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WATER RESOURCES OF THE MAHONING RIVER BASIN, OHIO

WITH SPECIAL REFERENCE TO THE YOUNGSTOWN AREA

By W. P. Cross, M. E. Schroeder, and S. E. Norris

UNITED STATES DEPARTMENT OF THE INTERIOR
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GEOLOGICAL SURVEY
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BASED ON DATA COLLECTED IN COOPERATION WITH THE
DIVISION OF WATER, OHIO DEPARTMENT OF NATURAL RESOURCES
AND
PITTSBURGH DISTRICT, CORPS OF ENGINEERS, U. S. ARMY

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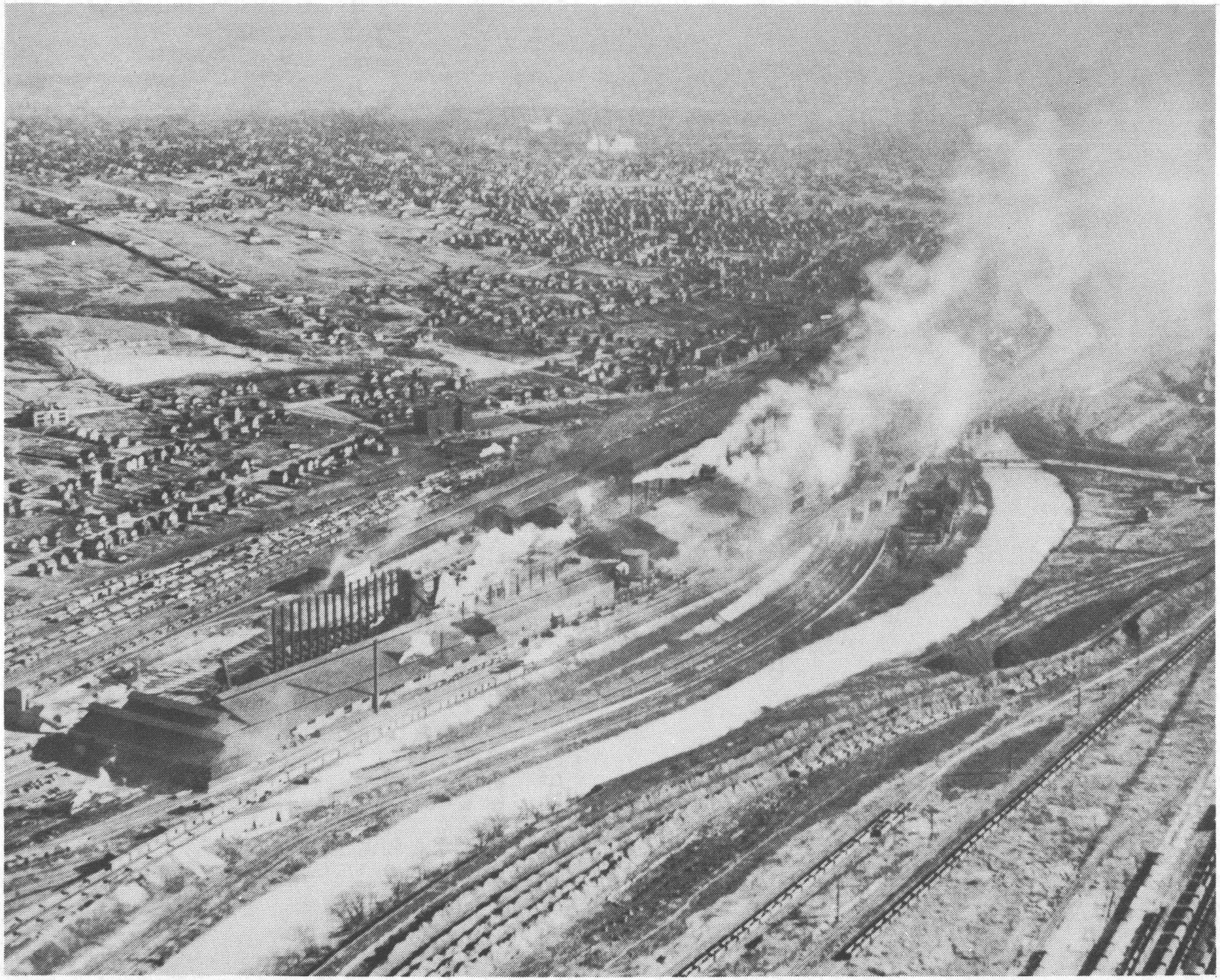

Plate 1. -View of industrial development along the Mahoning River at Youngstown (Courtesy of Youngstown Vindicator, Youngstown, Ohio).

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WATER RESOURCES OF THE MAHONING RIVER BASIN, OHIO

WITH SPECIAL REFERENCE TO THE YOUNGSTOWN AREA

INTRODUCTION

Purpose

The purpose of this report is to summarize the available information on water for the Youngstown area that will assist with the further proper development, control and use of the water resources of this industrial region. Shortage of water for industrial use, gross pollution, high temperature of river water and danger of floods present serious water problems to the Youngstown area. Plate 1 shows a view of the industrial development along the Mahoning River in Youngstown. Approximately 11 percent of the Nation's steel producing capacity is in the Mahoning River valley, from Warren through Niles and Youngstown to the Pennsylvania-Ohio State line. The population of this heavily industrialized area is about one-third of a million. The Mahoning River is used for domestic and industrial water supply as well as for disposal of sewage and industrial waste. The river below Youngstown is reported to be among the worst polluted streams in the United States. High temperatures of the river water, sometimes as great as 120 F, combined with low volumes of flow and gross pollution, constitutes a critical water problem. Added to this is the danger of floods which is accentuated by channel constrictions. Although the four reservoirs that have been constructed in the Mahoning River basin since the disastrous flood of 1913 provide some degree of flood protection, a storm of cloudburst proportions, particularly in uncontrolled areas, might be a crippling blow to a vital part of the United States industry.

Many plans have been considered for the Mahoning River valley to provide flood control, low-water regulation, temperature and pollution abatement, and transportation by canal from the Ohio River to Lake Erie. Despite many technical and related reports on these subjects, the several interrelated water problems have been only partially solved. The available information on water resources is summarized in this report. Other important aspects, such as the consideration of costs and benefits, must also be carefully studied but are beyond the scope of this report. References are made to sources of information throughout this report, and the appended selected bibliography lists all of the more important of the many previous studies that have been published.

Acknowledgments

This report is one of a series concerning water-supply conditions in certain selected areas of strategic importance and is intended to provide information of value for national defense and related purposes. These reports are sponsored by and prepared with the guidance of the Water Utilization Committee in the Water Resources Division of the U. S. Geological Survey, which is under the general supervision of Carl G. Paulsen, Chief Hydraulic Engineer.

The factual and interrelated information as summarized in this report have been accumulated during a quarter of a century by Federal, State, and local agencies as well as by private organizations in connection with the reports and investigations for water developments in the Mahoning River valley.

Some of the basic water-resources data used in this report have been collected by the Geological Survey in cooperation with agencies of the State of Ohio and the Pittsburgh District, Corps of Engineers. Other data and information have been taken directly from technical reports of the Corps of Engineers, Bureau of Census, U. S. Weather Bureau , U. S. Public Health Service, Ohio Geological Survey, Ohio Department of Natural Resources, and several consulting engineers. These sources of data are generally indicated through bibliographical references which will serve as a guide to principal informants.

However, because of their particular interest and understanding of the problems, several organizations and individuals favored us with their confidence and assistance. Acknowledgments are especially due the Pittsburgh District, Corps of Engineers; Division of Water, Ohio Department of Natural Resources; Mahoning Valley Sanitary District; Mahoning Valley Industrial Council; Ohio Water Service Company; Youngstown Sheet and Tube Company; cities of Alliance, Newton Falls, Warren, and Youngstown; and the Ohio Department of Health for providing specific information and advice in connection with the preparation of this report.

The Illustrations for this report were prepared under the direction of John C. Krolczyk, Ohio Division of Water.

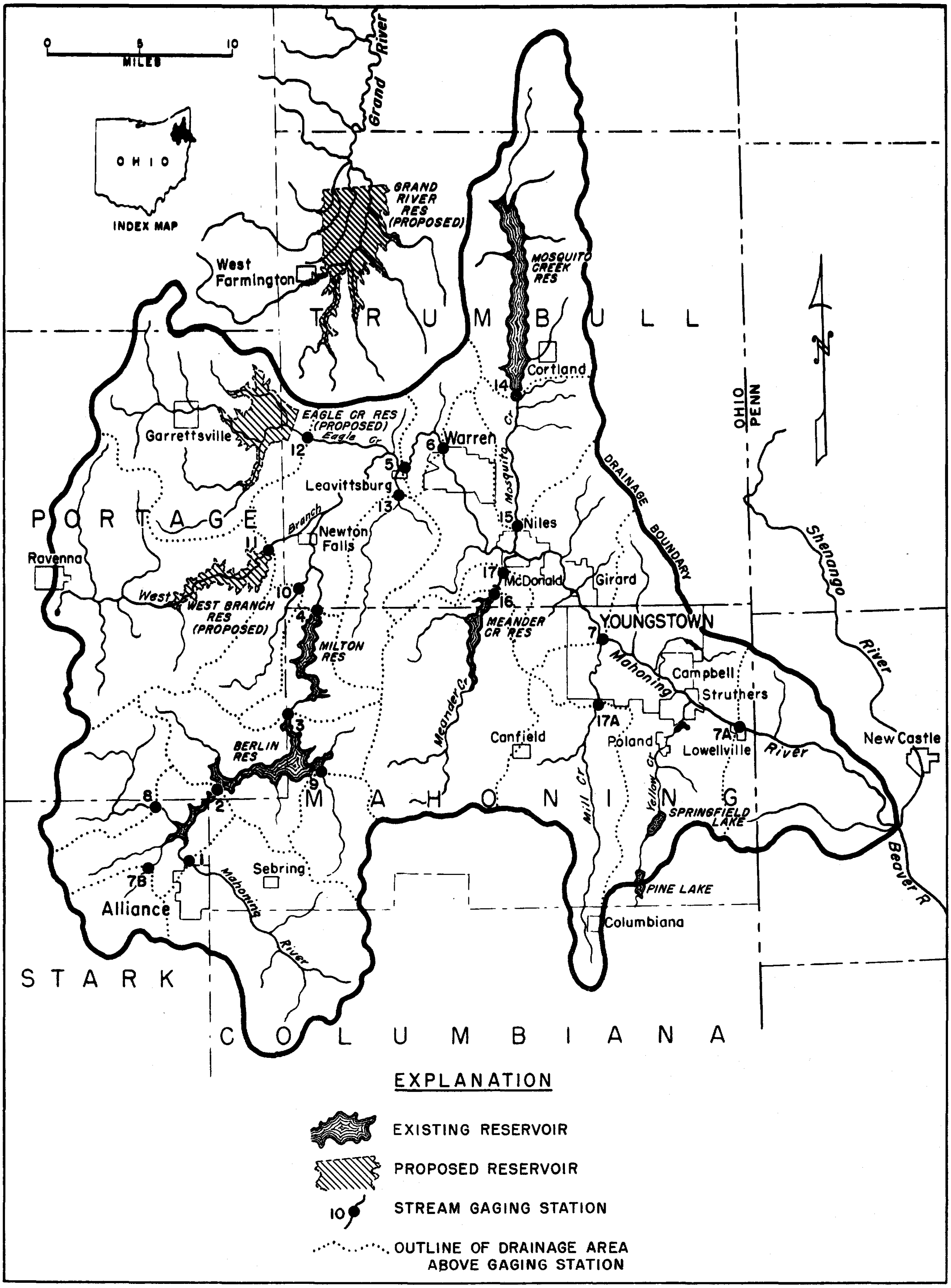

Figure 1.–Map of Mahoning River basin showing principal cities, reservoirs, and gaging stations.

Description of Area

The Mahoning River basin lies in northeastern Ohio (see fig. 1). The source of the Mahoning River is southeast of Alliance, in Stark County, and it flows northeastward to near Warren, where it turns sharply to the southeast, and flows about 40 miles to its mouth near New Castle, Pa. There it joins the Shenango River to form the Beaver River, a tributary of the Ohio. The principal tributaries are the West Branch which empties into the Mahoning River below Newton Falls, Eagle Creek which enters from the west above Warren, Mosquito Creek which flows in from the north at Niles, and Meander Creek empties into it from the south at Niles. The river drains 599 sq mi at Warren, 899 sq mi at Youngstown, and 1,133 sq mi at the mouth. Of the total area, 1,078 sq mi are in Ohio.

Like many Ohio River tributaries, the Mahoning River is steepest in its lower reaches. The average stream slope is 2.2 ft per mile from Milton Dam to Warren, and 2.6 ft per mile from Warren to the mouth. The valley is moderately broad below Niles, averaging about one-half mile in width. Above Niles the valley sides become progressively flatter upstream. In the industrial area below Warren there are a series of low dams, ponding water for cooling purposes. In this reach, particularly in the vicinity of Youngstown, earth fills and dumps occupied by railroads and mills constrict the natural stream channel.

The entire Mahoning River basin is within the glaciated section of the Allegheny Plateau and has the characteristic rolling terrain of glaciated areas. The basin is relatively flat in the north where it merges with the glacial plains; in the southeast it has steeper hill slopes and deeper tributary valleys.

The glaciers blocked northward flowing streams in the basin, reversed their direction of flow, and rearranged drainage patterns. The sharp bend in the Mahoning River north of Warren was caused by a glacier blocking the river which formerly flowed northward past Warren and on through the present Grand River valley.

Climate

Ohio normally has an abundance of precipitation, which is well distributed throughout the year. Serious floods and droughts have not occurred as frequently in the Mahoning River basin as in some nearby areas. Summer temperatures are usually high, but not unduly oppressive; winter temperatures ordinarily are not severe, and snowfall is generally moderate. The average temperature for the State is about 51 F, and the average annual rainfall for the 65-year period ending in 1948 is 37.93 in. (Division of Water, Ohio Department of Natural Resources, 1950).

The average annual precipitation and temperature in the Mahoning River basin is about the same as the average for the State. The average annual precipitation at Warren for the 25-year period ending in 1945, is 37.39 in., and the average temperature for the same period is 50.7 F. An area south of Warren has slightly less than average precipitation. At Canfield the 25-year average annual precipitation is 34.23 in., and the average temperature is 49.4 F for the same period. The fact that the Mahoning River valley is beyond the ameliorating effect of Lake Erie has more effect on the climate than the above averages would indicate. Winter temperatures are on the average the lowest in the State and the average length of growing season between killing frosts in the uplands is about 145 days, shorter than for any other region in Ohio (U. S. Department of Agriculture, 1941). The average depth of snow reported at Warren for the 25-year period ending in 1945 is 49.3 in., or about the highest for the State.

The questions of changing climate, cycles of wet and dry years, and trends are of considerable interest, but unfortunately the available records are too short to give definite answers. In other parts of the country there appears to be a slight trend toward a drier, warmer climate, and in Ohio the temperature records indicate a possible slight trend toward increasing temperatures in winter, but there is no suggestion of a change in precipitation, therefore it must be concluded that our climate is not changing at a significant rate.

Averages of temperature and rainfall are misleading because the records may conceal wide variations from year to year. There are large random variations in temperature and precipitation from year to year throughout Ohio. For example, during the drought period 1930-36 the precipitation at Warren was 18.56 in. less than normal, or an average of 34.74 in. of annual precipitation as compared with the long-period average of 37.39 in. Variations within a year are shown by figures 2 and 3. These charts give the mean temperature and precipitation by months for the station at Warren, and also indicate the variation of the maximum and minimum from the mean. The large range in precipitation is a definite indication that occasional severe floods and droughts are to be anticipated in the Mahoning River basin.

Population

The Mahoning River basin is densely populated, particularly in the vicinity of the heavy industrial and commercial development which flanks the river on both sides from Warren to the Ohio-Pennsylvania State line. The 1930, 1940, and 1950 population of the three counties with major portions of their areas within the Mahoning River basin, and of all urban areas within the basin, are listed in table 1.

The increase in population in the area covered by this report follows the trend throughout the State. Ohio gained about 15 percent in population during the last decade, and Mahoning and Trumbull Counties combined gained about 12 percent. As in other parts of the State, the largest rate of increase was in the rural nonfarm areas. The total urban population of the Mahoning River basin as listed in the table increased from 299,982 to 318,830, or about 6 percent. The fact that some of the smaller communities were not listed in 1940 accounts for part of the apparent gain.

The population for the 10 cities and towns in the valley between Milton Dam and the Ohio-Pennsylvania State line has increased from 271,667 to 280,964 in the past 10 yr, or about 3 percent. The increase in population in the Mahoning River basin has been less than had been predicted (Ohio State Planning Board, 1936). This might be construed as indicating that the area is

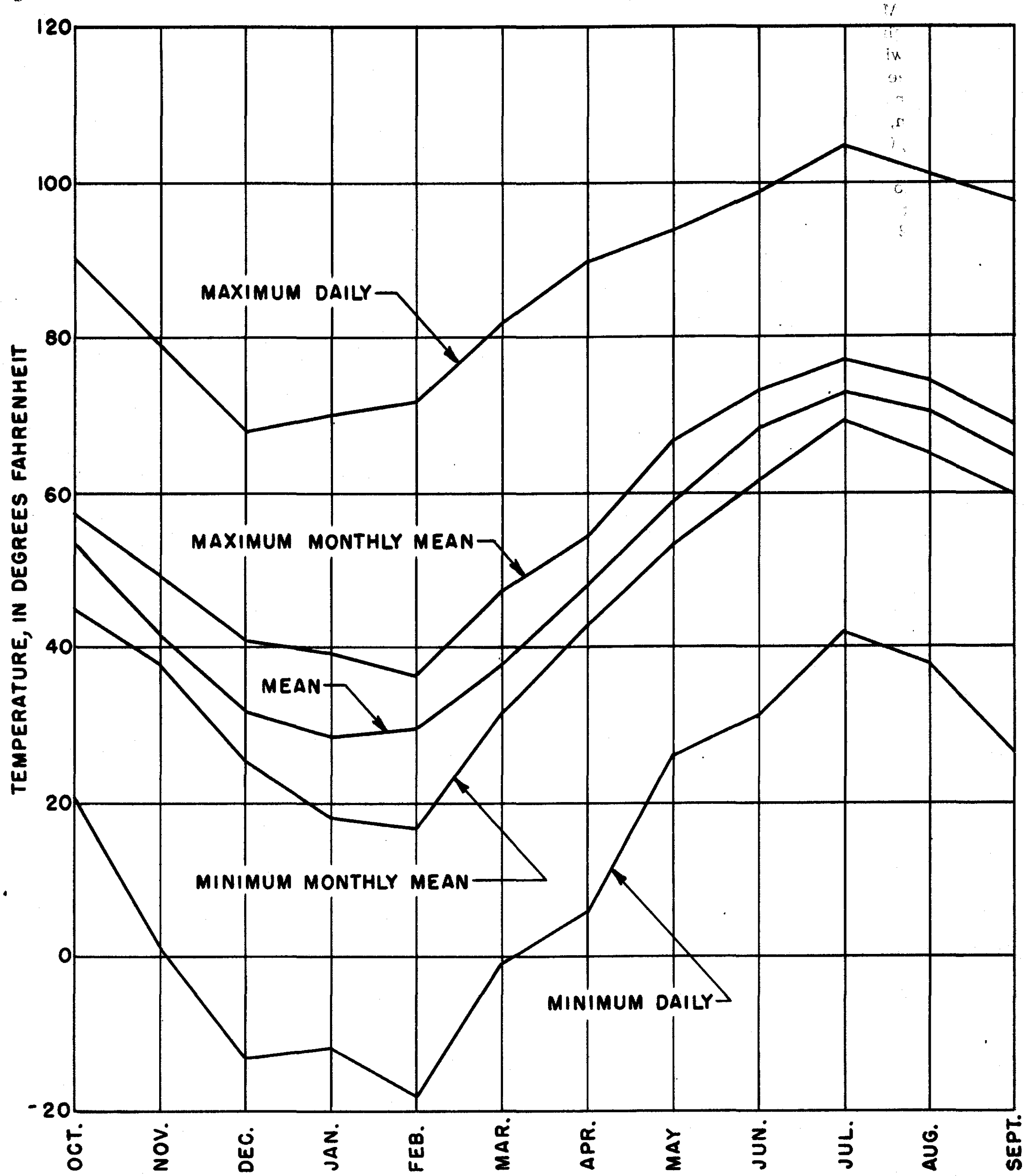

Figure 2.-Air temperatures at Warren, 1921-45.

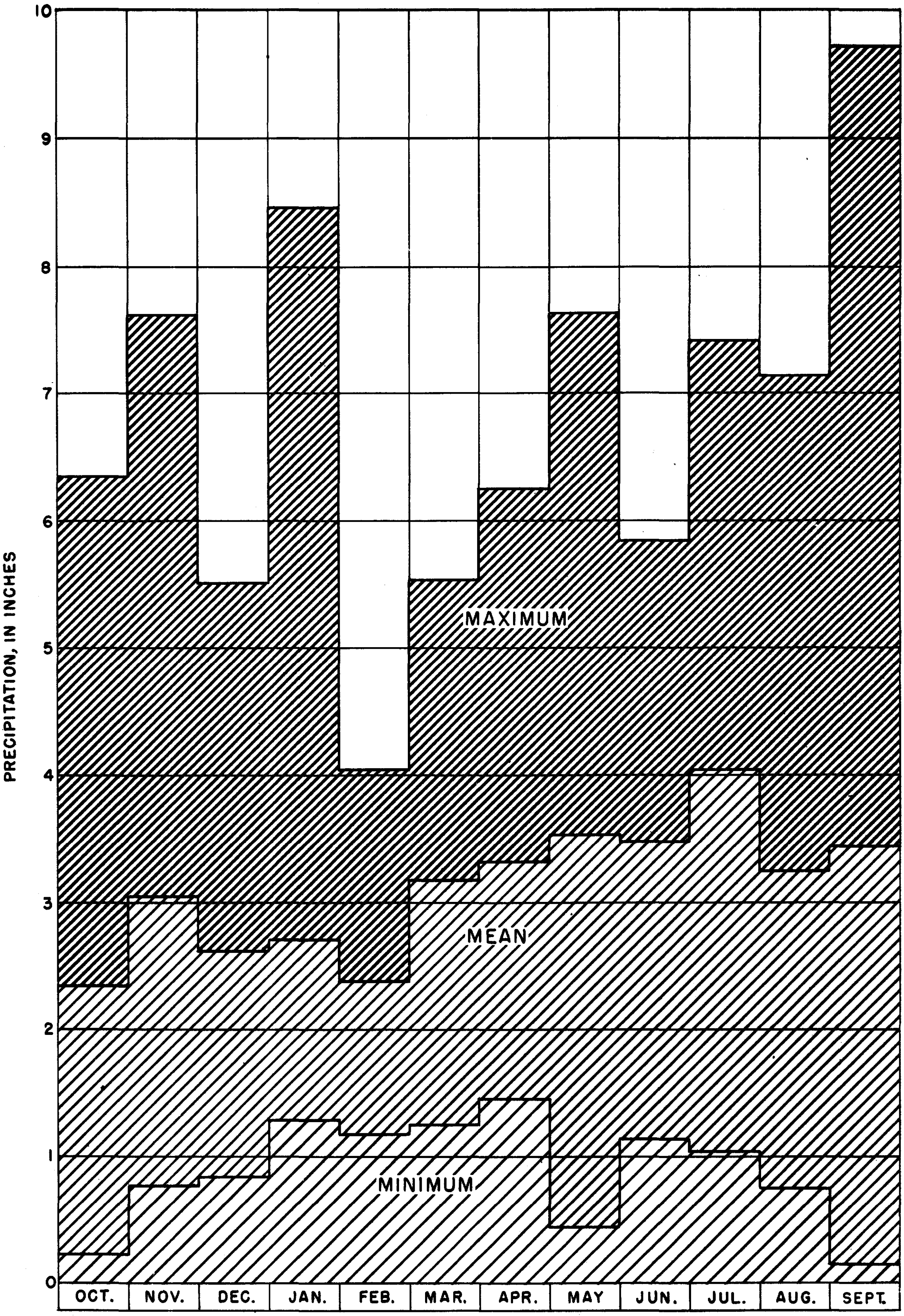

Figure 3.—Monthly precipitation at Warren, 1921-45.

Table 1. –Population of Youngstown area

(Bureau of Census data)

Subdivision (by county)	Population in year indicated		
	1930	1940	1950
Trumbull County	123,063	132,315	158,915
Cortland		1,014	1,259
*Girard	9,859	9,805	10,113
Halls Corners			254
*Leavittsburg			2,533
*McDonald		1,529	1,858
*Newton Falls	3,458	3,120	4,451
*Niles	16,314	16,273	16,773
*Warren	41,062	42,837	49,856
Mahoning County	236,142	240,251	257,629
Beloit		706	778
Canfield		1,141	1,465
*Campbell	14,673	13,785	12,882
*Craig Beach		198	569
East Alliance			1,474
*Lowellville	2,550	2,359	2,227
Poland		1,240	1,652
Sebring	3,949	3,902	4,045
*Struthers	11,249	11,739	11,941
*Youngstown[a]	170,002	167,720	168,330
Portage County	42,682	46,660	63,954
Garrettsville		1,264	1,504
Windham		316	3,968
Stark County:			
Alliance	23,047	22,405	26,161
Limaville		209	209
Columbiana County:			
Columbiana		2,687	3,369

[a]Partly in Trumbull County.
*Adjacent to Mahoning River.

barely maintaining its place as a leading industrial region; but production, employment, and water consumption data show that the population figures are misleading in some respects. The total demand for water has increased beyond expectations and as in many other cities the average per capita use has spiraled upward.

People generally are living farther from their work and the movement to suburbs and rural homes in the Youngstown area in the last decade has been typical of nearly all large metropolitan areas. This suburban movement and the formation of new households have produced many problems among which is that of an adequate water supply. Moreover, industrial use of water has grown at tremendous rates with expanding productive capacity.

Industrial Development

During the last 100 yr the Youngstown area has been one of the Nation's leading iron and steel centers. At first local ores and fuels from nearby forests were utilized. When more distant ores and fuels were used, the Youngstown area grew and prospered as an iron and steel center because of its strategic location on major transportation routes between the sources of ore and fuel. Today the Youngstown steel district is the fourth largest in the United States. Table 2 shows the annual capacity and production of coke, pig iron, and ingot steel for the year 1948 (Pittsburgh District, Corps of Engineers, 1950).

Table 2. --Capacity and production of steel industry in the Youngstown area, 1948

Coke:	
Number of byproduct ovens	710
Annual capacity, net tons	3,182,000
Percent of U. S. capacity	5.1
1948 production, net tons	3,046,000
Pig iron:	
Number of blast furnaces	25
Annual capacity, net tons	7,464,000
Percent of U. S. capacity	11.3
1948 production, net tons	7,023,000
Steel ingots and steel for castings:	
Number of open hearths	81
Annual capacity, net tons	7,686,000
Number of Bessemer converters	6
Annual capacity, net tons	1,724,000
Number of electric furnaces	11
Annual capacity, net tons	522,000
Total capacity, net tons	9,932,000
Percent of U. S. capacity	10.5
1948 production, net tons	10,500,000

The steel and metal-fabrication industry employs about 70,000 persons in the Youngstown area, and it is estimated that 85 percent of industrial workers in the area are supported directly or indirectly by this industry. Other industries include aluminum extrusion and the manufacture of electrical products, bronze, aluminum, rubber, stone, glass, clay, concrete, wood, leather, paint and chemicals. Limestone used for fluxing in the manufacture of steel is quarried in the Mahoning River valley in Pennsylvania. High silica sandstone is quarried near Phalanx, Ohio, for manufacturing high-silicon steel, molding, filtering, sand blasting, and other purposes.

The Youngstown area is an important transportation center because it is situated in the narrow gap between the barriers of Lake Erie on the north and the rough terrain of the unglaciated Allegheny Plateau to the south, and on the shortest route from the Ohio River to Lake Erie. It is served by four major railroads; the Pennsylvania, Baltimore and Ohio, Erie, and Pittsburgh and Lake Erie, and many connecting and steel company railroads. It is served by two airlines as well as several Federal and State highways.

Because of the phenomenal amounts of water required for steel manufacture, most of the industry is concentrated on the banks of the Mahoning River in the 25-mile stretch from Warren to Lowellville. Five steam-power plants serving the industry, which utilize vast quantities of river water for condenser cooling are also situated in this area.

Water Development

The first large reservoir built in the Mahoning River basin was Milton Reservoir, constructed by the city of Youngstown in 1916-17. The dam is located about 5 miles above Newton Falls. The drainage area above the dam is 276 sq mi and the total capacity of the reservoir is 29,150 acre-ft. It was intended to provide water for public and industrial use in the Youngstown area, and orginal plans included conduits from the reservoir to Youngstown. However, legal complications concerning riparian rights in the river between the dam and Youngstown prevented the construction of conduits, and the reservoir has been used for low-flow regulation, flood control, and recreation. At the present time the operation of Milton and Berlin Reservoirs is coordinated.

The Mahoning River was used as the source of municipal water for Youngstown and Niles for many years, but because of insufficient quantity of water and gross pollution the supply became increasingly critical. In 1926 the Mahoning Valley Sanitary District was formed for the purpose of providing a satisfactory domestic water supply for these two municipalities. Plans were drawn for a reservoir on Meander Creek (W. H. Dittoe, 1926). The Mineral Ridge Dam on Meander Creek 2 miles above Niles was completed in 1930, the gates closed on January 1, 1931, and water was piped to Niles and Youngstown for the first time in July 1932. This reservoir has a usable capacity of 32,400 acre-ft, with a drainage area of 84.9 sq mi. The reservoir was designed to provide a safe yield of approximately 30 million gallons per day (mgd), an amount believed at the time of design to be sufficient for use until about 1960. Increases in water demand have exceeded expectations, however, and though the reservoir has provided water about as planned, it can no longer satisfy the needs for domestic and industrial water for the two cities.

As part of the general comprehensive plan for flood control in the Ohio River basin, several reservoir projects have been considered for the Mahoning River basin. Two of these–Berlin Reservoir above Milton Reservoir on the Mahoning River and Mosquito Creek Reservoir 9 miles above Niles–were constructed during World War II. The Mosquito Creek Reservoir as originally planned was a dual-purpose project for flood control and low streamflow regulation. Its construction was authorized during the war period to provide augmentation of low flow in the Mahoning River for industrial water-supply purposes. Its operation during that period of emergency was in accordance with the intent of the original plan. The Berlin Reservoir as originally planned was primarily for flood control with incidental storage for low-water regulation during the summer. However, the storage allocation was modified for the period of the emergency to provide greater low-flow augmentation than would have been possible under the original plan of operation.

Berlin Reservoir, with total capacity of 91,200 acre-ft, and a drainage area of 249 sq mi was placed in operation in July 1943, and is used in combination with Milton Reservoir for flood control and low-flow augmentation. Plans have been made for a project which will divert water from Berlin Reservoir into Meander Creek Reservoir, thereby eventually providing an additional 34 mgd public water supply for Youngstown and Niles. These plans for diversion are being made by the Mahoning Valley Sanitary District under a contract with the Federal Government for the purchase of water from Berlin Reservoir. Some delay in construction of the diversion project has been encountered because of litigation.

Mosquito Creek Reservoir, completed in April 1944, with a capacity of 104,100 acre-ft, and a drainage area of 97.4 sq mi, located on the upper reaches of Mosquito Creek, has an uncontrolled wasteway into the Grand River basin, which has not yet been used. Mosquito Creek Reservoir has a large capacity in relation to the flow of Mosquito Creek. It will store more than the runoff from an average year. It has been used for flood control and low-flow augmentation. However, facilities are being planned and constructed for the diversion of water from Mosquito Creek Reservoir for the public water supply of Warren. The water is to be purchased from the Federal Government under contract. Contracts have been awarded for a new water-purification plant and pipelines, which will provide Warren with up to 16 mgd for public use from Mosquito Creek Reservoir. At present Warren uses the highly polluted water of the Mahoning River, a source that is becoming increasingly costly because the treatment requirements are rapidly changing.

The City of Alliance in the headwaters of the Mahoning River uses the river as a source of public water supply. Increased consumption and low flows during drought periods have created difficulties. Plans have been completed for the construction of a dam and reservoir on Deer Creek near the upper end of the Berlin Reservoir. The storage will be about 1 billion gal (3,100 acre-ft) and the estimated yield 7 mgd.

Several small dams and reservoirs have been built on the minor tributaries of the Mahoning River near Youngstown by private water companies for the purpose of supplying raw water to industry. The first dam was built at Lake Hamilton on Yellow Creek in 1906, and the last reservoir, Evans Lake, was built on Yellow Creek in 1949. The Ohio Water Service Company, the successor of several earlier private water companies, now has a supply system comprising nine reservoirs. Four of these are on Yellow Creek which flows into the Mahoning River from the south at Struthers below Youngstown. Burgess Lake is on a tributary of Yellow Creek. Dry Run Lake is on Dry Run, a tributary flowing into the Mahoning River from the north at the center of Youngstown. Girard Lake and two other small lakes are on Squaw Creek, which flows into the Mahoning River from the north at Girard. The total capacity of all of these lakes is 7.2 billion gal (22,000 acre-ft) with a yield of about 30 mgd. The Ohio Water Service Company furnishes domestic water to Struthers, Poland, and adjacent small areas, and sells raw water to Campbell. However, these public supplies are only about 7 percent of the water sold by this company. Raw water of relatively good quality is delivered to many industries by means of a distribution system extending throughout the valley from Girard to Struthers.

QUANTITY AND QUALITY OF WATER AVAILABLE

Surface Water

Discharge

Stream-gaging stations in the Mahoning River basin are shown on figure 1 and the periods of record and a summary of the data are listed in table 3. The numbers on figure 1 correspond to the station numbers in table 3. The records cover only a few years, and interpretation is complicated by the regulation at the four storage reservoirs. It should be noted that of the 899 sq mi of drainage area above Youngstown, 459 sq mi are now above reservoir dams. The records collected on the Mahoning River below Milton Dam since 1917 are affected by regulation. The records collected on Meander Creek, Mosquito Creek, and the Mahoning River near Berlin Center since the completion of the reservoirs on these streams are affected by regulation.

The average annual runoff for Ohio is about 13 in. As might be expected from the rainfall and temperature data, the average annual runoff in the Mahoning River basin is also about 13 in. The variations in the average discharge in inches for the gaging stations shown in table 3 are mostly the result of random variations in annual rainfall rather than an indication of significant differences in runoff or in the rainfall-runoff relation. No corrections have been made for regulation or evaporation in reservoirs, for diversion around some of the gages, nor for the variations in lengths and dates of record. All these factors should be kept in mind in studying the streamflow data.

The mean discharge of the Mahoning River at Youngstown for the 29 yr ending in 1950 is 809 cfs. Water diverted for the public supply of Youngstown is not included because it bypasses the gage. The water intake is upstream from the gage and most of the sewer outlets are downstream from the gage. The water demand of Youngstown has gradually increased until in 1950 it was approximately 30 cfs. It may be concluded from this comparatively long record that the average discharge at Youngstown cannot be materially increased above about 800 cfs or 0.89 cfs per square mile without diversion into the Mahoning River from outside the basin or less diversion around the gage. Records in table 3 show an average discharge of about 0.9 cfs per square mile for a number of points in the basin.

Although no significant trends have been detected in the annual mean runoff seasonal runoff varies greatly. Flow-duration curves and tables reveal this characteristic strikingly. The flow-duration curve is a cumulative frequency curve, prepared by arranging all daily discharges of record in order of magnitude, and dividing them according to percentages of time during which specific flows are equalled or exceeded (Ohio Division of Water, 1949). Figures 4, 5, and 6 show flow-duration curves for the flow at five gaging stations in the upper Mahoning River basin, and several points on the flow-duration curve are shown in table 3 for all stations in the basin.

The general slope of the flow-duration curve is an indication of the natural storage in a basin. For example, if a basin were entirely paved, a flood would occur immediately after every rain followed by a short period of decreasing flow as the stream drained out, and finally a period of no flow until the next rain. The duration curve would be very steep. For a lake or swamp, on the other hand, there would be only slight increase in flow. The duration curve would be nearly horizontal. Large quantities of stored ground water would have the same effect as a lake in reducing high flows and increasing low-water flows. The effect of a storage reservoir on the flow of the Mahoning River below Berlin Dam near Berlin Center is shown on figure 6. Flood flows are reduced and the mean flow is unchanged. Part of the time most inflow is stored in the reservoir, then the discharge is less below the dam than it would have been without storage in the reservoir. However, when a large part of the flow into the reservoir is stored, the streamflow is usually not low; therefore, the tributary inflow below the dam is sufficient to supply all demands. It is to be emphasized, however, that figure 6 shows only regulated flow at the dam; whereas, regulation is maintained not for the effect immediately below the dam but for the effect in the industrial region from Warren to Youngstown.

A study of the flow-duration curves of figures 4, 5, and 6 shows that the streams in the upper end of the Mahoning River basin are fairly well sustained during dry weather. The general slopes of the duration curves shown are about the same as the average for the State. The records, as summarized in table 3, making due allowance for the short records and the variable periods of time covered, indicate that Deer Creek, Eagle Creek and West Branch generally have better sustained flow than the lower tributaries, and that much of the dry-weather flow of the Mahoning River, other than reservoir outflow, comes from this western part of the basin. Mosquito Creek, prior to regulation, had extremely low sustained flows in dry weather. It is unfortunate that all of the flow records of any length not affected by artificial storage are for the area of relatively high sustained flow.

Table 3.—Summary of streamflow data for streams in the Mahoning River basin

No. on fig. 1	Stream and location	County	Drainage area (sq mi)	Years of record[a]	Discharge: Average cfs/sq mi	Discharge: Average Inches	Discharge: Maximum (cfs/sq mi)	Discharge: Minimum (cfs/sq mi)	Flow-duration (percent of time), Discharge equaled or exceeded: 10 cfs/sq mi	25 cfs/sq mi	50 cfs/sq mi	75 cfs/sq mi	90 cfs/sq mi	Storage required to maintain[c]: Flow of 0.5 cfs/sq mi (million cu ft/sq mi)	Storage required to maintain[c]: Average discharge (million cu ft/sq mi)
1	Mahoning River at Alliance[d]	Stark	87.9	9, 1942-50	0.845	11.47	79.6	0	1.88	0.683	0.191	0.025	0.001		
2	Mahoning River near Deerfield	Portage	175	8, 1924-31	1.03	13.98	58.9	.013	2.54	.966	.331	.126	.073	12.9	74.9
3	Mahoning River near Berlin Center	Mahoning	247	12, 1931-42	.854	11.59	34.9	.008	2.19	.599	.202	.081	.036	13.5	51.6
3	Mahoning River below Berlin Dam near Berlin Center[e]	Mahoning	249	7, 1944-50	.888	12.03	14.3	0	1.76	1.18	.683	.201	.004		
4	Mahoning River at Pricetown[e]	Mahoning	276	21, 1930-50	.859	11.65	24.5	.001	2.04	.942	.406	.228	.115		
5	Mahoning River at Leavittsburg[e]	Trumbull	580	9, 1942-50	.921	12.50	13.6	.116	1.98	.866	.536	.366	.272		
6	Mahoning River at Warren[e/f]	Trumbull	599	11, 1925-35	.845	11.47	17.5	.010	2.04	.760	.282	.155	.093		
7	Mahoning River at Youngstown[g/e]	Mahoning	899	29, 1922-50	.900	12.22	19.6	.031	2.47	.980	.384	.187	.119		
7A	Mahoning River at Lowellville[e]	Mahoning	1,076	7, 1944-50	.883	11.99	21.4	.118	1.88	.925	.533	.344	.243		
7B	Beach Creek near Bolton	Stark	18.8	7, 1944-50	.894	12.11	118	.005	1.98	.632	.172	.064	.033	16.8	72.1
8	Deer Creek at Limaville	Stark	31.9	9, 1942-50	.956	12.98	39.2	.038	2.11	.743	.264	.138	.097	15.3	69.1
9	Mill Creek near Berlin Center	Mahoning	19.7	9, 1942-50	.853	11.55	96.4	.005	1.82	.579	.139	.053	.028	18.6	67.4
10	Kale Creek near Pricetown	Trumbull	21.7	9, 1942-50	.908	12.33	167	.001	2.06	.544	.091	.023	.011	17.0	77.1
11	West Branch Mahoning River near Newton Falls	Portage	97.8	24, 1927-50	.950	12.87	51.1	.030	2.03	.755	.273	.133	.089	10.7	72.2
12	Eagle Creek at Phalanx Station[h]	Trumbull	97.0	19, 1927-33, 1939-50	1.06	14.39	35.9	.006	2.54	.876	.357	.190	.124	13.7	76.3
13	Duck Creek at Leavittsburg	Trumbull	35.2	6, 1942-47	.770	10.45	31.2	.001	1.76	.588	.125	.040	.017		
14	Mosquito Creek near Cortland	Trumbull	97.6	3, 1927-29	1.41	19.14	19.4	.004	4.25	1.64	.338	.041	.011		
14	Mosquito Creek below Mosquito Creek Dam near Cortland[e]	Trumbull	97.6	7, 1944-50	.916	12.43	13.1	0	2.58	1.57	.057	>.01	>.01		
15	Mosquito Creek at Niles	Trumbull	139	14, 1930-43	.777	10.55	22.2	0	2.48	.755	.129	.017	.002	17.8	60.8
15	Mosquito Creek at Niles[e]	Trumbull	139	7, 1944-50	.892	12.11	10.8	.001	2.06	1.43	.461	.091	.038		
16	Meander Creek at Ohlstown	Trumbull	77.2	3, 1927-29	1.30	17.65	68.0	.012	3.17	1.06	.347	.118	.051		
17	Meander Creek at Mineral Ridge[i/e]	Trumbull	84.9	21, 1930-50	.505	6.86	64.8	0	1.22	.177	.021	>.01	>.01		
17A	Mill Creek at Youngstown	Mahoning	68.4	6, 1945-50	.810	10.98	89.2	.001	2.00	.703	.192	.063	.028	21.3	69.5

a/ Complete water years through 1950.
b/ Based on complete water years through 1950.
c/ Based on records of unregulated flow and adjusted to base period 1921-45.
d/ Does not include diversion for municipal water supply of Alliance. Diversion averaged 7.3 cfs during 1950 water year.
e/ Flow regulated by reservoirs.
f/ Does not include diversion for municipal water supply of Warren. Diversion averaged 4.1 cfs during 1935 water year.
g/ Does not include diversion for municipal water supply of Youngstown. Diversion approximately 30 cfs during 1950 water year.
h/ Low flow slightly regulated by mill several miles above station.
i/ Does not include diversion for municipal water supply of McDonald, Youngstown, and Niles. Diversion averaged 38.4 cfs during 1950 water year.

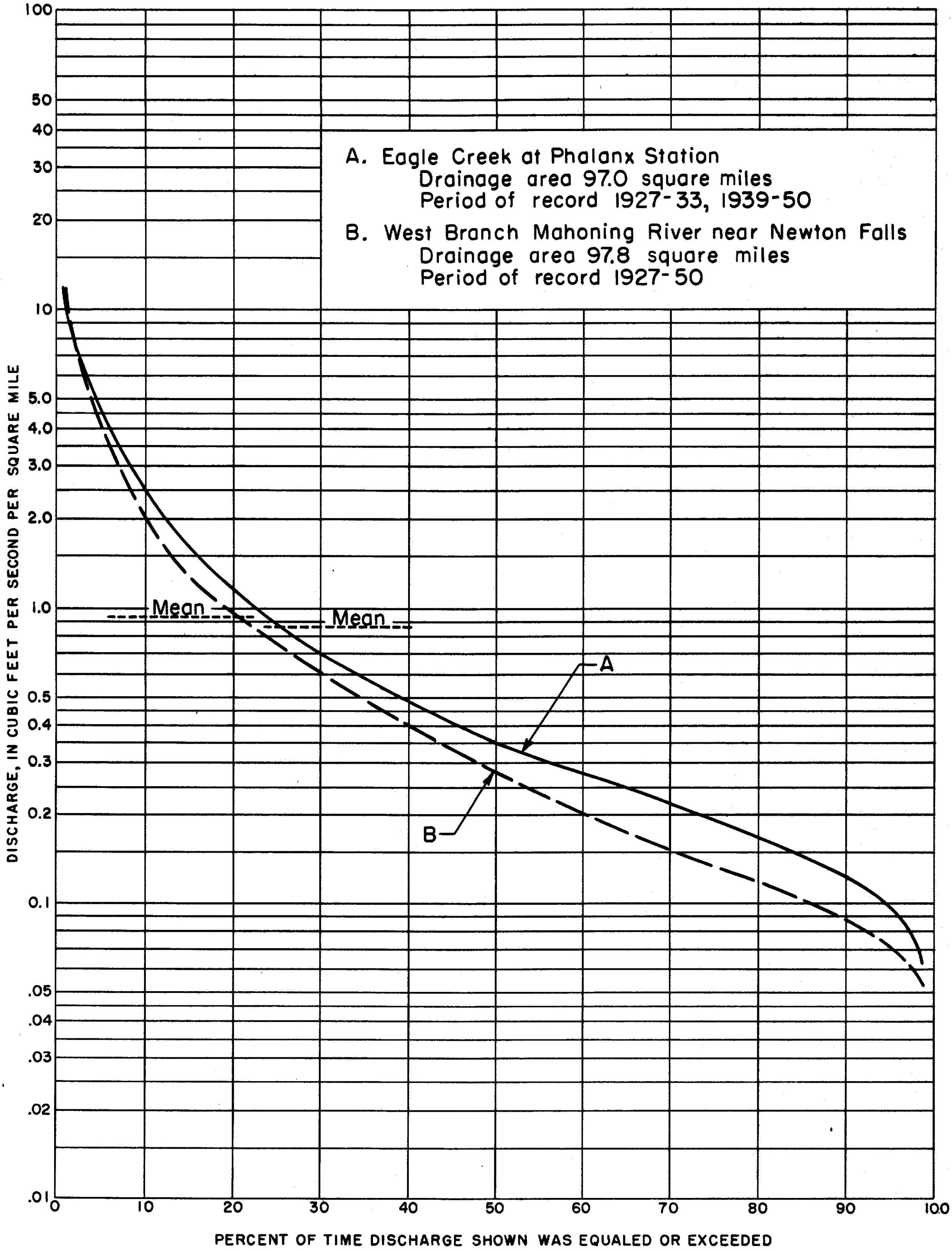

Figure 4. –Flow-duration curves, Eagle Creek at Phalanx Station and West Branch Mahoning River near Newton Falls.

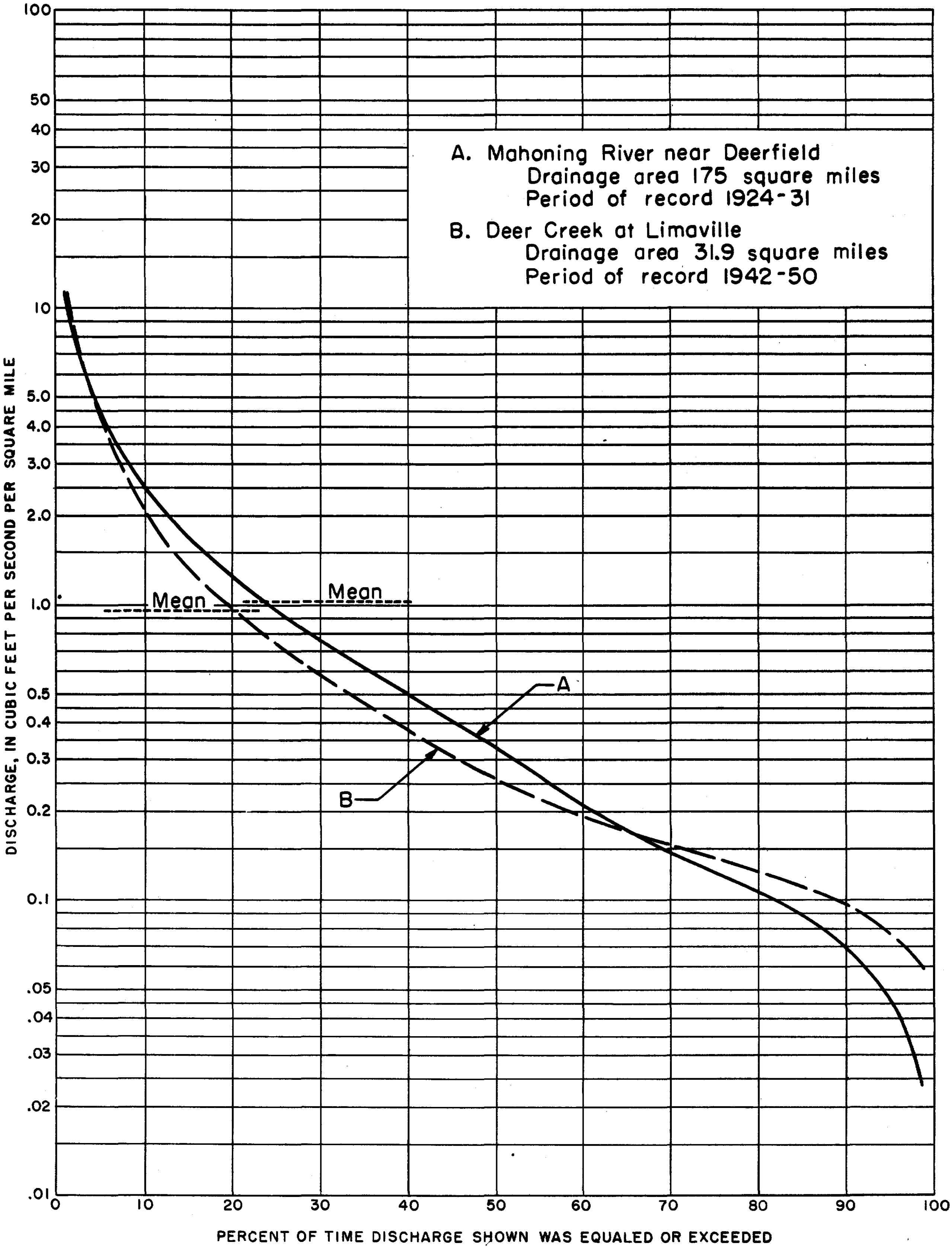

Figure 5. -Flow-duration curves, Mahoning River near Deerfield and Deer Creek at Limaville.

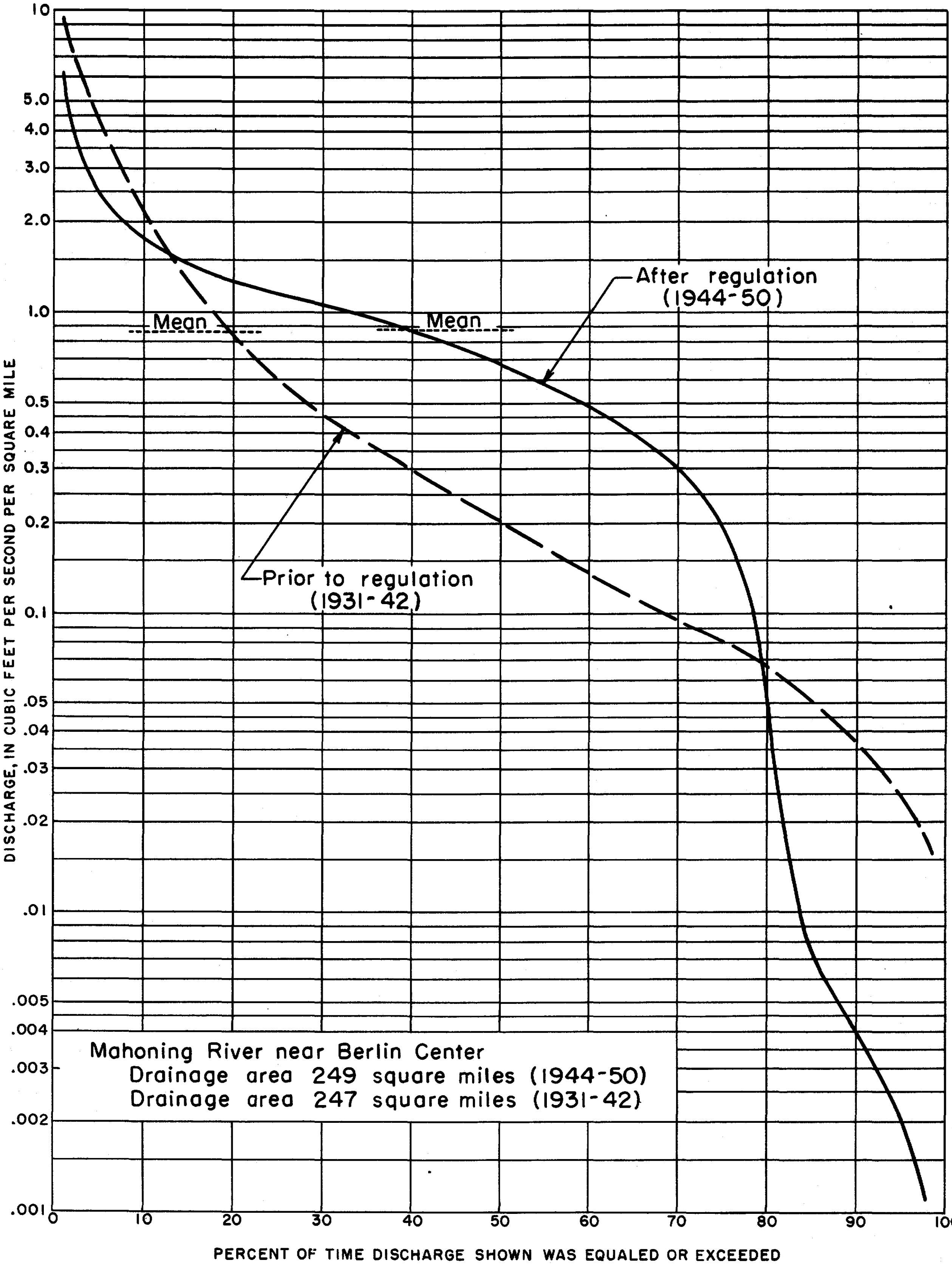

Figure 6. –Flow-duration curves, Mahoning River near Berlin Center.

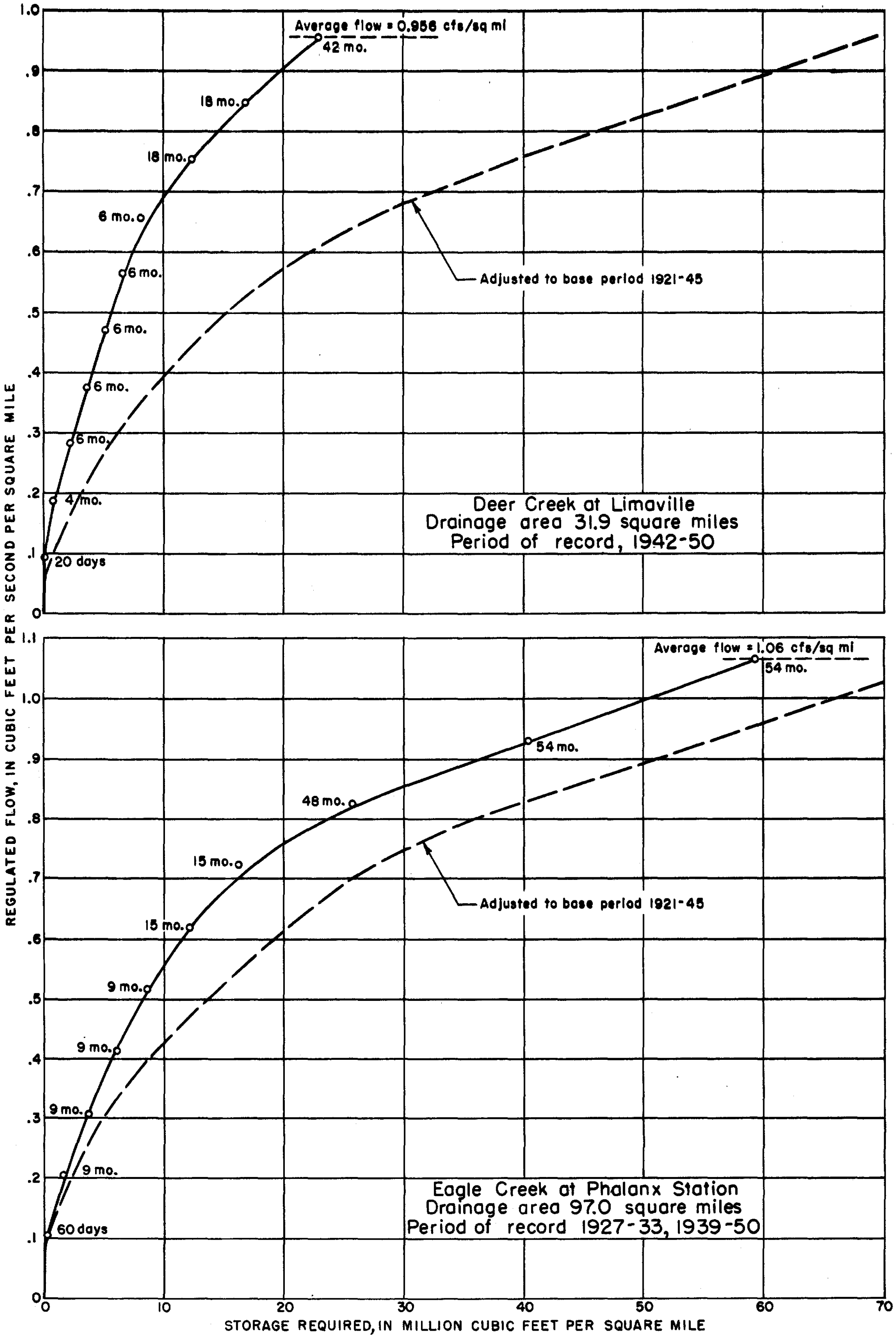

Figure 7. –Unit-storage graphs, Deer Creek at Limaville and Eagle Creek at Phalanx Station.

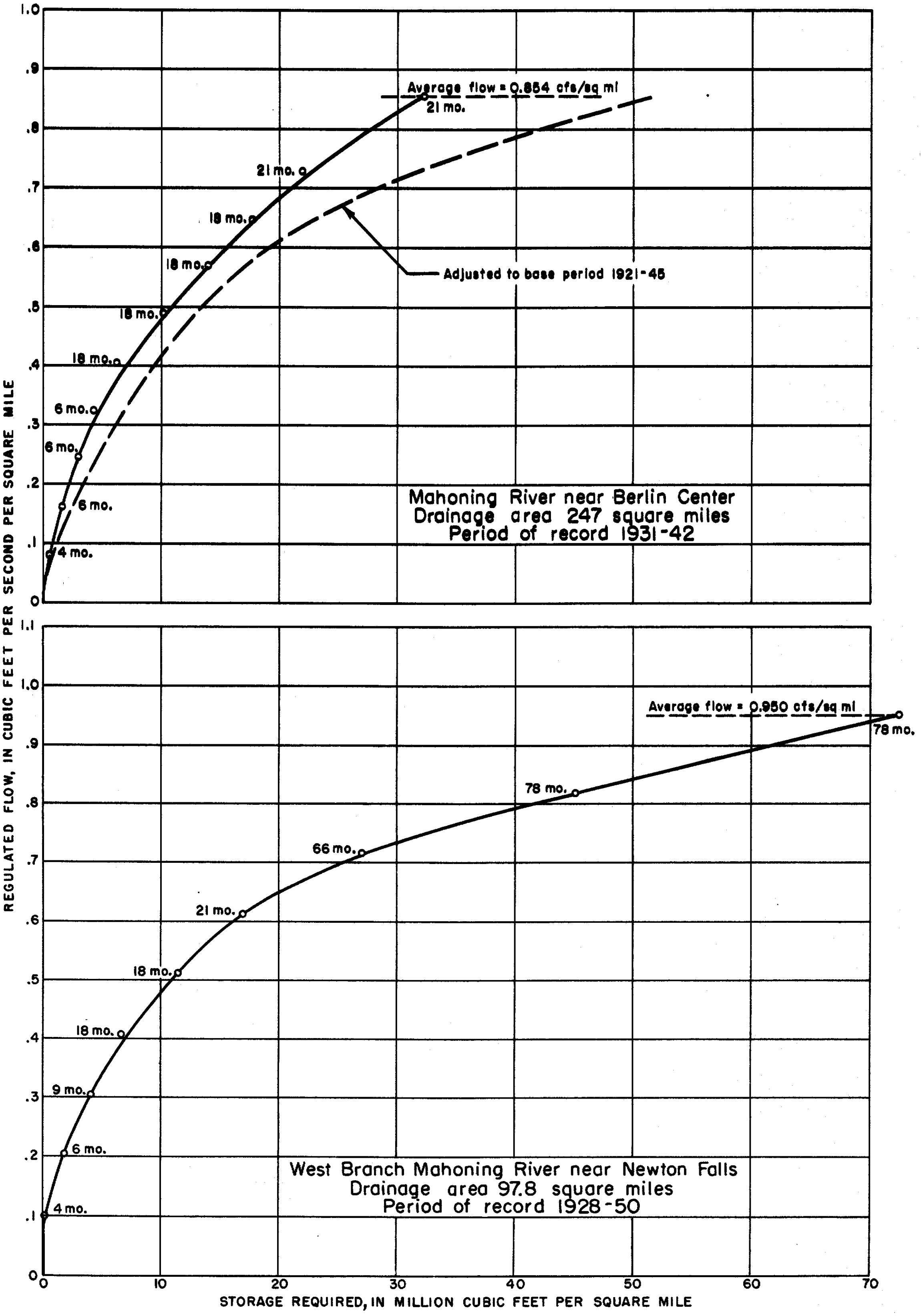

Figure 8.–Unit-storage graphs, Mahoning River near Berlin Center and West Branch Mahoning River near Newton Falls.

Another means of studying the flow characteristics of streams is the unit-storage or storage-required curve. This, in effect, is a mass-curve analysis, in which the maximum deficiencies in flow volumes, below specified outflow rates, are determined. The results of such detailed anaylses for four of the unregulated streams in the Mahoning River basin are shown in figures 7 and 8. The diagrams show the additional net storage, disregarding evaporation and dead storage, required to maintain specific outflow rates at the gaging stations. Higher rates of flow could be maintained at critical downstream points in the Mahoning River basin. Storage required to maintain one-half second foot per square mile and mean discharge for the nonregulated gaging stations (having sufficient length of record) are shown in table 3. These data confirm the relatively high sustained flows in the upper part of the basin and the low sustained flows of downstream tributaries.

According to the Corps of Engineers, Pittsburgh District, reservoirs in the Mahoning River basin are operated so that average monthly flows are at least as great as those shown in the following table:

Month	Minimum average regulated discharge at Youngstown in cubic feet per second
November through March	185
April	202
May	295
June	413
July	470
August	425
September	333
October	235
Average for year	275

Flows at least as great as those shown in the above table are required to prevent nuisance from pollution according to the U. S. Public Health Service or are required during a month of average temperature to maintain the desired water temperature at the Youngstown Sheet and Tube Co.

Obviously, in a year of average discharge, the flow would be of the order of 800 cfs rather than 275 cfs.

Droughts

The study of droughts and drought frequencies for streams in the Mahoning River basin is complicated by the short length of record and in many cases the effects of regulation and diversion. The drought of 1930 is the worst of record. Table 4 lists the minimum daily flows for the gaging station at Youngstown and shows a minimum of 30 cfs for 1930. However, at that time Milton Reservoir was in use and undoubtedly increased the drought flows. The minimum flow in 1908 is believed to have been about half the flow available in 1930 (House Doc. 277, 73rd Congress, 2nd Sess., 1934). Since 1930 three more reservoirs have been built and the minimum flows at Youngstown correspondingly increased.

The minimum instantaneous flows of record, in cubic feet per second per square mile, for all gaging stations in the basin, are listed in table 3. These records

Table 4. –Minimum daily flows, Mahoning River at Youngstown

Water year	Cubic feet per second
1922	64
1923	64
1924	78
1925	62
1926	79
1927	118
1928	88
1929	68
1930	30
1931	42
1932	67
1933	52
1934	40
1935	58
1936	56
1937	110
1938	66
1939	66
1940	79
1941	74
1942	92
1943	138
1944	138
1945	160
1946	206
1947	202
1948	182
1949	206
1950	129

indicate that extremely low flows have occurred throughout the basin. However, in water supply problems involving storage, the instantaneous minimum flow is not as critical as the deficiencies in flow-volumes over periods of time. The unit-storage analyses show that the critical periods for a flow rate of one-half cubic foot per second per square mile are 6 to 21 months. One of the most critical periods of low flow for the Mahoning River at Youngstown is that of 1930-31. The 19-month period, May 1, 1930, to November 30, 1931, had an average flow of only 272 cfs corresponding to a yield of 313,000 acre-ft or an annual yield of 197,000 acre-ft. During this period the storage in Meander Reservoir increased about 16,000 acre-ft, but the storage in Milton Reservoir decreased about 13,000 acre-ft, indicating slight effect of regulation on the average flow for the period. The minimum average flow for 12 consecutive months was 223 cfs, or a volume of 161,000 acre-ft.

Drought frequency curves based on annual minimum flows for four stations in the upper Mahoning River basin are shown in figures 9 and 10. These curves show the recurrence interval or probable return period for droughts of 1 day, 1 week, 1 month, 2 months, and 6 months duration. All of the stations shown are in the area of high sustained flow. The data for the Mahoning River at Berlin Center is for the 12 yr including the drought of the 1930's and probably gives results that are too low. The one-day graph for Eagle Creek is affected by run-of-river regulation by a small mill dam upstream. With these two exceptions the

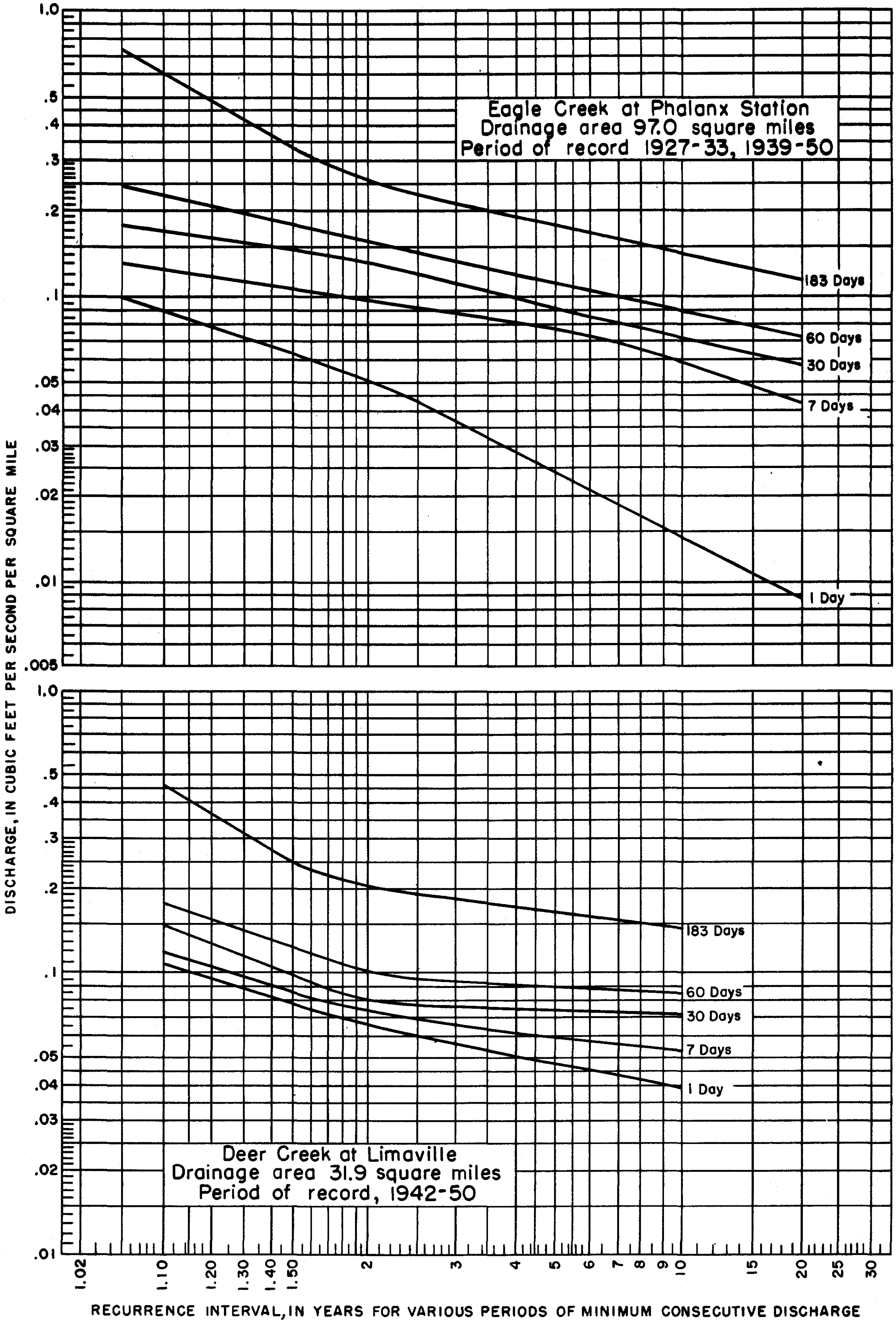

Figure 9.—Drought-frequency graphs for Eagle Creek at Phalanx Station and Deer Creek at Limaville.

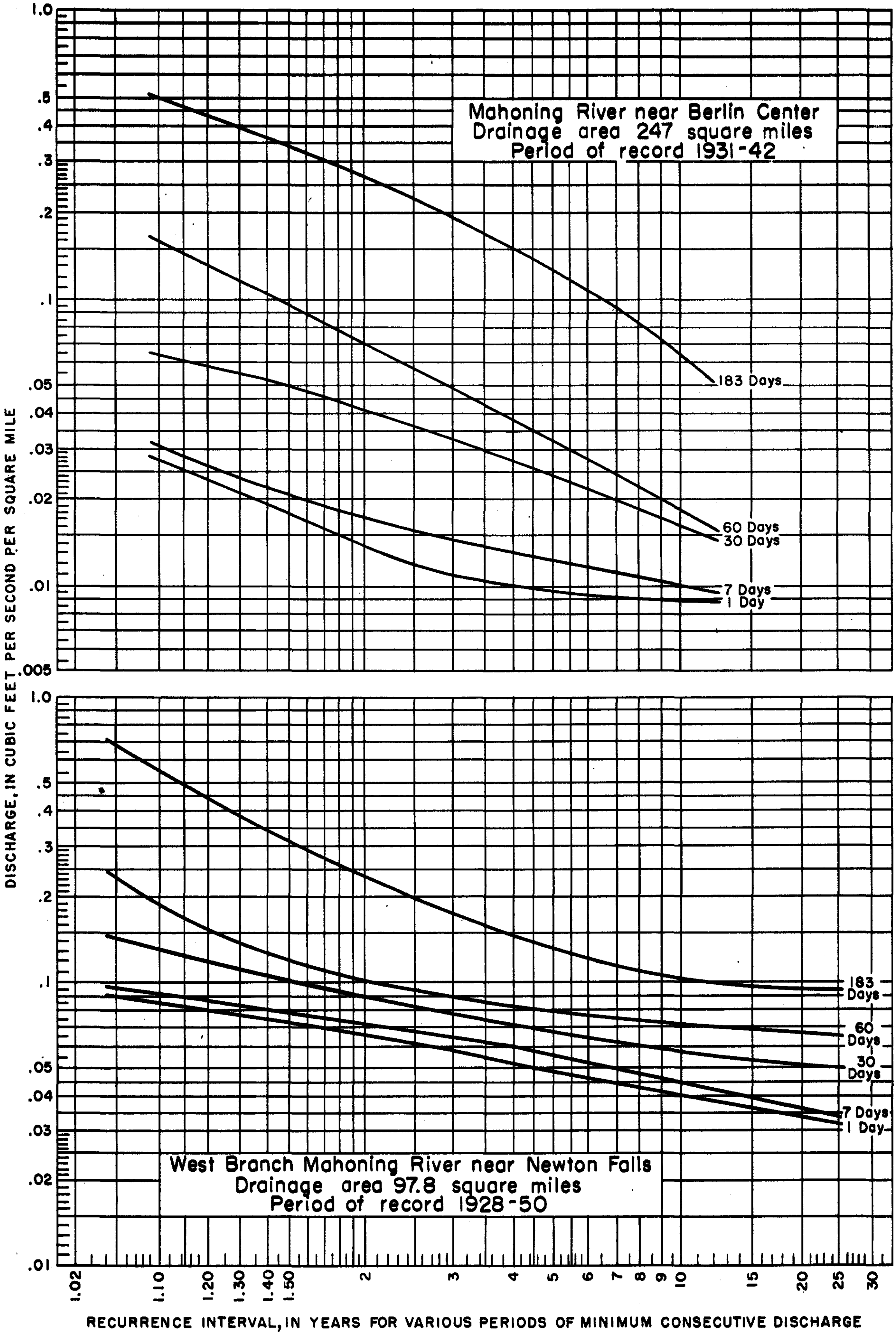

Figure 10.—Drought-frequency graphs for Mahoning River near Berlin Center and West Branch Mahoning River near Newton Falls.

groups of curves are very similar for all stations. The curves cannot be used as an indication of the probable frequency of drought flows throughout the entire Mahoning River basin because the stations are all in the area of high sustained flows. Lower tributary streams are affected by regulation, or records are too short for analysis. The flow from the 139 sq mi area above Niles on Mosquito Creek reached zero during three of the 13 yr of record which were unaffected by storage.

The effects of regulation on low flows of the Mahoning River are shown in table 5. It is impossible to convert regulated low flows as recorded to natural flows; they might have been without regulation because storage, diversion, and evaporation complicate the problem, and such conversion might give misleading results. Low-water regulation by the reservoirs has greatly improved the low-flow conditions in the Mahoning River but does not approach the extent necessary to prevent possible critical water shortages.

Floods

The Mahoning River valley has not had a major flood since March 1913. It was the largest flood known in the Mahoning River valley. This flood, though disastrous, was not as great on the Mahoning River as in other parts of Ohio. Since 1913 two flood-control reservoirs have been completed, and the other two reservoirs, though without storage reserved for flood control, will have some storage effect on floods. These facts may seem to indicate that floods are less severe in the Mahoning River basin than elsewhere in the same general region and that the control provided by the four reservoirs will be sufficient to reduce probable flood damage to insignificance. Experience elsewhere in this part of the country shows this reasoning to be fallacious and dangerous.

The 1913 flood in Ohio was outstanding, and for many years was believed to be in the nature of an upper limit for floods in the Middle West. During recent years, however, larger floods have been experienced on some streams in the States adjacent to Ohio (U. S. Geological Survey Water Supply Papers). The rainfall causing the 1913 flood was heaviest in the Miami River valley. The same storm, if centered over the Mahoning River valley, would have caused runoff greatly exceeding the 1913 peak. Recent hydrometeorological studies indicate that the maximum possible precipitation that might occur in northeastern Ohio is several times as great as that of the 1913 storm (U. S. Weather Bureau, 1947). Assuming that the four reservoirs could completely control the flood runoff from their respective areas (impossible even with the sacrifice of all the storage for low-water augmentation) a cloudburst-type storm over the uncontrolled area of 440 sq mi could cause a flood at Youngstown in excess of the flood of

Table 5.—Flood stages and discharges, Mahoning River at Youngstown[a]

Year	Month	Day	Recorded gage height (feet)	Recorded discharge (second-feet)	Natural gage height (feet)[f]	Reduced gage height (feet)[f]	Reduction (feet)[f]
1910	Mar.	2	16.3	[b]20,200			
1911	Oct.	2	14.3	[b]16,600			
1913	Mar.	26	26.5	[b]42,500		22.5	4.0
1914	May	13	14.2	[b]16,400			
1915	Feb.	2	12.4	[b]13,200			
1916	Jan.	3	13.8	[b]15,500			
1916	Mar.	27	13.3	[b]14,600			
1927	Mar.	22	11.8	[c]12,400			
1927	Dec.	1	12.5	[c]13,500			
1927	Dec.	14	12.7	[c]13,900			
1929	Feb.	28	12.1	[c]12,900			
1929	Apr.	5	12.6	[c]13,700			
1936	Mar.	25	14.3	[c, d]16,600		11.95	2.35
1937	Jan.	15	12.5	[c]13,500			
1937	Jan.	22	13.1	[c]13,400			
1937	Jan.	25	14.9	[c]16,100		11.9	3.0
1940	Apr.	21	12.8	[c, d]13,000			
1942	Apr.	10	11.9	[c]11,700			
1942	Dec.	30	14.0	[c, d]13,300	15.8	13.0	2.8
1946	May	28	14.2	[d, e]11,400	18.5		4.3
1947	June	3	10.5	[e]9,660	13.3		2.8

a/ Includes all floods above a stage of 12 ft (flood damage begins at about 12 ft).
b/ From U. S. Weather Bureau records adjusted to present datum.
c/ Affected by Milton Reservoir storage.
d/ Affected by backwater from Mill Creek.
e/ Affected by Milton, Berlin and Mosquito Creek storage.
f/ Reductions affected by present reservoirs, or that would have been affected had existing reservoirs been in operation.

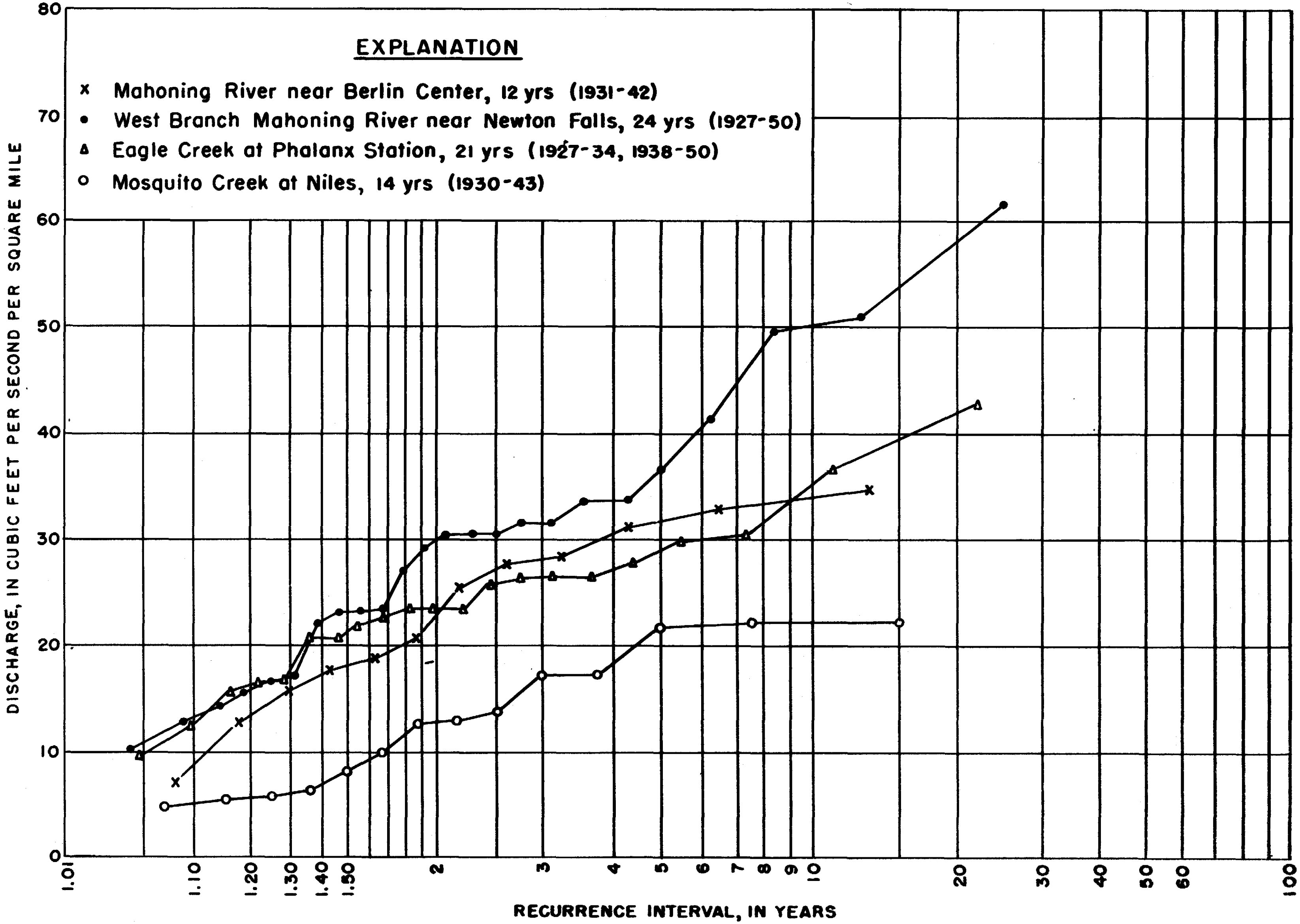

Figure 11.—Flood frequencies for annual floods on selected streams in the Mahoning River basin.

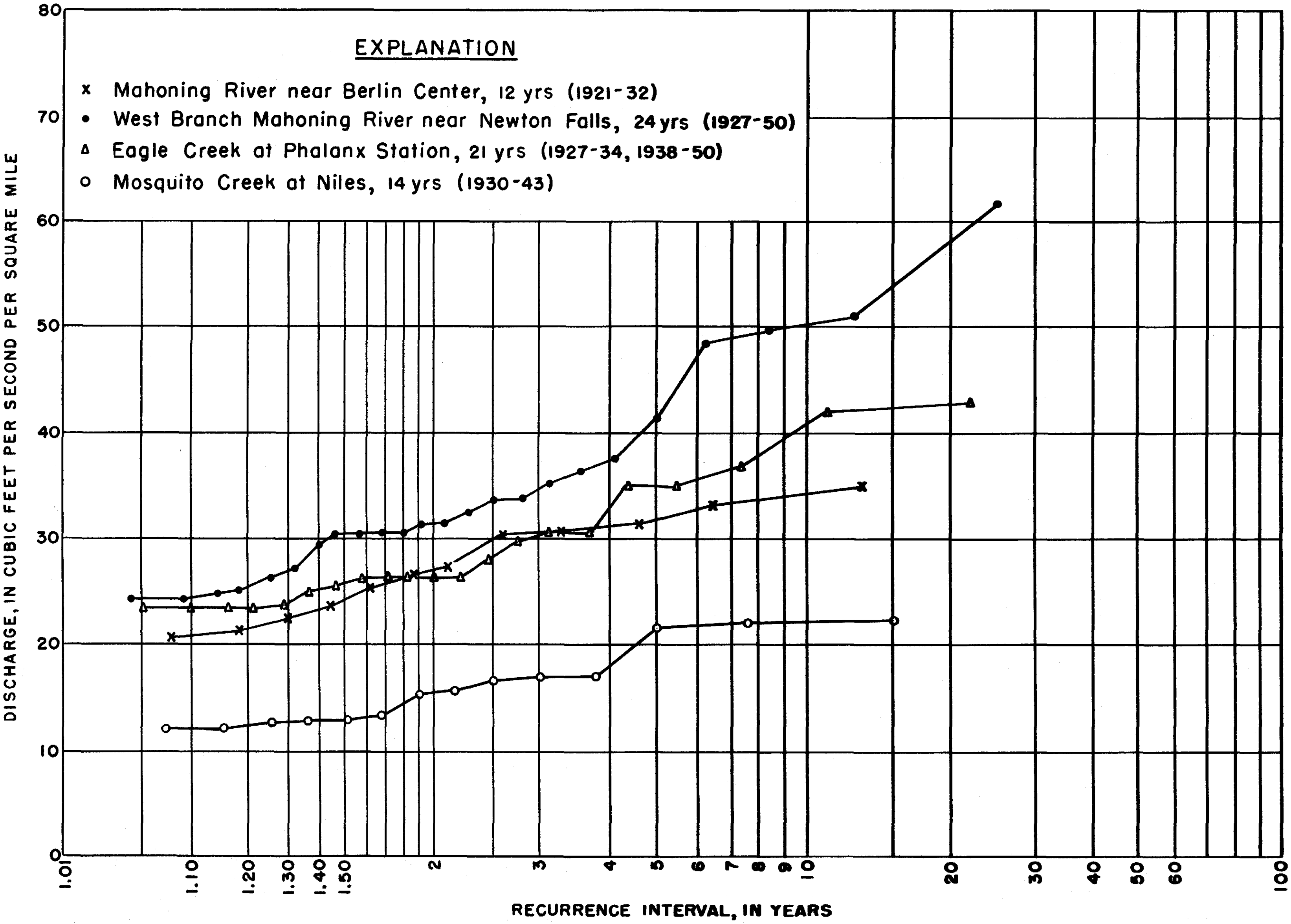

Figure 12.—Flood frequencies for all floods on selected streams in the Mahoning River basin.

1913 (Mahoning Valley Industrial Council, 1951). Another flood as great as that of 1913 in the Mahoning River valley would be a national catastrophe, with much greater damage than in 1913, because of the vast industrial developments built on the river banks since that date.

The maximum discharges for the gaging stations listed in table 3 are not outstanding when compared with floods recorded elsewhere in Ohio (Ohio State University Engineering Experiment Station, 1947). Flood frequency graphs for four streams unaffected by storage are plotted on figures 11 and 12. Figure 11 shows the recurrence interval for annual floods and figure 12 shows the recurrence interval for all floods. An annual flood is the highest flood during a year; therefore, only the greatest flood in each year was used in preparing figure 11 although other notable floods occurred during the year. Therefore, figure 11 shows the recurrence interval for a flood occurring as the greatest during the year. Figure 12 shows the recurrence interval for a flood whether or not it is the maximum for the year. From these data it appears that a flood peak of about 60 cfs per sq mi on an area of about 100 sq mi might occur on the average as often as once in 25 yr. Extrapolation beyond the period of record cannot be made with any degree of certainty, and it must be concluded that the available records give little indication of the maximum floods possible in the basin.

Damaging floods at Youngstown have been frequent, as shown by table 5. The record of flood stages and discharges, based on the U. S. Weather Bureau record 1908-18 and the U. S. Geological Survey record after 1921, indicates that damaging stages occurred on the average every two or three years, prior to the completion of Berlin and Mosquito Creek Reservoirs, and that serious floods can occur with the present reservoirs. The table also shows the amount of reduction provided by the present reservoirs for six representative floods. With the present operation of reservoirs there would have been only four damaging floods in the past 42 yr, or about one every 10 yr. Since industry is centered on the Mahoning River, in order to take advantage of the water supply, this marked reduction in the frequency and severity of floods has brought about substantial savings in flood damages. However, available storage is insufficient to prevent tremendous loss in the event of another flood as great as that of 1913, nor can all the lower floods be reduced to non-damage stages.

A comprehensive plan for the development of the water resources of the Mahoning River valley may logically provide sufficient storage reserved for flood control to prevent the recurrence of the 1913 disaster, and reduce all lower floods to below the damage stage. Sufficient storage for this and other requirements is not available within the Mahoning River basin.

Chemical quality

An investigation of the chemical and physical quality of the surface waters of the Mahoning River and its tributaries was started in May 1946. An intensive study of the character of the water in Mahoning River at Warren was made between July 1946 and September 1948. A sampling program in the lower portion of the Mahoning River basin was started on October 1, 1951. Daily samples are being collected at Lowellville and monthly samples at Youngstown and Leavittsburg. In addition 36 samples have been collected since May 1946 at 20 selected sites throughout the basin (fig. 13).

The chemical quality of water in the upper reaches of the Mahoning River and of its tributaries above the industrial area of the lower Mahoning Valley is generally good (table 6). However, there is some upstream pollution by industrial water and municipal sewage and this is of concern to the City of Warren, because its water supply is at present obtained from the Mahoning River. In some places, especially during low flow, the quality of water in the main stream, even above Warren, or of a tributary may be critically impaired by pollution. For example, a sample of Meander Creek at Niles was distinctly acid, with a pH of 2.90, total acidity as sulfuric acid of 154 ppm, and dissolved solids of 736 ppm (table 6). This occurred during a period of practically no flow and was due to local pollution. A sample collected the same day in the Meander Creek Reservoir just a few miles above Niles was alkaline and contained only 150 ppm of dissolved solids.

The water in the reservoirs is generally of better quality and lower in dissolved solids than the other surface water in the basin (table 6). The better quality is due mainly to the fact that the reservoirs are filled during periods of high flow when a large part of the water is flood flow and the effects of industrial or municipal pollution and highly mineralized ground water are at a minimum. Mosquito Creek Reservoir contains some of the best quality surface water in the basin (fig. 14). Analyses made in May and September 1946 and in November 1951 indicated dissolved solids of 110, 123 (calculated), and 96 ppm, respectively.

The chemical quality of the Mahoning River is improved by the good quality of the water from the three flood-control reservoirs. Further improvement of the chemical quality could be affected by additional reservoirs for the storage of flood waters to augment low flow and with increased treatment of sewage and industrial wastes.

Daily samples were collected during the intensive study at Warren. Before analysis these samples were composited to make three samples per month (table 7). Most of the industrial wastes and sewage are discharged into the Mahoning River at and below Warren. The sampling station at Warren was above most of the sources of pollution, and, therefore, the analyses are of the better quality upstream waters. The analytical results show that the Mahoning River water is generally, but not always, of a good chemical quality as it enters the highly industrialized zone. It compares very favorably in dissolved solids with other rivers of the State on which daily chemical quality stations have been maintained. There is, however, considerable variation in the chemical character of the river at this point throughout the year and from year to year. These day to day variations are indicated by the results for specific conductance in figure 15. This figure also shows the relation of total hardness, dissolved solids, and specific conductance of the Mahoning River at Warren to streamflow at Leavittsburg, 6 miles upstream from Warren, during the water year October 1946 to September 1947. The flow at Warren and Leavittsburg is substantially the same except during periods of heavy local rains. During the period of record at War-

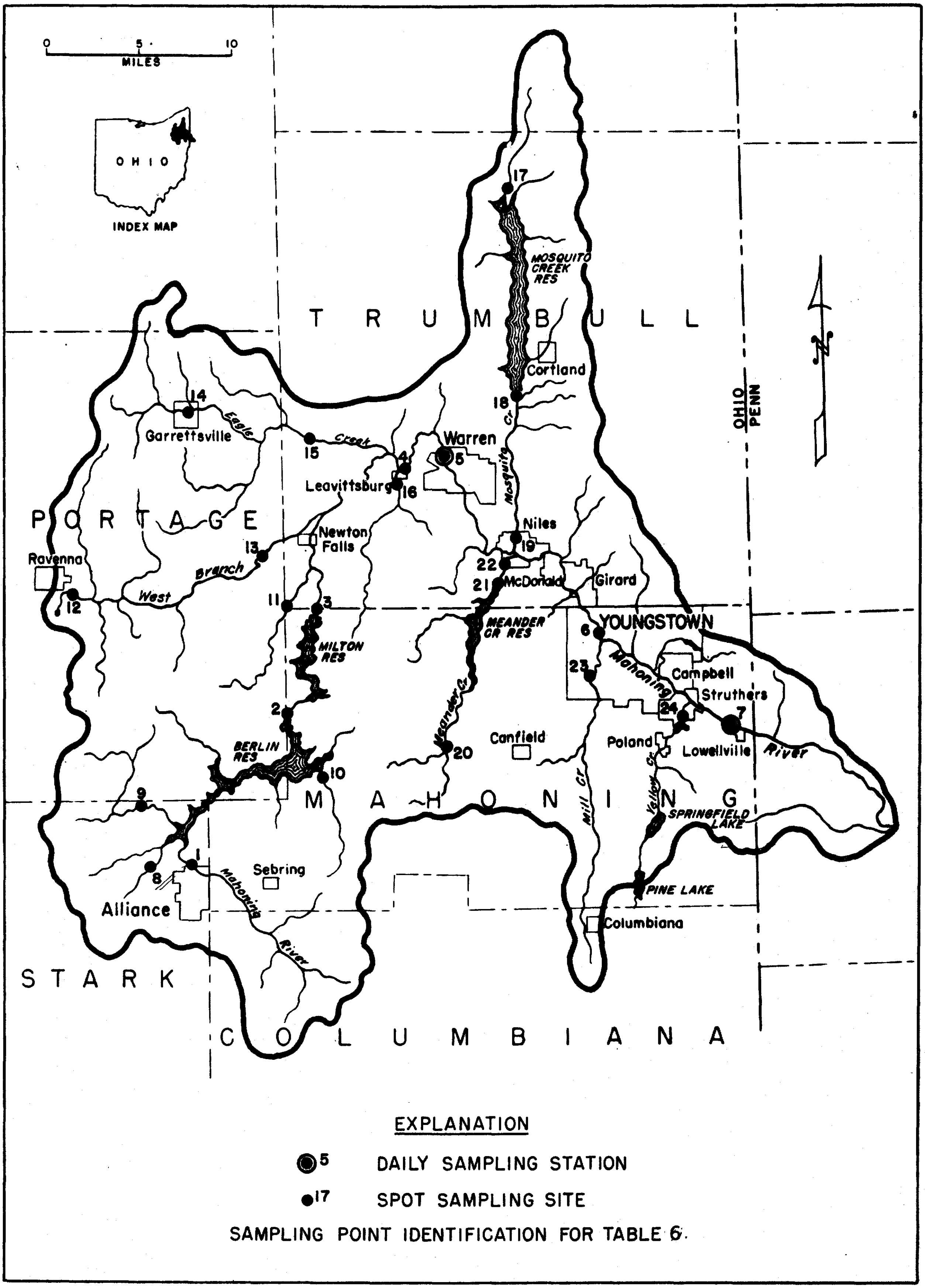

Figure 13.--Map of Mahoning River basin showing points at which surface-water samples were collected

Table 6.–Mineral constituents and related physical measurements for surface waters in the Mahoning River basin

Point a/ on map	Source	Date	Mean discharge (second-feet) b/	Color	pH	Specific conductance (micromhos at 25 C.)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$ Total	Hardness as $CaCO_3$ Noncarbonate
1	Mahoning River at Alliance	May 7, 1946---	22	10	7.4	596	4.4	.10	68	21	23		171	136	15	.4	1.8	376	256	116
2	Mahoning River below Berlin Dam, near Berlin Center ----------------	Oct. 7, 1949 --	125	5	7.5	476	.8	.06	52	15	17	3.0	80	120	28	.4	1.8	310	191	126
3	Mahoning River at Pricetown--------------	May 7, 1946---	92	14	7.3	299	1.6	.04	32	10	8.9		50	82	7.9	.1	3.3	178	121	80
3	Mahoning River at Pricetown--------------	Sept. 25, 1946-	307	10	7.1	283	.4	.03	34	8.6	9.5		67	73	5.8	.3	1.3	173	120	65
4	Mahoning River at Leavittsburg -----------	Oct. 6, 1951 --	--	7	7.6	372	3.4	.02	38	13	12	2.6	79	88	14	.2	1.2	223	150	84
5	Mahoning River at Warren (average Oct. 1946 to Sept. 1947)-------------	1946-1947-----	709	11	7.1	308	5.2	.06	36	9.8	7.8	2.8	61	74	7.7	.3	13	196	130	80
6	Mahoning River at Youngstown ------------	Sept. 26, 1946-	373	12	6.6	408	2.4	.09	48	10	24		35	138	23	1.1	7.0	269	161	132
6	Mahoning River at Youngstown ------------	Oct. 6, 1951 --	--	7	6.5	496	4.9	.06	44	14	20	6.9	23	161	24	1.4	2.8	312	166	148
7	Mahoning River at Lowellville-------------	May 7, 1946 --	581	15	6.1	585	4.6	.02	61	12	30		17	211	21	1.6	.2	c/374	202	188
7	Mahoning River at Lowellville-------------	Sept. 26, 1946-	434	8	6.1	605	5.2	.04	60	12	34		9	207	32	1.6	.1	381	199	192
7	Mahoning River at Lowellville-------------	Oct. 1-10, 1951		8	7.5	625	16	.04	64	18	27	13	77	197	32	1.4	.2	416	234	171
7	Mahoning River at Lowellville-------------	Oct. 11-20, 1951		5	7.6	717	19	.04	73	22	33	14	98	223	42	1.5	.2	479	273	192
7	Mahoning River at Lowellville-------------	Oct. 21-31, 1951		5	7.3	761	9.1	.04	77	20	35	15	69	247	45	1.8	.3	496	274	218
8	Beech Creek near Bolton -	Sept. 25, 1946--	.6	6	7.6	720	1.6	.03	86	27	32		284	121	24	.1	4.2	457	326	93
8	Beech Creek near Bolton -	Oct. 5, 1949 ---	.60	5	8.1	736	4.0	.05	94	32	27	4.6	d/312	129	17	.2	1.3	471	366	110

Table 6.—Mineral constituents and related physical measurements for surface waters in the Mahoning River basin—Continued

Point a/ on map	Source	Date	Mean discharge (second-feet) b/	Color	pH	Specific conductance (micromhos at 25 C.)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$ Total	Hardness as $CaCO_3$ Noncarbonate
9	Deer Creek at Limaville	Sept. 25, 1946	2.4	10	8.0	584	7.6	.06	83	25	7.7		279	85	6.0	.1	1.0	369	310	81
9	Deer Creek at Limaville	Oct. 28, 1947	4.7	18	8.2	557	8.4	.07	77	29	--		e/266	80	6.0	.1	.4	354	311	93
9	Deer Creek at Limaville	Mar. 16, 1948	129	14	7.2	292	4.6	.03	36	9.9	4.6		63	72	6.5	.3	5.1	178	130	79
9	Deer Creek at Limaville	Oct. 5, 1949	3.27	5	8.1	593	5.2	.06	88	26	5.0	1.6	f/278	88	6.5	.2	.7	372	326	99
10	Mill Creek near Berlin Center	Sept. 25, 1946	.6	46	7.9	1,140	18	.12	77	30	153		g/410	281	11	.8	.8	780	315	0
11	Kale Creek near Pricetown	Sept. 25, 1946	.1	10	7.6	961	4.0	.02	98	44	54		321	244	18	.1	.5	676	425	162
12	West Branch Mahoning River near Ravenna	Sept. 25, 1946	--	2	7.8	515	9.6	.03	74	20	7.8		249	71	4.0	.1	.2	320	267	63
13	West Branch Mahoning River near Newton Falls	May 7, 1946	67	36	7.5	337	4.4	.11	42	12	5.7		100	73	5.6	.2	.1	218	154	72
13	West Branch Mahoning River near Newton Falls	Sept. 25, 1946	7.4	7	8.0	621	7.6	.02	83	28	12		e/259	120	7.5	.1	.2	403	322	110
14	Eagle Creek at Garrettsville	Sept. 25, 1946	h/18	3	7.3	443	7.6	.04	60	18	5.1		202	60	3.8	.2	1.2	266	224	58
15	Eagle Creek at Phalanx Station	June 26, 1946	22	--	7.5	322	8.0	.04	42	11	6.5		122	50	6	.2	4.0	196	150	50
15	Eagle Creek at Phalanx Station	Sept. 25, 1946	15	6	7.6	411	4.0	.06	50	15	19		178	58	10	.2	1.0	244	181	36
16	Duck Creek at Leavittsburg	Sept. 25, 1946	.2	12	7.7	752	.2	.03	62	37	43		176	228	13	.1	.8	518	307	163
17	Mosquito Creek near Greene	Sept. 26, 1946	--	15	7.8	437	4.0	.08	56	18	12		250	28	4.0	.2	.4	252	214	9
18	Mosquito Creek below Mosquito Creek Dam, near Cortland	May 7, 1946	0	32	7.2	165	.8	.10	20	5.1	2.3		46	31	3.1	.2	1.2	110	71	33
18	Mosquito Creek below Mosquito Creek Dam, near Cortland	Sept. 26, 1946	38	27	6.6	184	--	--	--	--	--		59	--	--	.2	5.3	--	--	--

Table 6. –Mineral constituents and related physical measurements for surface waters in the Mahoning River basin–Continued

Point a/ on map	Source	Date	Mean discharge (second-feet)b/	Color	pH	Specific conductance (micromhos at 25 C.)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$ Total	Hardness as $CaCO_3$ Noncarbonate
18	Mosquito Creek below Mosquito Creek Dam, near Cortland ---------	Nov. 5, 1951 ---	--	10	6.9	142	.4	.03	17	4.0	2.7	2.3	32	30	3.8	.2	3.1	96	58	33
19	Mosquito Creek at Niles	Sept. 26, 1946--	35	22	6.7	199	.4	.04	24	5.4	5.5		53	29	4.2	3.2	7.6	136	82	39
20	Meander Creek near Ellsworth -------------	Sept. 25, 1946--	--	5	7.9	654	6.4	.02	86	27	14		236	146	7.5	.1	.2	431	326	132
21	Meander Creek Reservoir at Mineral Ridge-------	May 9, 1946----	--	13	7.4	294	.8	.11	31	11	7.2		51	84	5.5	.1	1.2	177	123	81
21	Meander Creek Reservoir at Mineral Ridge-------	Sept. 27, 1946--	--	9	7.2	244	.2	.03	28	8.8	6.4		58	64	3.5	.2	.4	150	106	58
22	Meander Creek at Niles	Sept. 27, 1946--	--	5	2.90	1,330	14	4.1	121	13	23		0	517	7.0	.3	1.8	i/736	501	501
22	Meander Creek at Niles	Nov. 5, 1951 ---	--	5	7.4	705	4.6	.02	86	29	22	11	71	310	12	.2	1.5	529	331	276
23	Mill Creek at Youngstown	May 7, 1946----	17	8	7.6	472	2.2	.08	56	18	11		106	129	11	.3	.4	299	214	127
23	Mill Creek at Youngstown	Sept. 26, 1946--	1.7	9	7.4	580	1.6	.08	70	24	17		147	165	12	.4	.7	382	273	153
23	Mill Creek at Youngstown	Nov. 3, 1951 ---	--	7	7.4	636	3.6	.02	75	29	15	5.8	122	223	13	.4	1.0	442	304	206
24	Hamilton Lake near Struthers -------------	Sept. 26, 1946--	--	9	6.8	276	1.2	.04	34	9.0	5.8		55	74	5.5	.3	4.6	176	122	77

a/ See numbered points on map (fig. 13) for location.
b/ Water discharge records for October 1949 are current meter measurements. or computed provisional discharge at time of sampling.
c/ Includes 0.45 part of manganese (Mn).
d/ Includes equivalent of 18 parts carbonate (CO_3).
e/ Includes equivalent of 7 parts carbonate (CO_3).
f/ Includes equivalent of 8 parts carbonate (CO_3).
g/ Includes equivalent of 13 parts of carbonate (CO_3).
h/ Current meter measurement at time of sampling.
i/ Includes 11 parts aluminum (Al); 1.2 parts manganese (Mn); total acidity is 154 parts as H_2SO_4.

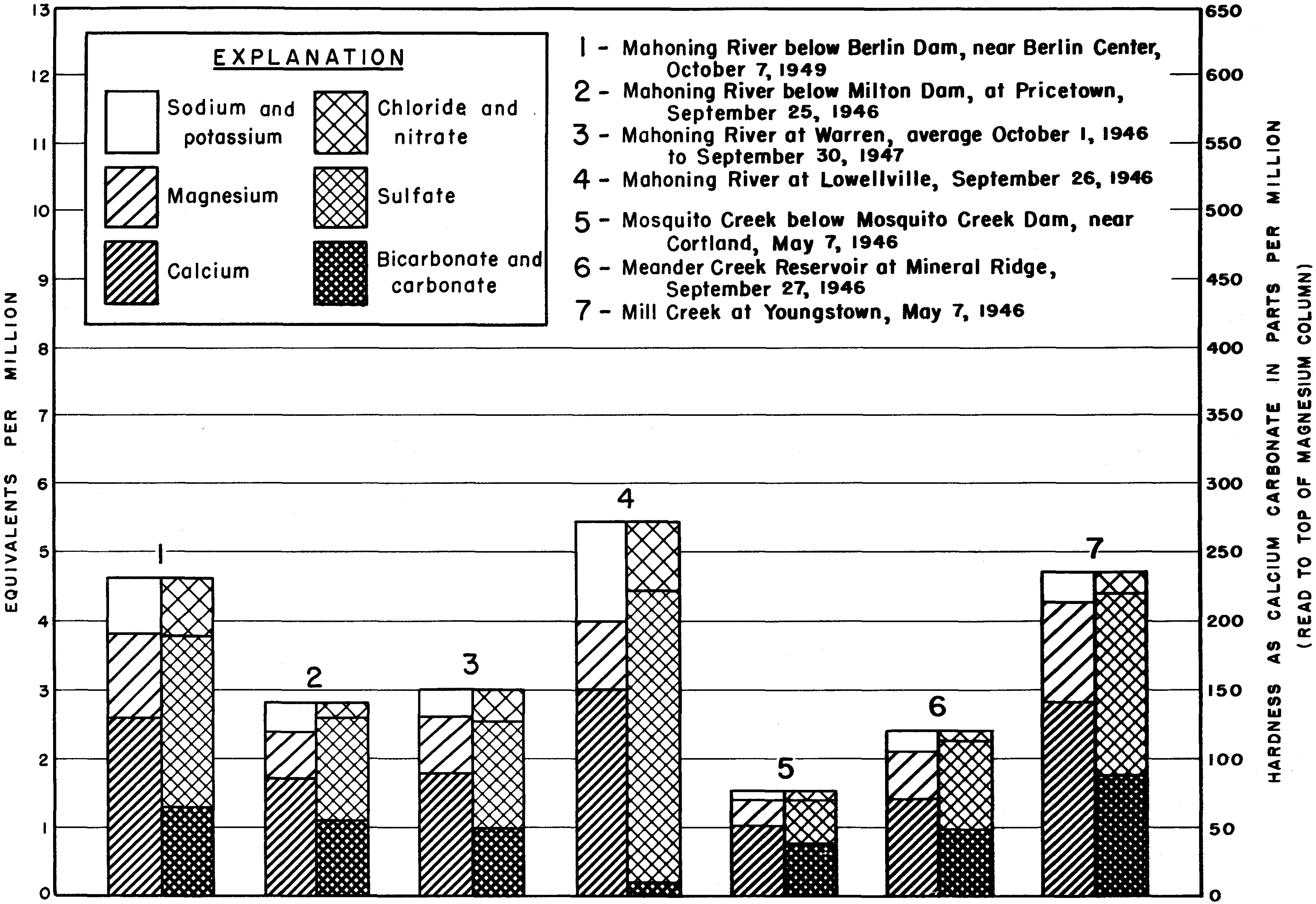

Figure 14.--Composition of selected surface waters in the Mahoning River basin.

Table 7.–Mineral constituents and related physical measurements for daily sampling station on Mahoning River at Warren, Ohio, during July 1946 to September 1948

Date	Mean discharge (second-feet)	Temperature (°F.)	Color	pH	Specific conductance (micromhos at 25°C.)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$	
																		Total	Noncarbonate
July 1-10, 1946---	363	76	7	7.1	290	4.3	0.02	34	9.9	7.2	2.8	64	77	6.8	0.2	2.4	188	126	73
July 11-20 -------	352	77	6	7.2	296	4.7	.02	34	10	7.3	2.6	65	74	7.0	.1	2.8	187	126	73
July 21-31 -------	361	75	6	7.2	296	4.4	.03	35	10	7.2	2.6	68	74	7.5	.2	2.8	189	128	73
Aug. 1-10 -------	350	75	13	7.3	290	3.8	.06	34	9.5	8.4	3.0	68	72	6.8	.2	2.5	180	124	68
Aug. 11-20 ------	357	73	13	7.3	292	4.4	.04	35	9.3	8.5	3.2	68	74	6.5	.3	2.4	181	126	70
Aug. 21-31 ------	345	71	13	7.4	292	3.5	.02	34	9.4	8.4	3.1	70	74	7.5	.2	1.8	181	124	66
Sept. 1-10 -------	340	70	13	7.4	287	2.0	.02	34	9.3	7.9	3.1	68	72	7.2	.2	1.8	178	123	67
Sept. 11-20 ------	343	70	8	7.2	289	2.0	.01	35	9.7	7.3	2.9	72	73	6.8	.2	1.5	180	127	68
Sept. 21-30 ------	341	70	9	7.4	302	8.6	.02	36	9.3	7.7	3.3	77	70	7.1	.2	3.2	188	128	65

Table 7. –Mineral constituents and related physical measurements for daily sampling station on Mahoning River at Warren, Ohio, during July 1946 to September 1948–Continued

Date	Mean discharge (second-feet)	Temperature (° F.)	Color	pH	Specific conductance (micromhos at 25° C.)	Silica (SiO$_2$)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO$_3$)	Sulfate (SO$_4$)	Chloride (Cl)	Fluoride (F)	Nitrate (NO$_3$)	Dissolved solids	Hardness as CaCO$_3$	
																		Total	Noncarbonate
Oct. 1-10, 1946	238	63	10	7.2	321	2.0	0.01	38	10	8.5	3.1	85	73	7.8	0.3	1.4	198	136	66
Oct. 11-20	245	61	12	7.4	366	3.4	.01	43	12	9.8	3.7	100	83	8.6	.3	1.2	230	157	75
Oct. 21-31	209	60	10	7.3	369	3.7	.01	44	12	9.8	3.7	96	86	9.5	.3	1.4	233	159	80
Nov. 1-10	199	61	10	7.4	373	3.8	.01	46	12	11	3.4	102	85	9.8	.2	1.2	230	164	80
Nov. 11-20	211	50	10	7.5	395	3.6	.01	48	13	13	2.9	109	89	10	.3	1.4	245	173	84
Nov. 21-30	265	46	9	7.3	403	2.8	.02	48	14	13	3.5	103	96	11	.3	3.8	254	177	93
Dec. 1-10	194	43	4	7.3	423	3.5	.02	49	14	12	3.6	98	102	12	.3	6.7	263	180	100
Dec. 11-20	469	40	10	7.2	369	7.1	.05	42	12	9.7	3.7	69	95	10	.2	7.6	234	154	98
Dec. 21-31	241	39	6	7.2	445	6.5	.03	50	15	13	3.4	92	104	14	.3	12	281	186	111
Jan. 1-10, 1947	533	36	8	7.2	317	6.7	.04	36	10	8.2	3.1	56	83	9.0	.2	7.4	200	131	85
Jan. 11-20	810	37	8	7.1	320	6.6	.05	36	11	7.2	2.6	54	84	9.0	.2	8.2	202	135	91
Jan. 21-31	1,596	37	8	7.0	269	7.8	.07	32	9.4	6.1	3.0	42	75	7.1	.2	9.4	184	118	64
Feb. 1-10	1,276	37	5	7.1	345	8.8	.07	40	11	8.9	3.0	59	94	9.1	.1	10	231	145	97
Feb. 11-20	377	36	8	6.8	367	5.6	.04	41	12	11	3.4	51	93	10	.2	22	236	152	110
Feb. 21-28	298	36	8	6.9	357	5.6	.02	41	12	10	3.6	56	92	10	.1	19	232	152	106
Mar. 1-10	300	35	6	6.7	389	8.0	.07	41	11	9.3	3.1	44	88	10	.3	45	241	148	112
Mar. 11-20	460	37	8	7.0	321	7.7	.26	35	9.5	8.6	1.5	48	77	8.9	.2	25	202	126	87
Mar. 21-31	996	38	8	6.8	256	7.3	.12	29	7.3	5.8	2.4	32	65	7.4	.2	14	166	102	76
Apr. 1-10	1,687	48	20	6.8	185	6.2	.22	22	5.4	3.8	2.6	26	48	4.9	.4	10	122	77	56
Apr. 11-20	496	53	15	6.9	275	5.5	.07	31	8.8	6.5	2.6	50	67	7.4	.2	13	178	114	73
Apr. 21-30	1,356	51	27	6.7	210	5.5	.13	24	6.2	4.7	2.2	38	55	4.6	.2	8.4	139	85	54
May 1-10	660	56	12	7.1	256	5.0	.04	29	7.9	6.1	2.3	48	61	5.5	.1	9.0	165	105	60
May 11-20	569	60	16	7.1	280	4.7	.05	32	9.0	6.7	2.4	51	66	5.8	.1	14	180	117	75
May 21-31	2,434	64	18	7.0	207	5.1	.07	24	6.8	4.5	2.1	44	53	4.4	.5	6.1	137	88	52
June 1-10	3,401	67	27	7.1	209	5.7	.13	25	6.5	4.2	2.2	43	54	4.4	.5	5.3	137	89	54
June 11-20	1,386	70	17	7.1	255	5.9	.07	30	8.0	3.2	2.3	54	61	5.4	.5	12	166	108	64
June 21-30	475	73	12	7.2	281	6.9	.04	34	9.1	5.7	2.4	55	68	5.6	.4	24	185	122	77
July 1-10	442	74	7	7.3	286	4.4	.04	33	8.8	6.5	2.2	56	67	6.4	.5	18	184	119	73
July 11-20	397	75	10	7.2	309	4.5	.04	36	9.6	7.3	2.2	56	68	7.4	.3	28	202	129	83
July 21-31	381	73	18	7.1	290	3.6	.05	35	8.9	7.9	2.4	58	69	7.2	.2	15	186	124	76
Aug. 1-10	319	77	7	7.5	288	5.1	.02	35	9.1	6.8	2.5	60	67	5.9	.3	13	185	125	81
Aug. 11-20	474	79	10	7.3	277	5.4	.03	32	8.9	6.8	2.9	58	66	5.9	.4	14	176	116	69
Aug. 21-31	554	77	7	7.1	264	5.1	.04	32	8.1	5.9	2.7	50	60	5.6	.4	23	168	113	72
Sept. 1-10	494	76	8	7.1	269	4.1	.02	32	8.8	5.7	2.6	49	58	5.8	.4	24	166	116	76
Sept. 11-20	448	76	3	7.2	267	3.1	.02	31	8.4	5.8	2.9	48	60	5.8	.2	21	166	112	73
Sept. 21-30	417	66	7	7.0	280	2.4	.01	33	8.7	6.0	3.0	52	62	6.4	.2	22	169	118	76
Average	709	56	11	--	308	5.2	.06	36	9.8	7.8	2.8	61	74	7.7	.3	13	196	130	80

Table 7. –Mineral constituents and related physical measurements for daily sampling station on Mahoning River at Warren, Ohio, during July 1946 to September 1948–Continued

Date	Mean discharge (second-feet)	Temperature (°F.)	Color	pH	Specific conductance (micromhos at 25 C.)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$	
																		Total	Noncarbonate
Oct. 1-10, 1947 --	312	62	20	6.8	286	2.6	0.06	33	9.2	4.2		42	66	6.0	0.3	21	194	120	86
Oct. 11-20 -------	277	63	20	6.8	292	--	--	--	--	--		43	67	7.2	--	--	--	--	--
Oct. 21-31 -------	278	61	25	6.9	307	--	--	--	--	--		51	72	8.0	--	--	--	--	--
Nov. 1-10--------	288	54	25	7.0	357	--	--	--	--	--		60	79	9.0	--	--	--	--	--
Nov. 11-20-------	251	45	30	7.0	357	--	--	--	--	--		56	81	10	--	--	--	--	--
Nov. 21-30-------	232	39	30	7.0	397	--	--	--	--	--		60	84	11	--	--	--	--	--
Dec. 1-10--------	231	39	5	6.6	442	--	--	--	--	--		58	93	13	--	66	--	--	--
Dec. 11-20-------	233	37	7	6.7	473	--	--	--	--	--		59	102	13	--	92	--	--	--
Dec. 21-31-------	178	39	8	6.6	497	--	--	--	--	--		55	112	18	--	68	--	--	--
Jan. 1-10, 1948 --	418	37	13	6.7	429	4.6	.08	45	15	10		38	105	15	.2	43	270	174	143
Jan. 11-20 ------	207	37	7	6.6	508	--	--	--	--	--		56	121	18	--	61	--	--	--
Jan. 21-31 -------	169	40	9	6.5	575	--	--	--	--	--		54	125	20	--	111	--	--	--
Feb. 1-10--------	160	40	17	6.8	598	--	--	--	--	--		84	124	22	--	100	--	--	--
Feb. 11-13-------	180	41	9	6.7	632	--	--	--	--	--		60	117	23	--	77	--	--	--
Feb. 14-20-------	1,209	36	18	6.8	249	--	--	--	--	--		25	61	9	--	22	--	--	--
Feb. 21-29-------	386	38	17	6.5	336	--	--	--	--	--		23	78	11	--	39	--	--	--
Mar. 1-10 -------	364	36	13	6.8	333	--	--	--	--	--		28	87	12	--	28	--	--	--
Mar. 11-20 ------	818	40	17	6.5	355	--	--	--	--	--		34	87	12	.2	34	--	--	--
Mar. 21-31 ------	615	48	28	6.8	283	--	--	--	--	--		32	74	8	.2	20	--	--	--
Apr. 1-10--------	248	55	7	6.8	356	4.0	.06	40	12	8.2		50	84	11	.1	30	227	149	108
Apr. 11-20-------	975	53	21	6.8	260	--	--	--	--	--		38	69	6	--	11	--	--	--
Apr. 21-30-------	562	59	13	7.1	306	--	--	--	--	--		55	72	8	--	12	--	--	--
May 1-10 --------	1,670	57	24	7.1	232	--	--	--	--	--		40	59	6	--	6.3	--	--	--
May 11-20 -------	1,251	61	20	7.2	262	--	--	--	--	--		44	64	8	--	9.9	--	--	--
May 21-31 -------	391	62	8	7.0	313	--	--	--	--	--		54	81	10	--	14	--	--	--
June 1-10 --------	362	65	9	7.3	334	--	--	--	--	--		51	85	12	--	19	--	--	--
June 11-20 -------	419	69	8	7.1	343	--	--	--	--	--		58	86	10	--	17	--	--	--
June 21-30 -------	377	74	7	7.2	334	--	--	--	--	--		58	81	10	--	14	--	--	--
July 1-10 --------	343	73	7	7.1	341	4.4	.06	38	11	7.1		53	82	10	.2	15	206	140	97
July 11-20 -------	322	75	6	7.3	339	--	--	--	--	--		57	84	9	--	15	--	--	--
July 21-31 -------	368	74	7	7.1	351	--	--	--	--	--		57	84	12	--	18	--	--	--
Aug. 1-10--------	328	71	4	7.3	353	--	--	--	--	--		62	76	10	--	10	--	--	--
Aug. 11-20-------	418	71	6	7.1	350	--	--	--	--	--		60	69	10	--	21	--	--	--
Aug. 21-31-------	338	75	6	7.3	344	--	--	--	--	--		68	75	10	--	9.5	--	--	--
Sept. 1-10 -------	331	71	7	7.1	359	--	--	--	--	--		63	90	13	--	13	--	--	--
Sept. 11-20 ------	340	70	8	7.2	359	--	--	--	--	--		66	92	14	--	9.2			
Sept. 21-30 ------	349	65	6	7.2	373	--	--	--	--	--		68	89	13	--	14	--	--	--
Average ------	436	55	13	--	368	--	--	--	--	--		52	85	12	--	32	--	--	--

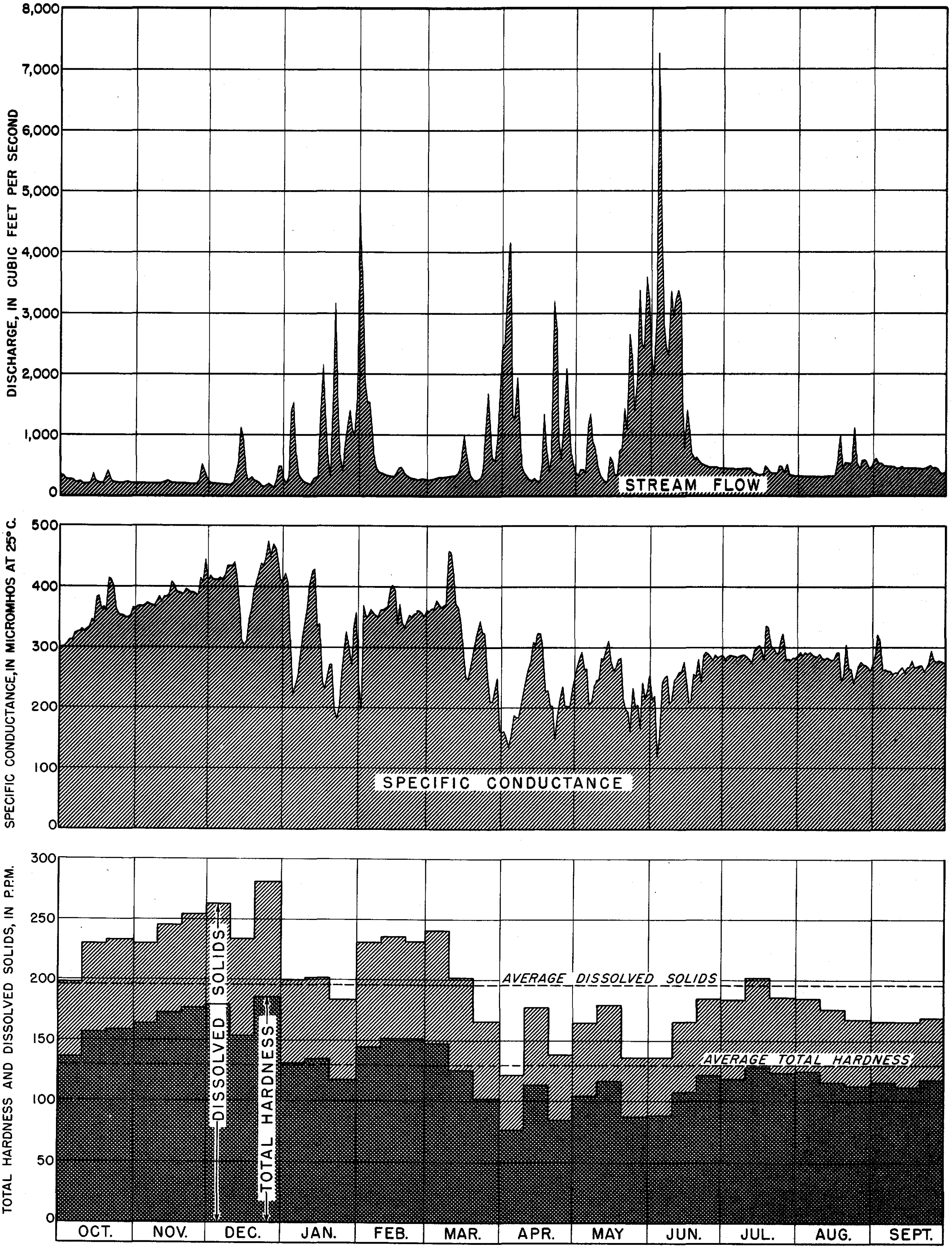

Figure 15.—Relation of total hardness, dissolved solids, and specific conductance to streamflow, Mahoning River at Warren, Ohio, water year Oct. 1946 to Sept. 1947.

ren the daily specific conductance of the water varied from 119 to 680 micromhos. The specific conductance of water is a measure of the extent of ionized chemicals dissolved in the water. From the specific conductance it can be estimated that the dissolved solids at Warren varied during the 2¼ yr period from about 75 to about 430 ppm. This great variation is due to a combination of pollution and many natural factors, such as climatic conditions, which affect the chemical character of a stream, and which could be expected to be even greater if it were not for the diluting effect of water from Berlin and Milton Reservoirs.

During the water year October 1947 to September 1948 pollution of the Mahoning River with nitrate wastes was particularly noticeable at Warren and the maximum mean concentration for a 10-day period reached 111 ppm (table 7). High-nitrate waters are of critical significance because of the probable relationship between the presence of appreciable concentration of nitrate in drinking water and the incidence of methemoglobinemia—the condition causing "blue babies." This high-nitrate content was due to industrial pollution and alleviation of this condition is now reported by the Ohio State Department of Health. Recent analyses of the Mahoning River at Leavittsburg, Youngstown, and Lowellville show that the nitrate is low (table 6).

Information on the suspended sediment was obtained from the composite samples taken from the Mahoning River at Warren. The samples were collected primarily to represent the dissolved constituents in the river water; therefore, the results for suspended sediment do not give a reliable indication of the sediment concentration, size, or type of material. They do, however, give a rough measure of sediment carried and the three-per-month composites during the period of record showed a range of concentration of suspended sediment from about 7 to about 99 ppm. Some reduction in sediment concentration is to be expected by the flood storage reservoirs.

A comparison between the October 6, 1951, analysis at Youngstown and the October 1-10, 1951, composite analysis at Lowellville (see table 6) indicates an increase of about 100 ppm in the dissolved solids at Lowellville. The increase is mainly in the calcium, bicarbonate, sulfate, and chloride. Most of this increase is from industrial and municipal pollution between Youngstown and Lowellville. The average dissolved solids at Lowellville during October 1951 was more than twice as much as the average at Warren during the water year 1946-47. Samples collected at Lowellville about every 2 weeks during October and November 1951 showed a range of 0.044 to 0.557 ppm of phenols; cyanide ranged from 0.1 to 0.5 ppm; dissolved oxygen ranged from 1.8 to 5.1 ppm. The station at Lowellville has not been in operation long enough to include the warm months or the lowest streamflow periods; therefore, the results do not show the worst conditions. For example, dissolved oxygen has at times been reported as low as zero at various points in the river between Lowellville and Warren. Copper and chromium were determined as zero in the composite samples for October. The water temperature during October was rather high, ranging from 85 F to 104 F. In November the water temperatures ranged from 48 F to 93 F.

Table 8 shows the range in concentration of chemical constituents and in related physical measurements of the surface waters throughout the basin. It is based on a total of 123 analyses of spot samples and composites of daily samples. A more complete coverage might indicate even a greater range in the chemical quality. To illustrate the different qualities of waters found in the Mahoning River basin, the main dissolved constituents found in selected water samples are shown graphically in figure 14. The heights of the sections on the left side of each double column are proportional to the equivalents per million of the principal cations (positive ions), calcium, magnesium, and sodium plus potassium. The heights of the sections on the right side of each double column are proportional to the equivalents per million of the principal anions (negative ions), bicarbonate plus carbonate, sulfate, and chloride plus nitrate. Total hardness may be measured on these diagrams, in parts per million of calcium carbonate, to the top of the magnesium column using the scale on the right side of the figure.

The analyses in figures 14 and 22 are expressed in equivalents per million instead of parts per million. The equivalents per million for each constituent is calculated by dividing its concentration in parts per million by its chemical combining weight. Equivalents per million are more useful than parts per million when hypothetical combinations are being made of positive and negative ions. For example, 1 equivalent per million of sodium would combine with 1 equivalent per million of chloride or with 1 equivalent per million of sulfate. However, 23 ppm of sodium would combine with 35.46 ppm of chloride or with 48.03 ppm of sulfate.

Table 8.—Range in concentration of chemical constituents and in related physical measurements of surface waters in the Mahoning River basin, based on 123 analyses

[Chemical results in parts per million]

	Minimum	Maximum		Minimum	Maximum
pH	2.90	8.2	Bicarbonate (HCO_3)	0	410
Specific conductance micromhos at 25 C	142	1,330	Sulfate (SO_4)	28	517
Silica (SiO_2)	.2	18	Chloride (Cl)	3.1	32
Iron (Fe)	.01	4.1	Fluoride (F)	.1	3.2
Calcium (Ca)	17	121	Nitrate (NO_3)	.1	111
Magnesium (Mg)	4.0	44	Dissolved solids	96	780
Sodium + Potassium (Na+K)	2.3	153	Hardness as $CaCO_3$	58	501

Temperature

The excessively high temperatures of Mahoning River water constitute one of the serious water problems facing the Youngstown area. A series of low dams in the heavily industrialized reach of the river from Warren to Lowellville form pools from which water is pumped into power plants, steel mills and other industries. About 95 percent of the pumped water is used for cooling purposes and is returned to the river unchanged in quality except for higher temperature. The total industrial pumpage from the river in 1949 averaged about 1,200 mgd, or 1,800 cfs. This pumpage is more than twice the average annual flow, and about 14 times the minimum daily flow that has occurred since the last of the four reservoirs was placed in operation. Recent expansion, including the addition of the power plant at Niles, has increased the industrial use of Mahoning River water to more than 1,500 mgd (Mahoning Valley Industrial Council, 1951).

Several of the industrial plants using Mahoning River water observe water temperatures at their intake structures. River temperatures have been measured continuously since 1935 at the no. 5 power house intake of the Campbell plant of the Youngstown Sheet and Tube Company, and intermittently prior to that date. The maximum daily and the mean monthly temperatures from June 1943 to date, at this location, are shown in table 9. Recently, the U. S. Geological Survey has installed recording thermometers at Niles and Lowellville, and a nonrecording thermometer at Leavittsburg. The maximum daily and mean monthly temperatures for the year ending September 30, 1950, at these locations are shown graphically on figure 16.

River temperatures on streams unaffected by industrial use approximate the mean monthly air temperatures. The difference between mean air temperatures and mean river temperatures is therefore a measure of the effect of industrial use on river temperatures. The increase in temperature is affected by the flow of the river, the total water circulated through industrial plants, and the heat added to this water. The river temperatures therefore vary with air temperatures, streamflow, pumpage and plant operation. In the Youngstown area production has been maintained at a high rate during and since World War II, except during a strike in October-November 1949; and pumpage is at a remarkably uniform but increasing rate. Generally the river temperature depends on air temperature and streamflow.

The highest daily mean water temperature recorded at the Campbell plant was 117 F in July 1941, with a monthly mean temperature of 107.8 F. Since 1944, when the last of the four reservoirs went into operation flows have been such that maximum daily temperatures have been only occasionally above 100 F, and monthly mean temperatures have been below 98 F. Thus the increased low water flows from the operation of Berlin and Mosquito Creek Reservoirs have had a beneficial effect on river temperatures. However, the temperatures are still extremely high with adverse effect on plant operation and economy of production.

Barnes, in a report on the proposed Lowellville Dam and Pool (Barnes, 1941), reached the conclusion that the cooling effect in the pools in the Mahoning River could not be substantially increased because of lack of space in the valley. As shown on figure 17 increased streamflow reduces the difference between stream temperatures and air temperatures. However, as pointed out by Barnes, the reduction is less than might be expected because of reduced time of travel through the pools, and less thorough mixing. During freezing weather there apparently is less mixing than usual so that increases in river temperatures are abnormally high, but this is not critical because of the low air and river temperatures. Some of the scattering of the data of figure 17 is caused by this effect, and some by variations in pumpage and production. This diagram would indicate that increasing low flows to 400 cfs would markedly reduce river temperatures; increasing flows from 400 to 800 cfs would further reduce river temperatures, but less markedly; increasing flows beyond 800 cfs would only slightly improve temperature conditions. The Corps of Engineers has prepared curves similar to figure 17 for each year since completion of Berlin and Mosquito Creek Reservoirs. These curves vary from year to year, apparently in proportion to steel production.

High river temperatures may be considered as pollution – in fact, it is difficult to separate the deleterious effects of high temperatures, raw sewage, and heavy concentrations of industrial wastes. In addition to condenser cooling, water is used in large quantity for cooling bearings, oil, air compressors, rolls in the steel mills, and other machinery; for spray cleaning of steel and other products; for pickling; for sanitary uses and other miscellaneous purposes. High temperatures of cooling water decrease the efficiency of machinery and therefore increase cost of pumping and decrease total production. When the cooling fluid is a mixture of river water, raw sewage and concentrated industrial wastes as in the Youngstown area, the high temperatures not only cause obnoxious odors and unsanitary conditions but also hasten the deterioration of equipment, thereby greatly increasing replacement and maintenance costs. High temperatures also diminish the effectiveness of natural processes in streams that reduce organic pollution, by inhibiting bacteria and by decreasing the dissolved oxygen content essential for such processes. Fish and other aquatic life likewise are adversely affected by high water temperatures.

Increasing low water streamflow would aid materially in solving the pollution problem, both in reducing the temperatures and in diluting the sewage and waste pollution.

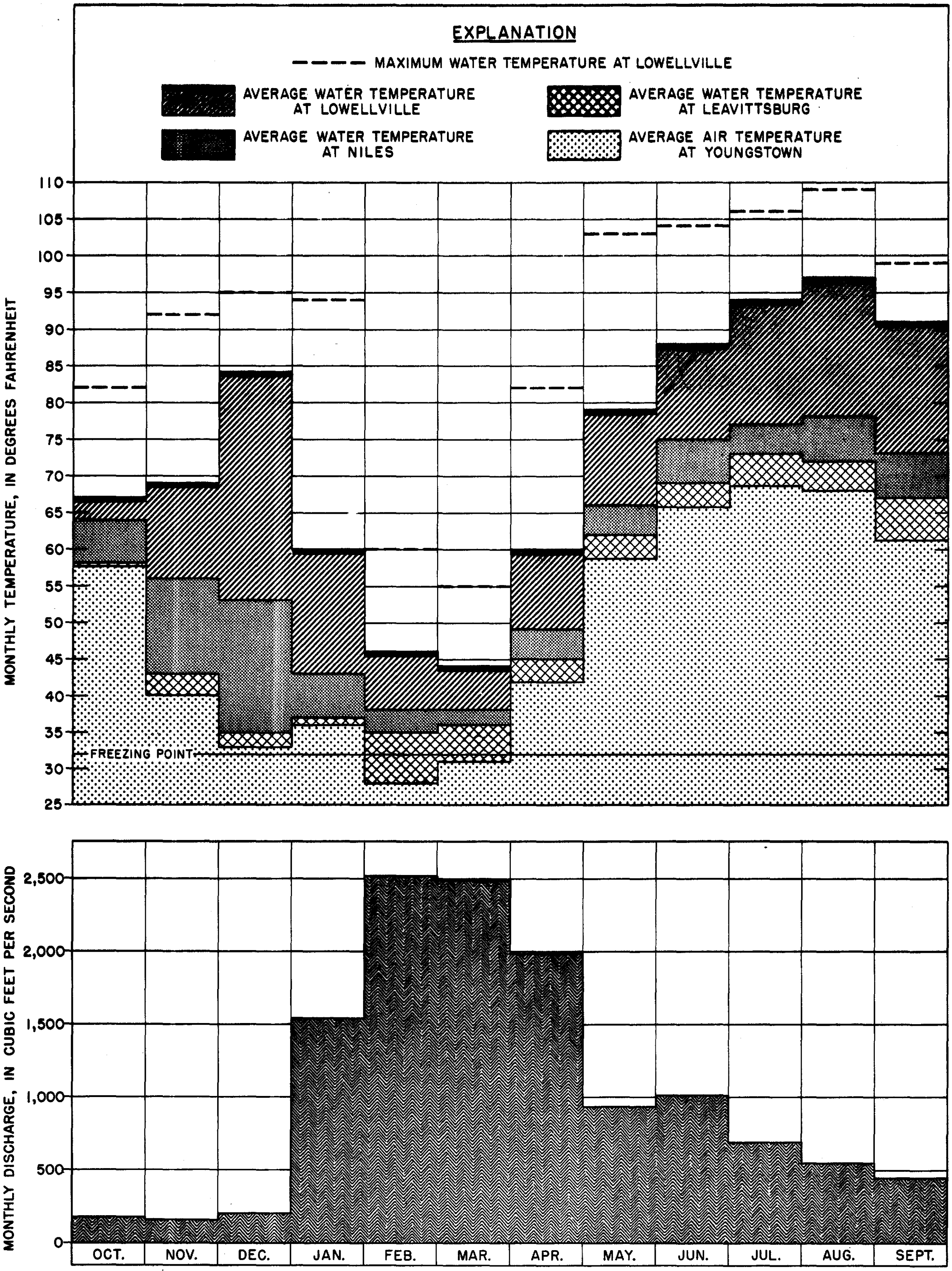

Figure 16. -Water temperatures, air temperatures, and flow of Mahoning River for year ending September 30, 1950.

Table 9.–Maximum daily and monthly mean temperature of Mahoning River water at the No. 5 power house intake of the Campbell Plant of the Youngstown Sheet and Tube Co.

[Maximum average daily temperatures and mean temperatures, by months, in degrees F]

	October		November		December		January		February		March	
Water year	Maximum daily	Monthly mean	Maximum daily	Monthly mean	Maximum daily	Monthly mean	Maximum daily	Monthly mean	Maximum daily	Monthly mean	Maximum daily	Monthly mean
1940												
1941	106	99.5										
1942	111	100.5	98	86.4								
1943												
1944	99.0	90.6	90.0	81.6	90.0	79.9	92.0	80.3	88.5	74.4	76.5	62.1
1945	101.5	94.2	96.5	87.7	90.0	79.5	79.0	72.2	85.0	63.0	75.0	58.8
1946	85.5	70.1	77.0	64.2	61.0	55.0	56.0	48.5	58.0	45.8	76.5	57.8
1947	96.0	89.7	95.5	82.7	77.0	64.8	74.0	54.0	65.0	53.6	72.0	60.0
1948	96.5	93.0	92.0	82.0	83.0	75.5	81.0	70.1	84.0	65.9	77.0	63.9
1949	98.5	91.6	96.0	86.4	87.0	70.1	73.5	57.5	68.0	54.0	73.0	59.6
1950	*70.5	*60.8	87.0	68.0	85.0	79.2	84.0	53.5	52.0	42.8	55.0	47.6
1951	100.0	94.7	97.0	79.0	67.0	52.8	71.0	53.1	53.0	47.5	56.0	50.4

	April		May		June		July		August		September	
Water year	Maximum daily	Monthly mean	Maximum daily	Monthly mean	Maximum daily	Monthly mean	Maximum daily	Monthly mean	Maximum daily	Monthly mean	Maximum daily	Monthly mean
1940											110	104.2
1941			110	102.9	116	103.1	117	107.8	115	105.5	115	109.8
1942	102	73.1	104	87.5	110	99.7	115	108.2				
1943					110.0	97.7	108.5	103.1	110.5	102.7	102.5	94.4
1944	85.0	70.9	104.5	93.0	108.5	100.9	104.0	100.6	107.0	101.0	104.0	96.0
1945	84.5	74.2	88.0	78.3	101.0	90.7	101.0	96.3	100.5	92.7	100.0	91.1
1946	86.5	79.5	89.0	69.6	95.5	80.0	99.5	93.5	97.0	92.1	99.0	94.3
1947	73.0	58.3	75.0	67.2	86.0	74.3	95.0	86.3	97.5	93.2	98.0	90.9
1948	79.0	67.8	92.0	72.3	98.0	92.0	99.0	94.8	99.0	93.7	99.0	95.2
1949	81.5	69.3	100.5	89.9	100.0	95.8	98.5	92.4	97.0	92.6	96.0	89.6
1950	77.0	61.5	95.5	78.3	97.5	88.1	98.5	93.8	102.0	97.3	98.0	95.1
1951	75.0	59.8	96.0	84.1	104.0	95.6	101.0	96.2	100.0	96.7	100.0	95.2

*Affected by strike.

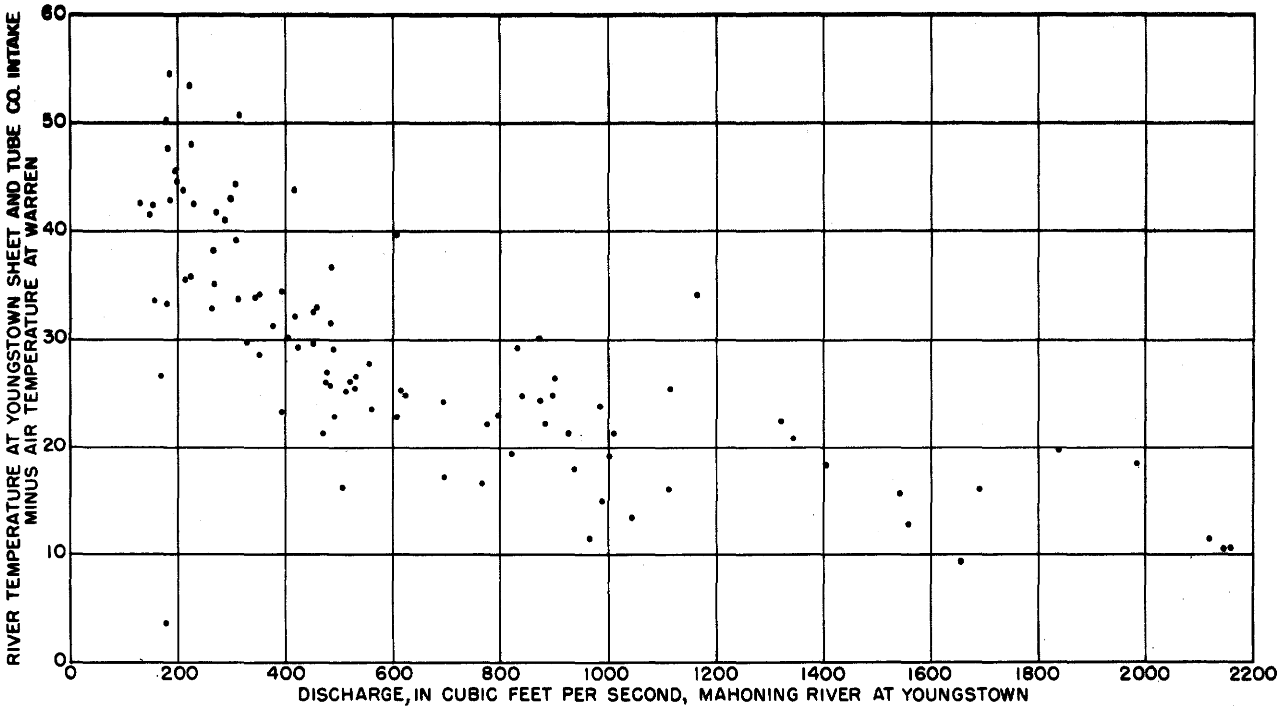

Figure 17.–Temperature-discharge relations, Mahoning River at Youngstown.

Pollution

The water in the upper reaches of the Mahoning River and its tributaries is satisfactory for most purposes but increasing pollution is prevalent downstream to such an extent that below Warren the river has become unsuitable for public water supply. Very few municipalities in this basin have sewage treatment plants at present though many are planning to construct sewage treatment facilities in the near future. The Ohio Department of Health reports that in the Mahoning River basin the reduction in municipal sewage pollution loads by treatment, as of October 1951, amounts to only 9.6 percent. This reduces the pollution load from municipal sources to 336,528 population equivalents of organic or oxygen-demanding products. More than 80 percent of the sewage enters the river in the 25-mile stretch between Warren and Lowellville.

The following summary furnished by the Ohio Department of Health shows the extent, as of October 1951, of the municipal and industrial pollution (organic) loads discharged into the Mahoning River basin expressed as population equivalents:

Pollution loads prior to treatment

Municipal (pop. equiv.)	Industrial (pop. equiv.)	Total (pop. equiv.)	Municipal load as part of total (percent)
372,891	265,630	638,521	58.5

Percent reduction in loads effected by treatment

Municipal	Industrial	Total
9.6	51.7	27.4

Pollution loads as discharged after treatment

Municipal (pop. equiv.)	Industrial (pop. equiv.)	Total (pop. equiv.)	Municipal load as part of total (percent)
336,528	128,160	464,688	72.4

In the above summary, industrial loads are estimates based upon information obtained from industrial managements on preliminary evaluation (fact finding) surveys. Industrial loads take account of oxygen-demanding properties of liquid wastes from two tar-refining plants and four byproduct coke plants. Approximately 15,000 tons of coal are carbonized (coked) daily in the Warren-Youngstown area.

Phenol characteristics of these industrial wastes present a pollution problem (taste and odor) which has particular significance in the use of the Beaver River for municipal water supply. Recent periodic determinations of phenols in the Mahoning River at Lowellville by the Ohio Department of Health indicated a maximum at that point of 1.2 ppm. At several points upstream from Lowellville the phenol was sometimes higher.

In addition to the organic loads, forty-two major industrial establishments in the Mahoning River basin produce liquid wastes containing toxic metals, acid-iron wastes, and/or other mineral matter that are pollutants but which cannot be expressed satisfactorily in population equivalents. These are: seven blast furnace plants, seventeen steel mills, twelve steel and metal fabrication plants, and six electroplating establishments.

The Ohio Department of Health is working with the industries and municipalities in an effort to decrease further the amount of pollution load in the Mahoning River. The efficiency of phenol-removal measures has been greatly increased and other reductions in pollution loads have already been accomplished as a result of this cooperation.

Ground Water

Sources of ground water

The fresh ground-water resources of the Mahoning River basin are derived from precipitation that falls in the basin as rain and snow. Part of the precipitation infiltrates into the ground, and the part that is not retained in the soil moves downward to the zone in which all openings in the rock are filled with water. The number, size, and interconnection of the water-bearing openings in the different water-bearing formations vary greatly, so that wide variations in ground-water conditions are found from place to place.

The water-yielding formations, or aquifers, in Ohio are the glacial deposits and the bedrock formations.

Glacial deposits. —The continental glaciers of the Pleistocene epoch (popularly called the "ice age") deposited two basic types of material as "glacial drift". One of these is till, a generally impermeable mixture of clay and stones, usually compacted into a hard matrix called "hardpan" by well drillers. Till, in the form of a widespread deposit called ground moraine, underlies almost all the surface of the Mahoning River basin to a depth averaging about 25 ft. It is absent in some fairly large areas where the bedrocks are exposed, but the till is 100 ft or more thick where it covers preglacial valleys or other depressions in the surface of the bedrocks, or where it has been deposited as end-moraine ridges. Till generally yields water to wells in only small quantities, which in places are sufficient for domestic or farm use.

The other basic type of material deposited by the glaciers is called outwash, and consists of sand and gravel in several topographic forms. Most large ground-water supplies in Ohio are obtained from glacial outwash gravels, called valley train, deposited in stream valleys. Where these deposits are permeable, and receive recharge from streamflow under pumping conditions, very large industrial and municipal supplies have been developed.

In the Dayton area, for example, ground-water pumpage from valley-train gravels in the Miami and Mad River valleys exceeds an average of 100,000,000 gpd. In the Canton area, a few miles from the Mahoning River basin, the valley-train deposits along the Middle and West Branches of Nimishillen Creek yield an average of more than 41,000,000 gpd.

In the Mahoning River basin in the glacial outwash deposits are not as extensive as in many other parts of the State, nor are the deposits very permeable. Conditions for large amounts of recharge are not favorable. For these reasons, and because the best deposits in the Mahoning River basin are not found in the heavily industrialized areas, no large ground-water supplies have been developed so far. The total ground-water pumpage from the glacial deposits in the Mahoning River basin averages less than 1,000,000 gpd.

Figure 18 shows the distribution of the glacial deposits in the Mahoning River basin. Outwash gravels within the basin are chiefly in the form of kames, which are hummocky mounds rising above the general level of the ground surface, or as kame terraces along the valley walls. Kames and kame terraces generally lie above the level of the major streams.

Valley-train deposits are present in the Mahoning River valley at Youngstown and in a number of small areas between Newton Falls and Ravenna. The deposits are thin and not permeable enough for development of large ground-water supplies.

Outwash deposits covered by till are present in parts of the upper Mill Creek valley and at the Milton Reservoir in Mahoning County. These buried outwash deposits consist of sand, silt, and scattered layers of gravel. Buried outwash gravel as much as 100 ft thick is reported to underlie the Mahoning River valley in the southwestern part of the basin. These deposits consist of relatively coarse gravels in the Alliance area where they have been explored.

Bedrocks. —The bedrocks of the Mahoning River basin are of sedimentary origin and consist mostly of shale, lesser amounts of sandstone, and minor beds of limestone. The rocks originated as sediment and organic debris which accumulated over the bottom of the large inland sea that from time to time in the geologic past covered Ohio and the surrounding States. The sediments in the course of time became compacted and cemented and were raised by slow and extensive earth movements from the waters of the sea and became part of the land mass. The principal bedrock units in the Mahoning River basin above the Berea sandstone are shown in table 10. The water-bearing properties of the principal units are also shown.

The Cuyahoga formation of Mississippian age, and the Pottsville and Allegheny formations of Pennsylvania age, have been divided into more than 40 members. Not all the members may be present at any given place, for many of them are discontinuous. Figure 19 shows the bedrocks of the Mahoning River basin as they underlie the glacial drift or are exposed at the surface. The regional dip of the bedrock strata within the basin is to the south or southeast, the older rocks being exposed to the north.

Of the bedrocks in the Mahoning River basin, only the sandstones are important sources of ground water. Total pumpage from these aquifers averages slightly

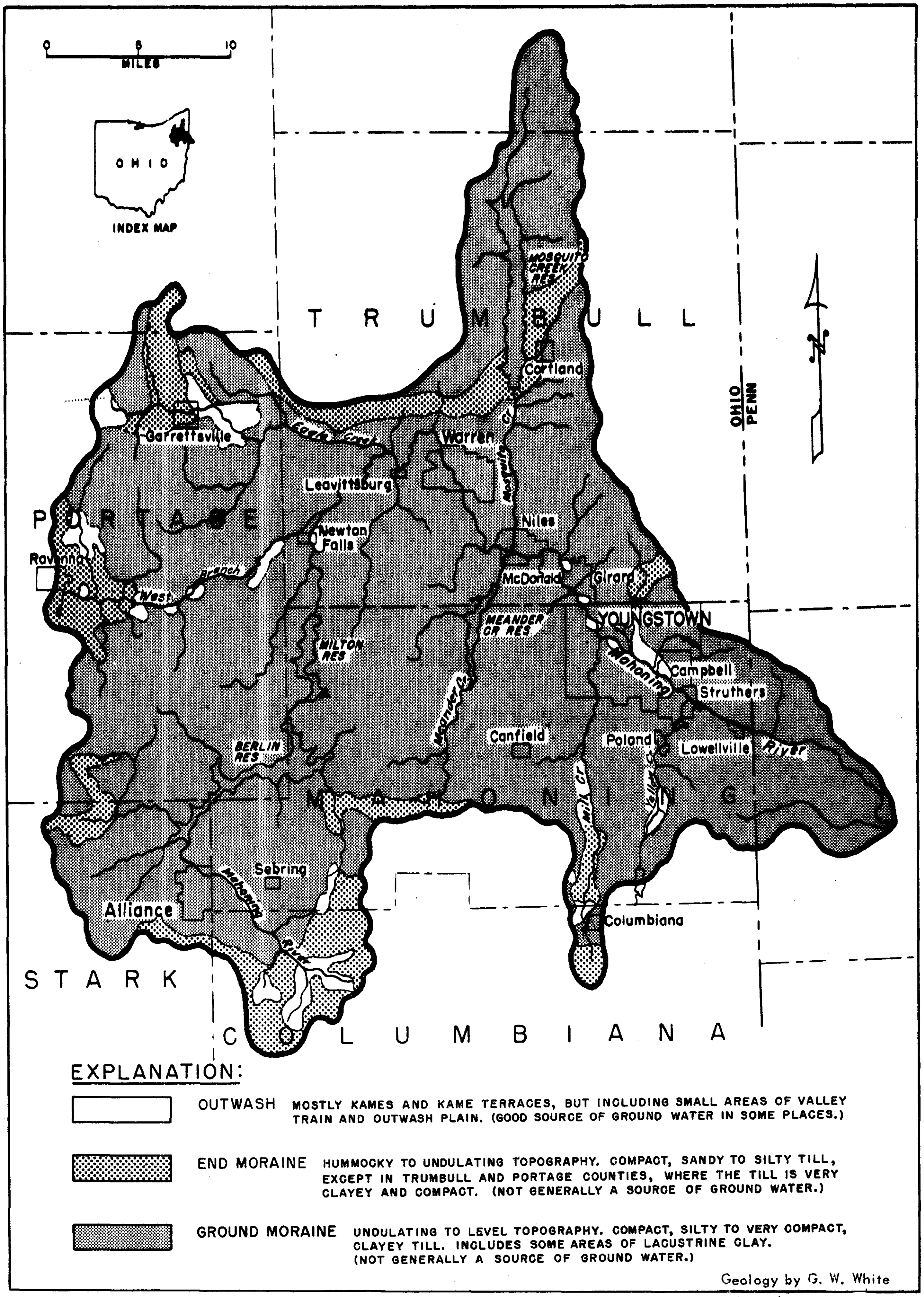

Figure 18.–Map of Mahoning River basin showing the distribution and water-bearing characteristics of the glacial deposits (Geology by G. W. White).

Table 10. –Water-bearing properties of the principal bedrock formations in the Mahoning River basin

System	Series	Formation	Average thickness (feet)	Character of material	Principal aquifers (members)	Water-bearing properties
Carboniferous	Pennsylvania	Allegheny formation	100	Variable sequence of sandstone, shale, clay, coal, and limestone. The sandstones are generally thin-bedded or shaly and of limited lateral extent.	Butler sandstone member. Freeport sandstone member. Kitanning sandstone member. Clarion sandstone	No really good supplies. Sandstone strata locally yield domestic supplies.
		Pottsville formation	150	Variable sequence of sandstone, shale, clay, coal, and limestone. The sandstones are locally expanded into very massive beds. Shales are predominantly sandy.	Homewood sandstone member. Connoquenessing sandstone member. Sharon sandstone member.	Sharon and Connoquenessing sandstone member locally yield excellent supplies for domestic and small industrial demand.
	Mississippian	Cuyahoga formation	175	Alternating beds of shale and sandstone. Sandstones thicker and more massive in the upper part and locally expanded into considerable thicknesses.	Sharpsville sandstone member (locally called Injun or Squaw by drillers).	Good domestic supplies from the sandstone beds.
		Sunbury shale	35	Thin-bedded nonporous red, brown, or black shale.		Contains very little water.
		Berea sandstone	30	Gray to white sandstone, massive, porous, permeable.		Generally yields brine or brackish water. Oil, gas, and fresh water reported locally.

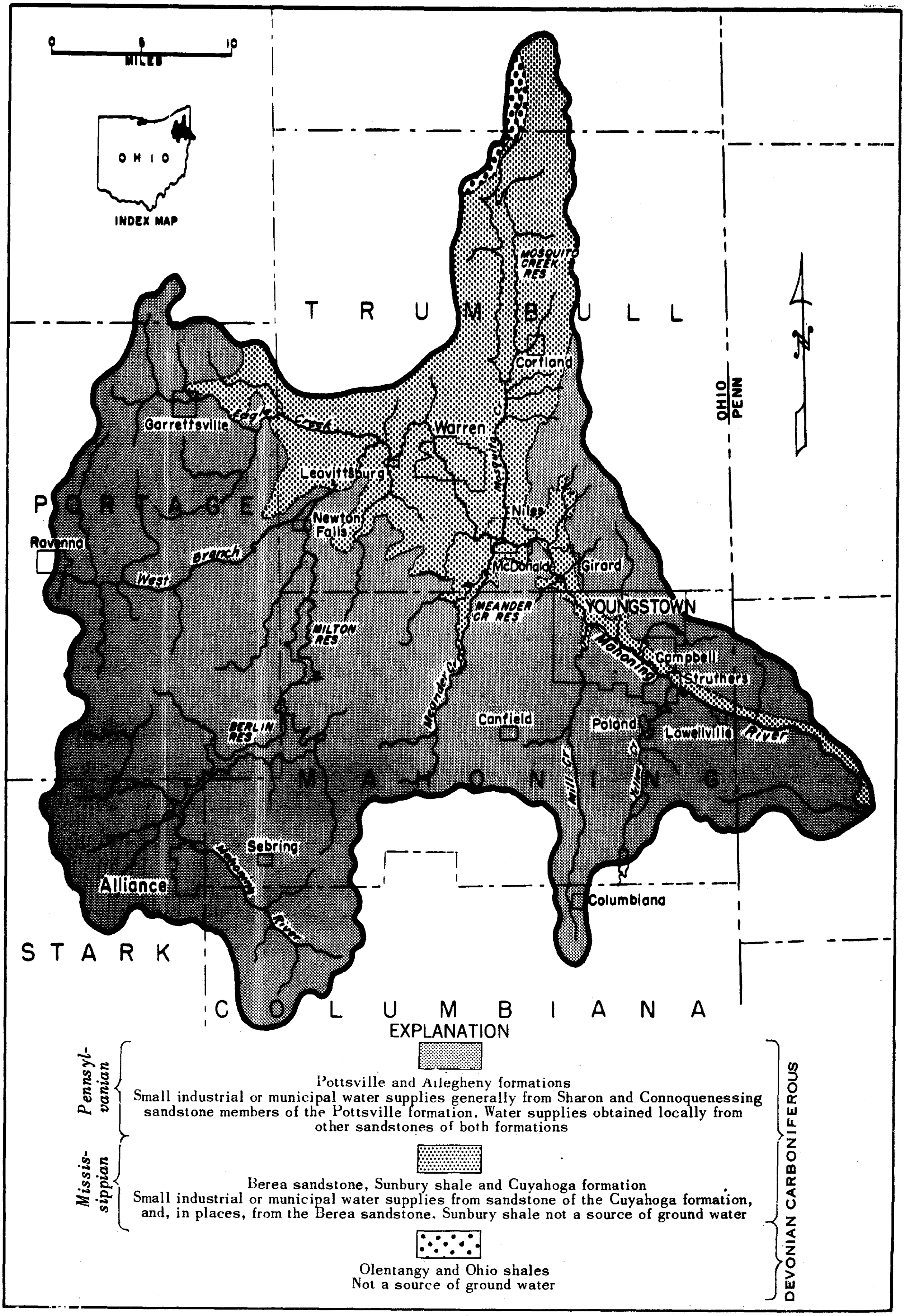

Figure 19. –Map of Mahoning River basin showing the distribution and water-bearing characteristics of the [illegible]d rocks.

more than 7,000,000 gpd. Yields of wells vary from place to place because of the wide range in thickness and permeability of these aquifers. The aquifers of greatest areal extent are the Berea sandstone, the sandstones of the Cuyahoga formation, and the Sharon and Connoquenessing sandstone members of the Pottsville formation. The Sharon and Connoquenessing members are present only in the southern part of the basin, having been removed by erosion in the northern part. In some localities the Connoquenessing and Homewood sandstone members of the Pottsville formation, and the Clarion, Kittanning, and Freeport sandstone members of the Allegheny formation also are important aquifers.

The Berea sandstone underlies nearly the entire Mahoning River basin and crops out north of Warren in Trumbull County. In Mahoning County it lies at depths ranging from less than 300 ft in the northeastern part to more than 800 ft in the southern part. The Berea sandstones generally yield brine and in places may yield oil and gas. It marks the lower limit of the fresh-water reservoir, no fresh water having been reported below it within the basin. The Berea sandstone is massive and firmly cemented. It ranges generally from 30 to 40 ft in thickness in the southern parts of the basin, and is as much as 60 ft thick in southern Trumbull County.

The water-bearing sandstones in the upper part of the Cuyahoga formation are lenticular and are not present everywhere in the area. The most prominent beds are called the Injun and Squaw sands by some drillers. These sandstones generally contain layers of shale and are less than 50 ft thick.

The Sharon sandstone, member of the Pottsville formation, one of the most important of the bedrock aquifers, overlies the Cuyahoga formation in the southern part of the basin. The interval between the Sharon sandstone member and the Berea sandstone ranges from 120 to 350 ft and averages about 200 ft.

The Sharon sandstone member at its type locality at Sharon, Pa., consists of two units, the lower being a loosely cemented mass of white quartz pebbles, held together by silica and occasional bands of iron minerals, the upper being a white friable fine-grained sandstone. In the Mahoning River basin the Sharon sandstone member does not generally conform to its character at its type locality, and individual exposures may resemble in their entirety either of the two lithologic units described above, depending on the locality. The Sharon was deposited on a former erosion surface and for this reason it is very irregular in thickness. It may be absent at places within its normal distribution area, and it is commonly less than 50 ft thick. Near Windham, Portage County, it is reported to be 175 ft thick.

Another important sandstone aquifer in the southern part of the Mahoning River basin is the Connoquenessing sandstone member of the Pottsville formation, which overlies the Sharon sandstone member. The Connoquenessing ranges generally from 20 to 80 ft in thickness, except where it is contiguous with the lower part of the member, which in places increases the total thickness of the sandstone to more than 100 ft. Near the southern part of Youngstown, for example, 140 ft of sandstone is reported, and in Mill Creek Park in Youngstown 81 ft of sandstone is exposed. The Connoquenessing sandstone ranges from massive and cross-bedded to shaly and thin-bedded.

General principles of occurrence

Ground water in sand and gravel occurs in the interstices or "pore spaces" between the individual particles. The size, shape, and arrangement of the particles determine the amount of water that can be stored in the deposit and the rate at which it can be transmitted to wells or other points of discharge. Water in sandstones or other rocks that are well cemented and firmly compacted is carried mostly in joint cracks and along bedding planes. Many sandstones, however, are sufficiently porous, or so poorly compacted, that water occurs mainly in the pore spaces between the individual particles.

Water-table and artesian conditions

The water in rock openings may occur under either water-table or artesian conditions. The important distinction between these two conditions has been given by McGuinness (1951, pp. 12-15): "....Under water-table conditions the top of the zone of saturation is a "free" water surface at atmospheric pressure, and the ground water behaves much like water in a surface reservoir, except that friction makes it move much more slowly. The zone of saturation extends downward to impermeable rocks that prevent the water from descending further toward the center of the earth. This depth varies from place to place but is generally many hundreds of feet; however, in many regions only the upper few hundred feet is of importance.

"Under artesian conditions water becomes confined under pressure between two bodies of impermeable rock. It does so by entering the ground, reaching the water table, and then flowing down with the slope of the water table to a point where the zone of saturation is interrupted by an impermeable bed. Part of the water may pass above the bed and continue to flow under water-table conditions, and part of it flows beneath the bed. Now it is confined, pressing upward against the impermeable bed with a head equivalent to the difference in elevation between that point and the elevation of the water table in the area of recharge, less the loss in head resulting from friction in movement. This is confined or artesian water; it will rise in a tightly cased well to a height above the bottom of the confining bed equivalent to the pressure head at that point. If the head happens to be above the land surface, as it commonly is in the valleys or along the coast in areas characterized by artesian formations, the well will flow... Artesian aquifers are comparable to systems of piping; they are full of water at all times, receiving water at the upper end of the system and discharging it at the lower.... "

Throughout most of the Mahoning River basin shallow ground water is believed to occur under water-table conditions. In some areas the till probably acts as a confining layer, causing local semiartesian conditions. In general, local infiltration is effective, so that most wells reflect recharge from rain and snow within a period of a few days or weeks.

Typical artesian conditions have not been found to exist in the fresh-water shallow aquifers over any large area within the Mahoning River basin. Thus, there is no appreciable movement of fresh ground water into or out of the basin.

Water-level fluctuations

Ground-water levels are seldom stationary but rise and decline in response to changes in rainfall, changes in the stages of surface streams, pumping from wells, and other factors. In humid areas such as Ohio, there are natural variations having seasonal trends, water levels being highest in the spring and lowest in the late summer or fall. The amount of change in water levels is important in estimating allowable drawdowns in pumping wells. In the Mahoning River basin ground-water levels fluctuate several feet a year owing to natural causes. Depending on topography, and on whether there is heavy pumping in an area, water levels range from less than 10 to more than 100 ft below the land surface. Because the aquifers in the basin are not highly permeable, drawdowns in pumping wells are generally large.

The graphs in figures 20 and 21 show the fluctuations in water levels measured in four wells in the Mahoning River basin. These wells are maintained as permanent observation wells by the U. S. Geological Survey and the Ohio Division of Water. Water-level records for the wells are published annually in bulletins of the Ohio Division of Water and by the U. S. Geological Survey in a series of water-supply papers entitled "Water levels and artesian pressures in observation wells in the United States."

Well Ma-1 is at Canfield in the waterworks well field near the race track. The well was 278 ft deep originally but was plugged to 205 ft. The principal water-bearing formation is probably sandstone reported in the well log between depths of 140 and 152 ft, although water is also contributed from other beds. The hydrograph shows the water level to have been more than 100 ft below the surface most of the time during the years 1946-47. During that period the water level was affected by pumping from nearby wells for the village supply. In 1947 the village abandoned its well field and bought water from the Mahoning Valley Sanitary District. The water level in well Ma-1 rose to about 31 ft below the ground surface when pumping stopped. Since that time seasonal fluctuations have amounted to about 4 to 5 ft each year.

Well Ma-3 is in the basement of the Tod Hotel in the center of Youngstown. The well is 400 ft deep and taps several water-bearing formations, chief among which are the Sharon sandstone member of the Pottsville formation and the sandstones of the Cuyahoga formation. The hydrograph reflects mostly the normal effects of seasonal variations in precipitation. The range of fluctuation has amounted to less than 3 ft, and the water level followed a slightly rising trend in the period 1948-51. This trend probably reflects reductions in pumping in the area and more favorable precipitation in the past few years.

Observation well T-2 is 3 miles north of Warren on the property of the Copperweld Steel Co. The well is 124 ft deep and taps the Berea sandstone. The hydrograph shows that the water level in well T-2 is affected by pumping from nearby wells, from which a supply of more than 1,000,000 gpd is obtained. The effects of the pumping are not sufficient, however, to obscure the normal seasonal fluctuation of as much as 10 ft between high and low periods. The hydrograph shows a net decline during the past 2 yr, which may mark the beginning of a trend and indicate that the aquifer is being overpumped.

Well Po-1 is situated at Windham in Portage County. It is 55 ft deep and taps an aquifer of the Pottsville formation, probably the Sharon sandstone member. The hydrograph shows a normal range of fluctuation of the water level between depths of 14 and 22 ft, varying in accordance with seasonal factors, which produced generally lower levels in 1948 and 1949. In 1948 low water levels were recorded in wells throughout the State.

Although a long or comprehensive record of water-level fluctuations in the basin is not available, there is no present indication that water levels in general are following either an upward or a downward trend. Thus the quantity of ground water stored in the Mahoning River basin is not changing appreciably, except for seasonal fluctuations and local variations resulting from pumping.

Yield of wells

When wells tap a water-bearing formation a new factor is introduced into the natural hydraulic system of the aquifer. When pumping begins, most of the water is taken from storage in the immediate vicinity of the pumped well. As pumping continues, more water flows to the pumped well from greater and greater distances and less is removed from storage in the immediate vicinity of the well. Thus hydraulic gradients are created around the pumped well that form a "cone of depression." The shape of the cone, and its rate and extent of growth, are related to the storage properties of the aquifer, and to its transmissibility or capacity to transmit water, and to the distance of the pumped well from the areas in which recharge and natural discharge of the aquifer occur.

Perennial yields of wells depend ultimately on the amount of recharge the aquifer receives. Recharge may be induced from a surface stream by lowering water levels in the aquifer by pumping, or it may be derived from the infiltration of rainfall, or both. To make an accurate evaluation of a specific supply, or of the water-bearing properties of an aquifer at a specified location usually requires test drilling and an analysis based on a controlled pumping test, or long-term pumping and water-level records.

Of the total quantity of ground water pumped in the Mahoning River basin each day, more than 90 percent is taken from the bedrocks, the remainder from the glacial deposits. The average depth of 133 wells studied is 188 ft. They are nearly all drilled wells and range in diameter from 4 to about 10 in.

Wells drilled into the glacial till of the Mahoning River basin generally yield less than 5 gpm. Throughout much of the area the till is thin and of low permeability, so that few wells yield more than domestic requirements.

The more favorable areas underlain by outwash materials have not been tested sufficiently to permit an evaluation of well yields from those sources. How-

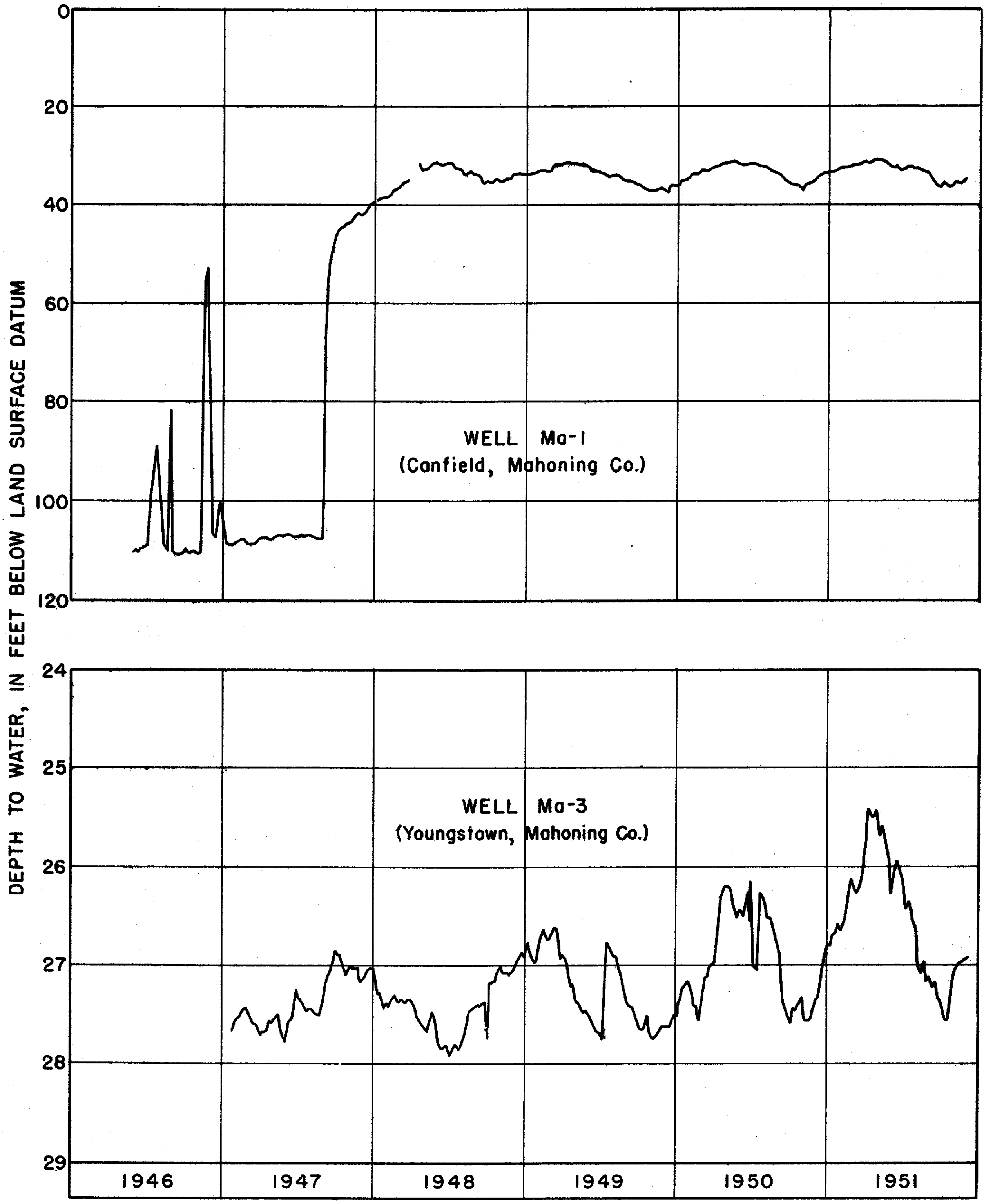

Figure 20. -Graphs showing fluctuations in water levels in wells at Canfield and Youngstown.

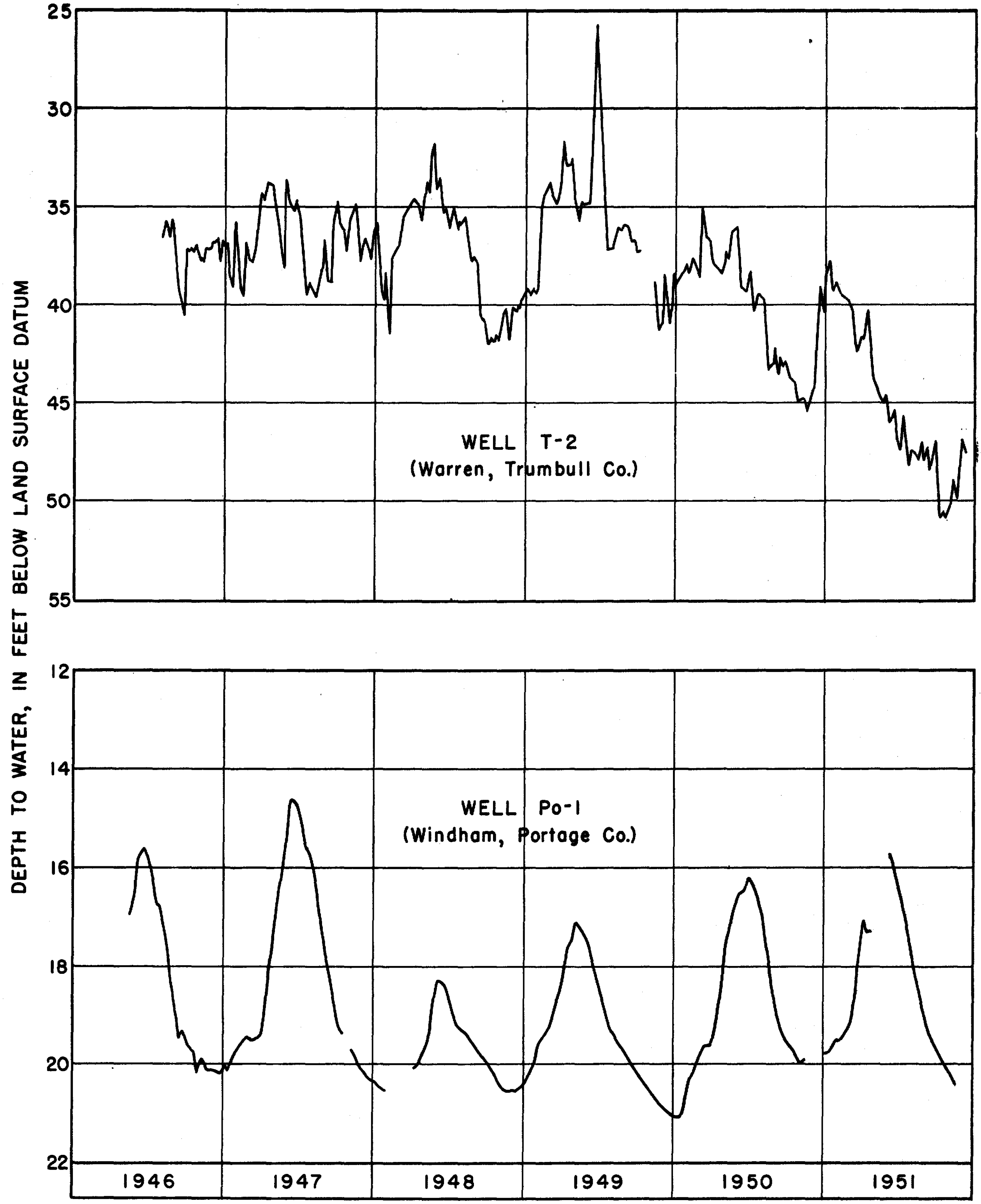

Figure 21.—Graphs showing fluctuations in water levels in wells at Warren and Windham.

ever, wells tapping such deposits can be expected to yield substantially larger quantities than wells in the glacial till. Yields exceeding 1,000 gpm have been obtained from wells in outwash deposits in other areas in Ohio, giving some idea of the difference in water-bearing properties between till and outwash deposits. The potential yields of wells in the outwash deposits in the Mahoning River basin are no doubt below the av erage for the State but may be substantial in the most favorable areas.

Wells drilled into the bedrock aquifers that yield fresh water in the Mahoning River basin generally av erage about 25 gpm when pumped continuously, and yields vary widely from place to place. Generally speaking, yields are greatest near the area of outcrop of the formation or where the water-bearing formations have their greatest thickness.

Wells tapping the Berea sandstone generally yield brine in amounts as high as 250 gpm. Wells in the Sharon sandstone member of the Pottsville formation may yield as much as 100 gpm but yields of about 20 gpm are most common. Wells in the Cuyahoga formation generally do not yield more than 30 gpm.

The Connoquenessing sandstone member of the Pottsville formation has yielded more than 500 gpm to some wells. One such well was a municipal well at Canfield, in Mahoning County, where the initial yield from the Connoquenessing sandstone member was reported to be 600 gpm with 100 ft of drawdown. In 1947 the yield of the same well was 45 gpm with 70 ft of drawdown. Another well, at Craig Beach, Mahoning County, under test produced 20 gpm from the Massillon sandstone, with 50 ft of drawdown.

Yields from wells in the other bedrock aquifers in the Mahoning River basin—namely, the lower parts of the Connoquenessing and Homewood sandstone members of the Pottsville formation, and the Clarion, Kittanning, and Freeport sandstone members of the Allegheny formation—generally do not exceed 20 gpm; locally, however, where these beds attain their maximum thicknesses, the yields may be appreciably larger. This is the case at Lowellville where the municipal supply is obtained from wells tapping the Clarion sandstone member. The Freeport sandstone member is important only for farm or home supplies and in some places is insufficient for these moderate needs.

In the Mahoning River basin the transmissibilities of the bedrock aquifers are relatively low, storage capacities are small, and the amount of water a well yields is generally small unless the steepness of the cone of depression and the drawdown in the well are considered. An example of the hydraulic characteristics of a better-than-average sandstone aquifer in the Mahoning River basin is afforded by the test of a well at Lowellville in Mahoning County as reported by Cummins (in preparation).

".... Two wells (designated as wells 1 and 2 by the Lowellville Water Department) are in a pump house along the south side of Newcastle Road about a mile north of Lowellville. Well 2 is pumped intermittently as needed and well 1 (located 17 ft east-northeast of well 2) is pumped only in emergencies. Well 3, located about a half-mile north of wells 1 and 2 is pumped intermittently. Each of these wells yields about 120 gpm under present intermittent operation. All three wells produce from the Clarion sandstone (member of the Allegheny formation).

A pumping test of well 2 was conducted on May 4, 1949, to determine drawdowns produced at various distances from the pumping well and to learn as much as possible about the hydraulic properties of the aquifer. Well 2 was pumped for 7 hours and 15 minutes at a constant rate of 100 gpm. Water levels in the pumping well and in nearby observation wells were measured at frequent intervals during the period of the test.... "

Analyses of the test data show that the aquifer is locally artesian and that the permeability changes in different directions from the well, indicating the presence of geologic boundaries which, at various distances, impede or stop the flow of water from those directions.

According to Cummins (in preparation), "The findings of the above test emphasize that relatively high initial yields of wells as shown by pumping tests of short duration may be misleading with respect to ultimate yields to be expected from wells tapping these aquifers. In development of important municipal and industrial water supplies from aquifers of the type described, controlled pumping tests should be conducted and carefully analyzed to determine proper pump capacities and optimum spacing of wells.... "

Chemical quality

There appears to be no consistent correlation between the water-bearing formations and the chemical quality of the ground water in the Mahoning River basin, except that in general fresh water is not found in the bedrocks below the Berea sandstone. Highly mineralized water may also be found in the rocks above the Berea sandstone at some places in the basin. Water from the Berea sandstone is suitable for drinking purposes in the northern part of the basin but, because of its high chloride content, is not suitable in the southern part.

The Cuyahoga formation generally yields water of good quality in the northern part of the basin where it directly underlies the glacial drift, but it is likely to yield brackish water in the southern part of the basin where the rocks are more deeply buried. The Connoquenessing sandstone member of the Pottsville formation also yields fresh water generally but it has similarly been reported to yield salt water in some places. Water from the Sharon sandstone of the Pottsville member is fairly soft generally, but in some places it is high in iron and may also contain hydrogen sulfide.

Water from the other bedrock aquifers is generally of reasonably good quality but may vary considerably from place to place. The glacial deposits generally yield water of a quality satisfactory for most uses in the basin, except that it is hard. Supplies from the outwash are generally of better quality than supplies from the till.

Analyses of fresh ground water from wells ranging in depth from 40 to 431 ft show considerable variation in the amount and character of the dissolved constituents in the waters from the different wells. The water ranges from soft to hard in quality and from low to high in mineral content. Because there is such a wide

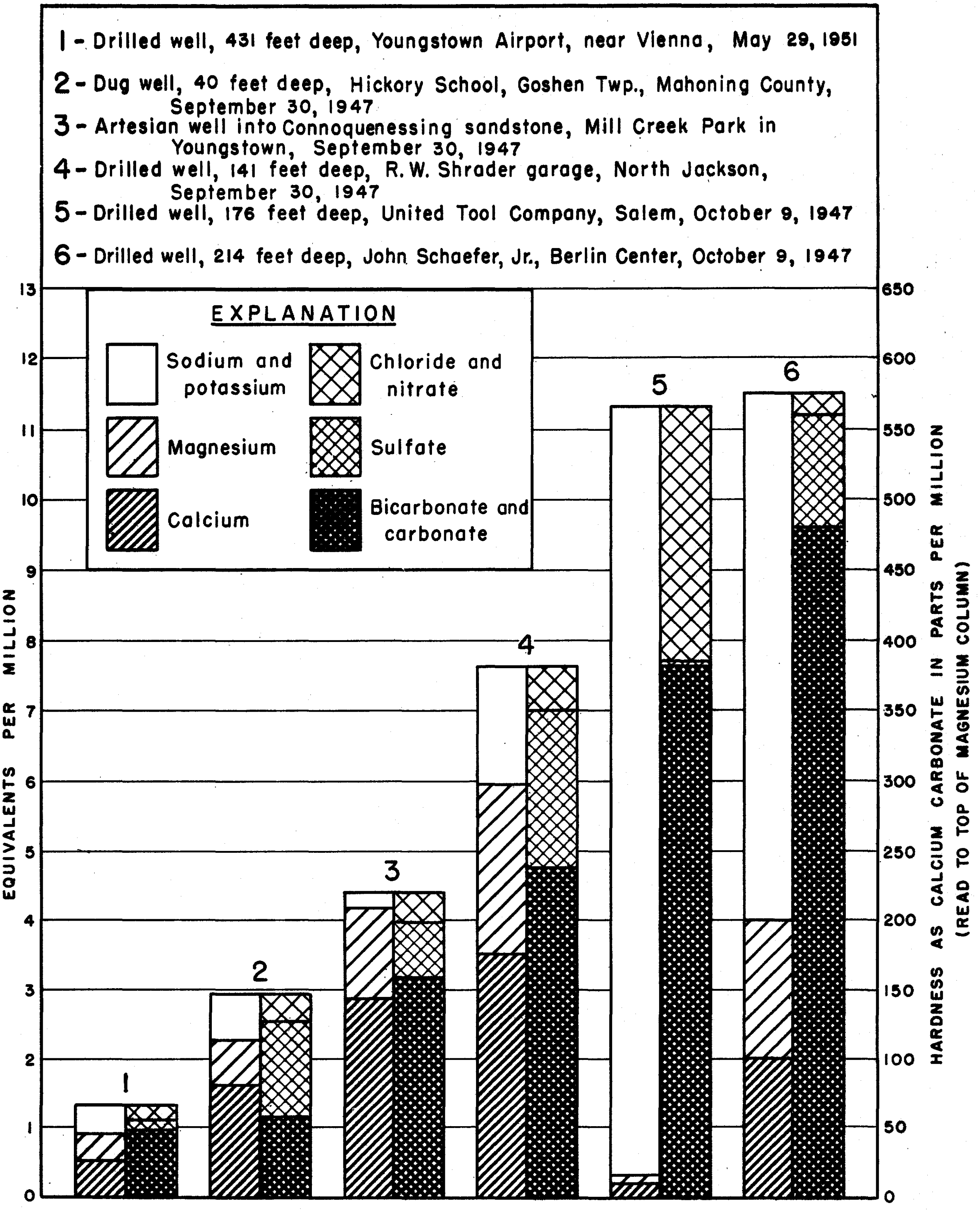

Figure 22. –Composition of selected ground waters in the Mahoning River basin.

Table 11.--Range in concentration of chemical constituents and in related physical measurements of fresh ground waters in the Mahoning River basin, based on 14 analyses

[Chemical results in parts per million]

	Minimum	Maximum		Minimum	Maximum
pH	5.8	8.5	Bicarbonate (HCO_3)	28	585
Specific conductance micromhos at 25 C.	76.1	2,210	Sulfate (SO_4)	1.4	189
Silica (SiO_2)	2.0	19	Chloride (Cl)	2.8	570
Iron (Fe)	.05	6.2	Fluoride (F)	.0	1.0
Calcium (Ca)	3.6	220	Nitrate (NO_3)	.0	43
Magnesium (Mg)	1.4	59	Dissolved solids	51	1,410
Sodium + Potassium (Na+K)	5.6	254	Hardness as $CaCO_3$	15	792

variation in the chemical quality of ground water in the basin it is not possible to select any particular analysis as typical. The range in concentration of various chemical constituents and in related physical measurements of 14 samples of ground water are given in table 11.

The chemical analyses of six selected ground-water samples are shown graphically in figure 22. These analyses may be considered fairly representative of the range and character of the fresh underground waters. Samples 5 and 6 show that, although the water from two wells may have about an equal amount of dissolved solids, the character of the dissolved constituents may vary considerably.

Most of the ground waters analyzed may be classed as hard, only five samples had a total hardness of less than 175 ppm. Three of the samples were soft and of very good quality except that the iron content was high. The iron content of most of the samples was high enough to require treatment to make the water suitable for general use in homes or industries.

There is a possibility that brine from the deeper wells could be used to recharge zeolite softeners for fresh ground water or surface water. An analysis, made in 1930 by the Ohio Geological Survey, of brine from a well 620 ft deep in Beaver Township, Mahoning County, is given as follows:

Dissolved solids 108,600 ppm

Specific gravity at 15 C, 1.064

Composition of saline matter

	Percent		Percent
Silica (SiO_2)	0.03	Bicarbonate (HCO_3)	0.065
Calcium (Ca)	7.83	Sulfate (SO_4)	.055
Magnesium (Mg)	2.30	Chloride (Cl)	62.07
Sodium (Na)	26.80	Bromide (Br)	.41
Potassium (K)	.025	Ferric oxide (Fe_2O_3)	.37
		Aluminum oxide (Al_2O_3)	.045

Temperature

The temperature of the ground water from any particular source in the Mahoning River basin remains essentially constant throughout the year. If it is obtained at shallow depths, the temperature is approximately equal to the mean annual air temperature of about 51 F. In general, the temperature of well water increases 1 F for each 60 to 100 ft of increase in depth from the land surface. Therefore, fresh water supplies in the basin that are obtained from wells not affected by river recharge may be expected to range from 51 to 54 F throughout the year.

In the Youngstown area any wells that may be developed in the valley-train deposits, and which induce infiltration from the Mahoning River, may be expected to yield water of considerably higher temperature than the average.

PRESENT WATER USE

Public Supplies

A population of about 320,000 is served by public water supply systems from surface-water sources in the Mahoning River basin. In addition eight cities and villages supply a total of about 24,000 people from ground-water sources. The average pumpage from surface water in 1950 was 62.4 mgd, and from ground water about 1.5 mgd. The use of surface water from public supplies has more than doubled in the past 20 years; additional development is required and is now being planned and constructed. Development of ground water for public supplies is limited by the general lack of ground water in considerable quantity, and is confined to villages of small population.

The spectacular increase in use of surface water for public supply is shown in table 12 which lists the average pumpage for the years 1930-50, for each of the municipalities. The increase in population served is not great, the estimated population (based in part on census tabulations) being 283,000 in 1930, 288,000 in 1940, and 317,000 in 1950. The increase in average pumpage is caused almost entirely by increased industrial use of public water supplies. An analysis of the records indicate that the strictly domestic use of water has been practically static, and has never exceeded about 40 gal per capita per day. Table 13 shows the

Table 12.–Average use of surface water in the Mahoning River basin for public supplies (1930-50)

[Million gallons per day]

Year	Alliance	Campbell (a, g)	McDonald (b)	Newton Falls (c)	Niles (d)	Sebring	Struthers & Poland (a)	Warren	Youngs-town (d)	Total
1930	4.05	(e)			2.52	0.45	0.47	3.34	13.28	[f]29
1931	3.38	(e)			1.72	.42	.39	3.02	11.85	[f]26
1932	2.88	5.7			1.22	.34	.39	2.40	9.80	22.7
1933	3.06	7.84			1.18	.34	.43	2.65	9.26	24.8
1934	3.30	7.85			1.37	.42	.46	2.78	10.23	26.4
1935	3.22	7.1			1.40	.43	.51	2.74	10.47	25.9
1936	3.97	10.66			2.11	.47	.55	3.85	11.55	33.2
1937	3.89	12.88			2.45	.48	.62	3.85	11.14	35.3
1938	3.34	9.8			2.06	.47	.62	3.40	10.66	30.4
1939	3.52	12.85			2.57	.50	.64	3.85	10.73	34.7
1940	3.72	16.6			2.70	.47	.66	4.04	11.39	39.6
1941	4.44	19.1			3.09	.49	.68	5.35	13.18	46.3
1942	4.36	19.3			3.11	.51	.69	5.39	13.29	46.6
1943	4.92	21.2			3.78	.52	.72	6.67	13.92	51.7
1944	5.05	17.5	0.42	0.26	4.34	.63	.62	7.30	15.21	51.3
1945	5.28	17.9	.41	.35	4.60	.63	.69	7.07	15.05	52.0
1946	5.41	18.0	.39	.44	4.81	.65	.70	6.92	15.97	53.3
1947	5.86	20.4	.47	.61	6.03	(e)	.75	7.67	17.99	[f]60
1948	5.89	22.0	.50	.64	6.31	(e)	.78	7.21	19.58	[f]64
1949	5.11	19.7	.55	.81	5.58	(e)	.86	7.07	18.78	[f]59
1950	4.81	20.9	.70	.87	6.50	.82	.96	7.56	19.33	62.4

a/ Supplied by Ohio Water Service Co. from small lakes on Yellow Creek and elsewhere.
b/ Ground-water sources prior to August 1, 1944, Mahoning Valley Sanitary District thereafter.
c/ Ground-water sources prior to 1944.
d/ Supplied by Mahoning Valley Sanitary District after July 11, 1932.
e/ No records available.
f/ Partly estimated.
g/ Includes industrial use supplied by Ohio Water Service Co. throughout the Mahoning Valley other than by Struthers Plant.

Table 13.—Use of water in the Mahoning River basin from public supplies having surface sources, 1950

Public supply	Alliance	Campbell*	McDonald	Newton Falls	Niles	Sebring	Struthers and Poland	Warren	Youngs-town	Total
Average pumpage (mgd)	4.81	20.9	0.70	0.87	6.50	0.82	0.96	7.56	19.33	62.4
Population supplied	28,500	12,882	1,520	4,550	18,400	d/4,045	15,805	51,954	183,000	320,656
Number of consumers	7,101	(c)	478	1,350	4,802	(c)	4,047	13,444	41,195	
Domestic and commercial	7,067	(c)	477	1,344	4,739	(c)	(c)	a/13,118	(c)	
Industrial	34	(c)	1	6	63	(c)	(c)	b/302	(c)	
Consumption in percent of total										
Domestic and commercial	26.5	4.2	12	18.5	8.6	(c)	62	a/23.3	a/37.3	
Industrial	42.7	89.7	73	70.0	77.4	(c)	6	b/53.0	b/38.8	
City use	30.8	6.1	15	11.5	14.0	(c)	32	23.7	23.9	

*/ Includes industrial use supplied by Ohio Water Service Co. other than by the Struthers Plant.
a/ Does not include commercial.
b/ Includes commercial.
c/ Information not available.
d/ From census.

Table 14.—Industrial use of water in the Mahoning River basin from public supplies using surface sources, 1950

[Use by industry in percent of total industrial use]

Industry	Public supply						
	Alliance	Ohio Water Service Co.	McDonald	Newton Falls	Niles	Warren	Youngs-town
Steel and allied industry	71.5	87.5	100	90	77.8	61.7	73.2
Railroads	9.7	9.34			5.6		2.8
Oil refining					.5		
Clay industries	10.7				.1		
Chemical industry		.025			1.5		
Ice and fuel					.1	.9	
Power						.8	5.1
Laundry and cleaning							4.7
Meat and canning	.6						1.0
Dairy products	2.7					2.9	6.0
Leather products		3.1					
Accounting machines	1.3						
Irrigation (hot house)				10			
Electrical products					12.8	25.3	1.3
Miscellaneous	2.7	.035			1.6	8.4	7.7

use of water from public supplies, having surface water sources and indicates the relatively large share taken by industry. In 1950 about 38 mgd, or 63 percent of the public supply was used by industry. About half of this industrial supply is treated water. All the public supplies shown in table 12 are treated except that for Campbell. The Campbell public supply, purchased from the Ohio Water Service Co., is treated by the city, but the industrial supply included in this column is raw water from surface reservoirs sold through the distribution system of this private water company. Because this water is of such relatively good quality compared to the raw water pumped directly from the Mahoning River, and because the distribution in many aspects is similar to the public systems, the figures for the Ohio Water Service Company are included in the tables of public supply.

Table 14 shows the large share of the total quantity of industrial water taken from public supplies that is used by the steel and allied industries. In 1950 about half the total surface supplies pumped by municipalities and the supply furnished by one private water company were used by the steel industry. The expansion of the steel industry has affected the entire economy in the Mahoning River valley, particularly with reference to water supplies. The diagram of pumpage shown in figure 23 for all municipalities in the Mahoning River basin and for the Mahoning Valley Sanitary District reveal the large increase in use of water from surface sources for public supplies in the past 20 years. They are similar to charts of steel production.

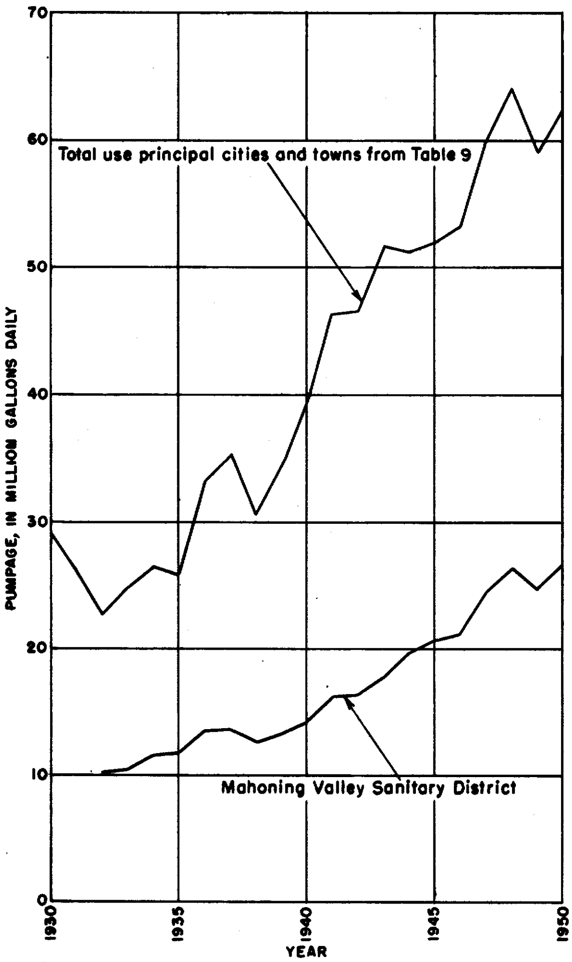

Figure 23.—Municipal use of surface water in the Mahoning River basin, 1930-50.

In addition to the public supplies from surface-water sources there are eight municipalities supplied from ground-water sources (see table 15). These ground-water supplies are for domestic and commercial use, and a small amount is used by industries. Girard, the largest of these municipalities is supplied from an abandoned coal mine. The location and magnitude of the public supplies using ground water are shown on figure 24.

Table 15.—Use of ground water for public supplies in the Mahoning River basin

Municipality	Population in 1950	Average daily pumpage (mgd)	Year compiled
Columbiana	3,363	.225	1951
Cortland	1,258	.200	1950
Craig Beach	562	.015	1947
Garrettsville	1,504	.090	1944
Girard	10,068	.700	1948
Hiram	979	.045	1950
Lowellville	2,246	.140	1949
Windham	3,947	.135	1950
Total	23,927	1.550	

Private Industrial Supplies

The locations and magnitude of industrial ground-water supplies are also shown on figure 24. The total ground-water pumpage for industry is nearly 7 mgd, about half of which is for steel and allied metal manufacturing. Table 16 shows the quantity of ground water used in the Mahoning River basin by various industries.

Table 16.—Industrial use of ground water in the Mahoning River basin, about 1946

Industry	Quantity used (gallons per day)
Air conditioning	123,030
Breweries and bottlers	3,900
Ceramic products	92,600
Dairy products	246,800
Explosives	2,000,000
Food processing	160,800
Ice	54,100
Institutions	19,200
Irrigation	7,200
Meat packing	30,600
Metal products	1,248,520
Rubber	272,786
Steel	2,272,500
Miscellaneous	303,241
Total	6,835,277

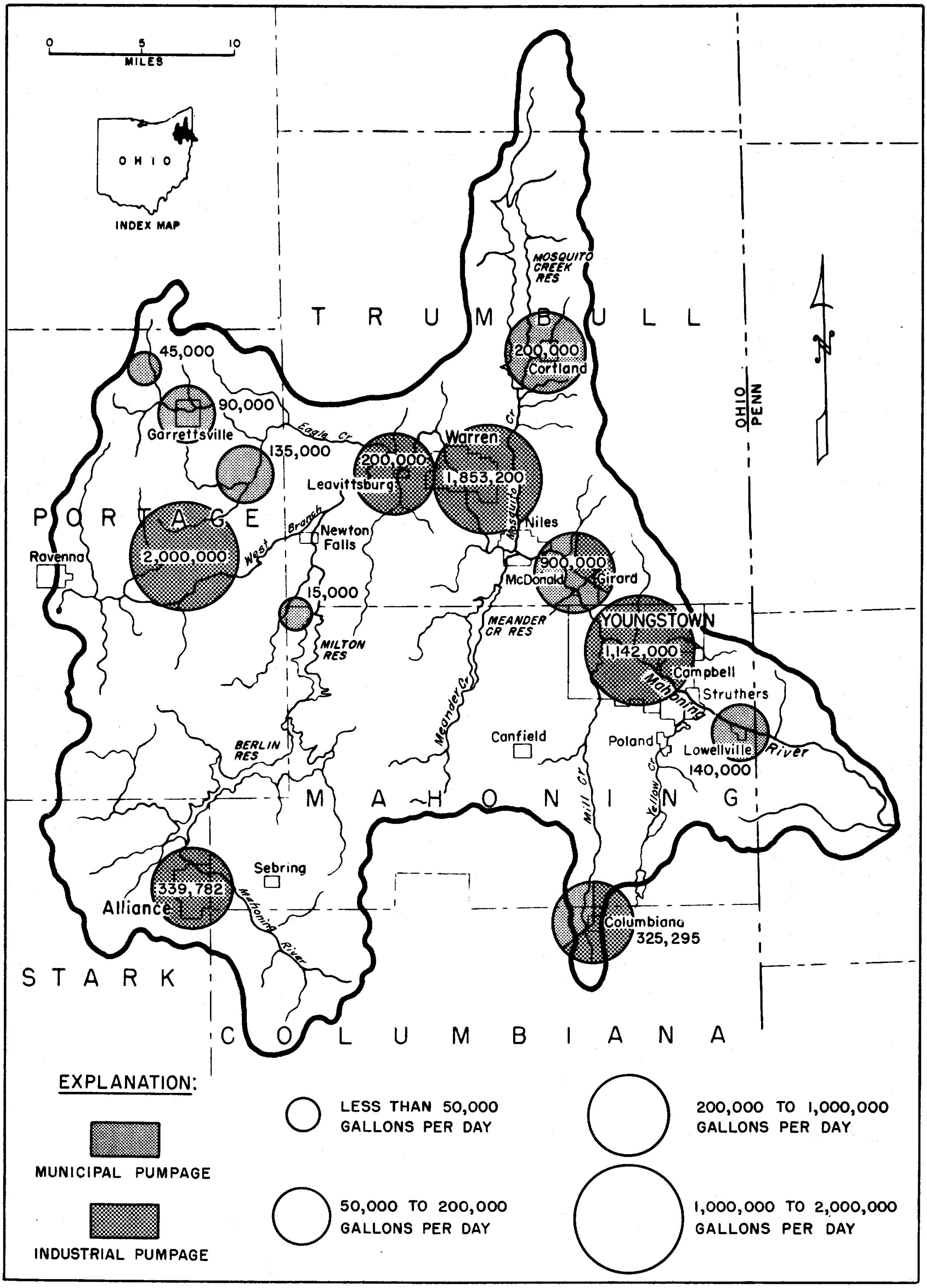

Figure 24. –Map of Mahoning River basin showing areas of principal ground-water pumpage

Table 17.-Industrial use of raw river water in the Mahoning River basin

[From Mahoning Valley Industrial Council, 1951]

Industry	Oct. 17, 1949 (gallons per day)	Estimated additional use under all out war production Jan. 22, 1951 (gallons per day)
Standard Steel Spring Co. (Newton Falls)	1,000,000	2,500,000
Thomas Steel Co. (above Warren)	1,000,000	500,000
Copperweld Steel Co.	14,400,000	55,600,000
City of Warren	8,000,000	
Ohio Public Service Co.	160,000,000	
Republic Steel Corp. (Warren)	100,000,000	15,600,000
Recirculated	56,000,000	
Ohio Edison (new Niles plant)		200,000,000
United States Steel Co. (McDonald plant)	55,000,000	
Youngstown Sheet and Tube Co. (District)	260,000,000	40,000,000
United States Steel Co. (Youngstown plant)	135,000,000	
Recirculated	80,000,000	
Republic Steel Corp. (Youngstown)	237,315,000	
Coke plant recirculate	5,520,000	
Struthers Iron and Steel Co.	20,000,000	
Sharon Steel Corp.	30,000,000	3,000,000
Ohio Edison Co. (Lowellville)	57,000,000	
Total	1,220,235,000	317,200,000

The largest use is at the Ravenna Ordnance Plant, in Portage County, where 17 wells are reported to yield about 2 mgd, mostly from the Sharon sandstone member of the Pottsville formation. Other large supplies include that of the Copperweld Steel Co. at Warren where slightly more than 1 mgd, is pumped from sandstones in the upper part of the Cuyahoga formation.

Industry uses tremendous quantities of the polluted Mahoning River water daily principally for cooling purposes in the steel plants in addition to the 38 mgd of good quality surface water and the 7 mgd of ground water. A complete analysis of the total use of river water is not possible because of the many intakes and the repeated recirculation of water. The quantity of water used from the Mahoning River on October 17, 1949, and the estimated additional use under all out war-production conditions by the principal industrial water users are shown in table 17. Use by many of the smaller industrial plants is not included but considerable recirculation within a plant system without return to the river is included. The total use of 1,220 mgd is more than 10 times the flow of the Mahoning River at Youngstown on the date of the inventory (120,000,000 gal) indicating the repeated use of river water throughout the industrial reach from Newton Falls to Lowellville. During periods of low flow the water may be used more than 15 times.

The "cost" of steel in terms of water consumption is amazingly high. It has been estimated that 65,000 gal of water are used in producing a ton of finished steel. Water consumption data in the Youngstown area are of limited applicability because of the complications of repeated recirculation, high water temperatures, and the transfer of iron and steel from plant to plant and to and from plants outside the Youngstown area during processing. However, the records of production and water pumpage for the three plants of the Youngstown Sheet and Tube Co. for 1949 are worthy of study. The total production of steel ingots for the three plants that year was 2,222,327 tons. The grand total of water pumped for the 324 days of production was 356 mgd. Of this total, 13 was pumped directly from the river to condensers for cooling pumping equipment, 241 was pumped directly from the river for use in the plants, and 102 was recirculation pumping within the plants. These figures for total water pumped amount to 51,932 gal per ton of ingots or 216 tons of water per ton of ingots produced. Considering direct pumpage from the river, and omitting recirculation and cooling of pumping equipment, the use is 35,118 gal of water per ton of ingots or 146 tons of water per ton of ingots. Water used in finishing steel and in production of power for the use of steel plates is not included. How much the enormous quantities of water used might be reduced by lower river temperatures is conjectural. The critical relation of water supply to steel production is obvious.

WATER REQUIREMENTS

It would be ideal if every area had an ample supply of cool, pure water for all purposes. Such a condition is not economically feasible in the Mahoning River basin. After minimum standards for the protection of public health have been obtained the benefits of additional water must be carefully weighed against costs, and the most economical solution decided upon. The first step in the solution of the Youngstown area water problem is, therefore, the determination of minimum standards to prevent further endangering of public health by stream pollution.

Complete control of pollution by treatment only requires methods beyond known practices and prohibitive costs. The only practicable supplement to the treatment of sewage and industrial wastes is dilution by low-flow regulation. Based on a dissolved oxygen content of 3.0 ppm (the minimum standard adopted by the U. S. Public Health Service to prevent nuisance conditions in a stream, with only primary treatment of all sewage and with an allowance of 20 percent for future increases in population and water consumption) the average monthly flows required at Youngstown are as follows (Pittsburgh District, Corps of Engineers, 1950):

Month	Flow required (cfs)	Month	Flow required (cfs)
January	290	July	755
February	295	August	730
March	335	September	630
April	450	October	490
May	575	November	380
June	695	December	310
		Average for the year	495

These flows are the minimum required to prevent nuisance conditions in the Mahoning River, with a minimum of sewage treatment. A flow regime lower than this would call for secondary treatment of sewage and more complete treatment of industrial wastes. A careful cost analysis probably will reveal that additional water (by storage) is less costly than additional treatment. Even this program will not completely restore natural stream conditions, but has the limited objective of prevention of nuisance conditions. Maintenance of these discharges would provide substantial temperature reductions as well as improved chemical quality. For example, the improvement in temperature would average about 10 F for a year-long drought. For the year 1949 temperatures would have been improved an average of about 6 F during 7 months. Maximum water temperatures would be reduced about 10 F. The savings in fuel due to increased efficiency would be substantial. It seems probable, in view of the costs involved, that this minimum solution is as much as can be achieved.

A preliminary estimate of the approximate additional storage capacity required to maintain the minimum standards of flow may be made by subtracting from the average annual requirement (495 cfs) the average minimum maintained by present operation (275 cfs) to obtain 220 cfs or 160,000 acre-ft. An 18-month drought with insufficient water to replenish storage would thus call for 240,000 acre-ft of storage. This is considerably more than would be made available by the proposed Eagle Creek and West Branch reservoirs combined.

Another rough estimate of the total storage required may be made from the 1930-31 drought. During the 19-month period, May 1, 1930, to November 30, 1931, the total accumulated deficiency, compared with the 495 cfs per year standard, amounts to 304,000 acre-ft.

The following table gives the storage reserved for low-flow regulation as now planned for existing reservoirs and proposed reservoirs (Pittsburgh District, Corps of Engineers, 1950):

Storage reserved for low-flow regulation

Reservoir	Drainage area (sq mi)	Summer (acre-ft)	Winter (acre-ft)
Berlin plus Milton	275	58,000	35,800
Mosquito Creek	97	74,400	63,100
Total now available	372	133,200	98,900
Eagle Creek	95	54,500	41,500
West Branch	81	50,000	39,200
Total proposed	176	104,500	80,700
Total available and proposed	548	237,700	179,600

If another drought as severe as that of 1930 occurs, minimum-flow requirements cannot be met by the existing and the proposed reservoirs without a dangerous reduction in the capacity reserved for flood-control storage.

It is evident that a decision on the minimum storage capacity to be reserved for flood control is necessary to the overall problem of water control. The flood storage as designed for the existing and proposed reservoirs is given in the following table (Pittsburgh District, Corps of Engineers, 1950):

Storage capacity reserved for flood control

Reservoir	Storage (acre-ft)		Equivalent runoff above reservoir (in.)		Equivalent runoff at Youngstown (in.)	
	Winter	Summer	Winter	Summer	Winter	Summer
Berlin plus Milton....................	61,300	38,300	4.2	2.6	1.3	0.8
Mosquito Creek.........................	33,000	21,700	6.4	4.2	.7	.5
Total now available.............	94,300	60,000			2.0	1.2
Eagle Creek............................	38,500	25,500	7.6	5.0	.8	.5
West Branch............................	32,800	22,000	7.6	5.1	.7	.5
Total proposed....................	71,300	47,500			1.5	1.0
Total available and proposed	165,600	107,500			3.5	2.2

Some additional water would be stored in Meander Creek Reservoir, which has no storage reserved for flood control but would store considerable water during a major flood. With the two proposed reservoirs, plus Meander Creek Reservoir, only 265 sq mi of uncontrolled area would remain above Youngstown. There will be additional storage above the spillways of the dams in the event of a major flood, so that the flood runoff in inches stored above Youngstown would exceed the total shown in the table.

Despite the above considerations, the total available storage (existing and proposed) seems insufficient to protect Youngstown against major floods. Experience elsewhere in Ohio tends to confirm this. For example, the total reservoir capacity above Dayton, with 2,500 sq mi drainage area is 5.5 in., and the total above Hamilton, with 3,500 sq mi drainage area, is 4.5 in. These cities are better protected than other Ohio cities, but there is no evidence from the record of operation of the Miami Conservancy District that the project is overdesigned. There is no reason to believe that other parts of Ohio are less likely to have great floods than has the Dayton region, and because of the smaller drainage area above Youngstown, area-wide storms might be more intense, so that more flood storage in inches is required above Youngstown than above Dayton to obtain the same degree of protection given Dayton by the Miami Conservancy District dams. The 1913 storm, if transposed from the Miami River valley to the Mahoning River basin would have resulted in about 9.4 in. of rainfall over the basin in a 4-day period. As noted previously, experience in states adjacent to Ohio in recent years would indicate that the lack of outstanding floods in Ohio since 1913 is a chance occurrence rather than any indication of lower flood-producing characteristics in the State. The total storage capacity available in the Mahoning River basin, without prohibitive costs, is insufficient to give adequate flood protection and the desired low-water flows.

Although some ground-water sources are available, the total ground-water supply in the entire basin is insignificant compared to the large requirements of water for industry. For this reason ground water is not considered as pertinent to the major water problems which can only be solved by substantial increases in storage.

POSSIBILITIES OF EXPANDING WATER SUPPLY

Surface Water Supply

The storage possibilities of two proposed reservoir sites on Eagle Creek and West Branch Mahoning River, have been discussed under Water Requirements to illustrate the difficulty, if not impossibility, of satisfying water demands from within the Mahoning River basin. The Eagle Creek Reservoir project has been authorized, and the West Branch Reservoir is listed by the U. S. Engineers as a possible alternative for Eagle Creek Reservoir. The Eagle Creek dam site is 5½ miles above the mouth of Eagle Creek, has a drainage area of 95 sq mi, and a usable reservoir capacity of 80,000 acre-ft. The West Branch dam site is 10 miles above the mouth, has a drainage area of 81 sq mi and a usable reservoir capacity of 72,000 acre-ft (Pittsburgh District, Corps of Engineers, 1950).

Several proposals have been made for augmenting the low-water flow of the Mahoning River from outside the basin, or diverting the flood flow to another river basin. Some of these proposals, such as pumping water from Lake Erie or the Ohio River are of questionable económic and physical feasibility. Several plans of diversion from or flood storage in the Grand River basin have been given consideration. The proposal that seems to be most feasible is the plan for diverting flood discharges from the Mahoning River into a large capacity reservoir on the Grand River for flood control and returning it to the Mahoning River basin by pumping for low-flow regulation. In this plan a diversion dam on the Mahoning River just above Warren would divert flood flows through a dug channel into the Grand River. A dam and reservoir on the Grand River near Orwell would provide a gross storage of 640,000 acre-ft. A pump station at the diversion dam, with a capacity of 150,000 gpm or 334 cfs, would provide for the return of water into the Mahoning River as required for low-flow regulation. This reservoir and the pres ent reservoirs operated as a comprehensive coordinated system, would provide the 495 cfs average flow required for sanitary purposes in the Mahoning River. Temperature conditions would be improved and the effect on floods would be substantial. According to studies by the Corps of Engineers, all floods of record, except the super flood of 1913, would have been reduced to below damage stage at Youngstown if these reservoirs had been in operation. The 1913 flood would have been 0.3 ft above damage stage. Flood reductions would be effected along the Mahoning River, Beaver River, and with progressively lesser reduction downstream along the Ohio River. Substantial flood control and low-water regulation would be given the Grand River below the reservoir dam. The Grand River during the 1934 drought had no flow at the gaging station near Madison, where the drainage area is 587 sq mi. It drains the largest area of any stream in Ohio having a record of no flow. The proposed minimum-flow regulation of 50 cfs during the summer would greatly improve low-water flow conditions and benefit developments in the Grand River basin, and probably would result in industrial expansion.

Other benefits to be derived from the Grand River diversion and storage would include recreational use of the reservoir, pollution abatement in the Grand River and improved sanitary conditions and hardness reduction below Youngstown in the Mahoning, Beaver, and Ohio Rivers.

The Grand River diversion plan appears to be a technically practicable solution to a difficult problem. However, the estimated costs are large and opposition has been expressed in hearings held by the Corps of Engineers. The estimated first cost was $54,664,000, with an annual maintenance and operation cost of $281,000. Of these costs, local interests would have to assume approximately one-third or $18,531,000 first cost, and $95,300 annual charge (Pittsburgh District, Corps of Engineers, 1950). The project has been under regular process of survey and review by the Corps of Engineers during the last two years.

Ground Water Supply

The area within the Mahoning River basin which seems to offer the best possibilities for the development of large ground-water supplies is the Mahoning River valley in the extreme southwestern part. The valley in that area is underlain by coarse and permeable outwash gravels similar to some of the better aquifers in the State. In 1949 the deposits were investigated by the Ranney Methods Water Supply Co., Columbus, Ohio, to determine whether a ground-water supply of 6 mgd could be developed for the city of Alliance. The areas explored were the lower valley of Beech Creek and the valley of the Mahoning River above the mouth of Beech Creek.

It was concluded that of those areas studied the area above the mouth of Beech Creek was the most favorable for the development of a supply of this magnitude. The desired supply could be obtained if the aquifer were recharged with river water by means of a recharge collector. The Ranney Co. also stated that a supply of considerable magnitude could be obtained without the use of a recharge collector, although it would be less than the desired 6 mgd.

Another potential ground-water area in the Mahoning River basin is probably the lower Mill Creek valley in the Youngstown area, where geologic conditions are similar to those in the Alliance area, because the valley is underlain by glacial outwash gravels of considerable thickness. In the lower Mill Creek valley, however, the use of a large area for metropolitan park purposes may preclude the development of ground-water supplies. This geologically favorable area may never be adequately tested or exploited. The area should be kept in mind as an emergency source of supply for civil-defense purposes.

The kame deposits near Garrettsville, which are most prominent near Mantua, just outside the Mahoning River basin, consist mostly of coarse sand and medium-fine gravel and should be a good source of ground water for small industrial or commercial enterprises. A test well near Mantua was drilled through 73 ft of gravel and coarse sand without encountering bedrock. This is a considerable thickness of permeable material and it certainly bears investigating with respect to the potential development of ground-water supplies. The outwash material serves as an important ground-water reservoir, for the area contributes substantially to streamflow in dry weather periods. About 5 miles west of Garrettsville, the deposits are a source of springs caused by interbedded till layers which deflect ground water to the surface.

Kame deposits in the North Georgetown area in the southern part of the basin also consist largely of coarse gravels, which are a source of small supply.

In the remainder of the Mahoning River basin, the glacial drift, where it is as much as about 50 ft or more in thickness, can be expected to provide small water supplies, generally sufficient for farm or domestic use. In those areas supplies adequate for small industrial or commercial needs can generally be obtained from the bedrock aquifers; and in some places the bedrocks yield fairly large supplies.

In the southern part of the Mahoning River basin the bedrock aquifers of greatest importance are the Sharon and Connoquenessing sandstone members of the Pottsville formation. Sandstones of the upper part of the Cuyahoga formation are important aquifers in the northern part of the basin, and the Kittanning and Clarion sandstone members of the Allegheny formation are the principal aquifers in portions of southwestern and eastern Mahoning County, and in southwestern Trumbull County.

The specific areas where the consolidated rock aquifers may be expected to yield the largest supplies cannot be predicted with certainty, except that, generally speaking, yields are greatest where the aquifers are thickest. It is important to provide sufficient spacing of wells to reduce interference effects as much as possible, which, as shown by the Lowellville pumping test, described in a preceding section, extend over large areas in these aquifers. In some places, such as the Ravenna ordnance plant, acidizing of wells has been very successful in increasing yields.

Another potential source of water in the Mahoning River basin, is the abandoned and flooded coal mines which afford large reservoir capacity (Fuller, 1942). Fuller states that the combined capacity of 38 mines, of a total of more than 100 which are known to exist, is sufficient to hold 630 million gallons of water. Most of the abandoned mines are in the Sharon coal area. The village of Girard obtains its supply from this source. Another mine, located east of Canfield in Mahoning County, reportedly yielded 3,000,000 gpd for a brief period.

WATER LAWS

Ohio water laws are based primarily on common law and with a few important exceptions, there are no legislative acts governing water ownership. The doctrine of riparian rights applies to surface water and "definite underground streams". The common law doctrine of reasonable use, or the "American rule", applies to "percolating waters". Ground water is assumed to be percolating unless shown otherwise.

Following the catastrophic 1913 flood the Ohio legislature passed the Conservancy District Act as a measure to prevent the recurrence of such disasters. This outstanding legislation was a pioneering effort in water conservation law and has served as a model for other states to follow. It has withstood the test of time and changing conditions, and with minor changes is still in effect. The act authorizes counties or groups of counties by themselves or in cooperation with the State or Federal Government to establish complete systems of water conservation and flood control: to prevent floods, regulate stream channels, reclaim wet and overflowed lands, provide for irrigation where needed, regulate streamflow and conserve the water, divert or eliminate watercourses, provide water for domestic, industrial, or public use, collect and dispose of sewage or other liquid wastes, and arrest erosion along the Lake Erie shore line. Water rights existing before formation of a district are recognized; additional waters made available through activities of the district belong to the district and rights to them can be leased, sold, or assigned in return for reasonable compensation, those who have been assessed a part of the cost of construction of facilities having the first right to purchase such waters. The district may claim riparian rights also where it is a riparian landowner. In granting rights to use of waters of the district, preference is given (1) to domestic and municipal use, (2) to industrial use, steam-power production, and cooling uses, and (3) to irrigation, hydropower production, recreation, fisheries, and other uses. The conservancy law has been construed not to allow recovery of damages for loss of "percolating waters" as a result of construction of a conservancy project.

The Ohio Water Supply Board was formed in 1941, was succeeded in 1945 by the Ohio Water Resources Board, and is now known as the Division of Water of the Department of Natural Resources. The duties of this Division are to study the water resources of the State. It has authority to regulate the drilling, operation, maintenance, and abandonment of water wells, mainly to prevent contamination of the ground waters of the State. Waste of water from flowing wells is prohibited, as is use of wells for disposal of sewage or other contaminating waste. A 1945 regulation requires filing of logs of water wells, except farm and domestic wells. In 1947 the provision was broadened to include all wells.

The Chief of the Division of Water has authority to plan and construct projects to conserve the waters of the State in order to insure and promote the public health, welfare and safety. Subject to the written approval of the Director of Natural Resources and the Governor of the State, he may acquire necessary lands, waters and riparian rights by purchase or condemnation. There has been some agitation for control of diversion of ground water in certain heavily pumped areas, but there has also been some opposition. State officials believe that regulation will be achieved through the action of local interests and will be at the local level.

Pollution of streams and watercourses has been the subject of legislation for many years, but until recently provisions for the enforcement of the control of pollution have not been strict. Ohio ratified the Ohio River Compact in 1939, providing for control of pollution in the Ohio River and tributaries, but all of the affected states did not agree to the compact until 1948, at which time the Compact Commission was formed. The control of pollution in the Ohio River basin is a tremendous undertaking, and work of the commission thus far has been largely in planning. The Ohio Water Pollution Control Act of 1951 sets up a water control board for the State, and provides penalties for noncompliance with the act and decisions of the Board. Programs of the Ohio River Compact Commission and the Water Control Board represent great advances toward eventual control of pollution in Ohio streams. Practical solutions to the immense and complex problems of pollution control, though extremely costly, may be reached in the not too distant future.

There appears to be a real need for the codification of water laws for Ohio, to clarify some of the perplexing legal questions concerning water resources. A survey of the laws affecting water resources in Ohio is underway by the Ohio Division of Water and the College of Law, Ohio State University.

SUMMARY

Earlier reports have covered various phases of the water resources of the area in a rather comprehensive manner. However, there appears to have been no previous attempt to summarize and document the more essential information for convenient reference. Consequently, one of the primary purposes of this report is to fulfill the need for a general summary, not all-inclusive in detail, but to assist with a technical perspective for consideration of the water resources, particularly their surface and underground quantity, quality, and availability for water supplies in the area.

The U. S. Geological Survey and its cooperating agencies are continually collecting hydrologic data which will further assist with the evaluation of water conditions within the area, and topographic mapping is being brought up to date in cooperation with the county engineer of Mahoning County. With respect to the water situation, at the present time, the following itemization will outline salient factors:

1. No significant trends have been detected in mean annual runoff but there is a great variability in seasonal and annual runoff in the area. The average yield in the basin is about 0.9 cfs per sq mi.

2. Industrial use of water has grown at tremendous rates with expanding productive capacity.

3. Mahoning River water is generally of moderately good chemical quality as it enters the highly industrialized zone. The water in the reservoirs is usually of better quality and lower in dissolved solids than the other surface water in the basin. Range of chemical quality of surface and ground water is indicated in tables 8 and 11 and figures 14 and 22.

4. Excessively high water temperature during low flow in the Mahoning River combined with gross pollution causes a critical water problem at times.

5. Low-water regulation by existing reservoirs has greatly improved flow conditions but additional storage is required to prevent possible critical water shortages.

6. Geological conditions are not favorable for large ground-water yields in the Mahoning River basin. Such sources are meager and incapable of sustaining even a small fraction of the present water use requirements.

7. A comprehensive plan for development of the water resources of the Mahoning River valley should provide adequate storage reserve for flood control to prevent possible flood disaster. Undeveloped sites to provide sufficient storage for this and other indicated requirements do not appear to be available within the Mahoning River basin but a diversion project in the Grand River basin has been studied by the Corps of Engineers.

SELECTED BIBLIOGRAPHY

Barnes, George E., 1941, Studies on Mahoning River for the Mahoning Valley Water Defense Committee, Warren, Ohio: Wilbur Watson and Associates, Architects and Engineers.

———, 1942, Study of Lowellville dam and pool for the Mahoning Valley Industrial Council, Youngstown, Ohio, Consulting Engineer, Cleveland, Ohio.

Congressional documents, 69th Cong., 1st sess., H. Doc. 308, U. S. Army, Chief of Engineers, Pittsburgh district, July 1, 1939, Report upon Beaver River system, Pennsylvania and Ohio.

———, 73d Cong., 2d sess., H. Doc. 277, U. S. Army, Chief of Engineers, 1934, Preliminary examination and survey, Beaver, Shenango, and Mahoning Rivers, Pennsylvania and Ohio.

———, 74th Cong., 1st sess., H. Doc. 306, U. S. Army, Chief of Engineers, 1936, A general plan for the improvement of the Ohio River.

———, 75th Cong., 1st sess., H. Doc. 1, April 1937, Report upon comprehensive flood control plan for Ohio and lower Mississippi Rivers; Committee on Flood Control.

———, 75th Cong., 3d sess., H. Rept. 2353, May 1938, Report upon comprehensive flood control plans and works for reservoirs, levees, and flood walls.

———, 76th Cong., 1st sess., H. Doc. 178, U. S. Army, Chief of Engineers, 1939, Report on survey for Lake Erie and Ohio River canal.

———, 78th Cong., 1st sess., H. Doc. 266, U. S. Army, Chief of Engineers and U. S. Public Health Service, 1944, Ohio River pollution control, in 2 parts (3 volumes). Part 1 (vol. 1) is a report of the Ohio River Committee. Part 2 (vols. 2 and 3) is a report by the U. S. Public Health Service.

———, 78th Cong., 2d sess., H. Rept. 3961, 1944, Hearings before a subcommittee of the Committee on Commerce, U. S. Senate, Rivers and Harbors Omnibus Bill, Beaver and Mahoning Rivers Project, part 2, May 1 and 2, 1944.

Cross, W. P., 1946, Floods in Ohio; magnitude and frequency: Ohio Dept. of Nat. Resources, Div. of Water Bull. 7.

Cross, W. P., and Bernhagen, R. J., 1949, Ohio streamflow characteristics, part 1, Flow duration: Ohio Dept. of Nat. Resources, Div. of Water Bull. 10.

Cross, W. P., and Webber, E. E., 1950, Ohio streamflow characteristics, part 2, Water supply and storage requirements: Ohio Dept. of Nat. Resources, Div. of Water Bull. 13.

Cummins, J. W., 1952 ?, The ground-water resources of Mahoning County, Ohio: Ohio Dept. of Nat. Resources, Div. of Water Bull. (in preparation).

Dittoe, W. H., Dec. 1926, Report of the chief engineer upon sources of water supply, Mahoning Valley Sanitary District.

Fuller, J. O., June 1942, Alleviation of the Mahoning Valley water shortage, Ohio State University Engineering Experiment Station News.

Knappen Tippets Abbett Engineering Co., New York, Nov. 17, 1948, Engineering and economic report on Lake Erie-Ohio River waterway, a report for the Ohio Valley Improvement Association, for presentation to the Board of Engineers for Rivers and Harbors at a hearing in Pittsburg, Pa.

———, New York, January 1949, Preliminary report on Mahoning and Grand River floodway, a report for the Mahoning Valley Industrial Council, investigating a modified floodway and flood-control project.

Lamar, W. L., and Schroeder, M. E., 1951, Chemical character of surface waters of Ohio 1946-50: Ohio Dept. of Nat. Resources, Div. of Water Bull. 23.

Mahoning Valley Industrial Council, February 27, 1943, Justification for immediate construction of a low rolled fill earth dam for flood control and low flow regulation on Mosquito Creek, Trumbull County, Ohio, to the War Production Board.

———, January 22, 1951, Justification for immediate construction of a flood diversion wasteway north of Warren, Ohio, and a low rolled fill earth dam near Orwell, Ohio, for flood control and low flow regulation, to protect and supply the Mahoning Valley production area.

Mahoning Valley Sanitary District, March 13, 1948, Water supply application for obtaining raw water from Berlin Reservoir.

McGuinness, C. L., 1951, Water situation in the United States, with special reference to ground water: U. S. Geol. Survey, Circ. 114, pp. 12-15.

Ohio State Planning Board, Columbus, Ohio, June 19, 1936, A tentative plan for the control and utilization of water resources in the Mahoning watershed.

Ohio Valley Improvement Assoc., Inc., Cincinnati, Ohio, 1947, Abstract of review of reports on Lake Erie and Ohio River canal.

Parsons, Brinkerhoff, Hogan, and MacDonald, May 1949, Plan for an auxiliary water supply from Berlin Reservoir and improvement of the Meander

Creek plant. Report to the Board of Directors, the Mahoning Valley Sanitary District.

Potter, Alexander, November 1, 1920, Report on the development of the water resources of the Mahoning River, including stream control for sanitary purposes and for water supply, to the City of Warren, Ohio, Consulting Engineer, New York, N. Y.

President's Water Resources Policy Commission, 1950, Ten rivers in America's future. Includes section on the Ohio River. Vol. 2 of the report of the President's Water Resources Policy Commission.

Prosser, C. S., 1912, The Devonian and Mississippian formations of Northeastern Ohio: Ohio Geol. Survey, 4th ser., Bull. 15.

Sanderson, E. E., 1950, The climatic factors of Ohio's water resources: Ohio Dept. of Nat. Resources, Div. of Water Bull. 15.

Secretary of War (Acting), 1944, Letter on Ohio River pollution control, Congressional documents: 78th Cong., 1st sess., H. Doc. 266.

Stout, Wilber, 1939, Generalized section of the coal-bearing rocks of Ohio: Ohio Geol. Survey, 4th ser., Information Circ. 2.

Stout, Wilber, and Schaaf, Downs, 1932, Brines of Ohio: Ohio Geol. Survey, 4th ser., Bull. 37.

Stout, Wilber, Ver Steeg, Karl, and Lamb, G. F., 1943, Geology of Water in Ohio: Ohio Geol. Survey, 4th ser., Bull. 44.

Sturgeon, M. T., 1943, Contributions to the stratigraphy of the Allegheny series in Columbiana and Mahoning Counties, Ohio: Ohio Jour. Sci., vol. 43.

U. S. Army, Chief of Engineers, Pittsburgh District, July 1, 1939, Report upon Beaver River system, Pennsylvania and Ohio, in accordance with Congressional document, 69th Cong., 1st sess., H. Doc. 308.

——, May 31, 1943, Definite project report, Mosquito Creek Reservoir near Warren, Ohio.

U. S. Army, Corps of Engineers, Pittsburgh District, March 1944, Interim report on the Mahoning-Grand River flood wasteway, an interim report upon review of reports on the Mahoning and Grand River basins, Ohio, prepared in accordance with resolution of June 17, 1942, by the Committee on Commerce of the U. S. Senate.

——, August 1947, Review of reports on Lake Erie and Ohio River canal, Pittsburgh-Ashtabula route.

——, January 1950, Review of reports upon Mahoning and Grand River basins, Ohio.

U. S. Dept. of Agriculture, 1941, Climate and man: Yearbook of agriculture.

U. S. Geological Survey, Surface water supply of the United States, part 3, Ohio River basin, issued annually as Water Supply Papers.

U. S. House of Representatives, May 1941, Hearings before the Committee on Rivers and Harbors, House of Representatives, 77th Cong., 1st sess., on the Improvement of the Beaver and Mahoning Rivers, Pennsylvania and Ohio, September 30, October 1, 2, 3, and 6, 1941.

U. S. Weather Bureau, June 1947, Generalized estimates of maximum possible precipitation over the United States, Hydrometeorological Rept. 23, U. S. Weather Bureau and U. S. Army, Corps of Engineers.

Woodward and Co., August 1941, Industrial survey of Youngstown, Ohio, prepared for the Mahoning Valley Resources Committee, Lectonia, Ohio.

Woodward, R. L., and LeBosquet, M., May 1949, Effects of reservoir operation on stream water quality (mimeographed), Environmental Health Center, Cincinnati, Ohio.

Youngquist, C. V., 1947, Ohio streamflow, part 2, Summary of streamflow records in Ohio, 1898-1944: Ohio State Univ. Eng. Exper. Sta., Bull. 127.

Youngstown Vindicator, 1945, Youngstown's case for the Beaver-Mahoning Waterway, published by the Youngstown Vindicator.

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