the river serves as the boundary between states. From Morrisville it flows southeast to Bordentown, then generally southwest beyond the area of this report. The channel is broad, having low banks and many low islands. The river averages about 1,000 feet in width at Morrisville and broadens somewhat downstream.

Of the 42 inches of precipitation falling on the watershed of the Delaware River above Morrisville in any normal year, about 24 inches, or slightly more than half of the original precipitation, enters the Delaware River--directly or after having passed through the ground-- and finally runs off to the sea. The remaining 18 inches is evaporated from ground and water surfaces or transpired by vegetation.

Navigation:-- The Delaware River is navigable from Trenton, N. J., to the sea. Congress has authorized a ship channel having a minimum depth of 25 feet and a width of about 300 feet between Allegheny Avenue in Philadelphia and the Marine Terminal at Trenton. However, surveys in June 1949 indicate that depths are considerably less than 25 feet in most channel ranges at the present time. Detailed information concerning depths, widths, ranges, and anchorages can be obtained from the Corps of Engineers, Philadelphia, Pa.

Table 2.--Average monthly and annual discharge of Delaware River at Trenton, N.J. (Morrisville, Pa.)

(Cubic feet per second)

[These figures include diversion above the gage in the Delaware and Raritan Canal, Delaware Division of the Pennsylvania Canal, and the Trenton power race except when it is returned to the river above the gage. They have been adjusted for change in contents in Lakes Hopatcong and Wallenpaupack and in Toronto, Cliff Lakes, and Swinging Bridge Reservoirs. They therefore indicate approximately the natural flow that would have occurred if these developments had not been in operation. In recent years the diversions in the Delaware and Raritan Canal and in the Delaware Division of the Pennsylvania Canal have been small, the sum of mean annual diversions ranging between 10 and 35 cfs. At the present time, water diverted to the Trenton power race is returned to the river above the gage.]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1913	-	-	-	-	-	30,200	24,700	11,600	6,790	2,940	3,100	2,590	-
1913-14	3,860	11,600	10,200	7,600	12,500	20,400	33,700	16,000	5,240	5,900	4,470	3,200	11,300
1914-15	2,030	2,290	4,080	23,400	23,300	11,300	12,300	8,980	5,910	8,550	12,300	6,980	9,980
1915-16	5,540	6,080	10,800	15,600	14,100	13,100	36,200	11,200	11,800	10,300	5,190	3,490	11,900
1916-17	3,500	3,460	8,390	12,600	5,740	21,800	18,500	8,710	16,900	9,170	5,710	3,630	9,870
1917-18	5,020	11,300	4,130	4,620	20,000	26,500	20,700	10,800	7,630	3,350	2,690	3,230	9,900
1918-19	4,400	5,120	8,700	13,000	7,800	22,900	19,400	17,400	6,120	10,600	8,740	5,300	10,800
1919-20	5,520	18,000	13,400	5,200	3,410	35,900	27,600	11,200	7,390	10,100	9,070	7,040	12,800
1920-21	10,700	13,400	23,600	10,500	7,640	33,100	17,100	13,300	3,980	5,790	4,100	2,800	12,200
1921-22	3,330	10,100	16,000	5,590	11,500	28,100	24,200	12,000	16,300	9,480	4,180	4,190	12,100
1922-23	2,990	2,290	2,410	8,780	6,220	28,400	19,600	15,000	5,410	2,710	2,560	3,220	8,290
1923-24	4,010	4,700	15,900	20,500	7,870	11,600	32,600	21,300	7,360	5,280	2,850	2,850	11,400
1924-25	15,900	4,050	6,470	3,600	27,600	17,500	12,900	10,400	5,070	6,150	6,490	5,980	10,000
1925-26	5,410	16,200	14,300	8,890	13,200	19,000	20,500	7,370	5,510	2,820	6,870	6,400	10,500
1926-27	10,500	25,400	10,100	11,500	15,200	27,400	11,800	16,300	9,490	5,550	9,040	10,400	13,500
1927-28	24,600	27,700	29,100	12,600	18,000	13,900	25,100	19,800	20,200	23,900	13,800	10,200	19,900
1928-29	4,620	3,920	5,130	8,210	9,070	27,700	30,100	18,700	6,450	4,040	3,290	3,850	10,400
1929-30	8,170	11,200	12,400	12,800	12,400	20,500	14,900	7,750	9,500	4,100	1,930	2,240	9,810
1930-31	1,610	2,420	3,160	3,730	5,270	14,200	21,800	16,600	9,460	11,800	4,050	2,770	8,090
1931-32	1,750	1,950	4,980	13,800	13,500	10,500	25,000	10,600	7,670	4,200	2,280	1,440	8,100
1932-33	10,200	27,300	8,550	10,300	11,100	21,700	30,900	10,900	5,130	3,460	19,500	22,700	15,100
1933-34	7,827	6,855	8,037	15,540	5,214	15,190	25,840	11,930	6,214	4,600	3,589	11,520	10,210
1934-35	10,870	11,200	20,440	14,190	9,475	22,670	14,780	11,490	5,239	17,370	4,374	4,307	12,260
1935-36	2,970	22,500	14,360	14,570	7,252	63,290	26,370	8,606	6,694	2,808	2,938	2,494	14,610
1936-37	3,663	7,094	13,780	25,080	18,980	12,390	26,210	15,920	9,710	6,154	6,948	5,415	12,570
1937-38	10,960	13,800	12,600	14,580	17,270	15,270	16,380	9,304	9,562	18,220	12,460	18,580	14,050
1938-39	7,845	10,870	26,140	10,160	24,970	25,850	27,970	8,603	3,901	2,414	2,395	1,546	12,640
1939-40	3,567	7,620	5,766	4,515	4,787	18,900	54,450	16,040	11,570	5,377	2,789	9,618	12,030
1940-41	3,889	14,410	14,660	11,500	9,478	12,200	22,620	5,533	5,011	4,498	3,855	1,764	9,095
1941-42	1,503	3,175	7,754	8,285	9,579	23,630	15,410	20,470	12,030	5,769	13,090	11,120	11,000
1942-43	16,860	16,850	18,930	18,530	17,730	26,100	16,630	24,890	11,910	4,170	2,459	1,672	14,740
1943-44	5,175	16,450	4,821	5,880	6,732	20,390	24,840	11,170	6,821	3,261	2,036	3,104	9,197
1944-45	2,510	4,583	10,290	9,948	9,150	38,720	16,570	20,290	14,300	25,660	13,700	12,160	14,900
1945-46	12,940	18,120	14,960	17,360	7,147	24,560	8,446	20,940	17,920	7,753	5,131	3,816	13,320
1946-47	5,547	4,307	4,409	12,680	11,820	19,820	27,190	31,180	14,030	19,990	8,435	4,332	13,670
1947-48	2,406	15,350	7,384	5,567	11,340	35,650	26,650	22,590	13,120	7,552	5,226	2,264	12,920
1948-49	2,296	6,039	11,240	33,390	19,470	13,450	16,740	16,300	5,136	3,315	2,236	2,360	10,970
Maximum	24,600	27,700	29,100	33,390	27,600	63,290	54,450	31,180	20,200	25,660	19,500	22,700	19,900
Minimum	1,503	1,950	2,410	3,600	3,410	10,500	8,446	5,533	3,901	2,414	1,930	1,440	8,090
Mean	6,514	10,770	11,320	12,070	12,110	22,800	22,880	14,360	8,962	7,814	6,051	5,691	11,780

Range of tide:-- The head of tidewater is at the Pennsylvania Railroad bridge at Trenton Falls. Below Trenton and at Bordentown the mean monthly range in tide is 6.7 feet and at Philadelphia, 6.0 feet. Variations in the tidal range are caused principally by the seasonal change in the fresh-water inflow. The effect of fresh-water flow on the range in tide along the estuary decreases downstream.

Salinity:-- Salinity has never been a problem in this area. Even during the extreme drought period in 1931-32, salt water from the sea was never recorded above the Philadelphia-Bucks County line. During years of normal summer flow the salinity front in Delaware River does not advance nearer than 25 to 30 miles below Bristol.

Gaging and Sampling Station:-- A continuous record of the stage and flow of the Delaware River has been obtained at the Calhoun Street Bridge at Trenton, N. J., since February 1913. The datum of the page is 7.77 feet above mean sea level, datum of 1929. In recent years records have also included chemical quality, temperature, and suspended-sediment discharge. Daily

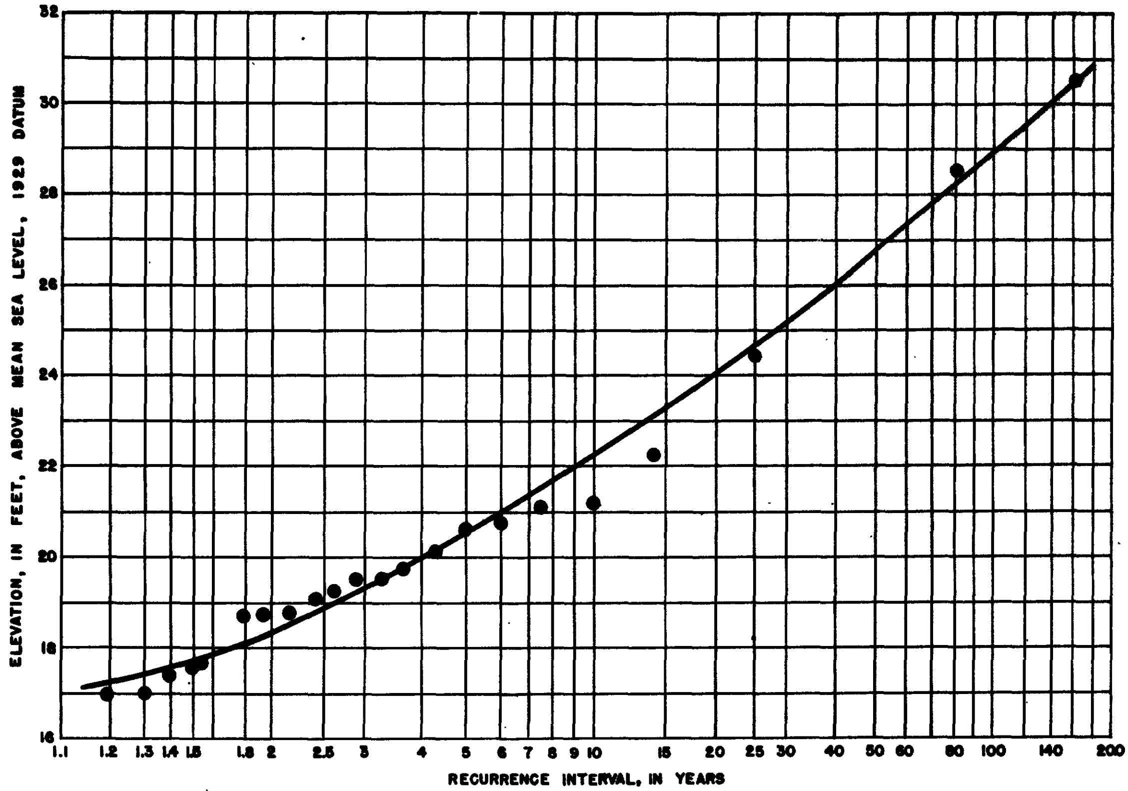

Figure 2.--Flood frequencies on Delaware River at Trenton, N. J.

records of chemical quality and water temperature are available from October 1944 to date. Records of suspended-sediment discharge date from September 1949.

Pertinent hydrologic data collected at the Trenton station follow:

Drainage area: 6,780 square miles.

Average discharge (1913-49):-- 36 years, 11,780 cubic feet per second [1] (including actual flow at the gage plus diversion past the gage in the Delaware and Raritan Canal, Delaware Division of the Pennsylvania Canal, and the Trenton power race).

Monthly discharge: Monthly mean discharge for the period 1913-49 is given in table 2.

Minimum discharge (1913-49) 1,220 cfs, Sept. 18, 19, 1932 (not including approximately 150 cfs diverted in the Trenton power race and the Delaware and Raritan Canal); minimum gage height 0.43 foot, Sept. 30, 1943.

Floods:-- Records of floods in the lower Delaware River go back to October 1786. The greatest flood in this period of 164 years was that of October 1903. The flood caused the inundation of considerable land along the river. From a hydrologic point of view the flood of October 1903 is considered outstanding. However, it cannot be considered so great that it will not recur within this generation. A similar or even greater flood, probably aggravated by storm-raised tides, is easily possible. This should be borne in mind when permanent developments are being planned in the area.

[1] In many Geological Survey reports the term second-feet is used in place of cubic feet per second. One cubic foot per second (cfs) equals 0.646 million gallons per day (mgd).

Crest elevations, in feet above mean sea level (msl), Sandy Hook datum, of the flood of October 11, 1903, from Scudders Falls, N. J., to Philadelphia, Pa., follow:

Miles below Scudders Falls	Location	Crest elevation (feet above msl)
0.0	Scudders Falls, N. J.; Bungalow Colony	44.4
1.6	Yardley, Pa.; highway bridge	39.1
5.2	Morrisville, Pa.; 465 N. Delmarr St.	27.8
8.9	Upper end of Duck Island at canal	18.8
11.0	Bordentown, N. J.; Crosswicks Creek	17.5
13.3	Newbold Island; Potters House	16.1
17.0	Florence, N. J.	13.6
20.1	Bristol, Pa.	10.1
21.3	Burlington, N. J.; waterworks	9.7
39.0	Philadelphia, Pa.; Race Street	7.5

These are sufficient data for a profile of the flood to be drawn for this stretch of the Delaware River.

Crest heights below Morrisville, Pa., were affected by tides. Furthermore, the records were doubtless obtained a considerable distance back from the river and in some instances may not represent the true crests. The records were obtained from private sources and furnished by the Corps of Engineers, Philadelphia, Pa.

The crest heights, elevations, and discharges of all major floods (more than 20 feet above mean sea level) at Trenton, N. J., 1903-50, are given in table 3.

The flood-frequency curve as given in figure 2 was developed from all known authentic data collected at Trenton and from records of the elevations of historic floods that could be referred to the Trenton gage datum. The curve may be used to estimate the probability of the recurrence of a flood of a certain magnitude. It should be recognized that such estimates although based upon available experience cannot have a high degree of accuracy.

Water temperature:-- During the 5-year period ended Sept. 30, 1949, the water temperature of the Delaware River at Trenton, N. J., was measured once each day. The maximum temperature observed was 88° F. Temperatures near the freezing point of water were found in the coldest parts of each winter. The mean annual water temperature was 56° F.--2 degrees higher than the mean annual air temperature at Trenton. Maximum, minimum, and average water temperatures (°F.) and average air temperature (°F.) at Trenton, 1944-49, are given by months in table 4.

For the 5 years ended Sept. 30, 1949, the percentage of time during which the air or water temperature at Trenton equaled or exceeded any given temperature can be determined from the curves shown in figure 3.

Table 3.--Major floods in Delaware River at Trenton, N. J., 1903-50

[Gage height plus 7.77 equals mean sea level elevation, datum of 1929]

Date	Gage height (feet)	Elevation above msl (feet)	Discharge (cfs)
1903, Oct. 11	20.7[a]	28.5[a]	295,000[a]
1904, Mar. 8	22.8[b]	30.6[b]	---
1913, Mar. 28	13.3	21.1	160,000
1914, Mar. 29	12.0	19.8	143,000
1924, Oct. 2	12.5	20.3	144,000
1925, Feb. 13	13.0	20.8	154,000
1933, Aug. 25	12.66[b]	20.4[b]	146,000
1934, Mar. 5	14.20[b]	22.0[b]	---
1936, Jan. 3	16.12[b]	23.9[b]	---
1936, Mar. 13	15.34	23.1	198,000
1936, Mar. 19	16.66	24.4	227,000
1940, Apr. 1	12.85	20.6	152,000
1942, May 24	13.35	21.1	161,000

[a] Estimated [b] Ice Jam

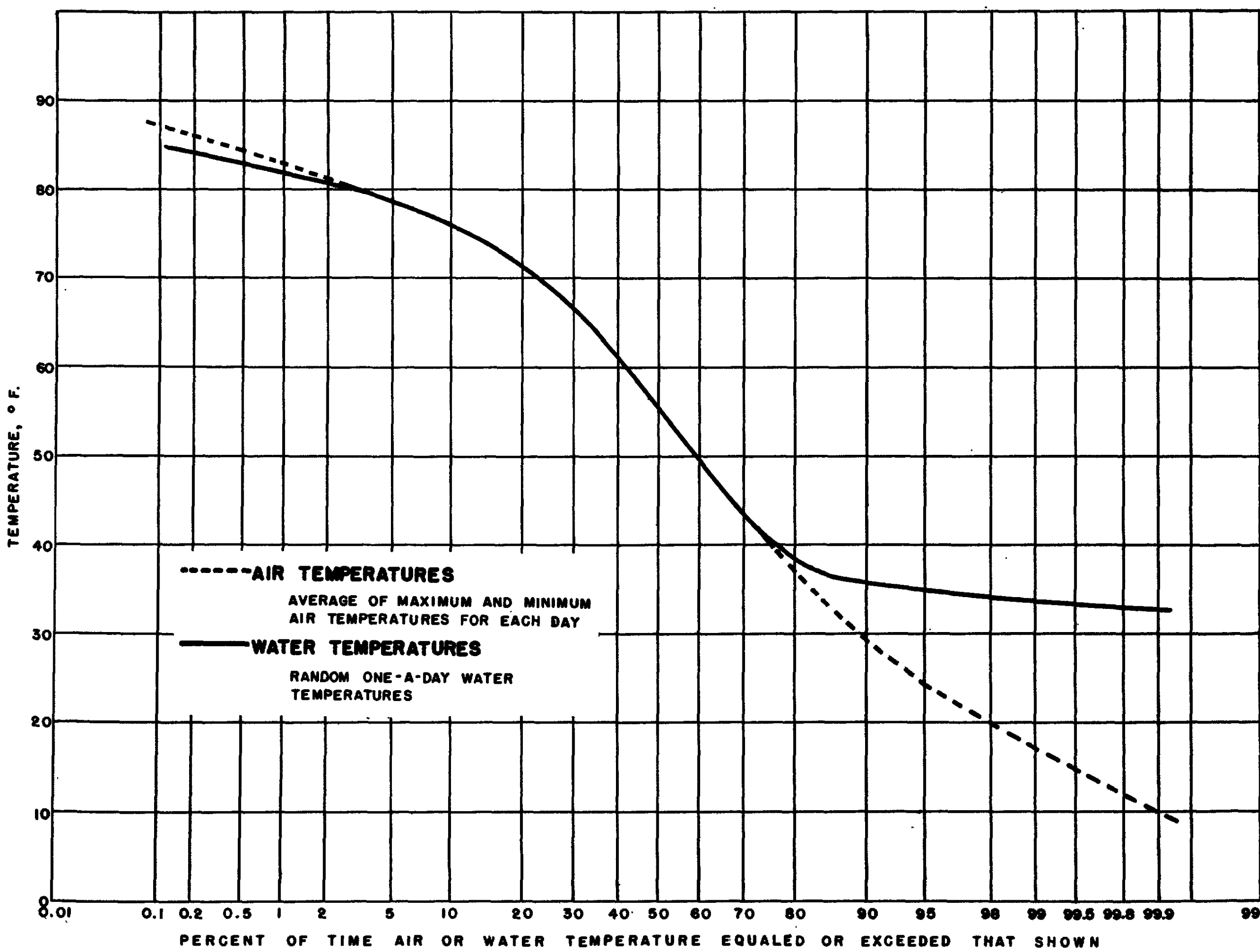

Figure 3.--Air temperature and Delaware River water temperature duration curves, Morrisville, Pa., 1944-49

Table 4.--Air and water temperature, Trenton, N. J.

(Degrees Fahrenheit)

Month	Delaware River			Air Average
	Maximum	Minimum	Average	
January	46	34	37	32
February	45	33	37	33
March	59	36	44	45
April	64	45	54	52
May	72	52	61	61
June	82	56	70	70
July	88	68	77	76
August	84	64	75	73
September	82	59	71	67
October	69	49	59	57
November	66	40	50	47
December	48	33	38	37

Chemical quality of water:-- Chemical analyses of water samples collected daily from the Delaware River at Trenton, N. J. (Morrisville, Pa.), have been made since Oct. 1, 1944. For each month there were three composite samples, consisting of equal volumes of daily samples for the dates 1-10, 11-20, and 21 to end-of-month. Average analyses for the 5 years of record, and analyses for the periods having maximum and minimum concentrations of dissolved solids are given in table 5.

Values for dissolved solids in the daily samples ranged from a low of 32 parts per million on Mar. 19, 1945, to a high of 148 parts per million on Sept. 15, 1949. The percentage of time in the 5-year period that the concentration of dissolved solids in daily samples equaled or exceeded any given concentration is shown in figure 4.

Suspended-sediment discharge.-- Suspended-sediment discharge of the Delaware River at Trenton, N. J., has been determined since September 1949. Water discharge in second-foot-days and suspended-sediment discharge in tons are given in table 6 for the period September 1949 through September 1950. The maximum daily suspended-sediment discharge for the period was 68,700 tons Mar. 30, 1950; the minimum was 9.2 tons Sept. 30, 1950. The maximum daily suspended-sediment concentration was 328 parts per million Dec. 14, 1949; the minimum was 1 part per million on many days.

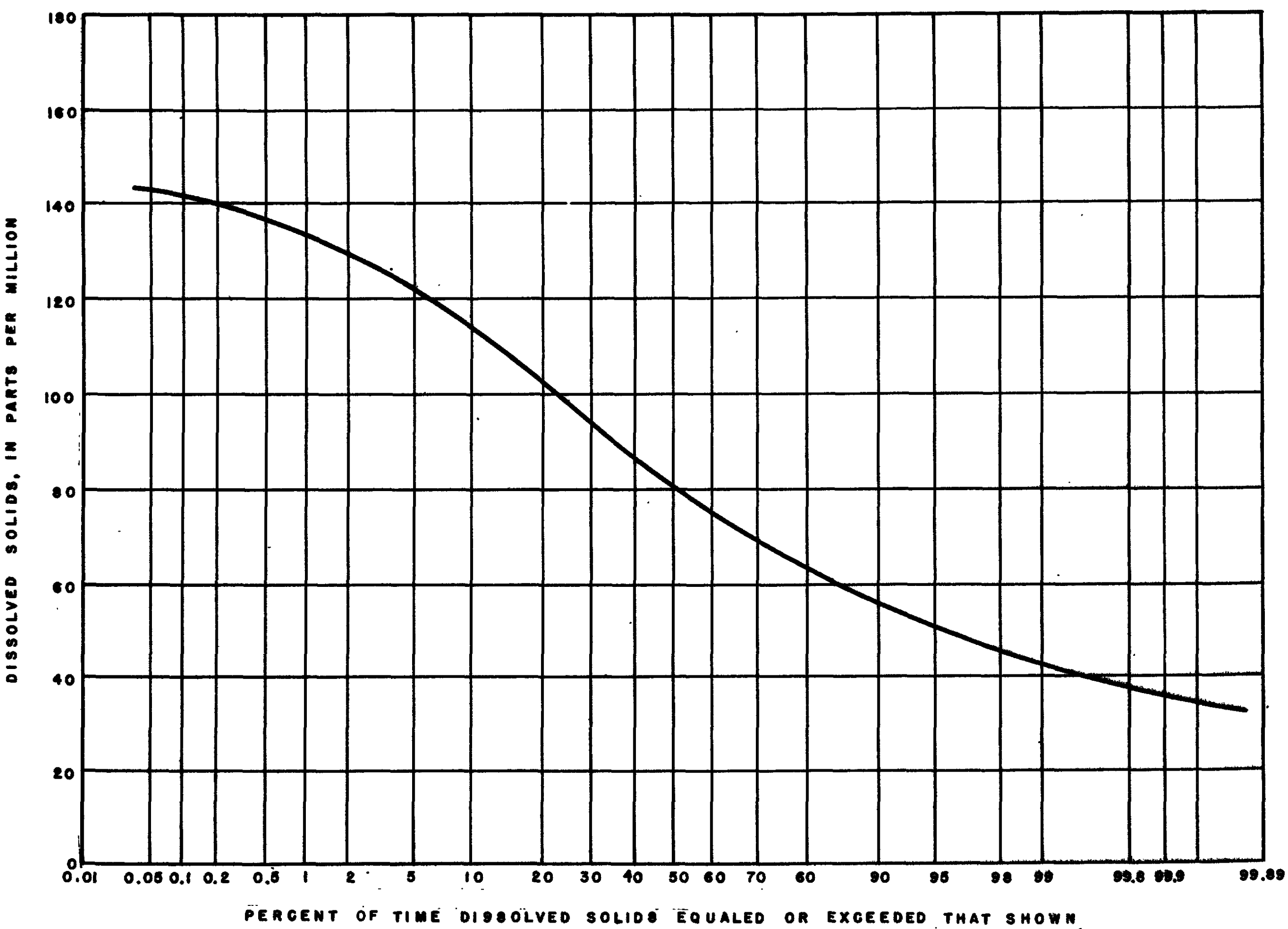

Figure 4.--Dissolved-solids duration curve, Delaware River at Morrisville, Pa., 1944-49

Table 5.--Chemical analyses of Delaware River water at Trenton, N. J. (Morrisville, Pa.) 1944-49

(Chemical results in parts per million)

Date of collection	Average 1944-45	Average 1945-46	Average 1946-47	Average 1947-48	Average 1948-49	Minimum March 21-31, 1945	Maximum September 21-30, 1949
Silica (SiO_2)	3.8	4.0	3.8	--	--	4.2	5.8
Iron (Fe)	.04	.03	.05	--	--	.02	.04
Calcium (Ca)	13	14	14	--	--	7.6	21
Magnesium (Mg)	4.2	4.6	4.4	--	--	2.3	7.3
Sodium (Na)	3.5	4.2 (Na + K)	3.9 (Na + K)	--	--	2.3	8.1 (Na + K)
Potassium (K)	1.3			--	--	.7	
Carbonate (CO_3)	0	0	0	0	0	0	0
Bicarbonate (HCO_3)	33	38	35	40	43	19	66
Sulfate (SO_4)	22	22	23	23	24	14	30
Chloride (Cl)	3.8	4.4	4.4	--	--	1.8	8.2
Fluoride (F)	.1	.1	--	--	--	.1	.1
Nitrate (NO_3)	3.2	3.0	3.2	--	3.1	1.6	3.5
Dissolved solids	74	79	80	--	--	44	129
Total hardness (as $CaCO_3$)	50	54	53	--	--	28	82
Noncarbonate hardness	23	23	24	--	--	13	28
Specific conductance (Micromhos at 25° C)	122	132	127	144	151	72.1	214
Color	13	10	5	4	6	10	4
pH	6.9	7.1	7.0	7.1	7.1	6.7	7.2
Manganese (Mn)	.0	--	--	--	--	.0	--
Water discharge, cfs	14,760	13,420	13,620	12,940	10,970	31,940	2,421

Table 6.--Suspended-sediment discharge, Delaware River at Trenton, N. J., September 1949-September 1950

Month	Water discharge (second-foot-days)[1]	Suspended-sediment discharge (tons)
September 1949	81,560	3,420
October	86,320	1,150
November	139,800	6,350
December	339,000	62,580
January 1950	429,900	16,760
February	372,900	15,380
March	677,700	200,700
April	730,800	85,470
May	420,300	10,830
June	346,500	12,460
July	234,800	8,670
August	152,400	6,730
September	141,600	9,300

[1] One second-foot-day is the volume of water represented by a flow of 1 second-foot for 24 hours. It is equivalent to 86,400 cubic feet or 646,317 gallons.

Delaware Division of Pennsylvania Canal

The Delaware Division of the Pennsylvania Canal was constructed by the Commonwealth of Pennsylvania in 1830 as a link in the proposed waterway system connecting Philadelphia and Pittsburgh. After being operated by many private owners during intervening years, it was acquired by the Commonwealth through gift in 1950. The canal, 60 miles in length, originates in the Lehigh River at Easton and closely follows the Delaware River to Morrisville, Pa. It runs in almost a straight line from Morrisville to its outlet at Bristol.

Since barge traffic was discontinued on it in 1931, pipes have carried the flow of the canal through Morrisville and at many road crossings between Morrisville and Bristol. About 4.5 million gallons a day is diverted from the canal between Morrisville and Bristol for industrial and irrigational uses. Little additional water can be provided for potential water users in the area because of the restricted carrying capacity of the pipes. The Commonwealth has no projects under consideration at the present time to increase the flow in this section of the canal.

Neshaminy Creek

Neshaminy Creek drains an area of 233 square miles, mostly agricultural and almost entirely within Bucks County. About one-tenth of its drainage basin lies within the area covered by this report. The Philadelphia Suburban Water Service Co. diverts about 3 million gallons a day from Neshaminy Creek at Neshaminy Falls. The Philadelphia Suburban Water Service Co. was granted a permit in 1941 by the Water and Power Resources Board to construct a reservoir with a capacity of 650 million gallons on Iron Works Creek at a point half a mile above its mouth. The drainage area above the dam is 6.4 square miles. The permit stipulates that a flow of not less than 1 cubic foot per second shall be maintained below the dam except when the natural flow into the reservoir is less than 1 cubic foot per second; then the natural flow into the reservoir shall be maintained below the dam. Water released from the reservoir flows in the natural stream channels to Neshaminy Falls where it is diverted. This current use of Neshaminy Creek must be taken into consideration, when planning future developments. Although Neshaminy Creek is capable of greater utilization, development probably will be slow because of the lack of favorable sites for dams and storage reservoirs.

Gaging and sampling station:--Information has been obtained from time to time during recent years on the temperature and the chemical quality of Neshaminy Creek water. A continuous record of creek heights and flow has been kept since October 1934. Inasmuch as there were no severe droughts in the period October 1934 to September 1949, an estimate of the low-flow characteristics of the creek has been made on the basis of comparison with Assunpink Creek at Trenton, N. J., for which records have been collected since 1924, and with the North Branch Rancocas Creek at Pemberton, N. J., for which records have been collected since 1921.

Pertinent data on Neshaminy Creek follow:

Location of station: At bridge on State Highway 213, half a mile downstream from Mill Creek and 1.7 miles west of Langhorne, Pa. The datum of the gage is 40.57 feet above mean sea level, datum of 1929, New York-Pennsylvania supplementary adjustment of 1943.

Drainage area: 210 square miles.

Average discharge: 15 years (1934-49), 265 cfs.
28 years (1921-49), 230 cfs (estimated.)

Monthly discharge: Average monthly discharges for the period 1934-49 are given in table 7.

Extremes: 1934-49--Maximum discharge, 24,800 cfs, July 23, 1938 (gage height, 15.94 feet); minimum 5.8 cfs; Nov. 20, 1941; minimum gage height, 0.58 foot, Oct. 4, 1937, Aug. 31 and Sept. 1, 1944; minimum daily discharge, 7.1 cfs, Sept. 24, 1939.

Maximum stage known, 17.3 feet, Aug. 23, 1933 (discharge, 30,000 cfs.)

Probable flow variation:--The probable flow variation of Neshaminy Creek, is shown by the flow-duration curve, figure 5, and the curve showing the discharge available without storage, figure 6. The flow-duration curve shows the percent of time that a specified daily discharge in cubic feet per second per square mile has been equaled or exceeded. It may be treated as a probability curve and used to estimate the probability of occurrence of a specified discharge. Figure 6 shows the longest period of time that the discharge was less than a specified amount.

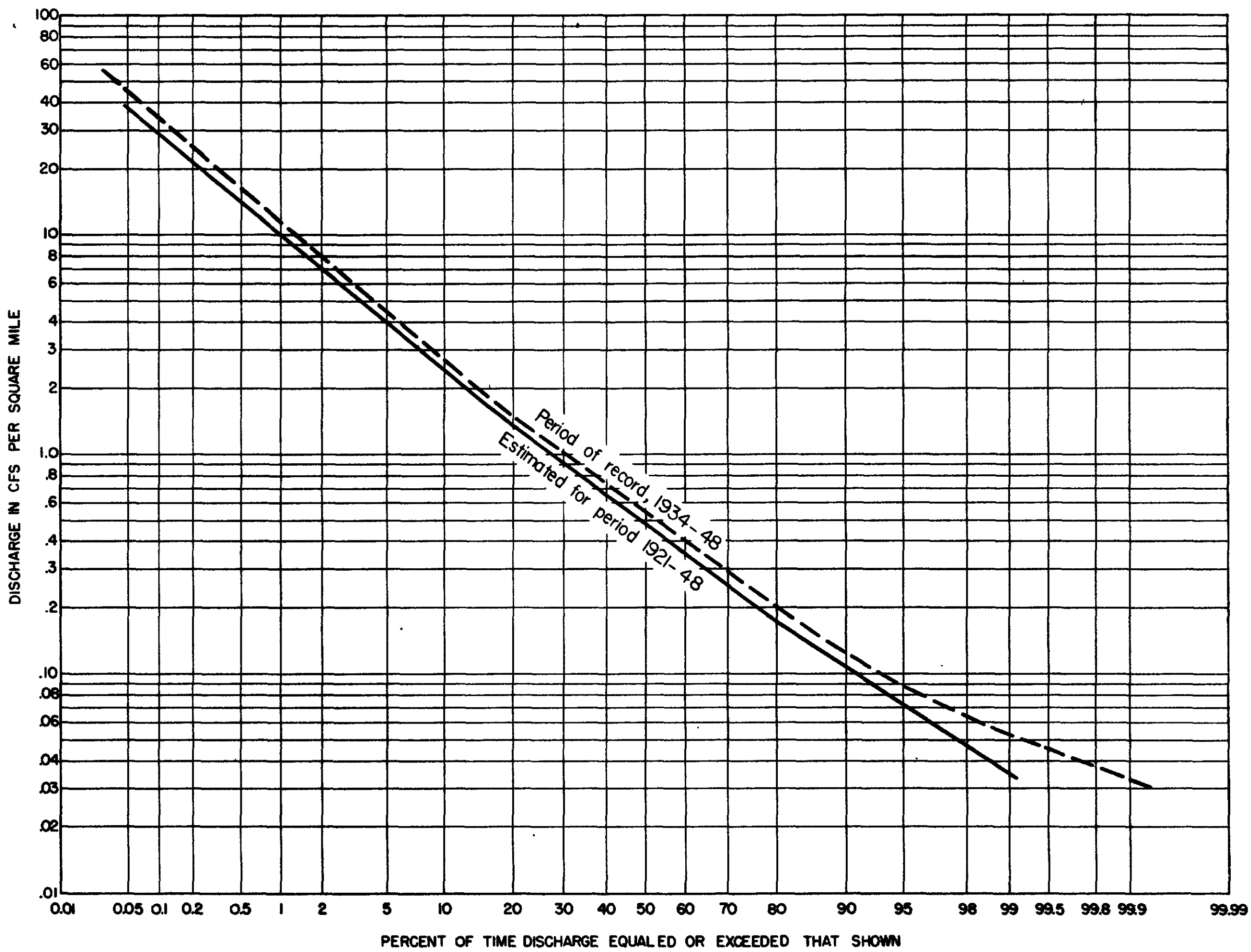

Figure 5.--Flow-duration curve for Neshaminy Creek near Langhorne, Pa.

Table 7--Average monthly and annual discharge of Neshaminy Creek near Langhorne, Pa.

(Cubic feet per second)

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1934-35	228	135	271	306	548	394	177	83.1	58.2	117	105	223	218
1935-36	85.6	411	214	771	349	1,163	410	138	58.6	41.5	59.6	23.8	311
1936-37	36.1	23.2	362	750	402	309	334	221	74.5	64.7	39.8	20.2	219
1937-38	80.6	481	152	308	380	339	149	85.2	289	1,161	174	633	352
1938-39	126	103	625	349	1,074	610	713	140	75.2	33.0	65.8	16.1	323
1939-40	28.0	80.4	47.7	101	352	858	882	264	139	50.4	43.6	92.6	244
1940-41	48.0	379	342	316	296	479	319	55.9	62.5	330	95.8	28.1	229
1941-42	16.4	29.2	120	157	325	562	255	74.1	49.1	78.4	313	57.3	169
1942-43	82.2	214	559	236	571	391	197	336	213	87.1	30.8	16.2	243
1943-44	119	264	107	496	201	668	608	192	124	32.0	15.8	65.5	241
1944-45	25.3	208	261	333	642	383	226	293	157	629	232	348	309
1945-46	111	393	575	336	208	422	151	287	712	443	106	58.5	318
1946-47	44.2	36.7	69.0	241	115	343	278	594	220	75.6	71.6	67.1	180
1947-48	41.3	444	173	283	645	596	421	849	374	149	150	60.1	347
1948-49	34.1	79.0	578	848	593	369	286	240	69.7	127	39.2	82.3	278
Maximum	228	481	625	848	1,074	1,163	882	849	712	1,161	313	633	352
Minimum	16.4	23.2	47.7	101	115	309	149	55.9	49.1	32.0	15.8	16.1	169
Mean	73.7	219	297	389	447	526	360	257	178	228	103	119	265

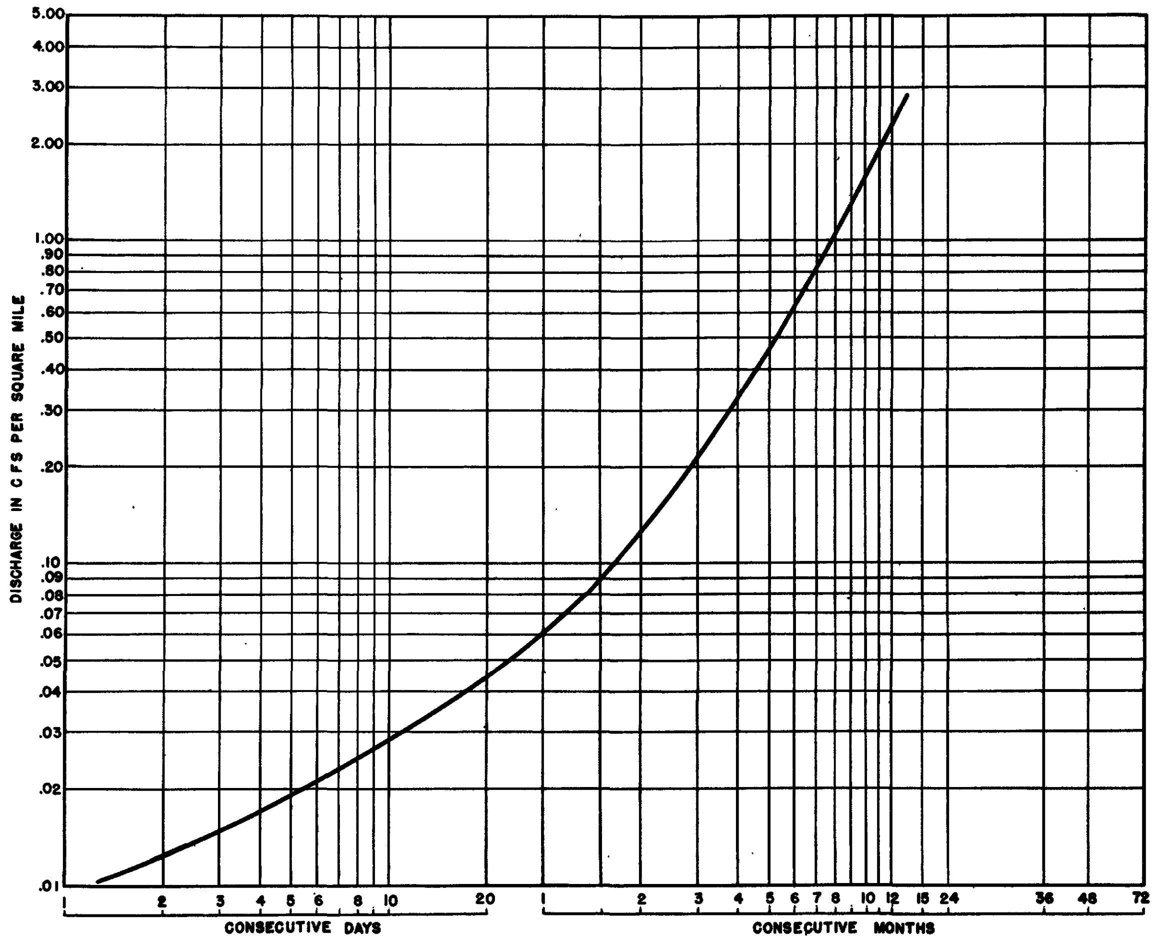

Figure 6.--Discharge available without storage in Neshaminy Creek near Langhorne, Pa.

In addition to giving graphically the general flow characteristics of the stream, these curves are valuable for use in solving problems of plant location and operation. For example, assume that it is desired to locate a manufacturing plant on Neshaminy Creek at a point where the drainage area happens to be 200 square miles. Construction of a storage dam is not contemplated. A flow of 10 cubic feet per second, or 0.05 cubic foot per second per square mile, is required to operate the plant. It is necessary to know the average number of days each year that there will be a shortage of water. Using the curve based on the estimated 1921-48 record (solid line, fig. 5) it is seen that a flow equal to or exceeding 0.05 foot per second per square mile will prevail during 98 percent of the time. The estimated curve for the period 1921-48 is used because that period included extreme droughts and floods and is considered to be more nearly representative of average conditions than the period of actual record, 1934-48. For an average year there would be sufficient water 98 percent of 365, or 358 days, and a shortage for only 7 days. It may be possible to operate the plant for short periods on less than 10 cubic feet per second. However, it is necessary to know the maximum number of consecutive days, even in unusual years, that the flow will be less than 10 cubic feet per second. Figure 6, based on the estimated record for the period 1921-48, shows that the flow of Neshaminy Creek may be expected to be less than 0.05 cubic foot per second per square mile for not more than 24 consecutive days.

Water temperature:--No daily measurements of temperature have been made. However, miscellaneous measurements made from 1944 to 1950 indicate that the stream is at its warmest during July, when a high of about 80° F. may be expected. Slightly lower temperatures can be expected during August. Temperatures ranging from 32° to 80° F. have been measured at the Langhorne station.

Chemical quality of water:--Thirty-five analyses of samples collected from Neshaminy Creek at Langhorne are available for the period from 1944 to 1950. Samples having the lowest and highest concentrations of dissolved solids, as indicated by specific conductance, together with an analysis considered typical of the water in the stream much of the time, are given in table 8.

Other Streams

There are three other streams of significance in the area. They are Mill, Common, and Poquessing Creeks. Their draining areas are 19.2, 11.9, and 21 square miles, respectively. Gaging stations here have not been maintained on these streams.

The most serious drought of record in Bucks County was that of 1930, when a total of only 30.81 inches of precipitation was recorded at George School. No discharge measurements were made of any of the foregoing streams during that critical period. However, the flow of Mill Creek and Common Creek was measured several

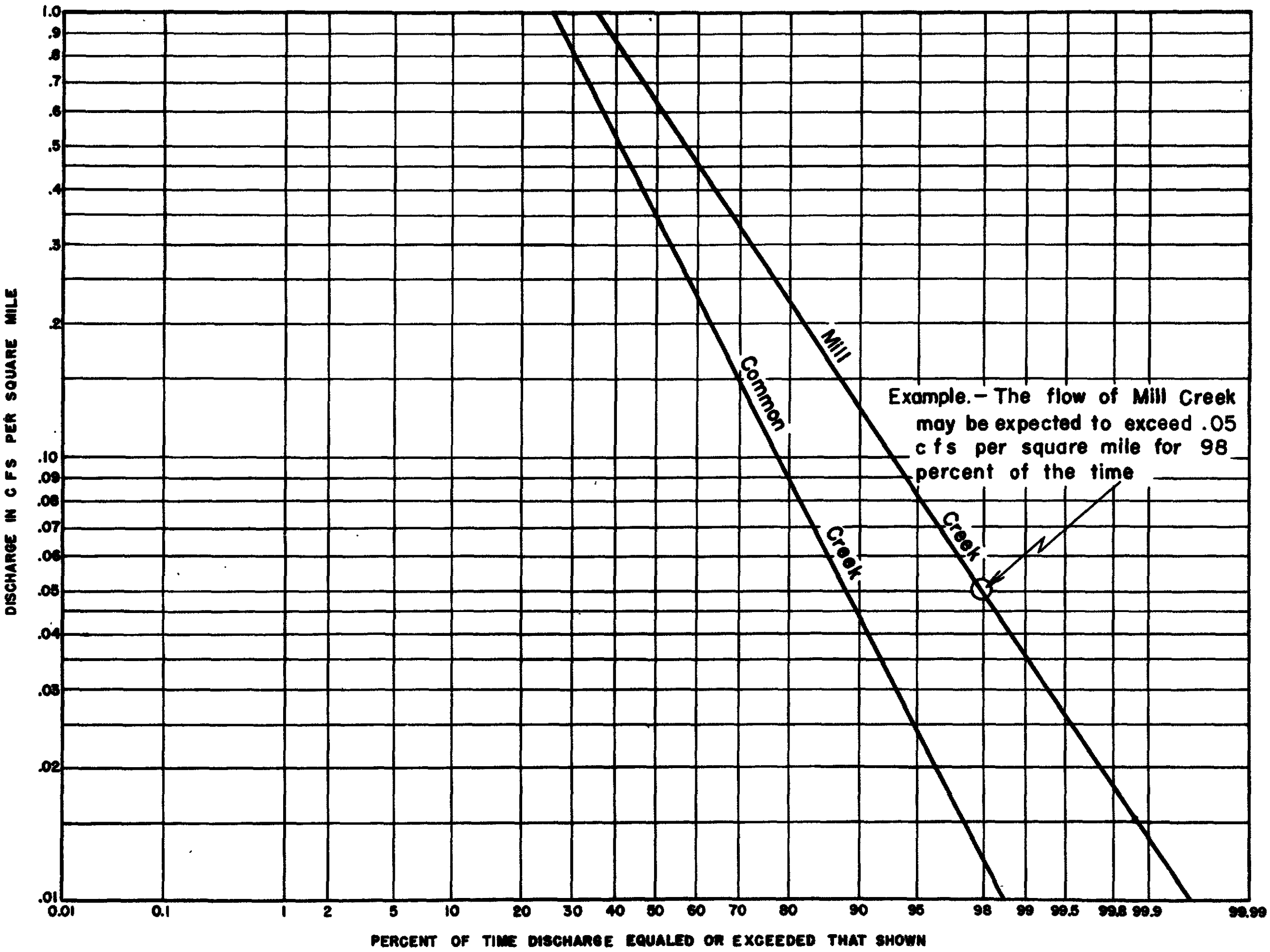

Figure 7.--Flow-duration curves for Mill Creek and Common Creek

Table 8.--Chemical quality of Neshaminy Creek water near Langhorne, Pa.

(Chemical results in parts per million)

Date of collection	Lowest Feb. 19, 1948	Highest Dec. 14, 1949	Typical May 19, 1950
Silica (SiO_2)	---	---	8.4
Iron (Fe)	---	---	.22
Calcium (Ca)	9.6	---	14
Magnesium (Mg)	4.6	---	5.8
Sodium (Na), Potassium (K)	2.8	---	10
Carbonate (CO_3)	0	0	0
Bicarbonate (HCO_3)	16	70	42
Sulfate (SO_4)	23	34	31
Chloride (Cl)	4	17	7.1
Fluoride (F)	---	---	.2
Nitrate (NO_3)	7.6	8.8	5.4
Dissolved solids	---	---	116
Total hardness (as $CaCO_3$)	43	82	59
Noncarbonate hardness	30	---	24
Specific conductance (Micromhos at 25° C)	107	267	174
Color	30	28	26
pH	6.1	7.7	6.9

times during 1950. These discharge measurements have been correlated with continuous discharge records for Neshaminy Creek near Langhorne, Pa., Assunpink Creek at Trenton, N. J., and the North Branch of Rancocas Creek at Pemberton, N. J., in order to estimate the low-flow and other hydrologic characteristics of Mill and Common Creeks.

The average discharge is a measure of the total flow and is therefore equal to the ultimate supply that can be developed from the stream. The estimated average discharges for Mill Creek and Common Creek are 0.9 and 0.6 cubic foot per second per square mile, respectively. The low discharge portions of the flow-duration curves for these streams are shown in figure 7. The maximum number of consecutive days that the discharge may be expected to be less than a given amount is shown in figure 8.. An example of the use of these figures is given with the data for Neshaminy Creek (p.11).

Chemical analyses of water from small streams in the area are given in table 9. Although the analyses doubtless do not represent extremes of concentrations that may be obtained, they probably are typical of the quality of the water available in the streams much of the time.

PLANS FOR THE REGULATION OF THE SURFACE WATERS OF THE DELAWARE RIVER BASIN

The Delaware River Basin and the adjoining territory to which it is economically related have aptly been referred to as the heart of the northeastern section of the United States. About 5 million people reside within the Basin. An

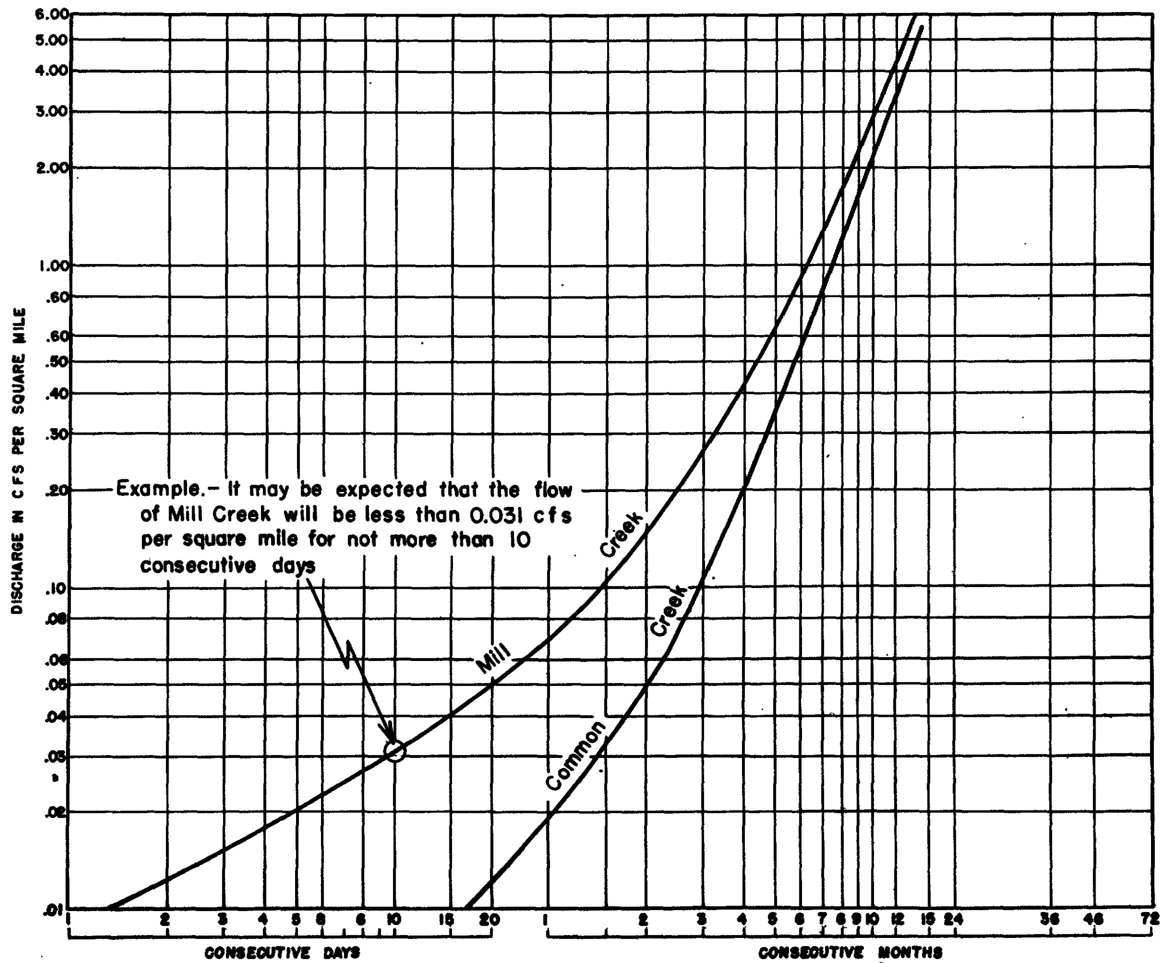

Table 9--Chemical quality of the waters of small streams in southeastern Bucks County, Pa.

(Chemical results in parts per million)

Location	1	2	3	4	5	6	7	8
Date of collection	June 7, 1950	May 4, 1950	June 7, 1950	June 23, 1950	Aug. 16, 1950	Aug. 16, 1950	Aug. 16, 1950	July 28, 1950
Silica (SiO_2)	8.6	---	6.7	7.6	7.6	3.8	3.4	12
Iron (Fe)	.69	---	.81	.14	.16	.28	.17	.20
Calcium (Ca)	8.7	---	9.4	13	17	17	17	12
Magnesium (Mg)	4.2	---	5.0	7.6	9.3	8.7	8.7	4.6
Sodium (Na)	3.2	---	5.8	8.0	4.7	6.0	6.1	11
Potassium (K)	1.5	---	2.1	3.0	3.0	2.6	1.4	2.3
Carbonate (CO_3)	0	0	0	0	0	0	0	0
Bicarbonate (HCO_3)	16	13	11	3	0	50	33	28
Sulfate (SO_4)	20	28	36	61	143	40	50	20
Chloride (Cl)	7.0	7	7.2	9.0	16	11	12	16
Fluoride (F)	.2	---	.2	.2	.1	.1	.1	.1
Nitrate (NO_3)	5.4	3.0	3.9	5.8	.9	.1	.2	13
Dissolved solids	90	---	99	126	228	132	129	128
Total hardness (as $CaCO_3$)	39	36	44	64	159	78	78	49
Noncarbonate hardness	26	25	35	61	159	37	51	26
Specific conductance (Micromhos at 25° C.)	119	112	136	204	354	195	203	180
Color	18	26	13	4	8	8	7	35
pH	6.7	6.7	6.5	4.6	3.75	6.9	6.5	6.9
Water discharge, cfs	13	---	6.6	2.3	---	---	---	12

1. Mill Creek at Magnolia Avenue, Bristol, Pa.
2. Queen Anne Creek near Bristol, Pa.
3. Common Creek at Tullytown, Pa.
4. Common Creek at Tullytown, Pa.
5. Rock Run at Tyburn Road, Fallsington, Pa.
6. Scotts Creek-Penn Manor Lake near Tullytown, Pa.
7. Van Sciver Lake at Bordentown Road near Tullytown, Pa.
8. Poquessing Creek at Philadelphia, Pa.

additional 10 million people, largely in the metropolitan areas of New York City and northeastern New Jersey, are dependent in part upon the development and utilization of its water resources.

Anticipating future needs, the States of New York, New Jersey, and Pennsylvania have individually carried on many studies in the past to develop a plan to utilize the head waters of the basin. It was not until 1949 that these States took definite steps toward an integrated plan for meeting the prospective water-supply requirements of their political divisions and metropolitan areas. During the 1949 legislative sessions, the States of New York, New Jersey, and Pennsylvania passed reciprocal acts directing the Interstate Commission on the Delaware River Basin (Incodel) to be responsible for surveys and investigations to gain this objective.

A full report setting forth its conclusions and recommendations is to be made by Incodel to the Governors and Legislatures of the three States by January 15, 1951. A preliminary report by Incodel states that the first stage of the development should be construction in the upper basin of storage reservoirs of sufficient capacity to satisfy the additional water requirements of northern New Jersey and the New York City metropolitan area for the next 25 years and to maintain a minimum flow of 4,000 cubic feet per second in the Delaware River at Trenton.

GROUND WATER

Ground water occurs in abundance in southeastern Bucks County. Wherever it flows from springs or is pumped from wells it is characteristically clear. Its nearly constant temperature is about the same as the average annual air temperature. It is clear because sediment and other suspended matter settle or filter out as the water slowly moves from the point where it enters the ground toward some lower outlet. The water has a very small temperature range because the earth does not vary much in temperature throughout the year at depths more than a few feet below the land surface.

These properties make ground water desirable, particularly for industrial cooling processes where constant temperatures are necessary. At present, industries and municipalities in the area use about 12 million gallons of water a day during summer and perhaps 7 to 8 million gallons a day during winter, when the demand is least. Most of this water is obtained from relatively shallow wells in sand and gravel near the Delaware River. Many of these wells are capable of yielding several hundred gallons a minute. Only a small part of the ground water used is obtained from springs.

Geology of the Area

The geologic and geographical characteristics of an area, together with its climate, control the occurrence of ground water. The kinds of formations under the land surface and their shape and attitude in relation to one another and to the land surface determine the amount of water held in the ground and its movement from areas of recharge to discharge.

The oldest geologic formations in southeastern Bucks County belong to the pre-Cambrian era generally considered to have ended 500 million years ago. These are consolidated rock formations somewhat similar in physical properties to granite, and are called schist, gneiss, and quartzite. In the Piedmont region of low hills outside the Delaware River Valley these formations lie just beneath the soil cover. At the fall line (see pl. 1) where the low hills (those between 40 and 200 feet above mean sea level) meet the flat valley plain of the Delaware, the rock surface dips beneath a series of clay, sand, and gravel layers. The oldest of these layers of sediment were deposited perhaps 100 to 150 million years ago. The younger sediments were laid down considerably later, within the past million years and during the glacial period. Beneath these layers of clay, sand, and gravel the pre-Cambrian rock surface dips southeast 40 to 60 feet to the mile. At the widest part of the Valley in southern Bucks County the rock surface is generally 100 to 200 feet below the land surface. Land-surface elevations in the Valley are mostly between 10 and 40 feet above mean sea level.

Relation of Geology to Ground-Water Supply

There is a great difference geologically between the hard rocks northwest of the fall line, and the clay, sand, and gravel sediments of the Coastal Plain and lower Delaware River Valley, and there is just as great a difference in the ground-water resources of the two areas. The hard rocks forming the low hills northwest of the fall line and the bedrock surface beneath the Delaware River Valley are not very permeable. Water is present and moves largely in crevices or fractures, produced by earth movements and, in some rocks enlarged by weathering and solution. These openings normally make up only a small percentage of the total mass of the rock. Consequently, the quantity of water that can be stored in such rock is small. No valid methods have yet been devised for predicting, from the surface, the precise location of these secondary openings in rocks and for determining their water-bearing properties in advance of drilling. Experience has shown, however, that more water-bearing openings are likely to be present in these rocks beneath valleys than beneath hills. Drilling is necessary in each case before the yield of a well in such rocks can be determined.

Conversely, the unconsolidated materials, such as the sands and gravels, partly filling the valley of the Delaware River and forming the extensive Coastal Plain, contain innumerable small openings or pores between the grains making up the sediments. Such openings generally provide a much more dependable and larger yield than is common for the hard-rock formations. It is frequently possible to make relatively accurate estimates of the depth to these water-bearing layers, yield, and even temperature and quality of the water at a given site before a well is drilled. Such estimates are based on careful study of records for other wells in the area and on knowledge of the local geology.

Figure 9 is a map of southeastern Bucks County showing areas of low and high yield of wells and areas of present heavy pumping from wells.

A comparison of the average depth and yield of municipal and industrial wells for the Piedmont area and the area of sand and gravel follows:

Water-bearing formations	No. of wells	Average depth (feet)	Yield Average (gpm)	Yield Maximum (gpm)
Consolidated rocks (schist, gneiss, quartzite)	31	241	54	275
Sands and gravels	41	61	320	1,050

Chemical Quality of Ground Water

The small amount of information available indicates that the chemical quality of ground waters within the area varies from place to place. No information is available concerning the variation in chemical quality of any one ground-water source over a period of years. In general, the ground waters have about the same chemical quality as that of streams during periods when the stream flow is unaffected by surface runoff from precipitation. In Falls Township it has been noted that the water from shallow wells is higher than normal in concentration of dissolved solids. This is believed to be the result of repeated application of fertilizer to the land in the area and of poor drainage. The chemical quality of water in shallow wells close to the Delaware River is similar to the quality of river water. The temperature of the ground water where it is unaffected by river infiltration remains fairly constant throughout the year, in the range of 53° to 58° F. It is believed that the water is satisfactory for most uses. However, in a few localities the iron content may be too high to permit use of the water without treatment.

Analyses of water from 24 wells in southeastern Bucks County in the area southeast of the fall line were made in 1950. Those showing the highest and lowest concentrations of dissolved solids, together with five other analyses considered representative of ground-water quality, are given in table 10. All wells sampled yield water from sand-and-gravel aquifers at depths ranging from 20 to 70 feet below the land surface.

Ground-Water Potentialities in the Valley Deposits

Ground-water supplies in sufficient quantity to supply municipalities and to attract industry are confined largely to the sand-and-gravel area southeast of the fall line. Although large quantities of water are being withdrawn from these deposits at a few localities, such as the Bristol municipal well field and at the Rohm and Haas Chemical Co. plant at Bristol, much greater supplies are believed to be available, if properly developed. It is probable that several times the quantity of ground water now being used could be pumped from undeveloped areas in the valley deposits, even ignoring induced infiltration from the river. The broad valley plain is underlain in large part by sand and gravel or sandy soil, which permit rapid infiltration of precipitation to the underground

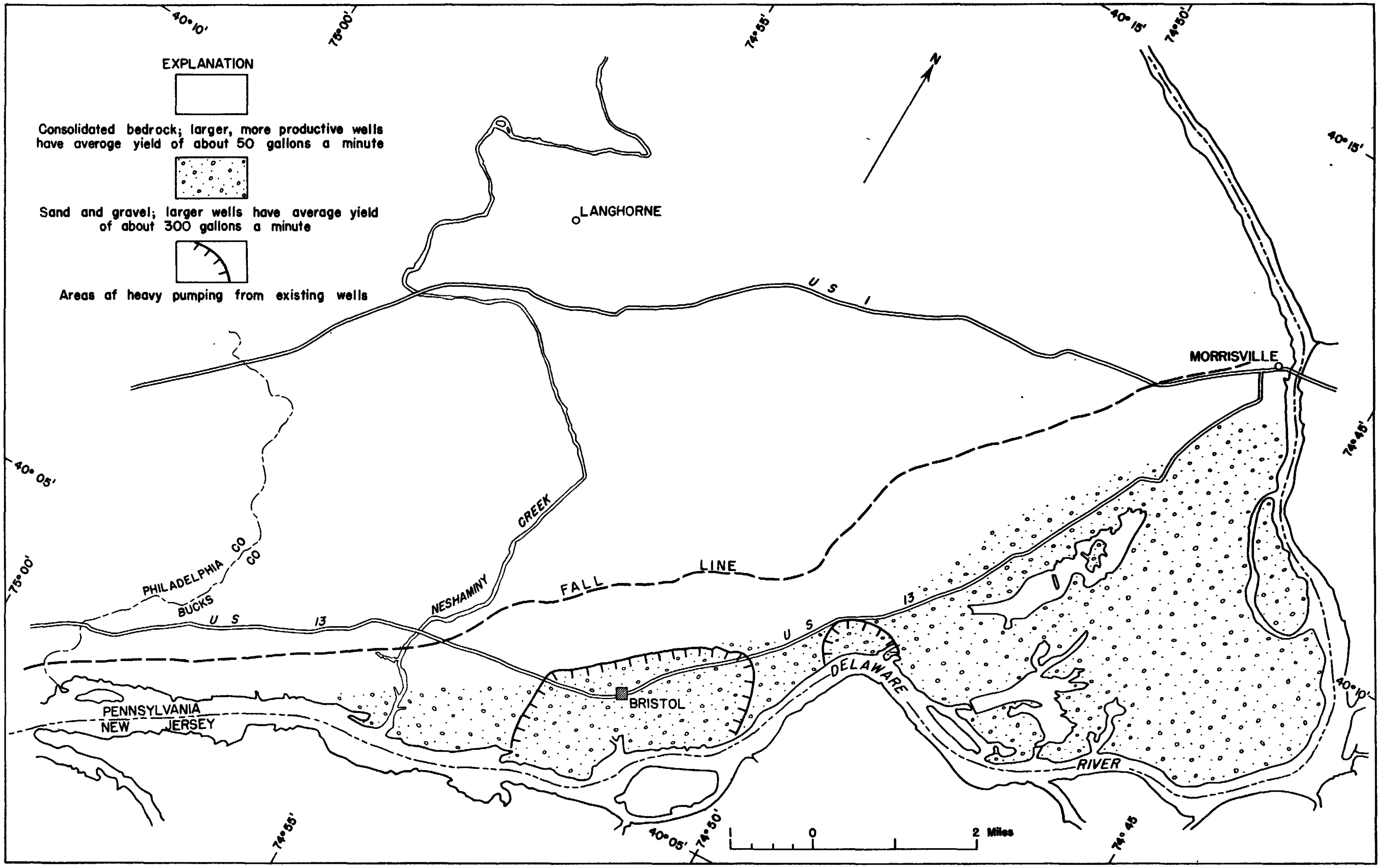

Figure 9.--Areas of high and low ground-water yield and areas of heavy pumping

Table 10.--Chemical quality of ground water in southeastern Bucks County, Pa.

(Chemical results in parts per million)

Location	1	2	3	4	5	6
Date of collection, 1950 ...	Aug. 18	May 25	June 13	June 13	May 25	June 13
Silica (SiO_2)..............	--	12	14	6.9	7.4	9.9
Iron, in solution (Fe).....	--	.03	.11	.04	.06	.10
Iron, total (Fe)...........	--	--	2.0	1.6	--	.43
Calcium (Ca)...............	--	9.4	8.2	22	47	57
Magnesium (Mg).............	--	4.4	7.6	8.5	25	43
Sodium (Na)................	--	4.8	11	5.6	5.9	76
Potassium (K)..............	--	.9	1.8	2.5	3.4	12
Carbonate (CO_3)............	0	0	0	0	0	0
Bicarbonate (HCO_3).........	8	24	8	62	60	53
Sulfate (SO_4)..............	3.3	20	45	37	113	189
Chloride (Cl)..............	5.0	5.2	17	9.9	24	122
Fluoride (F)...............	--	.1	.1	.0	.1	0
Nitrate (NO_3)..............	6.6	5.8	1.2	3.4	42	107
Dissolved solids............	--	77	115	134	334	716
Specific conductance (micromhos at 25° C.)......	72.5	118	183	225	503	1,090
Total hardness (as $CaCO_3$)..	16	42	52	90	220	319
Color.......................	1	6	3	2	3	3
pH..........................	5.9	6.5	5.2	6.5	6.4	6.3
Temperature (°F.)..........	56	56	53	58	56	53

1. Well No. 4 (Bath Wells) at Bristol.
2. King Farms Company well No. 4, 1.9 miles east of Tullytown, depth 65 feet.
3. Starkey-Hollywood No. 1 well, 4.1 miles east of Tullytown, depth about 20 feet.
4. Pennsbury well No. 2, 2.5 miles east of Tullytown, depth about 40 feet.
5. Starkey farms well No. 1, 3.7 miles east of Tullytown, depth 40 feet.
6. Starkey-Berry No. 1 well, 3.8 miles east of Tullytown, depth about 20 feet.

reservoir. One of the largest sand and gravel dredging operations in the Commonwealth is being carried on by the Warner Co. in the middle of the valley plain near Tullytown. Penn Manor and Van Sciver Lakes, which were produced by this dredging, are shown on plate 1. However, not all the valley-plain deposits contain such high percentages of sand and gravel at shallow depth as found on the Warner property. Figure 10 indicates this variability of both depth and lateral extension.

Nevertheless, the 34 square miles underlain by the unconsolidated sediments of the valley plain constitute a large ground-water reservoir essentially filled with water which at present is only lightly developed. The relatively high porosity (perhaps 25 percent) of the sand and gravel make possible the temporary storage of billions of gallons of ground water. The normal volume of water stored in Van Sciver and Penn Manor Lakes, comprising a total area of 1.42 square miles, is approximately 1,150 million cubic feet, or nearly 9,000 million gallons.

In 1948 the Geological Survey made a geophysical study of the sand-and-gravel areas in order to ascertain the thickness of the sediments and to establish in general terms the relative amounts of sand, gravel, and clay. Figure 11 is a map showing, by contours, the configuration of the floor, as determined from the geophysical survey and data on borings and wells. The thickness of the unconsolidated sediments can be computed as the difference between the surface altitude at any one point and the corresponding bedrock surface altitude as shown by the contours.

A striking feature of the geology of the area is the valley-like depressions in the bedrock shown in figure 10. These depressions are the result of prehistoric river erosion. The identification of former river channels which are filled with sands and gravels is of practical importance, for such areas normally contain the greatest thickness of the most permeable material and consequently provide the greatest yields to wells.

Water levels in wells and lakes, except where lowered locally by heavy pumping, generally are between 5 and 20 feet below the average land surface, and are roughly at river level. The ground-water surface slopes gently toward the river except in time of flood. The river-surface altitude is the controlling factor influencing ground-water levels. The saturated thickness of the sands, gravels, and clays may be approximated at any point by subtracting the altitude of the bedrock surface shown in figure 11 from the altitude of the river surface.

Possible Use of Wells for Developing Surface-Water Infiltration

In many areas throughout the country, where perennial streams are underlain by highly permeable materials, the use of wells for inducing infiltration from the river has been found practical. This procedure has been particularly successful in the Ohio River Valley, a valley cut in bedrock and then partially filled with permeable sand and gravel deposits originating in the glaciated headwater areas. The geology of the shallow sand and gravel materials in southeastern Bucks County indicates a similar

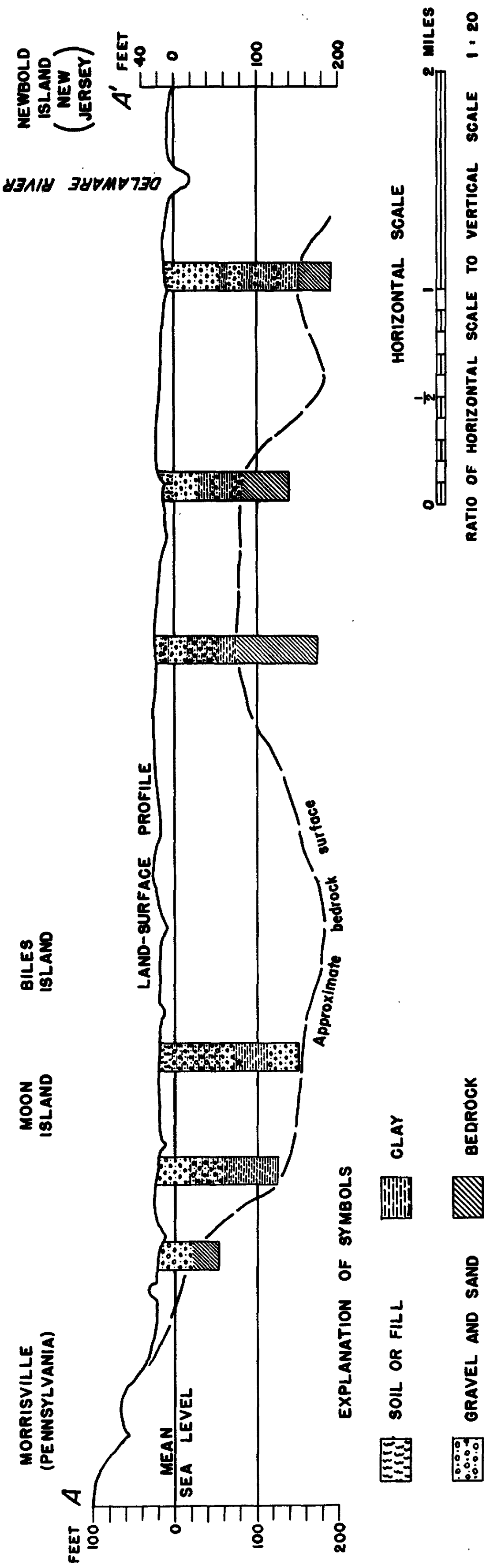

Figure 10.--North-south geologic section from Morrisville, Pa., to the Delaware River near Newbold Island, N. J.

history and equally favorable ground-water conditions.

The Delaware has 26 miles of frontage in the area. It is probable that along parts of this frontage the permeability of the river bed and of the sediments near the river is great enough to permit rapid inflow of river water to wells near the river's edge. In order to induce such infiltration it is necessary to reverse the flow of ground water, which normally is from the valley plain to the river. This reversal of flow is accomplished by pumping heavily enough to lower the ground-water surface below river level. As a result of such drawdown, ground water flowing to points of natural discharge in the river will be intercepted by the well, and at the same time water will be caused to move from the river toward the well. Similar favorable conditions exist for inducing infiltration from the lakes in the dredging basins and from the several small tributaries to the Delaware River where they cross its valley plain. The principle of reversing the natural ground-water gradient and inducing infiltration from surface water is illustrated in figure 12. The advantages of such installations are the perennial source of recharge from surface water and a somewhat greater yield than that from wells farther from the source of recharge. Disadvantages of wells relying on induced infiltration are fluctuations in the temperature and quality of the ground water in response to changes in surface-water temperature and quality. The experience with such installations in other river valleys, however, has indicated that wells drilled on the banks or even through the beds of rivers generally yield water having a maximum temperature at least 15° lower than the maximum river-water temperature. Comparison of chemical analyses of the water from such wells and from the adjacent river indicates that, soon after pumping begins, the well water becomes similar in chemical character to the river water. However, all suspended matter is normally removed in the natural filtration taking place between river bed and well. It appears, also that some objectionable tastes and odors are removed from the river water during the filtration process, and that the natural filtration assists in the removal of harmful bacterial organisms.

In addition to the geologic evidence favorable to induced river infiltration, there are hydraulic, chemical, and thermometric evidences that some of the existing wells, particularly in the Bristol area, are fed in part by seepage from the Delaware River. The temperature of one such well has been reported as high as 72° F.; such a temperature could not reasonably be explained by anything other than infiltration of river water. In chemical quality some well waters are very similar to Delaware River water.

WATER LAWS

All agencies or private interests contemplating any development involving natural surface waters should first communicate with the proper State agency at Harrisburg, Pa. The Commonwealth of Pennsylvania has laws that relate to its natural surface waters. The Pennsylvania Department of Forests and Waters and the Water and Power Resources Board have jurisdiction over the construction of dams and other obstructions that might change in any way the course, velocity, or cross section of any stream. They are also empowered to allocate all surface waters for public supply. The Pennsylvania Department of Health and the Sanitary Water Board administer water laws that relate to sanitation and pollution.

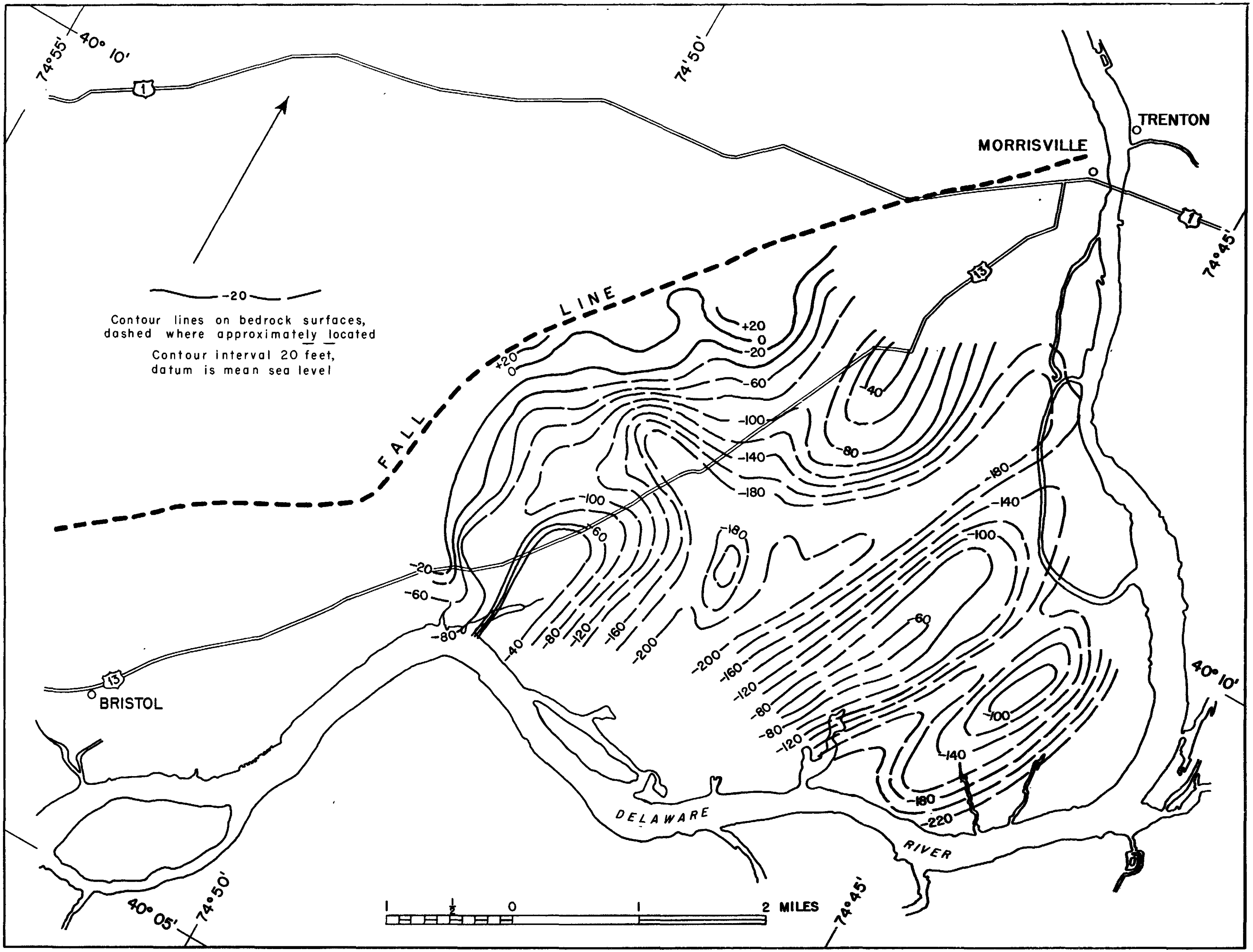

Figure 11.--Configuration of bedrock surface in southeastern Bucks County, Pa.

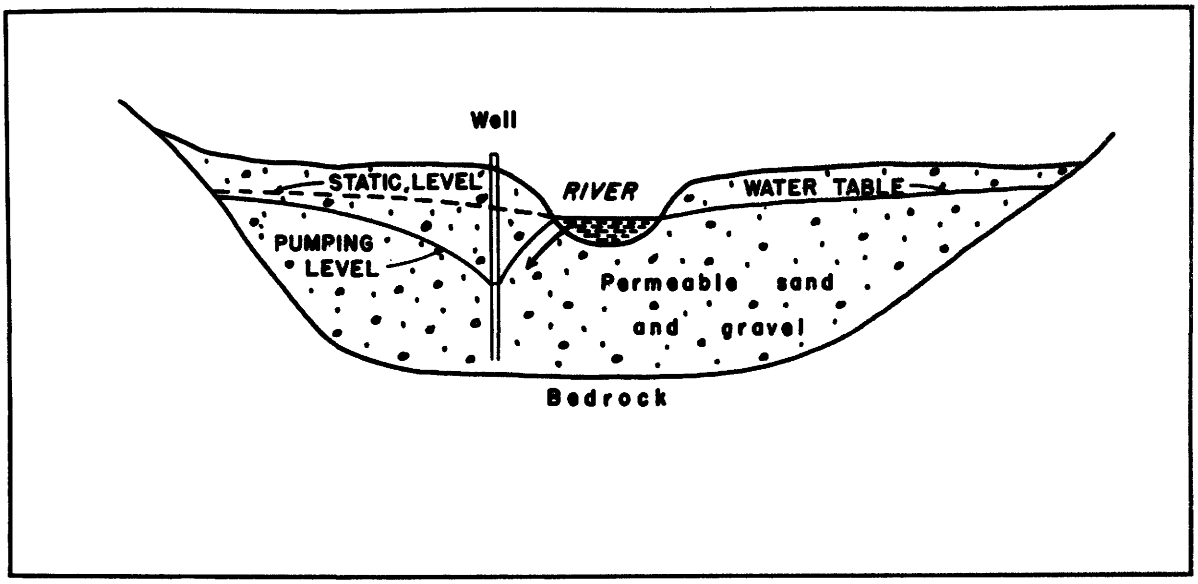

Figure 12.--Schematic cross section of a river valley showing infiltration of river water to a nearby well

The Delaware River has been classified as a navigable stream by the Federal Government. Consequently, dam and bridge projects are also subject to the jurisdiction of the Corps of Engineers. Furthermore, the Delaware River is a state-boundary stream, and water projects of an interstate nature make necessary concurrent legislation in each state.

New Jersey is the only one of the three Delaware Basin States hrving state-wide laws pertaining to ground water. Similar legislation may be enacted soon in Pennsylvania and New York.

SUMMARY

If any region is to attain industrial greatness, water must be available in sufficient quantities and of proper quality to satisfy all domestic and industrial needs. Southeastern Bucks County appears to meet these requirements satisfactorily.

The Delaware River is the principal source of water supply for large industrial users in the region, although several other streams could lend themselves to small withdrawals. The supply of Delaware River water available is far in excess of the present demand. Even with increased industrial development it appears safe to assume that favorable water conditions will continue for many years.

Delaware River water passing the area is of satisfactory quality for most industrial uses but is subject to some pollution. However, this condition should be materially improved before long, now that the Delaware Basin States have undertaken a vigorous campaign to reduce the pollution load of the river by requiring municipalities and industries to install or improve facilities for treating sewage.

The present use of ground water in the area is only a small fraction of the potential supply. Large undeveloped quantities of ground water are present underneath the broad alluvial plain of southeastern Bucks Couhty. Abundant perennial supplies can be developed by wells that are located along the Delaware River so as to induce infiltration from the river.

The chemical quality of the ground water is generally satisfactory except for excessive iron and nitrate content in some lacalities. The ground water is relatively constant in temperature and is cool in the summer, making it well suited for a coolant.

The water resources of an area are continually changing. Construction of reservoirs, the growth of cities and industries, the change in industrial processes, and the addition of new industries all affect the quantity and quality of water available. Reduction of domestic and industrial pollution improves the quality of the water. The U. S. Geological Survey and its cooperating agencies are continually collecting hydrologic data to permit evaluation of current water conditions within the area.

SOURCES OF ADDITIONAL INFORMATION

Inquiries relating to current water-resources information may be addressed to the following officers:

Quality of water:

Philadelphia	District Chemist U. S. Geological Survey Building 720 U. S. Naval Shipyard Philadelphia 12, Pa.

Ground water:

Philadelphia	District Geologist U. S. Geological Survey 19th St. and Parkway Philadelphia 3, Pa.

Surface water:

Harrisburg	District Engineer U. S. Geological Survey P. O. Box 421 Harrisburg, Pa.
Trenton	District Engineer U. S. Geological Survey P. O. Box 967 Trenton, N. J.

Topographic maps:	Director U. S. Geological Survey Washington 25, D. C.

More detailed information on various aspects of water resources in southeastern Bucks County may be obtained from the following selected references.

Selected references

Bascom, F., and others, 1909, Trenton folio of geologic atlas: U. S. Geol. Survey Geologic Atlas of the United States, folio 167. 24 folio pp., 2 quadrangle maps, 1 columnar-section sheet.
Describes geology in detail and summarizes the mineral and water resources of the Trenton (30-minute) quadrangle, which includes southeastern Bucks County, with maps of topography and areal geology.

Grover, N. C., 1937, Floods of March 1936, Part 2, Hudson River to Susquehanna River region: U. S. Geol. Survey Water-Supply Paper 799, 380 pp. 49 figs., 12 pls. (Offset.)
Describes flood conditions and related meteorologic and hydrologic data, including bihourly discharges of the Delaware River at Morrisville, Mar. 8 to 25, 1936, and maps of flood conditions for the whole river basin.

Hall, G. M., 1934, Ground water in southeastern Pennsylvania: Pennsylvania Dept. of Internal Affairs, Topog. and Geol. Survey, 4th ser., Bull. W2, 255 pp., 7 figs., 7 pls.
Describes geologic and ground-water conditions by water-bearing formations and by county areas, including data on 15 wells in southeastern Bucks County, and an areal geologic map on a scale of 1 inch equals 6 miles.

Hartwell, O. W., 1929, Surface water supply of New Jersey, to Sept. 30, 1928: New Jersey Dept. of Cons. and Devel., Bull. 33, 301 pp., 11 pls.
Contains daily discharge records, including the Delaware River at Morrisville, 1913-28, and photograph of the gaging station.

Hartwell, O. W., 1936, Surface water supply of New Jersey, Oct. 1, 1928 to Sept. 30, 1934: New Jersey Water Policy Comm. Special Report 5, 253 pp., 8 figs. (Offset.)
Contains daily discharge records, including the Delaware River at Morrisville, 1928-34, and graph showing daily discharge during 1932.

Hartwell, O. W., 1944, Surface water supply of New Jersey, Oct. 1, 1934 to Sept. 30, 1940: New Jersey Water Policy Comm. Special Report 9, 444 pp., 4 figs. (Offset.)
Contains daily discharge records, including the Delaware River at Morrisville, 1934-40.

Malcolm Pirnie Engineers, and Albright and Friel, Inc., 1950. Report on the utilization of the waters of the Delaware River Basin for the Interstate Commission on the Delaware River Basin, 154 pp., 19 figs., 37 pls.
Describes needs of, problems of, and detailed project recommendations for the river basin, based primarily on increasing the minimum flow of the Delaware River at Morrisville to at least 4,000 cubic feet per second, and at the same time providing larger water supplies for the basin states.

Mangan, J. W., 1940, Natural water losses from Pennsylvania drainage basins: Pennsylvania Dept. of Forests and Waters, 73 pp. (Offset.)
Includes summary of annual precipitation, runoff, and water loss of that part of Delaware River Basin that is upstream from Morrisville, 1921-39, and of Neshaminy Creek upstream from Langhorne, 1935-39.

Mangan, J. W., 1946, Temperatures of natural waters in Pennsylvania: Pennsylvania Dept. of Forests and Waters, 222 pp.
Contains daily temperatures of the Delaware River at Morrisville and 40 temperatures of Neshaminy Creek near Langhorne, during water year 1944-45.

Pennsylvania Dept. of Forests and Waters, Stream flow records of Pennsylvania, issued at intervals of 1 to 4 years for water years 1921-22 to 1940-41.
Contains daily discharge records, including the Delaware River at Morrisville, 1922-41, and Neshaminy Creek near Langhorne, 1934-41.

Pennsylvania State Planning Board, 1947: Industrial utility of water in Pennsylvania, chemical character of surface water, 1944-46, Pub. 17, 172 pp., 9 figs.
Contains chemical analyses of composites of daily water samples from the Delaware River at Morrisville, water years 1944-45 and 1945-46, and four analyses of water from Neshaminy Creek near Langhorne.

Pennsylvania Water Supply Commission, 1917, Water resources inventory report, Part 3, Gazetteer of streams, 657 pp., 20 pls.
Summarizes natural, hydrographic, and artificial features of each of 644 principal streams, including the Delaware River and Neshaminy Creek, and also the names and drainage areas of all minor streams.

Regional Planning Federation of the Philadelphia Tri-State District, 1932, Regional plan of the Philadelphia tri-state district, 589 pp., profusely illustrated.
Describes all phases of regional planning, including water supply and sanitation, for

the region consisting of New Castle County, Del.; Mercer, Burlington, Camden, Gloucester, and Salem Counties, N. J.; and Bucks, Montgomery, Philadelphia, Chester, and Delaware Counties, Pa.

U. S. Coast and Geodetic Survey, issued annually, Current tables, Atlantic Coast, North America.
Gives predicted times of slack water and times and velocities of maximum strength of current, including such data for the Delaware Bay entrance and conversion factors for tidal locations along the river as far upstream as Bristol.

U. S. Coast and Geodetic Survey, issued annually, Tide tables, Atlantic Ocean, and Tide tables, east coast, North and South America.
Gives predicted times and heights of high and low tides, including such data for the Delaware River at Philadelphia and conversion factors for other tidal locations along the river as far upstream as Morrisville.

U. S. Geological Survey, issued annually (see below), Surface water supply of the United States, Part 1, North Atlantic slope basins. (Offset.)
Contains daily discharge records, including the Delaware River at Trenton, N. J. (Morrisville, Pa.) 1913-47, and Neshaminy Creek near Langhorne, 1934-47:

Water year	Publication	Water year	Publication
1913-22	W.S.P. 541	1934-35	W.S.P. 781
1922-23	561	1935-36	801
1923-24	581	1936-37	821
1924-25	601	1937-38	851
1925-26	621	1938-39	871
1926-27	641	1939-40	891
1927-28	661	1940-41	921
1928-29	681	1941-42	951
1929-30	696	1942-43	971
1930-31	711	1943-44	1001
1931-32	726	1944-45	1031
1932-33	741	1945-46	1051
1933-34	756	1946-47	1081

U. S. Geological Survey, Quality of surface waters in the United States in 1946: Water supply Paper 1050 (in press).
Will contain chemical analyses of the Delaware River at Morrisville, 1946.